Oracle® Database

Graph Developer's Guide for Property Graph

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Preface

This document provides conceptual and usage information about Oracle Database support for working with property graph data.

- Audience
- Documentation Accessibility
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Audience

This document is intended for database and application developers in an Oracle Database environment.

Documentation Accessibility

For information about Oracle's commitment to accessibility, visit the Oracle Accessibility Program website at http://www.oracle.com/pls/topic/lookup?ctx=acc&id=docacc.

Access to Oracle Support

Oracle customers that have purchased support have access to electronic support through My Oracle Support. For information, visit http://www.oracle.com/pls/topic/lookup?ctx=acc&id=info or visit http://www.oracle.com/pls/topic/lookup?ctx=acc&id=trs if you are hearing impaired.

Related Documents

For more information, see the following documents:

- *Oracle Spatial Developer's Guide*
- *Oracle Database Graph Developer's Guide for RDF Graph*
- *Oracle Spatial GeoRaster Developer's Guide*
- *Oracle Spatial Topology and Network Data Model Developer's Guide*
- *Oracle Big Data Spatial and Graph User's Guide and Reference*

Conventions

The following text conventions are used in this document:

Convention	Meaning
boldface	Boldface type indicates graphical user interface elements associated with an action, or terms defined in text or the glossary.
italic	Italic type indicates book titles, emphasis, or placeholder variables for which you supply particular values.
`monospace`	Monospace type indicates commands within a paragraph, URLs, code in examples, text that appears on the screen, or text that you enter.

Changes in This Release for This Guide

The following changes apply to property graph support that is shipped with Oracle Graph Server and Client.

Oracle Graph Server and Client is required for using the property graph feature of Oracle Database (see Oracle Graph Server and Client Installation), and is released four times a year.

New Features

Significant New Features in Oracle Graph Server and Client 23.1 That Work With Oracle Database 23c

Oracle Graph Server and Client Release 23.1 works with the following property graph features of Oracle Database 23c:

- Added support for creating property graph SQL-schema object in Oracle Database.
  See Introduction to SQL Property Graphs for more information.
- Added support for running graph queries on SQL property graphs.
  See SQL GRAPH_TABLE Queries for more information.
- Added support for running PGQL SELECT queries against SQL property graphs.
  See Executing PGQL Queries Against SQL Property Graphs for more information.
- Added support for visualizing SQL `GRAPH_TABLE` queries on graphs in the database.
  See Visualizing Graph Queries on SQL Property Graphs for more information.

Significant New Features in Oracle Graph Server and Client 23.1 (Applies for 23c and Prior Oracle Database Releases)

- Added support to create property graph views by importing graph data from a GraphSON file.
  See Creating a PG View By Importing a GraphSON file for more information.
- Added support for explicitly specifying the schema name when:
  - Loading a property graph view into the graph server (PGX) using the `readGraphByName` API.
    See Specifying the Schema Name for the readGraphByName API for more information.
  - Loading a subgraph into memory in the graph server (PGX).
    See Loading a Subgraph by Explicitly Specifying the Schema Name for more information.
  - Expanding an in-memory subgraph .
    See Expanding a Subgraph by Explicitly Specifying the Schema Name for more information.

- Added a new release artifact, `oracle-graph-visualization-library-23.1.0.zip`, to the Oracle Graph Server and Client deployment. This contains a JavaScript library for the Graph Visualization interface which you can embed in your web application.
  See Embedding the Graph Visualization Library in a Web Application for more information.
- Enhanced the graph server (PGX) `ServerInstance#getServerState` API to provide the session user information.
  See Get Inspection Data for more information.
- Added v2 for the Graph Visualization `GET /graphs` REST endpoint.
  See List Graphs for more information.
- Added support for Supervised EdgeWise graph algorithm in the PgxML Library.
  See Using the Supervised EdgeWise Algorithm (Edge Embeddings and Classification) for more information.
- Added support for regression tasks on Supervised GraphWise Models.
  See Classification Versus Regression Models on Supervised GraphWise Models for more information.

Deprecated Features

- **GraphServer#getInstance API**
  The following `GraphServer#getInstance` APIs are deprecated:
  - `GraphServer.getInstance(ClientConfig clientConfig, String username, char[] password, int refreshTimeBeforeTokenExpiry)`
  - `GraphServer.getInstance(String baseUrl, String username, char[] password, int refreshTimeBeforeTokenExpiry)`
  - `GraphServer.getInstance(String baseUrl, String kerberosTicketPath, int refreshTimeBeforeTokenExpiry)`

  Instead, configure the `refresh_time_before_token_expiry_seconds` parameter in the `pgx.conf` file.
- **opg_apis.get_version()**
  The `OPG_APIS.GET_VERSION()` function is deprecated and will be desupported in a future release. Instead, use OPG_APIS.GET_OPG_VERSION.
- **Apache HDFS support for Cloudera CDH6**
  Support for Apache HDFS on Cloudera CDH6 is deprecated.
- **Methods deprecated for `PgqlViewGraphExpander`**
  `PgqlViewGraphExpander.schema(String)` and `PgqlViewGraphExpander.owner(String)` are deprecated. Instead, use `PgqlViewGraphExpander.fromPgView(String, String)`.
- **Graph Server (PGX) Configuration Fields**
  The graph server configuration fields, `server_cert` and `server_private_key` are deprecated. Instead, use `server_keystore`.
- **PyPGX**
  - The following attributes on `Operation` are now deprecated: `graph_id`, `operation_type`, `cost_estimate`, `total_cost_estimate`, `cardinality_estimate`, `pattern_info`, and `children`. Instead, use the corresponding getter methods, such as `get_graph_id()`, `get_operation_type()`, and so on.
  - The `pgx_version` attribute in `ServerInstance` class is deprecated. Instead, use `get_version()`.

  - The attribute `pg_view_name` in `PartitionedGraphConfig` is deprecated. Instead, use `source_name` and `source_type` (set to `pg_view`).
  - `set_standarize` in `GraphWiseModelConfig` is deprecated. Instead, use `set_standardize`.
  - The return value of `PgqlResultSet.get_vertex_labels` may or may not be a list.
- **Subgraph Loading**
  Creating Subgraphs using filter expressions is deprecated. Instead, use Loading a Subgraph from Property Graph Views.
- **PgxML: `inferAndGetExplanation` Function**
  `GraphWiseModel.inferAndGetExplanation()` is deprecated. Instead, use `GraphWiseModel.gnnExplainer()` to obtain a `GnnExplainer` object for the model and use `GnnExplainer.inferAndExplain()`.
- `Pg2vecModelBuilder.setUseGraphletSize(java.lang.Boolean useGraphletSize)` method in `oracle.pgx.api.mllib` API is deprecated. Instead, use the `Pg2vecModelBuilder.setUseGraphletSize(boolean useGraphletSize)` method.
- **PgxML: `SupervisedGraphWiseModelBuilder.setLossFunction` Function**
  `SupervisedGraphWiseModelBuilder.setLossFunction(SupervisedGraphWiseModelConfig.LossFunction ...)` is deprecated. Instead, use `SupervisedGraphWiseModelBuilder.setLossFunction(LossFunction ...)` function.
- **PL/SQL API OPG_APIS.GET_SCN Function**
  The PL/SQL API OPG_APIS.GET_SCN function is deprecated. Instead, to retrieve the current SCN (system change number), use the DBMS_FLASHBACK.GET_SYSTEM_CHANGE_NUMBER function:

```
SELECT dbms_flashback.get_system_change_number FROM DUAL;
```

Desupported Features

- Groovy support for using the Java API in Apache Zeppelin client is desupported.
- Oracle Linux 6 is desupported.
- Oracle Text with property graph schema graphs is desupported.
- Apache HBase is desupported.
- Support for mixed case string arguments in PyPGX for cases where there are a fixed, enumerated list of possible values (such as, `['linear', 'tanh', 'relu']`) are desupported. Only lower case arguments are now supported.
- The two-table format is desupported.
- The following Java API classes are desupported:
  - `oracle.pg.rdbms.OraclePgqlColumnDescriptor.java`
  - `oracle.pg.rdbms.OraclePgqlColumnDescriptorImpl.java`
  - `oracle.pg.rdbms.OraclePgqlExecution.java`
  - `oracle.pg.rdbms.OraclePgqlExecutionFactory.java`

  - oracle.pg.rdbms.OraclePgqlPreparedStatement.java
  - oracle.pg.rdbms.OraclePgqlResult.java
  - oracle.pg.rdbms.OraclePgqlResultElement.java
  - oracle.pg.rdbms.OraclePgqlResultElementImpl.java
  - oracle.pg.rdbms.OraclePgqlResultImpl.java
  - oracle.pg.rdbms.OraclePgqlResultIterable.java
  - oracle.pg.rdbms.OraclePgqlResultIteratorImpl.java
  - oracle.pg.rdbms.OraclePgqlResultSet.java
  - oracle.pg.rdbms.OraclePgqlResultSetImpl.java
  - oracle.pg.rdbms.OraclePgqlResultSetMetaData.java
  - oracle.pg.rdbms.OraclePgqlResultSetMetaDataImpl.java
  - oracle.pg.rdbms.OraclePgqlSqlTrans.java
  - oracle.pg.rdbms.OraclePgqlSqlTransImpl.java
  - oracle.pg.rdbms.OraclePgqlStatement.java

- The following Java API methods, objects and fields in oracle.pgx.api are no longer supported:
  Desupported Methods:
  - PgxCollection methods:
    - addAllAsync(Collection<E> source)
    - removeAllAsync(Collection<E> source)
    - addAll(ID...ids)
    - removeAll(ID...ids)
  - PgqlResultSet methods:
    - getResults(): instead, use PgqlResultSet to directly iterate the result set
    - destroy()
  - User-defined pattern matching semantic methods:
    - PgxGraph#queryPgql(String, PatternMatchingSemantic): instead, use PgxGraph#queryPgql(String)
    - PgxSession.setPatternMatchingSemantic(..)
  - GraphMetaData constructors and related methods:
    - GraphMetaData()
    - GraphMetaData(GraphMetaData other, java.net.URI baseUri)
    - GraphMetaData(IdType vertexIdType)
    - GraphMetaData.setVertexIdType()
    - GraphMetaData.setEdgeIdType()
  - PgxSession#getAvailableSnapshots(GraphConfig): instead, use PgxSession#getAvailableSnapshots(PgxGraph)

  - All `Analyst#filteredBfs` and `Analyst#filteredDfs` methods that accepts `filter` parameter: instead, use the `navigator` parameter

  Desupported Objects

  - `PgqlResult`(a result of `resultSet.getResults().iterator().next()`: instead, use `PgxResult` as returned from `resultSet.iterator().next()`

  Desupported Fields

  - `pattern_matching_semantic` configuration field

- The Java API method `AbstractGraphConfigBuilder#setNodeIdType` in `oracle.pgx.config` is desupported. Instead, use `AbstractGraphConfigBuilder#setVertexIdType()`.
- The following PyPGX classes are desupported in `pypgx` package. Instead, use `pypgx.api.filters` subpackage to access these classes:
  - `EdgeFilter`
  - `GraphFilter`
  - `VertexFilter`
- The following PyPGX classes are desupported in `pypgx.api` package. Instead, use `pypgx.api.frames` subpackage to access these classes:
  - `PgxCsvFrameReader`
  - `PgxCsvFrameStorer`
  - `PgxDbFrameReader`
  - `PgxDbFrameStorer`
  - `PgxFrame`
  - `PgxFrameBuilder`
  - `PgxFrameColumn`
  - `PgxGenericFrameReader`
  - `PgxGenericFrameStorer`
  - `PgxPgbFrameReader`
  - `PgxPgbFrameStorer`
- The following Python API packages are no longer supported:
  - `common`: This internal package is desupported. Few of the classes from this package are moved to the public package `pypgx.api`.
  - `utils`: This internal package is renamed to `_utils`.
- Graph property text search based on Apache Solr/Lucene is desupported. Instead, use PGQL query expressions.
- The PGX property type DATE is desupported. Instead, use LOCAL_DATE or TIMESTAMP.
- Property Graph support for data stored in Oracle NoSQL Database is desupported.
- Support for Gremlin Groovy shell is desupported.

- Apache Tinkerpop API support for Oracle Database is desupported.
- Loading data from flat file formats into the property graph schema is desupported.
- Support for the Apache Groovy-based shell was deprecated in 19c and is now desupported.
- Support for Apache HBase and Apache HDFS on Cloudera CDH5 is desupported.

Part I

Getting Started with Oracle Property Graphs

Part I provides the fundamental information to get you started on the property graph feature of Oracle Database.

This part covers the following:

- Introduction to Property Graphs
  Property graphs give you a different way of looking at your data.
- Using Oracle Graph with the Autonomous Database
  Oracle Graph with the Autonomous Database allows you to create property graphs from data in your Autonomous Database.

1 Introduction to Property Graphs

Property graphs give you a different way of looking at your data.

You can model your data as a graph by making data entities **vertices** in the graph, and relationships between them as **edges** in the graph. For example, in a bank, customer accounts can be vertices, and cash transfer relationships between them can be edges.

When you view your data as a graph, you can analyze your data based on the connections and relationships between them. You can run graph analytics algorithms like PageRank to measure the relative importance of data entities based on the relationships between them (for instance, links between web pages).

- What Are Property Graphs?
  A property graph consists of a set of objects or **vertices**, and a set of arrows or **edges** connecting the objects.
- About the Property Graph Feature of Oracle Database
  The Property Graph feature delivers advanced graph query and analytics capabilities in Oracle Database.
- Overview of Property Graph Architecture
  The property graph feature of Oracle Database supports the following architecture models.
- Learn About the Graph Server (PGX)
  The in-memory graph server layer enables you to analyze property graphs using parallel in-memory execution.
- Security Best Practices with Graph Data
  Several security-related best practices apply when working with graph data.
- About Oracle Graph Server and Client Accessibility
  This section provides information on the accessibility features for Oracle Graph Server and Client.

1.1 What Are Property Graphs?

A property graph consists of a set of objects or **vertices**, and a set of arrows or **edges** connecting the objects.

Vertices and edges can have multiple properties, which are represented as key-value pairs.

Each vertex has a unique identifier and can have:

- A set of outgoing edges
- A set of incoming edges
- A collection of properties

Each edge has a unique identifier and can have:

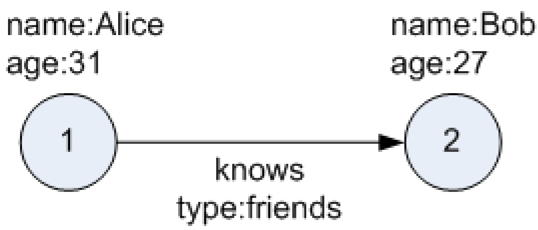
- An outgoing vertex
- An incoming vertex

- A text label that describes the relationship between the two vertices
- A collection of properties

For vertices and edges, each property is identified with a unique name.

The following figure illustrates a very simple property graph with two vertices and one edge. The two vertices have identifiers 1 and 2. Both vertices have properties `name` and `age`. The edge is from the outgoing vertex 1 to the incoming vertex 2. The edge has a text label `knows` and a property `type` identifying the type of relationship between vertices 1 and 2.

Figure 1-1 Simple Property Graph Example



A property graph can have self-edges (that is, an edge whose source and destination vertex are the same), as well as multiple edges between the same source and destination vertices.

A property graph can also have different types of vertices and edges in the same graph. For example a graph can have a set of vertices with label `Person` and a set of vertices with label `Place`, with different properties relevant to these two sets of vertices.

The property graph data model is similar to the W3C standards-based Resource Description Framework (RDF) graph data model; however, the property graph data model is simpler and less precise than RDF.

The property graph data model features and analytic APIs make property graphs a good candidate for use cases such as these:

- Identifying influencers in a social network
- Predicting trends and customer behavior
- Discovering relationships based on pattern matching
- Identifying clusters to customize campaigns

1.2 About the Property Graph Feature of Oracle Database

The Property Graph feature delivers advanced graph query and analytics capabilities in Oracle Database.

This feature supports graph operations, indexing, queries, search, and in-memory analytics.

Graphs manage networks of linked data as vertices, edges, and properties of the vertices and edges. Graphs are commonly used to model, store, and analyze relationships found in social networks, cybersecurity, utilities and telecommunications, life sciences and clinical data, and knowledge networks.

Typical graph analyses encompass graph traversal, recommendations, finding communities and influencers, and pattern matching. Industries including telecommunications, life sciences and healthcare, security, media, and publishing can benefit from graphs.

The property graph features of Oracle Database support those use cases with the following capabilities:

- A scalable graph database
- Developer-based APIs based upon PGQL and Java graph APIs
- A parallel, in-memory graph server (PGX) for running graph queries and graph analytics
- A fast, scalable suite of social network analysis functions that include ranking, centrality, recommender, community detection, and path finding
- Parallel bulk load and export of property graph data in Oracle-defined flat files format
- A powerful Graph Visualization application
- Notebook support through integration with Jupyter

1.3 Overview of Property Graph Architecture

The property graph feature of Oracle Database supports the following architecture models.

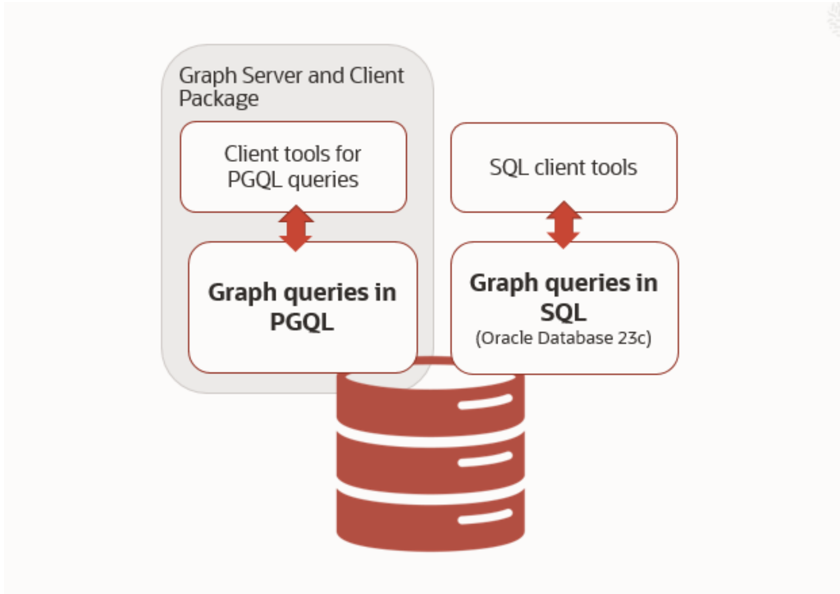
- Architecture Model for Running Graph Queries in the Database
  Using any of the supported client tools, you can directly interact with the graph data stored in the relational tables in the database.
- Architecture Model for Running Graph Analytics
  You can load your property graph into the graph server (PGX) in order to perform specialized graph computations.
- Developing Applications Using Graph Server Functionality as a Library
  The graph functions available with the graph server (PGX) can be used as a library in your application.

1.3.1 Architecture Model for Running Graph Queries in the Database

Using any of the supported client tools, you can directly interact with the graph data stored in the relational tables in the database.

This approach runs graph queries, as shown in the following figure.

Figure 1-2 Property Graph Architecture for Running Graph Queries



This model allows you to create a property graph using any one of the following supported options:

- Create a SQL property graph directly over existing database schema objects using SQL DDL statement. See SQL Property Graphs for more information.
- Create a property graph view directly over the graph data in the tables. See Property Graph Views for more information.

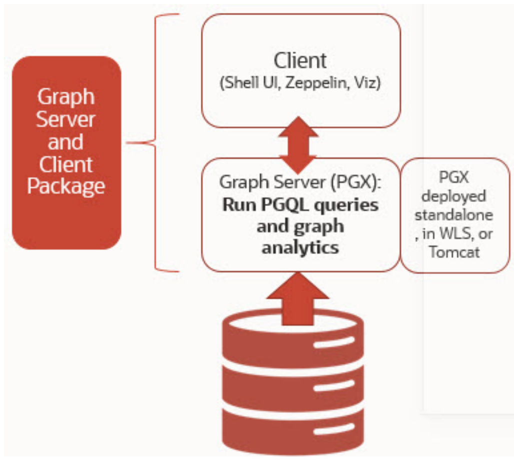
You can directly query the graphs, without loading the graphs into the graph server (PGX), using PGQL. Additionally, you can also run graph pattern matching queries on SQL property graphs using the `GRAPH_TABLE` operator. See SQL GRAPH_TABLE Queries for more information.

However, if you want to run graph analytics algorithms, then you must load this graph into the graph server (PGX). You can configure the graph server to periodically fetch data updates from the database to keep the graph synchronized. Note that loading the graph into the graph server (PGX) and performing graph synchronization operations are supported only for property graph views.

1.3.2 Architecture Model for Running Graph Analytics

You can load your property graph into the graph server (PGX) in order to perform specialized graph computations.

Figure 1-3 Property Graph Architecture for Running Graph Analytics



As seen in the preceding architecture design, the graph server (PGX) is a mid-tier server that can run as a standalone, or in a container like Oracle WebLogic Server or Apache Tomcat. Using this approach, you can load your property graph into the graph server (PGX). This allows you to run graph queries and analytical operations in memory in the graph server.

The graph can be created directly from the relational tables, or loaded from a property graph view which stores the graph in the database. You can modify the graph in memory (insert, update, and delete vertices and edges, and create new properties for results of executing an algorithm). The graph server does not write the modifications back to the relational tables.

Property Graph Sizing Recommendations

You can compute the memory required by the graph server (PGX) by using this calculator, Graph Size Estimator.

For example, the following table shows the memory estimated by the calculator for the given input:

Table 1-1 Graph Size Estimator

Number of vertices	Number of Edges	Properties per Vertex	Properties per Edge	Estimated graph size
10M	100M	• 4 - Integer Type • 1 - String Type(15 characters)	• 4 - Integer Type • 1 - String Type(15 characters)	15 GB
100M	1B	• 4 - Integer Type • 1 - String Type(15 characters)	• 4 - Integer Type • 1 - String Type(15 characters)	140 GB

> **Note:**
>
> - Reading a graph into memory can take upto twice the amount of memory needed to represent it in memory. So when you calculate the memory required for running PGX it is recommended that you double the amount of memory of the estimated graph size.
> - **CPU Processors:** The recommended number of CPU processors for a graph with 10M vertices and 100M edges is 2-4 processors, and up to 16 processors for more compute-intensive workloads. Increasing CPU processors will improve performance.

1.3.3 Developing Applications Using Graph Server Functionality as a Library

The graph functions available with the graph server (PGX) can be used as a library in your application.

After the rpm install of the graph server, all the jar files can be found in `/opt/oracle/graph/lib`. In this case, the server installation and the client user application are in the same machine.

For such use cases, development and testing can be done using the interactive Java shell or the Python shell in embedded (local) mode. This means a local PGX instance is created and runs in the same JVM as the client. If you start the shell without any parameters it will start a local PGX instance and run in embedded mode.

See Using the Graph Server (PGX) as a Library for more information to obtain reference to a local PGX instance.

1.4 Learn About the Graph Server (PGX)

The in-memory graph server layer enables you to analyze property graphs using parallel in-memory execution.

It provides over 60 analytic functions. Examples of the categories and specific functions include:

- Centrality - Degree Centrality, Eigenvector Centrality, PageRank, Betweenness Centrality, Closedness Centrality
- Component and Community - Strongly Connected Components (Tarjan's and Kosaraju's). Weakly Connected Components
- Twitter's Who-To-Follow, Label Propagation.
- Path Finding - Single source all destination (Bellman-Ford), Dijsktra's shortest path, Hop Distance (Breadth-first search)
- Community Evaluation - Coefficient (Triangle Counting), Conductance, Modularity, Adamic-Adar counter.

- Overview of the Graph Server (PGX)
  The Graph Server (PGX) is an in-memory accelerator for fast, parallel graph query and analytics. The server uses light-weight in-memory data structures to enable fast execution of graph algorithms.

Related Topics

- Installing Oracle Graph Server
- Getting Started with the Graph Server (PGX)
  Once you have installed the graph server (PGX), you can start and connect to a graph server instance.

1.4.1 Overview of the Graph Server (PGX)

The Graph Server (PGX) is an in-memory accelerator for fast, parallel graph query and analytics. The server uses light-weight in-memory data structures to enable fast execution of graph algorithms.

There are multiple options to load a graph into the graph server either from Oracle Database or from files.

The graph server can be deployed standalone (it includes an embedded Apache Tomcat instance), or deployed in Oracle WebLogic Server or Apache Tomcat.

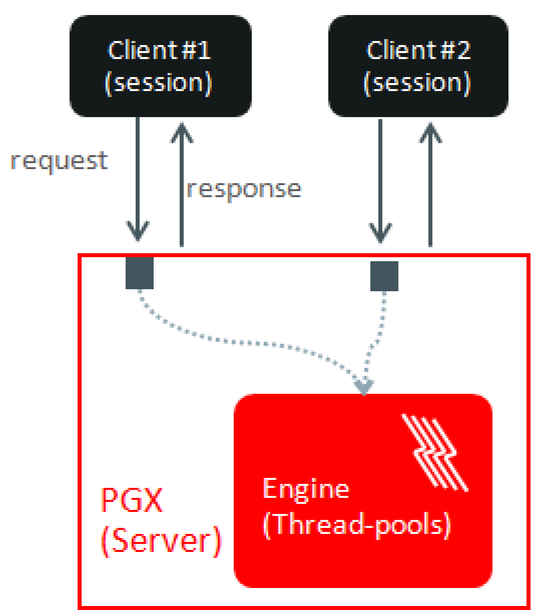
- Design of the Graph Server (PGX)
- Usage Modes of the Graph Server (PGX)

1.4.1.1 Design of the Graph Server (PGX)

The design of the graph server (PGX) is based on a Server-Client usage model. See Usage Modes of the Graph Server (PGX) for more details on the different graph server (PGX) execution modes.

The following figure shows the graph server (PGX) design:

Figure 1-4 Graph Server (PGX) Design



The core concepts of the graph server (PGX) design are as follows:

- Multiple graph clients can connect to the graph server at the same time.
- Each client request is processed by the graph server asynchronously. The client requests are queued up first and processed later, when resources are available. The client can poll the server to check if a request has been finished.
- Internally, the server maintains its own engine (thread pools) for running parallel graph algorithms and queries. The engine tries to process each analytics request concurrently with as many threads as possible.

Isolation Between Concurrent Clients

The graph server (PGX) supports data isolation between concurrent clients. Each client has its own private workspace, called session. Sessions are isolated from each other. Each client can load a graph instance into its own session, independently from other clients. Therefore, each client can load a graph instance (as well as its properties) into its own session, independently from other clients.

1.4.1.2 Usage Modes of the Graph Server (PGX)

This section presents an overview of the different usage modes of the graph server (PGX). The graph server can be executed in one of the following usage modes.

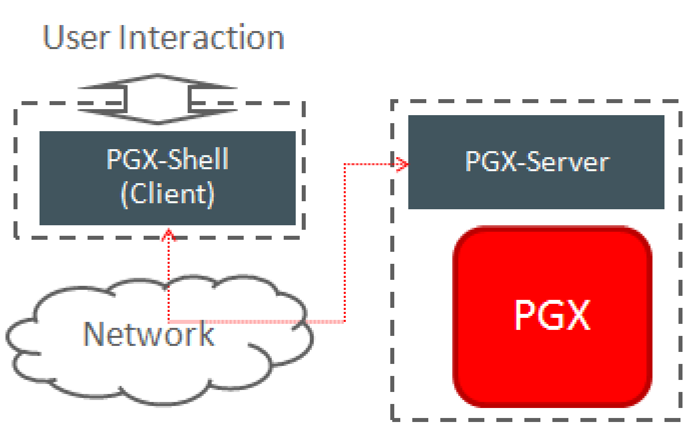
Remote Server Mode

In the remote server mode, the main PGX execution engine is deployed as a RESTful application on a powerful server machine, and you can connect to it remotely from your machine using graph shell. Also, multiple clients can connect to the same graph server (PGX) at the same time and therefore the graph server is time-shared among these clients.

See Interactive Graph Shell CLIs for more information on the graph shell.

The following figure shows the graph server (PGX) in a remote execution mode:

Figure 1-5   Remote Server Mode



The remote server mode is useful for the following situations where you want to:

- Perform graph analysis on a large data set with a powerful server-class machine that has many cores and a large memory.
- The server-class machine is shared by multiple clients.

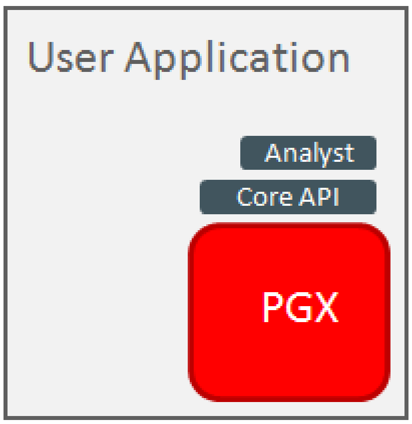
See Starting the Graph Server (PGX) for instructions on how to start the graph server (PGX) in remote server mode.

Using Graph Server (PGX) as a Library

You can also include the graph server (PGX) as a normal Java library in your application.

The following figure shows the graph server (PGX) used as a library in an application:

Figure 1-6 PGX as a Library



The embedded mode is useful when you want to build an application having graph analysis as a part of its functionality.

See Using the Graph Server (PGX) as a Library for more information.

Deploying Graph Server (PGX) as Servlet Web Application

You can deploy the graph server (PGX) as a web application using Apache Tomcat or Oracle WebLogic Server.

See Deploying Oracle Graph Server to a Web Server for instructions to deploy the graph server (PGX) in Apache Tomcat or Oracle WebLogic Server.

1.5 Security Best Practices with Graph Data

Several security-related best practices apply when working with graph data.

Sensitive Information

Graph data can contain sensitive information and should therefore be treated with the same care as any other type of data. Oracle recommends the following considerations when using a graph product:

- Avoid storing sensitive information in your graph if that information is not required for analysis. If you have existing data, only model the relevant subset you need for analysis as a graph, either by applying a preprocessing step or by using subgraph and filtering techniques that are part of graph product.

- Model your graph in a way that vertex and edge identifiers are not considered sensitive information.
- Do not deploy the product into untrusted environments or in a way that gives access to untrusted client connections.
- Make sure all communication channels are encrypted and that authentication is always enabled, even if running within a trusted network.

Least Privilege Accounts

The database user account that is being used by the graph server (PGX) to read data should be a low-privilege, read-only account. PGX is an in-memory accelerator that acts as a read-only cache on top of the database, and it does not write any data back to the database.

If your application requires writing graph data and later analyzing it using PGX, make sure you use two different database user accounts for each component.

Public Health Endpoint Security

Unless you run multiple graph servers behind a load balancer (Deploying Oracle Graph Server Behind a Load Balancer), it is a good security practice to disable the public endpoint of the graph server, which load balancers need to determine the health of the graph servers.

To disable the endpoint:

1. Locate the `WAR` file of the graph server. If you installed the graph server via RPM, then the file is located at `/opt/oracle/graph/pgx/server/pgx-webapp-<version>.war`.
2. Unzip the `.war` file into a location of your choice and then edit the `WEB-INF/web.xml` file inside the unzipped directory with a text editor of your choice.
3. Locate the `pgx.auth.exceptions` parameter in the file. The list of public endpoints can be seen as shown:

```
<init-param>
    <param-name>pgx.auth.exceptions</param-name>
    <param-value>isReady;isRunning;auth/token</param-value>
</init-param>
```

4. Remove the `isReady` endpoint from the list of public endpoints as shown:

```
<init-param>
    <param-name>pgx.auth.exceptions</param-name>
    <param-value>isRunning;auth/token</param-value>
</init-param>
```

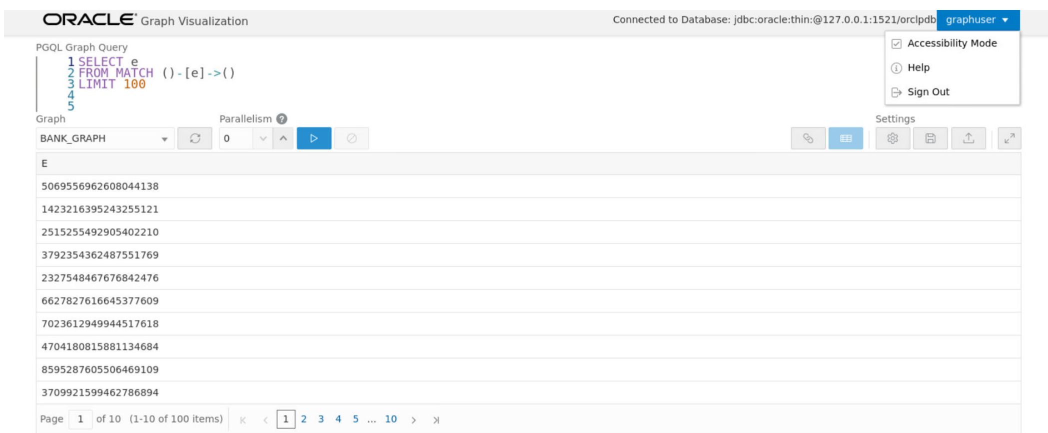
5. Save your changes, repackage the `WAR` file and redeploy the file to its original location.
6. Restart the graph server.

1.6 About Oracle Graph Server and Client Accessibility

This section provides information on the accessibility features for Oracle Graph Server and Client.

- For information on addressing accessibility for the Java and Python command line interfaces, which are installed on Oracle Linux, see Working With Accessibility Features in Oracle Linux 7.
- For information on keyboard shortcuts for the Java command line interface, which is built on top of the Java Shell (JShell), see Keyboard Shortcuts for JShell.
- For information on addressing accessibility for the Graph Visualization Application, which is based on Oracle JET, see About Oracle JET and Accessibility.
- You can enable accessibility in the Graph Visualization application by selecting the **Accessibility Mode** check box option from the user account drop-down menu on the top-right of the user interface. Once enabled, the query output is always displayed in a tabular layout as shown:

Figure 1-7 Enabling Accessibility in the Graph Visualization Application



2 Using Oracle Graph with the Autonomous Database

Oracle Graph with the Autonomous Database allows you to create property graphs from data in your Autonomous Database.

When using Autonomous Database in a shared deployment, you can use Graph Studio, a fully managed service with a powerful user interface for developing applications that use graph analysis. Using Graph Studio, you can automate the modeling of graphs from tables in Autonomous Database. You can interactively analyze and visualize the graph queries using advanced notebooks with multiple visualization options. You can execute over 60 built-in graph algorithms in Graph Studio to gain useful insights on your graph data. See Using Graph Studio in Oracle Autonomous Database for more information.

You can also access few Graph Studio features using the Autonomous Database Graph Client API using the client shell CLIs or through your Java or Python application. See Using Autonomous Database Graph Client for more information.

Alternatively, you can use any version of Oracle Graph Server and Client with the family of Oracle Autonomous Database to create and work with property graphs. This includes any version of Oracle Autonomous Database (shared) or Oracle Autonomous Database (dedicated). You can always upgrade to the latest version of Graph Server and Client regardless of the version of your Autonomous Database. Note that the graph server is managed by the application in this case.

You can connect in two-tier mode (connect directly to Autonomous Database) or three-tier mode (connect to PGX on the middle tier, which then connects to Autonomous Database).

The database schema storing the graph must have the privileges listed in Required Privileges for Database Users.

- Two-Tier Deployments of Oracle Graph with Autonomous Database
  In two-tier deployments, the client graph application connects directly to the Autonomous Database.
- Three-Tier Deployments of Oracle Graph with Autonomous Database
  In three-tier deployments, the client graph application connects to PGX in a middle tier, and PGX connects to the Autonomous Database.

Related Topics

- Using Autonomous Database Graph Client
  Using the `AdbGraphClient` API, you can access Graph Studio features in Autonomous Database programmatically using the Oracle Graph Client or through your Java or Python application.

2.1 Two-Tier Deployments of Oracle Graph with Autonomous Database

In two-tier deployments, the client graph application connects directly to the Autonomous Database.

1. Install Oracle Graph Client, as explained in Installing the Java Client From the Graph Server and Client Downloads.
2. Establish a JDBC connection, as described in the Oracle Autonomous Warehouse documentation.
   You must download the wallet and unzip it to a secure location. You can then reference it when establishing the connection as shown in Example 2-1.
3. Start the Java Shell as shown in the code:

   ```
   /bin/opg4j --no_connect
   ```

4. Connect to your database as shown in Example 2-1.

> **Note:**
>
> If you need to use the Graph Visualization Application, you must additionally install the Oracle Graph Server.
>
> - See Installing Oracle Graph Server for more details.
> - See Deploying the Graph Visualization Application for more details on deploying the Graph Visualization Application in Tomcat or Oracle WebLogic Server.

Example 2-1 Creating a Database Connection in a Two-Tier Graph Deployment with Autonomous Database

```
opg4j> var jdbcUrl = "jdbc:oracle:thin:@<tns_alias>?
TNS_ADMIN=<wallet_location>" // jdbc url to the DB
opg4j> var user = "<user>"
opg4j> var pass = "<password>"
opg4j> var conn = DriverManager.getConnection(jdbcUrl, user, pass) //
connecting to the DB
conn ==> oracle.jdbc.driver.T4CConnection@57e6cb01
```

In the preceding example:

- **<tns_alias>:** TNS alias used in `tnsnames.ora` file
- **<wallet_location>:** Path to the directory where the wallet is stored
- **<user>:** Name of the database user
- **<password>:** Password for the user

2.2 Three-Tier Deployments of Oracle Graph with Autonomous Database

In three-tier deployments, the client graph application connects to PGX in a middle tier, and PGX connects to the Autonomous Database.

The wallets downloaded from the Oracle Cloud Console are mainly *routing wallets*, meaning they are used to route the connection to the right database and to encrypt the connection. In most cases, they are not auto-login wallets, so they do not contain the password for the actual connection. The password usually needs to be provided separately to the wallet location.

The graph server does not support a wallet stored on the client file system or provided directly by remote users. The high level implications of this are:

- The server administrator provides the wallet and stores the wallet securely on the server's file system.
- Similar to Java EE connection pools, remote users will use that wallet when connecting. This means the server administrator trusts all remote users to use the wallet. As with any production deployments, the PGX server must be configured to enforce authentication and authorization to establish that trust.
- Remote users still need to provide a user name and password when sending a graph read request, just as with non-autonomous databases.
- You can only configure one wallet for each PGX server.

Having the same PGX server connecting to multiple Autonomous Databases is not supported. If you have that use case, start one PGX server for each Autonomous Database.

Pre-loaded graphs

To read a graph from Autonomous Database into PGX at server startup, follow the steps described in Store the Database Password in a Keystore to:

1. Create a Java Keystore containing the database password
2. Create a PGX graph configuration file describing the location and properties of the graph to be loaded
3. Update the `/opt/oracle/graph/pgx.conf` file to reference the graph configuration file

As root user, edit the service file at `/etc/systemd/system/pgx.service` and specify the environment variable under the [Service] directive:

```
Environment="JAVA_OPTS=-Doracle.net.tns_admin=/etc/oracle/graph/wallets"
```

Make sure that the directory (`/etc/oracle/graph/wallets` in the preceding code) is readable by the Oracle Graph user, which is the user that starts up the PGX server when using `systemd`.

In addition, edit the `ExecStart` command to specify the location of the keystore containing the password:

```
ExecStart=/bin/bash start-server --secret-store /etc/keystore.p12
```

> **Note:**
>
> Please note that `/etc/keystore.p12` must not be password protected for this to work. Instead protect the file via file system permission that is only readable by `oraclegraph` user.

After the file is edited, reload the changes using:

```
systemctl daemon-reload
```

Finally start the server:

```
sudo systemctl start pgx
```

On-demand graph loading

To allow remote users of PGX to read from the Autonomous Database on demand, you can choose from two approaches:

- Provide the path to the wallet at server startup time via the `oracle.net.tns_admin` system property. Remote users have to provide the TNS address name, username and keystore alias (password) in their graph configuration files. The wallet is stored securely on the graph server's file system, and the server administrator trusts all remote users to use the wallet to connect to an Autonomous Database.

  For example, the server administrator edits the service file at `/etc/systemd/system/pgx.service` and specifies the environment variable the under the [Service] directive:

  ```
  Environment="JAVA_OPTS=-Doracle.net.tns_admin=/etc/oracle/graph/
  wallets"
  ```

  and then start the server using

  ```
  systemctl start pgx
  ```

  The `/etc/oracle/graph/wallets/tnsnames.ora` file contains an address as follows:

  ```
  sombrero_medium = (description= (retry_count=20)(retry_delay=3)
  (address=(protocol=tcps)(port=1522)(host=adb.us-
  ashburn-1.oraclecloud.com))
  (connect_data=(service_name=l8lgholga0ujxsa_sombrero_medium.adwc.ora
  clecloud.com))(security=(ssl_server_cert_dn="CN=adwc.uscom-
  ```

```
east-1.oraclecloud.com,OU=Oracle BMCS US,O=Oracle Corporation,L=Redwood
City,ST=California,C=US")))
```

Now remote users can read data into the server by sending a graph configuration file with the following connection properties:

```
{
  ...
  "jdbc_url": "jdbc:oracle:thin:@sombrero_medium",
  "username": "hr",
  "keystore_alias": "database1",
  ...
}
```

Note that the keystore still lives on the client side and should contain the password for the `hr` user referenced in the config object, as explained in Store the Database Password in a Keystore. A similar approach works for Tomcat or WebLogic Server deployments.

- Use Java EE connection pools in your web application server. Remote users only have to provide the name of the datasource in their graph configuration files. The wallet and the connection credentials are stored securely in the web application server's file system, and the server administrator trusts all remote users to use a connection from the pool to connect to an Autonomous Database.

  You can find instructions how to set up such a data source at the following locations:

  – WebLogic Server: Configuring a WebLogic Data Source to use ATP

  – Tomcat: https://www.oracle.com/technetwork/database/application-development/jdbc/documentation/atp-5073445.html#Tomcat

  If you gave the data source the name *adb_ds*, you can the reference them by sending a graph configuration file with the following connection properties:

```
{
  ...
  "datasource_id": "adb_ds",
  ...
}
```

Part II

SQL Property Graphs

Learn and work with SQL property graphs.

Effective with Oracle Database Release 23c, you can create and query SQL property graphs.

The following chapters provide in-depth information on SQL property graphs:

- Introduction to SQL Property Graphs
  You can work with SQL property graphs in any SQL based interface (such as SQL Developer, SQLPLUS, or SQLcl) or from a Java program using JDBC.
- SQL DDL Statements for Property Graphs
  You can create, revalidate, and drop SQL property graphs using SQL data definition language (DDL) statements.
- SQL GRAPH_TABLE Queries
  You can query a SQL property graph using the `GRAPH_TABLE` operator to express graph pattern matching queries.
- Executing PGQL Queries Against SQL Property Graphs
  You can directly run PGQL queries against a SQL property graph in the database.

3 Introduction to SQL Property Graphs

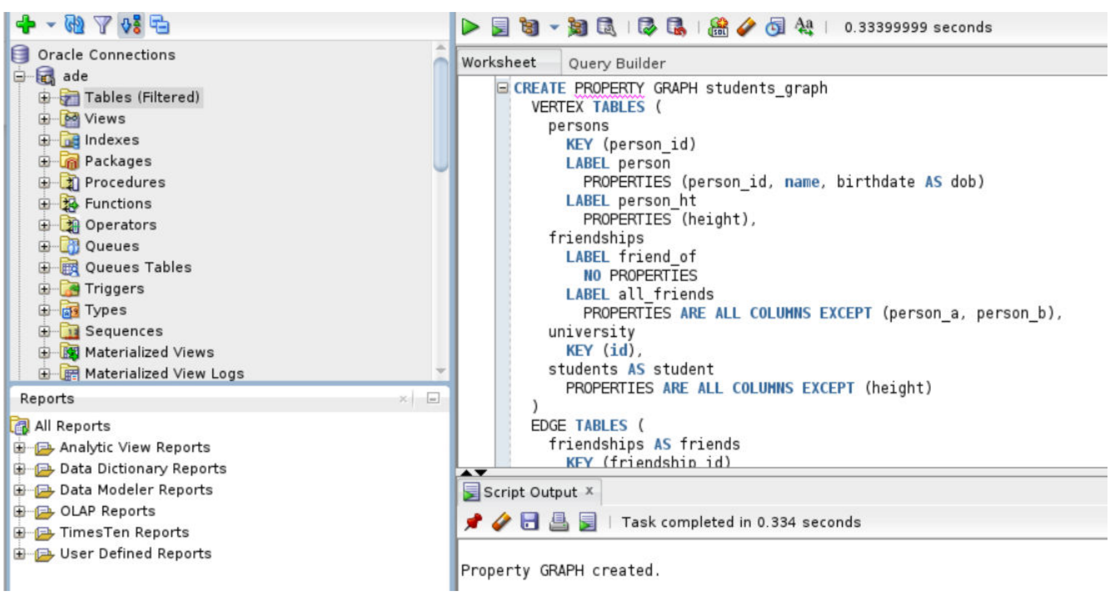
You can work with SQL property graphs in any SQL based interface (such as SQL Developer, SQLPLUS, or SQLcl) or from a Java program using JDBC.

Using SQL statements, you can perform the following:

- Create a SQL property graph from existing database objects in your schema, such as:
  - Tables (with some exceptions as listed in Limitations of Creating a SQL Property Graph)
  - Materialized views
  - External tables
  - Synonyms for any of the preceding database objects
- Create a synonym for a SQL property graph.
- Revalidate a SQL property graph.
- Run graph pattern matching queries on a SQL property graph.
- Drop a SQL property graph.

For example, the following figure shows the creation of a SQL property graph using the SQL Developer tool.

Figure 3-1 Using SQL Developer to Create a SQL Property Graph



- Quick Start for Working with SQL Property Graphs
  This tutorial helps you get started on creating and querying a SQL property graph.

3.1 Quick Start for Working with SQL Property Graphs

This tutorial helps you get started on creating and querying a SQL property graph.

In order to try this tutorial, ensure that you meet the following requirements:

- Load the sample bank graph data provided with the graph server installation in the database tables. See Using Sample Data for Graph Analysis for more information.
- You have the required privileges to create and drop a SQL property graph. See Granting System and Object Privileges for SQL Property Graphs for more information.

In the following tutorial, the examples in Step 1, Step 2, and Step 4 are performed using the SQLcl tool. However, you can run these examples using any SQL based interface.

1. Create a SQL property graph using the `CREATE PROPERTY GRAPH` DDL statement.

```
SQL> CREATE PROPERTY GRAPH bank_sql_pg
       VERTEX TABLES (
         bank_accounts
         KEY (id)
         LABEL account
         PROPERTIES ALL COLUMNS
       )
       EDGE TABLES (
         bank_txns
           KEY (txn_id)
           SOURCE KEY (from_acct_id) REFERENCES bank_accounts (id)
           DESTINATION KEY (to_acct_id) REFERENCES bank_accounts
(id)
           LABEL transfer
           PROPERTIES ALL COLUMNS
       );

Property created.
```

   On execution, the `bank_sql_pg` graph schema object is created in the database. The graph is made up of one vertex graph element table (`bank_accounts`) and one edge graph element table (`bank_txns`).

   See Creating a SQL Property Graph to learn the concepts of graph element tables, keys, labels and properties.

2. Run a `GRAPH_TABLE` query, on the newly created graph, to list all the transactions from the account with `id` value `816`.

```
SQL> SELECT * FROM GRAPH_TABLE (bank_sql_pg
       MATCH
       (a IS account WHERE a.id = 816) -[e IS transfer]-> (b IS
account)
       COLUMNS (a.id AS acc_a, e.amount AS amount, b.id AS acc_b)
     );
```

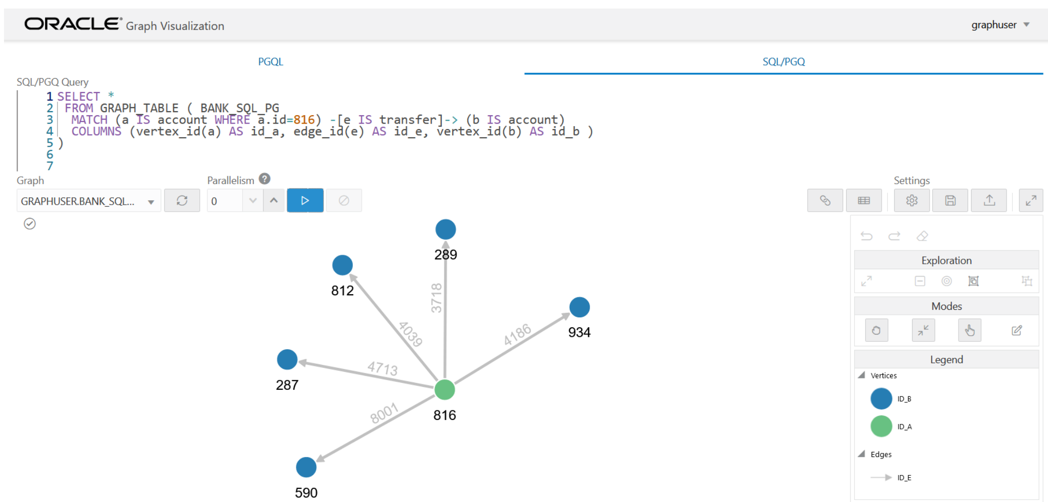
```
     ACC_A      AMOUNT      ACC_B
__________ ___________ __________
       816        4713        287
       816        8001        590
       816        4186        934
       816        3718        289
       816        4039        812
```

See SQL GRAPH_TABLE Queries to understand more about `GRAPH_TABLE` queries..

3. Optionally, if you have installed the graph server (PGX), then you can also visualize the preceding `GRAPH_TABLE` query, using the graph visualization tool.

   The only difference is that you must return the vertex and edge IDs in order to visualize the vertices and edges of the `GRAPH_TABLE` query together with their IDs and all their labels and properties. Note that the `COLUMNS` clause in the following example uses the `VERTEX_ID` and `EDGE_ID` operators:

Figure 3-2   Visualizing GRAPH_TABLE Query



- See Vertex and Edge Identifiers to learn more about the `VERTEX_ID` and `EDGE_ID` operators.
- See Visualizing Graph Queries on SQL Property Graphs for more details.

4. Drop the SQL property graph after running the graph queries.

```
SQL> drop property graph bank_sql_pg;

Property dropped.
```

4
SQL DDL Statements for Property Graphs

You can create, revalidate, and drop SQL property graphs using SQL data definition language (DDL) statements.

- Creating a SQL Property Graph
  Using the `CREATE PROPERTY GRAPH` DDL statement, you can create a property graph schema object directly in an Oracle Database.
- Revalidating a SQL Property Graph
  Using the `ALTER PROPERTY GRAPH COMPILE` DDL statement, you can revalidate an existing property graph schema object in the database.
- Dropping a SQL Property Graph
  Using the `DROP PROPERTY GRAPH` DDL statement, you can remove a property graph schema object in Oracle Database.
- JSON Support in SQL Property Graphs
  When creating a SQL property graph, you can define a label property over a JSON data type column using simplified dot notation. You can later access this property inside the `GRAPH_TABLE` query.

4.1 Creating a SQL Property Graph

Using the `CREATE PROPERTY GRAPH` DDL statement, you can create a property graph schema object directly in an Oracle Database.

Example 4-1 Creating a SQL Property Graph Using the `CREATE PROPERTY GRAPH` DDL Statement

This example creates a SQL property graph, `students_graph`, using `persons`, `university`, `friendships`, and `students` as the underlying database tables for the graph.

In order to run this example, ensure the following:

1. Set up the sample tables in the database as explained in Setting Up Sample Data in the Database.
2. See Granting System and Object Privileges for SQL Property Graphs to ensure you have the required privileges to create a SQL property graph.

```
CREATE PROPERTY GRAPH students_graph
  VERTEX TABLES (
    persons KEY (person_id)
      LABEL person
        PROPERTIES (person_id, name, birthdate AS dob)
      LABEL person_ht
        PROPERTIES (height),
    friendships
      LABEL friend_of
        NO PROPERTIES
      LABEL all_friends
```

```
      PROPERTIES ARE ALL COLUMNS EXCEPT (person_a, person_b),
  university KEY (id),
  students AS student
      PROPERTIES ARE ALL COLUMNS EXCEPT (height)
)
EDGE TABLES (
  friendships AS friends
    KEY (friendship_id)
    SOURCE KEY (person_a) REFERENCES persons(person_id)
    DESTINATION KEY (person_b) REFERENCES persons(person_id)
    PROPERTIES (friendship_id, meeting_date),
  students AS student_of
    SOURCE KEY (s_person_id) REFERENCES persons(person_id)
    DESTINATION KEY (s_univ_id) REFERENCES university(id)
    PROPERTIES (subject)
);
```

On execution, the preceding example creates a SQL property graph object that uses the tables in your schema to define its graph element tables. Note that the creation of the new property graph schema object, results only in the storage of the property graph metadata, and there is no copying of data from the underlying database objects into the graph element tables. This implies that when querying a SQL property graph, all `GRAPH_TABLE` queries are performed on the current graph data in the database. You may also specify another schema to contain the SQL property graph provided that you have sufficient privileges.

The graph definition in the example creates a graph that comprises:

- Four vertex graph element tables:
  - **`persons`:** The table has an explicitly defined unique key, `person_id`, and it is associated with two labels:
    - `person`: This label exposes `person_id`, `name` and `birthdate` as properties.
    - `person_ht`: This label exposes only the `height` property.
  - **`friendships`:** The unique key is implicitly inferred from the underlying database object and the table is associated with two labels:
    - `friend_of`: This label exposes no properties.
    - `all_friends`: This label exposes all columns of the underlying database table as properties, except `person_a` and `person_b`.
  - **`university`:** The label for the table is implicitly inferred and by default all visible columns of the underlying database table are exposed as properties.
  - **`students`:** The table uses a table alias `student` and exposes all columns of the underlying database table as properties, except `height`.
- Two edge graph element tables:
  - **`friends`:** The edge table references `persons` as the underlying database table for both the source and destination vertex tables. The source and destination keys (`person_a` and `person_b`) for the edge table correspond to the unique key of the source and destination vertex tables respectively. The label for the edge table is automatically inferred from the name of the graph element table

(`friends`, in this case) and exposes `friendship_id` and `meeting_date` as properties.

– **`student_of`:** The edge table references `persons` and `university` as the underlying database tables for the source and destination vertex tables respectively. The source and destination keys (`s_person_id` and `s_univ_id`) for the edge table correspond to the unique key of the source and destination vertex tables respectively. The label for the edge table is automatically inferred from the name of the graph element table (`student_of`, in this case) and exposes `subject` as the property.

It is important to note that once a SQL property graph is created, you cannot alter the graph definition. However, you can redefine a SQL property graph using the `OR REPLACE` clause in the `CREATE PROPERTY GRAPH` DDL statement. You can use this clause to change the definition of an existing SQL property graph without dropping, re-creating, and regranting object privileges that were earlier granted on it.

> **See Also:**
>
> CREATE PROPERTY GRAPH in *Oracle Database SQL Language Reference*

The following sections explain more on the concepts of the graph element tables, keys, labels and properties:

- About Vertex and Edge Graph Element Tables
  The vertices and edges of a SQL property graph defined from the underlying database objects are stored in the graph element tables.
- About Vertex and Edge Table Keys
  Each vertex and edge table used in a SQL property graph definition must have a key in order to identify a unique vertex or an edge in a SQL property graph.
- About Labels and Properties
  Labels can be associated to one or more graph element tables and they enrich the graph definition. A label can be defined with or without properties.
- Using Graph Options to Create SQL Property Graphs
  You can use graph options to control the behavior of a SQL property graph at the time of its creation.
- Granting System and Object Privileges for SQL Property Graphs
  Oracle Database 23c introduces new system and object privileges for performing operations on the property graph schema objects.
- Retrieving SQL Creation DDL Using the DBMS_METADATA Package
- Limitations of Creating a SQL Property Graph
  This section lists a few restrictions that apply when creating a SQL property graph.

4.1.1 About Vertex and Edge Graph Element Tables

The vertices and edges of a SQL property graph defined from the underlying database objects are stored in the graph element tables.

A graph element table can either be a vertex table or an edge table.

Refer to the graph definition in Example 4-1 to easily understand the following sections:

Vertex graph element table

- A vertex table is defined using the `VERTEX TABLES` clause.
- Each row in a vertex table corresponds to a vertex of the graph.
- A vertex graph element table has a name that is independent from the name of the underlying database object.
- By default, the name of the vertex graph element table is the same as the name of the underlying database object.
- A vertex table name must be unique for a graph. In case you want to define a SQL property graph with multiple graph element tables from the same database object, then you must specify an alternate graph element table name using the `AS` clause.

Edge graph element table

- An edge table is defined using the `EDGE TABLES` clause.
- It specifies a direct relationship between the source vertex table and the destination vertex table using the `SOURCE` and `DESTINATION` keywords that `REFERENCES` the respective vertex tables.
- Each row in an edge table corresponds to an edge of the graph.
- An edge graph element table has a name that is independent from the name of the underlying database object.
- By default, the name of the edge graph element table is the same as the name of the underlying database object.
- The edge table name must be unique for a graph. An edge table name cannot be shared with a vertex table or another edge table. For instance, in Example 4-1, since the source `friendships` table is used both as a vertex and an edge table, a table alias `friends` is declared using the `AS` clause when defining the edge table.

4.1.2 About Vertex and Edge Table Keys

Each vertex and edge table used in a SQL property graph definition must have a key in order to identify a unique vertex or an edge in a SQL property graph.

The key is defined from one or more columns of the underlying table. The key may be implicitly inferred based on an existing primary key or a unique constraint defined on the underlying table, or explicitly defined. The key should be unique.

However, note that the uniqueness constraint for the key column is required if you create the graph in `ENFORCED MODE`. Otherwise, you can create the graph in `TRUSTED MODE` using key columns that do not have a uniqueness constraint. See Using Graph Options to Create SQL Property Graphs for more information on the different modes that can be applied during graph creation.

Vertex or edge table keys can be defined for any of the following built-in data type columns:

- `VARCHAR2`
- `NVARCHAR2`
- `NUMBER`

- BINARY_FLOAT
- BINARY_DOUBLE
- CHAR
- NCHAR
- DATE
- INTERVAL (both YEAR TO MONTH and DAY TO SECOND)
- TIMESTAMP

Note that the TIMESTAMP WITH TIME ZONE data type is not supported.

Refer to the SQL property graph definition in Example 4-1 to easily understand the following sections:

Vertex Table Key

- By default, the key for a vertex table is automatically identified from a single PRIMARY KEY or UNIQUE key constraint on the underlying database object. If both exist, then the PRIMARY KEY constraint takes precedence over the UNIQUE key constraint.
- If the vertex table key is automatically inferred based on a single UNIQUE key, then the set of columns in that UNIQUE key must also be NOT NULL.
- If the underlying database object does not contain a unique constraint to enforce uniqueness, then you must explicitly define the KEY subclause in the VERTEX TABLES clause, to identify the columns that define a unique key for the vertex table. Note that the column names must match the column names of the underlying database object.
- Composite vertex table keys are also supported.

Edge Table Key

- By default, the key for an edge table is automatically identified from a single PRIMARY KEY or UNIQUE key constraint on the underlying database object. If both exist, then the PRIMARY KEY constraint takes precedence over the UNIQUE key constraint.
- If the edge table key is automatically inferred based on a single UNIQUE key, then the set of columns in that UNIQUE key must also be NOT NULL.
- If the underlying database object does not contain a unique constraint to enforce uniqueness, then you must explicitly define the KEY subclause in the EDGE TABLES clause, to identify the columns that define a unique key for the edge table. Note that the column names must match the column names of the underlying database object.
- By default, the SOURCE and DESTINATION table keys are automatically obtained from a single FOREIGN KEY constraint between the edge table and the underlying source and destination tables respectively.
- However, you must explicitly specify the KEY subclause for the SOURCE and DESTINATION vertex tables, if any of the following applies:
  - There is no FOREIGN KEY constraint between the edge and the referenced vertex tables.
  - There are multiple FOREIGN KEY constraints between the edge and the referenced vertex tables.

- The underlying database objects for the edge table and its source and destination vertex tables are materialized views or external tables.

> **Note:**
>
> All restrictions that apply for primary key constraints on a database object also apply on vertex and edge table keys.

4.1.3 About Labels and Properties

Labels can be associated to one or more graph element tables and they enrich the graph definition. A label can be defined with or without properties.

You can optionally define `LABELS` and `PROPERTIES` for the vertex and edge tables in your graph. When not specified, the graph element tables are automatically assigned a label with the name of the graph element table, and all visible columns are exposed as properties, using the column name as property name.

Refer to the SQL property graph definition in Example 4-1 to easily understand the following sections:

Labels

- By default, the vertex and edge tables are automatically assigned a label with the name of the respective graph element tables.
- The `DEFAULT LABEL` subclause can also be used to explicitly apply the preceding rule.
- You can explicitly assign a new label name to a vertex or an edge graph element table using the `LABEL` subclause.
- Multiple labels can be associated with the same graph element table.
- The same label can be **shared** with multiple graph element tables.
  A label can be associated with more than one graph element table (shared label) provided the following conditions apply:
  - All graph element tables that share this label declare the same set of property names. Note that the property order does not matter in the label definition.
  - Different columns or value expression exposed by the same property name have ***union compatible*** types.
- Also, refer to Type Compatibility Rules for Determining Property Types for more information.

Properties

- By default, all the visible columns of a vertex or an edge table are automatically exposed as properties if there is no label declaration or if the `DEFAULT LABEL` subclause is used in the property graph definition. The property names are the same as the column names of the underlying database object.
- Columns of any Oracle built-in data types can be exposed as properties of labels in a SQL property graph. This includes virtual columns, JSON data type columns, `CLOB` and `BLOB` data types.
  However, the following are not supported:

  - XMLType and SDO_GEOMETRY type columns are not supported.
  - SQL/XML value expressions over XMLType column stored as binary XML, and SDO_GEOMETRY built-in functions over SDO_GEOMETRY object datatype column are allowed as long as they return a value of a type supported for properties. Any general object data type and user defined data type and their corresponding SQL operator value expression over them are not supported.
  - Columns of type ANYTYPE cannot be exposed as property.
- At the time of the SQL property graph creation, the data type of a vertex or edge property is determined as follows:
  - Distinct properties associated with distinct labels have the same data type as the underlying database columns.
  - Properties with the same name coming from different labels have the same data type as the underlying database columns. However, you must use the ALLOW MIXED PROPERTY TYPES option when creating the SQL property graph.
    See Using Graph Options to Create SQL Property Graphs for an example using a shared property name.
  - Properties with the same name coming from the same label will have the UNION ALL compatible type of the underlying database columns. In addition, you must use the ALLOW MIXED PROPERTY TYPES option when creating the SQL property graph:
    * See Using Graph Options to Create SQL Property Graphs for an example using a shared property name in a shared label.
    * See Type Compatibility Rules for Determining Property Types for more information on the type rules that determine the property type.
- If you want to explicitly define the vertex or edge properties for a label, then the following property declarations are supported:
  - **PROPERTIES [ARE] ALL COLUMNS:** To expose all the visible columns of the graph element table as label properties. However, if any columns are added or deleted in the source database object, after the creation of the SQL property graph, then these will not be reflected on the graph.
  - **PROPERTIES [ARE] ALL COLUMNS EXCEPT(<*column_names_list*>):** To expose all the visible columns of the graph element table as label properties except those that are explicitly listed.
  - **PROPERTIES(<*list_of_column_names*>):** To expose only those columns of the graph element table that are explicitly listed as label properties. The property name defaults to the column name.
  - **PROPERTIES(<*column_name AS property_name,...*>):** Same as the preceding option. However, if AS *property_name* is appended to the *column_name*, then *property_name* is used as the property name.
  - **PROPERTIES(<*column_expressions AS property_name,...*>):** To declare a property which is an expression over columns. The AS clause is mandatory in this case. A value expression can either be a SQL operator expression defined over scalar data type columns or JSON expression. See JSON Support in SQL Property Graphs for an example using JSON expressions.
  - **NO PROPERTIES:** No columns are exposed for a label.
- Peudo-columns cannot be exposed as a label property.

4.1.4 Using Graph Options to Create SQL Property Graphs

You can use graph options to control the behavior of a SQL property graph at the time of its creation.

Graph options can be specified at the end of the `CREATE PROPERTY GRAPH` DDL statement using the `OPTIONS` clause. You can use either the `MODE` or `MIXED PROPERTY TYPES` option, or both as required.

Using an Option to Specify the Mode of the Graph

You can specify the **`MODE`** of the graph by using one of the following option values at the time of creating the SQL property graph:

- **`ENFORCED MODE:`** This ensures that there is a dependency to the unique key constraint on the underlying database tables. If used when creating a SQL property graph, the `CREATE PROPERTY GRAPH` statement will throw an error if any of the following conditions apply:
  - The specified vertex or edge table `KEY` for the graph element table is neither a `PRIMARY KEY` nor a `UNIQUE` key defined on `NOT NULL` columns.
  - There is no explicit vertex or edge table `KEY` defined for the graph element table and also the system is unable to automatically identify the default vertex or edge key, as there is no single `PRIMARY KEY` or a single `UNIQUE` key constraint on `NOT NULL` columns on the underlying database table.
  - For a specified edge source key and corresponding source vertex key or for a specified edge destination key and corresponding destination vertex key, there does not exist a corresponding `FOREIGN KEY` between the underlying tables.
  - An edge table has no explicit keys for the source or for the destination and the system is unable to implicitly infer the keys, as there is no single `FOREIGN KEY` constraint between the edge table and the referenced source (or destination) vertex table.

  For example, consider the following `t1` table in the database that does not have any primary key, unique key or a `NOT NULL` constraint.

  ```
  SQL> CREATE TABLE t1 (id NUMBER, name VARCHAR2(10));

  INSERT INTO t1 (id, name) VALUES (1,'John');
  INSERT INTO t1 (id, name) VALUES (2, 'Mary');
  ```

  Create a SQL property graph using `OPTIONS(ENFORCED MODE)` as shown:

  ```
  CREATE PROPERTY GRAPH g
     VERTEX TABLES (
        t1 KEY (id)
           LABEL t PROPERTIES ARE ALL COLUMNS
     ) OPTIONS(ENFORCED MODE);
  ```

  The graph creation fails with the following error as there are no key constraints to enforce uniqueness:

```
ORA-42434: Columns used to define a graph element table key must be NOT NULL
in ENFORCED MODE
```

If you omit the `KEY` clause in the preceding graph definition, then the following error is thrown:

```
ORA-42402: cannot infer key for graph element table T1
```

- **`TRUSTED MODE` (default):** There is no dependency to the unique key constraint on the underlying database tables when using the `TRUSTED` mode. Therefore, the preceding example when run in `TRUSTED` mode will not throw any error. This implies that if you choose to use this option, then you must guarantee the uniqueness of primary keys on each of the graph element tables, as well as valid foreign key references between an edge table and its source and destination tables. Otherwise, your graph query results may be incorrect as the expected guarantees are not met.

Using an Option to Allow or Disallow Different Property Types for Shared Property Names

You can specify the **`MIXED PROPERTY TYPES`** options using one of the following values:

- **`ALLOW MIXED PROPERTY TYPES`:** This ensures that:
  - If two properties with the same name belong to different labels, then they can have completely different types.
    For example, in addition to the sample tables `persons` and `students` (see Setting Up Sample Data in the Database), create the following additional table:

    ```
    CREATE TABLE t2 (id NUMBER, name VARCHAR2(10), height VARCHAR2(4),
    CONSTRAINT t2_pk PRIMARY KEY (id));

    INSERT INTO t2 (id, name, height) VALUES (1,'John', '1.80');
    INSERT INTO t2 (id, name, height) VALUES (2,'Mary','1.65');
    ```

    Run the following `CREATE PROPERTY GRAPH` DDL statement which uses three distinct labels for the same property name, `height`.

    ```
    CREATE PROPERTY GRAPH g1
       VERTEX TABLES (
          persons
            LABEL person PROPERTIES (name, height),
          students
            LABEL student PROPERTIES (height),
          t2
            LABEL t2 PROPERTIES (height)
       )OPTIONS(ALLOW MIXED PROPERTY TYPES);
    ```

    When the graph is created, the property type for `height` in the vertex tables associated with:

    * `LABEL person` is `FLOAT`
    * `LABEL student` is `BINARY_DOUBLE`
    * `LABEL t2` is `VARCHAR`

However, when querying this graph, the property type for `height` is dependent on the label constraint used in the `GRAPH_TABLE` query. See Accessing Label Properties for more information.

– If you are sharing property names inside shared labels, then they should be all union compatible types.
For example, run the following `CREATE PROPERTY GRAPH` DDL statement where the property name `height` is used inside the shared label `t`:

```
CREATE PROPERTY GRAPH g2
   VERTEX TABLES (
      persons
        LABEL t PROPERTIES (height),
      t2
        LABEL t PROPERTIES (height)
   )OPTIONS(ALLOW MIXED PROPERTY TYPES);
```

The graph creation fails as the column `height` in the tables `persons` and `t2` has the data type `FLOAT` and `VARCHAR` respectively which are union incompatible. Therefore, the following error is thrown:

```
ORA-42414: cannot use mixed type for property HEIGHT of label T
```

However, the following graph will get created successfully as `FLOAT` and `BINARY_DOUBLE` belong to the numeric group and are union compatible.

```
CREATE PROPERTY GRAPH g3
   VERTEX TABLES (
      persons
        LABEL t PROPERTIES (height),
      students
        LABEL t PROPERTIES (height)
   )OPTIONS(ALLOW MIXED PROPERTY TYPES);
```

See Type Compatibility Rules for Determining Property Types for more information.

- **`DISALLOW MIXED PROPERTY TYPES` (default):** This ensures that a property with the same name should strictly be the same data type. This applies to all labels irrespective of whether they are associated with a single or multiple graph element tables.
For example, run the following DDL statement using `persons` and `t2` as the underlying database tables:

```
CREATE PROPERTY GRAPH g4
   VERTEX TABLES (
      persons
        LABEL person PROPERTIES (name, height),
      t2
        LABEL t2 PROPERTIES (height)
   );
```

The preceding code uses the default `DISALLOW MIXED PROPERTY TYPES` graph option and therefore throws an error as mixed property types are used in the graph definition:

```
ORA-42414: cannot use mixed type for property HEIGHT of label T2
```

The following table summarizes compatibility rules with respect to the MIXED PROPERTY TYPES options

Description	ALLOW	DISALLOW
Properties with the same name exposed by shared labels[1]	Union-compatible	Types must match
Shared properties[2]	Any	Types must match

1 A label with the same name can be associated with more than one graph element table.

2 A property with the same name can be exposed by different labels.

4.1.5 Granting System and Object Privileges for SQL Property Graphs

Oracle Database 23c introduces new system and object privileges for performing operations on the property graph schema objects.

Table 4-1 System Privileges for Property Graph Schema Objects

System Privileges	Description
CREATE PROPERTY GRAPH	To create a SQL property graph in the grantee's schema
CREATE ANY PROPERTY GRAPH	To create a SQL property graph in any schema except SYS and AUDSYS
ALTER PROPERTY GRAPH	To alter a SQL property graph in the grantee's schema
ALTER ANY PROPERTY GRAPH	To alter a SQL property graph in any schema except SYS and AUDSYS
READ PROPERTY GRAPH	To query a SQL property graph in the grantee's schema
READ ANY PROPERTY GRAPH	To query a SQL property graph in any schema except SYS and AUDSY
SELECT PROPERTY GRAPH	To query a SQL property graph in the grantee's schema
DROP ANY PROPERTY GRAPH	To drop a SQL property graph in any schema except SYS and AUDSYS

Table 4-2 Object Privileges for SQL Property Graphs

Object Privileges	Description
ALTER	To alter a SQL property graph
READ	To query a SQL property graph with a GRAPH_TABLE query
[1]SELECT	To query a SQL property graph with a GRAPH_TABLE query

1 Note that the SELECT privilege behaves exactly as the READ privilege for the SQL property graph object. It is mainly present for compatibility with the SQL standards for a property graph object.

The following shows the examples for granting and revoking the SQL property graph related privileges. Ensure you have SYSDBA access to grant and revoke these privileges:

```
GRANT CREATE PROPERTY GRAPH, CREATE ANY PROPERTY GRAPH,
      ALTER ANY PROPERTY GRAPH, DROP ANY PROPERTY GRAPH,
      READ ANY PROPERTY GRAPH TO <graphuser>;


REVOKE CREATE PROPERTY GRAPH, CREATE ANY PROPERTY GRAPH,
      ALTER ANY PROPERTY GRAPH, DROP ANY PROPERTY GRAPH,
      READ ANY PROPERTY GRAPH FROM <graphuser>;
```

You can share your SQL property graph in the database with another user as shown.

```
GRANT SELECT ON PROPERTY GRAPH <graph_name> TO <schema_user>;
```

4.1.6 Retrieving SQL Creation DDL Using the DBMS_METADATA Package

You can retrieve the creation DDL for you property graph schema object using the `DBMS_METADATA` package.

The following example displays the DDL for the graph created in Creating a SQL Property Graph using the `DBMS_METADATA` package.

```
SQL> SELECT DBMS_METADATA.GET_DDL('PROPERTY_GRAPH', 'STUDENTS_GRAPH')
FROM DUAL;


  CREATE PROPERTY GRAPH "GRAPHUSER"."STUDENTS_GRAPH"
  VERTEX TABLES (
   "GRAPHUSER"."FRIENDSHIPS" AS "FRIENDSHIPS" KEY ("FRIENDSHIP_ID")
      LABEL ALL_FRIENDS PROPERTIES ("FRIENDSHIP_ID", "MEETING_DATE")
      LABEL FRIEND_OF NO PROPERTIES,
   "GRAPHUSER"."PERSONS" AS "PERSONS" KEY ("PERSON_ID")
      LABEL PERSON PROPERTIES ("PERSON_ID", "NAME", "BIRTHDATE" AS
"DOB")
      LABEL PERSON_HT PROPERTIES ("HEIGHT"),
   "GRAPHUSER"."STUDENTS" AS "STUDENT" KEY ("S_ID")
      PROPERTIES ("S_ID", "S_UNIV_ID", "S_PERSON_ID", "SUBJECT"),
   "GRAPHUSER"."UNIVERSITY" AS "UNIVERSITY" KEY ("ID")
      PROPERTIES ("ID", "NAME") )
  EDGE TABLES (
   "GRAPHUSER"."FRIENDSHIPS" AS "FRIENDS" KEY ("FRIENDSHIP_ID")
      SOURCE KEY("PERSON_A") REFERENCES PERSONS ("PERSON_ID")
      DESTINATION KEY("PERSON_B") REFERENCES PERSONS ("PERSON_ID")
     PROPERTIES ("FRIENDSHIP_ID", "MEETING_DATE"),
   "GRAPHUSER"."STUDENTS" AS "STUDENT_OF" KEY ("S_ID")
      SOURCE KEY("S_PERSON_ID") REFERENCES PERSONS ("PERSON_ID")
      DESTINATION KEY("S_UNIV_ID") REFERENCES PERSONS ("ID")
```

```
    PROPERTIES ("SUBJECT") )
OPTIONS (TRUSTED MODE, DISALLOW MIXED PROPERTY TYPES)
```

4.1.7 Limitations of Creating a SQL Property Graph

This section lists a few restrictions that apply when creating a SQL property graph.

- Hybrid partitioned tables, as well as views derived from these tables, cannot be used as graph element tables in a SQL property graph.
- Database links, as well as views defined using these links, cannot be used as graph element tables in a SQL property graph.
- Object tables (that is, table created with `CREATE TABLE x OF myObjectType`) and object views cannot be used as graph element tables in a SQL property graph.
- XMLType table (that is, table created with `CREATE TABLE x OF XMLTYPE ...`) cannot be used as graph element tables in a SQL property graph. However SQL/XML operators, `XMLExists()`, `XMLCast(XMLQuery())` over `XMLType` column stored as binary XML to define property as SQL value expression is supported.
- Columns of type `ANYTYPE` cannot be exposed as properties or as keys for graph element tables.
- Pseudo-columns cannot be exposed as properties or as keys for graph element tables.
- Column expressions that comprise invocations to PL/SQL functions cannot be exposed as properties. Similarly, virtual columns defined over column expressions that comprise invocations to PL/SQL functions cannot be exposed as properties.
- SQL property graph are not editionable.
- A SQL property graph definition cannot be modified once the graph is created. However, you can redefine a SQL property graph using the `OR REPLACE` clause in the `CREATE PROPERTY GRAPH` DDL statement.
- SQL property graph creation is not supported in a shard catalog. However, you can create a property graph over sharded tables in the local shards.

4.2 Revalidating a SQL Property Graph

Using the `ALTER PROPERTY GRAPH COMPILE` DDL statement, you can revalidate an existing property graph schema object in the database.

A SQL property graph schema may become invalid due to the alteration of the underlying database objects. For instance, adding or dropping a column from the underlying database tables, used in the graph definition, can cause the graph to become invalid. Any invalidation of the graph will also invalidate cursors depending on the graph object. In such a case, you can recover your property graph from an **invalid** state as shown in the following example. Also, refer to Granting System and Object Privileges for SQL Property Graphs to ensure you have the required privilege to perform the `ALTER PROPERTY GRAPH` operation.

Example 4-2 Revalidating a SQL Property Graph

```
ALTER PROPERTY GRAPH students_graph COMPILE;
```

See Also:

ALTER PROPERTY GRAPH in *Oracle Database SQL Language Reference*

4.3 Dropping a SQL Property Graph

Using the `DROP PROPERTY GRAPH` DDL statement, you can remove a property graph schema object in Oracle Database.

See Granting System and Object Privileges for SQL Property Graphs to ensure you have the required privilege to drop a SQL property graph.

Example 4-3 Dropping a SQL Property Graph

The following example removes the SQL property graph, `students_graph`, in the database.

```
DROP PROPERTY GRAPH students_graph;
```

Similar to database views, dropping a property graph schema object does not remove the underlying database tables.

See Also:

DROP PROPERTY GRAPH in *Oracle Database SQL Language Reference*

4.4 JSON Support in SQL Property Graphs

When creating a SQL property graph, you can define a label property over a JSON data type column using simplified dot notation. You can later access this property inside the `GRAPH_TABLE` query.

The label property defined over a JSON data type column can be of common SQL scalar data types, such as:

- `VARCHAR`
- `NUMBER`
- `BINARY_FLOAT`
- `BINARY_DOUBLE`
- `DATE`
- `TIMESTAMP`
- raw JSON data converted to a SQL data type via `.string()`, `.number()`, `.float()`, `.double()`, `.date()`, `.timestamp()`, `.binary()` or their equivalent using the `JSON_VALUE` operator

Therefore, you can use either a JSON dot notation or the `JSON_VALUE` operator to select a scalar value in the JSON data to define a SQL property graph label property.

This also applies when accessing a label property defined over the JSON data type column inside a `GRAPH_TABLE` query.

Example 4-4 Defining a SQL Property Graph Using JSON Dot Notation and JSON Expressions for Label Properties

The following example creates a SQL property graph that contains label properties defined over a JSON data type column. The graph is created using the sample database tables (`persons` and `friendships`) defined in Setting Up Sample Data in the Database. The example uses both the JSON dot notation and the `JSON_VALUE` expression to define the label property.

```
CREATE PROPERTY GRAPH friends_graph
  VERTEX TABLES (
      persons AS p KEY (person_id)
        LABEL person
          PROPERTIES (name, birthdate AS dob,
               p.person_data.department.string() AS "works_in",
               JSON_VALUE(person_data, '$.role') AS "works_as")
  )
  EDGE TABLES (
      friendships AS friends
        KEY (friendship_id)
        SOURCE KEY (person_a) REFERENCES p(person_id)
        DESTINATION KEY (person_b) REFERENCES p(person_id)
        PROPERTIES (meeting_date)
  );
```

The graph gets created successfully and you can query the graph as shown in the following example:

Example 4-5 Querying a SQL Property Graph and Accessing Label Properties Defined As SQL/JSON Expressions

The following example queries the SQL property graph created in the preceding example to access the label properties created over a JSON data type column.

```
SELECT * FROM GRAPH_TABLE (friends_graph
  MATCH
   (a IS person) -[e IS friends]-> (b IS person)
   COLUMNS (a.name AS a,
            a."works_in" AS "a_works_in",
            e.meeting_date,
            b.name AS b)
);
```

The query produces the following output:

```
A     a_works_in MEETING_D B
----- ---------- --------- -----
John  IT         01-SEP-00 Bob
Mary  HR         19-SEP-00 Alice
Mary  HR         19-SEP-00 John
Bob   IT         10-JUL-01 Mary
```

Example 4-6 Creating and Querying a SQL Property Graph with JSON Data Type Label Property

The following example creates a SQL property graph with JSON data type label property:

```
CREATE PROPERTY GRAPH friends_graph_new
  VERTEX TABLES (
      persons AS p KEY (person_id)
        LABEL person
          PROPERTIES (name, birthdate AS dob, p.person_data AS
"p_data")
  )
  EDGE TABLES (
      friendships AS friends
        KEY (friendship_id)
        SOURCE KEY (person_a) REFERENCES p(person_id)
        DESTINATION KEY (person_b) REFERENCES p(person_id)
        PROPERTIES (meeting_date)
  );
```

You can then query the graph using a `JSON_VALUE` expression as shown:

```
SELECT * FROM GRAPH_TABLE (friends_graph_new
  MATCH
   (a IS person WHERE JSON_VALUE(a."p_data", '$.department') = 'IT') -
[e]-> (b)
   COLUMNS (a.name AS a,
           a."p_data".department.string() AS "a_works_in",
           a."p_data".role.string() AS "a_works_as",
           e.meeting_date,
           b.name AS b)
  );


A     a_works_in a_works_as           MEETING_D B
----- ---------- -------------------- --------- -----
John  IT         Software Developer   01-SEP-00 Bob
Bob   IT         Technical Consultant 10-JUL-01 Mary
```

5 SQL GRAPH_TABLE Queries

You can query a SQL property graph using the `GRAPH_TABLE` operator to express graph pattern matching queries.

Graph pattern matching allows you to define a path pattern and match it against a graph to obtain a set of solutions. You must provide the graph to be queried as an input to the `GRAPH_TABLE` operator along with the `MATCH` clause containing the graph patterns to be searched as shown:

```
SELECT * FROM GRAPH_TABLE (students_graph
  MATCH
  (a IS person) -[e IS friends]-> (b IS person WHERE b.name = 'Mary')
  WHERE a.name='John'
  COLUMNS (a.name AS person_a, b.name AS person_b)
);
```

A basic `GRAPH_TABLE` query is made up of the following components:

- **`FROM` clause:** It includes the `GRAPH_TABLE` operator which takes the input graph name as the first parameter.
- **`MATCH` clause:** It expresses the graph element patterns (vertex or edge pattern) to be searched on the SQL property graph. It can optionally include an element pattern `WHERE` clause as seen in the preceding example (`(b IS person WHERE b.name = 'Mary')`) query. This in-line `WHERE` clause can access any matched variable.
- **`WHERE` clause:** This is an optional out-of-line `WHERE` clause. Similar to the element pattern `WHERE` clause, it has access to all the graph pattern variables and expresses a predicate that applies to the entire pattern in the `MATCH` clause.
- **`COLUMNS` clause:** This contains the query output columns.

> **See Also:**
>
> GRAPH_TABLE Operator in *Oracle Database SQL Language Reference*

The following sections explain `GRAPH_TABLE` queries in detail:

- About Graph Patterns
  A SQL `GRAPH_TABLE` query is composed of graph patterns.
- Variable-Length Path Patterns
  Variable-length graph patterns provide advanced querying support for SQL property graphs.
- Complex Path Patterns
  You can query a SQL property graph using complex path patterns.

- Vertex and Edge Identifiers
  You can uniquely identify each vertex and edge in a SQL property graph with the `VERTEX_ID` and `EDGE_ID` operators, respectively, in a `GRAPH_TABLE` query.
- Running GRAPH_TABLE Queries at a Specific SCN
  You can run a `GRAPH_TABLE` query at a given System Change Number (SCN) or timestamp value.
- Privileges to Query a SQL Property Graph
  You must have the `READ` or `SELECT` object privilege to query a SQL property graph.
- Examples for SQL Property Graph Queries
  This section contains a few examples for querying a SQL property graph with fixed-length and variable-length graph pattern matching queries.
- Supported Features and Limitations for Querying a SQL Property Graph
  This section provides the list of supported and unsupported features for querying a SQL Property Graph.
- Tuning SQL Property Graph Queries
  You can tune a SQL `GRAPH_TABLE` query using the `EXPLAIN PLAN` statement.
- Type Compatibility Rules for Determining Property Types
  When using shared property names that are union compatible, the property type is determined by certain type compatibility rules.

5.1 About Graph Patterns

A SQL `GRAPH_TABLE` query is composed of graph patterns.

Graph patterns are expressed between the input graph name and the `COLUMNS` clause in a `GRAPH-TABLE` query.

Graph patterns are made up of one or more vertex and edge patterns. For example, the following graph pattern has two vertex patterns and one edge pattern:

```
(v1) -[e]-> (v2)
```

A vertex pattern is enclosed in parentheses and specifies how to match a single vertex. An edge pattern is enclosed by a square bracket with delimiters on the left and right side of the edge pattern and specifies how to match a single edge.

Also, the available arrow tokens for edge patterns are summarized in the following table:

Table 5-1 Arrow Tokens for Edge Patterns

Directionality	Bracketed Syntax	Abbreviated Syntax[1]
Directed to the right	`-[ ]->`	`->`
Directed to the left	`<-[ ]-`	`->`
Any directed edge (right or left)	`<-[ ]->` or `-[ ]-`	`-`

1
- There are no brackets for the arrows in the “abbreviated syntax” column.
- All edge labels will be considered as no edge label is specified. Hence, filtering on a specific edge is not supported.

A graph element pattern (which can either be a vertex or an edge pattern) may in turn optionally include:

- An element variable.
- A label expression which is that part in an element pattern that starts with the keyword `IS` and is followed by a list of one or more label names. If there is more than one label name, then these are separated by vertical bars.
- An element pattern `WHERE` clause which expresses a search condition on the element variable declared by the element pattern.

The following sections explain the graph pattern concepts more in detail:

- Graph Element Variables
  Vertex and edge pattern variables ranges over vertices and edges respectively.
- Label Expressions
  A label expression in a vertex or an edge element pattern is introduced by the keyword `IS`.
- Accessing Label Properties
  You can access a property inside a graph element pattern, in the out-of-line `WHERE` clause or in the `COLUMNS` clause.

5.1.1 Graph Element Variables

Vertex and edge pattern variables ranges over vertices and edges respectively.

For example, consider the following graph pattern which contains three graph element variables.

```
(v1)–[e]->(v2)
```

In the preceding graph pattern, `v1` and `v2` are two vertex pattern variables and `e` is an edge pattern variable.

Ensure that you apply the following rules for the graph pattern variables:

- You cannot use the same variable name for both a vertex and an edge.
- You can use the same variable name in two different vertex patterns as shown:
  `MATCH (a IS person) -> (a IS person)`

  In the preceding example, the vertex variable `a` is used in two vertex patterns - `(a IS person)` and `(a IS person)`. This implies that the two vertex patterns that declare the same vertex variable must bind to the same vertex. Thus the vertex variable binds to a unique vertex but the vertex pattern can appear multiple times in the same graph pattern.
- You can use the same variable name in two different edge patterns.
- Anonymous (that is, omitted) vertex and edge variables are supported. See Example 5-8.

5.1.2 Label Expressions

A label expression in a vertex or an edge element pattern is introduced by the keyword `IS`.

For example, in the following graph pattern, the vertex pattern associated with the graph element variable `v1` has the label `person`. Also, the edge pattern associated with the graph element variable `e` contains the label `friendOf`:

```
(v1 IS person)-[e IS friendOf]->(v2)
```

If the label is omitted in a graph element pattern, then the default is to query all vertices or edges.

A label expression can also include an optional in-line SQL search condition that can access any matched variable. When accessing a property, you must specify a graph pattern variable.

The supported vertex and edge label expressions are described in the following table:

Table 5-2 Supported Vertex and Edge Label Expressions

Vertex Label Expression	Edge Label Expression	Description
`(a)`	`[e]`	• The vertex graph pattern variable `a` may match a vertex with any label. • The edge graph pattern variable `e` may match an edge with any label.
`()`	`[]`	• The vertex pattern has no label and can match any vertex. • The edge pattern has no label and can match any edge. When a graph pattern variable is not specified, a unique vertex or edge variable name is internally generated by the system. Therefore, you cannot reference the vertex or edge elsewhere in the query, as it is unknown.
`(IS person)`	`[IS friend_of]`	• The vertex pattern has only the `person` label. • The edge pattern has only the `friend_of` label. When a graph pattern variable is not specified, a unique vertex or edge variable name is internally generated by the system. Therefore, you cannot reference the vertex or edge elsewhere in the query, as it is unknown.
`(IS person|place|thing)`	`[IS friend_of|student_of]`	• The vertex pattern has an alternation of three labels, `person`, `place` and `thing`. This implies that the vertex pattern can match any vertex having those labels. • The edge pattern has an alternation of two labels, `friend_of` and `student_of`. This implies that the edge pattern can match any edge having those labels. As there is no explicit graph pattern variable in the vertex or edge pattern, you cannot reference this vertex or edge elsewhere in the query.

Table 5-2 (Cont.) Supported Vertex and Edge Label Expressions

Vertex Label Expression	Edge Label Expression	Description
`(a IS person|place|thing)`	`[e IS friend_of|student_of]`	Same as the preceding table entry. However, the vertex and edge patterns contain `a` and `e` as vertex and edge graph pattern variables respectively. Therefore, you can reference the vertex or edge using the respective graph pattern variables elsewhere in the query. See Example 5-12 which describes a `GRAPH_TABLE` query that uses label disjunction in the vertex pattern.
`(a IS person), (a IS car)`	`(a)-[e IS L1]->(b), (a)-[e is L2]->(b)`	• The vertex pattern `a IS person` implies that `a` must match vertices having the label `person`, and the vertex pattern `a IS car` implies that `a` must match vertices having the label `car`. Therefore, this represents that `a` must match vertices having both `person` and `car` as labels, effectively an `AND` of these two conditions. Also, you can reference a vertex as `a` elsewhere in the query. • The edge pattern `e IS L1` implies that `e` must match edges having the label `L1`, and the edge pattern `e IS L2` implies that `e` must match edges having the label `L2`. Therefore, this represents that `e` must match edges having both `L1` and `L2` as labels, effectively an `AND` of these two conditions. Also, you can reference an edge as `e` elsewhere in the query. See Example 5-13 which describes a `GRAPH_TABLE` query that uses conjunction of labels in the vertex pattern.
`(a IS person WHERE a.name = 'Fred')`	`[e IS student_of WHERE e.subject = 'Arts']`	• The vertex pattern has a label `person` and a vertex graph pattern variable `a`, which is qualified in the element pattern `WHERE` clause. • The edge pattern has a label `student_of` and an edge graph pattern variable `e`, which is qualified in the element pattern `WHERE` clause. The only graph pattern variable that is visible within an element pattern is the graph pattern variable defined locally by the element pattern. Graph pattern variables from another element patterns cannot be accessed. See Example 5-5.

5.1.3 Accessing Label Properties

You can access a property inside a graph element pattern, in the out-of-line WHERE clause or in the COLUMNS clause.

Consider the following graph element pattern where a is a graph element variable and name is a property name:

```
(a IS person WHERE a.name='John')
```

You can then reference the property in the WHERE clause inside the graph element pattern as a.name. This means a.name references the property name of the graph element bound to the graph pattern variable a.

Also, the following conditions apply when accessing a property:

- The property name is part of at least one table that satisfies the label expression.
- A graph variable name must always be used to access a property.
- At the time of the GRAPH_TABLE query compilation, certain type checking rules apply for the vertex or edge table properties. See Type Compatibility Rules for Determining Property Types for more information.

The following examples describe a few scenarios for determining property types when querying SQL property graphs. Note that Example 5-1 to Example 5-3 refer to the SQL property graph definition for g1 which contains height as a shared property across different labels.

Example 5-1 Determining the Property Type for a Single Label

The data type for a.height in the following query is FLOAT:

```
SELECT * FROM GRAPH_TABLE (g1
MATCH
(a IS person)
COLUMNS (a.height)
);
```

The query output is as shown:

```
HEIGHT
----------
       1.8
      1.65
      1.75
       1.7
```

Example 5-2 Determining Union Compatible Property Type for Two Different Labels

The data type for a.height in the following query is the union compatible type between FLOAT and BINARY_DOUBLE:

```
SELECT * FROM GRAPH_TABLE (g1
MATCH
(a IS person|student)
COLUMNS (a.height)
);
```

The query output is as shown:

```
HEIGHT
----------
  1.8E+000
 1.65E+000
 1.75E+000
  1.7E+000
  1.8E+000
 1.65E+000
 1.75E+000
  1.7E+000
```

In the SQL property graph g1, the property type for height associated with the labels person and student is FLOAT and BINARY_DOUBLE respectively. BINARY_DOUBLE takes precedence over FLOAT and hence the resulting output property type for a.height is BINARY_DOUBLE.

Example 5-3 No Union Compatible Property Type for Two Different Labels

Error is thrown for the following query as the data type for a.height is not union compatible across the tables, person (FLOAT) and t2 (VARCHAR):

```
SELECT * FROM GRAPH_TABLE (g1
  MATCH
   (a IS person|t2)
  COLUMNS (a.height)
  );
```

On execution. the preceding query throws the error - ORA-01790: expression must have same datatype as corresponding expression

Example 5-4 Determining Union Compatible Property Type for Shared Labels

Consider the SQL property graph definition for g3 which uses a shared label (t) that is associated with a shared property name (height).

When querying g3, the data type for a.height in the following GRAPH_TABLE query is BINARY_DOUBLE:

```
SELECT * FROM GRAPH_TABLE (g3
MATCH
(a IS t)
```

```
COLUMNS (a.height)
);
```

The query output is a union of the property columns across all the graph element tables sharing the label. Also, the property type is BINARY_DOUBLE as per the Type Compatibility Rules for Determining Property Types:

```
HEIGHT
----------
  1.8E+000
 1.65E+000
 1.75E+000
  1.7E+000
  1.8E+000
 1.65E+000
 1.75E+000
  1.7E+000
```

5.2 Variable-Length Path Patterns

Variable-length graph patterns provide advanced querying support for SQL property graphs.

Variable-length graph patterns require recursion such that there is a variable number of joins when translated into a relational query.

Bounded recursive path patterns that include one or more of the following quantifiers are supported:

Table 5-3 Quantifier Support for Variable-Length Graph Patterns

Quantifier	Description
{n}	Exactly n
{n, m}	Between n and m (inclusive)
{, m}	Between 0 and m (inclusive)
?	0 or 1

Note that the maximum upper bound limit for the quantifiers in the preceding table is 10.

See Example 5-14 for sample GRAPH_TABLE queries using the quantifiers described in the preceding table.

5.3 Complex Path Patterns

You can query a SQL property graph using complex path patterns.

Cyclic Path Patterns

Vertex and edge path patterns can form cycles. For instance, consider the following graph pattern:

```
MATCH (a IS person) -[IS friends]-> (a IS person)
```

The preceding graph pattern describes a single path pattern, and it contains the vertex variable `a` twice. Thus, this finds cycles in the graph such that `a` binds to a `person` that has a `friends` edge to itself.

Also, note the following:

- The label `person` for the vertex variable `a` need not be repeated twice. The result is the same with or without repeating the label expression.
- You can use multiple in-line `WHERE` clauses to add conditions on the same pattern variable.
- Using the same edge variable twice in a path pattern also has the semantics that the edges must be the same.

Cycles can be longer than a single edge. See Example 5-11.

Multiple Path Patterns

A `MATCH` clause may have more than one path pattern, in a comma-separated list. For instance, the following example shows two path patterns:

```
MATCH (a IS person WHERE a.name='John') -[IS student_of]-> (b IS university),
(a IS person WHERE a.name='John') -[IS friends]-> (c IS person)
```

Any graph pattern variables in common between two path patterns denotes an overlap between the path patterns. In the preceding example, the vertex variable `a` is shared. Note that the variable `a` must bind to the same graph element table in each element pattern of the graph pattern, and thus there is an implicit natural inner join on such repeated graph pattern variables.

If there are no shared variables between the two path patterns, then the resulting output set is a cross product of the outputs of the individual path patterns. See Example 5-9 and Example 5-10.

5.4 Vertex and Edge Identifiers

You can uniquely identify each vertex and edge in a SQL property graph with the `VERTEX_ID` and `EDGE_ID` operators, respectively, in a `GRAPH_TABLE` query.

Graph element identifiers are based on the key value defined for the graph element tables. Therefore, it is important to note the following:

- Graphs in `TRUSTED` mode may produce duplicate identifiers for different vertices if some key columns do not have a `UNIQUE` constraint.
- Graphs in `ENFORCED` mode are guaranteed to always produce unique identifiers.

The `VERTEX_ID` and `EDGE_ID` operators can be used in any expression appearing in the `COLUMNS` or `WHERE` clause in a `GRAPH_TABLE` query.

> **Note:**
>
> In order to use the VERTEX_ID and EDGE_ID operators, you must ensure that you have the READ or SELECT privilege on both the property graph object and its underlying database tables.

The input to the VERTEX_ID operator is a single vertex graph pattern variable coming from a matched vertex pattern as shown:

```
MATCH (v) COLUMNS(VERTEX_ID(v) AS v_id)
```

Similarly, the EDGE_ID operator takes as input a single edge graph pattern variable coming from a matched edge pattern as shown:

```
MATCH (v1)-[e]->(v2) COLUMNS(EDGE_ID(e) AS e_id)
```

The output of these operators is a vertex or an edge identifier of JSON data type. The following shows an example of a JSON output describing the vertex identifier:

```
{
  "GRAPH_OWNER": "GRAPHUSER",
  "GRAPH_NAME": "STUDENTS_GRAPH",
  "ELEM_TABLE": "PERSONS",
  "KEY_VALUE": {
    "PERSON_ID": 1
  }
}
```

In the preceding JSON output:

- **GRAPH_OWNER:** Owner of the property graph object
- **GRAPH_NAME:** Name of the property graph object
- **ELEM_TABLE:** Name of the vertex table
- **KEY_VALUE:** Name and value of the key column

The same list of JSON output fields apply to an edge identifier also. However, the ELEM_TABLE field represents the name of an edge table. Also, all operations that can be performed on a JSON data type can be performed on the vertex and edge identifiers.

See Example 5-19 for more information.

VERTEX_EQUAL and EDGE_EQUAL Predicates

The VERTEX_EQUAL and EDGE_EQUAL predicates can be used to, respectively, compare two vertex and edge identifiers and return TRUE if they are equal.

The inputs to the VERTEX_EQUAL predicate are two vertex graph pattern variables. Similarly for EDGE_EQUAL, both inputs must be edge graph pattern variables. These predicates can be used in the WHERE clause in a GRAPH_TABLE query.

See Example 5-20 for more information.

5.5 Running GRAPH_TABLE Queries at a Specific SCN

You can run a `GRAPH_TABLE` query at a given System Change Number (SCN) or timestamp value.

The graph name, which is the first operand of a `GRAPH_TABLE` query, can be associated with either of the following clauses:

- `AS OF SCN`: Refer to Example 5-17
- `AS OF TIMESTAMP`: Refer to Example 5-18

5.6 Privileges to Query a SQL Property Graph

You must have the `READ` or `SELECT` object privilege to query a SQL property graph.

If you are the graph creator, then you can allow other graph users to query your graph by granting any one of the following privileges:

```
GRANT READ ON PROPERTY GRAPH <graph_name> TO <schema_user>;
GRANT SELECT ON PROPERTY GRAPH <graph_name> TO <schema_user>;
```

It is important to note that granting the preceding privileges allows access only to the property graph object and not to its underlying database tables.

This allows the graph user to successfully run `GRAPH_TABLE` queries on your graph without having access to the underlying tables. For example:

```
GRANT READ ON PROPERTY GRAPH students_graph TO hr;

SQL> conn hr/<password_for_hr>;
Connected.
SQL> SELECT * FROM GRAPH_TABLE (graphuser.students_graph MATCH (a IS person)
COLUMNS (a.name AS person_a));

PERSON_A
----------
John
Mary
Bob
Alice
```

However, to perform `GRAPH_TABLE` queries with `VERTEX_ID` and `EDGE_ID` operators, the graph user must additionally have `READ` or `SELECT` privilege on the underlying database tables.

5.7 Examples for SQL Property Graph Queries

This section contains a few examples for querying a SQL property graph with fixed-length and variable-length graph pattern matching queries.

All the queries shown in the examples are run on the SQL property graph, `students_graph`, created in Example 4-1:

Example 5-5 GRAPH_TABLE Query Using An Edge Pattern Directed Left-To-Right

The following example shows a `GRAPH_TABLE` query containing an edge pattern (`-[e IS friends]->`) which is directed from left-to-right:

```
SELECT * FROM GRAPH_TABLE (students_graph
  MATCH
  (a IS person) -[e IS friends]-> (b IS person WHERE b.name='Alice')
  WHERE a.name='Mary'
  COLUMNS (a.name AS person_a, b.name AS person_b)
);
```

The code produces the following output:

```
PERSON_A   PERSON_B
---------- ----------
Mary       Alice
```

Example 5-6 GRAPH_TABLE Query Using An Edge Pattern Directed Right-To-Left

The following example shows a `GRAPH_TABLE` query containing an edge pattern (`<-[e IS friends]-`) which is directed from right-to-left:

```
SELECT * FROM GRAPH_TABLE (students_graph
  MATCH
  (a IS person) <-[e IS friends]- (b IS person WHERE b.name='Mary')
  WHERE a.name='Alice'
  COLUMNS (a.name AS person_a, b.name AS person_b)
);
```

The code produces the following output:

```
PERSON_A   PERSON_B
---------- ----------
Alice      Mary
```

Example 5-7 GRAPH_TABLE Query Using Any-Directed Edge Pattern

The following example shows a `GRAPH_TABLE` query which contains any-directed edge pattern (`-[e IS friends]-`):

```
SELECT * FROM GRAPH_TABLE (students_graph
  MATCH
  (a IS person) -[e IS friends] - (b IS person WHERE b.name='Alice' OR
b.name='Mary')
  WHERE (a.name='Alice' OR a.name='Mary')
  COLUMNS (a.name AS person_a, b.name AS person_b)
);
```

The code produces the following output:

```
PERSON_A   PERSON_B
---------- ----------
Mary       Alice
Alice      Mary
```

Example 5-8 `GRAPH_TABLE` Query Using an Anonymous Edge Variable

The following example shows a `GRAPH_TABLE` query where the edge element variable is omitted:

```
SELECT * FROM GRAPH_TABLE (students_graph
  MATCH
  (a IS person) -[]-> (b IS person)
  COLUMNS (a.name AS person_a, b.name AS person_b)
  );
```

Alternatively, you can replace the bracketed syntax for the edge pattern (`-[]->`) in the preceding query with an abbreviated syntax `->`.

The code produces the following output:

```
PERSON_A   PERSON_B
---------- ----------
Mary       John
Bob        Mary
John       Bob
Mary       Alice
```

Example 5-9 `GRAPH_TABLE` Query Using Multiple Path Patterns

The following example shows a `GRAPH_TABLE` query containing two path patterns (`a)->(b)`, `(a)->(c)`) which have a common vertex as shown:

```
SELECT * FROM GRAPH_TABLE (students_graph
  MATCH
  (a IS person WHERE a.name = 'John') -> (b IS person),(a IS person WHERE
a.name = 'John') -> (c IS university)
  COLUMNS (a.name AS person_a, b.name AS person_b,c.name as university)
  );
```

The preceding code produces the following output:

```
PERSON_A   PERSON_B   UNIVERSITY
---------- ---------- ----------
John       Bob        ABC
```

Example 5-10 GRAPH_TABLE Query Using Disjoint Path Patterns

The following example shows a GRAPH_TABLE query containing two disjoint path patterns:

```
SELECT * FROM GRAPH_TABLE (students_graph
MATCH (a IS person WHERE a.name='John') -[IS student_of]-> (b IS
university),
(x IS person) -[IS friends]-> (y IS person)
COLUMNS (a.name AS a, b.name as university, x.name AS x, y.name as y)
);
```

The resulting output is as shown:

```
A          UNIVERSITY X          Y
---------- ---------- ---------- ----------
John       ABC        Mary       John
John       ABC        Bob        Mary
John       ABC        John       Bob
John       ABC        Mary       Alice
```

Example 5-11 GRAPH_TABLE Query Using Cyclic Path Patterns

The following example uses a cyclic path pattern (`MATCH (a)-[]->(b)-[]->(c)-[]->(a)`) as shown. Note that the example uses the same vertex pattern variable name `a` (which is bound to `person`) twice. Thus, this finds cycles in the graph containing three edges that finally bind to `a` itself.

```
SELECT * FROM GRAPH_TABLE (students_graph
  MATCH
  (a IS person) -[IS friends]-> (b IS person) -[IS friends]->
  (c IS person) -[IS friends]-> (a)
  COLUMNS (a.name AS person_a, b.name AS person_b, c.name AS person_c)
  );
```

The preceding code produces the following output:

```
PERSON_A   PERSON_B   PERSON_C
---------- ---------- ----------
Bob        Mary       John
John       Bob        Mary
Mary       John       Bob
```

Example 5-12 GRAPH_TABLE Query Using Label Disjunction

The following example uses label disjunction in the vertex label expression:

```
SELECT * FROM GRAPH_TABLE (students_graph
MATCH
(a is person|university)
COLUMNS (a.name, a.dob)
);
```

The code produces the following output:

```
NAME       DOB
---------- ---------
John       13-JUN-63
Mary       25-SEP-82
Bob        11-MAR-66
Alice      01-FEB-87
ABC        NULL
XYZ        NULL

6 rows selected.
```

Example 5-13 GRAPH_TABLE Query Using Label Conjunction

The following example uses label conjunction in the vertex label expression:

```
SELECT * FROM GRAPH_TABLE (students_graph
MATCH
(a IS person), (a IS person_ht)
COLUMNS (a.name as name, a.dob as dob, a.height as height )
);
```

The code produces the following output:

```
NAME       DOB           HEIGHT
---------- --------- ----------
John       13-JUN-63        1.8
Mary       25-SEP-82       1.65
Bob        11-MAR-66       1.75
Alice      01-FEB-87        1.7
```

Example 5-14 GRAPH_TABLE Queries Using Recursive Path Patterns with Bounded Quantifiers

The following example uses a recursive path pattern to retrieve all friends within two hops:

```
SELECT * FROM GRAPH_TABLE (students_graph
MATCH (a is person WHERE a.name='Mary') -[is friends]->{2} (b is person)
COLUMNS (a.name AS a , b.name AS b)
);
```

The preceding code produces the following output:

```
A          B
---------- ----------
Mary       Bob
```

The following example uses a recursive path pattern to retrieve all friends between one and two hops (inclusive):

```
SELECT * FROM GRAPH_TABLE (students_graph
MATCH (a is person WHERE a.name='Mary') -[is friends]->{1, 2} (b is
person)
COLUMNS (a.name AS a , b.name AS b)
);
```

The preceding code produces the following output:

```
A          B
---------- ----------
Mary       Alice
Mary       John
Mary       Bob
```

The following example uses a recursive path pattern to retrieve all friends by performing from zero to two iterations:

```
SELECT * FROM GRAPH_TABLE (students_graph
MATCH (a is person WHERE a.name='Mary') -[is friends]->{,2} (b is
person)
COLUMNS (a.name AS a , b.name AS b)
);
```

The preceding code produces the following output:

```
A          B
---------- ----------
Mary       Mary
Mary       Alice
Mary       John
Mary       Bob
```

Note that in the first line of the preceding output, `Mary` is bound to both the element pattern variables, `a` and `b`. This is because the `GRAPH_TABLE` query includes a zero hop iteration and therefore, the vertex pattern to the left and the vertex pattern to the right must bind to the same graph element.

Example 5-15 `GRAPH_TABLE` Query Using Bind Variables

The example declares a bind variable, `name` and assigns a value as shown:

```
SQL> variable name VARCHAR2(10);
SQL> BEGIN
  2  :name := 'Bob';
  3  END;
  4  /

PL/SQL procedure successfully completed.
```

Using this bind variable, the following GRAPH_TABLE query is performed:

```
SELECT * FROM GRAPH_TABLE (students_graph
  MATCH
  (a IS person) -[e IS friends]-> (b IS person WHERE b.name=:name)
  WHERE a.name='John'
  COLUMNS (a.name AS person_a,
           b.name AS person_b,
           e.meeting_date AS met_on)
);
```

The code produces the following output:

```
A          B          MET_ON
---------- ---------- ---------
John       Bob        01-SEP-00
```

Example 5-16 GRAPH_TABLE Query Invoking a PL/SQL function Inside an Expression and in the COLUMNS Clause

The example declares a user defined function(UDF) as shown:

```
CREATE OR REPLACE FUNCTION get_age(
    id NUMBER
)
RETURN NUMBER
AS
    age NUMBER := 0;
BEGIN
    -- get age
      SELECT (EXTRACT(YEAR from SYSDATE) - EXTRACT(YEAR from birthdate))
      INTO age
      FROM persons
      WHERE person_id=id;
    -- return age
    RETURN age;
END;
/

Function created.
```

The following GRAPH_TABLE query invokes the UDF inside an expression in the WHERE clause and again in the COLUMNS clause:

```
SELECT * FROM GRAPH_TABLE (students_graph
  MATCH
   (a IS person) -[e IS friends]-> (b IS person)
  WHERE (get_age(a.person_id) > 40)
  COLUMNS (a.name AS a,
        get_age(a.person_id) AS age,
           b.name AS b,
```

```
          e.meeting_date AS met_on)
  );
```

The code produces the following output:

```
A                 AGE B          MET_ON
---------- ---------- ---------- ---------
Bob                56 Mary       10-JUL-01
John               59 Bob        01-SEP-00
```

Example 5-17 `GRAPH_TABLE` Query Using `SCN`

Determine the current `SCN` value of the database as shown:

```
SQL>  SELECT TIMESTAMP_TO_SCN(SYSDATE) FROM DUAL;

TIMESTAMP_TO_SCN(SYSDATE)
-------------------------
                  2117789
```

The following `GRAPH_TABLE` query using the preceding `SCN` value as shown:

```
SELECT * FROM GRAPH_TABLE (students_graph AS OF SCN 2117789
  MATCH
   (a IS person) -[e]-> (b IS person)
  COLUMNS (a.name AS a, b.name AS b, e.meeting_date AS met_on)
  );
```

The query produces the following output:

```
A          B          MET_ON
---------- ---------- ---------
Mary       John       19-SEP-00
Bob        Mary       10-JUL-01
John       Bob        01-SEP-00
Mary       Alice      19-SEP-00
```

Example 5-18 `GRAPH_TABLE` Query Using `TIMESTAMP`

The following `GRAPH_TABLE` query uses a `TIMESTAMP` value as shown:

```
SQL> SELECT * FROM GRAPH_TABLE (students_graph AS OF TIMESTAMP
SYSTIMESTAMP
  MATCH
   (a IS person WHERE a.name='John') -[e]-> (b IS person)
  COLUMNS (a.name AS a, b.name AS b, e.meeting_date AS met_on)
  );
```

The query produces the following output:

```
A          B          MET_ON
---------- ---------- ---------
John       Bob        01-SEP-00
```

Example 5-19 GRAPH_TABLE Query Using the VERTEX_ID and EDGE_ID Identifiers

```
SELECT * FROM GRAPH_TABLE (students_graph
MATCH
 (a IS person ) -[e IS friends]-> (b IS person)
COLUMNS (JSON_SERIALIZE(VERTEX_ID(a)) AS id_a , JSON_SERIALIZE(EDGE_ID(e))
AS id_e)
);
```

The query produces a JSON data type output that includes the graph owner, graph name and graph element table name and the key value as shown:

```
ID_A                           ID_E
---------------------------- ------------------------------
{"GRAPH_OWNER":"GRAPHUSER",  {"GRAPH_OWNER":"GRAPHUSER","GR
"GRAPH_NAME":"STUDENTS_GRAP  APH_NAME":"STUDENTS_GRAPH","EL
H","ELEM_TABLE":"PERSONS","  EM_TABLE":"FRIENDS","KEY_VALUE
KEY_VALUE":{"PERSON_ID":1}}  ":{"FRIENDSHIP_ID":1}}

{"GRAPH_OWNER":"GRAPHUSER",  {"GRAPH_OWNER":"GRAPHUSER","GR
"GRAPH_NAME":"STUDENTS_GRAP  APH_NAME":"STUDENTS_GRAPH","EL
H","ELEM_TABLE":"PERSONS","  EM_TABLE":"FRIENDS","KEY_VALUE
KEY_VALUE":{"PERSON_ID":2}}  ":{"FRIENDSHIP_ID":2}}

{"GRAPH_OWNER":"GRAPHUSER",  {"GRAPH_OWNER":"GRAPHUSER","GR
"GRAPH_NAME":"STUDENTS_GRAP  APH_NAME":"STUDENTS_GRAPH","EL
H","ELEM_TABLE":"PERSONS","  EM_TABLE":"FRIENDS","KEY_VALUE
KEY_VALUE":{"PERSON_ID":2}}  ":{"FRIENDSHIP_ID":3}}

{"GRAPH_OWNER":"GRAPHUSER",  {"GRAPH_OWNER":"GRAPHUSER","GR
"GRAPH_NAME":"STUDENTS_GRAP  APH_NAME":"STUDENTS_GRAPH","EL
H","ELEM_TABLE":"PERSONS","  EM_TABLE":"FRIENDS","KEY_VALUE
KEY_VALUE":{"PERSON_ID":3}}  ":{"FRIENDSHIP_ID":4}}
```

Example 5-20 GRAPH_TABLE Query Using the VERTEX_EQUAL Predicate

```
SELECT * FROM GRAPH_TABLE (students_graph
MATCH
 (a IS person WHERE a.name='John') -[e IS friends]->{,1} (b IS person)
WHERE VERTEX_EQUAL(a,b)
COLUMNS (JSON_SERIALIZE(VERTEX_ID(a)) AS id_a , JSON_SERIALIZE(VERTEX_ID(b))
AS id_b)
);
```

The query produces a JSON data type output that includes the graph owner, graph name and graph element table name and the key value as shown:

```
ID_A                         ID_B
---------------------------  ---------------------------
{"GRAPH_OWNER":"GRAPHUSER",  {"GRAPH_OWNER":"GRAPHUSER",
"GRAPH_NAME":"STUDENTS_GRAP  "GRAPH_NAME":"STUDENTS_GRAP
H","ELEM_TABLE":"PERSONS","  H","ELEM_TABLE":"PERSONS","
KEY_VALUE":{"PERSON_ID":1}}  KEY_VALUE":{"PERSON_ID":1}}
```

- Setting Up Sample Data in the Database

5.7.1 Setting Up Sample Data in the Database

In order to create the SQL property graph, `students_graph`, shown in Creating a SQL Property Graph, the following sample tables with data need to be set up in the database.

1. Connect to the database as the schema user.
2. Run the following SQL script to create the `university`, `persons`, `students`, and `friendships` tables with sample data in the database.

```
CREATE TABLE university (
    id NUMBER GENERATED ALWAYS AS IDENTITY (START WITH 1 INCREMENT
BY 1),
    name VARCHAR2(10),
    CONSTRAINT u_pk PRIMARY KEY (id));

INSERT INTO university (name) VALUES ('ABC');
INSERT INTO university (name) VALUES ('XYZ');

CREATE TABLE persons (
     person_id NUMBER GENERATED ALWAYS AS IDENTITY (START WITH 1
INCREMENT
     BY 1),
     name VARCHAR2(10),
     birthdate DATE,
     height FLOAT DEFAULT ON NULL 0,
     person_data JSON,
     CONSTRAINT person_pk PRIMARY KEY (person_id)
   );

INSERT INTO persons (name, height, birthdate, person_data)
       VALUES ('John', 1.80, to_date('13/06/1963', 'DD/MM/YYYY'),
'{"department":"IT","role":"Software Developer"}');

INSERT INTO persons (name, height, birthdate, person_data)
       VALUES ('Mary', 1.65, to_date('25/09/1982', 'DD/MM/YYYY'),
'{"department":"HR","role":"HR Manager"}');

INSERT INTO persons (name, height, birthdate, person_data)
       VALUES ('Bob', 1.75, to_date('11/03/1966', 'DD/MM/YYYY'),
'{"department":"IT","role":"Technical Consultant"}');
```

```
INSERT INTO persons (name, height, birthdate, person_data)
       VALUES ('Alice', 1.70, to_date('01/02/1987', 'DD/MM/YYYY'),
'{"department":"HR","role":"HR Assistant"}');

CREATE TABLE students (
      s_id NUMBER GENERATED ALWAYS AS IDENTITY (START WITH 1 INCREMENT BY
1),
      s_univ_id NUMBER,
      s_person_id NUMBER,
      subject VARCHAR2(10),
      height BINARY_DOUBLE,
      CONSTRAINT stud_pk PRIMARY KEY (s_id),
      CONSTRAINT stud_fk_person FOREIGN KEY (s_person_id) REFERENCES
persons(person_id),
      CONSTRAINT stud_fk_univ FOREIGN KEY (s_univ_id) REFERENCES
university(id)
    );


INSERT INTO students(s_univ_id, s_person_id,subject, height) VALUES
(1,1,'Arts',1.80);
INSERT INTO students(s_univ_id, s_person_id,subject, height) VALUES
(1,3,'Music',1.65);
INSERT INTO students(s_univ_id, s_person_id,subject, height) VALUES
(2,2,'Math',1.75);
INSERT INTO students(s_univ_id, s_person_id,subject, height) VALUES
(2,4,'Science',1.70);

CREATE TABLE friendships (
    friendship_id NUMBER GENERATED ALWAYS AS IDENTITY (START WITH 1
INCREMENT BY 1),
    person_a NUMBER,
    person_b NUMBER,
    meeting_date DATE,
    CONSTRAINT fk_person_a_id FOREIGN KEY (person_a) REFERENCES
persons(person_id),
    CONSTRAINT fk_person_b_id FOREIGN KEY (person_b) REFERENCES
persons(person_id),
    CONSTRAINT fs_pk PRIMARY KEY (friendship_id)
);

INSERT INTO friendships (person_a, person_b, meeting_date) VALUES (1, 3,
to_date('01/09/2000', 'DD/MM/YYYY'));
INSERT INTO friendships (person_a, person_b, meeting_date) VALUES (2, 4,
to_date('19/09/2000', 'DD/MM/YYYY'));
INSERT INTO friendships (person_a, person_b, meeting_date) VALUES (2, 1,
to_date('19/09/2000', 'DD/MM/YYYY'));
INSERT INTO friendships (person_a, person_b, meeting_date) VALUES (3, 2,
to_date('10/07/2001', 'DD/MM/YYYY'));
```

5.8 Supported Features and Limitations for Querying a SQL Property Graph

This section provides the list of supported and unsupported features for querying a SQL Property Graph.

Supported Features

- Single label, no label, label disjunction and label conjunction are supported in label expressions inside a graph pattern. For more information, see:
  - Table 5-2 in Label Expressions
  - Examples for SQL Property Graph Queries
- Any directed edge patterns (`MATCH (a)-[e]-(b)`) are supported.
  See Example 5-7.
- Anonymous vertex (`MATCH ()-[e]->()`) and edge (`MATCH (a)-[]->(b)`) variables are supported.
  See Example 5-8.
- Complex path pattern queries are supported.
  See Example 5-9, Example 5-10 and Example 5-11.
- Bounded recursive path pattern queries are supported.
  See Example 5-14.
- Bind variables are supported inside a `WHERE` clause.
  See Example 5-15.
- `VERTEX_ID` and `EDGE_ID` operators that uniquely identify a vertex and an edge respectively can be used within a SQL `GRAPH_TABLE` query.
  - See Vertex and Edge Identifiers.
  - See Example 5-19.
- `VERTEX_EQUAL` and `EDGE_EQUAL` predicates for matching vertex and edge identifiers are supported.
  - See Vertex and Edge Identifiers.
  - See Example 5-20.
- SQL and JSON expressions are supported inside `WHERE` and `COLUMNS` clauses.
  See Example 4-6.
- JSON simplified syntax is supported to access properties of type `JSON`.
  See Example 4-6.
- PL/SQL functions are supported inside a `WHERE` or `COLUMNS` clause.
  See Example 5-16.
- Single line and multi-line comments are supported within a graph query.
- All identifiers within a `GRAPH_TABLE` query, such as graph names, alias names, graph element pattern variable names, labels and property names follow the standard SQL rules about case sensitivity:
  - Identifiers within double quotes are case sensitive.

- Identifiers not enclosed in double quotes are implicitly converted to uppercase and enclosed in double quotes.

- SQL hints are supported inside and outside the `GRAPH_TABLE` query for tuning.
  See Tuning SQL Property Graph Queries for more information.
- You can query a graph defined in another schema if you have the required privileges.
  See Granting System and Object Privileges for SQL Property Graphs for more information.

Limitations

- Variable-length pattern matching goals (such as `ANY`, `ALL`, `ALL SHORTEST`, `ANY CHEAPEST`, and so on) are not supported.
- Path pattern variables (`MATCH p = (n)-[e]->(m)`) are not supported.
- Clauses such as `COST` and `TOTAL_COST` are not supported.
- Inline subqueries and `LATERAL` inline views are not supported.
- SQL Macros are not supported.

5.9 Tuning SQL Property Graph Queries

You can tune a SQL `GRAPH_TABLE` query using the `EXPLAIN PLAN` statement.

A `GRAPH_TABLE` query is internally translated into equivalent SQL. You can therefore generate the `EXPLAIN PLAN` for the property graph query as shown:

```
SQL> EXPLAIN PLAN FOR SELECT * FROM GRAPH_TABLE (students_graph
MATCH (a is person)-[e is friends]-> (b is person)
COLUMNS (a.name AS a , b.name AS b)
);
Explained.
```

The `EXPLAIN PLAN` can be viewed as shown:

```
SQL> SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY(format=>'ALL'));

Plan hash value: 1420380663
-----------------------------------------------------------------------------
------
| Id  | Operation           | Name         | Rows  | Bytes | Cost (%CPU)|
Time     |
-----------------------------------------------------------------------------
------
|   0 | SELECT STATEMENT    |              |     4 |   264 |    10  (10)|
00:00:01 |
|*  1 |  HASH JOIN          |              |     4 |   264 |    10  (10)|
00:00:01 |
|*  2 |   HASH JOIN         |              |     4 |   184 |     7  (15)|
00:00:01 |
|   3 |    TABLE ACCESS FULL| PERSONS      |     4 |    80 |     3   (0)|
00:00:01 |
|   4 |    TABLE ACCESS FULL| FRIENDSHIPS  |     4 |   104 |     3   (0)|
00:00:01 |
```

```
|   5 |   TABLE ACCESS FULL | PERSONS     |     4 |    80 |     3
(0)| 00:00:01 |
------------------------------------------------------------------------
------------

Query Block Name / Object Alias (identified by operation id):
-------------------------------------------------------------
   1 - SEL$B92C7F25
   3 - SEL$B92C7F25 / "A"@"SEL$213F43E5"
   4 - SEL$B92C7F25 / "E"@"SEL$213F43E5"
   5 - SEL$B92C7F25 / "B"@"SEL$213F43E5"
```

You can tune the preceding `GRAPH_TABLE` query by using optimizer hints. For instance, the following example uses the `PARALLEL` hint and the hint usage can be seen in the following execution plan:

```
SQL> EXPLAIN PLAN FOR SELECT /*+ PARALLEL(4) */ * FROM GRAPH_TABLE
(students_graph
MATCH (a is person)-[e is friends]-> (b is person)
COLUMNS (a.name AS a , b.name AS b)
);
Explained.

SQL>  SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY(format=>'ALL'));

Plan hash value: 1486901074
------------------------------------------------------------------------
------------------------------------------------------
| Id  | Operation                        | Name        | Rows  | Bytes
| Cost (%CPU)| Time      |    TQ  |IN-OUT| PQ Distrib |
------------------------------------------------------------------------
------------------------------------------------------
|   0 | SELECT STATEMENT                 |             |     4 |   264
|     4   (0)| 00:00:01 |        |      |            |
|   1 |  PX COORDINATOR                  |             |       |
|             |           |        |      |            |
|   2 |   PX SEND QC (RANDOM)            | :TQ10000    |     4 |   264
|     4   (0)| 00:00:01 |  Q1,00 | P->S | QC (RAND)  |
|   3 |    NESTED LOOPS                  |             |     4 |   264
|     4   (0)| 00:00:01 |  Q1,00 | PCWP |            |
|   4 |     NESTED LOOPS                 |             |     4 |   264
|     4   (0)| 00:00:01 |  Q1,00 | PCWP |            |
|   5 |      NESTED LOOPS                |             |     4 |   184
|     3   (0)| 00:00:01 |  Q1,00 | PCWP |            |
|   6 |       PX BLOCK ITERATOR          |             |       |
|             |           |  Q1,00 | PCWC |            |
|   7 |        TABLE ACCESS FULL         | FRIENDSHIPS |     4 |   104
|     2   (0)| 00:00:01 |  Q1,00 | PCWP |            |
|   8 |       TABLE ACCESS BY INDEX ROWID| PERSONS     |     1 |    20
|     0   (0)| 00:00:01 |  Q1,00 | PCWP |            |
|*  9 |        INDEX UNIQUE SCAN         | PERSON_PK   |     1 |
|     0   (0)| 00:00:01 |  Q1,00 | PCWP |            |
|* 10 |      INDEX UNIQUE SCAN           | PERSON_PK   |     1 |
|     0   (0)| 00:00:01 |  Q1,00 | PCWP |            |
```

```
|  11 |      TABLE ACCESS BY INDEX ROWID   | PERSONS      |      1 |     20 |
0   (0)| 00:00:01 |  Q1,00 | PCWP |            |
-----------------------------------------------------------------------------
------------------------------------------------

Query Block Name / Object Alias (identified by operation id):
-------------------------------------------------------------
   1 - SEL$B92C7F25
   7 - SEL$B92C7F25 / "E"@"SEL$213F43E5"
   8 - SEL$B92C7F25 / "A"@"SEL$213F43E5"
   9 - SEL$B92C7F25 / "A"@"SEL$213F43E5"
  10 - SEL$B92C7F25 / "B"@"SEL$213F43E5"
  11 - SEL$B92C7F25 / "B"@"SEL$213F43E5"

Hint Report (identified by operation id / Query Block Name / Object Alias):
Total hints for statement: 1
---------------------------------------------------------------------------
  0 -  STATEMENT

PLAN_TABLE_OUTPUT
---------------------------------------------------------------------------
           -  PARALLEL(4)
Note
-----
   - dynamic statistics used: dynamic sampling (level=2)
   - Degree of Parallelism is 4 because of hint
```

5.10 Type Compatibility Rules for Determining Property Types

When using shared property names that are union compatible, the property type is determined by certain type compatibility rules.

The following summarizes the rules for determining the type of a property for union compatible properties at the time of DDL creation and also during query compilation:

- If expressions exposed by a same property of a shared label are character data, then the data type of the property is determined as follows:
  - If all expressions are of data type `CHAR` of equal length, then the property has a data type `CHAR` of that length. If the expression are all of data type `CHAR`, but with different lengths, then the property type is `VARCHAR2` with the length of the larger `CHAR` type.
  - If any, or all of the expressions are of data type `VARCHAR2`, then the property has data type `VARCHAR2`. The length of the `VARCHAR2` is the maximum length size of the input columns.
- If expressions exposed by a same property of a shared label are numeric data, then the data type of the property is determined by numeric precedence:
  - If any expression exposed by a property is of data type `BINARY DOUBLE`, then the property has the data type `BINARY DOUBLE`.
  - If no expression defining the property are of data type `BINARY DOUBLE`, but any expression is of type `BINARY FLOAT`, then the property has data type `BINARY FLOAT`.
  - If all expressions defining the property are of data type `NUMBER`, then the property has data type `NUMBER`.

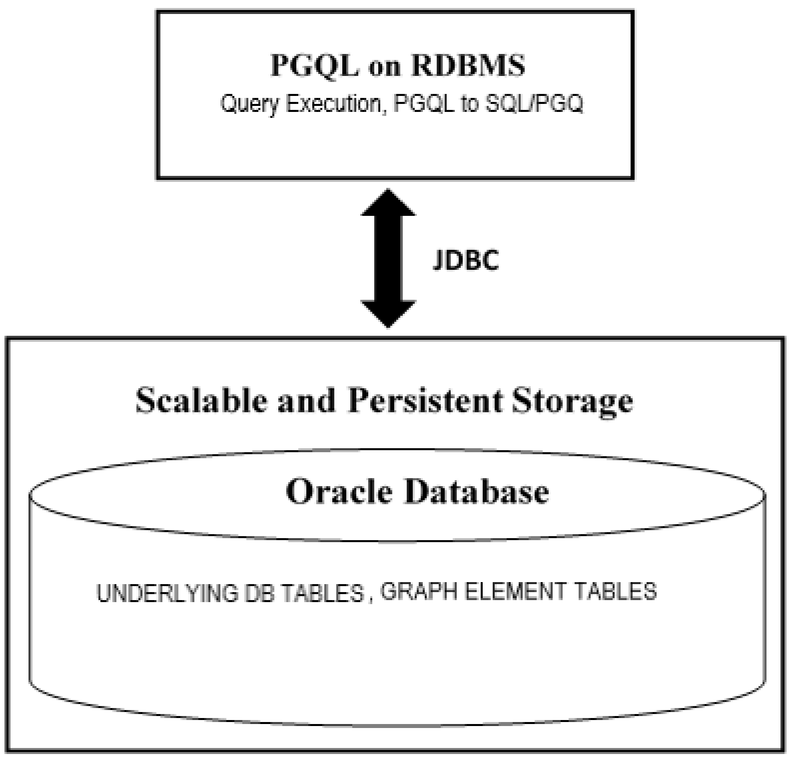
- If expressions exposed by a same property of a shared label are date and timestamp data, then the data type of the property is determined as follows:
  - If all expressions are of data type `DATE`, then property has data type `DATE`.
  - If any, or all of the expressions are of data type `TIMESTAMP`, then the property has data type `TIMESTAMP`.

6
Executing PGQL Queries Against SQL Property Graphs

You can directly run PGQL queries against a SQL property graph in the database.

The PGQL query execution flow is shown in the following figure:

Figure 6-1 PGQL on SQL Property Graphs in Oracle Database



The basic execution flow is:

1. The PGQL query is performed on a SQL property graph through a Java API.
2. The PGQL query is translated to SQL/PGQ (`GRAPH_TABLE` query).
3. The translated SQL/PGQ is submitted to Oracle Database by JDBC.
4. The SQL/PGQ result set is wrapped as a PGQL result set and returned to the caller.

See Supported PGQL Features and Limitations for SQL Property Graphs for a complete list of supported and unsupported features.

- Executing PGQL SELECT Queries on a SQL Property Graph
  You can execute PGQL `SELECT` queries, on a SQL property graph, using the Java API in the `oracle.pg.rdbms.pgql` package.
- Supported PGQL Features and Limitations for SQL Property Graphs
  Learn about the supported PGQL features and limitations for SQL property graphs.

6.1 Executing PGQL SELECT Queries on a SQL Property Graph

You can execute PGQL `SELECT` queries, on a SQL property graph, using the Java API in the `oracle.pg.rdbms.pgql` package.

The following example shows a PGQL `SELECT` query execution:

- JShell
- Java
- Python

JShell

```
opg4j> var jdbcUrl="jdbc:oracle:thin:@<host_name>:<port>/<db_service>"
opg4j> var conn =
DriverManager.getConnection(jdbcUrl,"<username>","<password>")
opg4j> conn.setAutoCommit(false)
opg4j> var pgqlConn = PgqlConnection.getConnection(conn)
opg4j> var pgqlStmt = pgqlConn.createStatement()
opg4j> String query = "SELECT n.name FROM MATCH (n:person) ON
STUDENTS_GRAPH"
opg4j> var rs = pgqlStmt.executeQuery(query)
opg4j> rs.print()
+--------+
| NAME   |
+--------+
| John   |
| Mary   |
| Bob    |
| Alice  |
+--------+
```

Java

```
Connection conn =
DriverManager.getConnection("<jdbcUrl>","<username>","<password>");
        conn.setAutoCommit(false);
        PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
        PgqlStatement pgqlStmt = pgqlConn.createStatement();
        String query = "SELECT n.name FROM MATCH (n:person) ON
```

```
STUDENTS_GRAPH";
        PgqlResultSet rs = pgqlStmt.executeQuery(query);
        rs.print();
```

Python

```
>>> pgql_conn = opg4py.pgql.get_connection("<username>","<password>",
"<jdbcUrl>")
>>> pgql_statement = pgql_conn.create_statement()
>>> query = "SELECT n.name FROM MATCH (n:person) ON STUDENTS_GRAPH"
>>> rs = pgql_statement.execute_query(query)
>>> rs.print()
+--------+
| NAME   |
+--------+
| John   |
| Mary   |
| Bob    |
| Alice  |
+--------+
```

6.2 Supported PGQL Features and Limitations for SQL Property Graphs

Learn about the supported PGQL features and limitations for SQL property graphs.

The following table provides the complete list of supported and unsupported PGQL functionalities for SQL property graphs:

Table 6-1 Supported PGQL Functionalities and Limitations for SQL Property Graphs

Features	PGQL on SQL Property Graphs
`CREATE PROPERTY GRAPH`	Supported
`DROP PROPERTY GRAPH`	Supported
Fixed-length pattern matching	Supported
Variable-length pattern matching goals	Not Supported
Variable-length pattern matching quantifiers	Not Supported
Variable-length path unnesting	Not Supported
`GROUP BY`	Supported
`HAVING`	Supported
Aggregations	Supported: • `COUNT` • `MIN`, `MAX`, `AVG`, `SUM` • `LISTAGG` Not supported: • `ARRAY_AGG`

Table 6-1 (Cont.) Supported PGQL Functionalities and Limitations for SQL Property Graphs

Features	PGQL on SQL Property Graphs
`DISTINCT` • `SELECT DISTINCT` • Aggregation with `DISTINCT` (such as, `COUNT(DISTINCT e.prop)`)	Supported
`SELECT v.*`	Not Supported
`ORDER BY (+ASC/DESC), LIMIT, OFFSET`	Supported
Data Types	All available Oracle RDBMS data types supported

JSON	Supported:
	• JSON storage:
	  – JSON strings (`VARCHAR2`)
	  – JSON objects
	• JSON functions:
	Any JSON function call that follows the syntax, `json_function_name(arg1, arg2,…)`. For example:
	`json_value(department_data, '$.department')`
	Limitations:
	• Simple Dot Notation
	• Any optional clause in a JSON function call (such as `RETURNING`, `ERROR`, and so on) is not supported. For example:
	`json_value(department_data, '$.employees[1].hireDate' RETURNING DATE)`

Operators	Supported: • Relational: `+`, `-`, `*`, `/`, `%`, `-` (unary minus) • Arithmetic: `=`, `<>`, `<`, `>`, `<=`, `>=` • Logical: `AND`, `OR`, `NOT` • String: `||` (concat)
Functions and predicates	Supported are all available functions in the Oracle RDBMS that take the form `function_name(arg1, arg2, ...)` with optional schema and package qualifiers. Supported PGQL functions/predicates: • `IS NULL`, `IS NOT NULL` • `LOWER`, `UPPER` • `SUBSTRING` • `ABS`, `CEIL/CEILING`, `FLOOR`, `ROUND` • `EXTRACT` • `CAST` • `CASE` • `IN` and `NOT IN` Unsupported PGQL functions/predicates are all vertex/edge functions

Table 6-1 (Cont.) Supported PGQL Functionalities and Limitations for SQL Property Graphs

Features	PGQL on SQL Property Graphs
User-defined functions	Supported: • PL/SQL functions • Functions created via the Oracle Database Multilingual Engine (MLE)
Subqueries: • Scalar subqueries • `EXISTS` and `NOT EXISTS` subqueries	Supported subqueries: • EXISTS • NOT EXISTS Not supported: • Scalar subqueries
`INSERT/UPDATE/DELETE`	Not supported
`INTERVAL` literals and operations	Not supported

Part III

Property Graph Views

Learn and work with property graph views.

You can work with property graph views if you are using Oracle Database 23c or earlier.

7

About Property Graph Views

You can create property graph views (PG Views) over data stored in Oracle Database. You can perform various graph analytics operations using PGQL on these views.

The following sections explain PG Views in detail:

- Creating Property Graph Views on Oracle Database Tables
  The CREATE PROPERTY GRAPH statement in PGQL can be used to create a view-like object that contains metadata about the graph. This graph can be queried using PGQL.
- Creating a PG View By Importing a GraphSON file
  Using the `GraphImporterBuilder` API, you can create a property graph view (PG View) by importing graph data from a GraphSON file.
- Using JSON to Store Vertex and Edge Properties
  You can adopt a flexible schema approach in a property graph view (PG View) by encoding the vertex and edge properties as a single JSON value. You can then map this to a property value in a PG View.

7.1 Creating Property Graph Views on Oracle Database Tables

The CREATE PROPERTY GRAPH statement in PGQL can be used to create a view-like object that contains metadata about the graph. This graph can be queried using PGQL.

The property graph views are created directly over data that exists in the relational database tables. Since the graph is stored in the database tables it has a schema. This is unlike the graphs created with a flexible schema, where the data is copied from the source tables to property graph schema tables as described in Property Graph Schema Objects for Oracle Database.

One of the main benefits of property graph views, is that all updates to the database tables are immediately reflected in the graph.

Metadata Tables for PG Views

Each time a `CREATE PROPERTY GRAPH` statement is executed, metadata tables are created in the user's own schema.

The following table describes the set of metadata tables that are created for each graph on executing `CREATE PROPERTY GRAPH` statement.

All columns shown underlined in the Table 7-1 are part of the primary key of the table. Also all columns have a `NOT NULL` constraint.

Table 7-1 Metadata Tables for PG Views

Table Name	Description
graphName_**ELEM_TABLE**$	Metadata for graph element (vertex/edge) tables (one row per element table): • ET_NAME: the name of the element table (the "alias") • ET_TYPE: either "VERTEX" or "EDGE" • SCHEMA_NAME: the name of the schema of the underlying table • TABLE_NAME: the name of underlying table
graphName_**LABEL$**	Metadata on labels of element tables (one row per label; one label per element table): • LABEL_NAME: the name of the label • ET_NAME: the name of the element table (the "alias") • ET_TYPE: either "VERTEX" or "EDGE"
graphName_**PROPERTY**$	Metadata describing the columns that are exposed through a label (one row per property) • PROPERTY_NAME: the name of the property • ET_NAME: the name of the element table (the "alias") • ET_TYPE: either "VERTEX" or "EDGE" • LABEL_NAME: the name of the label that this property belongs to • COLUMN_NAME: the name of the column (initially, only the case where property names equal column names is allowed)
graphName_**KEY**$	Metadata describing a vertex/edge key (one row per column in the key) • COLUMN_NAME: the name of the column in the key • COLUMN_NUMBER: the number of the column in the key For example, in KEY (a, b, c), "a" has number 1, "b" has number 2 and "c" has number 3. • KEY_TYPE: either "VERTEX" or "EDGE" • ET_NAME: the name of the element table (the "alias")
graphName_**SRC_DST_KEY**$	Metadata describing the edge source/destination keys (one row per column of a key): • ET_NAME: the name of the element table (the "alias"), which is always an edge table • VT_NAME: the name of the vertex table • KEY_TYPE: either "EDGE_SOURCE" or "EDGE_DESTINATION" • ET_COLUMN_NAME: the name of the key column • ET_COLUMN_NUMBER: the number of the column in the key. For example, in KEY (a, b, c), "a" has number 1, "b" has number 2 and "c" has number 3. **Note:** Currently, support is only for **SOURCE KEY (...) REFERENCES T1**. So only the edge source/destination key is stored.

Example 7-1 To create a Property Graph View

Consider the following CREATE PROPERTY GRAPH statement:

```
CREATE PROPERTY GRAPH student_network
  VERTEX TABLES(
```

```
    person
      KEY ( id )
      LABEL student
      PROPERTIES( name ),
    university
      KEY ( id )
      PROPERTIES( name )
  )
  EDGE TABLES(
    knows
      key (person1, person2)
      SOURCE KEY ( person1 ) REFERENCES person (id)
      DESTINATION KEY ( person2 ) REFERENCES person (id)
      NO PROPERTIES,
    person AS studentOf
      key (id, university)
      SOURCE KEY ( id ) REFERENCES person (id)
      DESTINATION KEY ( university ) REFERENCES university (id)
      NO PROPERTIES
  )
  OPTIONS (PG_VIEW)
```

The `OPTIONS` clause allows the creation of a property graph view instead of the creation of property graph schema graph. You must simply pass the `CREATE PROPERTY GRAPH` statement to the `execute` method:

> **Note:**
>
> - You can create property graph views using the RDBMS Java API or through SQLcl.
> - You can query property graph views using the graph visualization tool or SQLcl.

```
stmt.execute("CREATE PROPERTY GRAPH student_network ...");
```

This results in the creation of the following metadata tables:

```
SQL> SELECT * FROM STUDENT_NETWORK_ELEM_TABLE$;

ET_NAME         ET_TYPE    SCHEMA_NAME     TABLE_NAME
--------------- ---------- --------------- ---------------
PERSON          VERTEX     SCOTT           PERSON
UNIVERSITY      VERTEX     SCOTT           UNIVERSITY
KNOWS           EDGE       SCOTT           KNOWS
STUDENTOF       EDGE       SCOTT           PERSON

SQL> SELECT * FROM STUDENT_NETWORK_LABEL$;

LABEL_NAME      ET_NAME         ET_TYPE
--------------- --------------- ----------
```

```
STUDENT          PERSON           VERTEX
UNIVERSITY       UNIVERSITY       VERTEX
KNOWS            KNOWS            EDGE
STUDENTOF        STUDENTOF        EDGE

SQL> SELECT * FROM STUDENT_NETWORK_PROPERTY$;

PROPERTY_NAME   ET_NAME          ET_TYPE    LABEL_NAME       COLUMN_NAME
--------------- --------------- ---------- ---------------
---------------
NAME            PERSON           VERTEX     STUDENT          NAME
NAME            UNIVERSITY       VERTEX     UNIVERSITY       NAME

SQL> SELECT * FROM STUDENT_NETWORK_KEY$;

COLUMN_NAME     COLUMN_NUMBER KEY_TY ET_NAME
--------------- ------------- ------ ---------------
ID                          1 VERTEX PERSON
ID                          1 VERTEX UNIVERSITY
PERSON1                     1 EDGE   KNOWS
PERSON2                     2 EDGE   KNOWS
ID                          1 EDGE   STUDENTOF
UNIVERSITY                  2 EDGE   STUDENTOF

SQL> SELECT * FROM STUDENT_NETWORK_SRC_DST_KEY$;

ET_NAME     VT_NAME        KEY_TYPE         ET_COLUMN_NAME
ET_COLUMN_NUMBER
--------------- ---------- ---------------- ---------------
----------------
KNOWS        PERSON         EDGE_SOURCE
PERSON1                         1
KNOWS        PERSON         EDGE_DESTINATION
PERSON2                         1
STUDENTOF    PERSON         EDGE_SOURCE
ID                              1
STUDENTOF    UNIVERSITY     EDGE_DESTINATION
UNIVERSITY                      1
```

You can now run PGQL queries on the property graph view `student_network`.

See Executing PGQL Queries Against Property Graph Views for more details to create, query and drop property graph views.

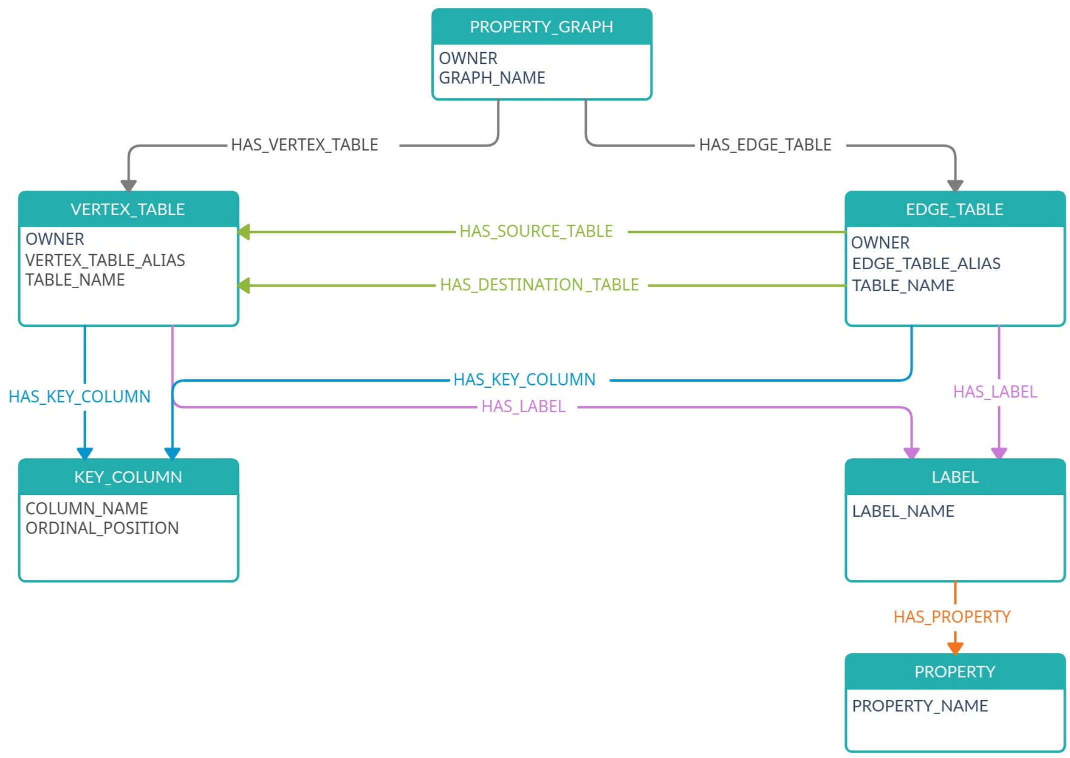
- Retrieving Metadata for Property Graph Views
  You can retrieve the metadata of property graph views created in the database using the built-in `PROPERTY_GRAPH_METADATA` graph in your PGQL queries.

7.1.1 Retrieving Metadata for Property Graph Views

You can retrieve the metadata of property graph views created in the database using the built-in `PROPERTY_GRAPH_METADATA` graph in your PGQL queries.

The PROPERTY_GRAPH_METADATA graph structure including properties is as shown:

Figure 7-1 PROPERTY_GRAPH_METADATA Graph Design



The following describes the preceding design of the metadata graph:

```
PROPERTY_GRAPH -[:HAS_VERTEX_TABLE]-> VERTEX_TABLE
               -[:HAS_EDGE_TABLE]-> EDGE_TABLE

VERTEX_TABLE -[:HAS_KEY_COLUMN]-> KEY_COLUMN
             -[:HAS_LABEL]-> LABEL

EDGE_TABLE -[:HAS_KEY_COLUMN]-> KEY_COLUMN
           -[:HAS_LABEL]-> LABEL
           -[:HAS_SOURCE_TABLE]-> VERTEX_TABLE
           -[:HAS_DESTINATION_TABLE]-> VERTEX_TABLE

LABEL -[:HAS_PROPERTY]-> PROPERTY
```

It is is important to note the following when using PROPERTY_GRAPH_METADATA in PGQL queries:

- PROPERTY_GRAPH_METADATA is automatically created and updated the first time you attempt to access it in a PGQL query.
- When running PGQL queries using the Java API, you must disable autocommit on the JDBC connection (`conn.setAutoCommit(false)`). This ensures that PROPERTY_GRAPH_METADATA graph gets created automatically.

The following examples show using `PROPERTY_GRAPH_METADATA` in PGQL queries to retrieve the required metadata.

You can retrieve the list of graphs to which you have access as shown:

- JShell
- Java
- Python

JShell

```
opg4j> String pgql =
...> "SELECT g.graph_name "
...> +"FROM MATCH (g:property_graph) ON property_graph_metadata "
...> +"ORDER BY g.graph_name"
pgql ==> "SELECT g.graph_name FROM MATCH (g:property_graph) ON
property_graph_metadata ORDER BY g.graph_name"
opg4j> pgqlStmt.executeQuery(pgql).print()
```

Java

```
String pgql = "SELECT g.graph_name "+
"FROM MATCH (g:property_graph) ON property_graph_metadata "+
"ORDER BY g.graph_name";
PgqlResultSet rs = pgqlStmt.executeQuery(pgql);
rs.print();
```

Python

```
>>> pgql = '''
... SELECT g.graph_name
... FROM MATCH (g:property_graph) ON property_graph_metadata
... ORDER BY g.graph_name
... '''
>>> pgql_statement.execute_query(pgql).print()
```

On execution, the preceding query produces the following result:

```
+------------------------+
| GRAPH_NAME             |
+------------------------+
| BANK_GRAPH_VIEW        |
| FINANCIAL_TRANSACTIONS |
| FRIENDS                |
+------------------------+
```

You can retrieve the vertex properties of a graph as shown:

- JShell
- Java
- Python

JShell

```
opg4j> String pgql =
...> "SELECT p.property_name "
...> +"FROM MATCH(g:property_graph)-[:has_vertex_table]->(v)-[:has_label]-
>(l:label)-[:has_property]->(p:property) "
...> +"ON property_graph_metadata "
...> +"WHERE g.graph_name = 'FRIENDS' "
pgql ==> "SELECT p.property_name FROM MATCH(g:property_graph)-
[:has_vertex_table]->(v)-[:has_label]->(l:label)-[:has_property]-
>(p:property) ON property_graph_metadata WHERE g.graph_name = 'FRIENDS' "
opg4j> pgqlStmt.executeQuery(pgql).print()
```

Java

```
String pgql = "SELECT p.property_name "+
"FROM MATCH(g:property_graph)-[:has_vertex_table]->(v)-[:has_label]-
>(l:label)-[:has_property]->(p:property) "+
"ON property_graph_metadata "+
"WHERE g.graph_name = 'FRIENDS' ";
PgqlResultSet rs = pgqlStmt.executeQuery(pgql);
rs.print();
```

Python

```
>>> pgql = '''
... SELECT p.property_name
... FROM MATCH(g:property_graph)-[:has_vertex_table]->(v)-[:has_label]-
>(l:label)-[:has_property]->(p:property)
... ON property_graph_metadata
... WHERE g.graph_name = 'FRIENDS'
... '''
>>> pgql_statement.execute_query(pgql).print()
```

On execution, the preceding query produces the following result:

```
+---------------+
| PROPERTY_NAME |
+---------------+
| BIRTHDATE     |
```

```
| HEIGHT          |
| NAME            |
+-----------------+
```

7.2 Creating a PG View By Importing a GraphSON file

Using the `GraphImporterBuilder` API, you can create a property graph view (PG View) by importing graph data from a GraphSON file.

This import functionality consists of the following steps:

1. Parsing of the GraphSON to a data structure.
2. Creating the SQL tables from the data structure and inserting the data.
3. Generating and running the `CREATE PROPERTY GRAPH` statement.

The following example show using the `GraphImporterBuilder` API to create a PG View from a GraphSON file.

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pg.imports.*
opg4j> var importer = new GraphImporter.Builder().
...>     setFilePath("<path_to_graphson_file>").
...>     setBatchSize(2).
...>     setInputFormat(GraphImportInputFormat.GRAPHSON).
...>     setOutputFormat(GraphImportOutputFormat.PG_VIEW).
...>     setThreads(4).
...>     setDbJdbcUrl("<jdbc_url>").
...>     setDbUsername("<username>").
...>     setDbPassword("<password>").
...>     setGraphName("mygraph").
...>     build()
importer ==> oracle.pg.imports.GraphImporter@5d957cf0
opg4j> var ddl = importer.importGraph()
```

Java

```
import oracle.pg.imports.*;
GraphImporter importer = new GraphImporter.Builder()
     .setFilePath("<path_to_graphson_file>")
     .setBatchSize(2)
     .setInputFormat(GraphImportInputFormat.GRAPHSON)
     .setOutputFormat(GraphImportOutputFormat.PG_VIEW)
     .setThreads(4)
     .setDbJdbcUrl("<jdbc_url>")
```

```
    .setDbUsername("<username>")
    .setDbPassword("<password>")
    .setGraphName("mygraph")
    .build();
```

Python

```
>>> from opg4py.graph_importer import GraphImporter
>>> config = {
...       'jdbc_url'     : '<jdbc_url>',
...       'username'     : '<username>',
...       'password'     : '<password>',
...       'file_path'    : '<path_to_graphson_file>',
...       'graph_name'   : 'mygraph',
...       'output_format': 'pg_view',
...       'input_format' : 'graphson'
... }
>>> importer = GraphImporter(config)
>>> importer.import_graph()
```

The preceding example sets up the required SQL tables in the database, generates and runs the DDL statement to create *mygraph*. For instance, this example generates the following `CREATE PROPERTY GRAPH` DDL statement:

```
"CREATE PROPERTY GRAPH mygraph
           VERTEX TABLES (
             software
               KEY (id)
               LABEL software
               PROPERTIES ARE ALL COLUMNS,
             person
               KEY (id)
               LABEL person
               PROPERTIES ARE ALL COLUMNS
           )
           EDGE TABLES (
             created
               KEY (id)
               SOURCE KEY (sid) REFERENCES person (id)
               DESTINATION KEY (did) REFERENCES software (id)
               LABEL created
               PROPERTIES ARE ALL COLUMNS,
             knows
               KEY (id)
               SOURCE KEY (sid) REFERENCES person (id)
               DESTINATION KEY (did) REFERENCES person (id)
               LABEL knows
               PROPERTIES ARE ALL COLUMNS
           ) OPTIONS ( pg_view )"
```

Alternatively, you can also create a connection to the database by using a data source to connect to the database as shown in the following example:

- JShell
- Java

JShell

```
opg4j> import oracle.pg.imports.*
opg4j> import oracle.jdbc.pool.OracleDataSource

opg4j> var ds = new OracleDataSource() // setup the data source
ds ==> oracle.jdbc.pool.OracleDataSource@4154ecd3
ds.setURL("<jdbc_url>")
ds.setUser("<username>")
ds.setPassword("<password>")

opg4j> var importer = new GraphImporter.Builder().
...>     setFilePath("<path_to_graphson_file>").
...>     setBatchSize(2).
...>     setInputFormat(GraphImportInputFormat.GRAPHSON).
...>     setOutputFormat(GraphImportOutputFormat.PG_VIEW).
...>     setThreads(4).
...>     setDataSource(ds).
...>     setGraphName("mygraph").
...>     build()
importer ==> oracle.pg.imports.GraphImporter@5d957cf0
opg4j> var ddl = importer.importGraph()
```

Java

```
import oracle.pg.imports.*;
import oracle.jdbc.pool.OracleDataSource;
//Setup the datasource
var ds = new OracleDataSource();
ds.setURL(<jdbc_url>)
ds.setUser(<username>);
ds.setPassword(<password>);
//Setup the GraphImporter
GraphImporter importer = new GraphImporter.Builder()
     .setFilePath("<path_to_graphson_file>")
     .setBatchSize(2)
     .setInputFormat(GraphImportInputFormat.GRAPHSON)
     .setOutputFormat(GraphImportOutputFormat.PG_VIEW)
     .setThreads(4)
     .setDataSource(ds)
     .setGraphName("mygraph")
     .build();
var ddl = importer.importGraph();
```

Also, note the following:

- The `GraphImporterBuilder` API supports GraphSON file format version 3.0 only.
- Only GraphSON data types listed in Table 7-6 are supported.

The following sections provide more details on the `GraphImporter` parameters and the data type mapping between GraphSON and Oracle Database.

- Additional Information on the GraphImporter Parameters
  Learn more about the parameters used by the `GraphImporter`.
- Mapping GraphSON Types to Oracle Database Data Types
  The GraphSON data types can be mapped to their corresponding Oracle Database data types.

7.2.1 Additional Information on the GraphImporter Parameters

Learn more about the parameters used by the `GraphImporter`.

Table 7-2 Database Connection Parameters

Parameter	Description	Setter in API	Default Value	Optional
`dataSource`	Data source for the database	`setDataSource`	`NULL`	Only if passing `dbJdbcUrl`, `dbUsername` and `dbPassword`
`dbJdbcUrl`	JDBC url of the database	`setDbJdbcUrl`	`""`	Only if passing a `dataSouce`
`dbPassword`	Database password	`setDbPassword`	`""`	Only if passing a `dataSouce`
`dbUsername`	Database user name	`setDbUsername`	`""`	Only if passing a `dataSouce`

Table 7-3 GraphImporter Configuration Parameters

Parameter	Description	Setter in API	Default Value	Optional
`pathName`	Path to the GraphSON file	`setPathname`	`""`	No
`graphName`	Resulting graph name	`setGraphName`	`""`	Yes
`inFormat`	Input format for the importer	`setInputFormat`	`GraphImportInputFormat.GRAPHSON`	Yes
`outFormat`	Output format for the importer	`setOutputFormat`	`GraphImportOutputFormat.PG_VIEW`	Yes

Table 7-3 (Cont.) GraphImporter Configuration Parameters

Parameter	Description	Setter in API	Default Value	Optional
`batchSize`	Number of rows read before inserting data to the database	`setBatchSize`	`1000`	Yes
`threads`	Number of threads to be used to insert to the database	`setThreads`	`1`	Yes

Table 7-4 SQL Storage Parameters

Parameter	Description	Setter in API	Default Value	Optional
`stringFieldSize`	GraphSON `String` data type is translated as `VARCHAR2` in the database. This parameter represents the `VARCHAR2` size for the data storage.	`setStringFieldsSize`	`100`	Yes
`fractionalSecondsPrecision`	The fractional seconds precision parameter found in `TIMESTAMP` data type in the Oracle Database.	`setFractionalSecondsPrecision`	`6`	Yes

Table 7-5 PGQL Supported Parameters

Parameter	Description	Setter in API	Default Value	Optional
`parallel`	Degree of parallelism to use for query and update operations	`setPathname`	`0`	Yes
`dynamicSampling`	Dynamic sampling value	`setGraphName`	`2`	Yes
`matchOptions`	Additional options used to influence query translation and execution	`setMatchOptions`	`NULL`	Yes

Table 7-5 (Cont.) PGQL Supported Parameters

Parameter	Description	Setter in API	Default Value	Optional
options	Additional options used to influence modify translation and execution	setOptions	NULL	Yes

7.2.2 Mapping GraphSON Types to Oracle Database Data Types

The GraphSON data types can be mapped to their corresponding Oracle Database data types.

The following table shows GraphSON data types mapping to Oracle Database data types:

Table 7-6 Mapping GraphSON Types to Oracle Database Types

GraphSON Type	Oracle Database Type
String	VARCHAR2[1]
g:Int32	NUMBER(10)
g:Int64	NUMBER(10)
g:Float	FLOAT
g:Double	FLOAT
g:Date	DATE
g:Timestamp	TIMESTAMP[2]
g:UUID	CHAR(36)

1 You can use the stringFieldSize parameter to determine the string size for the database to store on the String columns.

2 You can use the fractionalSecondsPrecision parameter to specify the precision on the columns of type Timestamp.

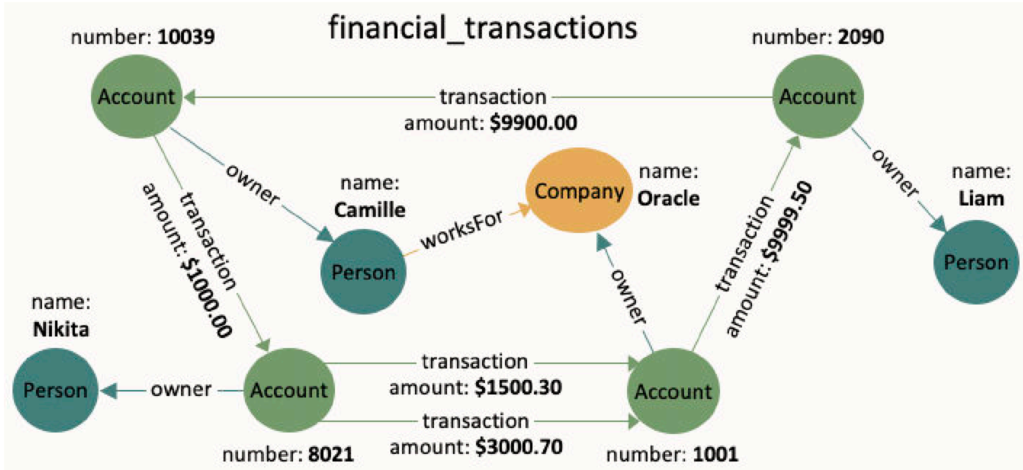
7.3 Using JSON to Store Vertex and Edge Properties

You can adopt a flexible schema approach in a property graph view (PG View) by encoding the vertex and edge properties as a single JSON value. You can then map this to a property value in a PG View.

PG Views do not provide schema flexibility by nature since adding a new label requires adding a new vertex or edge table, and adding a new property requires adding a new column, both of which are schema update operations. However, through the use of JSON you can model schema flexibility on top of PG Views.

For example, consider the following graph which represents financial transactions between two Account vertices. The Account can be owned either by a Person or a Company.

Figure 7-2 Financial Transactions Graph



You can create a single table for storing all the vertices and another single table for storing all the edges, as shown:

```
CREATE TABLE fin_vertex_table (
  id NUMBER PRIMARY KEY,
  properties VARCHAR2(2000)
);

INSERT INTO fin_vertex_table VALUES ( 1,
'{"type":"Person","name":"Nikita"}');
INSERT INTO fin_vertex_table VALUES ( 2,
'{"type":"Person","name":"Camille"}');
INSERT INTO fin_vertex_table VALUES ( 3,
'{"type":"Person","name":"Liam"}');
INSERT INTO fin_vertex_table VALUES ( 4,
'{"type":"Company","name":"Oracle"}');
INSERT INTO fin_vertex_table VALUES ( 5,
'{"type":"Account","number":10039}');
INSERT INTO fin_vertex_table VALUES ( 6,
'{"type":"Account","number":2090}');
INSERT INTO fin_vertex_table VALUES ( 7,
'{"type":"Account","number":8021}');
INSERT INTO fin_vertex_table VALUES ( 8,
'{"type":"Account","number":1001}');

CREATE TABLE fin_edge_table (
  id NUMBER PRIMARY KEY,
  src NUMBER REFERENCES fin_vertex_table ( id ),
  dst NUMBER REFERENCES fin_vertex_table ( id ),
  properties VARCHAR2(2000)
);

INSERT INTO fin_edge_table VALUES ( 1, 7, 1, '{"type":"owner"}');
INSERT INTO fin_edge_table VALUES ( 2, 5, 2, '{"type":"owner"}');
INSERT INTO fin_edge_table VALUES ( 3, 6, 3, '{"type":"owner"}');
INSERT INTO fin_edge_table VALUES ( 4, 8, 4, '{"type":"owner"}');
```

```
INSERT INTO fin_edge_table VALUES ( 5, 2, 4, '{"type":"worksFor"}');
INSERT INTO fin_edge_table VALUES ( 6, 5, 7,
'{"type":"transaction","amount":1000.00}');
INSERT INTO fin_edge_table VALUES ( 7, 7, 8,
'{"type":"transaction","amount":1500.30}');
INSERT INTO fin_edge_table VALUES ( 8, 7, 8,
'{"type":"transaction","amount":3000.70}');
INSERT INTO fin_edge_table VALUES ( 9, 8, 6,
'{"type":"transaction","amount":9999.50}');
INSERT INTO fin_edge_table VALUES ( 10, 6, 5,
'{"type":"transaction","amount":9900.00}');
```

As seen in the preceding code, each vertex and edge is represented by a single row in the respective tables. The first column is the unique key of the vertex or the edge. The second and third columns of the edge table are its source key and destination key respectively. The last column of the vertex and edge tables encodes all the properties as well as the labels in a JSON object. A JSON is an unordered set of name and value pairs. Here, you can use such pairs to encode the property names and their values as well as the label's value. In case of the label, you can choose an arbitrary name such as "type" or "label". In this example we use "type".

Because all the labels and properties of a vertex or an edge are encoded as a single JSON value, you do not need to update the schema when new labels or properties are added to the graph. Instead, you can add new labels and properties by inserting additional vertices and edges or by updating the JSON value in the underlying table through SQL.

The following two examples demonstrate how you can extract labels and property values from JSON objects for PGQL on RDBMS and PGQL on PGX respectively.

Example 7-2 Extracting JSON properties using JSON_VALUE (PGQL on RDBMS)

The following code creates a PG View using the `fin_vertex_table` and `fin_edge_table` tables and executes a PGQL `SELECT` query:

```
PgqlStatement pgqlStmnt = pgqlConn.createStatement();

/* Create the property graph */
pgqlStmnt.execute(
  "CREATE PROPERTY GRAPH financial_transactions " +
  "  VERTEX TABLES ( " +
  "    fin_vertex_table PROPERTIES ( properties ) ) " +
  "  EDGE TABLES ( " +
  "    fin_edge_table " +
  "      SOURCE KEY ( src ) REFERENCES fin_vertex_table (id) " +
  "      DESTINATION KEY ( dst ) REFERENCES fin_vertex_table (id) " +
  "      PROPERTIES ( properties ) ) " +
  "  OPTIONS ( PG_VIEW )");

/* Set the name of the graph so that we can omit the ON clause from queries
*/
pgqlConn.setGraph("FINANCIAL_TRANSACTIONS");

/* PGQL query: find all outgoing transactions from account 8021. Output the
   transaction amount and the destination account number. */
PgqlResultSet rs = pgqlStmnt.executeQuery(
  "SELECT JSON_VALUE(trans.properties, '$.amount') AS transaction_amount, " +
```

```
  "       JSON_VALUE(account2.properties, '$.number') AS
account_number " +
  "FROM MATCH (account1) -[trans]-> (account2) " +
  "WHERE JSON_VALUE(account1.properties, '$.number') = 8021 " +
  "  AND JSON_VALUE(trans.properties, '$.type') = 'transaction'");

rs.print();
rs.close();
pgqlStmnt.close();
```

In the preceding code, the `CREATE PROPERTY GRAPH` statement maps the JSON column into a property named "`properties`". This property will thus contain all the labels and properties of the vertex or the edge. The PGQL `SELECT` query extracts these labels and properties using **`JSON_VALUE`**.

For example, instead of `account1.number = 8021`, you must use `JSON_VALUE(account1.properties, '$.number') = 8021`. This causes the query to become a bit lengthier.

The output of the Java code is:

```
+-------------------------+
| AMOUNT | ACCOUNT_NUMBER |
+-------------------------+
| 1500.3 | 1001           |
| 3000.7 | 1001           |
+-------------------------+
```

Example 7-3 Using a UDF to extract a JSON property value (PGQL on PGX)

This example consists of two parts. The first part shows the creation of a UDF and the second part shows loading of the graph into the graph server (PGX) followed by the execution of a PGQL query using the UDF.

Since the Graph Server (PGX) does not have a built-in `JSON_VALUE` function like in PGQL on RDBMS, you can create a Java UDF instead.

Create the Java class (`MyJsonUtils.java`) that implements the UDF:

```
import com.fasterxml.jackson.core.JsonProcessingException;
import com.fasterxml.jackson.databind.JsonNode;
import com.fasterxml.jackson.databind.ObjectMapper;

public class MyJsonUtils {

  private final static ObjectMapper mapper = new ObjectMapper();

  public static String get_prop(String json_string, String prop_name)
throws JsonProcessingException {
    JsonNode node =  mapper.readTree(json_string);
    return node.path(prop_name).asText();
  }
}
```

Compile the class with the JARs from `/opt/oracle/graph/pgx/server/lib/*` added to the class path. This is because the library folder contains the necessary Jackson libraries that are required to parse the JSON.

```
mkdir ./target
javac -classpath .:/opt/oracle/graph/pgx/server/lib/* -d ./target *.java
cd target
jar cvf MyJsonUtils.jar *
```

Using the following UDF JSON configuration file (`my_udfs.json`), you can now register the Java UDF on the graph server (PGX) by following step-3 to step-6 in User-Defined Functions (UDFs) in PGX:

```
{
  "user_defined_functions": [
    {
      "namespace": "my",
      "function_name": "get_prop",
      "language": "java",
      "implementation_reference": "MyJsonUtils",
      "return_type": "string",
      "arguments": [
        {
          "name": "json_string",
          "type": "string"
        },
        {
          "name": "prop_name",
          "type": "string"
        }
      ]
    }
  ]
}
```

On implementing the UDF for extracting property values from the JSON, you can now load the graph into the Graph Server (PGX) and issue a PGQL query:

```
/* Load the graph into the Graph Server (PGX) */
ServerInstance instance = GraphServer.getInstance("http://localhost:7007",
username, password.toCharArray());
session = instance.createSession("my-session");
PgxGraph g = session.readGraphByName("FINANCIAL_TRANSACTIONS",
GraphSource.PG_VIEW);

/* PGQL query: find all shortest paths from account 10039 to account 2090
following only outgoing transaction
   edges. Output the list of transaction amounts along each path as well as
the total amount of the transactions
   along each path. */
g.queryPgql(
  "  SELECT LISTAGG(my.get_prop(e.properties, 'amount'), ' + ') || ' = ' AS
amounts_along_path, " +
```

```
  "          SUM(CAST(my.get_prop(e.properties, 'amount') AS DOUBLE))
AS total_amount " +
  "     FROM MATCH ALL SHORTEST (a) (-[e]-> WHERE
my.get_prop(e.properties, 'type') = 'transaction')* (b) " +
  "    WHERE my.get_prop(a.properties, 'number') = '10039' AND " +
  "          my.get_prop(b.properties, 'number') = '2090' " +
  "ORDER BY total_amount").print().close();
```

The output of the Java code is:

```
+---------------------------------------------+
| amounts_along_path          | total_amount |
+---------------------------------------------+
| 1000.0 + 1500.3 + 9999.5 =  | 12499.8      |
| 1000.0 + 3000.7 + 9999.5 =  | 14000.2      |
+---------------------------------------------+
```

8

Loading a PG View into the Graph Server (PGX)

There are several ways to load a property graph view (PG View) into the graph server (PGX).

- Loading a PG View Using the readGraphByName API
  You can load a graph into the graph server (PGX) from a property graph view (PG View) by name.
- Loading a Graph Using a JSON Configuration File
  In order to load a property graph view into the graph server (PGX), you can create a graph configuration file, which contains the metadata of the graph to be loaded.
- Loading a Graph by Defining a Graph Configuration Object
  You can load a graph from Oracle Database by first defining the graph configuration object using the `GraphConfigBuilder` class and then reading the graph into the graph server (PGX).
- Loading a Subgraph from Property Graph Views
  You can create a subgraph from a property graph view and load it into memory in the graph server (PGX).

8.1 Loading a PG View Using the readGraphByName API

You can load a graph into the graph server (PGX) from a property graph view (PG View) by name.

You can use the `PgxSession#readGraphByName` API to load a graph from a PG View:

```
readGraphByName(String schemaName, String graphName, GraphSource source,
ReadGraphOption options)
```

The arguments used in the method are described in the following table:

Table 8-1 Parameters for the `readGraphByName` method

Parameter	Description	Optional
`schemaName`	Schema owner	Yes
`graphName`	Name of the PG View	No
`source`	Source format for the graph (`GraphSource.PG_VIEW`)	No
`options`	Represents the graph optimization options	Yes

The `readGraphByName()` method reads the PG View metadata tables and internally generates the graph configuration to load the graph. You must have `PGX_SESSION_NEW_GRAPH` permission to use this API.

For example you can load the graph from a property graph view as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("BANKDATAVIEW", 
GraphSource.PG_VIEW)
$12 ==> PgxGraph[name=bankdataview,N=1000,E=5001,created=1625730942294]
```

Java

```
PgxGraph graph = session.readGraphByName("BANKDATAVIEW", 
GraphSource.PG_VIEW);
Graph: PgxGraph[name=bankdataview,N=1000,E=5001,created=1625732149262]
```

Python

```
>>> graph = session.read_graph_by_name('BANKDATAVIEW', 'pg_view')
>>> graph
PgxGraph(name: bankdataview, v: 1000, e: 5001, directed: True, 
memory(Mb): 0)
```

- Specifying Options for the readGraphByName API
  You can specify graph optimization options, `OnMissingVertexOption` or both when using the `readGraphByName` API for loading a property graph view (PG View).
- Specifying the Schema Name for the readGraphByName API
  You can specify the schema name when using the `readGraphByName` API for loading a property graph view (PG View).

8.1.1 Specifying Options for the `readGraphByName` API

You can specify graph optimization options, `OnMissingVertexOption` or both when using the `readGraphByName` API for loading a property graph view (PG View).

The ReadGraphOption interface supports an additional `options` parameter when loading a PG View by name.

The following sections explain the various options supported by the `ReadGraphOption` interface.

Using the Graph Optimization Options

You can optimize the read or update performance when loading a PG View by name by using one of the following `options`:

- **`ReadGraphOption.optimizeFor(GraphOptimizedFor.READ)`:** Specifies that the loaded graph is optimized for READ.
- **`ReadGraphOption.optimizeFor(GraphOptimizedFor.UPDATES)`:** Specifies that the loaded graph is optimized for UPDATE.
- **`ReadGraphOption.synchronizable()`:** Specifies that the loaded graph can be synchronized.

It is important to note the following:

- `synchronizable()` option can be used in combination with `UPDATE` and `READ`. However, the `UPDATE` and `READ` options cannot be used at the same time.
- If you are loading a PG View for `SYNCHRONIZABLE` option, then ensure that the vertex and edge keys are numeric and non-composite.

The following example loads a PG View for `READ` and `SYNCHRONIZABLE` options:

- JShell
- Java

JShell

```
opg4j> var graph = session.readGraphByName("BANK_GRAPH_VIEW",
GraphSource.PG_VIEW,
...>
ReadGraphOption.optimizeFor(GraphOptimizedFor.READ),
...>                                ReadGraphOption.synchronizable())
graph ==>
PgxGraph[name=BANK_GRAPH_VIEW_2,N=1000,E=5001,created=1648457198462]
```

Java

```
PgxGraph graph = session.readGraphByName("BANKDATAVIEW",
GraphSource.PG_VIEW, "BANK_GRAPH_VIEW", GraphSource.PG_VIEW,

ReadGraphOption.optimizeFor(GraphOptimizedFor.READ),

ReadGraphOption.synchronizable());
```

Using the `OnMissingVertex` Options

If either the source or destination vertex or both are missing for an edge, then you can use the `OnMissingVertexOption` which specifies the behavior for handling the edge with the missing vertex. The following values are supported for this option:

- **`ReadGraphOption.onMissingVertex(OnMissingVertex.ERROR)`:** This is the default option and this specifies that an error must be thrown for edges with missing vertices.

- **`ReadGraphOption.onMissingVertex(OnMissingVertex.IGNORE_EDGE):`** Specifies that the edge for a missing vertex must be ignored.
- **`ReadGraphOption.onMissingVertex(OnMissingVertex.IGNORE_EDGE_LOG):`** Specifies that the edge for a missing vertex must be ignored and all ignored edges must be logged.
- **`ReadGraphOption.onMissingVertex(OnMissingVertex.IGNORE_EDGE_LOG_ONCE):`** Specifies that the edge for a missing vertex must be ignored and only the first ignored edge must be logged.

The following example loads the PG View by ignoring the edges with missing vertices and logging only the first ignored edge. Note, to view the logs, you must update the default Logback configuration file in `/etc/oracle/graph/logback.xml` and the graph server (PGX) logger configuration file in `/etc/oracle/graph/logback-server.xml` to log the DEBUG logs. You can then view the ignored edges in `/var/opt/log/pgx-server.log` file.

- JShell
- Java

JShell

```
opg4j> session.readGraphByName("REGIONS", GraphSource.PG_VIEW,
...>
ReadGraphOption.onMissingVertex(OnMissingVertex.IGNORE_EDGE_LOG_ONCE))
$7 ==> PgxGraph[name=REGIONVIEW_3,N=27,E=18,created=1655903219910]
```

Java

```
PgxGraph graph = session.readGraphByName("REGIONS",
GraphSource.PG_VIEW,
ReadGraphOption.onMissingVertex(OnMissingVertex.IGNORE_EDGE_LOG_ONCE));
```

8.1.2 Specifying the Schema Name for the readGraphByName API

You can specify the schema name when using the `readGraphByName` API for loading a property graph view (PG View).

This feature allows you load a PG View from another user schema into the graph server (PGX). However, ensure that you have `READ` permission on all the underlying metadata and data tables when loading a PG View from another schema.

The following example loads a PG View from the `GRAPHUSER` schema:

- JShell

- Java

JShell

```
opg4j> var graph = session.readGraphByName("GRAPHUSER", "FRIENDS",
GraphSource.PG_VIEW)
graph ==> PgxGraph[name=FRIENDS,N=6,E=4,created=1672743474212]
```

Java

```
PgxGraph graph = session.readGraphByName("GRAPHUSER", "FRIENDS",
GraphSource.PG_VIEW);
```

8.2 Loading a Graph Using a JSON Configuration File

In order to load a property graph view into the graph server (PGX), you can create a graph configuration file, which contains the metadata of the graph to be loaded.

The following shows a sample JSON configuration file:

```
{
  "name": "BANK_GRAPH",
  "source_name": "BANK_GRAPH",
  "source_type": "pg_view",
  "jdbc_url":"jdbc:oracle:thin:@localhost:1521/orclpdb",
  "username":"graphuser",
  "keystore_alias":"database1",
  "vertex_providers":[
        {
            "name":"Accounts",
            "format":"rdbms",
            "database_table_name":"BANK_ACCOUNTS",
            "key_column":"ID",
            "key_type": "integer",
            "parallel_hint_degree": 3,
             "props":[
                {
                        "name":"ID",
                        "type":"integer"

                },
                 {
                        "name":"NAME",
                        "type":"string"
                 }

            ]


        }
```

```
    ],
    "edge_providers":[
        {
            "name":"Transfers",
            "format":"rdbms",
            "database_table_name":"BANK_TXNS",
            "key_column":"ID",
            "parallel_hint_degree": 3,
            "source_column":"FROM_ACCT_ID",
            "destination_column":"TO_ACCT_ID",
            "source_vertex_provider":"Accounts",
            "destination_vertex_provider":"Accounts",
            "props":[
                {
                        "name":"FROM_ACCT_ID",
                        "type":"integer"
                },
                {
                        "name":"TXN_AMOUNT",
                        "type":"float",
                        "column":"AMOUNT"
                },
                {
                        "name":"DESCRIPTION",
                        "type":"string"
                },
                {
                        "name":"TO_ACCT_ID",
                        "type":"integer"
                }
            ]
        }
    ]
}
```

The preceding configuration uses a Java keystore alias to reference the database password that is stored in a keystore file. See Store the Database Password in a Keystore for more information.

Also, the edge property `AMOUNT` is renamed to `TXN_AMT`. This implies that when loading a graph into the graph server (PGX), you can optionally rename vertex or edge properties to have different names other than the names of the underlying columns in the database.

See Also:

- Configuring PARALLEL Hint when Loading a Graph
- Graph Configuration Options for more details on the graph configuration options.

You can now read the graph into the graph server as shown:

- JShell
- Java

JShell

```
./bin/opg4j --secret_store /etc/oracle/graph/keystore.p12
enter password for keystore /etc/oracle/graph/keystore.p12:
For an introduction type: /help intro
Oracle Graph Server Shell 23.1.0
Variables instance, session, and analyst ready to use
opg4j> var g =
session.readGraphWithProperties("<path_to_json_configuration>")
g ==> PgxGraph[name=BANK_GRAPH_NEW,N=999,E=4993,created=1675960224397]
```

Java

```
ServerInstance instance = GraphServer.getInstance("https://localhost:7007",
<username>, <password>.toCharArray());
PgxSession session = instance.createSession("my-session");
String keystorePath = "/etc/oracle/graph/keystore.p12";
char[] keystorePassword = "<keystore_password>".toCharArray();
session.registerKeystore(keystorePath, keystorePassword);
PgxGraph g = session.readGraphWithProperties("<path_to_json_configuration>");
System.out.println("Graph: " + g);
```

- Configuring PARALLEL Hint when Loading a Graph

8.2.1 Configuring PARALLEL Hint when Loading a Graph

You can also optimize the graph loading performance by configuring a specific parallel hint value using the GraphConfig field, `PARALLEL_HINT_DEGREE`, which will be used by the underlying SQL queries. This can be applied when loading a graph using a JSON configuration file or through the `GraphConfigBuilder` API.

The following table describes how the internal queries are configured based on the specified `PARALLEL_HINT_DEGREE` values.

Table 8-2 PARALLEL_HINT_DEGREE values

`PARALLEL_HINT_DEGREE` Value	**Parallel hint used in the SQL Statement**
Positive integer(`n`)	Uses the given `n` degree: `SELECT /*+ PARALLEL(n) */ ...`
Zero	Uses a plain hint: `SELECT /*+ PARALLEL */ ...`
Negative integer (Default value: `-1`)	No PARALLEL hint: `SELECT ...`

See Also:

- Loading a Graph Using a JSON Configuration File for an example using parallel hint configuration.
- Loading a Graph by Defining a Graph Configuration Object for an example using parallel hint configuration.

8.3 Loading a Graph by Defining a Graph Configuration Object

You can load a graph from Oracle Database by first defining the graph configuration object using the `GraphConfigBuilder` class and then reading the graph into the graph server (PGX).

The following example loads a property graph view into memory, authenticating as <database user>/<database password> with the database:

- JShell
- Java

JShell

```
opg4j> var vertexConfig = new RdbmsEntityProviderConfigBuilder().
...>                                             setName("Account").
...>                                             setKeyColumn("ID").
...>                                             setParallelHintDegree(3).
...>
setDatabaseTableName("BANK_ACCOUNTS").
...>                                             addProperty("ID",
PropertyType.INTEGER).
...>                                             build()

opg4j> var edgeConfig = new RdbmsEntityProviderConfigBuilder().
...>                                        setName("Transfer").
...>                                        setKeyColumn("TXN_ID").
...>
setSourceColumn("FROM_ACCT_ID").
...>
setDestinationColumn("TO_ACCT_ID").
...>
setSourceVertexProvider("Account").
...>
setDestinationVertexProvider("Account").
...>                                        setParallelHintDegree(3).
...>                                        createKeyMapping(true).
```

```
...>                                       setDatabaseTableName("BANK_TXNS").
...>                                       addProperty("FROM_ACCT_ID", 
PropertyType.INTEGER).
...>                                       addProperty("TO_ACCT_ID", 
PropertyType.INTEGER).
...>                                       addProperty("AMOUNT", 
PropertyType.FLOAT).
...>                                       build()

opg4j> var cfg = GraphConfigBuilder.forPartitioned().
...>                     setJdbcUrl("jdbc:oracle:thin:@localhost:1521/orclpdb").
...>                     setUsername("graphuser").
...>                     setPassword("<password>").
...>                     setName("bank_graph").
...>                     setSourceName("bank_graph").
...>                     setSourceType(SourceType.PG_VIEW).
...>                     setVertexIdType(IdType.INTEGER).
...>                     addVertexProvider(vertexConfig).
...>                     addEdgeProvider(edgeConfig).
...>                     build()

opg4j> var g = session.readGraphWithProperties(cfg)
g ==> PgxGraph[name=bank_graph,N=999,E=4993,created=1676806306348]
```

Java

```
// Build the vertex provider
RdbmsEntityProviderConfig vertexConfig = new 
RdbmsEntityProviderConfigBuilder()
                                             .setName("Account")
                                             .setKeyColumn("ID")
                                             .setParallelHintDegree(3)
                                             .setDatabaseTableName("BANK_ACC
OUNTS")
                                             .addProperty("ID", 
PropertyType.INTEGER)
                                             .build();
// Build the edge provider
RdbmsEntityProviderConfig edgeConfig = new RdbmsEntityProviderConfigBuilder()
                                             .setName("Transfer")
                                             .setKeyColumn("TXN_ID")
                                             .setSourceColumn("FROM_ACCT_ID"
)
                                             .setDestinationColumn("TO_ACCT_
ID")
                                             .setSourceVertexProvider("Accou
nt")
                                             .setDestinationVertexProvider("
Account")
                                             .setParallelHintDegree(3)
                                             .createKeyMapping(true)
                                             .setDatabaseTableName("BANK_TXN
S")
                                             .addProperty("FROM_ACCT_ID", 
```

```
PropertyType.INTEGER)
                                                  .addProperty("TO_ACCT_ID"
, PropertyType.INTEGER)
                                                  .addProperty("AMOUNT",
PropertyType.FLOAT)
                                                  .build();
// Build the graph
GraphConfig cfg = GraphConfigBuilder.forPartitioned()
                           .setJdbcUrl("jdbc:oracle:thin:@localhost:152
1/orclpdb")
                           .setUsername("graphuser")
                           .setPassword("<password>")
                           .setName("bank_graph")
                           .setSourceName("bank_graph")
                           .setSourceType(SourceType.PG_VIEW)
                           .setVertexIdType(IdType.INTEGER)
                           .addVertexProvider(vertexConfig)
                           .addEdgeProvider(edgeConfig)
                           .build();

PgxGraph g = session.readGraphWithProperties(cfg);
```

See Also:

Configuring PARALLEL Hint when Loading a Graph

8.4 Loading a Subgraph from Property Graph Views

You can create a subgraph from a property graph view and load it into memory in the graph server (PGX).

Instead of loading a full graph into memory, you can load a subgraph. This would consume less memory.

The following sections explain in detail on loading and expanding of subgraphs:

- PGQL Based Subgraph Loading
  You can use the `PgViewSubgraphReader#fromPgView` API to create an in-memory subgraph from a property graph view (PG View) using a set of PGQL queries.
- Prepared PGQL Queries
  You can also use prepared queries when loading a subgraph from a property graph view.
- Providing Database Connection Credentials
  You can specify the database connection credentials with the `PgViewSubgraphReader#fromPgView` API instead of using the default credentials of the current user.

- Dynamically Expanding a Subgraph
  You can expand an in-memory subgraph by loading another subgraph into memory and merging it with the current in-memory subgraph.

8.4.1 PGQL Based Subgraph Loading

You can use the `PgViewSubgraphReader#fromPgView` API to create an in-memory subgraph from a property graph view (PG View) using a set of PGQL queries.

These PGQL queries define the vertices and edges that are to be loaded into the subgraph. You can also use multiple PGQL queries and the resulting output graph is a union of the subgraphs, each being loaded independently by each PGQL query.

> **Note:**
>
> - Only non-composite vertex and edge keys are supported.
> - Only numeric edge keys are supported.
> - PGQL queries with `GROUP BY` or `ORDER BY` clauses are not supported for loading of subgraphs from a property graph view.

The following example creates a subgraph from a PG View using multiple PGQL queries:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readSubgraph().
...>                        fromPgView("FRIENDS").
...>                        queryPgql("MATCH (v1:Person)-[e:FRIENDOF]-
>(v2:Person) WHERE id(v1) = 'PERSONS(1)'").
...>                        queryPgql("MATCH (v:Person) WHERE id(v) =
'PERSONS(2)'").
...>                        load()
graph ==> PgxGraph[name=FRIENDS,N=3,E=1,created=1646726883194]
```

Java

```
PgxGraph graph = session.readSubgraph()
                       .fromPgView("FRIENDS")
                       .queryPgql("MATCH (v1:Person)-[e:FRIENDOF]-
>(v2:Person) WHERE id(v1) = 'PERSONS(1)'")
                       .queryPgql("MATCH (v:Person) WHERE id(v) =
```

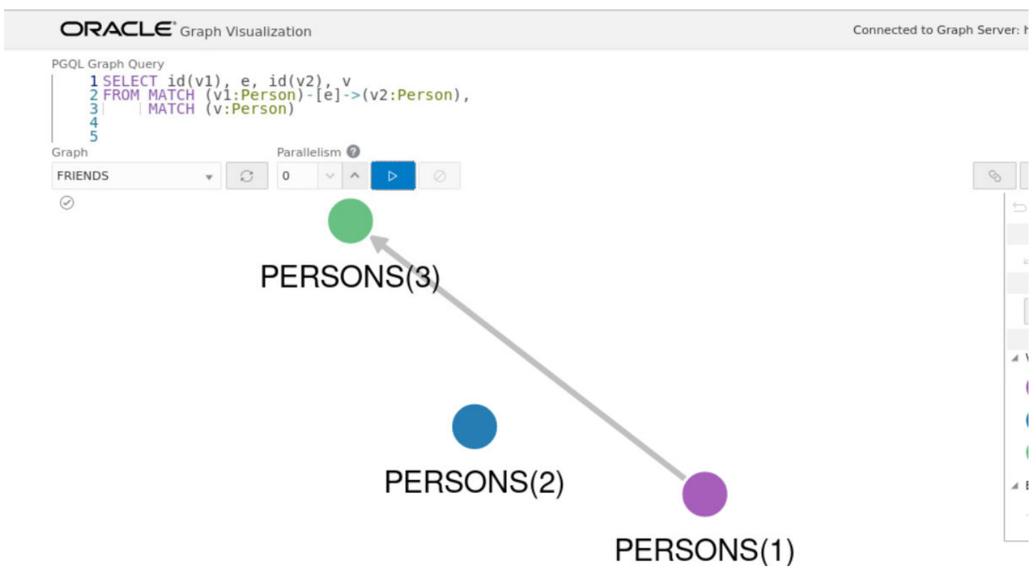
```
'PERSONS(2)'")
                        .load();
```

Python

```
>>> graph = session.read_subgraph_from_pg_view("FRIENDS", ["MATCH
(v1:Person)-[e:FRIENDOF]->(v2:Person) WHERE id(v1) = 'PERSONS(1)'",
...                              "MATCH (v:Person) WHERE id(v) =
'PERSONS(2)'"])
>>> graph
PgxGraph(name: FRIENDS, v: 3, e: 1, directed: True, memory(Mb): 0)
```

The following displays the output for the preceding PGQL query using the graph visualization tool.

Figure 8-1 Subgraph Visualization



Loading Subgraphs with Custom Names

By default, the new subgraph gets created with the same name as the PG View graph. Alternatively, if you want to load a subgraph with a custom name, then you can configure the subgraph name as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readSubgraph().
...>                      fromPgView("FRIENDS").
...>                      queryPgql("MATCH (v1:Person)-[e:FRIENDOF]->(v2:Person)
WHERE id(v1) = 'PERSONS(1)'").
...>                      queryPgql("MATCH (v:Person) WHERE id(v) =
'PERSONS(2)'").
...>                      load("friends_network")
graph ==> PgxGraph[name=friends_network,N=3,E=1,created=1664458398090]
```

Java

```
PgxGraph graph = session.readSubgraph()
                       .fromPgView("FRIENDS")
                       .queryPgql("MATCH (v1:Person)-[e:FRIENDOF]-
>(v2:Person) WHERE id(v1) = 'PERSONS(1)'")
                       .queryPgql("MATCH (v:Person) WHERE id(v) =
'PERSONS(2)'")
                       .load("friends_network");
```

Python

```
>>> graph = session.read_subgraph_from_pg_view("FRIENDS",
...                      ["MATCH (v1:Person)-[e:FRIENDOF]->(v2:Person) WHERE
id(v1) = 'PERSONS(1)'",
...                       "MATCH (v:Person) WHERE id(v) = 'PERSONS(2)'"],
...                      graph_name="friends_network")
>>> graph
PgxGraph(name: friends_network, v: 3, e: 1, directed: True, memory(Mb): 0)
```

Loading a Subgraph by Explicitly Specifying the Schema Name

If you want to load a subgraph by reading a PG View from another schema, you can additionally provide the schema name as an argument to the `PgViewSubgraphReader#fromPgView` API . You must also ensure that you have `READ` permission on all the underlying metadata and data tables for the PG View.

For example:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readSubgraph()
...> .fromPgView("GRAPHUSER", "FRIENDS")
...> .queryPgql("MATCH (v:Person) WHERE id(v) = 'PERSONS(2)'")
...> .load()
graph ==> PgxGraph[name=FRIENDS,N=1,E=0,created=1672743755511]
```

Java

```
PgxGraph graph = session.readSubgraph()
                        .fromPgView("GRAPHUSER", "FRIENDS")
                        .queryPgql("MATCH (v:Person) WHERE id(v) =
'PERSONS(2)'")
                        .load();
```

Python

```
>>> graph = session.read_subgraph_from_pg_view("FRIENDS",
...  ["MATCH (v:Person) WHERE id(v) = 'PERSONS(2)'"],
...  schema="GRAPHUSER")
```

8.4.2 Prepared PGQL Queries

You can also use prepared queries when loading a subgraph from a property graph view.

You can pass bind variables using prepared PGQL queries. The `PreparedPgViewPgqlQuery#preparedPgqlQuery` method adds a prepared query to a list of queries that are executed to load the subgraph. The `PreparedPgViewPgqlQuery` API sets the bindings for the variables and continues with the loading of the subgraph.

For example:

- JShell
- Java
- Python

JShell

```
opg4j> var pgViewSubgraphReader = session.readSubgraph().
...>                                     fromPgView("FRIENDS")
pgViewSubgraphReader ==>
oracle.pgx.api.subgraph.PgViewSubgraphReader@33bfe6d3
opg4j> var preparedPgqlQuery =
pgViewSubgraphReader.preparedPgqlQuery("MATCH (v1:Person)-[e:FriendOf]-
```

```
>(v2:Person) WHERE id(v2)=?")
preparedPgqlQuery ==>
oracle.pgx.api.subgraph.PreparedPgViewPgqlQuery@2e6b379c
opg4j> preparedPgqlQuery = preparedPgqlQuery.withStringArg(1, "PERSONS(3)")
preparedPgqlQuery ==>
oracle.pgx.api.subgraph.PreparedPgViewPgqlQuery@2e6b379c
opg4j> var graph = preparedPgqlQuery.load()
graph ==> PgxGraph[name=FRIENDS_2,N=3,E=2,created=1648566047855]
```

Java

```
import oracle.pgx.api.subgraph.*;
…
…
PgViewSubgraphReader pgViewSubgraphReader=
session.readSubgraph().fromPgView("FRIENDS");
PreparedPgViewPgqlQuery preparedPgqlQuery =
pgViewSubgraphReader.preparedPgqlQuery("MATCH (v1:Person)-[e:FriendOf]-
>(v2:Person) WHERE id(v2)=?");
preparedPgqlQuery = preparedPgqlQuery.withStringArg(1, "PERSONS(3)");
PgxGraph graph = preparedPgqlQuery.load();
```

Python

```
>>> from pypgx.api import PreparedPgqlQuery
>>> from pypgx.api import PreparedPgqlQueryStringArgument
>>> graph = session.read_subgraph_from_pg_view("FRIENDS",
...   [PreparedPgqlQuery("MATCH (v1:Person)-[e:FriendOf]->(v2:Person) WHERE
id(v2)=?", [PreparedPgqlQueryStringArgument("PERSONS(3)")])])
>>> graph
PgxGraph(name: FRIENDS, v: 3, e: 2, directed: True, memory(Mb): 0)
```

8.4.3 Providing Database Connection Credentials

You can specify the database connection credentials with the `PgViewSubgraphReader#fromPgView` API instead of using the default credentials of the current user.

The following example shows loading of a subgraph for non-default database connection settings:

- JShell
- Java

JShell

```
opg4j> var graph = session.readSubgraph().
...>                         fromPgView("FRIENDS").
...>                         username("graphuser").
...>                         password("<password_for_graphuser>").
...>                         keystoreAlias("database1").
...>                         schema("graphuser").
...>                         jdbcUrl("jdbc:oracle:thin:@localhost:1521/
orclpdb").
...>                         connections(12).
...>                         queryPgql("MATCH (a:Person)").
...>                         load()
graph ==> PgxGraph[name=FRIENDS,N=4,E=0,created=1648541234520]
```

Java

```
PgxGraph graph = session.readSubgraph()
                        .fromPgView("FRIENDS")
                        .username("graphuser")
                        .password("<password_for_graphuser>")
                        .keystoreAlias("database1")
                        .schema("graphuser")
                        .jdbcUrl("jdbc:oracle:thin:@localhost:1521/
orclpdb")
                        .connections(12)
                        .queryPgql("MATCH (a:Person)")
                        .load();
```

8.4.4 Dynamically Expanding a Subgraph

You can expand an in-memory subgraph by loading another subgraph into memory and merging it with the current in-memory subgraph.

The `PgxGraph.expandGraph()` method can be used to expand a subgraph. The following applies when merging two graphs:

- Both the graphs can have separate sets of providers.
- A graph can have some providers same as the other graph. In this case:
  - The providers with the same names must have the same labels.
  - The graph being merged must have the same or a common subset of properties as the base graph. However, it is possible that either of the graphs may have more number of properties.

The following example shows the expansion of the subgraph created in PGQL Based Subgraph Loading:

- JShell

- Java
- Python

JShell

```
opg4j> graph = graph.expandGraph().
...>           withPgql().
...>           fromPgView("FRIENDS").
...>           queryPgql("MATCH (v1:PERSON) -[e:FRIENDOF]-> (v2:PERSON) WHERE 
id(v1) = 'PERSONS(2)'").
...>           preparedPgqlQuery("MATCH (v:PERSON) WHERE id(v) 
in ?").withStringArg(1, "PERSONS(4)").
...>           expand()
graph ==> PgxGraph[name=anonymous_graph_152,N=4,E=3,created=1647347092964]
```

Java

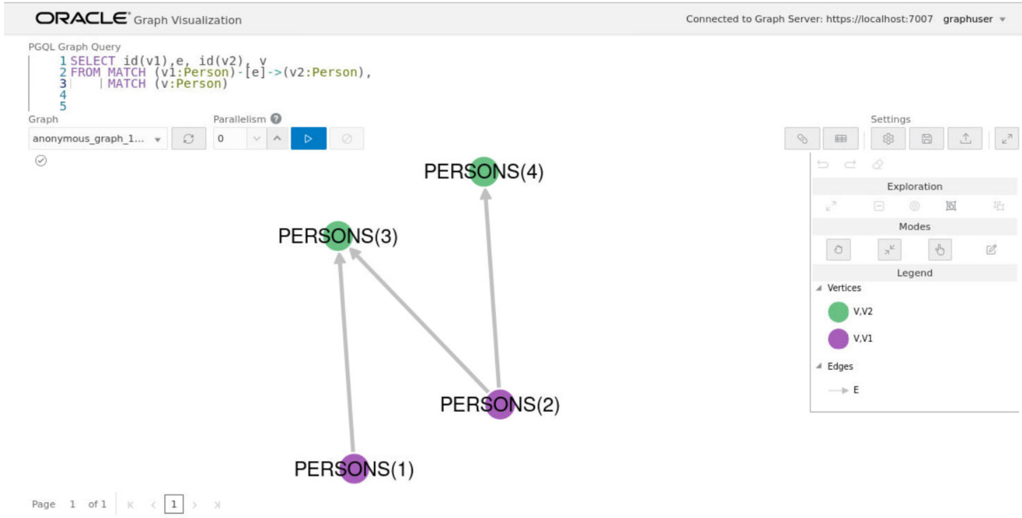
```
graph = graph.expandGraph()
             .withPgql()
             .fromPgView("FRIENDS")
             .queryPgql("MATCH (v1:PERSON) -[e:FRIENDOF]-> (v2:PERSON) WHERE 
id(v1) = 'PERSONS(2)'")
             .preparedPgqlQuery("MATCH (v:PERSON) WHERE id(v) 
in ?").withStringArg(1, "PERSONS(4)")
             .expand();
```

Python

```
>>> from pypgx.api import PreparedPgqlQuery
>>> from pypgx.api import PreparedPgqlQueryStringArgument
>>> graph = graph.expand_with_pgql(["MATCH (v1:PERSON) -[e:FRIENDOF]->
(v2:PERSON) WHERE id(v1) = 'PERSONS(2)'",
...                  PreparedPgqlQuery("MATCH (v:Person) WHERE id(v)=?", 
[PreparedPgqlQueryStringArgument("PERSONS(4)")])],
...                  pg_view_name="FRIENDS")
>>> graph
PgxGraph(name: anonymous_graph_66, v: 4, e: 3, directed: True, memory(Mb): 0)
```

The following displays the output for the preceding PGQL query using the graph visualization tool. The subgraph is now expanded to include the `friendOf` relationship for `PERSONS(2)` in addition to `PERSONS(1)` which was already existing in the subgraph.

Figure 8-2   Expanding a Subgraph



Expanding a Subgraph by Explicitly Specifying the Schema Name

When expanding a graph, you can load another subgraph by reading a PG View from a different schema. For this, you must provide the schema name as an argument to the `PgqlViewGraphExpander#fromPgView` API. You must also ensure that you have `READ` permission on all the underlying metadata and data tables for the PG View.

For example:

- JShell
- Java
- Python

JShell

```
opg4j> graph = graph.expandGraph().
...>           withPgql().
...>           fromPgView("GRAPHUSER", "FRIENDS").
...>           queryPgql("MATCH (v:Person) WHERE id(v) =
'PERSONS(1)'").
...>           expand()
graph ==>
PgxGraph[name=anonymous_graph_18,N=1,E=0,created=1672848726308]
```

Java

```
graph = graph.expandGraph()
             .withPgql()
             .fromPgView("GRAPHUSER", "FRIENDS")
```

```
              .queryPgql("MATCH (v:Person) WHERE id(v) = 'PERSONS(1)'")
              .expand();
```

Python

```
>>> graph = graph.expand_with_pgql("MATCH (v:Person) WHERE id(v) =
'PERSONS(1)'",
...  pg_view_name="FRIENDS", schema="GRAPHUSER")
>>> graph
PgxGraph(name: anonymous_graph_6, v: 2, e: 0, directed: True, memory(Mb): 0)
```

Using Merging Strategy

When expanding a graph, some vertices and edges that are in the new graph data may have already been loaded in the base graph. In such cases, if the vertex and edge property values differ for all vertices and edges that are both in the base graph and in the new graph to be merged, then the following applies:

- If the merging strategy is `KEEP_CURRENT_VALUES`, then the vertex and edge property values coming from the new graph are ignored.
- If the merging strategy is `UPDATE_WITH_NEW_VALUES`, then the vertex and edge property values are updated with the ones found in the new graph.

For example:

- JShell
- Java

JShell

```
opg4j> import oracle.pgx.api.expansion.PropertyMergeStrategy
opg4j> graph = graph.expandGraph().
...>          withPgql().
...>          fromPgView("FRIENDS").
...>          queryPgql("MATCH (v1:PERSON) -[e:FRIENDOF]-> (v2:PERSON) WHERE
id(v1) = 'PERSONS(2)'").
...>          preparedPgqlQuery("MATCH (v:PERSON) WHERE id(v)
in ?").withStringArg(1, "PERSONS(4)").
...>
vertexPropertiesMergingStrategy(PropertyMergeStrategy.UPDATE_WITH_NEW_VALUES)
.
...>          expand()
```

Java

```
import oracle.pgx.api.expansion.PropertyMergeStrategy;
graph = graph.expandGraph()
```

```
             .withPgql()
             .fromPgView("FRIENDS")
             .queryPgql("MATCH (v1:PERSON) -[e:FRIENDOF]-> (v2:PERSON)
WHERE id(v1) = 'PERSONS(2)'")
             .preparedPgqlQuery("MATCH (v:PERSON) WHERE id(v)
in ?").withStringArg(1, "PERSONS(4)")
             .vertexPropertiesMergingStrategy(PropertyMergeStrategy.UPD
ATE_WITH_NEW_VALUES)
             .expand();
```

9

Quick Starts for Using Property Graph Views

This chapter contains quick start tutorials and other resources to help you get started on working with property graph views.

- Using Sample Data for Graph Analysis
- Quick Start: Working with Property Graph Views
  This tutorial helps you get started on creating, querying and executing graph algorithms on property graph views.
- Quick Start: Using the Python Client as a Module
  This section describes how to use the Python client as a module in Python applications.
- Oracle LiveLabs Workshops for Graphs
  You can also explore Oracle Property Graph features using the graph workshops in Oracle LiveLabs.

9.1 Using Sample Data for Graph Analysis

The rpm installation of the graph server provides you with sample graph data in `/opt/oracle/graph/data` directory.

The `bank_graph` folder contains data that represent the vertices and edges of a graph in `bank_nodes.csv` and `bank_edges_amt.csv` files respectively. You can import the graph data from these `.csv` files into the database. You can then create a graph for querying and analyses.

- Importing Data from CSV Files

9.1.1 Importing Data from CSV Files

You can import data from CSV files into the database through Oracle SQL Developer or by using Oracle Database utilities (such as SQL*Loader or External Tables).

- See Data Import Wizard in *Oracle SQL Developer User's Guide* on how to import data from files into tables.
- See Oracle Database Utilities for more information on data transfer utilities.

The following instructions enable you to load data into the database tables using Oracle SQL Loader.

As a prerequisite requirement, you must execute the following SQL statements to create the vertex (`bank_accounts`) and edge (`bank_txns`) tables in the database:

```
CREATE TABLE bank_accounts(id NUMBER, name VARCHAR2(10));


CREATE TABLE bank_txns(from_acct_id NUMBER, to_acct_id NUMBER, description
VARCHAR2(10), amount NUMBER);
```

You can then perform the following steps to load the data:

1. Create a SQL*Loader control file to load the vertices from `bank_nodes.csv` as shown:

   ```
   load data
   infile '<path_to_bank_nodes.csv>'
   into table bank_accounts
   fields terminated by "," optionally enclosed by '"'
   ( id, name )
   ```

2. Invoke SQL*Loader from the command line to load the vertices in `bank_accounts` table, using the preceding configuration file as shown:

   ```
   sqlldr <dbuser>/<password> CONTROL=<path_to_vertex_loader.ctl>
   ```

   The `bank_accounts` table gets successfully loaded with 1000 rows.
3. Create a SQL*Loader control file to load the edge from `bank_edges_amt.csv` as shown:

   ```
   load data
   infile '<path_to_bank_edges_amt.csv>'
   into table bank_txns
   fields terminated by "," optionally enclosed by '"'
   (from_acct_id,to_acct_id,description,amount)
   ```

4. Invoke SQL*Loader from the command line to load the edges in `bank_txns` table, using the preceding configuration file as shown:

   ```
   sqlldr <dbuser>/<password> CONTROL=<path_to_edge_loader.ctl>
   ```

   The `bank_txns` table gets successfully loaded with 4996 rows.
5. Execute the following SQL statement to add the primary key constraint in the `bank_accounts` table:

   ```
   ALTER TABLE bank_accounts ADD PRIMARY KEY (id);
   ```

6. Execute the following SQL statements to add a primary key column to the `bank_txns` table, populate it with `ROWNUM` values and then define the primary key constraint:

   ```
   ALTER TABLE bank_txns ADD txn_id NUMBER;
   UPDATE bank_txns SET txn_id = ROWNUM;
   COMMIT;
   ALTER TABLE bank_txns ADD PRIMARY KEY (txn_id);
   ```

7. Execute the following SQL statements to add the foreign key constraints to the `bank_txns` table:

   ```
   ALTER TABLE bank_txns MODIFY from_acct_id REFERENCES
   bank_accounts(id);
   ```

```
ALTER TABLE bank_txns MODIFY to_acct_id REFERENCES bank_accounts(id);
```

The sample bank graph data is now available in the database tables.

9.2 Quick Start: Working with Property Graph Views

This tutorial helps you get started on creating, querying and executing graph algorithms on property graph views.

The instructions assume that you have loaded the sample bank graph data provided with the graph server installation in the database tables. See Using Sample Data for Graph Analysis for more information.

The following instructions are supported with examples that can be executed either with the OPG4J Java shell or OPG4PY Python shell or through a Java program using the PGX API.

1. Start the interactive graph shell CLI:

   - JShell
   - Python

   ### JShell

   ```
   cd /opt/oracle/graph
   ./bin/opg4j --no_connect
   Oracle Graph Server Shell 23.1.0
   ```

   ### Python

   ```
   cd /opt/oracle/graph
   ./bin/opg4py --no_connect
   Oracle Graph Server Shell 23.1.0
   ```

2. Obtain a JDBC database connection, if using OPG4J shell or a Java program.

   - JShell
   - Java

   ### JShell

   ```
   opg4j> var jdbcUrl="jdbc:oracle:thin:@<host>:<port>/<sid>"
   jdbcUrl ==> "jdbc:oracle:thin:@localhost:1521/orclpdb"
   opg4j> var conn =
   DriverManager.getConnection(jdbcUrl,"<username>","<password>")
   ```

```
conn ==> oracle.jdbc.driver.T4CConnection@7d463c9f
opg4j> conn.setAutoCommit(false);
```

Java

```
import java.sql.DriverManager;
import java.sql.Connection;
import java.sql.Statement;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pgx.api.*;
import oracle.pg.rdbms.GraphServer;
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;
…
…
// Get a jdbc connection
DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
String jdbcUrl="jdbc:oracle:thin:@"+<host>+":"+<port>+"/"+<sid>;
conn = DriverManager.getConnection(jdbcUrl, <username>, <password>);
conn.setAutoCommit(false);
```

3. Create a PGQL connection.

- JShell
- Java
- Python

JShell

```
opg4j> var pgqlConn = PgqlConnection.getConnection(conn)
pgqlConn ==> oracle.pg.rdbms.pgql.PgqlConnection@5c5c784c
```

Java

```
PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
```

Python

```
>>> pgql_conn =
opg4py.pgql.get_connection("<username>","<password>",
"jdbc:oracle:thin:@<host>:<port>/<sid>")
```

4. Create a PGQL statement to execute PGQL queries.

- JShell
- Java
- Python

JShell

```
opg4j> var pgqlStmt = pgqlConn.createStatement()
pgqlStmt ==> oracle.pg.rdbms.pgql.PgqlExecution@29e3c28
```

Java

```
PgqlStatement pgqlStmt = pgqlConn.createStatement();
```

Python

```
>>> pgql_statement = pgql_conn.create_statement()
```

5. Create a property graph view using the `CREATE PROPERTY GRAPH` statement:

- JShell
- Java
- Python

JShell

```
opg4j> String pgql =
...> "CREATE PROPERTY GRAPH bank_graph_view "
...> + "VERTEX TABLES ( BANK_ACCOUNTS AS ACCOUNTS "
...> + "KEY (ID) "
...> + "LABEL ACCOUNTS "
...> + "PROPERTIES (ID, NAME) "
...> + ") "
...> + "EDGE TABLES ( BANK_TXNS AS TRANSFERS "
...> + "KEY (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT) "
...> + "SOURCE KEY (FROM_ACCT_ID) REFERENCES ACCOUNTS (ID) "
...> + "DESTINATION KEY (TO_ACCT_ID) REFERENCES ACCOUNTS (ID) "
...> + "LABEL TRANSFERS "
...> + "PROPERTIES (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT, DESCRIPTION) "
...> + ") OPTIONS (PG_VIEW) "
opg4j> pgqlStmt.execute(pgql)
```

Java

```
String pgql =
        "CREATE PROPERTY GRAPH " + graph + " " +
        "VERTEX TABLES ( BANK_ACCOUNTS AS ACCOUNTS " +
        "KEY (ID) " +
        "LABEL ACCOUNTS " +
        "PROPERTIES (ID, NAME)" +
        ") " +
        "EDGE TABLES ( BANK_TXNS AS TRANSFERS " +
        "KEY (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT) " +
        "SOURCE KEY (FROM_ACCT_ID) REFERENCES ACCOUNTS (ID) " +
        "DESTINATION KEY (TO_ACCT_ID) REFERENCES ACCOUNTS (ID) " +
        "LABEL TRANSFERS " +
        "PROPERTIES (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT,
DESCRIPTION)" +
        ") OPTIONS(PG_VIEW)";

      pgqlStmt.execute(pgql);
```

Python

```
>>> pgql = """
...         CREATE PROPERTY GRAPH bank_graph_view
...         VERTEX TABLES (
...           BANK_ACCOUNTS
...           LABEL ACCOUNTS
...           PROPERTIES (ID, NAME)
...         )
...         EDGE TABLES (
...           BANK_TXNS
...             SOURCE KEY (FROM_ACCT_ID) REFERENCES BANK_ACCOUNTS
(ID)
...             DESTINATION KEY (TO_ACCT_ID) REFERENCES
BANK_ACCOUNTS (ID)
...             LABEL TRANSFERS
...             PROPERTIES (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT,
DESCRIPTION)
...         ) OPTIONS(PG_VIEW)
... """
>>> pgql_statement.execute(pgql)
False
```

The property graph view `bank_graph_view` gets created successfully.

6. Execute the following query to retrieve the first 10 elements of the graph as shown:

- JShell

- Java
- Python

JShell

```
opg4j> String pgqlQuery =
...> "SELECT e.from_acct_id, e.to_acct_id, e.amount FROM "
...> + "MATCH (n:ACCOUNTS) -[e:TRANSFERS]-> (m:ACCOUNTS) ON
BANK_GRAPH_VIEW "
...> + "LIMIT 10"
opg4j> var rs = pgqlStmt.executeQuery(pgqlQuery)
rs ==> oracle.pg.rdbms.pgql.pgview.PgViewResultSet@1e368085
opg4j> rs.print()
+-----------------------------------+
| FROM_ACCT_ID | TO_ACCT_ID | AMOUNT |
+-----------------------------------+
| 121          | 94         | 1000   |
| 121          | 255        | 1000   |
| 121          | 221        | 1000   |
| 122          | 27         | 1000   |
| 122          | 606        | 1000   |
| 122          | 495        | 1000   |
| 122          | 640        | 1000   |
| 122          | 140        | 1000   |
| 123          | 95         | 1000   |
| 123          | 130        | 1000   |
+-----------------------------------+
$16 ==> oracle.pg.rdbms.pgql.pgview.PgViewResultSet@1e368085
```

Java

```
String pgqlQuery =
        "SELECT e.from_acct_id, e.to_acct_id, e.amount FROM " +
        "MATCH (n:ACCOUNTS) -[e:TRANSFERS]-> (m:ACCOUNTS) ON
BANK_GRAPH_VIEW " +
        "LIMIT 10";
PgqlResultSet rs = pgqlStmt.executeQuery(pgqlQuery);
rs.print();
```

Python

```
>>> pgql = """
... SELECT e.from_acct_id, e.to_acct_id, e.amount FROM
... MATCH (n:ACCOUNTS) -[e:TRANSFERS]-> (m:ACCOUNTS) on BANK_GRAPH_VIEW
... limit 10
... """
>>> pgql_statement.execute_query(pgql).print()
+-----------------------------------+
| FROM_ACCT_ID | TO_ACCT_ID | AMOUNT |
+-----------------------------------+
| 121          | 94         | 1000   |
| 121          | 255        | 1000   |
```

```
| 121          | 221        | 1000   |
| 122          | 27         | 1000   |
| 122          | 606        | 1000   |
| 122          | 495        | 1000   |
| 122          | 640        | 1000   |
| 122          | 140        | 1000   |
| 123          | 95         | 1000   |
| 123          | 130        | 1000   |
+-------------------------------------+
```

7. Load the graph into the graph server (PGX). This will enable you to run a variety of different built-in algorithms on the graph and will also improve query performance for larger graphs.

- JShell
- Java
- Python

JShell

```
opg4j> var instance = GraphServer.getInstance("https://
localhost:7007", "<username>", "<password>".toCharArray())
instance ==> ServerInstance[embedded=false,baseUrl=https://
localhost:7007]
opg4j> var session = instance.createSession("mySession")
session ==>
PgxSession[ID=43653128-59cd-4e69-992c-1a2beac05857,source=mySession]
opg4j> var graph =
session.readGraphByName("BANK_GRAPH_VIEW",GraphSource.PG_VIEW)
graph ==>
PgxGraph[name=BANK_GRAPH_VIEW,N=1000,E=4996,created=1643308582055]
```

Java

```
ServerInstance instance = GraphServer.getInstance("https://
localhost:7007", "<username>", "<password>".toCharArray());
PgxSession session = instance.createSession("my-session");
PgxGraph graph =
session.readGraphByName("BANK_GRAPH_VIEW",GraphSource.PG_VIEW);
```

Python

```
>>> instance = graph_server.get_instance("https://
localhost:7007","<username>","<password>")
>>> session = instance.create_session("my_session")
>>> graph = session.read_graph_by_name('BANK_GRAPH_VIEW', 'pg_view')
>>> graph
```

```
PgxGraph(name: BG_PY_VIEW, v: 1000, e: 4996, directed: True, memory(Mb):
0)
```

8. Execute the PageRank algorithm as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var analyst = session.createAnalyst()
analyst ==> NamedArgumentAnalyst[session=3f0a9a71-f349-4aac-b75f-
a7c4ae50851b]
opg4j> analyst.pagerank(graph)
$10 ==> VertexProperty[name=pagerank,type=double,graph=BANK_GRAPH_VIEW]
```

Java

```
Analyst analyst = session.createAnalyst();
analyst.pagerank(graphView);
```

Python

```
>>> analyst = session.create_analyst()
>>> analyst.pagerank(graph)
VertexProperty(name: pagerank, type: double, graph: BANK_GRAPH_VIEW)
```

9. Query the graph to list the top 10 accounts by pagerank:

- JShell
- Java
- Python

JShell

```
opg4j> String pgql ==> "SELECT a.id, a.pagerank FROM MATCH (a) ON
BANK_GRAPH_VIEW ORDER BY a.pagerank DESC LIMIT 10"
opg4j> session.queryPgql(pgql).print()
+-----------------------------+
```

```
| id  | pagerank              |
+-----------------------------+
| 387 | 0.007292323575404966  |
| 406 | 0.0067300944623203615 |
| 135 | 0.0067205459831892545 |
| 934 | 0.00663484385036358   |
| 397 | 0.005693569761570973  |
| 559 | 0.0052584383114609844 |
| 352 | 0.005216329599236731  |
| 330 | 0.005093350408942336  |
| 222 | 0.004682551613749817  |
| 4   | 0.004569682370461633  |
+-----------------------------+
$18 ==> PgqlResultSetImpl[graph=BANK_GRAPH_VIEW,numResults=10]
```

Java

```
String pgQuery = "SELECT a.id, a.pagerank FROM MATCH (a) ON
BANK_GRAPH_VIEW ORDER BY a.pagerank DESC LIMIT 10";
session.queryPgql(pgQuery).print();
```

Python

```
>>> pgql = "SELECT a.id, a.pagerank FROM MATCH (a) ON
BANK_GRAPH_VIEW ORDER BY a.pagerank DESC LIMIT 10"
>>> session.query_pgql(pgql).print()
+-----------------------------+
| id  | pagerank              |
+-----------------------------+
| 387 | 0.007292323575404966  |
| 406 | 0.0067300944623203615 |
| 135 | 0.0067205459831892545 |
| 934 | 0.00663484385036358   |
| 397 | 0.005693569761570973  |
| 559 | 0.0052584383114609844 |
| 352 | 0.005216329599236731  |
| 330 | 0.005093350408942336  |
| 222 | 0.004682551613749817  |
| 4   | 0.004569682370461633  |
+-----------------------------+
```

9.3 Quick Start: Using the Python Client as a Module

This section describes how to use the Python client as a module in Python applications.

Remote Server

For this mode, all you need is the Python client to be installed. In your Python program, you must authenticate with the remote server before you can create a session as illustrated in the following example. Note that you must replace the values for `base_url`, `jdbc_url`, `username`, and `password` with values to match your environment details.

```
import pypgx
import opg4py
import opg4py.graph_server as graph_server
pgql_conn = opg4py.pgql.get_connection("<username>","<password>",
"<jdbc_url>")
pgql_statement = pgql_conn.create_statement()
pgql = """
        CREATE PROPERTY GRAPH bank_graph
        VERTEX TABLES (
          bank_accounts
            LABEL ACCOUNTS
            PROPERTIES (ID, NAME)
        )
        EDGE TABLES (
          bank_txns
            SOURCE KEY (from_acct_id) REFERENCES bank_accounts
            DESTINATION KEY (to_acct_id) REFERENCES bank_accounts
            LABEL TRANSFERS
            PROPERTIES (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT, DESCRIPTION)
        ) OPTIONS(PG_VIEW)
"""
pgql_statement.execute(pgql)
instance = graph_server.get_instance("<base_url>", "<username>",
"<password>")
session = instance.create_session("my_session")
graph = session.read_graph_by_name('BANK_GRAPH', 'pg_view')
analyst = session.create_analyst()
analyst.pagerank(graph)
rs = graph.query_pgql("SELECT id(x), x.pagerank FROM MATCH (x) LIMIT 5")
rs.print()
```

To execute, save the above program into a file named `program.py` and run the following command:

```
python3 program.py
```

You will see the following output:

```
+-------------------------------------------+
| id(x)             | pagerank              |
+-------------------------------------------+
| BANK_ACCOUNTS(2)  | 9.749447313256548E-4  |
| BANK_ACCOUNTS(4)  | 0.004584001759076056  |
| BANK_ACCOUNTS(6)  | 5.358461393401424E-4  |
| BANK_ACCOUNTS(8)  | 0.0013051552434930175 |
| BANK_ACCOUNTS(10) | 0.0015040122009364232 |
+-------------------------------------------+
```

Converting PGQL result set into pandas dataframe

Additionally, you can also convert the PGQL result set to a `pandas.DataFrame` object using the `to_pandas()` method. This makes it easier to perform various data filtering operations on the result set and it can also be used in Lambda functions. For example,

```
example_query = (
    "SELECT n.name AS name, n.age AS age "
    "WHERE (n)"
)
result_set = sample_graph.query_pgql(example_query)
result_df = result_set.to_pandas()

result_df['age_bin'] = result_df['age'].apply(lambda x: int(x)/20) #
create age bins based on age ranges
```

> **Note:**
>
> To view the complete set of available Python APIs, see OPG4PY Python API Reference.

Embedded Server

For this mode, the Python client and the Graph Server RPM package must be installed on the same machine.

```
import os
os.environ["PGX_CLASSPATH"] = "/opt/oracle/graph/lib/*"
instance = graph_server.get_embedded_instance()
session = instance.create_session("python_pgx_client")
print(session)
```

To execute, save the above program into a file named `program.py` and run the following command.

```
python3 program.py
```

After successful login, you must see a similar message indicating a PGX session was created:

```
PgxSession(id: 32fc7037-18f1-4381-ba94-107e5f63aec2, name:
python_pgx_client)
```

> **Note:**
>
> To view the complete set of available Python APIs, see OPG4PY Python API Reference.

9.4 Oracle LiveLabs Workshops for Graphs

You can also explore Oracle Property Graph features using the graph workshops in Oracle LiveLabs.

See the Oracle LiveLabs Workshop for a complete example on querying, analyzing and visualizing graphs using data stored in a free tier Autonomous Database instance. You will provision a new free tier Autonomous Database instance, load data into it, create a graph, and then query, analyze and visualize the graph.

10

Getting Started with the Client Tools

You can use multiple client tools to interact with the graph server (PGX) or directly with the graph data in the database.

The following sections explain how to use the various client tools:

- Interactive Graph Shell CLIs
  Both the Oracle Graph server and client packages contain interactive command-line applications for interacting with the Java APIs and the Python APIs of the product, locally or on remote computers.
- Using Autonomous Database Graph Client
  Using the `AdbGraphClient` API, you can access Graph Studio features in Autonomous Database programmatically using the Oracle Graph Client or through your Java or Python application.
- Using the Graph Visualization Web Client
  You can use the Graph Visualization application to visualize graphs that are either loaded into the graph server (PGX) or stored in the database.
- Using the Jupyter Notebook Interface
  You can use the Jupyter notebook interface to create, load, and query property graphs through Python.
- Additional Client Tools for Querying PG Views
  When working with property graph views (PG Views) in the database, you can use other supported client tools.

Related Topics

- Oracle Graph Client Installation
  You can interact with the various graph features using the client CLIs and the graph visualization web client.

10.1 Interactive Graph Shell CLIs

Both the Oracle Graph server and client packages contain interactive command-line applications for interacting with the Java APIs and the Python APIs of the product, locally or on remote computers.

The interactive graph shells dynamically interpret command-line inputs from the user, execute them by invoking the underlying functionality, and can print results or process them further. The graph shells provide a lightweight and interactive way of exercising graph functionality without creating a Java or Python application.

The graph shells are especially helpful if you want to do any of the following:

- Quickly run a "one-off" graph analysis on a specific data set, rather than creating a large application
- Run getting started examples and create demos on a sample data set
- Explore the data set, trying different graph analyses on the data set interactively

- Learn how to use the product and develop a sense of what the built-in algorithms are good for
- Develop and test custom graph analytics algorithms

The graph shell for the Java API (OPG4J) is implemented on top of the Java Shell tool (JShell). As such, it inherits all features provided by JShell such as tab-completion, history, reverse search, semicolon inference, script files, and internal variables. The graph shell for the Python API (OPG4Py) uses IPython in case it is installed.

The following sections explain in detail on how to start the graph shell CLIs:

- Starting the OPG4J Shell
- Starting the OPG4Py Shell

See Also:

- Java API Reference for information on the Java APIs
- Python API Reference for information on the Python APIs

10.1.1 Starting the OPG4J Shell

Launching the OPG4J Shell

The Java shell executables are found in `/opt/oracle/graph/bin` after the graph server (PGX) installation, and in `<CLIENT_INSTALL_DIR>/bin` after the Java client installation.

The OPG4J shell uses JShell, which means the shell needs to run on Java 11 or later. See Installing the Java Client From the Graph Server and Client Downloads for more details on the prerequisites. You can then launch the OPG4J shell by entering the following in your terminal:

```
cd /opt/oracle/graph
./bin/opg4j
```

When the shell has started, the following command line prompt appears:

```
For an introduction type: /help intro
Oracle Graph Server Shell 23.1.0
Variables instance, session, and analyst ready to use.
opg4j>
```

By default, the OPG4J shell creates a local PGX instance, to run graph functions in the same JVM as the shell as described in Developing Applications Using Graph Server Functionality as a Library.

Command-line Options

To view the list of available command-line options, add `--help` to the `opg4j` command:

```
./bin/opg4j --help
```

To start the opg4j shell without connecting to the graph server (PGX), use the `--no_connect` option as shown:

```
./bin/opg4j --no_connect
```

Starting the OPG4J Shell on Remote Mode

The OPG4J shell can connect to a graph server (PGX) instance that is running on another JVM (possibly on a different machine). In order to launch the OPG4J shell in remote mode, you must specify the `--base_url` parameter as shown:

```
./bin/opg4j --base_url https://<host>:7007 --username <graphuser>
```

where :

- `<host>`: is the server host
- `<graphuser>`: is the database user
  You will be prompted for the database password.

> **Note:**
>
> The graph server (PGX), listens on port `7007` by default. If needed, you can configure the graph server to listen on a different port by changing the port value in the server configuration file (`server.conf`). See Configuring the Graph Server (PGX) for details.

When the shell has started, the following command line prompt appears:

```
Oracle Graph Server Shell 23.1.0
Variables instance, session, and analyst ready to use.
opg4j>
```

If you have multiple versions of Java installed, you can easily switch between installations by setting the JAVA_HOME variable before starting the shell. For example:

```
export JAVA_HOME=/usr/lib/jvm/java-11-oracle
```

Batch Execution of Scripts

The OPG4J shell can execute a script by passing the path(s) to the script(s) to the `opg4j` command. For example:

```
./bin/opg4j /path/to/script.jsh
```

Predefined Functions

The OPG4J shell provides the following utility functions:

- `println(String)`: A shorthand for System.out.println(String).
- `loglevel(String loggerName, String levelName)`: A convenient function to set the loglevel.

The `loglevel` function allows you to set the log level for a logger. For example, `loglevel("ROOT", "INFO")` sets the level of the root logger to `INFO`. This causes all logs of `INFO` and higher (`WARN`, `ERROR`, `FATAL`) to be printed to the console.

Script Arguments

You can also provide parameters to the script executed by the graph server (PGX). For example:

```
./bin/opg4j /path/to/script.jsh script-arg-1 script-arg-2
```

The script `/path/to/script.jsh` can then access the arguments through the `arguments.scriptArgs` variable. The arguments are provided as an array of strings (`String[]`). For example:

```
Arrays.stream(arguments.scriptArgs).forEach((a) ->
    System.out.println(a));
```

The preceding example prints the output as shown:

```
script-arg-1
script-arg-2
```

Staying in Interactive Mode

By default, the OPG4J shell exits after it finishes execution. To stay in interactive mode after the script finishes *successfully*, pass the `--keep_running` flag to the shell. For example:

```
./bin/opg4j -b https://myserver.com:7007/ /path/to/script.jsh --
keep_running
```

10.1.2 Starting the OPG4Py Shell

Launching the OPG4Py Shell

The OPG4Py shell executables are found in `/opt/oracle/graph/bin` after the graph server (PGX) installation, and in `<CLIENT_INSTALL_DIR>/bin` after the Python client installation.

Before launching the OPG4Py shell, verify that your system meets the prerequisites explained in Prerequisites for Installing the Python Client. You can then launch the OPG4Py shell by entering the following in your terminal:

```
cd /opt/oracle/graph
./bin/opg4py
```

When the shell has started, the following command line prompt appears:

```
Oracle Graph Server Shell 23.1.0
>>>
```

If IPython is installed the following prompt will appear:

```
In [1]:
```

By default, the OPG4Py shell creates a local PGX instance, to run graph functions in the same JVM as the shell as described in Developing Applications Using Graph Server Functionality as a Library.

Command-line Options

To view the list of available command-line options, add `--help` to the `opg4py` command:

```
./bin/opg4py --help
```

To start the PyPGX shell without connecting to the graph server (PGX), use the `--no_connect` option as shown:

```
./bin/opg4py --no_connect
```

Starting the OPG4Py Shell on Remote Mode

The OPG4Py shell can connect to a graph server (PGX) instance that is running on another JVM (possibly on a different machine). In order to launch the OPG4Py shell in remote mode, you must specify the `--base_url` parameter as shown:

```
./bin/opg4py --base_url https://<host>:7007 --username <graphuser>
```

where :

- `<host>`: is the server host
- `<graphuser>`: is the database user
  You will be prompted for the database password.

Note:

The graph server (PGX), listens on port `7007` by default. If needed, you can configure the graph server to listen on a different port by changing the port value in the server configuration file (`server.conf`). See Configuring the Graph Server (PGX) for details.

When the OPG4Py shell has started, the following command line prompt appears:

```
Oracle Graph Server Shell 23.1.0
>>>
```

10.2 Using Autonomous Database Graph Client

Using the `AdbGraphClient` API, you can access Graph Studio features in Autonomous Database programmatically using the Oracle Graph Client or through your Java or Python application.

This API provides the following capabilities:

- Authenticate with Autonomous Database
- Manage the Graph Studio environment
- Execute graph queries and algorithms against the graph server (PGX)
- Execute graph queries directly against Oracle Database

To use the `AdbGraphClient` API, you must have access to Oracle Graph Client installation. The API is provided by the Oracle Graph Client library which is a part of the Oracle Graph Server and Client distribution. See Installing Oracle Graph Client on how to install and get started with the graph client shell CLIs for Java or Python.

Also, prior to using the Autonomous Database Graph Client, ensure you meet all the prerequisite requirements explained in Prerequisites for Using Autonomous Database Graph Client.

The following example shows using the `AdbGraphClient` API to establish a connection to Graph Studio, start an environment with allocated memory, load a PG View graph into memory, execute PGQL queries and run algorithms against the graph.

Note:

See the Javadoc and Python API Reference for more information on `AdbGraphClient` API.

1. Start the interactive graph shell CLI and connect to your Autonomous Database instance as shown:

   - JShell

- Java
- Python

JShell

```
cd /opt/oracle/graph
./bin/opg4j --no_connect
For an introduction type: /help intro
Oracle Graph Server Shell 23.1.0
opg4j> import oracle.pg.rdbms.*
opg4j> var config = AdbGraphClientConfiguration.builder()
opg4j> config.database("<DB_name>")
opg4j> config.tenancyOcid("<tenancy_OCID>")
opg4j> config.databaseOcid("<database_OCID>")
opg4j> config.username("ADBDEV")
opg4j> config.password("<password_for_ADBDEV>")
opg4j> config.endpoint("https://<hostname-
prefix>.adb.<region>.oraclecloudapps.com/")
opg4j> var client = new AdbGraphClient(config.build())
client ==> oracle.pg.rdbms.AdbGraphClient@7b8d1537
```

Java

```
import oracle.pg.rdbms.*;

var config = AdbGraphClientConfiguration.builder();
config.tenancyOcid("<tenancy_OCID>");
config.databaseOcid("<database_OCID>");
config.database("<DB_name>");
config.username("ADBDEV");
config.password("<password_for_ADBDEV>");
config.endpoint("https://<hostname-
prefix>.adb.<region>.oraclecloudapps.com/");

var client = new AdbGraphClient(config.build());
```

Python

```
cd /opt/oracle/graph
./bin/opg4py --no_connect
Oracle Graph Server Shell 23.1.0
>>> from opg4py.adb import AdbClient
>>> config = {
...          'tenancy_ocid': '<tenancy_OCID>',
...          'database': '<DB_name>',
...          'database_ocid': '<DB_OCID>',
...          'username': 'ADBDEV',
...          'password': '<password_for_ADBDEV>',
...          'endpoint': 'https://<hostname-
prefix>.adb.<region>.oraclecloudapps.com/'
... }
>>> client = AdbClient(config)
```

2. Start the PGX server environment with the desired memory as shown in the following code.

   This submits a job in Graph Studio for environment creation. `job.get()` waits for the environment to get started. You can always verify if the environment has started successfully with `client.isAttached()`. The method returns a boolean `true` if the environment is running.
   However, you can skip the step of creating an environment, if `client.isAttached()` returns `true` in the first step of the code.

- JShell
- Java
- Python

JShell

```
opg4j> client.isAttached()
$9 ==> false
opg4j> var job=client.startEnvironment(10)
job ==> oracle.pg.rdbms.Job@117e9a56[Not completed]
opg4j> job.get()
$11 ==> null
opg4j> job.getName()
$11 ==> "Environment Creation - 16 GBs"
opg4j> job.getType()
$12 ==> ENVIRONMENT_CREATION
opg4j> job.getCreatedBy()
$13 ==> "ADBDEV"
opg4j> client.isAttached()
$11 ==> true
```

Java

```
 if (!client.isAttached()) {
         var job = client.startEnvironment(10);
         job.get();
         System.out.println("job details: name=" + job.getName() + 
"type= " + job.getType() +"created_by= " + job.getCreatedBy());
      }
job details: name=Environment Creation - 16 GBstype=
ENVIRONMENT_CREATIONcreated_by= ADBDEV
```

Python

```
>>> client.is_attached()
False
>>> job = client.start_environment(10)
>>> job.get()
```

```
>>> job.get_name()
'Environment Creation - 16 GBs'
>>> job.get_created_by()
'ADBDEV'
>>> client.is_attached()
True
```

3. Create an instance and a session object as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var instance = client.getPgxInstance()
instance ==> ServerInstance[embedded=false,baseUrl=https://<hostname-
prefix>.adb.<region>.oraclecloudapps.com/graph/pgx]
opg4j> var session = instance.createSession("AdbGraphSession")
session ==> PgxSession[ID=c403be26-
ad0c-45cf-87b7-1da2a48bda54,source=AdbGraphSession]
```

Java

```
ServerInstance instance = client.getPgxInstance();
PgxSession session = instance.createSession("AdbGraphSession");
```

Python

```
>>> instance = client.get_pgx_instance()
>>> session = instance.create_session("adb-session")
```

4. Load a PGView graph from your Autonomous Database instance into memory.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("BANK_GRAPH",
GraphSource.PG_VIEW)
graph ==>
PgxGraph[name=BANK_GRAPH,N=1000,E=5001,created=1647800790654]
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_GRAPH",
GraphSource.PG_VIEW);
```

Python

```
>>> graph = session.read_graph_by_name("BANK_GRAPH", "pg_view")
```

5. Create an Analyst and execute a Pagerank algorithm on the graph as shown:

- JShell
- Java
- Python

JShell

```
opg4j> session.createAnalyst().pagerank(graph)
$16 ==> VertexProperty[name=pagerank,type=double,graph=BANK_GRAPH]
```

Java

```
session.createAnalyst().pagerank(graph);
```

Python

```
>>> session.create_analyst().pagerank(graph)
VertexProperty(name: pagerank, type: double, graph: BANK_GRAPH)
```

6. Execute a PGQL query on the graph and print the result set as shown:

- JShell
- Java

- Python

JShell

```
opg4j> graph.queryPgql("SELECT a.acct_id AS source, a.pagerank, t.amount,
b.acct_id AS destination FROM MATCH (a)-[t]->(b) ORDER BY a.pagerank DESC
LIMIT 3").print()
```

Java

```
PgqlResultSet rs = graph.queryPgql("SELECT a.acct_id AS source,
a.pagerank, t.amount, b.acct_id AS destination FROM MATCH (a)-[t]->(b)
ORDER BY a.pagerank DESC LIMIT 3");
rs.print();
```

Python

```
>>> rs = graph.query_pgql("SELECT a.acct_id AS source, a.pagerank,
t.amount, b.acct_id AS destination FROM MATCH (a)-[t]->(b) ORDER BY
a.pagerank DESC LIMIT 3").print()
```

On execution, the query produces the following output:

```
+-------------------------------------------------------+
| source | pagerank             | amount | destination |
+-------------------------------------------------------+
| 387    | 0.007302836252205922 | 1000.0 | 188         |
| 387    | 0.007302836252205922 | 1000.0 | 374         |
| 387    | 0.007302836252205922 | 1000.0 | 577         |
+-------------------------------------------------------+
```

7. Optionally, you can execute a PGQL query directly against the graph in the database as shown in the following code.

   In order to establish a JDBC connection to the database, you must download the wallet and save it in a secure location. See JDBC Thin Connections with a Wallet on how to determine the JDBC URL connection string.

- JShell
- Java
- Python

JShell

```
opg4j> String jdbcUrl="jdbc:oracle:thin:@<tns_alias>?
TNS_ADMIN=<path_to_wallet>"
```

```
opg4j> var conn =
DriverManager.getConnection(jdbcUrl,"ADBDEV","<password_for_ADBDEV>"
)
conn ==> oracle.jdbc.driver.T4CConnection@36ee8c7b
opg4j> var pgqlConn = PgqlConnection.getConnection(conn)
pgqlConn ==> oracle.pg.rdbms.pgql.PgqlConnection@5f27d271
opg4j> var pgqlStmt = pgqlConn.createStatement()
pgqlStmt ==> oracle.pg.rdbms.pgql.PgqlExecution@4349f52c
opg4j> pgqlStmt.executeQuery("SELECT a.acct_id AS source, t.amount,
b.acct_id AS destination FROM MATCH (a)-[t]->(b) ON BANK_GRAPH
LIMIT 3").print()
```

Java

```
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pgx.api.*;
import oracle.pg.rdbms.GraphServer;
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;
….
DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
String jdbcUrl="jdbc:oracle:thin:@<tns_alias>?
TNS_ADMIN=<path_to_wallet>";
Connection conn =
DriverManager.getConnection(jdbcUrl,"ADBDEV","<password_for_ADBDEV>"
);
PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
PgqlStatement pgqlStmt = pgqlConn.createStatement();
PgqlResultSet rs = pgqlStmt.executeQuery("SELECT a.acct_id AS
source, t.amount, b.acct_id AS destination FROM MATCH (a)-[t]->(b)
ON BANK_GRAPH LIMIT 3");
rs.print();
```

Python

```
>>> jdbcUrl = "jdbc:oracle:thin:@<tns_alias>?
TNS_ADMIN=<path_to_wallet>"
>>> pgql_conn =
opg4py.pgql.get_connection("ADBDEV","<password_for_ADBDEV>",
jdbcUrl)
>>> pgql_statement = pgql_conn.create_statement()
>>> pgql_statement.execute_query("SELECT a.acct_id AS source,
t.amount, b.acct_id AS destination FROM MATCH (a)-[t]->(b) ON
BANK_GRAPH LIMIT 3").print()
```

On execution, the query produces the following output:

```
+-------------------------------+
| SOURCE | AMOUNT | DESTINATION |
```

```
+------------------------------+
| 1000    | 1000    | 921      |
| 1000    | 1000    | 662      |
| 1000    | 1000    | 506      |
+------------------------------+
```

8. Close the session after executing all graph queries as shown:

- JShell
- Java
- Python

JShell

```
opg4j> session.close()
```

Java

```
opg4j> session.close();
```

Python

```
>>> session.close()
```

- Prerequisites for Using Autonomous Database Graph Client

10.2.1 Prerequisites for Using Autonomous Database Graph Client

As a prerequisite requirement to get started with the `AdbGraphClient` API, you must:

- Provision an Autonomous Database instance in Oracle Autonomous Database.
- Obtain the following tenancy details to connect:

Key	Description	More Information
tenancy OCID	The Oracle Cloud ID (OCID) of your tenancy	To determine the OCID for your tenancy, see "Where to Find your Tenancy's OCID" in: Oracle Cloud Infrastructure Documentation.

Key	Description	More Information
database	Database name of your Autonomous Database instance	1. Open the OCI console and click **Oracle Database** in the left navigation menu. 2. Click **Autonomous Database** and navigate to the Autonomous Databases page. 3. Select the required Autonomous Database under the **Display Name** column and navigate to the Autonomous Database Details page. 4. Note the **Database Name** under "General Information" in the **Autonomous Database Information** tab.
database OCID	The Oracle Cloud ID (OCID) of your Autonomous Database	1. Open the OCI console and click **Oracle Database** in the left navigation menu. 2. Click **Autonomous Database** and navigate to the Autonomous Databases page. 3. Select the required Autonomous Database under the **Display Name** column and navigate to the Autonomous Database Details page. 4. Note the **Database OCID** under "General Information" in the **Autonomous Database Information** tab.
username	Graph enabled Autonomous Database username, used for logging into Graph Studio	See Create a Graph User for more information.
password	Database password for the graph user	If the password for a graph user is forgotten, then you can always reset password for the graph user by logging into Database Actions as the ADMIN user. See Edit User for more information.
endpoint	Graph Studio endpoint URL	1. Select your Autonomous Database instance and navigate to the the Autonomous Database Details page. 2. Click the **Tools** tab. 3. Click on **Graph Studio**. 4. Copy the URL of the new tab that opens the Graph Studio login screen. 5. Edit the URL to remove the part after *oraclecloudapps.com* to obtain the endpoint URL. For example, the following shows the format of a sample endpoint URL: `https://<hostname_prefix>.adb.<region_identifier>.oraclecloudapps.com`

- Access Graph Studio and create a PG View graph.
- Download, install and start the Oracle Graph Java or Python client.

10.3 Using the Graph Visualization Web Client

You can use the Graph Visualization application to visualize graphs that are either loaded into the graph server (PGX) or stored in the database.

To run the graph visualization application for your installation, see Graph Visualization Web Client.

Related Topics

- Graph Visualization Application
  The Graph Visualization application enables interactive exploration and visualization of property graphs. It can also visualize graphs stored in the database.

10.4 Using the Jupyter Notebook Interface

You can use the Jupyter notebook interface to create, load, and query property graphs through Python.

Perform the following steps to perform graph analysis using Jupyter Notebook:

1. Install the Jupyter Notebook application following the Jupyter documentation. The following example installs Jupyter with pip:

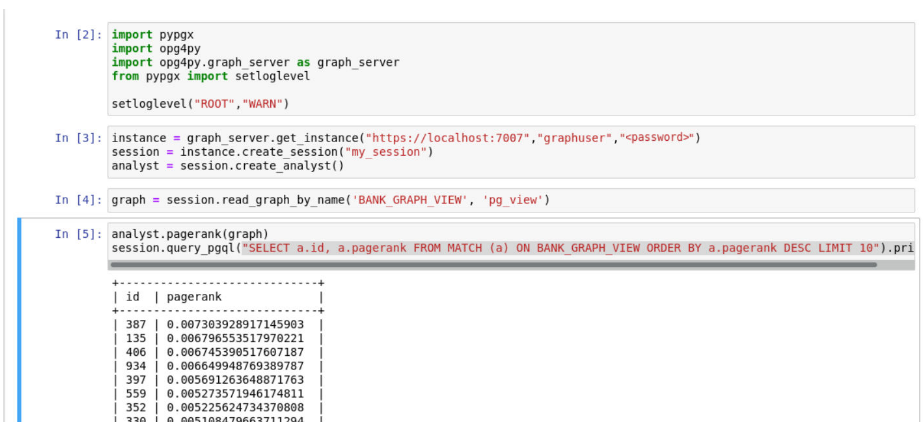
   ```
   pip3 install --user jupyter
   ```

2. Ensure that your Jupyter installation is added to the `PATH` environment variable.
3. Run the notebook server using the `jupyter notebook` command.
4. Launch the web application using the generated URL and open a new notebook.
5. Create and analyse a property graph.
   - The following example shows creating a property graph view (PG View) and running graph queries:

Figure 10-1 Creating a PG View in Jupyter Notebook

- The following example shows loading the PG View into the graph server (PGX) and running graph algorithms for analysis:

Figure 10-2 Running Graph Algorithms in Jupyter Notebook



10.5 Additional Client Tools for Querying PG Views

When working with property graph views (PG Views) in the database, you can use other supported client tools.

- Using Oracle SQLcl
  You can access the graph in the database using SQLcl.
- Using Oracle SQL Developer
  You can use Oracle SQL Developer to execute PGQL statements and queries directly on graphs in Oracle Database.

10.5.1 Using Oracle SQLcl

You can access the graph in the database using SQLcl.

You can run PGQL queries on the graph in SQLcl with a plug-in that is available with Oracle Graph Server and Client. See PGQL Plug-in for SQLcl in *Oracle SQLcl User's Guide* for more information.

The example in this section helps you get started on executing PGQL queries on a graph in SQLcl. As a prerequisite, to perform the steps in the example, you must set up the bank graph data in your database schema using the sample data provided with the graph server installation. See Using Sample Data for Graph Analysis for more information.

The following example creates a property graph view using the PGQL `CREATE PROPERTY GRAPH` statement, executes PGQL queries against the graph and finally drops the graph using SQLcl.

1. Start SQLcl with your database schema credentials. In the following command, *graphuser* is the database user used to connect to SQLcl.

   ```
   sql graphuser/<password_for_graphuser>@<tns_alias>

   SQLcl: Release 21.2 Production on Sun Jan 30 04:30:09 2022
   Copyright (c) 1982, 2022, Oracle.  All rights reserved.
   Connected to:
   Oracle Database 21c Enterprise Edition Release 21.0.0.0.0 - Production
   Version 21.3.0.0.0
   ```

2. Enable PGQL mode as shown:

   ```
   SQL> pgql auto on;

   PGQL Auto enabled for schema=[null], graph=[null], execute=[true],
   translate=[false]
   ```

   Note that no arguments are used in the preceding PGQL command.

3. Create a property graph view on the bank graph data tables.

   ```
   PGQL> CREATE PROPERTY GRAPH bank_graph
     2          VERTEX TABLES (
     3            bank_accounts
     4              LABEL ACCOUNTS
     5              PROPERTIES (ID, NAME)
     6          )
     7          EDGE TABLES (
     8            bank_txns
     9              SOURCE KEY (from_acct_id) REFERENCES bank_accounts (id)
    10              DESTINATION KEY (to_acct_id) REFERENCES bank_accounts
   (id)
    11              LABEL TRANSFERS
    12              PROPERTIES (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT,
   DESCRIPTION)
    13*         ) OPTIONS(PG_VIEW);
   ```

```
Graph created
```

4. Set `bank_graph` as the default graph using the `graph` argument when enabling PGQL mode.

```
PGQL> pgql auto on graph bank_graph;

PGQL Auto enabled for schema=[null], graph=[BANK_GRAPH],
execute=[true], translate=[false]
```

5. Execute PGQL queries against the default graph. For example, the following PGQL query retrieves the total number of vertices as shown:

```
PGQL> SELECT COUNT(*) AS num_vertices FROM MATCH(n);

   NUM_VERTICES
_______________
           1000
```

Note that in the preceding query, the graph name is not specified using the `ON` clause as part of the `MATCH` clause.

6. Reconnect to SQLcl as another schema user.

```
PGQL> conn system/<password_for_system>@<tns_alias>;
Connected.
```

7. Enable PGQL mode using the `schema` argument to set the default schema used for creating the graph. Also, set `bank_graph` as the default graph using the `graph` argument :

```
PGQL> pgql auto on schema graphuser graph bank_graph;

PGQL Auto enabled for schema=[graphuser], graph=[BANK_GRAPH],
execute=[true], translate=[false]
```

8. Execute a PGQL query to retrieve all the edge properties on the graph as shown:

```
PGQL> SELECT e.* FROM MATCH (n:accounts) -[e:transfers]->
(m:accounts) LIMIT 10;

   AMOUNT    DESCRIPTION    FROM_ACCT_ID    TO_ACCT_ID
_________ ______________ _______________ _____________
     1000 transfer                   178           921
     1000 transfer                   178           462
     1000 transfer                   179           688
     1000 transfer                   179           166
     1000 transfer                   179           397
     1000 transfer                   179           384
     1000 transfer                   179           900
     1000 transfer                   180           855
     1000 transfer                   180           984
     1000 transfer                   180           352
```

```
10 rows selected.
```

Therefore, you can set a default schema and execute PGQL queries against a default graph in SQLcl.

9. Finally, drop the graph after executing the required graph queries.

```
PGQL> DROP PROPERTY GRAPH bank_graph;

Graph dropped
```

Also, see Execute PGQL Queries in SQLcl for more information.

10.5.2 Using Oracle SQL Developer

You can use Oracle SQL Developer to execute PGQL statements and queries directly on graphs in Oracle Database.

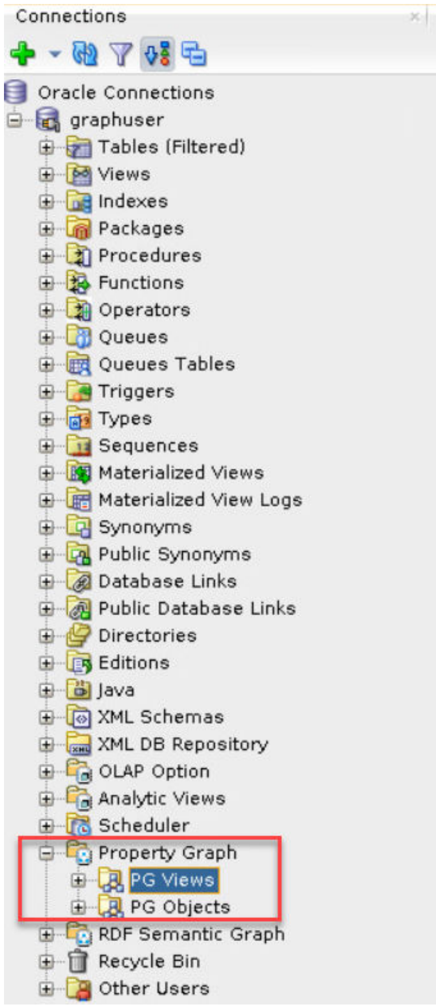
- About Property Graph Support in SQL Developer
  Starting from SQL Developer Release 22.2 onwards, property graph support is available in SQL Developer. Therefore, you can run PGQL queries on property graphs using SQL Developer.
- Working with Property Graph Views
  You can view all the property graph views existing in your database schema by expanding **PG Views** under the **Property Graph** node in the **Connections** navigator.

10.5.2.1 About Property Graph Support in SQL Developer

Starting from SQL Developer Release 22.2 onwards, property graph support is available in SQL Developer. Therefore, you can run PGQL queries on property graphs using SQL Developer.

You can access the **Property Graph** node in the Connections navigator to work with property graphs.

Figure 10-3   Property Graph Support in SQL Developer



Using SQL Developer, you can perform the following PGQL operations in the PGQL Worksheet:

- Create a property graph view or a property graph object against the graph data in the database.
- Apply a filter on the **PG Views** or **PG Objects** node to list graphs based on the specified filter criteria.
- Execute a PGQL `INSERT`, `UPDATE`, `SELECT`, or `DELETE` query against the graph.
- Drop the property graph view or the property graph object.

10.5.2.2 Working with Property Graph Views

You can view all the property graph views existing in your database schema by expanding **PG Views** under the **Property Graph** node in the **Connections** navigator.

You can run PGQL queries for a property graph view in a **PGQL Worksheet**. Note that you can execute only one PGQL query at a time in the worksheet.

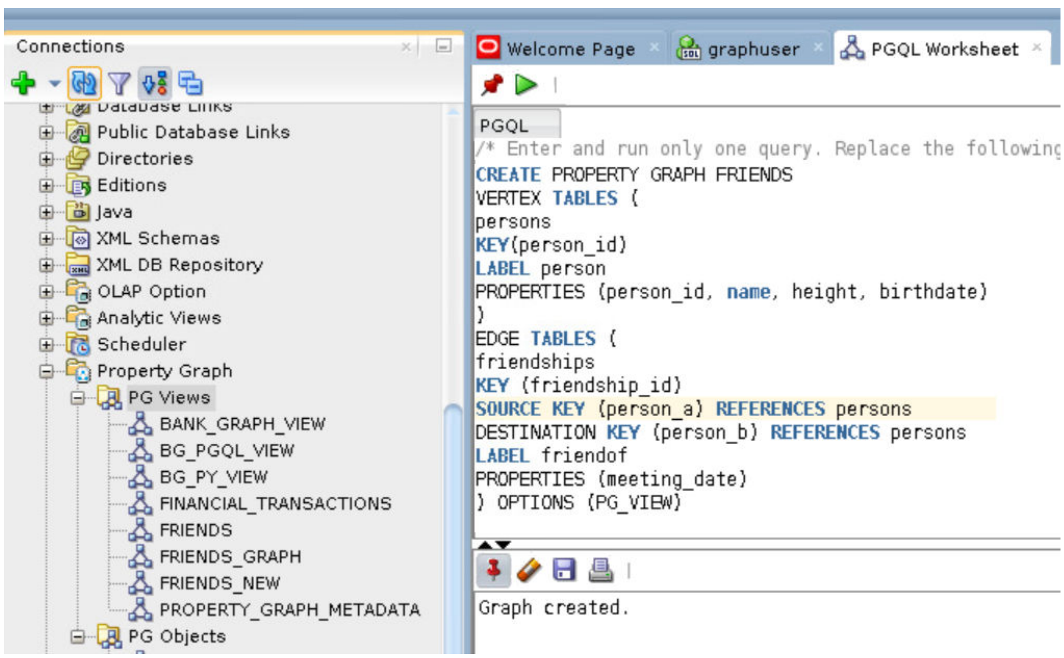
The following steps show a few examples for creating, updating and dropping a property graph view using SQL Developer.

1. Right-click the **Property Graph** node and select **Open PGQL Worksheet**.

   PGQL Worksheet opens in a new tab and it contains the **Run Query** icon for executing PGQL queries.

2. Create a property graph view by running a `CREATE PROPERTY GRAPH` statement in the PGQL Worksheet. For example:

   Figure 10-4 Create a Property Graph View

   The result of the query execution is displayed in the bottom pane of the Editor. On successful query execution, you can right click and refresh the **PG Views** object to view the newly created graph under **PG Views**.

3. Click on the newly created graph.

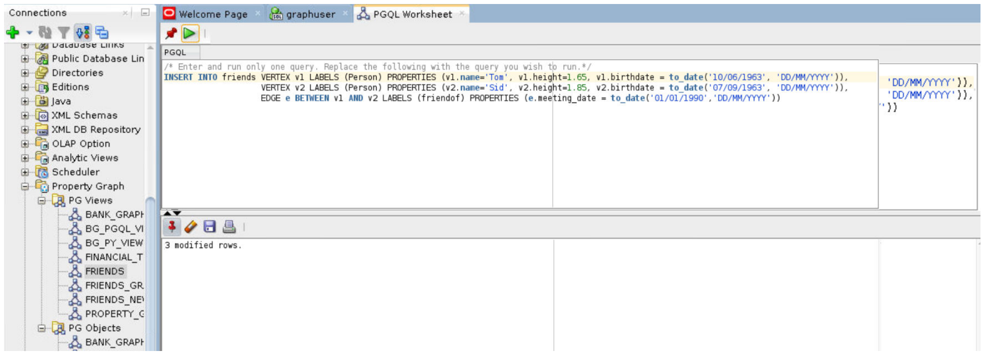
   This opens a **PGQL Worksheet** in a new tab with the following default query:

   ```
   SELECT e, v, n FROM MATCH (v)-[e]-(n) ON <graph_name> LIMIT 100
   ```

4. Run any PGQL update query like performing an `INSERT` or an `UPDATE` operation against a property graph view.

   For example, the following shows the execution of a PGQL `INSERT` query:

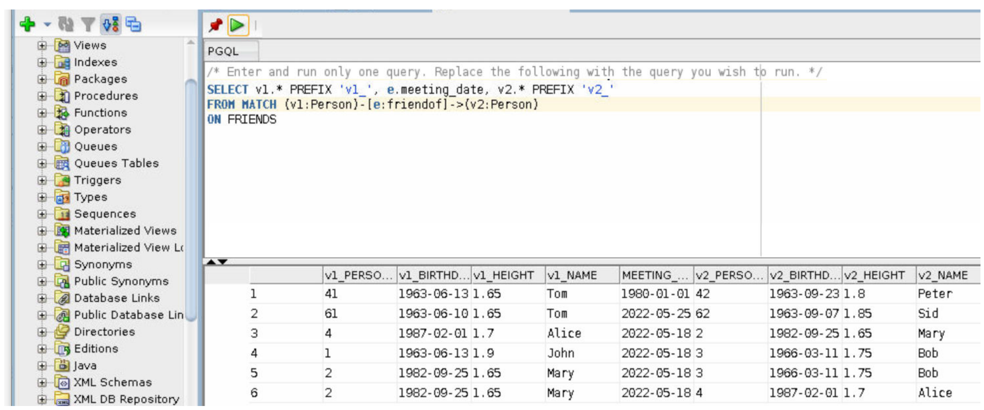
Figure 10-5 Running a PGQL INSERT Query



The vertices and edges are added to the graph.

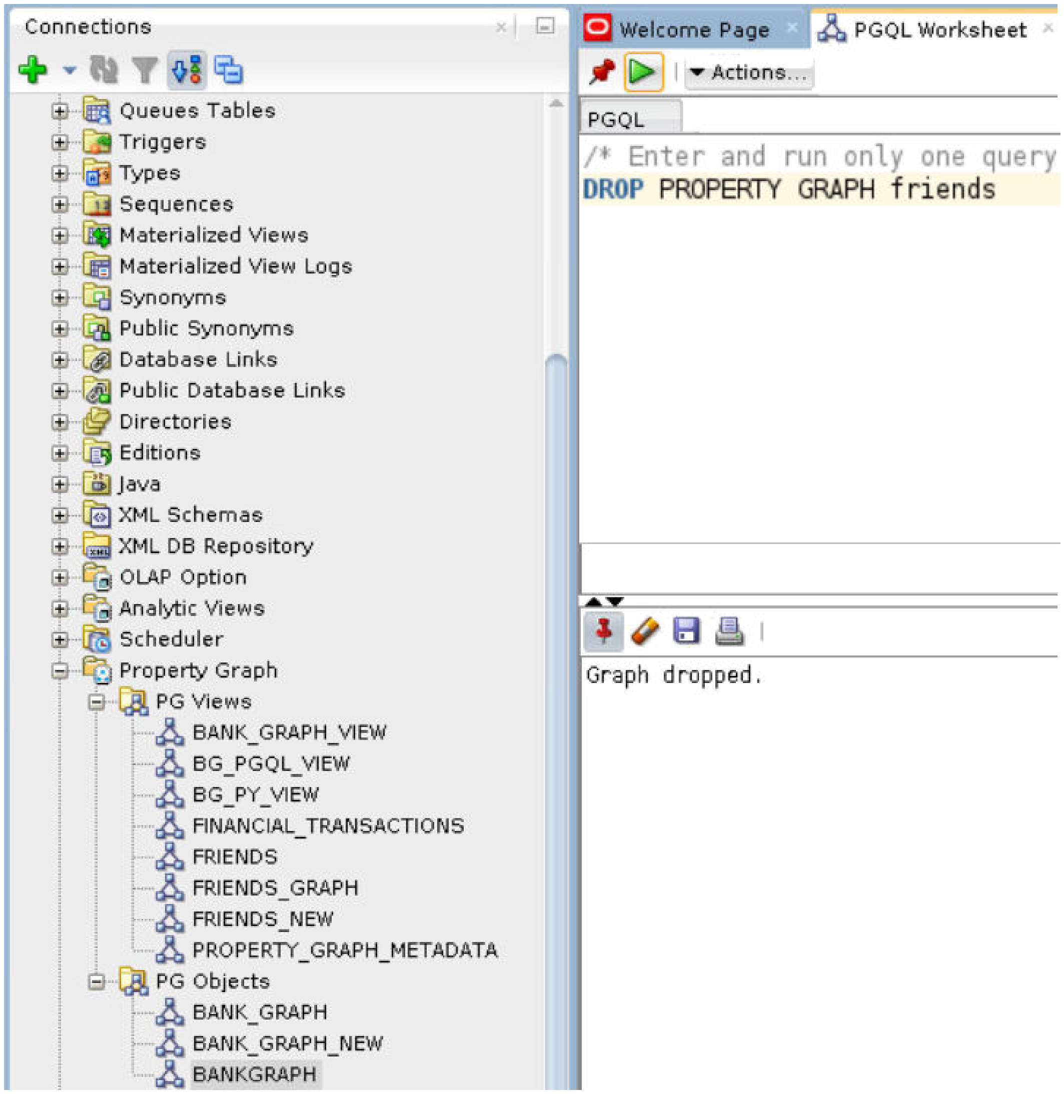
5. Run a PGQL `SELECT` query to view the newly inserted vertices and edges as shown:

Figure 10-6 Running a PGQL SELECT Query



6. Delete the Property Graph View as shown:

Figure 10-7 Dropping a Property Graph View



The graph is dropped.

11 Property Graph Query Language (PGQL)

PGQL is a SQL-like query language for property graph data structures that consist of *vertices* that are connected to other vertices by *edges*, each of which can have key-value pairs (properties) associated with them.

The language is based on the concept of *graph pattern matching*, which allows you to specify patterns that are matched against vertices and edges in a data graph.

> **Note:**
>
> The graph server (PGX) 23.1.0 supports PGQL 1.5 and earlier versions.

The property graph support provides two ways to execute Property Graph Query Language (PGQL) queries through Java APIs:

- Use the `oracle.pgx.api` Java package to query an in-memory snapshot of a graph that has been loaded into the graph server (PGX), as described in Executing PGQL Queries Against the Graph Server (PGX).
- Use the `oracle.pg.rdbms.pgql` Java package to directly query graph data stored in Oracle Database. See Executing PGQL Queries Against Property Graph Views and Executing PGQL Queries Against SQL Property Graphs for more information.

For more information about PGQL, see the PGQL Specification.

11.1 Creating a Property Graph Using PGQL

`CREATE PROPERTY GRAPH` is a PGQL DDL statement to create a property graph view (PG View) from the database tables.

The `CREATE PROPERTY GRAPH` statement starts with the name you give the graph, followed by a set of vertex tables and edge tables. The graph can have no vertex tables or edge tables (an empty graph), or vertex tables and no edge tables (a graph with only vertices and no edges), or both vertex tables and edge tables (a graph with vertices and edges). However, a graph cannot be specified with only edge tables and no vertex tables.

Consider the bank_accounts and bank_txns database tables created using the sample graph data in opt/oracle/graph/data directory. See Importing Data from CSV Files for more information.

- **BANK_ACCOUNTS** is a table with columns id, name. A row is added into this table for every new account.
- **BANK_TXNS** is a table with columns txn_id, from_acct_id, to_acct_id, description, and amount. A row is added into this table for every new transaction from from_acct_id to to_acct_id.

You can create a PG View using the database tables as shown:

```
CREATE PROPERTY GRAPH bank_graph
     VERTEX TABLES(
       bank_accounts AS accounts
         KEY(id)
         LABEL accounts
         PROPERTIES (id, name)
     )
     EDGE TABLES(
       bank_txns AS transfers
         KEY (txn_id)
         SOURCE KEY (from_acct_id) REFERENCES accounts (id)
         DESTINATION KEY (to_acct_id) REFERENCES accounts (id)
         PROPERTIES (description, amount)
     ) OPTIONS (PG_VIEW)
```

The following graph concepts are explained by mapping the database tables to the graph and using the preceding PGQL DDL statement:

- **Vertex tables**: A table that contains data entities is a vertex table (for example, bank_accounts).
  - Each row in the vertex table is a vertex.
  - The columns in the vertex table are properties of the vertex.
  - The name of the vertex table is the default label for this set of vertices. Alternatively, you can specify a label name as part of the CREATE PROPERTY GRAPH statement.
- **Edge tables**: An edge table can be any table that links two vertex tables, or a table that has data that indicates an action from a source entity to a target entity. For example, transfer of money from FROM_ACCOUNT_ID to TO_ACCOUNT_ID is a natural edge.
  - Foreign key relationships can give guidance on what links are relevant in your data. CREATE PROPERTY GRAPH will default to using foreign key relationships to identify edges.
  - Some of the properties of an edge table can be the properties of the edge. For example, an edge from from_acct_id to to_acct_id can have properties description and amount.
  - The name of an edge table is the default label for the set of edges. Alternatively, you can specify a label name as part of the CREATE PROPERTY GRAPH statement.

- **Keys**:
  - **Keys in a vertex table**: The key of a vertex table identifies a unique vertex in the graph. The key can be specified in the CREATE PROPERTY GRAPH statement; otherwise, it defaults to the primary key of the table. If there are duplicate rows in the table, the CREATE PROPERTY GRAPH statement will return an error.
  - **Key in an edge table**: The key of an edge table uniquely identifies an edge in the graph. The KEY clause when specifying source and destination vertices uniquely identifies the source and destination vertex keys.
- **Table aliases**: Vertex and edge tables must have unique names. If you need to identify multiple vertex tables from the same relational table, or multiple edge tables from the same relational table, you must use aliases. For example, you can create two vertex tables `bank_accounts` and `accounts` from one table `bank_accounts`, as shown:

```
CREATE PROPERTY GRAPH bank_transfers
     VERTEX TABLES (bank_accounts KEY(id)
                    bank_accounts AS accounts KEY(id))
```

  In case any of your vertex and edge table share the same name, then you must again use a table alias. In the following example, table alias is used for the edge table, DEPARTMENTS, as there is a vertex table referenced with the same name:

```
CREATE PROPERTY GRAPH hr
VERTEX TABLES (
  employees KEY(employee_id)
    PROPERTIES ARE ALL COLUMNS,
  departments KEY(department_id)
    PROPERTIES ARE ALL COLUMNS
 )
EDGE TABLES (
  departments AS managed_by
    SOURCE KEY ( department_id ) REFERENCES departments ( department_id )
    DESTINATION employees
    PROPERTIES ARE ALL COLUMNS
 )OPTIONS (PG_VIEW)
```

- **Properties**: The vertex and edge properties of a graph are derived from the columns of the vertex and edge tables respectively and by default have the same name as the underlying table columns. However, you can choose a different property name for each column. This helps to avoid conflicts when two tables have the same column name but with different data types.
  In the following example, the vertex properties `id` and `name` are renamed to `acct_no` and `acct_name` respectively:

```
CREATE PROPERTY GRAPH bank_transfers
VERTEX TABLES (
  bank_accounts AS accounts
    LABEL accounts
    PROPERTIES (id AS acct_no, name AS acct_name)
)
```

- **REFERENCES clause**: This connects the source and destination vertices of an edge to the corresponding vertex tables.

For more details on the `CREATE PROPERTY GRAPH` statement, see the PGQL Specification.

Refer to the following table for creating a property graph:

Table 11-1 `CREATE PROPERTY GRAPH` Statement Support

Method	More Information
Create a property graph in the graph server (PGX) using the `oracle.pgx.api` Java package	Java APIs for Executing CREATE PROPERTY GRAPH Statements
Create a property graph in the graph server (PGX) using the `pypgx.api` Python package	Python APIs for Executing CREATE PROPERTY GRAPH Statements
Create a property graph view on Oracle Database tables	Creating a Property Graph View

11.2 Pattern Matching with PGQL

Pattern matching is done by specifying one or more path patterns in the MATCH clause. A single path pattern matches a linear path of vertices and edges, while more complex patterns can be matched by combining multiple path patterns, separated by comma. Value expressions (similar to their SQL equivalents) are specified in the WHERE clause and let you filter out matches, typically by specifying constraints on the properties of the vertices and edges

For example, assume a graph of TCP/IP connections on a computer network, and you want to detect cases where someone logged into one machine, from there into another, and from there into yet another. You would query for that pattern like this:

```
SELECT id(host1) AS id1, id(host2) AS id2, id(host3) AS id3         /*
choose what to return */
FROM MATCH
    (host1) -[connection1]-> (host2) -[connection2]-> (host3)       /*
single linear path pattern to match */
WHERE
    connection1.toPort = 22 AND connection1.opened = true AND
    connection2.toPort = 22 AND connection2.opened = true AND
    connection1.bytes > 300 AND                                     /*
meaningful amount of data was exchanged */
    connection2.bytes > 300 AND
    connection1.start < connection2.start AND                       /*
second connection within time-frame of first */
    connection2.start + connection2.duration < connection1.start +
connection1.duration
GROUP BY id1, id2, id3                                              /*
aggregate multiple matching connections */
```

For more examples of pattern matching, see the Writing simple queries section in the PGQL specification.

11.3 Edge Patterns Have a Direction with PGQL

An edge pattern has a direction, as edges in graphs do. Thus, `(a) <-[]- (b)` specifies a case where *b has an edge pointing at a*, whereas `(a) -[]-> (b)` looks for an edge in the opposite direction.

The following example finds common friends of April and Chris who are older than both of them.

```
SELECT friend.name, friend.dob
FROM MATCH                  /* note the arrow directions below */
  (p1:person) -[:likes]-> (friend) <-[:likes]- (p2:person)
WHERE
  p1.name = 'April' AND p2.name ='Chris' AND
  friend.dob > p1.dob AND friend.dob > p2.dob
ORDER BY friend.dob DESC
```

For more examples of edge patterns, see the Edge Patterns section in the PGQL specification.

11.4 Vertex and Edge Labels with PGQL

Labels are a way of attaching type information to edges and nodes in a graph, and can be used in constraints in graphs where not all nodes represent the same thing. For example:

```
SELECT p.name
FROM MATCH (p:person) -[e1:likes]-> (m1:movie),
     MATCH (p) -[e2:likes]-> (m2:movie)
WHERE m1.title = 'Star Wars'
  AND m2.title = 'Avatar'
```

The example queries a graph which contains a set of vertices with the label `person`, a set of vertices with the label `movie`, and a set of edges with the label `likes`. A label predicate can start with either a colon (`:`) or the keyword `IS` followed by one or more labels. If more than one label is used, then the labels are separated by a vertical bar (`|`).

The following query shows the preceding example query with the keyword `IS` for the label predicate:

```
SELECT p.name
FROM MATCH (p IS person) -[e1 IS likes]-> (m1 IS movie),
     MATCH (p IS person) -[e2 IS likes]-> (m2 IS movie)
WHERE m1.title = 'Star Wars'
  AND m2.title = 'Avatar'
```

See Also:

- Label Expressions section in the PGQL specification
- Label Predicates section in the PGQL specification

11.5 Variable-Length Paths with PGQL

Variable-length path patterns have a quantifier like * to match a variable number of vertices and edges. Using a PATH macro, you can specify a named path pattern at the start of a query that can be embedded into the MATCH clause any number of times, by referencing its name. The following example finds all of the common ancestors of Mario and Luigi.

```
PATH has_parent AS () -[:has_father|has_mother]-> ()
SELECT ancestor.name
FROM MATCH (p1:Person) -/:has_parent*/-> (ancestor:Person)
   , MATCH (p2:Person) -/:has_parent*/-> (ancestor)
WHERE
  p1.name = 'Mario' AND
  p2.name = 'Luigi'
```

The preceding path specification also shows the use of anonymous constraints, because there is no need to define names for intermediate edges or nodes that will not be used in additional constraints or query results. Anonymous elements can have constraints, such as `[:has_father|has_mother]` -- the edge does not get a variable name (because it will not be referenced elsewhere), but it is constrained.

For more examples of variable-length path pattern matching, see the Variable-Length Paths section in the PGQL specification.

11.6 Aggregation and Sorting with PGQL

Like SQL, PGQL has support for the following:

- GROUP BY to create groups of solutions
- MIN, MAX, SUM, and AVG aggregations
- ORDER BY to sort results

And for many other familiar SQL constructs.

See Also:

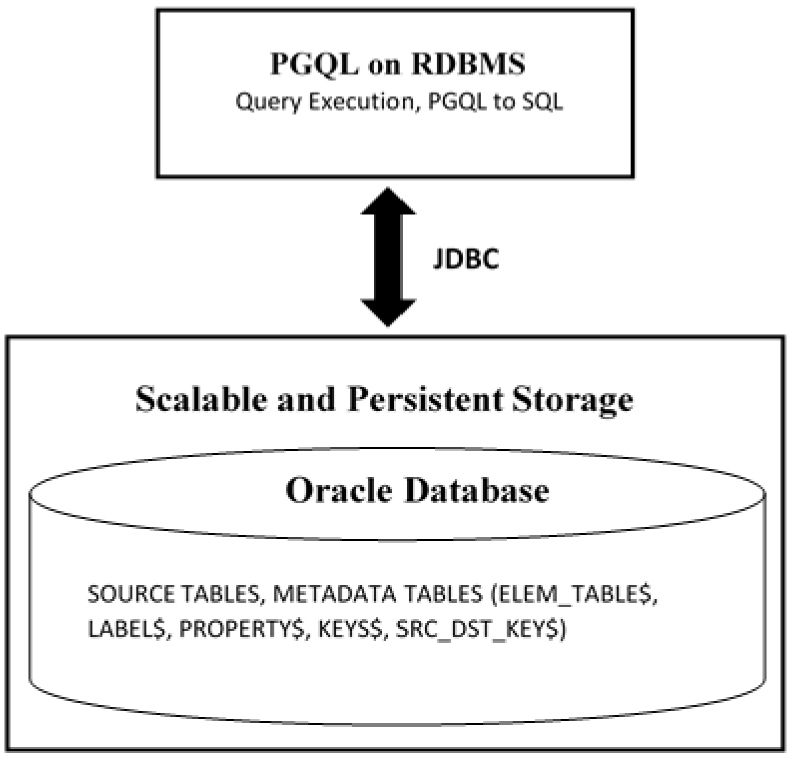
- See Grouping and Aggregation for more information on `GROUP BY`
- See Sorting and Row Limiting for more information on `ORDER BY`

11.7 Executing PGQL Queries Against Property Graph Views

This topic explains how you can execute PGQL queries directly against the property graph views on Oracle Database tables.

The PGQL query execution flow is shown in the following figure.

Figure 11-1 PGQL on Property Graph Views in Oracle Database



The basic execution flow is:

1. The PGQL query is submitted to PGQL on RDBMS through a Java API.
2. The PGQL query is translated into SQL statements using the internal metadata tables for property graph views.
3. The translated SQL is submitted to Oracle Database by JDBC.
4. The SQL result set is wrapped as a PGQL result set and returned to the caller.

- Supported PGQL Features and Limitations for PG Views
  Learn about the supported PGQL features and limitations for property graph views (PG Views).
- Performance Considerations for PGQL Queries
- Using the Java and Python APIs to Run PGQL Queries

11.7.1 Supported PGQL Features and Limitations for PG Views

Learn about the supported PGQL features and limitations for property graph views (PG Views).

The following table describes the complete list of supported and unsupported PGQL features for PG Views:

Table 11-2 Supported PGQL Functionalities and Limitations for PG Views

Feature	PGQL on PG Views
`CREATE PROPERTY GRAPH`	Supported
`DROP PROPERTY GRAPH`	Supported
Fixed-length pattern matching	Supported
Variable-length pattern matching goals	Supported: • Reachability • `ANY` • `ANY SHORTEST` • `TOP k SHORTEST` • `ALL` Limitations: • `ALL SHORTEST` • `ANY CHEAPEST` • `TOP k CHEAPEST`
Variable-length pattern matching quantifiers	Supported: • * • + • ? • { n } • { n, } • { n, m } • { , m }
Variable-length path unnesting	Not supported
`GROUP BY`	Supported
`HAVING`	Supported
Aggregations	Supported: • `COUNT` • `MIN`, `MAX`, `AVG`, `SUM` • `LISTAGG` Limitations: • `ARRAY_AGG`
`DISTINCT` • `SELECT DISTINCT` • Aggregation with `DISTINCT` (such as, `COUNT(DISTINCT e.prop)`)	Supported
`SELECT v.*`	Supported
`ORDER BY (+ASC/DESC), LIMIT, OFFSET`	Supported
Data Types	All available Oracle RDBMS data types supported

Table 11-2 (Cont.) Supported PGQL Functionalities and Limitations for PG Views

<table>
<tr><th>Feature</th><th>PGQL on PG Views</th></tr>
<tr><td>JSON</td><td>Supported:
• JSON storage:
  – JSON strings (VARCHAR2)
  – JSON objects
• JSON functions:
Any JSON function call that follows the syntax, json_function_name(arg1, arg2,…). For example:
json_value(department_data, '$.department')
Limitations:
• Simple Dot Notation
• Any optional clause in a JSON function call (such as RETURNING, ERROR, and so on) is not supported. For example:
json_value(department_data, '$.employees[1].hireDate' RETURNING DATE)</td></tr>
<tr><td>Operators</td><td>Supported:
• Relational: +, -, *, /, %, - (unary minus)
• Arithmetic: =, <>, <, >, <=, >=
• Logical: AND, OR, NOT
• String: || (concat)</td></tr>
<tr><td>Functions and predicates</td><td>Supported are all available functions in the Oracle RDBMS that take the form function_name(arg1, arg2, ...) with optional schema and package qualifiers.
Supported PGQL functions/predicates:
• IS NULL, IS NOT NULL
• JAVA_REGEXP_LIKE (based on CONTAINS)
• LOWER, UPPER
• SUBSTRING
• ABS, CEIL/CEILING, FLOOR, ROUND
• EXTRACT
• ID
• LABEL, HAS_LABEL
• ALL_DIFFERENT
• CAST
• CASE
• IN and NOT IN
Limitations:
• LABELS
• IN_DEGREE, OUT_DEGREE</td></tr>
</table>

Table 11-2 (Cont.) Supported PGQL Functionalities and Limitations for PG Views

Feature	PGQL on PG Views
User-defined functions	Supported: • PL/SQL functions • Functions created via the Oracle Database Multilingual Engine (MLE)
Subqueries: • Scalar subqueries • `EXISTS` and `NOT EXISTS` subqueries	Supported
`INSERT/UPDATE/DELETE`	Supported
`INTERVAL` literals and operations	Not supported

- Additional Information on Supported PGQL Features with Examples

11.7.1.1 Additional Information on Supported PGQL Features with Examples

The following PGQL features are supported in property graph views (PG Views):

- Recursive queries are supported for the following variable-length path finding goals:
  - Reachability
  - ANY
  - ANY SHORTEST
  - TOP k SHORTEST
- Recursive queries are supported for the following horizontal aggregations:
  - LISTAGG

    ```
    SELECT LISTAGG(src.first_name || ' ' || src.last_name, ',')
    FROM MATCH TOP 2 SHORTEST ( (n:Person) ((src)-[e:knows]->)*
    (m:Person) )
    WHERE n.id = 1234
    ```

  - SUM

    ```
    SELECT SUM(e.weight + 3)
    FROM MATCH TOP 2 SHORTEST ( (n:Person) -[e:knows]->* (m:Person) )
    WHERE n.id = 1234
    ```

  - COUNT

    ```
    SELECT COUNT(e)
    FROM MATCH TOP 2 SHORTEST ( (n:Person) -[e:knows]->* (m:Person) )
    WHERE n.id = 1234
    ```

- AVG

```
SELECT AVG(dst.age)
FROM MATCH TOP 2 SHORTEST ( (n:Person) (-[e:knows]->(dst))*
(m:Person) )
WHERE n.id = 1234
```

- MIN (Only for property value or `CAST` expressions)

```
SELECT MIN(CAST(dst.age + 5 AS INTEGER))
FROM MATCH TOP 2 SHORTEST ( (n:Person) (-[e:knows]->(dst))*
(m:Person) )
WHERE n.id = 1234
```

- MAX (Only for property value or `CAST` expressions)

```
SELECT MAX(dst.birthday)
FROM MATCH TOP 2 SHORTEST ( (n:Person) (-[e:knows]->(dst))*
(m:Person) )
WHERE n.id = 1234
```

- The following quantifiers are supported in recursive queries:

Table 11-3 Supported Quantifiers in PGQL SELECT Queries

Syntax	Description
`*`	zero or more
`+`	one or more
`?`	zero or one
`{n}`	exactly *n*
`{n,}`	*n* or more
`{n,m}`	between *n* and *m* (inclusive)
`{,m}`	between zero and *m* (inclusive)

- Data type casting with precision and scale is supported:

```
SELECT CAST(v.id AS VARCHAR2(10)) || '→' || CAST(w.id AS VARCHAR2(10)) AS
friendOf
FROM MATCH (v) -[:friendOf]->(w)


SELECT CAST(e.mval AS NUMBER(5,2)) AS mval
FROM MATCH () -[e:knows]->()
WHERE e.mval = '342.5'
```

- Both built-in Oracle Database functions and user defined functions (UDFs) are supported. For example:

- Assuming a table has a JSON column with values such as, `{"name":"John", "age": 43}`:

  ```
  SELECT JSON_VALUE(p.attributes, '$.name') AS name
  FROM MATCH (p:Person)
  WHERE JSON_VALUE(p.attributes, '$.age') > 35
  ```

- Assuming an Oracle Text index exists on a text column in a table:

  ```
  SELECT n.text
  FROM MATCH (n)
  WHERE CONTAINS(n.text, 'cat', 1) > 0
  ```

- Assuming a UDF `updated_id` is registered with the graph server (PGX):

  ```
  SELECT my.updated_id(n.ID) FROM MATCH(n) LIMIT 10
  ```

- Selecting all properties of vertices or edges is supported through `SELECT v.*` clause, where `v` is the variable whose properties are selected. The following example retrieves all the edge properties of a graph:

  ```
  SELECT label(e), e.* FROM MATCH (n)-[e]->(m) ON bank_graph_view
  LIMIT 3
  ```

  On execution, the preceding query retrieves all the properties that are bound to the variable `e` as shown:

  ```
  +-------------------------------------------------------------+
  | label(e)  | AMOUNT | DESCRIPTION | FROM_ACCT_ID | TO_ACCT_ID |
  +-------------------------------------------------------------+
  | TRANSFERS | 1000   | transfer    | 178          | 921        |
  | TRANSFERS | 1000   | transfer    | 178          | 462        |
  | TRANSFERS | 1000   | transfer    | 179          | 688        |
  +-------------------------------------------------------------+
  ```

  A `PREFIX` can be specified to avoid duplicate column names in cases where you select all properties using multiple variables. For example:

  ```
  SELECT n.* PREFIX 'n_', e.* PREFIX 'e_', m.* PREFIX 'm_'
  FROM MATCH (n:Accounts) -[e:transfers]-> (m:Accounts)
  ON bank_graph_view LIMIT 3
  ```

  The query output is as follows:

  ```
  +--------------------------------------------------------------------
  -------------------------+
  | n_ID | n_NAME  | e_AMOUNT | e_DESCRIPTION | e_FROM_ACCT_ID |
  e_TO_ACCT_ID | m_ID | m_NAME  |
  +--------------------------------------------------------------------
  -------------------------+
  | 178  | Account | 1000     | transfer      | 178            |
  921          | 921  | Account |
  ```

```
| 178  | Account | 1000     | transfer      | 178            |
462          | 462  | Account |
| 179  | Account | 1000     | transfer      | 179            |
688          | 688  | Account |
+---------------------------------------------------------------------------
-------------------+
```

Label expressions can be used such that only properties that belong to the specified vertex or edge labels are selected:

```
SELECT LABEL(n), n.* FROM MATCH (n:Accounts) ON bank_graph_view LIMIT 3
```

The preceding query output is as shown:

```
+-----------------------+
| LABEL(n) | ID | NAME  |
+-----------------------+
| ACCOUNTS | 1  | User1 |
| ACCOUNTS | 2  | User2 |
| ACCOUNTS | 3  | User3 |
+-----------------------+
```

- Support for `ALL` path finding goal to return all the paths between a pair of vertices. However, to avoid endless cycling, only the following quantifiers are supported:
  - ?
  - {n}
  - {n.m}
  - {,m}

  For example, the following PGQL query finds all the transaction paths from account `284` to account `616` :

```
SELECT LISTAGG(e.amount, ' + ') || ' = ', SUM(e.amount) AS total_amount
FROM MATCH ALL (a:Accounts) -[e:Transfers]->{1,4}(b:Accounts)
WHERE a.id = 284 AND b.id = 616
ORDER BY total_amount
```

  On execution, the query produces the following result:

```
+---------------------------------------------------+
| LISTAGG(e.amount, ' + ') || ' = ' | TOTAL_AMOUNT |
+---------------------------------------------------+
| 1000 + 1000 + 1000 =              | 3000         |
| 1000 + 1500 + 1000 =              | 3500         |
| 1000 + 1000 + 1000 + 1000 =       | 4000         |
+---------------------------------------------------+
$16 ==> oracle.pg.rdbms.pgql.pgview.PgViewResultSet@4f38acf
```

- Scalar subqueries which return exactly one column and one row is supported.

For example:

```
SELECT p.name AS name , (
  SELECT SUM(t.amount)
  FROM MATCH (a) <-[t:transaction]- (:Account)
) AS sum_incoming , (
  SELECT SUM(t.amount)
  FROM MATCH (a) -[t:transaction]-> (:Account)
) AS sum_outgoing , (
  SELECT COUNT(DISTINCT p2)
  FROM MATCH (a) -[t:transaction]- (:Account) -[:owner]->
(p2:Person)
  WHERE p2 <> p
) AS num_persons_transacted_with , (
  SELECT COUNT(DISTINCT c)
  FROM MATCH (a) -[t:transaction]- (:Account) -[:owner]->
(c:Company)
) AS num_companies_transacted_with
FROM MATCH (p:Person) <-[:owner]- (a:Account)
ORDER BY sum_outgoing + sum_incoming DESC
```

- `EXISTS` and `NOT EXISTS` subqueries are supported. Such queries yield `TRUE` or `FALSE` depending on whether the query produces at least one results given the bindings of the outer query.
  For example:

```
SELECT fof.name, COUNT(friend) AS num_common_friends
FROM MATCH (p:Person) -[:knows]-> (friend:Person) -[:knows]->
(fof:Person)
WHERE NOT EXISTS (
  SELECT * FROM MATCH (p) -[:knows]-> (fof)
)
```

The following are a few PGQL features which are not supported:

- The following PGQL `SELECT` features are not supported:
  – Use of bind variables in path expressions.
    If you attempt to use a bind variable, it will result in an error as shown:

```
opg4j> String s = "SELECT id(a) FROM MATCH ANY SHORTEST (a) -[e]-
>* (b) WHERE id(a) = ?";
s ==> "SELECT id(a) FROM MATCH ANY SHORTEST (a) -[e]->* (b)
WHERE id(a) = ?"

opg4j> PgqlPreparedStatement ps = pgqlConn.prepareStatement(s);
ps ==> oracle.pg.rdbms.pgql.PgqlExecution@7806db3f

opg4j> ps.setString(1, "PERSON(3)");

opg4j> ps.executeQuery();
|  Exception java.lang.UnsupportedOperationException: Use of
bind variables for path queries is not supported
```

  – `in_degree` and `out_degree` functions.

> **Note:**
>
> - See Supported PGQL Features and Limitations for PG Views for a complete list of supported and unsupported PGQL features for PG Views.
> - See Performance Considerations for PGQL Queries for details on recommended practices to enhance query performance for recursive queries.

11.7.2 Performance Considerations for PGQL Queries

The following are some recommended practices for query performance.

- Recursive Queries
- Using Query Optimizer Hints
- Speed Up Query Translation Using Graph Metadata Cache and Translation Cache

Recursive Queries

The following indexes are recommended in order to speed up execution of recursive queries:

- For underlying VERTEX tables of the recursive pattern, an index on the key column
- For underlying EDGE tables of the recursive pattern, an index on the source key column

> **Note:**
>
> You can also create index on (source key, destination key).

For example, consider the following CREATE PROPERTY GRAPH statement:

```
CREATE PROPERTY GRAPH people
  VERTEX TABLES(
    person
      KEY ( id )
      LABEL person
      PROPERTIES( name, age )
  )
  EDGE TABLES(
    knows
      key (person1, person2)
      SOURCE KEY ( person1 ) REFERENCES person (id)
      DESTINATION KEY ( person2 ) REFERENCES person (id)
      NO PROPERTIES
  )
  OPTIONS ( PG_VIEW )
```

And also consider the following query:

```
SELECT COUNT(*)
FROM MATCH ANY SHORTEST ( (n:Person) -[e:knows]->* (m:Person) )
WHERE n.id = 1234
```

In order to improve performance of the recursive part of the preceding query, the following indexes must exist:

- `CREATE INDEX <INDEX_NAME> ON PERSON(ID)`
- `CREATE INDEX <INDEX_NAME> ON KNOWS(PERSON1)` or
  `CREATE INDEX <INDEX_NAME> ON KNOWS(PERSON1, PERSON2)`

Composite Vertex Keys

For composite vertex keys, query execution can be optimized with the creation of function-base indexes on the key columns:

- For underlying VERTEX tables of the recursive pattern, a function-based index on the comma-separated concatenation of key columns
- For underlying EDGE tables of the recursive pattern, a function-based index on the comma-separated concatenation of source key columns

> **Note:**
>
> You can also create index on (source key columns, destination key columns).

For example, consider the following CREATE PROPERTY GRAPH statement:

```
CREATE PROPERTY GRAPH people
  VERTEX TABLES(
    person
      KEY ( id1, id2 )
      LABEL person
      PROPERTIES( name, age )
  )
  EDGE TABLES(
    knows
      key (id)
      SOURCE KEY ( id1person1, id2person1 ) REFERENCES person (id1,id2)
      DESTINATION KEY ( id1person2, id2person2 ) REFERENCES person
(id1,id2)
      NO PROPERTIES
  )
  OPTIONS ( PG_VIEW )
```

And also consider the following query:

```
SELECT COUNT(*)
FROM MATCH ANY SHORTEST ( (n:Person) -[e:knows]->* (m:Person) )
WHERE n.id = 1234
```

In order to improve performance of the recursive part of the preceding query, the following indexes must exist:

- `CREATE INDEX <INDEX_NAME> ON PERSON (ID1 || ',' || ID2)`
- `CREATE INDEX <INDEX_NAME> ON KNOWS (ID1PERSON1 || ',' || ID2PERSON1)` or `CREATE INDEX <INDEX_NAME> ON KNOWS (ID1PERSON1 || ',' || ID2PERSON1, ID1PERSON2 || ',' || ID2PERSON2)`

If some of the columns in a composite vertex key is a string column, the column needs to be comma-escaped in the function-base index creation.

For example, if column `ID1` in table `PERSON` of the preceding example is of type `VARCHAR2(10)`, you need to escape the comma for the column as follows:

```
replace(ID1, ',', '\,')
```

So, the indexes to improve performance will result as shown:

- `CREATE INDEX <INDEX_NAME> ON PERSON (replace(ID1, ',', '\,') || ',' || ID2)`
- `CREATE INDEX <INDEX_NAME> ON KNOWS (replace(ID1PERSON1, ',', '\,') || ',' || ID2PERSON1)`

Using Query Optimizer Hints

The following hints can be used to influence translation of PGQL variable-length path patterns to SQL:

- **`REVERSE_PATH`:** Switches on or off the reverse path optimization (`ON` by default). If `ON`, it automatically determines if the pattern can best be evaluated from source to destination or from destination to source, based on specified filter predicates.
- **`PUSH_SRC_HOPS`:** Switches on or off pushing source filter optimization (`ON` by default). If `ON`, then filter predicates are used to limit the number of source vertices (or destination vertices if path evaluation is reversed) and thereby the search space of variable-length path pattern evaluations.
- **`PUSH_DST_HOPS`:** Switches on or off pushing destination filter optimization (`OFF` by default). If `ON`, then filter predicates are used to limit the number of destination vertices (or source vertices if path evaluation is reversed) and thereby the search space of variable-length path pattern evaluations.

The preceding hints can be configured as `options` parameter in the following Java API methods:

- `executeQuery(String pgql, String options)`
- `translateQuery(String pgql, String options)`
- `execute(String pgql, String matchOptions, String options)`

For example, consider the following PGQL query:

```
SELECT v1.name AS v1, v2.name AS v2, v3.name As v3
FROM MATCH (v1:Person)-[e1:friendOf]->(v2:Person),
MATCH ANY (v2:Person)-[e2:friendOf]->*(v3:Person)
WHERE v1.name= 'Bob'
```

When the preceding query is executed using the default option for `PUSH_SRC_HOPS`, the output for `start_nodes_translation` displays the filter expression as shown:

```
System.out.println(pgqlStatement.translateQuery(pgql).getSqlTranslatio
n())
...
...
start_nodes_translation => (to_clob('SELECT ''PERSONS'' AS
"src_table", e1.person_b AS "src_key"
FROM "GRAPHUSER"."PERSONS" "V1", "GRAPHUSER"."FRIENDSHIPS" "E1"
WHERE (((e1.person_a = v1.person_id) AND NOT(e1.person_b IS NULL)) AND
(v1.name = ''Bob''))')),
     end_nodes_translation => (to_clob('SELECT ''PERSONS'' AS
"dst_table", v3.person_id AS "dst_key"
FROM "GRAPHUSER"."PERSONS" "V3"')),
...
...
```

If the preceding query is executed with the hint `PUSH_SRC_HOPS=F`, then the query is translated into SQL as shown:

```
System.out.println(pgqlStatement.translateQuery(pgql,"PUSH_SRC_HOPS=F")
.getSqlTranslation())

...
...start_nodes_translation => (to_clob('SELECT ''PERSONS'' AS
"src_table", v2.person_id AS "src_key"
FROM "GRAPHUSER"."PERSONS" "V2"')),
     end_nodes_translation => (to_clob('SELECT ''PERSONS'' AS
"dst_table", v3.person_id AS "dst_key"
FROM "GRAPHUSER"."PERSONS" "V3"')),
...
...
```

Speed Up Query Translation Using Graph Metadata Cache and Translation Cache

The following global caches help to speed up PGQL query translation:

- **Graph Metadata Cache:** Stores graph metadata such as tables, labels, properties, and so on.
- **Translation Cache:** Stores PGQL to SQL translation.

You can configure the caches using the following Java APIs:

- `clearTranslationCache()`
- `disableTranslationCache()`
- `enableTranslationCache()`
- `setTranslationCacheMaxCapacity(int maxCapacity)`
- `clearGraphMetadataCache()`
- `disableGraphMetadataCache()`

- `enableGraphMetadataCache()`
- `setGraphMetadataCacheMaxCapacity(int maxCapacity)`

These preceding methods are part of the `PgqlConnection` class. Separate caches are maintained for each database user such that cached objects are shared between different `PgqlConnection` objects if they have the same connection URL and user underneath.

11.7.3 Using the Java and Python APIs to Run PGQL Queries

You can run PGQL queries using the Java API in the `oracle.pg.rdbms.pgql` package. Also, you can use the Python OPG4Py package for executing PGQL queries against the graph data in the Oracle Database. This package contains a sub-package `Pgql` with one or more modules that wraps around the Java API in the `oracle.pg.rdbms.pgql` package.

- Creating a Property Graph View
- Executing PGQL SELECT Queries
- Executing PGQL Queries Using JDBC Driver
- Executing PGQL Queries to Modify Property Graph Views
- Dropping A Property Graph View

11.7.3.1 Creating a Property Graph View

You can create a property graph view (PG View) using the `CREATE PROPERTY GRAPH` statement.

Example 11-1 Creating a Property Graph View

The following example describes the creation of a PG View.

- JShell
- Java
- Python

JShell

```
opg4j> var jdbcUrl="jdbc:oracle:thin:@<host_name>:<port>/<db_service>"
opg4j> var conn =
DriverManager.getConnection(jdbcUrl,"<username>","<password>");
opg4j> var pgqlConn = PgqlConnection.getConnection(conn)
opg4j> var pgqlStmt = pgqlConn.createStatement() //create a PGQL Statement
opg4j> conn.setAutoCommit(false)
opg4j> var pgql =
...> "CREATE PROPERTY GRAPH bank_graph "
...> + "VERTEX TABLES ( bank_accounts AS Accounts "
...> + "KEY (id) "
...> + "LABEL Accounts "
...> + "PROPERTIES (id, name) "
...> + ") "
...> + "EDGE TABLES ( bank_txns AS Transfers "
```

```
...> + "KEY (txn_id) "
...> + "SOURCE KEY (from_acct_id) REFERENCES Accounts (id) "
...> + "DESTINATION KEY (to_acct_id) REFERENCES Accounts (id) "
...> + "LABEL Transfers "
...> + "PROPERTIES (from_acct_id, to_acct_id, amount, description) "
...> + ") OPTIONS (PG_VIEW) "
opg4j> pgqlStmt.execute(pgql)
```

Java

```
import java.sql.Connection;
import java.sql.Statement;
import java.sql.DriverManager;
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;


/*
 * This example shows how to create a property graph view.
 */
public class PgqlCreate
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String jdbcUrl            = args[idx++];
    String username           = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];


    Connection conn = null;
    PgqlStatement pgqlStmt = null;

    try {
      //Get a jdbc connection
      DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
      conn = DriverManager.getConnection(jdbcUrl, username, password);
      conn.setAutoCommit(false);


      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);

      // Create a PGQL Statement
      pgqlStmt = pgqlConn.createStatement();
      // Execute PGQL Query
      String pgql =
        "CREATE PROPERTY GRAPH " + graph + " " +
        "VERTEX TABLES ( bank_accounts as Accounts " +
        "KEY (id) " +
        "LABEL \"Accounts\"" +
```

```
        "PROPERTIES (id, name)" +
        ") " +
        "EDGE TABLES ( bank_txns as Transfers " +
        "KEY (txn_id) " +
        "SOURCE KEY (from_acct_id) REFERENCES Accounts (id) " +
        "DESTINATION KEY (to_acct_id) REFERENCES Accounts (id) " +
        "LABEL \"Transfers\"" +
        "PROPERTIES (from_acct_id, to_acct_id, amount, description)" +
        ") OPTIONS (PG_VIEW) ";

      // Print the results
      pgqlStmt.execute(pgql);
    }
    finally {
      // close the statement
      if (pgqlStmt != null) {
         pgqlStmt.close();
         }
      // close the connection
      if (conn != null) {
         conn.close();
         }
      }
  }
}
```

Python

```
>>> pgql_conn = opg4py.pgql.get_connection("<username>","<password>",
"jdbc:oracle:thin:@localhost:1521/orclpdb")
>>> pgql_statement = pgql_conn.create_statement()
>>> pgql = """
...         CREATE PROPERTY GRAPH bank_graph
...         VERTEX TABLES (
...           bank_accounts
...             LABEL Accounts
...             PROPERTIES (id, name)
...         )
...         EDGE TABLES (
...           bank_txns
...             KEY (txn_id)
...             SOURCE KEY (from_acct_id) REFERENCES bank_accounts
...             DESTINATION KEY (to_acct_id) REFERENCES bank_accounts
...             LABEL TRANSFERS
...             PROPERTIES (from_acct_id, to_acct_id, amount, description)
...         ) OPTIONS(PG_VIEW)
... """
>>> pgql_statement.execute(pgql)
False
```

You can verify the property graph view creation by checking the metadata tables that get created in the database.

11.7.3.2 Executing PGQL SELECT Queries

You can run PGQL `SELECT` queries as described in the following examples.

Example 11-2 Running a Simple `SELECT` Query Using `PgqlStatement` and `PgqlResultSet`

In the following example, `PgqlConnection` is used to obtain a `PgqlStatement`. Then, it calls the `executeQuery` method of `PgqlStatement`, which returns a `PgqlResultSet` object. `PgqlResultSet` provides a `print()` method, which displays results in a tabular mode.

- JShell
- Java
- Python

JShell

```
opg4j> var jdbcUrl="jdbc:oracle:thin:@<host_name>:<port>/<db_service>"
opg4j> var conn =
DriverManager.getConnection(jdbcUrl,"<username>","<password>");
opg4j> var pgqlConn = PgqlConnection.getConnection(conn)
opg4j> pgqlConn.setGraph("BANK_GRAPH")
opg4j> var pgqlStmt = pgqlConn.createStatement() //create a PGQL
Statement
opg4j> String s = "SELECT n.* FROM MATCH (n:Accounts) LIMIT 3"
opg4j> var resultSet = pgqlStmt.executeQuery(s)
opg4j> resultSet.print() //Prints the query result set
+---------------+
| ID | NAME     |
+---------------+
| 1  | Account1 |
| 2  | Account2 |
| 3  | Account3 |
+---------------+
```

Java

```
import java.sql.Connection;
import java.sql.Statement;
import java.sql.DriverManager;
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

/*
```

```
 * This example shows how to execute a SELECT query on a property graph view.
 */
public class PgqlExample1
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String jdbcUrl            = args[idx++];
    String username           = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];


    Connection conn = null;
    PgqlStatement pgqlStmt = null;
    PgqlResultSet rs = null;

    try {
      //Get a jdbc connection
      DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
      conn = DriverManager.getConnection(jdbcUrl, username, password);
      conn.setAutoCommit(false);


      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PGQL Statement
      pgqlStmt = pgqlConn.createStatement();

      // Execute PGQL Query
      String query = "SELECT n.* FROM MATCH (n:Accounts) LIMIT 5";
      rs = pgqlStmt.executeQuery(query);

      // Print the results
      rs.print();
    }
    finally {
      // close the result set
      if (rs != null) {
         rs.close();
         }
      // close the statement
      if (pgqlStmt != null) {
         pgqlStmt.close();
         }
      // close the connection
      if (conn != null) {
         conn.close();
         }
      }
  }
}
```

Python

```
>>> pgql_conn = opg4py.pgql.get_connection("<username>","<password>",
"<jdbcUrl>")
>>> pgql_statement = pgql_conn.create_statement()
>>> pgql_conn.set_graph("BANK_GRAPH")
>>> s = "SELECT n.* FROM MATCH (n:Accounts) LIMIT 3"
>>> pgql_statement.execute_query(s)
>>> pgql_result_set = pgql_statement.execute_query(s)
>>> pgql_result_set.print()
+---------------+
| ID | NAME     |
+---------------+
| 1  | Account1 |
| 2  | Account2 |
| 3  | Account3 |
+---------------+
>>> pgql_result_set
PgqlResultSet(java_pgql_result_set:
oracle.pg.rdbms.pgql.PgqlResultSet, # of results: 3)
```

Also, you can convert the PGQL result set obtained in the preceding code to a Pandas dataframe using the `to_pandas()` method.

> **Note:**
>
> The `pandas` package must be installed in your system to successfully execute the call to `to_pandas()`. This package is automatically installed at the time of the Python client installation for versions Python 3.8 and Python 3.9. However, if your call to `to_pandas()` fails, verify if the `pandas` module is installed in your system. In case the module is found missing or your Python version differs from the earlier mentioned versions, then install the `pandas` package manually.

Example 11-3 Running a `SELECT` Query Using `PgqlPreparedStatement`

- JShell
- Java
- Python

JShell

```
opg4j> var jdbcUrl="jdbc:oracle:thin:@<host_name>:<port>/<db_service>"
opg4j> var conn =
DriverManager.getConnection(jdbcUrl,"<username>","<password>");
opg4j> var pgqlConn = PgqlConnection.getConnection(conn)
```

```
opg4j> pgqlConn.setGraph("BANK_GRAPH");
opg4j> String s = "SELECT n.* FROM MATCH (n:Accounts) LIMIT ?"
opg4j> var ps = pgqlConn.prepareStatement(s, 0 /* timeout */, 4 /* parallel
*/, 2 /* dynamic sampling */, -1 /* max results */, null /* match options
*/, null /* options */)
opg4j> ps.setInt(1, 3)
opg4j> var rs = ps.executeQuery()
opg4j> rs.print() //Prints the query result set
+----------------+
| ID | NAME      |
+----------------+
| 1  | Account1 |
| 2  | Account2 |
| 3  | Account3 |
+----------------+
```

Java

```
import java.sql.Statement;
import java.sql.DriverManager;
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;
import oracle.pg.rdbms.pgql.*;

public class PgqlExample2
{
  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String jdbcUrl            = args[idx++];
    String username           = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];


    Connection conn = null;
    PgqlStatement pgqlStmt = null;
    PgqlResultSet rs = null;

    try {
      //Get a jdbc connection
      DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
      conn = DriverManager.getConnection(jdbcUrl, username, password);
      conn.setAutoCommit(false);


      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);


      // Execute PGQL Query
      String s = "SELECT n.* FROM MATCH (n:Accounts) LIMIT ?";
      PgqlPreparedStatement pStmt = pgqlConn.prepareStatement(s, 0, 4 , 2 ,
-1 , null , null);
```

```
      pStmt.setInt(1,3);
      rs = pStmt.executeQuery();

      // Print the results
      rs.print();
    }
    finally {
      // close the result set
      if (rs != null) {
         rs.close();
         }
      // close the statement
      if (pgqlStmt != null) {
         pgqlStmt.close();
         }
      // close the connection
      if (conn != null) {
         conn.close();
         }
      }
  }
}
```

Python

```
>>> pgql_conn = opg4py.pgql.get_connection("<username>","<password>",
"<jdbcUrl>")
>>> pgql_statement = pgql_conn.create_statement()
>>> pgql_conn.set_graph("BANK_GRAPH")
>>> s = "SELECT n.* FROM MATCH (n:Accounts) LIMIT ?"
>>> ps = pgql_conn.prepare_statement(s, timeout=0, parallel=4,
dynamicSampling=2, maxResults=-1, matchOptions=None, options=None)
>>> ps.set_int(1,3)
>>> ps.execute_query().print()
+----------------+
| ID | NAME      |
+----------------+
| 1  | Account1 |
| 2  | Account2 |
| 3  | Account3 |
+----------------+
```

Example 11-4 Running a `SELECT` Query with Grouping and Aggregation

- JShell
- Java
- Python

JShell

```
opg4j> var jdbcUrl="jdbc:oracle:thin:@<host_name>:<port>/<db_service>"
opg4j> var conn =
DriverManager.getConnection(jdbcUrl,"<username>","<password>");
opg4j> var pgqlConn = PgqlConnection.getConnection(conn)
opg4j> pgqlConn.setGraph("BANK_GRAPH")
opg4j> var pgqlStmt = pgqlConn.createStatement() //create a PGQL Statement
opg4j> String query = "SELECT v1.id, COUNT(v2) AS numTxns "+
...>         "FROM MATCH (v1)-[e IS Transfers]->(v2) "+
...>         "GROUP BY v1 "+
...>         "ORDER BY numTxns DESC "+
...>         "LIMIT 3"
opg4j> var resultSet = pgqlStmt.executeQuery(query)
opg4j> resultSet.print() //Prints the query result set
+---------------+
| ID  | NUMTXNS |
+---------------+
| 687 | 6       |
| 195 | 5       |
| 192 | 5       |
+---------------+
```

Java

```
import java.sql.Connection;
import java.sql.Statement;
import java.sql.DriverManager;
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;


/*
 * This example shows how to execute a SELECT query with aggregation .*/
public class PgqlExample3
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String jdbcUrl            = args[idx++];
    String username           = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];


    Connection conn = null;
    PgqlStatement pgqlStmt = null;
    PgqlResultSet rs = null;

    try {
      //Get a jdbc connection
```

```
      DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
      conn = DriverManager.getConnection(jdbcUrl, username, password);
      conn.setAutoCommit(false);


      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PGQL Statement
      pgqlStmt = pgqlConn.createStatement();

      // Execute PGQL Query
      String query =
        "SELECT v1.id, COUNT(v2) AS numTxns "+
        "FROM MATCH (v1)-[e IS Transfers]->(v2) "+
        "GROUP BY v1 "+
        "ORDER BY numTxns DESC";

      rs = pgqlStmt.executeQuery(query);
      // Print the results
      rs.print();
    }
    finally {
      // close the result set
      if (rs != null) {
         rs.close();
         }
      // close the statement
      if (pgqlStmt != null) {
         pgqlStmt.close();
         }
      // close the connection
      if (conn != null) {
         conn.close();
         }
      }
  }
}
```

Python

```
>>> pgql_conn = opg4py.pgql.get_connection("<username>","<password>",
"<jdbcUrl>")
>>> pgql_statement = pgql_conn.create_statement()
>>> pgql_conn.set_graph("BANK_GRAPH")
>>> query = """
...          SELECT v1.id, COUNT(v2) AS numtxns
...          FROM MATCH (v1)-[e IS Transfers]->(v2)
...          GROUP BY v1
...          ORDER BY numtxns DESC
...          LIMIT 3
...          """
>>> pgql_statement.execute_query(query).print()
```

```
+----------------+
| ID   | NUMTXNS |
+----------------+
| 687 | 6        |
| 195 | 5        |
| 192 | 5        |
+----------------+
```

Example 11-5 Showing a PGQL Path Query

- JShell
- Java
- Python

JShell

```
opg4j> var jdbcUrl="jdbc:oracle:thin:@<host_name>:<port>/<db_service>"
opg4j> var conn =
DriverManager.getConnection(jdbcUrl,"<username>","<password>");
opg4j> var pgqlConn = PgqlConnection.getConnection(conn)
opg4j> pgqlConn.setGraph("BANK_GRAPH")
opg4j> var pgqlStmt = pgqlConn.createStatement() //create a PGQL Statement
opg4j> String query = "PATH onehop AS ()-[IS transfers]->() "+
...>         "SELECT v1.id FROM MATCH (v1)-/:onehop/->(v2) "+
...>         "WHERE v2.id = 365"
opg4j> var resultSet = pgqlStmt.executeQuery(query)
opg4j> resultSet.print() //Prints the query result set
+-----+
| ID  |
+-----+
| 132 |
| 435 |
| 296 |
| 327 |
| 328 |
| 399 |
| 684 |
| 919 |
| 923 |
| 771 |
+-----+
```

Java

```
import java.sql.Connection;
import java.sql.Statement;
import java.sql.DriverManager;
```

```
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;


/*
 * This example shows how to execute a PGQL PATH query.*/
public class PgqlExample4
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String jdbcUrl            = args[idx++];
    String username           = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];


    Connection conn = null;
    PgqlStatement pgqlStmt = null;
    PgqlResultSet rs = null;

    try {
      //Get a jdbc connection
      DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
      conn = DriverManager.getConnection(jdbcUrl, username, password);
      conn.setAutoCommit(false);


      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PGQL Statement
      pgqlStmt = pgqlConn.createStatement();

     // Execute PGQL Query
      String query =
                 "PATH onehop AS ()-[IS transfers]->() "+
                 "SELECT v1.id FROM MATCH (v1)-/:onehop/->(v2) "+
                 "WHERE v2.id = 365";
      rs = pgqlStmt.executeQuery(query);

      // Print the results
      rs.print();
    }
    finally {
      // close the result set
      if (rs != null) {
         rs.close();
         }
      // close the statement
      if (pgqlStmt != null) {
```

```
            pgqlStmt.close();
            }
         // close the connection
         if (conn != null) {
            conn.close();
            }
         }
     }
   }
```

Python

```
>>> pgql_conn = opg4py.pgql.get_connection("<username>","<password>",
"<jdbcUrl>")
>>> pgql_statement = pgql_conn.create_statement()
>>> pgql_conn.set_graph("BANK_GRAPH")
>>> query = """
...                   PATH onehop AS ()-[IS transfers]->()
...                   SELECT v1.id FROM MATCH (v1)-/:onehop/->(v2)
...                   WHERE v2.id = 365
...          """
>>> pgql_statement.execute_query(query).print()
+-----+
| ID  |
+-----+
| 132 |
| 435 |
| 296 |
| 327 |
| 328 |
| 399 |
| 684 |
| 919 |
| 923 |
| 771 |
+-----+
```

11.7.3.3 Executing PGQL Queries Using JDBC Driver

The Oracle Graph Server and Client Release 21.2.0 includes a JDBC driver which allows you to run PGQL queries directly against the Oracle Database. To use the driver, register the following class at the JDBC driver manager:

```
import java.sql.DriverManager;
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;
...
DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
```

To make JDBC use the driver, you need to prefix the JDBC URLs with `jdbc:oracle:pgql` as shown in this example:

```
import java.sql.Connection;
import java.sql.DriverManager;

Connection conn = DriverManager.getConnection("jdbc:oracle:pgql:@<DB
Host>:<DB Port>/<DB SID>", "<DB Username>", "<DB Password>");
```

The part after `jdbc:oracle:pgql` follows the same syntax as the regular Oracle JDBC thin driver. In other words, you can convert any valid Oracle JDBC thin driver URL into a PGQL driver URL by replacing `jdbc:oracle:thin` with `jdbc:oracle:pgql`. Once you obtained a connection object, you can use it to query property graphs using PGQL syntax. For example:

Example 11-6 Executing a PGQL Query using the PGQL JDBC driver

```
import java.sql.Connection;
import java.sql.DriverManager;
import java.sql.ResultSet;
import java.sql.PreparedStatement;
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;

public class PgqlJdbcTest {

  public static void main(String[] args) throws Exception {

    DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
    String jdbcUrl = "jdbc:oracle:pgql:@<DB Host>:<DB Port>/<DB SID>";
    String username = "<DB Username>";
    String password = "<DB Password>";

    try (Connection conn = DriverManager.getConnection(jdbcUrl,
username, password)) {
      String query = "SELECT n.name FROM MATCH(n) ON test_graph WHERE
id(n) = ?";
      PreparedStatement pstmt = conn.prepareStatement(query);
      pstmt.setLong(1, 10L);
      pstmt.execute();
      ResultSet rs = pstmt.getResultSet();
      while(rs.next()){
        System.out.println("NAME = " + rs.getString("name"));
      }
    }
  }
}
```

Save the preceding code in a file `PgqlJdbcTest.java` and compile using:

```
javac -cp "<graph-client>/lib/*" PgqlJdbcTest.java
```

The driver is also included in a regular graph server (RPM) install. For example:

```
javac -cp "/opt/oracle/graph/lib/*" PgqlJdbcTest.java
```

11.7.3.4 Executing PGQL Queries to Modify Property Graph Views

You can execute PGQL `INSERT`, `UPDATE` and `DELETE` queries against property graph views using the OPG4J Java shell, OPG4Py Python shell or through a Java or Python application.

It is important to note that unique IDs are not auto generated when inserting vertices or edges in a graph. Therefore, you must ensure that the key column values are either present in the graph properties or they are auto generated by the database (through `SEQUENCE` and `TRIGGERS` or implemented with auto increment functionality using `IDENTITY` column).

The following example inserts two new vertices and also adds an edge relationship between the two vertices.

- JShell
- Java
- Python

JShell

```
opg4j> String pgql =
...>     "INSERT VERTEX v1 LABELS (Person) PROPERTIES (v1.name= 'ABC',
v1.height=1.6, v1.birthdate = to_date('13/06/1963', 'DD/MM/YYYY')) "+
...>     "      , VERTEX v2 LABELS (Person) PROPERTIES (v2.name= 'XYZ',
v2.height=1.75, v2.birthdate = to_date('19/06/1963', 'DD/MM/YYYY')) "+
...>     "      , EDGE e BETWEEN v1 AND v2 LABELS (friendof) PROPERTIES
( e.meeting_date = to_date('19/06/2021', 'DD/MM/YYYY')) "
pgql ==> "INSERT VERTEX v1 LABELS (Person) PROPERTIES (v1.name= 'ABC',
v1.height=1.6, v1.birthdate = to_date('13/06/1963', 'DD/MM/YYYY'))      ,
VERTEX v2 LABELS (Person) PROPERTIES (v2.name= 'XYZ', v2.height=1.75,
v2.birthdate = to_date('19/06/1963', 'DD/MM/YYYY'))      , EDGE e BETWEEN v1
AND v2 LABELS (friendof) PROPERTIES ( e.meeting_date = to_date('19/06/2021',
'DD/MM/YYYY')) "
opg4j> pgqlStmt.execute(pgql)
$14 ==> false
```

Java

```
String pgql =
...>     "INSERT VERTEX v1 LABELS (Person) PROPERTIES (v1.name= 'ABC',
v1.height=1.6, v1.birthdate = to_date('13/06/1963', 'DD/MM/YYYY')) "+
...>     "      , VERTEX v2 LABELS (Person) PROPERTIES (v2.name= 'XYZ',
v2.height=1.75, v2.birthdate = to_date('19/06/1963', 'DD/MM/YYYY')) "+
...>     "      , EDGE e BETWEEN v1 AND v2 LABELS (friendof) PROPERTIES
( e.meeting_date = to_date('19/06/2021', 'DD/MM/YYYY')) ";
pgqlStmt.execute(pgql);
```

Python

```
>>> pgql = """
...     INSERT VERTEX v1 LABELS (Person) PROPERTIES (v1.name= 'ABC',
v1.height=1.6, v1.birthdate = to_date('13/06/1963', 'DD/MM/YYYY'))
...     , VERTEX v2 LABELS (Person) PROPERTIES (v2.name= 'XYZ',
v2.height=1.75, v2.birthdate = to_date('19/06/1963', 'DD/MM/YYYY'))
...     , EDGE e BETWEEN v1 AND v2 LABELS (friendof) PROPERTIES
( e.meeting_date = to_date('19/06/2021', 'DD/MM/YYYY'))
... """
>>> pgql_statement.execute(pgql)
False
```

The following example executes an `UPDATE` query to modify the edge property that was inserted in the preceding example and subsequently verifies the update operation through a `SELECT` query.

- JShell
- Java
- Python

JShell

```
opg4j> String pgql = "UPDATE e SET (e.meeting_date =
to_date('12/02/2022', 'DD/MM/YYYY')) "+
...>     "FROM MATCH (v1:Person)-[e:friendof]->(v2:Person) "+
...>     "WHERE v1.person_id = 27 AND v2.person_id = 28"
pgql ==> "UPDATE e SET (e.meeting_date = to_date('12/02/2022', 'DD/MM/
YYYY')) FROM MATCH (v1:Person)-[e:friendof]->(v2:Person) WHERE
v1.person_id = 27 AND v2.person_id = 28"
opg4j> pgqlStmt.execute(pgql)
$40 ==> false
opg4j>pgqlStmt.executeQuery("SELECT e.meeting_date FROM MATCH
(v1:Person)-[e:friendof]->(v2:Person) WHERE v1.person_id = 27").print()
+-----------------------+
| MEETING_DATE          |
+-----------------------+
| 2022-02-12 00:00:00.0 |
+-----------------------+
```

Java

```
String pgql ="UPDATE e SET (e.meeting_date = to_date('12/02/2022',
'DD/MM/YYYY')) "+
"FROM MATCH (v1:Person)-[e:friendof]->(v2:Person) "+
```

```
"WHERE v1.person_id = 27 AND v2.person_id = 28";
pgqlStmt.execute(pgql);
```

Python

```
>>> pgql = """
...     UPDATE e SET (e.meeting_date = to_date('12/02/2022', 'DD/MM/YYYY'))
...     FROM MATCH (v1:Person)-[e:friendof]->(v2:Person)
...     WHERE v1.person_id = 27 AND v2.person_id = 28
... """
>>> pgql_statement.execute(pgql)
False
>>> pgql_statement.execute_query("SELECT e.meeting_date FROM
MATCH(v1:Person)-[e:friendof]->(v2:Person) WHERE v1.person_id = 27").print()
+-----------------------+
| MEETING_DATE          |
+-----------------------+
| 2022-02-12 00:00:00.0 |
+-----------------------+
```

A `DELETE` query allows deleting of vertices and edges in a graph. The following example executes a `DELETE` query to delete an edge in the graph.

- JShell
- Java
- Python

JShell

```
opg4j> pgqlStmt.execute("DELETE e FROM MATCH (v1:Person)-[e:friendof]-
>(v2:Person) WHERE v.person_id=27")
$14 ==> false
```

Java

```
pgqlStmt.execute("DELETE e FROM MATCH (v1:Person)-[e:friendof]->(v2:Person)
WHERE v.person_id=27");
```

Python

```
>>> pgql_statement.execute("DELETE e FROM MATCH (v1:Person)-[e:friendof]-
>(v2:Person) WHERE v1.person_id=27")
False
```

11.7.3.5 Dropping A Property Graph View

You can use the PGQL `DROP PROPERTY GRAPH` statement to drop a property graph view (PG View). Note that all the metadata tables for the PG View are dropped.

Example 11-7 Creating a Property Graph View

The following example describes the creation of a PG View.

- JShell
- Java
- Python

JShell

```
opg4j> var jdbcUrl="jdbc:oracle:thin:@<host_name>:<port>/<db_service>"
opg4j> var conn =
DriverManager.getConnection(jdbcUrl,"<username>","<password>")
opg4j> var pgqlConn = PgqlConnection.getConnection(conn)
opg4j> var pgqlStmt = pgqlConn.createStatement() //create a PGQL
Statement
opg4j> pgqlStmt.execute("DROP PROPERTY GRAPH <pgview>")
$9 ==> false
```

Java

```
import java.sql.Connection;
import java.sql.Statement;
import java.sql.DriverManager;
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;
/**
 * This example shows how to drop a property graph view.
 */
public class DropPgView
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String jdbcUrl            = args[idx++];
    String username           = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement pgqlStmt = null;
```

```
    try {
      //Get a jdbc connection
      DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
      conn = DriverManager.getConnection(jdbcUrl, username, password);
      conn.setAutoCommit(false);

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);

      // Create PGQL Statement
      pgqlStmt = pgqlConn.createStatement();

      String query = "DROP PROPERTY GRAPH " +pgview;
      pgqlStmt.execute(query);

    }
    finally {
      // close the statement
      if (pgqlStmt != null) {
         pgqlStmt.close();
         }
      // close the connection
      if (conn != null) {
         conn.close();
         }
      }
  }
}
```

Python

```
>>> pgql_conn = opg4py.pgql.get_connection("<username>","<password>",
"jdbc:oracle:thin:@localhost:1521/orclpdb")
>>> pgql_statement = pgql_conn.create_statement()
>>> pgql = "DROP PROPERTY GRAPH <pgview>"
>>> pgql_statement.execute(pgql)
False
```

Part IV

Installing Oracle Graph Server (PGX) and Client

Get started on the installation of the Oracle Graph Server (PGX) and the graph clients.

12 Oracle Graph Server and Client Installation

This chapter describes the steps for installing the graph server and the graph clients.

- Before You Begin
  Before you begin to work with Oracle Property Graphs, you must understand the workflow for installing Oracle Graph Server and Client.
- Oracle Graph Server Installation
  You must install the Oracle Graph Server in order to run graph queries and analytics in the graph server (PGX).
- Oracle Graph Client Installation
  You can interact with the various graph features using the client CLIs and the graph visualization web client.
- Setting Up Transport Layer Security
  The graph server (PGX), by default, allows only encrypted connections using Transport Layer Security (TLS). TLS requires the server to present a server certificate to the client and the client must be configured to trust the issuer of that certificate.

12.1 Before You Begin

Before you begin to work with Oracle Property Graphs, you must understand the workflow for installing Oracle Graph Server and Client.

Table 12-1 Workflow for Installing Oracle Graph Server and Client

Sequence	Task	Description	More Information
1	Verify Oracle Database Requirements	Ensure that your Oracle Database version is 12.2 and higher.	Verifying Database Compatibility
2	Download Oracle Graph Server and Client	Download Oracle Graph Server and Client from Oracle Software Delivery Cloud or from Oracle Technology Network.	Downloading Oracle Graph Server and Client
3	Install the PL/SQL patch in your Oracle Database	Upgrade the PL/SQL Graph packages in your Oracle Database.	Installing PL/SQL Packages in Oracle Database
4	Install Oracle Graph Server	Install Oracle Graph server, which is available as a separate downloadable package.	Installing Oracle Graph Server
5	Install Oracle Graph Clients	Install the graph clients (such as the graph shell CLIs and graph visualization application) to work with property graphs.	Oracle Graph Client Installation

Table 12-1 (Cont.) Workflow for Installing Oracle Graph Server and Client

Sequence	Task	Description	More Information
6	Set up transport layer security	Configure the graph server and client to trust the self-signed certificate.	Setting Up Transport Layer Security
7	Add permissions to publish the graph	Grant permissions to publish graphs.	Adding Permissions to Publish the Graph

- Verifying Database Compatibility
- Downloading Oracle Graph Server and Client
- Installing PL/SQL Packages in Oracle Database
  Oracle Graph Server and Client will work with Oracle Database 12.2 onward. However, you must install the updated PL/SQL packages that are part of the Oracle Graph Server and Client download.

12.1.1 Verifying Database Compatibility

Oracle Graph Server and Client works with Oracle Database 12.2 onwards on both on-premises and cloud environments. The cloud environment includes working with all versions of Oracle Autonomous Database (shared) and Oracle Autonomous Database (dedicated).

However, modifying a property graph using a PGQL `INSERT`, `UPDATE`, or `DELETE` query is not supported for Oracle Database 12.2.

12.1.2 Downloading Oracle Graph Server and Client

You can download **Oracle Graph Server and Client** from Oracle Software Delivery Cloud or from Oracle Technology Network.

Table 12-2 summarizes all the files contained in the Oracle Graph Server and Client deployment.

<ver> denoted in the file name in the Table 12-2 reflects the downloaded Oracle Graph Server and Client version.

Table 12-2 Components in the Oracle Graph Server and Client Deployment

File	Component	Description
`oracle-graph-<ver>.rpm`	Oracle Graph Server	An rpm file to deploy Oracle Graph Server.
`oracle-graph-client-<ver>.zip`	Oracle Graph Client	A zip file containing Oracle Graph Client.
`oracle-graph-hdfs-connector-<ver>.zip`	Oracle Graph HDFS Connector	A zip file containing libraries to connect Oracle Graph Server with the Apache Hadoop Distributed Filesystem (HDFS).

Table 12-2 (Cont.) Components in the Oracle Graph Server and Client Deployment

File	Component	Description
`oracle-graph-sqlcl-plugin-<ver>.zip`	Oracle Graph PGQL Plugin for SQLcl	A plugin for SQLcl to run PGQL queries in SQLcl.
`oracle-graph-webapps-<ver>.zip`	Oracle Graph Web Applications	A zip file containing `.war` files for deploying graph servers in an application server.
`oracle-graph-plsql-<ver>.zip`	Oracle Graph PL/SQL Patch	A zip file containing PL/SQL packages. It is recommended to update the PL/SQL Graph packages in your database with these packages. Instructions are in the `README` file.
`oracle-graph-visualization-library-<ver>.zip`	Oracle Graph Visualization Library	A zip file containing a Java Script library for the Graph Visualization application.

12.1.3 Installing PL/SQL Packages in Oracle Database

Oracle Graph Server and Client will work with Oracle Database 12.2 onward. However, you must install the updated PL/SQL packages that are part of the Oracle Graph Server and Client download.

> **Note:**
>
> You can skip this section if you are using Graph Server and Client with Oracle Autonomous Database. You only need to create roles and assign permissions by executing step-5 and step-6 in Basic Steps for Using an Oracle Database for Authentication. You can run these steps using Database Actions in Oracle Cloud Infrastructure Console.

1. Download the Oracle Graph PL/SQL patch component, which is a part of the Oracle Graph Server and Client download from Oracle Software Delivery Cloud.
2. Unzip the file `oracle-graph-plsql-<ver>.zip` into a directory of your choice.

   <*ver*> denotes the version downloaded for the Oracle Graph PL/SQL Patch for PL/SQL.

3. Connect to the database as a user with DBA privileges and run the `create_graph_roles.sql` script.

```
-- Connect as SYSDBA
SQL> ALTER SESSION SET CONTAINER=<YOUR_PDB_NAME>;
SQL> @create_graph_roles.sql
```

   Optionally, if you plan to work with property graph schema (PG Schema) graphs, then you must install the PL/SQL packages by performing the following steps:

   - Choose one of the following directories in the `optional_pg_schema` folder:
     - `18c_and_below`: This applies only if you are working with Oracle Database 18c or below.
     - `19c_and_above`: This applies only if you are working with Oracle Database 19c or above.
   - As a database user with DBA privileges, follow the instructions in the `README.md` file in the appropriate directory (that matches your database version). You must do this for every PDB where you will use the graph feature. For example:

```
-- Connect as SYSDBA
SQL> ALTER SESSION SET CONTAINER=<YOUR_PDB_NAME>;
SQL> @opgremov.sql
SQL> @catopg.sql
```

   See Using the Property Graph Schema for more information on PG Schema graphs.

4. Connect as a database user with DBA privileges, create a user `<graphuser>`, and grant the following privileges:

```
SQL> GRANT CREATE SESSION, CREATE TABLE, CREATE VIEW TO <graphuser>
```

   Optionally, if you plan to work with property graph schema (PG Schema) graphs, then grant the following privileges:

```
SQL> GRANT CREATE SESSION, ALTER SESSION, CREATE TABLE, CREATE
PROCEDURE, CREATE TYPE, CREATE SEQUENCE, CREATE VIEW, CREATE
TRIGGER TO <graphuser>
```

5. Grant the appropriate roles (`GRAPH_DEVELOPER` or `GRAPH_ADMINISTRATOR`), to the database user created in step 4 for working with the graphs.

Note:

- See User Authentication and Authorization for more information on authorization rules for Graph Server (PGX) and Client 23.1.
- See Upgrading From Graph Server and Client 20.4.x to 21.x for more information if you are migrating to Graph Server (PGX) and Client 21.1 from an earlier version.

```
SQL> GRANT GRAPH_DEVELOPER to <graphuser>
SQL> GRANT GRAPH_ADMINISTRATOR to <adminuser>
```

12.2 Oracle Graph Server Installation

You must install the Oracle Graph Server in order to run graph queries and analytics in the graph server (PGX).

The following sections explain the steps to install the Oracle Graph Server in a standalone mode or deploy the server as a web application using Oracle WebLogic Server or Apache Tomcat.

- Using the RPM Installation
  You can run the downloaded RPM file to install the Oracle Graph Server.
- Deploying Oracle Graph Server to a Web Server
  You can deploy Oracle Graph Server to Apache Tomcat or Oracle WebLogic Server.
- User Authentication and Authorization
  The Oracle Graph server (PGX) uses an Oracle Database as identity manager. Both username and password based as well as Kerberos based authentication is supported.

Related Topics

- Learn About the Graph Server (PGX)
  The in-memory graph server layer enables you to analyze property graphs using parallel in-memory execution.

12.2.1 Using the RPM Installation

You can run the downloaded RPM file to install the Oracle Graph Server.

- Prerequisites for Installing Oracle Graph Server
- Installing Oracle Graph Server
- Uninstalling Oracle Graph Server
- Upgrading Oracle Graph Server

12.2.1.1 Prerequisites for Installing Oracle Graph Server

Your system must adhere to certain prerequisite requirements in order to install the Oracle Graph Server.

The prerequisites for installing the Oracle Graph Server are:

- Verify that you meet the following system requirements:
  - Oracle Linux 7 or 8 x64 or a similar Linux distribution such as RedHat

    Note:

    To run machine learning algorithms on Oracle Linux 8 (Using the Machine Learning Library (PgxML) for Graphs), you must additionally install `compat-libgfortran-48` in your system:
    `sudo yum install compat-libgfortran-48`

  - Oracle JDK 8, JDK 11, or JDK 17

    Note:

    * Due to a bug in Open JDK, it is recommended to avoid the following Oracle JDK versions:
      * JDK 11.0.9
      * JDK 11.0.10
      * JDK 11.0.11
      * JDK 11.0.12

      See this note for more details.
    * Compiling custom graph algorithms using the PGX Algorithm API is not supported on Oracle JDK 17.
- Verify if you already have an installed version of the graph server, by running the following command:

  ```
  sudo rpm -q oracle-graph
  [sudo] password for oracle:
  oracle-graph-23.1.0-0.x86_64
  ```

  Graph server installation may throw an error if an installation already exists. In that case, see Upgrading Oracle Graph Server to upgrade to a newer version.

12.2.1.2 Installing Oracle Graph Server

The installation steps for installing Oracle Graph Server in standalone mode are as shown:

1. As a `root` user or using `sudo`, install the RPM file using the rpm command line utility:

   ```
   sudo rpm -i oracle-graph-<version>.rpm
   ```

Where `<version>` reflects the version that you downloaded. (For example: `oracle-graph-23.1.0.x86_64.rpm`)

The `.rpm` file is the graph server.

The following post-installation steps are carried out at the time of the `RPM` file installation:

- Creation of a working directory in `/opt/oracle/graph/pgx/tmp_data`
- Creation of a log directory in `/var/log/oracle/graph`
- Automatic generation of self-signed TLS certificates in `/etc/oracle/graph`

> **Note:**
>
> – You can also choose to configure and set up transport layer security (TLS) in graph server. See Setting Up Transport Layer Security for more details.
>
> – For demonstration purposes, if you wish to disable transport layer security (TLS) in graph server, see Disabling Transport Layer Security (TLS) in Graph Server for more details.

2. As `root` or using `sudo`, add operating system users allowed to use the server installation to the operating system group `oraclegraph`. For example:

```
usermod -a -G oraclegraph <graphuser>
```

   This adds the specified graph user to the group `oraclegraph`.
   Note that *<graphuser>* must log out and log in again for this to take effect.

3. As *<graphuser>*, configure the server by modifying the files under `/etc/oracle/graph` by following the steps under Prepare the Graph Server for Database Authentication.
4. Ensure that authentication is enabled for database users that will connect to the graph server, as explained in User Authentication and Authorization.
5. As a `root` user or using `sudo`, start the graph server (PGX) by executing the following command:

```
sudo systemctl start pgx
```

You can verify if the graph server has started by executing the following command:

```
systemctl status pgx
```

- If the graph server has successfully started, the response may appear as:

```
● pgx.service - Oracle Graph In-Memory Server
   Loaded: loaded (/etc/systemd/system/pgx.service; disabled; vendor
preset: disabled)
   Active: active (running) since Wed 2021-01-27 10:06:06 EST; 33s ago
 Main PID: 32127 (bash)
   CGroup: /system.slice/pgx.service
           ├─32127 /bin/bash start-server
```

```
          └─32176 java -Dlogback.configurationFile=/etc/oracle/
graph/logback-server.xml -Doracle.jdbc.fanEnabled=false -cp /opt/
oracle/graph/pgx/bin/../../pgx/server/lib/jackson-databind...
```

  The graph server is now ready to accept requests.

- If the graph server has not started, then you must check the log files in `/var/log/oracle/graph` for errors. Additionally, you can also run the following command to view any `systemd` errors:

```
sudo journalctl -u pgx.service
```

Additional installation operations are required for specific use cases, such as:

- Analyze property graphs using Python (see Installing the Python Client From the Graph Server and Client Downloads).
- Deploy the graph server as a web application with Oracle WebLogic Server (see Deploying to Oracle WebLogic Server).
- Deploy GraphViz in Oracle WebLogic Server (see Deploying the Graph Visualization Application in Oracle WebLogic Server).
- Deploy the graph server as a web application with Apache Tomcat (see Deploying to Apache Tomcat).

For instructions to deploy the graph server in Oracle WebLogic Server or Apache Tomcat, see:

- Deploying to Oracle WebLogic Server
- Deploying to Apache Tomcat

You can also deploy the graph server behind a load balancer. See Deploying Oracle Graph Server Behind a Load Balancer for more information.

12.2.1.3 Uninstalling Oracle Graph Server

To uninstall the graph server, ensure that you first shut down the existing graph server version.

- Run the following command as a `root` user or with `sudo`:

```
sudo rpm -e oracle-graph
```

12.2.1.4 Upgrading Oracle Graph Server

To upgrade the graph server, ensure that you first shut down the existing graph server version. You can then run the following command with the newer RPM file as an argument.

- Run the following command as a `root` user or with `sudo`:

```
sudo rpm -U oracle-graph-23.1.0.x86_64.rpm
```

12.2.2 Deploying Oracle Graph Server to a Web Server

You can deploy Oracle Graph Server to Apache Tomcat or Oracle WebLogic Server.

The following explains the deployment instructions to a web server:

- Deploying to Apache Tomcat
  The example in this topic shows how to deploy the graph server as a web application with Apache Tomcat.
- Deploying to Oracle WebLogic Server
  The example in this topic shows how to deploy the graph server as a web application with Oracle WebLogic Server.

12.2.2.1 Deploying to Apache Tomcat

The example in this topic shows how to deploy the graph server as a web application with Apache Tomcat.

The graph server will work with Apache Tomcat 9.0.x.

1. Download the Oracle Graph Webapps zip file from Oracle Software Delivery Cloud. This file contains ready-to-deploy Java web application archives (`.war` files). The file name will be similar to this: `oracle-graph-webapps-<version>.zip`.
2. Unzip the file into a directory of your choice.
3. Locate the `.war` file that follows the naming pattern: `graph-server-<version>-pgx<version>.war`.
4. Configure the graph server.
   a. Modify authentication and other server settings by modifying the `WEB-INF/classes/pgx.conf` file inside the web application archive. See User Authentication and Authorization section for more information.
   b. Optionally, change logging settings by modifying the `WEB-INF/classes/logback.xml` file inside the web application archive.
   c. Optionally, change other servlet specific deployment descriptors by modifying the `WEB-INF/web.xml` file inside the web application archive.
5. Copy the `.war` file into the Tomcat `webapps` directory. For example:

```
cp graph-server-<version>-pgx<version>.war $CATALINA_HOME/webapps/pgx.war
```

> **Note:**
>
> The name you give the war file in the Tomcat `webapps` directory determines the context path of the graph server application. It is recommended naming the war file as `pgx.war`.

6. Configure Tomcat specific settings, like the correct use of TLS/encryption.
7. Ensure that port 8080 is not already in use.

8. Start Tomcat:

```
cd $CATALINA_HOME
./bin/startup.sh
```

The graph server will now listen on `localhost:8080/pgx`.

You can connect to the server from JShell by running the following command:

```
$ <client_install_dir>/bin/opg4j --base_url https://
localhost:8080/pgx -u <graphuser>
```

Related Topics

- The Tomcat documentation (select desired version)

12.2.2.2 Deploying to Oracle WebLogic Server

The example in this topic shows how to deploy the graph server as a web application with Oracle WebLogic Server.

This example shows how to deploy the graph server with Oracle WebLogic Server. Graph server supports WebLogic Server version 12.1.x and 12.2.x.

1. Download the Oracle Graph Webapps zip file from Oracle Software Delivery Cloud. This file contains ready-to-deploy Java web application archives (`.war` files). The file name will be similar to this: `oracle-graph-webapps-<version>.zip`.
2. Unzip the file into a directory of your choice.
3. Locate the `.war` file that follows the naming pattern: `graph-server-<version>-pgx<version>.war`.
4. Configure the graph server.
   a. Modify authentication and other server settings by modifying the `WEB-INF/classes/pgx.conf` file inside the web application archive.
   b. Optionally, change logging settings by modifying the `WEB-INF/classes/logback.xml` file inside the web application archive.
   c. Optionally, change other servlet specific deployment descriptors by modifying the `WEB-INF/web.xml` file inside the web application archive.
   d. Optionally, change WebLogic Server-specific deployment descriptors by modifying the `WEB-INF/weblogic.xml` file inside the web application archive.
5. Configure WebLogic specific settings, like the correct use of TLS/encryption.
6. Deploy the `.war` file to WebLogic Server. The following example shows how to do this from the command line:

```
. $MW_HOME/user_projects/domains/mydomain/bin/setDomainEnv.sh
. $MW_HOME/wlserver/server/bin/setWLSEnv.sh
java weblogic.Deployer -adminurl http://localhost:7001 -username
<username> -password <password> -deploy -source <path-to-war-file>
```

- Installing Oracle WebLogic Server

12.2.2.2.1 Installing Oracle WebLogic Server

To download and install the latest version of Oracle WebLogic Server, see

`http://www.oracle.com/technetwork/middleware/weblogic/documentation/index.html`

12.2.3 User Authentication and Authorization

The Oracle Graph server (PGX) uses an Oracle Database as identity manager. Both username and password based as well as Kerberos based authentication is supported.

The actions that you are allowed to do on the graph server are determined by the privileges enabled by roles that have been granted to you in the Oracle Database.

- Privileges and Roles in Oracle Database
  All database users that work with graphs require the `CREATE SESSION` privilege in the database.
- Basic Steps for Using an Oracle Database for Authentication
  You can follow the steps explained in this section to authenticate users to the graph server (PGX).
- Prepare the Graph Server for Database Authentication
  Locate the `pgx.conf` file of your installation.
- Store the Database Password in a Keystore
- Adding Permissions to Publish the Graph
  There are two ways by which you can view any graph in your graph server (PGX) session in the graph visualization application.
- Token Expiration
  By default, tokens are valid for 1 hour.
- Advanced Access Configuration
  You can customize the following fields inside the `pgx_realm` block in the `pgx.conf` file to customize login behavior.
- Customizing Roles and Permissions
  You can fully customize the permissions to roles mapping by adding and removing roles and specifying permissions for a role. You can also authorize individual users instead of roles.
- Revoking Access to the Graph Server
  To revoke a user's ability to access the graph server, either drop the user from the database or revoke the corresponding roles from the user, depending on how you defined the access rules in your pgx.conf file.
- Examples of Custom Authorization Rules
  You can define custom authorization rules for developers.
- Kerberos Enabled Authentication for the Graph Server (PGX)
  The graph server (PGX) can authenticate users using an Oracle Database with Kerberos enabled as identity provider.

12.2.3.1 Privileges and Roles in Oracle Database

All database users that work with graphs require the `CREATE SESSION` privilege in the database.

Roles that are created for working with graphs are in Table 12-3. These roles are created when you install the PL/SQL package of the Oracle Graph Server and Client distribution on the target database.

Table 12-3 Privileges and Roles in Oracle Database

Role	Operations enabled by this role	Used By
`PGX_SESSION_CREATE`	Create a new PGX session using the ServerInstance.createSession API.	Graph developers and graph users
`PGX_SERVER_GET_INFO`	Get status information on the PGX instance using the Admin API.	Users who administer PGX
`PGX_SERVER_MANAGE` (includes `PGX_SERVER_GET_INFO`)	Manage the PGX instance using the Admin API to stop or restart PGX.	Users who administer PGX
`PGX_SESSION_NEW_GRAPH`	Create a new graph in PGX by loading from the database using a config file, using the CREATE PROPERTY GRAPH statement in PGQL, creating a sub-graph from another graph, or using the GraphBuilder.	Graph developers and graph users
`PGX_SESSION_GET_PUBLISHED_GRAPH`	Query and view graphs published by another user to the public namespace.	Graph developers and graph users
`PGX_SESSION_ADD_PUBLISHED_GRAPH` (includes `PGX_SESSION_GET_PUBLISHED_GRAPH`)	Publish a graph to the public namespace.	Graph developers
`PGX_SESSION_COMPILE_ALGORITHM`	Compile an algorithm using the PGX Algorithm API.	Graph developers
`PGX_SESSION_READ_MODEL`	Load and use an ML model using PgxML.	Graph developers
`PGX_SESSION_MODIFY_MODEL`	Create, train, and store an ML model using PgxML.	Graph developers

Few additional roles are also created to group multiple roles together. They provide a convenient way to grant multiple roles to database users. See Mapping Graph Server Roles to Default Privileges for more information on these additional roles.

You can create additional groups that are useful for your application, as described in Adding and Removing Roles and Defining Permissions for Individual Users.

12.2.3.2 Basic Steps for Using an Oracle Database for Authentication

You can follow the steps explained in this section to authenticate users to the graph server (PGX).

1. Use an Oracle Database version that is supported by Oracle Graph Server and Client: version 12.2 or later, including Autonomous Database.

2. Be sure that you have ADMIN access (or SYSDBA access for non-autonomous databases) to grant and revoke users access to the graph server (PGX).
3. Be sure that all existing users to which you plan to grant access to the graph server have at least the CREATE SESSION privilege granted.
4. Be sure that the database is accessible via JDBC from the host where the Graph Server runs.
5. As ADMIN (or SYSDBA on non-autonomous databases), run the following procedure to create the roles required by the graph server:

> **Note:**
>
> You can skip this step if you install the PL/SQL packages as part of the Oracle Graph Server and Client installation. All the roles shown in the following code are created as part of the PL/SQL installation automatically. You need to add them separately only if you are using Oracle Graph Server and Client with Autonomous Database. You can run this code using Database Actions in Oracle Cloud Infrastructure Console.

```
DECLARE
  PRAGMA AUTONOMOUS_TRANSACTION;
  role_exists EXCEPTION;
  PRAGMA EXCEPTION_INIT(role_exists, -01921);
  TYPE graph_roles_table IS TABLE OF VARCHAR2(50);
  graph_roles graph_roles_table;
BEGIN
  graph_roles := graph_roles_table(
    'GRAPH_DEVELOPER',
    'GRAPH_ADMINISTRATOR',
    'GRAPH_USER',
    'PGX_SESSION_CREATE',
    'PGX_SERVER_GET_INFO',
    'PGX_SERVER_MANAGE',
    'PGX_SESSION_READ_MODEL',
    'PGX_SESSION_MODIFY_MODEL',
    'PGX_SESSION_NEW_GRAPH',
    'PGX_SESSION_GET_PUBLISHED_GRAPH',
    'PGX_SESSION_COMPILE_ALGORITHM',
    'PGX_SESSION_ADD_PUBLISHED_GRAPH');
  FOR elem IN 1 .. graph_roles.count LOOP
  BEGIN
    dbms_output.put_line('create_graph_roles: ' || elem || ': CREATE ROLE
' || graph_roles(elem));
    EXECUTE IMMEDIATE 'CREATE ROLE ' || graph_roles(elem);
  EXCEPTION
    WHEN role_exists THEN
      dbms_output.put_line('create_graph_roles: role already exists.
continue');
    WHEN OTHERS THEN
      RAISE;
    END;
```

```
  END LOOP;
EXCEPTION
  when others then
    dbms_output.put_line('create_graph_roles: hit error ');
    raise;
END;
/
```

6. Assign default permissions to the roles GRAPH_DEVELOPER, GRAPH_USER and GRAPH_ADMINISTRATOR to group multiple permissions together.

> **Note:**
>
> You can skip this step if you install the PL/SQL packages as part of the Oracle Graph Server and Client installation. All the grants shown in the following code are executed as part of the PL/SQL installation automatically. You need to execute these grants separately only if you are using Oracle Graph Server and Client with Autonomous Database. You can run this code using Database Actions in Oracle Cloud Infrastructure Console.

```
GRANT PGX_SESSION_CREATE TO GRAPH_ADMINISTRATOR;
GRANT PGX_SERVER_GET_INFO TO GRAPH_ADMINISTRATOR;
GRANT PGX_SERVER_MANAGE TO GRAPH_ADMINISTRATOR;
GRANT PGX_SESSION_CREATE TO GRAPH_DEVELOPER;
GRANT PGX_SESSION_NEW_GRAPH TO GRAPH_DEVELOPER;
GRANT PGX_SESSION_GET_PUBLISHED_GRAPH TO GRAPH_DEVELOPER;
GRANT PGX_SESSION_MODIFY_MODEL TO GRAPH_DEVELOPER;
GRANT PGX_SESSION_READ_MODEL TO GRAPH_DEVELOPER;
GRANT PGX_SESSION_CREATE TO GRAPH_USER;
GRANT PGX_SESSION_GET_PUBLISHED_GRAPH TO GRAPH_USER;
```

7. Assign roles to all the database developers who should have access to the graph server (PGX). For example:

```
GRANT graph_developer TO <graphuser>
```

   where `<graphuser>` is a user in the database. You can also assign individual permissions (roles prefixed with PGX_) to users directly.

8. Assign the administrator role to users who should have administrative access. For example:

```
GRANT graph_administrator to <administratoruser>
```

   where `<administratoruser>` is a user in the database.

12.2.3.3 Prepare the Graph Server for Database Authentication

Locate the `pgx.conf` file of your installation.

If you installed the graph server via RPM, the file is located at: `/etc/oracle/graph/pgx.conf`

If you use the `webapps` package to deploy into Tomcat or WebLogic Server, the `pgx.conf` file is located inside the web application archive file (WAR file) at: `WEB-INF/classes/pgx.conf`

Tip: On Linux, you can use vim to edit the file directly inside the WAR file without unzipping it first. For example:

```
vim graph-server-<version>-pgx<version>.war
```

Inside the `pgx.conf` file, locate the `jdbc_url` line of the realm options:

```
...
"pgx_realm": {
  "implementation": "oracle.pg.identity.DatabaseRealm",
  "options": {
    "jdbc_url": "<REPLACE-WITH-DATABASE-URL-TO-USE-FOR-AUTHENTICATION>",
    "token_expiration_seconds": 3600,
...
```

Replace the text with the JDBC URL pointing to your database that you configured in the previous step. For example:

```
...
"pgx_realm": {
  "implementation": "oracle.pg.identity.DatabaseRealm",
  "options": {
    "jdbc_url": "jdbc:oracle:thin:@myhost:1521/myservice",
    "token_expiration_seconds": 3600,
...
```

Then, start the graph server by running the following command as a `root` user or with `sudo`:

```
sudo systemctl start pgx
```

Preparing the Graph Server (PGX) to Connect to Autonomous Database

You can configure your graph server(PGX) to connect to an Autonomous Database instance.

Irrespective of whether your graph server (PGX) instance is running on premises or on Oracle Cloud Infrastructure (OCI), you can perform the following steps to determine the service name to connect to your Autonomous Database instance and update the JDBC URL in `/etc/oracle/graph/pgx.conf` file.

As a prerequisite requirement, you must generate an SSH key pair consisting of a public key and a private key in order to securely login to the environment where the graph server (PGX) is running.

1. Download and save the wallet for your Autonomous Database instance from the Oracle Cloud Infrastructure (OCI) Console. See Download Client Credentials (Wallets) for more information.

2. Upload the wallet from your local machine to the environment where your graph server instance is running with the `scp` command as shown:

```
scp -i <path_to_ssh_private_key> <path_to_Wallet_DBname>.zip
<username>@<public_ip>:/etc/oracle/graph/wallets
```

   The preceding command securely copies the wallet to `/etc/oracle/graph/wallets` directory on your graph server instance using your `ssh` private key.

3. Connect to your graph server instance using the `ssh` private key as shown:

```
ssh -i <ssh_private_key> <username>@<public_ip>
```

4. Unzip the wallet to `/etc/oracle/graph/wallets` directory and change the group permission as shown:

```
cd /etc/oracle/graph/wallets/
unzip <Wallet_DBname>.zip
chgrp oraclegraph *
```

5. Determine the connect identifier from the `tnsnames.ora` file in `/etc/oracle/graph/wallets` directory. For example, the entry must be similar to:

```
graphdb_low =
    description= (retry_count=20)(retry_delay=3)
        (address=
            (protocol=tcps)(port=1522)
            (host=adwc.example.oraclecloud.com)
        )

(connect_data=(service_name=graphdb_low.adwc.oraclecloud.com))

(security=(ssl_server_cert_dn="CN=adwc.example.oraclecloud.com,
OU=Oracle BMCS US, O=Oracle Corporation, L=Redwood City,
ST=California, C=US"))
)
```

   In the preceding example, `graphdb_low` is the connect identifier.

6. Update the JDBC URL in `/etc/oracle/graph/pgx.conf` file with the connect identifier determined in the preceding step along with the directory path to the unzipped wallet file. For example:

```
...
"pgx_realm": {
  "implementation": "oracle.pg.identity.DatabaseRealm",
  "options": {
    "jdbc_url": "jdbc:oracle:thin:@graphdb_low?TNS_ADMIN=/etc/
oracle/graph/wallets",
    "token_expiration_seconds": 3600,
...
```

7. Finally, restart the graph server as shown:

```
sudo systemctl restart pgx
```

12.2.3.4 Store the Database Password in a Keystore

PGX requires a database account to read data from the database into memory. The account should be a low-privilege account (see Security Best Practices with Graph Data).

As described in Reading Graphs from Oracle Database into the Graph Server (PGX), you can read data from the database into the graph server without specifying additional authentication as long as the token is valid for that database user. But if you want to access a graph from a different user, you can do so, as long as that user's password is stored in a Java Keystore file for protection.

You can use the `keytool` command that is bundled together with the JDK to generate such a keystore file on the command line. See the following script as an example:

```
# Add a password for the 'database1' connection
keytool -importpass -alias database1 -keystore keystore.p12
# 1. Enter the password for the keystore
# 2. Enter the password for the database

# Add another password (for the 'database2' connection)
keytool -importpass -alias database2 -keystore keystore.p12

# List what's in the keystore using the keytool
keytool -list -keystore keystore.p12
```

If you are using Java version 8 or lower, you should pass the additional parameter `-storetype pkcs12` to the keytool commands in the preceding example.

You can store more than one password into a single keystore file. Each password can be referenced using the alias name provided.

- Write the PGX graph configuration file to load a graph directly from relational tables
- Read the data
- Secure coding tips for graph client applications

Write the PGX graph configuration file to load a graph directly from relational tables

The following example loads a subset of the HR sample data from relational tables directly into PGX as a graph. The configuration file specifies a mapping from relational to graph format by using the concept of vertex and edge providers.

> **Note:**
>
> Specifying the `vertex_providers` and `edge_providers` properties loads the data into an optimized representation of the graph.

```
{
    "name":"hr",
    "jdbc_url":"jdbc:oracle:thin:@myhost:1521/orcl",
    "username":"hr",
    "keystore_alias":"database1",
    "vertex_id_strategy": "no_ids",
    "vertex_providers":[
        {
            "name":"Employees",
            "format":"rdbms",
            "database_table_name":"EMPLOYEES",
            "key_column":"EMPLOYEE_ID",
            "key_type": "string",
            "props":[
                {
                    "name":"FIRST_NAME",
                    "type":"string"
                },
                {
                    "name":"LAST_NAME",
                    "type":"string"
                },
                {
                    "name":"EMAIL",
                    "type":"string"
                },
                {
                    "name":"SALARY",
                    "type":"long"
                }
            ]
        },
        {
            "name":"Jobs",
            "format":"rdbms",
            "database_table_name":"JOBS",
            "key_column":"JOB_ID",
            "key_type": "string",
            "props":[
                {
                    "name":"JOB_TITLE",
                    "type":"string"
                }
            ]
        },
        {
            "name":"Departments",
```

```
                "format":"rdbms",
                "database_table_name":"DEPARTMENTS",
                "key_column":"DEPARTMENT_ID",
                "key_type": "string",
                "props":[
                    {
                        "name":"DEPARTMENT_NAME",
                        "type":"string"
                    }
                ]
            }
        ],
        "edge_providers":[
            {
                "name":"WorksFor",
                "format":"rdbms",
                "database_table_name":"EMPLOYEES",
                "key_column":"EMPLOYEE_ID",
                "source_column":"EMPLOYEE_ID",
                "destination_column":"EMPLOYEE_ID",
                "source_vertex_provider":"Employees",
                "destination_vertex_provider":"Employees"
            },
            {
                "name":"WorksAs",
                "format":"rdbms",
                "database_table_name":"EMPLOYEES",
                "key_column":"EMPLOYEE_ID",
                "source_column":"EMPLOYEE_ID",
                "destination_column":"JOB_ID",
                "source_vertex_provider":"Employees",
                "destination_vertex_provider":"Jobs"
            },
            {
                "name":"WorkedAt",
                "format":"rdbms",
                "database_table_name":"JOB_HISTORY",
                "key_column":"EMPLOYEE_ID",
                "source_column":"EMPLOYEE_ID",
                "destination_column":"DEPARTMENT_ID",
                "source_vertex_provider":"Employees",
                "destination_vertex_provider":"Departments",
                "props":[
                    {
                        "name":"START_DATE",
                        "type":"local_date"
                    },
                    {
                        "name":"END_DATE",
                        "type":"local_date"
                    }
                ]
            }
        ]
    }
```

Read the data

Now you can instruct PGX to connect to the database and read the data by passing in both the keystore and the configuration file to PGX, using one of the following approaches:

- **Interactively in the graph shell**
  If you are using the graph shell, start it with the `--secret_store` option. It will prompt you for the keystore password and then attach the keystore to your current session. For example:

  ```
  cd /opt/oracle/graph
  ./bin/opg4j --secret_store /etc/my-secrets/keystore.p12

   enter password for keystore /etc/my-secrets/keystore.p12:
  ```

  Inside the shell, you can then use normal PGX APIs to read the graph into memory by passing the JSON file you just wrote into the `readGraphWithProperties` API:

  ```
  opg4j> var graph = session.readGraphWithProperties("config.json")
  graph ==> PgxGraph[name=hr,N=215,E=415,created=1576882388130]
  ```

- **As a PGX preloaded graph**
  As a server administrator, you can instruct PGX to load graphs into memory upon server startup. To do so, modify the PGX configuration file at `/etc/oracle/graph/pgx.conf` and add the path the graph configuration file to the `preload_graphs` section. For example:

  ```
  {
    ...
    "preload_graphs": [{
      "name": "hr",
      "path": "/path/to/config.json"
    }],
    "authorization": [{
      "pgx_role": "GRAPH_DEVELOPER",
      "pgx_permissions": [{
        "preloaded_graph": "hr",
        "grant": "read"
      }]
    },
      ....
    ]
  }
  ```

  As root user, edit the service file at `/etc/systemd/system/pgx.service` and change the `ExecStart` command to specify the location of the keystore containing the password:

  ```
  ExecStart=/bin/bash start-server --secret-store /etc/keystore.p12
  ```

> **Note:**
>
> Please note that `/etc/keystore.p12` must not be password protected for this to work. Instead protect the file via file system permission that is only readable by `oraclegraph` user.

After the file is edited, reload the changes using:

```
sudo systemctl daemon-reload
```

Finally start the server:

```
sudo systemctl start pgx
```

- **In a Java application**
  To register a keystore in a Java application, use the `registerKeystore()` API on the `PgxSession` object. For example:

```
import oracle.pgx.api.*;

class Main {

  public static void main(String[] args) throws Exception {
    String baseUrl = args[0];
    String keystorePath = "/etc/my-secrets/keystore.p12";
    char[] keystorePassword = args[1].toCharArray();
    String graphConfigPath = args[2];
    ServerInstance instance = Pgx.getInstance(baseUrl);
    try (PgxSession session = instance.createSession("my-session")) {
      session.registerKeystore(keystorePath, keystorePassword);
      PgxGraph graph = session.readGraphWithProperties(graphConfigPath);
      System.out.println("N = " + graph.getNumVertices() + " E = " +
graph.getNumEdges());
    }
  }
}
```

  You can compile and run the preceding sample program using the Oracle Graph Client package. For example:

```
cd $GRAPH_CLIENT
// create Main.java with above contents
javac -cp 'lib/*' Main.java
java -cp '.:conf:lib/*' Main http://myhost:7007 MyKeystorePassword
path/to/config.json
```

Secure coding tips for graph client applications

When writing graph client applications, make sure to never store any passwords or other secrets in clear text in any files or in any of your code.

Do not accept passwords or other secrets through command line arguments either. Instead, use `Console.html#readPassword()` from the JDK.

12.2.3.5 Adding Permissions to Publish the Graph

There are two ways by which you can view any graph in your graph server (PGX) session in the graph visualization application.

When you log into the graph visualization tool in your browser, that will be a different session from your JShell session or application session. To visualize the graph you are working on in your JShell session or application session in your graph visualization session, you can perform one of the following two steps:

1. Get the session id of your working session using the `PgxSession` API, and use that session id when you log into the graph visualization application. This is the recommended option.

   ```
   opg4j> session.getId();
   $2 ==> "898bdbc3-af80-49b7-9a5e-10ace6c9071c"  //session id
   ```

   or

2. Grant `PGX_SESSION_ADD_PUBLISHED_GRAPH` permission and then publish the graph as shown:
   a. Grant `PGX_SESSION_ADD_PUBLISHED_GRAPH` role in the database to the user visualizing the graph as shown in the following statement:

      ```
      GRANT PGX_SESSION_ADD_PUBLISHED_GRAPH TO <graphuser>
      ```

   b. Publish the graph when you are ready to visualize the graph using the publish API.

> **Note:**
>
> - See User Authentication and Authorization for more information on authorization rules for Graph Server (PGX) and Client 21.1.
> - See Upgrading From Graph Server and Client 20.4.x to 21.x for more information if you are migrating to Graph Server (PGX) and Client 23.1 from an earlier version.

12.2.3.6 Token Expiration

By default, tokens are valid for 1 hour.

Internally, the graph client automatically renews tokens which are about to expire in less than 30 minutes. This is also configurable by re-authenticating your credentials with the database. By default, tokens can only be automatically renewed for up to 24 times, then you need to login again.

If the maximum amount of auto-renewals is reached, you can log in again without losing any of your session data by using the `GraphServer#reauthenticate (instance, "<user>", "<password>")` API.

> **Note:**
>
> If a session time out occurs before you re-authenticate, then you may lose your session data.

For example:

```
opg4j> var graph = session.readGraphWithProperties(config) // fails because
token cannot be renewed anymore
opg4j> GraphServer.reauthenticate(instance, "<user>",
"<password>".toCharArray()) // log in again
opg4j> var graph = session.readGraphWithProperties(config) // works now
```

12.2.3.7 Advanced Access Configuration

You can customize the following fields inside the `pgx_realm` block in the `pgx.conf` file to customize login behavior.

Table 12-4 Advanced Access Configuration Options

Field Name	Description	Default
`token_expiration_seconds`	After how many seconds the generated bearer token will expire.	3600 (1 hour)
`refresh_time_before_token_expiry_seconds`	After how many seconds a token is automatically refreshed before it expires. Note that this value must always be less than the `token_expiration_seconds` value.	1800
`connect_timeout_milliseconds`	After how many milliseconds an connection attempt to the specified JDBC URL will time out, resulting in the login attempt being rejected.	10000
`max_pool_size`	Maximum number of JDBC connections allowed per user. If the number is reached, attempts to read from the database will fail for the current user.	64
`max_num_users`	Maximum number of active, signed in users to allow. If this number is reached, the graph server will reject login attempts.	512
`max_num_token_refresh`	Maximum amount of times a token can be automatically refreshed before requiring a login again.	24

> **Note:**
>
> The preceding options work only if the realm implementation is configured to be `oracle.pg.identity.DatabaseRealm`.

12.2.3.8 Customizing Roles and Permissions

You can fully customize the permissions to roles mapping by adding and removing roles and specifying permissions for a role. You can also authorize individual users instead of roles.

This topic includes examples of how to customize the permission mapping.

- Checking Graph Permissions Using API
- Adding and Removing Roles
  You can add new role permission mappings or remove existing mappings by modifying the authorization list.
- Defining Permissions for Individual Users
  In addition to defining permissions for roles, you can define permissions for individual users.
- Defining Permissions to Use Custom Graph Algorithms
  You can define permissions to allow developers to compile custom graph algorithms.

12.2.3.8.1 Checking Graph Permissions Using API

You can view your roles and graph permissions using the following PGX API methods:

Table 12-5 API for Checking Graph Permissions

Class	Method	Description
`ServerInstance`	`getPgxUsername()`	Name of the current user
`ServerInstance`	`getPgxUserRoles()`	Role names of the current user
`ServerInstance`	`getPgxGenericPermissions()`	Non-graph (system) permissions of the current user: • Pgx system permissions • File-location permissions
`PgxGraph`	`getPermission()`	Permission on the graph instance for a current user

You can get all permission-related information using the API in JShell as shown:

- JShell
- Java

JShell

```
/bin/opg4j -b "https://<host>:<port>" -u "<graphuser>"
opg4j> instance
instance ==> ServerInstance[embedded=false,baseUrl=https://
<host>:<port>,serverVersion=null]
opg4j>instance.getPgxUsername()
$2 ==> "ORACLE"
opg4j>instance.getPgxUserRoles()
$3 ==> [GRAPH_DEVELOPER]
opg4j>instance.getPgxGenericPermissions()
$4 ==> [PGX_SESSION_CREATE, PGX_SESSION_READ_MODEL,
PGX_SESSION_ADD_PUBLISHED_GRAPH, PGX_SESSION_NEW_GRAPH,
PGX_SESSION_GET_PUBLISHED_GRAPH, PGX_SESSION_MODIFY_MODEL]
opg4jvar g = session.readGraphWithProperties("bank_graph_analytics.json")
g ==> PgxGraph[name=bank_graph_analytics,N=1000,E=5001,created=1625697341555]
opg4j>g.getPermission() // To get graph permissions
$9 ==> MANAGE
```

Java

```
import oracle.pg.rdbms.*;
import java.sql.Connection;
import java.sql.Statement;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;
import oracle.pgx.api.*;
import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;
import java.nio.file.Files;
import java.nio.file.Path;

/**
 * This example shows how to get all permissions.
 */
public class GetPermissions
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgxPreparedStatement stmt = null;

    try {

      // Get a jdbc connection
```

```
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();

pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +"/"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();
      conn.setAutoCommit(false);

      ServerInstance instance = GraphServer.getInstance("http://
localhost:7007", user, password.toCharArray());
      PgxSession session = instance.createSession("my-session");

      var statement = Files.readString(Path.of("/media/sf_Linux/Java/
create-pg.pgql"));
      stmt = session.preparePgql(statement);
      stmt.execute();

      PgxGraph g = session.getGraph(graph);
      System.out.println("Graph: "+ g);

      String userName = instance.getPgxUsername();
      var userRoles = instance.getPgxUserRoles();
      var genericPermissions = instance.getPgxGenericPermissions();
      String graphPermission = g.getPermission().toString();

      System.out.println("Username is " + userName);
      System.out.println("User Roles are " + userRoles);
      System.out.println("Generic permissions are " +
genericPermissions);
      System.out.println("Graph permission is " + graphPermission);

    }

    finally {
      // close the sql statment
      if (stmt != null) {
        stmt.close();
      }
      // close the connection
      if (conn != null) {
        conn.close();
      }
    }
  }
}
```

On execution, the code gives the following output:

```
Graph: PgxGraph[name=BANK_GRAPH_PG,N=1000,E=5001,created=1625731370402]
Username is ORACLE
User Roles are [GRAPH_DEVELOPER]
Generic permissions are [PGX_SESSION_MODIFY_MODEL, PGX_SESSION_CREATE,
PGX_SESSION_NEW_GRAPH, PGX_SESSION_READ_MODEL,
```

```
PGX_SESSION_ADD_PUBLISHED_GRAPH, PGX_SESSION_GET_PUBLISHED_GRAPH]
Graph permission is MANAGE
```

12.2.3.8.2 Adding and Removing Roles

You can add new role permission mappings or remove existing mappings by modifying the authorization list.

For example:

```
CREATE ROLE MY_CUSTOM_ROLE_1
GRANT PGX_SESSION_CREATE TO MY_CUSTOM_ROLE1
GRANT PGX_SERVER_GET_INFO TO MY_CUSTOM_ROLE1
GRANT MY_CUSTOM_ROLE1 TO SCOTT
```

12.2.3.8.3 Defining Permissions for Individual Users

In addition to defining permissions for roles, you can define permissions for individual users.

For example:

```
GRANT PGX_SESSION_CREATE TO SCOTT
GRANT PGX_SERVER_GET_INFO TO SCOTT
```

12.2.3.8.4 Defining Permissions to Use Custom Graph Algorithms

You can define permissions to allow developers to compile custom graph algorithms.

For example,

- Add the following static permission to the list of permissions:

  ```
  GRANT PGX_SESSION_COMPILE_ALGORITHM TO GRAPH_DEVELOPER
  ```

12.2.3.9 Revoking Access to the Graph Server

To revoke a user's ability to access the graph server, either drop the user from the database or revoke the corresponding roles from the user, depending on how you defined the access rules in your pgx.conf file.

For example:

```
REVOKE graph_developer FROM scott
```

Revoking Graph Permissions

If you have the MANAGE permission on a graph, you can revoke graph access from users or roles using the `PgxGraph#revokePermission` API. For example:

```
PgxGraph g = ...
g.revokePermission(new PgxRole("GRAPH_DEVELOPER")) // revokes
previously granted role access
g.revokePermission(new PgxUser("SCOTT")) // revokes previously granted
user access
```

12.2.3.10 Examples of Custom Authorization Rules

You can define custom authorization rules for developers.

- Example 12-1
- Example 12-2
- Example 12-3
- Example 12-4

Example 12-1 Allowing Developers to Publish Graphs

Sharing of graphs with other users should be done in Oracle Database where possible. Use GRANT statements on the database tables so that other users can create graphs from the tables.

In the graph server (PGX) you can use the following permissions to share a graph that is already in memory, with other users connected to the graph server.

Table 12-6 Allowed Permissions

Permission	Actions Enabled by this Permission
`READ`	• READ the graph via the PGX API or in PGQL queries in PGX, create a subgraph, or clone the graph
`MANAGE`	• Publish the graph or snapshot • Includes READ and EXPORT • Grant or revoke READ and EXPORT permissions on the graph
`EXPORT`	• Export the graph to a file. • Includes READ permission.

The creator of the graph automatically gets the MANAGE permission granted on the graph. If you have the MANAGE permission, you can grant other roles or users READ or EXPORT permission on the graph. You **cannot** grant MANAGE on a graph. The following example of a user named userA shows how:

```
import oracle.pgx.api.*
import oracle.pgx.common.auth.*
```

```
PgxSession session = GraphServer.getInstance("<base-url>", "<userA>",
"<password-of-userA").createSession("userA")
PgxGraph g = session.readGraphWithProperties("examples/sample-graph.json",
"sample-graph")
g.grantPermission(new PgxRole("GRAPH_DEVELOPER"), PgxResourcePermission.READ)
g.publish()
```

Now other users with the GRAPH_DEVELOPER role can access this graph and have READ access on it, as shown in the following example of userB:

```
PgxSession session = GraphServer.getInstance("<base-url>", "<userB>",
"<password-of-userB").createSession("userB")
PgxGraph g = session.getGraph("sample-graph")
g.queryPgql("select count(*) from match (v)").print().close()
```

Similarly, graphs can be shared with individual users instead of roles, as shown in the following example:

```
g.grantPermission(new PgxUser("OTHER_USER"), PgxResourcePermission.EXPORT)
```

where OTHER_USER is the user name of the user that will receive the EXPORT permission on graph `g`.

Example 12-2   Allowing Developers to Access Preloaded Graphs

To allow developers to access preloaded graphs (graphs loaded during graph server startup), grant the read permission on the preloaded graph in the pgx.conf file. For example:

```
"preload_graphs": [{
  "path": "/data/my-graph.json",
  "name": "global_graph"
}],
"authorization": [{
  "pgx_role": "GRAPH_DEVELOPER",
  "pgx_permissions": [{
    "preloaded_graph": "global_graph"
    "grant": "read"
  },
...
```

You can grant READ, EXPORT, or MANAGE permission.

Example 12-3   Allowing Developers Access to the Hadoop Distributed Filesystem (HDFS) or the Local File System

To allow developers to read files from HDFS, you must first declare the HDFS directory and then map it to a read or write permission. For example:

```
CREATE OR REPLACE DIRECTORY pgx_file_location AS 'hdfs:/data/graphs'
GRANT READ ON DIRECTORY pgx_file_location TO GRAPH_DEVELOPER
```

Similarly, you can add another permission with `GRANT WRITE` to allow write access. Such a write access is required in order to export graphs.

Access to the local file system (where the graph server runs) can be granted the same way. The only difference is that location would be an absolute file path without the `hdfs:` prefix. For example:

```
CREATE OR REPLACE DIRECTORY pgx_file_location AS '/opt/oracle/graph/
data'
```

Note that in addition to the preceding configuration, the operating system user that runs the graph server process must have the corresponding directory privileges to actually read or write into those directories.

Example 12-4 Allowing Access to Directories on Autonomous Database

To allow developers to read and write from files in Oracle Autonomous Database, you must perform the following steps:

1. Connect to your Autonomous Database instance as an ADMIN user using any of the SQL based Oracle Database tools or using Database Actions, the built-in web-based interface.

   > **See Also:**
   >
   > - Connect to Autonomous Database Using Oracle Database Tools
   > - Connect with Built-in Oracle Database Actions

2. Create the directory by specifying the path to the directory using the **`graph:`** prefix as shown:

   ```
   CREATE OR REPLACE DIRECTORY pgx_file_location AS 'graph:/opt/oracle/
   graph/data'
   ```

3. Grant read or write permissions to the directory for the desired role. For example:

   ```
   GRANT READ ON DIRECTORY pgx_file_location TO GRAPH_DEVELOPER
   ```

12.2.3.11 Kerberos Enabled Authentication for the Graph Server (PGX)

The graph server (PGX) can authenticate users using an Oracle Database with Kerberos enabled as identity provider.

You can log into the graph server using a Kerberos ticket and the actions which you are allowed to do on the graph server are determined by the roles that have been granted to you in the Oracle Database.

- Prerequisite Requirements
- Prepare the Graph Server for Kerberos Authentication
- Login to the Graph Server Using Kerberos Ticket

See Also:

Kerberos Enabled Authentication for the Graph Visualization Application

12.2.3.11.1 Prerequisite Requirements

In order to enable Kerberos authentication on the graph server (PGX), the following system requirements must be met:

- The database needs to have Kerberos authentication enabled. See Configuring Kerberos Authentication for more information.
- Both the database and the Kerberos Authentication Server need to be reachable from the host where the graph server runs.
- The database is prepared for graph server authentication. That is, relevant graph roles have been granted to users who will log into the graph server.

12.2.3.11.2 Prepare the Graph Server for Kerberos Authentication

The following are the steps to enable Kerberos authentication on the graph server (PGX):

1. Locate the `pgx.conf` file of your installation.

   Note:

   If you installed the graph server via RPM, the file is located at: `/etc/oracle/graph/pgx.conf`

2. Locate the `krb5_conf_file` line of the realm options, inside the `pgx.conf` file:

```
"pgx_realm": {
  "implementation": "oracle.pg.identity.DatabaseRealm",
  "options": {
    ...
    "krb5_conf_file": "<REPLACE-WITH-KRB5-CONF-FILE-PATH-TO-ENABLE-
KERBEROS-AUTHENTICATION>",
    "krb5_ticket_cache_dir": "/dev/shm",
    "krb5_max_cache_size": 1024
  }
},
```

3. Replace the text with the `krb5.conf` file that you are using for the database and user authentication. For example:

```
"pgx_realm": {
  "implementation": "oracle.pg.identity.DatabaseRealm",
  "options": {
    ...
    "krb5_conf_file": "/etc/krb5.conf",
    "krb5_ticket_cache_dir": "/dev/shm",
    "krb5_max_cache_size": 1024
```

```
    }
  },
```

> **Note:**
>
> The file provided for the `krb5_conf_file` option needs to be valid and readable by the graph server. In case you don't replace the `krb5_conf_file` value or the value is empty, then the graph server will not use Kerberos authentication.

Also, you can set the cache directory that will be used for the graph server to temporarily store Kerberos tickets given by clients as well as the maximum cache size after which new login attempts will be rejected. The cache size represents the maximum amount of concurrent Kerberos sessions active on the graph server.

12.2.3.11.3 Login to the Graph Server Using Kerberos Ticket

The following are the steps to login to the graph server (PGX) using Kerberos ticket:

1. Create a new Kerberos ticket using the `okinit` command:

   ```
   $ okinit <username>
   ```

   This will prompt for your password and then create a new Kerberos ticket.
2. Connect to a remote graph server with only the base URL parameter using JShell:

   ```
   $ opg4j -b https://localhost:7007
   ```

   Or using Python client:

   ```
   $ opg4py -b https://localhost:7007
   ```

   On Linux, JShell and Python interactive client shells automatically detect the Kerberos ticket on your local file system and use that to authenticate with the graph server.
3. In case the auto-detection is not working, you can also explicitly pass in the ticket to the shell. Run the `oklist` command, to find the location of the ticket on the local file system.

   ```
   $ oklist

   Kerberos Utilities for Linux: Version 19.0.0.0.0 - Production on 31-
   MAR-2021 15:26:46

   Copyright (c) 1996, 2019 Oracle.  All rights reserved.

   Configuration file : /etc/krb5.conf.
   Ticket cache: FILE:/tmp/krb5cc_54321
   Default principal: oracle@realm
   ```

4. Specify your Kerberos ticket path using the `--kerberos_ticket` parameter. For example, using JShell:

```
$ opg4j -b https://localhost:7007 --kerberos_ticket /tmp/krb5cc_54321
```

Or using Python Client:

```
$ opg4py -b https://localhost:7007 --kerberos_ticket /tmp/krb5cc_54321
```

If you are using a Java client program (or JShell on embedded mode), you can get a server instance using the following API:

```
...
ServerInstance instance = GraphServer.getInstance("https://
localhost:7007", "/tmp/krb5cc_54321");
PgxSession session = instance.createSession("my-session");
...
```

If you are using a Python Client program (or opg4py on embedded mode), you can get a server instance using the following API

```
...
instance = graph_server.get_instance("https://localhost:7007", "/tmp/
krb5cc_54321")
session = instance.create_session("my-session")
...
```

If you are connecting to a remote graph server, all you need is the Oracle Graph Client to be installed. For example:

```
import sys
import pypgx as pgx

sys.path.append("/path/to/graph/client/oracle-graph-client-21.2.0/python/
pypgx/pg/rdbms")

import graph_server

base_url = "https://localhost:7007"
kerberos_ticket = "/tmp/krb5cc_54321"

instance = graph_server.get_instance(base_url, kerberos_ticket)
print(instance)
```

12.3 Oracle Graph Client Installation

You can interact with the various graph features using the client CLIs and the graph visualization web client.

The following sections explain the steps to install the various clients:

- Graph Clients
  The Oracle Graph client installation supports a Java and a Python client.
- Graph Visualization Web Client
  You can run the Graph Visualization web application in a standalone mode or it can be deployed to a web container.

Related Topics

- Getting Started with the Client Tools
  You can use multiple client tools to interact with the graph server (PGX) or directly with the graph data in the database.

12.3.1 Graph Clients

The Oracle Graph client installation supports a Java and a Python client.

The following sections explain the steps to install the clients:

- Oracle Graph Java Client
  You can install the Java client from the `oracle-graph-client-23.1.0.zip` file that is shipped with Oracle Graph Server and Client or you can use the Java client on Maven Central.
- Oracle Graph Python Client
  You can install the Python client by downloading the `oracle-graph-client-23.1.0.zip` file that is shipped with Oracle Graph Server and Client or from PyPI.

12.3.1.1 Oracle Graph Java Client

You can install the Java client from the `oracle-graph-client-23.1.0.zip` file that is shipped with Oracle Graph Server and Client or you can use the Java client on Maven Central.

- Installing the Java Client From the Graph Server and Client Downloads
  You can download the zip file for Oracle Graph Client 23.1.0 and install the Java client.
- Using Oracle Graph Java Client on Maven Central
  You can obtain the property graph Java client from Maven Central.

12.3.1.1.1 Installing the Java Client From the Graph Server and Client Downloads

You can download the zip file for Oracle Graph Client 23.1.0 and install the Java client.

The prerequisites for installing the Java client are:

- A Unix-based operation system (such as Linux) or macOS or Microsoft Windows
- Oracle JDK 11 or JDK 17

> **Note:**
>
> Due to a bug in Open JDK, which causes a deadlock when you attempt to copy and paste into a JShell session, it is recommended that you avoid the following Oracle JDK versions:
>
> - JDK 11.0.9
> - JDK 11.0.10
> - JDK 11.0.11
> - JDK 11.0.12

1. Download the Oracle Graph Client from Oracle Software Cloud.

   For example, `oracle-graph-client-23.1.0.zip`.
2. Unzip the file into a directory of your choice.
3. Configure your client to trust the self-signed keystore. See Configuring a Client to Trust the Self-Signed Keystore for more information.
4. Start the OPG4J shell to connect to the graph server (PGX) as shown:

```
cd <CLIENT_INSTALL_DIR>
./bin/opg4j --base_url https://<host>:7007 --username <graphuser>
```

   In the preceding code:

   - **`<CLIENT_INSTALL_DIR>`:** Directory where the shell executables are located. The shell executables are generally found in `/opt/oracle/graph/bin` after server installation, and `<CLIENT_INSTALL_DIR>/bin` after the client installation.
   - **`<host>`:** Server host

     > **Note:**
     >
     > The graph server (PGX), listens on port `7007` by default. If needed, you can configure the graph server to listen on a different port by changing the port value in the server configuration file (`server.conf`). See Configuring the Graph Server (PGX) for details.

   - **`<graphuser>`:** Database user

   You will be prompted for the database password.

   See Starting the OPG4J Shell for more information on the different ways you can start the OPG4J shell.

   The OPG4J shell starts and the following command line prompt appears as shown:

```
For an introduction type: /help intro
Oracle Graph Server Shell 23.1.0
Variables instance, session, and analyst ready to use.
opg4j>
```

> **See Also:**
>
> Java API Reference for more information on the Java APIs

12.3.1.1.2 Using Oracle Graph Java Client on Maven Central

You can obtain the property graph Java client from Maven Central.

The Maven artifact for the graph Java client is described as follows:

- **Group Name:** com.oracle.database.graph
- **Artifact Name:** opg-client
- **Version:** 23.1.0

You can perform the following steps to use the graph Java client from Maven Central:

1. Download and Install Apache Maven on your system.

   See Apache Maven Project for more information.
2. Add the bin folder with the **mvn** command to the `PATH` variable.
3. Build your Maven project and navigate to the project directory.
4. Edit the `pom.xml` file on the following:
   a. Add the graph Java client dependency as shown:

```
<dependencies>
    <dependency>
      <groupId>com.oracle.database.graph</groupId>
      <artifactId>opg-client</artifactId>
      <version>23.1.0</version>
    </dependency>
</dependencies>
```

> **Note:**
>
> If you use Gradle as a build tool, then the equivalent dependency declaration for the Java client is:
>
> ```
> implementation group: 'com.oracle.database.graph', name:
> 'opg-client', version: '23.1.0'
> ```

   b. Add the following repository as the Java client depends on the Spoofax Language Workbench Library to compile PGQL queries:

```
<repositories>
    <repository>
      <id>spoofax</id>
      <url>https://artifacts.metaborg.org/content/repositories/
releases</url>
    </repository>
</repositories>
```

5. Optionally, you can skip step 4 and copy the following minimal POM configuration in *<project_dir>*/pom.xml file:

```
<project xmlns="http://maven.apache.org/POM/4.0.0" xmlns:xsi="http://
www.w3.org/2001/XMLSchema-instance"
         xsi:schemaLocation="http://maven.apache.org/POM/4.0.0 http://
maven.apache.org/maven-v4_0_0.xsd">
  <modelVersion>4.0.0</modelVersion>
  <groupId>com.mycompany.app</groupId>
  <artifactId>my-app</artifactId>
  <packaging>jar</packaging>
  <version>1.0-SNAPSHOT</version>
  <name>my-app</name>
  <repositories>
    <repository>
      <id>spoofax</id>
      <url>https://artifacts.metaborg.org/content/repositories/releases</
url>
    </repository>
  </repositories>
  <dependencies>
    <dependency>
      <groupId>com.oracle.database.graph</groupId>
      <artifactId>opg-client</artifactId>
      <version>23.1.0</version>
    </dependency>
  </dependencies>
</project>
```

6. Build your Java code in *<project_dir>*/src/main/java/com/mycompany/app and compile with Maven.

   For example, the following code is stored in a file *<project_dir>*/src/main/java/com/mycompany/app/App1.java:

```
package com.mycompany.app;

import java.sql.DriverManager;
import java.sql.Connection;
import java.sql.Statement;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pgx.api.*;
import oracle.pg.rdbms.GraphServer;
import oracle.pg.rdbms.pgql.jdbc.PgqlJdbcRdbmsDriver;

public class App1 {

  public static void main(String[] args) throws Exception {
    String dbConnectString = args[0];
    String username = args[1];
    String password = args[2];

    // Obtain a JDBC database connection
```

```
    DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
    String jdbcUrl = "jdbc:oracle:pgql:@" + dbConnectString;
    System.out.println("connecting to " + jdbcUrl);

    try (Connection conn = DriverManager.getConnection(jdbcUrl,
username, password)) {
      conn.setAutoCommit(false);

      // Create PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);

      // Create a PGQL statement to execute PGQL queries
      PgqlStatement pgqlStmt = pgqlConn.createStatement();

      // Create a property graph view using the CREATE PROPERTY
GRAPH statement
      String pgViewName = "BANK_GRAPH_VIEW";
      String createPgViewQuery =
          "CREATE PROPERTY GRAPH " + pgViewName + " " +
          "VERTEX TABLES ( BANK_ACCOUNTS AS ACCOUNTS " +
          "KEY (ID) " +
          "LABEL ACCOUNTS " +
          "PROPERTIES (ID, NAME)" +
          ") " +
          "EDGE TABLES ( BANK_TXNS AS TRANSFERS " +
          "KEY (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT) " +
          "SOURCE KEY (FROM_ACCT_ID) REFERENCES ACCOUNTS (ID) " +
          "DESTINATION KEY (TO_ACCT_ID) REFERENCES ACCOUNTS (ID) " +
          "LABEL TRANSFERS " +
          "PROPERTIES (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT,
DESCRIPTION)" +
          ") OPTIONS(PG_VIEW)";

      pgqlStmt.execute(createPgViewQuery);

      // Execute a query to retrieve the first 10 elements of the
graph
      String pgqlQuery =
          "SELECT e.from_acct_id, e.to_acct_id, e.amount FROM " +
          "MATCH (n:ACCOUNTS) -[e:TRANSFERS]-> (m:ACCOUNTS) ON " +
          pgViewName + " LIMIT 10";

      PgqlResultSet rs = pgqlStmt.executeQuery(pgqlQuery);
      rs.print();

      // Drop the property graph view using the DROP PROPERTY GRAPH
statement
      String dropPgViewQuery = "DROP PROPERTY GRAPH " + pgViewName;
      pgqlStmt.execute(dropPgViewQuery);
    }
    System.exit(0);
  }
}
```

You can then compile and run the preceding code by navigating to your project directory and running the following command:

```
mvn compile exec:java -Dexec.mainClass="com.mycompany.app.App1"-
Dexec.arguments='<db-connect-string>,<username>,<password>'
```

On successful processing, the code may produce an output similar to the following. Note, your output may be different depending on your *<db-connect-string>*.

```
[INFO] --- exec-maven-plugin:3.1.0:java (default-cli) @ my-app ---
connecting to jdbc:oracle:pgql:@myhost:1521/oradb
name = Baz
```

12.3.1.2 Oracle Graph Python Client

You can install the Python client by downloading the `oracle-graph-client-23.1.0.zip` file that is shipped with Oracle Graph Server and Client or from PyPI.

Alternatively, you can also install the python client in embedded mode.

- Prerequisites for Installing the Python Client
- Installing the Python Client From the Graph Server and Client Downloads
  You can download the zip file for `oracle-graph-client-23.1.0` from the Graph Server and Client downloads and install the Python client.
- Installing the Python Client from PyPI
  Starting from Oracle Graph Server and Client Release 23.1, you can install the Python client from PyPI.
- Installing the Python Client in Embedded Mode
  You can install and work with the Python client in embedded mode.
- Uninstalling the Python Client
  This section describes how to uninstall the Python client.

12.3.1.2.1 Prerequisites for Installing the Python Client

You must ensure that the following prerequisites are met before you install the Python client:

1. Make sure that the following software is installed in your system:
   - Oracle JDK 8 or later
   - Python 3.6 or later
     However, if you want to use Pandas related functionality, you must install Python 3.8 or Python 3.9. This is because the `pandas` package is only shipped for these Python versions.

     To verify you are using the right version of the Python client, run the following command:

     ```
     $> python3 --version
     Python 3.6.1
     ```

> **Note:**
>
> Python 2.x is not supported.
> For more information on installing Python 3 on Oracle Linux, see Python for Oracle Linux.

2. Ensure that `python3-devel` is installed in your system.

```
sudo yum install python3-devel
```

12.3.1.2.2 Installing the Python Client From the Graph Server and Client Downloads

You can download the zip file for `oracle-graph-client-23.1.0` from the Graph Server and Client downloads and install the Python client.

Prior to installing the Python client, ensure that your system meets all the required prerequisites.

You can perform the following steps to install and connect using the Python client:

1. Download the Oracle Graph Client from Oracle Software Cloud.

   For example, `oracle-graph-client-23.1.0.zip`.

2. Install the client through `pip`.

   For example,

   ```
   pip3 install --user oracle-graph-client-23.1.0.zip
   ```

3. Configure your client to trust the self-signed keystore. See Configuring a Client to Trust the Self-Signed Keystore for more information.

4. Start the OPG4Py shell to connect to the graph server(PGX) by running the following command:

   ```
   cd <CLIENT_INSTALL_DIR>
   ./bin/opg4py --base_url https://<host>:7007
   ```

   In the preceding code:

   - **`<CLIENT_INSTALL_DIR>`:** Directory where the shell executables are located. The shell executables are found in `<CLIENT_INSTALL_DIR>/bin` after the client installation.
   - **`<host>`:** Server host

   > **Note:**
   >
   > The graph server (PGX), listens on port `7007` by default. If needed, you can configure the graph server to listen on a different port by changing the port value in the server configuration file (`server.conf`). See Configuring the Graph Server (PGX) for details.

   You are prompted to enter your username and password.

See Starting the OPG4Py Shell for more information on the different ways you can start the OPG4Py shell.

The OPG4Py shell starts and the following command line prompt appears as shown:

```
Oracle Graph Server Shell 23.1.0
>>>
```

> **Note:**
>
> You can also install the python client library in Jupyter Notebook. Using the Python API, you can then connect to the graph server (PGX) to run PGQL queries and graph algorithms in a Jupyter Notebook environment. See Using the Jupyter Notebook Interface for more details.

> **See Also:**
>
> Python API Reference for more information on the Python APIs

12.3.1.2.3 Installing the Python Client from PyPI

Starting from Oracle Graph Server and Client Release 23.1, you can install the Python client from PyPI.

You can install the `oracle-graph-client-23.1.0.zip` package from the PyPI repository using `pip`.

Before installing the Python client from PyPI, your system must meet the prerequsites mentioned in Prerequisites for Installing the Python Client. In addition:

- Ensure that you set the `JAVA_HOME` environment variable.
- If you are behind a proxy, then set the `https_proxy` environment variable to the proxy server.

You can install and verify the Python client installation as shown:

1. Install the client through `pip`.

   For example,

   ```
   pip install --user oracle-graph-client
   ```

   This installs the Python client along with all the required dependencies.

2. Verify that your installation is successful.

   ```
   $ python3
   Python 3.8.12 (default, Apr  5 2022, 08:07:47)
   [GCC 8.5.0 20210514 (Red Hat 8.5.0-10.0.1)] on linux
   Type "help", "copyright", "credits" or "license" for more information.
   >>> import opg4py
   >>> import pypgx
   ```

> **See Also:**
>
> Python API Reference for more information on the Python APIs

12.3.1.2.4 Installing the Python Client in Embedded Mode

You can install and work with the Python client in embedded mode.

To install the embedded Python client:

1. Run the following `pip` command:

   ```
   pip3 install --user /opt/oracle/graph/client/
   ```

2. Start the OPG4Py shell in embedded mode as shown:

   ```
   cd /opt/oracle/graph
   ./bin/opg4py
   ```

   Note that the shell executables are found in `/opt/oracle/graph/bin` after the server installation.

   The OPG4Py shell starts and the following command line prompt appears as shown:

   ```
   Oracle Graph Server Shell 23.1.0
   >>> instance
   ServerInstance(embedded: True, version: 23.1.1)
   >>>
   ```

12.3.1.2.5 Uninstalling the Python Client

This section describes how to uninstall the Python client.

To uninstall the Python client, run the following command:

```
pip3 uninstall pypgx
```

12.3.2 Graph Visualization Web Client

You can run the Graph Visualization web application in a standalone mode or it can be deployed to a web container.

- Running the Graph Visualization Application in Standalone Mode
  If you install the graph server `rpm` file, the Graph Visualization application starts up by default when you start the PGX server.
- Deploying the Graph Visualization Application
  You must download the `oracle-graph-webapps-<version>.zip` package and deploy the web application archive (`WAR`) file into your Oracle Weblogic 12.2 (or later) or Apache Tomcat (9.x or later) web containers.

- Configuring Advanced Options for PGQL Driver Selection
  The Graph Visualization application can be configured to communicate either with the graph server (PGX) or to the Oracle Database.

12.3.2.1 Running the Graph Visualization Application in Standalone Mode

If you install the graph server `rpm` file, the Graph Visualization application starts up by default when you start the PGX server.

The Graph Visualization application requires Oracle Graph Server to be installed as a prerequisite component.
See Installing Oracle Graph Server for more information.

To start the Graph Visualization application in standalone mode:

1. Start the graph server (PGX) as shown:

   ```
   sudo systemctl start pgx
   ```

   The Graph Visualization application starts up by default.
2. Configure your Graph Visualization application to trust the self-signed keystore. See Configuring a Client to Trust the Self-Signed Keystore for more information.
3. Connect to your browser for running the Graph Visualization application as shown

   ```
   https://localhost:7007/ui
   ```

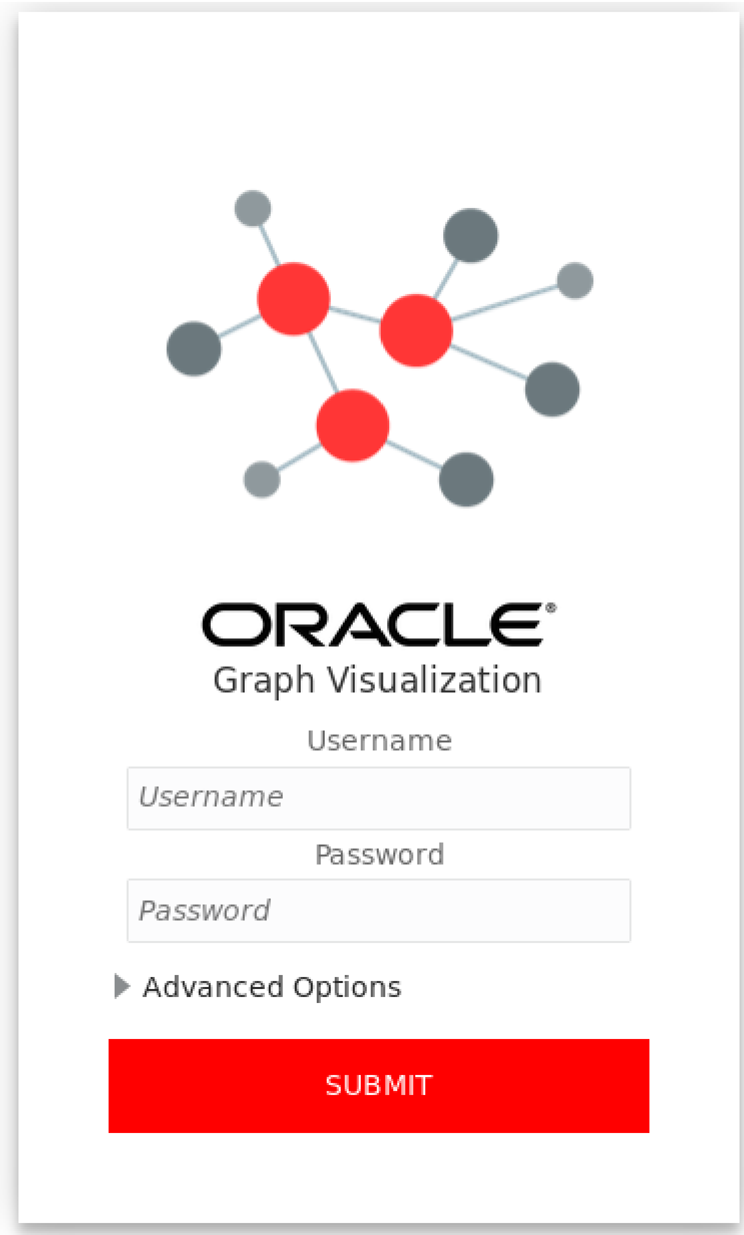
   One of the following messages may appear:

   - `Your connection is not private`
   - `Your connection is not secure`

   Click the Continue or Accept button to proceed.

   The Graph Visualization Login screen opens as shown:

Figure 12-1 Graph Visualization Login



4. Enter your database **Username** and **Password**.
5. Select and configure the required PGQL Driver.

   See Configuring Advanced Options for PGQL Driver Selection for more information.
6. Click **Submit**.

   You are now signed into the Graph Visualization application.

   The title bar on the query visualization page displays the connection mode along with the relevant URL.

12.3.2.2 Deploying the Graph Visualization Application

You must download the `oracle-graph-webapps-<version>.zip` package and deploy the web application archive (`WAR`) file into your Oracle Weblogic 12.2 (or later) or Apache Tomcat (9.x or later) web containers.

- Deploying the Graph Visualization Application to Apache Tomcat
- Deploying the Graph Visualization Application in Oracle WebLogic Server
  The following instructions are for deploying the Graph Visualization application in Oracle WebLogic Server 12.2.1.3. You might need to make slight modifications, as appropriate, for different versions of the Weblogic Server.

12.3.2.2.1 Deploying the Graph Visualization Application to Apache Tomcat

The following are the steps to deploy the Graph Visualization application to Apache Tomcat.

1. Download the Oracle Graph Webapps zip file from Oracle Software Delivery Cloud. This file contains ready-to-deploy Java web application archives (.war files). The file name will be similar to this: `oracle-graph-webapps-<version>.zip`.
2. Configure Tomcat specific settings, like the correct use of TLS/encryption.
3. Ensure that port 8080 is not already in use.
4. Start Tomcat:

   ```
   cd $CATALINA_HOME
   ./bin/startup.sh
   ```

   The Graph Visualization application is now listening on `localhost:8080/ui`
5. Navigate to the Graph Visualization Application using the URL, `localhost:8080/ui` in your browser.

   The Graph Visualization login page appears as shown in Figure 12-1.
6. Enter your database credentials and configure the required PGQL driver.

   See Configuring Advanced Options for PGQL Driver Selection for more information.
7. Click Submit.

   You are now signed into the Graph Visualization application.
   The title bar on the query visualization page displays the connection mode along with the relevant URL.

12.3.2.2.2 Deploying the Graph Visualization Application in Oracle WebLogic Server

The following instructions are for deploying the Graph Visualization application in Oracle WebLogic Server 12.2.1.3. You might need to make slight modifications, as appropriate, for different versions of the Weblogic Server.

1. Download the Oracle Graph Webapps zip file from Oracle Software Delivery Cloud. This file contains ready-to-deploy Java web application archives (.war files). The file name will be similar to this: `oracle-graph-webapps-<version>.zip`

2. Start WebLogic Server.

```
# Start Server
cd $MW_HOME/user_projects/domains/base_domain
./bin/startWebLogic.sh
```

3. Enable tunneling.
In order to be able to deploy the Graph Visualization application WAR file over HTTP, you must enable tunneling first. Go to the WebLogic admin console (by default on http://localhost:7001/console). Select **Environment** (left panel) > **Servers** (left panel). Click the server that will run Graph Visualization (main panel). Select (top tab bar), check **Enable Tunneling**, and click **Save**.

4. Deploy the graphviz-<version>-pgviz<graphviz-version>-wls.war file.
To deploy the WAR file to WebLogic Server, use the following command, replacing the <<...>> markers with values matching your installation:

```
cd $MW_HOME/user_projects/domains/base_domain
source bin/setDomainEnv.sh
java weblogic.Deployer -adminurl <<admin-console-url>> -username
<<admin-user>> -password <<admin-password>> -deploy -upload <<path/
to>>/graphviz-<<version>>-pgviz<<graphviz-version>>.war
```

To undeploy, you can use the following command:

```
java weblogic.Deployer -adminurl <<admin-console-url>> -username
<<admin-user>> -password <<admin-password>> -name <<path/to>>/
graphviz-<<version>>-pgviz<<graphviz-version>>.war -undeploy
```

To test the deployment, navigate using your browser to: https://<<fqdn-ip>>:<<port>>/ui.

The Graph Visualization Login screen appears as shown in Figure 12-1.

5. Enter your database credentials and configure the required PGQL driver.
See Configuring Advanced Options for PGQL Driver Selection for more information.

6. Click Submit.
You are now logged in and the Graph Visualization query user interface (UI) appears and the graphs from PGX are retrieved.

   The title bar on the query visualization page displays the connection mode along with the relevant URL.

12.3.2.3 Configuring Advanced Options for PGQL Driver Selection

The Graph Visualization application can be configured to communicate either with the graph server (PGX) or to the Oracle Database.

You can apply the required configuration at the time of login through the **Advanced Options** settings in the Graph Visualization login page.

You can dynamically change and configure the PGQL driver by following the instructions as appropriate for your preference:

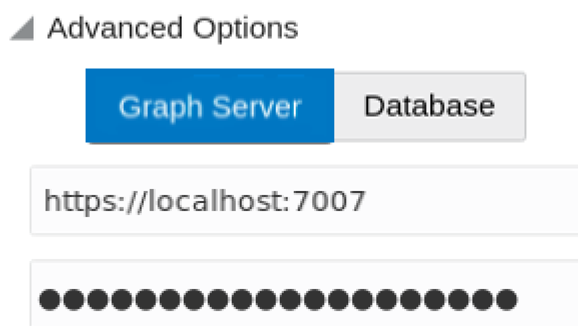
- Configuring the Graph Visualization Application for PGQL on Graph Server (PGX)
- Configuring the Graph Visualization Application for PGQL on Database

12.3.2.3.1 Configuring the Graph Visualization Application for PGQL on Graph Server (PGX)

To configure Graph Visualization application to communicate with a PGX deployment (PGQL on Graph Server):

1. Click **Advanced Options** in the Graph Visualization login page.
2. Select **Graph Server** as shown:

   Figure 12-2   PGQL on Graph Server (PGX)

3. Optionally, modify your **PGX Base URL**.

   > **Note:**
   >
   > - By default, the Graph Visualization application connects to the graph server (PGX) using the PGX base URL defined in the `web.xml` file for your installation.
   > - If you wish to disable transport layer security (TLS) in graph server, see Disabling Transport Layer Security (TLS) in Graph Server for more details.

4. Optionally, enter **Session Id**.

   When the Graph Visualization application is using PGQL on Graph Server (PGX), the application will use your Oracle Database as identity manager by default. This means that you log into the application using existing Oracle Database credentials (username and password), and the actions which you are allowed to do on the graph server are determined by the roles that have been granted to you in the Oracle Database.

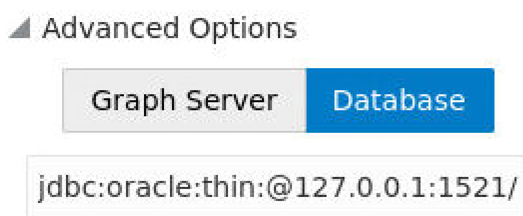
   > **Note:**
   >
   > If you wish to enable Kerberos Authentication for the Graph Visualization Application, see Kerberos Enabled Authentication for the Graph Visualization Application for more information.

12.3.2.3.2 Configuring the Graph Visualization Application for PGQL on Database

To configure the Graph Visualization application to communicate with Oracle Database (PGQL on Database):

1. Click **Advanced Options** in the Graph Visualization login page.
2. Select **Database** as shown:

Figure 12-3 PGQL on Database



3. Optionally, modify the **JDBC URL** for your Oracle database.

> **Note:**
>
> - By default, the Graph Visualization application connects to the database using the JDBC URL defined in the `web.xml` file for your installation.
> - If you wish to enable Kerberos Authentication for the Graph Visualization Application, see Kerberos Enabled Authentication for the Graph Visualization Application for more information.
> - If you wish to disable transport layer security (TLS) in graph server, see Disabling Transport Layer Security (TLS) in Graph Server for more details.

12.4 Setting Up Transport Layer Security

The graph server (PGX), by default, allows only encrypted connections using Transport Layer Security (TLS). TLS requires the server to present a server certificate to the client and the client must be configured to trust the issuer of that certificate.

In this release of Graph Server and Client, the RPM file installation, will generate a self-signed server keystore file by default. This `server_keystore.jks` file contains the server certificate and server private key and is generated into `/etc/oracle/graph`, for the server to enable TLS. Note that the default password for the generated keystore is `changeit` and this is configured using an environment variable `PGX_SERVER_KEYSTORE_PASSWORD` in `/etc/systemd/system/pgx.service` file as shown:

```
[Service]
Environment="PGX_SERVER_KEYSTORE_PASSWORD=changeit"
```

If this default keystore configuration is sufficient for you to get started and if your connections are only to `localhost`, you can skip to Configuring a Client to Trust the Self-Signed Keystore.

If you prefer to use a self-signed server certificate, then refer to Using a Self-Signed Server Certificate for more information. However, it is important to note that the server configuration fields, `server_cert` and `server_private_key` are deprecated and will be desupported in a future release. After that, you will be required to use the server keystore to store the server certificate and the server private key.

- Using a Self-Signed Server Keystore
  This section describes the steps to generate a self-signed keystore into `/etc/oracle/graph` and configure the graph server (PGX) and client to use the keystore.
- Using a Self-Signed Server Certificate
  This section describes the steps to generate a self-signed certificate into `/etc/oracle/graph` and configure the graph server (PGX) to use this certificate.

12.4.1 Using a Self-Signed Server Keystore

This section describes the steps to generate a self-signed keystore into `/etc/oracle/graph` and configure the graph server (PGX) and client to use the keystore.

- Generating a Self-Signed Server Keystore
  You can create a server key store using the `keytool` command.
- Configuring the Graph Server (PGX) When Using a Server Keystore
  You must specify the path to the server keystore in the graph server (PGX) configuration file.
- Configuring a Client to Trust the Self-Signed Keystore
  You must configure your client application to accept the self-signed keystore.

12.4.1.1 Generating a Self-Signed Server Keystore

You can create a server key store using the `keytool` command.

The following steps show how to create a server keystore with a self-signed certificate:

1. Go to the following directory:

   ```
   cd /etc/oracle/graph
   ```

2. Run the following command:

   ```
   keytool -genkey -alias pgx -keyalg RSA -keystore server_keystore.jks
   ```

3. Provide the requested details. For example:

   ```
   Enter keystore password:
   Re-enter new password:
   What is your first and last name?
     [Unknown]:  localhost
   What is the name of your organizational unit?
     [Unknown]:  OU
   What is the name of your organization?
     [Unknown]:  MyOrganization
   What is the name of your City or Locality?
   ```

```
  [Unknown]:  MyTown
What is the name of your State or Province?
  [Unknown]:  MyState
What is the two-letter country code for this unit?
  [Unknown]:  US
Is CN=localhost, OU=OU, O=MyOrganization, L=MyTown, ST=MyState,
C=US correct?
  [no]:  yes
```

The `server_keystore.jks` is created successfully in `cd /etc/oracle/graph`.

12.4.1.2 Configuring the Graph Server (PGX) When Using a Server Keystore

You must specify the path to the server keystore in the graph server (PGX) configuration file.

> **Note:**
>
> If you deploy the graph server into your web server using the web applications download package, then this section does not apply. Please refer to the manual of your web server for instructions on how to configure TLS.

1. Edit the file at `/etc/oracle/graph/server.conf` to specify server keystore alias, server keystore provider, server keystore type and the path to the server keystore as shown:

```
{
  "port": 7007,
  "enable_tls": true,
  "enable_client_authentication": false,
  "server_keystore": "/etc/oracle/graph/server_keystore.jks",
  "server_keystore_alias": "pgx",
  "server_keystore_type": "PKCS12",
  "server_keystore_provider": "SUN",
  "ca_certs": [],
  "working_dir": "/opt/oracle/graph/pgx/tmp_data"
}
```

2. Set the keystore password using an OS environment variable called `PGX_SERVER_KEYSTORE_PASSWORD` or with a java property called `pgx.SERVER_KEYSTORE_PASSWORD`.

   For example, to set the keystore password in `PGX_SERVER_KEYSTORE_PASSWORD`, edit the file at `/etc/systemd/system/pgx.service` as shown:

```
[Service]
Environment="PGX_SERVER_KEYSTORE_PASSWORD=<keystore_password>"
```

3. Reload the systemd configuration by running the following command:

   ```
   sudo systemctl daemon-reload
   ```

4. Restart the graph server.

   > **Note:**
   >
   > - You should use a certificate issued by a certificate authority (CA) which is trusted by your organization. If you do not have a CA certificate, you can temporarily create a self-signed certificate and get started.
   > - Always use a valid certificate trusted by your organization. We do not recommend the usage of self-signed certificates for production environments.

12.4.1.3 Configuring a Client to Trust the Self-Signed Keystore

You must configure your client application to accept the self-signed keystore.

To configure a client to trust the self-signed keystore, the root certificate must be imported to your Java installation local trust store.

- For a Java or a Python client, you must import the root certificate to all the Java installations used by all the clients.

  > **Note:**
  >
  > The JShell client requires Java 11 or later.

- For the Graph Visualization application, you must import the root certificate to the system Java installation of the environment running the graph server (PGX) or the web server serving the graph visualization application. That is, the JDK installation which is used by the OS user running the server that serves the Graph Visualization application.
- For the Graph Zeppelin interpreter client, you must import the root certificate to the Java installation used by the Zeppelin server.

You can import the root certificate as shown in the following step:

- Run the following command as a `root` user or with `sudo`:
  1. For Java 8 (make sure `JAVA_HOME` is set):

     ```
     sudo keytool -importkeystore -srckeystore /etc/oracle/graph/
     server_keystore.jks -destkeystore $JAVA_HOME/jre/lib/security/cacerts
     -deststorepass changeit -srcstorepass changeit -noprompt
     ```

  2. For Java 11 or later (make sure `JAVA_HOME` is set):

     ```
     sudo keytool -importkeystore -srckeystore /etc/oracle/graph/
     server_keystore.jks -destkeystore $JAVA_HOME/lib/security/cacerts -
     deststorepass changeit -srcstorepass changeit -noprompt
     ```

where `changeit` is the sample keystore password. You can change this password to a password of your choice. Be sure to remember this password as you will need it to modify the certificate.

1. If you are upgrading the graph server from a previous release, you must first delete the certificate by running the following command appropriate to your Java version. You must run the command using `sudo` or as a `root` user:

   For Java 8:

   ```
   sudo keytool -delete -alias pgx -keystore $JAVA_HOME/jre/lib/
   security/cacerts -storepass changeit
   ```

   For Java 11 or later:

   ```
   sudo keytool -delete -alias pgx -keystore $JAVA_HOME/lib/
   security/cacerts -storepass changeit
   ```

2. Import the new certificate as shown in the preceding step.

12.4.2 Using a Self-Signed Server Certificate

This section describes the steps to generate a self-signed certificate into `/etc/oracle/graph` and configure the graph server (PGX) to use this certificate.

- Generating a Self-Signed Server Certificate
  You can create a self-signed server certificate using the `openssl` command.
- Configuring the Graph Server (PGX)
  You must specify the path to the server certificate and the server's private key in PEM format in the graph server (PGX) configuration file.
- Configuring a Client to Trust the Self-Signed Certificate
  You must configure your client application to accept the self-signed graph server (PGX) certificate.

12.4.2.1 Generating a Self-Signed Server Certificate

You can create a self-signed server certificate using the `openssl` command.

The following steps show how to generate a self-signed server certificate.

1. Go to the following directory:

   ```
   cd /etc/oracle/graph
   ```

2. Execute the following commands:

   ```
   openssl req -new -newkey rsa:2048 -days 365 -nodes -x509 -subj "/
   C=US/ST=MyState/L=MyTown/O=MyOrganization/CN=ROOT" -keyout
   ca_key.pem -out ca_certificate.pem
   openssl genrsa -out server_key_traditional.pem 2048
   openssl pkcs8 -topk8 -in server_key_traditional.pem -inform pem -
   out server_key.pem -outform pem -nocrypt
   openssl req -new -subj "/C=US/ST=MyState/L=MyTown/O=MyOrganization/
   CN=localhost" -key server_key.pem -out server.csr
   ```

```
chmod 600 server_key.pem
openssl x509 -req -CA ca_certificate.pem -CAkey ca_key.pem -in server.csr
-out server_certificate.pem -days 365 -CAcreateserial
chown oraclegraph:oraclegraph server_key.pem
```

> **Note:**
>
> - The certificate mentioned in the above example will only work for the host `localhost`. If you have a different domain, you must replace `localhost` with your domain name.
> - The above self-signed certificate is valid only for 365 days.

12.4.2.2 Configuring the Graph Server (PGX)

You must specify the path to the server certificate and the server's private key in PEM format in the graph server (PGX) configuration file.

> **Note:**
>
> If you deploy the graph server into your web server using the web applications download package, then this section does not apply. Please refer to the manual of your web server for instructions on how to configure TLS.

1. Edit the file at `/etc/oracle/graph/server.conf`, and specify the paths to the server certificate and the server's private key in PEM format, as shown:

```
{
  "port": 7007,
  "enable_tls": true,
  "server_private_key": "/etc/oracle/graph/server_key.pem",
  "server_cert": "/etc/oracle/graph/server_certificate.pem",
  "enable_client_authentication": false,
  "working_dir": "/opt/oracle/graph/pgx/tmp_data"
}
```

2. Restart the graph server.

> **Note:**
>
> - You should use a certificate issued by a certificate authority (CA) which is trusted by your organization. If you do not have a CA certificate, you can temporarily create a self-signed certificate and get started.
> - Always use a valid certificate trusted by your organization. We do not recommend the usage of self-signed certificates for production environments.

12.4.2.3 Configuring a Client to Trust the Self-Signed Certificate

You must configure your client application to accept the self-signed graph server (PGX) certificate.

To configure a client to trust the self-signed certificate, the root certificate must be imported to your Java installation local trust store.

- For a Java or a Python client, you must import the root certificate to all the Java installations used by all the clients.

  > **Note:**
  >
  > The JShell client requires Java 11 or later.

- For the Graph Visualization application, you must import the root certificate to the system Java installation of the environment running the graph server (PGX) or the web server serving the graph visualization application. That is, the JDK installation which is used by the OS user running the server that serves the Graph Visualization application.
- For the Graph Zeppelin interpreter client, you must import the root certificate to the Java installation used by the Zeppelin server.

You can import the root certificate as shown in the following step:

- Run the following command as a `root` user or with `sudo`:
  1. For Java 8 (make sure `JAVA_HOME` is set):

     ```
     sudo keytool -import -trustcacerts -keystore $JAVA_HOME/jre/lib/
     security/cacerts -storepass changeit -alias pgx -file /etc/
     oracle/graph/ca_certificate.pem -noprompt
     ```

  2. For Java 11 or later (make sure `JAVA_HOME` is set):

     ```
     sudo keytool -import -trustcacerts -keystore $JAVA_HOME/lib/
     security/cacerts -storepass changeit -alias pgx -file /etc/
     oracle/graph/ca_certificate.pem -noprompt
     ```

  where `changeit` is the sample keystore password. You can change this password to a password of your choice. Be sure to remember this password as you will need it to modify the certificate.

  1. If you are upgrading the graph server from a previous release, you must first delete the certificate by running the following command appropriate to your Java version. You must run the command using `sudo` or as a `root` user:

     For Java 8:

     ```
     sudo keytool -delete -alias pgx -keystore $JAVA_HOME/jre/lib/
     security/cacerts -storepass changeit
     ```

For Java 11 or later:

```
sudo keytool -delete -alias pgx -keystore $JAVA_HOME/lib/security/
cacerts -storepass changeit
```

2. Import the new certificate as shown in the preceding step.

13

Getting Started with the Graph Server (PGX)

Once you have installed the graph server (PGX), you can start and connect to a graph server instance.

- Starting the Graph Server (PGX)
  This section describes the commands to start and stop the graph server (PGX).
- Connecting to the Graph Server (PGX)
  This section explains how to connect to the graph server (PGX) running in remote mode or when deployed as a web application on Apache Tomcat or Oracle WebLogic Server.

13.1 Starting the Graph Server (PGX)

This section describes the commands to start and stop the graph server (PGX).

A preconfigured version of Apache Tomcat is bundled, which allows you to start the graph server (PGX) by running a script.

As a prerequisite to start the graph server in remote mode, you must ensure that Oracle graph server is installed in your system. See Installing Oracle Graph Server for instructions to install the graph server (PGX).

> **Note:**
>
> See Usage Modes of the Graph Server (PGX) for more information on the different graph server execution modes.

- Starting and Stopping the Graph Server (PGX) Using the Command Line
- Configuring the Graph Server (PGX)

13.1.1 Starting and Stopping the Graph Server (PGX) Using the Command Line

PGX is integrated with `systemd` to run it as a Linux service in the background.

If you need to configure the server before starting it, see Configuring the Graph Server (PGX) and Configuration Parameters for the Graph Server (PGX) Engine for more information on the configuration options.

The commands to start and stop the graph server (PGX) and the PGX engine are as follows:

> **Note:**
>
> You can run the following commands without `sudo` if you are the root user.

To start the PGX server as a daemon process, run the following command:

```
sudo systemctl start pgx
```

To stop the server, run the following command:

```
sudo systemctl stop pgx
```

If the server does not start up, you can see if there are any errors by running:

```
sudo journalctl -u pgx.service
```

For more information about how to interact with `systemd` on Oracle Linux, see the Oracle Linux administrator's documentation.

13.1.2 Configuring the Graph Server (PGX)

You can configure the graph server (PGX) by modifying the `/etc/oracle/graph/server.conf` file. The following table shows the valid configuration options, which can be specified in JSON format.

Table 13-1 Configuration Parameters for the Graph Server (PGX)

Parameter	Type	Description	Default
`ca_certs`	`array of string`	List of files storing trusted certificates (PEM format). If `enable_tls` is set to `false`, this field has no effect.	`[]`

Table 13-1 (Cont.) Configuration Parameters for the Graph Server (PGX)

Parameter	Type	Description	Default
ciphers	array of string	List of cipher suites to be used by the server. For example, [cipher1, cipher2.]	["TLS_ECDHE_ECDSA_WITH_AES_128_GCM_SHA256", "TLS_ECDHE_ECDSA_WITH_AES_256_GCM_SHA384", "TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256", "TLS_ECDHE_RSA_WITH_AES_256_GCM_SHA384", "TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA256", "TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA256", "TLS_ECDHE_ECDSA_WITH_AES_256_CBC_SHA384", "TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA384", "TLS_DHE_RSA_WITH_AES_128_GCM_SHA256", "TLS_DHE_DSS_WITH_AES_128_GCM_SHA256", "TLS_DHE_RSA_WITH_AES_128_CBC_SHA256", "TLS_DHE_DSS_WITH_AES_128_CBC_SHA256", "TLS_DHE_DSS_WITH_AES_256_GCM_SHA384", "TLS_DHE_RSA_WITH_AES_256_CBC_SHA256", "TLS_DHE_DSS_WITH_AES_256_CBC_SHA256", "TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA", "TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA", "TLS_ECDHE_ECDSA_WITH_AES_256_CBC_SHA", "TLS_DHE_DSS_WITH_AES_128_CBC_SHA", "TLS_DHE_RSA_WITH_AES_128_CBC_SHA", "TLS_DHE_DSS_WITH_AES_256_CBC_SHA", "TLS_DHE_RSA_WITH_AES_256_CBC_SHA", "TLS_RSA_WITH_AES_128_GCM_SHA256", "TLS_DH_DSS_WITH_AES_128_GCM_SHA256", "TLS_ECDH_ECDSA_WITH_AES_128_GCM_SHA256", "TLS_RSA_WITH_AES_256_GCM_SH

Table 13-1 (Cont.) Configuration Parameters for the Graph Server (PGX)

Parameter	Type	Description	Default
			A384", "TLS_DH_DSS_WITH_AES_256_GCM_SHA384", "TLS_ECDH_ECDSA_WITH_AES_256_GCM_SHA384", "TLS_RSA_WITH_AES_128_CBC_SHA256", "TLS_DH_DSS_WITH_AES_128_CBC_SHA256", "TLS_ECDH_ECDSA_WITH_AES_128_CBC_SHA256", "TLS_RSA_WITH_AES_256_CBC_SHA256", "TLS_DH_DSS_WITH_AES_256_CBC_SHA256", "TLS_ECDH_ECDSA_WITH_AES_256_CBC_SHA384", "TLS_RSA_WITH_AES_128_CBC_SHA", "TLS_DH_DSS_WITH_AES_128_CBC_SHA", "TLS_ECDH_ECDSA_WITH_AES_128_CBC_SHA", "TLS_RSA_WITH_AES_256_CBC_SHA", "TLS_DH_DSS_WITH_AES_256_CBC_SHA", "TLS_ECDH_ECDSA_WITH_AES_256_CBC_SHA"]
context_path	string	This can be used to change the context path. For example, if you specify port as 7007 and context_path as /pgx, the server will listen on https://localhost:7007/pgx	/
enable_tls	boolean	If true, the server enables transport layer security (TLS).	true
port	integer	Port the graph server (PGX) server should listen on.	7007

Table 13-1 (Cont.) Configuration Parameters for the Graph Server (PGX)

Parameter	Type	Description	Default
server_cert	string	The path to the server certificate to be presented to TLS clients (PEM format). This file must only contain one certificate. If your certificate is a chain and contains a root certificate, add it to ca_certs instead. If enable_tls is set to false, this field has no effect **Note:** Starting from Graph Server and Client Release 22.3 onwards, this field is deprecated. Use server_keystore instead.	NULL
server_keystore	string	The path to the keystore to be used for server connections. If this field is present along with server_cert or server_private_key, then an error will be raised. If enable_tls is set to false, then this field has no effect.	NULL
server_keystore_alias	string	This is the server keystore alias of server_keystore.	NULL
server_keystore_provider	string	This is the server keystore provider of server_keystore.	SunJSSE
server_keystore_type	string	This is the server keystore type of server_keystore.	JKS

Table 13-1 (Cont.) Configuration Parameters for the Graph Server (PGX)

Parameter	Type	Description	Default
server_private_key	string	This is the path to the file storing the private key of the server (PEM format). For security reasons, the file must have only Read and Write permissions only for the owner (600 permissions in a POSIX filesystem), otherwise an error will be thrown. If enable_tls is set to false, this field has no effect. **Note:** Starting from Graph Server and Client Release 22.3 onwards, this field is deprecated. Use server_keystore instead.	NULL
tls_version	string	TLS version to be used by the server. For example, TLSv1.2	TLSv1.2
working_dir	string	The working directory used by the server to store temporary files. Needs to be writable by the process which started the server and should not be touched by any other process while the server is running.	

The graph server (PGX) enables two-way SSL/TLS (Transport Layer Security) by default. The server enforces TLS 1.2 and disables certain cipher suites known to be vulnerable to attacks. Upon a TLS handshake, both the server and the client present certificates to each other, which are used to validate the authenticity of the other party. Client certificates are also used to authorize client applications.

Example Configuration of `server.conf` File

```
{
  "port": 7007,
  "enable_tls": true,
  "server_cert": "server_cert.pem",
  "server_private_key": "server_key.pem",
  "ca_certs": [
    "server_cert.pem"
  ]
  }
```

Example Configuration of `server.conf` File Using a Keystore

```
{
  "port": 7007,
  "enable_tls": true,
  "enable_client_authentication": true,
  "server_keystore": "/pgx/cert/server_keystore.rsa",
  "server_keystore_alias": "pgx",
  "server_keystore_provider": "JsafeJCE",
  "server_keystore_type": "PKCS12"
}
```

13.2 Connecting to the Graph Server (PGX)

This section explains how to connect to the graph server (PGX) running in remote mode or when deployed as a web application on Apache Tomcat or Oracle WebLogic Server.

The prerequisite requirement to connect to the graph server is to have the graph server (PGX) up and running. See Starting and Stopping the Graph Server (PGX) Using the Command Line for more information on the commands to start the graph server.

> **Note:**
>
> If you are using the graph server (PGX) as a library, see Using the Graph Server (PGX) as a Library for more information.

- Connecting with the Graph Client CLIs
- Connecting with Java
- Connecting with Python

13.2.1 Connecting with the Graph Client CLIs

The simplest way to connect to a remote graph server (PGX) instance is to specify the base URL of the server along with the database user name required for the graph server (PGX) authentication as shown:

- JShell
- Python

JShell

```
cd /opt/oracle/graph
./bin/opg4j --base_url https://<host>:<port> --username <graphuser>
```

Python

```
cd /opt/oracle/graph
./bin/opg4py --base_url https://<host>:<port> --username <graphuser>
```

where :

- `<host>`: is the server host name
- `<port>`: is the server port
- `<graphuser>`: is the database user
  You will be prompted for the database password.

> **See Also:**
>
> - User Authentication and Authorization
> - Java API Reference for information on the Java APIs
> - Python API Reference for information on the Python APIs

About Logging HTTP Requests

The graph shell suppresses all debugging messages by default. To see which HTTP requests are executed, set the log level for `oracle.pgx` to `DEBUG`, as shown in this example:

> **Note:**
>
> Enabling these logs can lead to sensitive information like passwords getting printed on the screen.

- JShell
- Python

JShell

```
opg4j> loglevel("oracle.pgx","DEBUG")
===> Log level of oracle.pgx logger set to DEBUG
opg4j> session.readGraphWithProperties("bank_graph_analytics.json",
"bank_graph");
06:29:03,702 DEBUG CommonsVfsProvider - resolve
bank_graph_analytics.json
06:29:03,702 DEBUG AbstractConfigFactory - parse graph config from
bank_graph_analytics.json (parent: file:///opt/oracle/graph)
```

```
06:29:03,709 DEBUG RemoteUtils - create session cookie (session ID =
f5d029d7-2924-4cd4-86a9-6999c1ce5e3f)
06:29:03,713 DEBUG RemoteUtils - no value for the sticky cookie given
06:29:03,713 DEBUG RemoteUtils - create csrf token cookie (token =
36acbee2-6b78-4c13-b114-41040809833a)
06:29:03,713 DEBUG HttpRequestExecutor - Requesting POST https://
localhost:7007/core/v1/loadGraph HTTP/1.1 with payload
{"graphConfig":"HRcBVFVcO0dfXU9bUEhGEEYOdkMUElZYRFpcZgBeDxBYCxFcRGY2c21wIBUBE
ElAW11HQV5vVhpYAFRIFAMbeC5+NithRx9EEkwUVRADRlFBXVhGFlBpT0ZfSEFpAlZBQ1RXG1kTKi
EXSREVCUAWU1dmElJfRlxKa11GDBJdSV1EQwMPd1paVhZfFxYXSREIB1gBEggbMEVMXEpUUV9HQUg
WSV1FFVBDV01QVg1uAApZEF4IRA9GdHdqMGhkdhseFklREBBdQ1lCCFZDaU9cSxdUGzpFF1wQD1EB
QhADRnZOUVZHWllHQUgWQVdXBVBDURsDQkFSEQBUEVY5DVAdb19YFEdEXF4QDktVDxdRUBQUBVhZV
1tYSgZuFwRXCVY5CFQJVRADRnVsfHJtcWlzJjdrbHViQxUPXVxAZhdIEwAXXxEKCVsDEh4bAlhfX1
hGFhcWEQBWQEsUHGQBFE9cSxdUGzpFF1wQD1EBQkEbXmxWEFJXTXJXDAhBQFYUWxtkchsVGw1QDgA
XXxEnBVYLRVxNFxUBEFVdVUldDQMWF0MUAktIV01cZghUGjpYBEMWD1sDEghNFkJITxUQUExAAgZV
Xl1pFVhPWlxmVwJcBkcPR3EnKH47fn19IWQPHhtZUVRrFx1ESBoMQ1BDQlxeXBETT0dTCkELB0FGC
hBLAFVAQRtPaQEWDQVZSBoMQ1tMWFJmXhFQEw1qBF0HCkwQWVFKRkotMjkyAElr0w==","graphNa
me":"bank_graph","_csrf_token":"36acbee2-6b78-4c13-b114-41040809833a"}
06:29:03,788 DEBUG HttpRequestExecutor - received HTTP status 202
06:29:03,789 DEBUG HttpRequestExecutor -
{"futureId":"7f7a2206-8881-4c1e-909f-6e8778be617c"}
06:29:03,789 DEBUG PgxRemoteFuture - Requesting GET https://localhost:7007/
core/v1/futures/x-future-id/status HTTP/1.1
06:29:03,801 DEBUG PgxRemoteFuture - Requesting GET https://localhost:7007/
core/v1/futures/x-future-id/value HTTP/1.1
06:29:03,831 DEBUG RemoteUtils - received HTTP status 201
06:29:03,831 DEBUG RemoteUtils - {"id":"8B473228-0751-49A9-
A945-9A0E4011AB69","links":[{"href":"https://localhost:7007/core/v1/graphs/x-
graph-id","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"https://localhost:7007/core/v1/graphs/x-graph-
id","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"graphName":"bank_graph","vertexTables":{"Accounts":
{"name":"Accounts","metaData":{"name":"Accounts","idType":"integer","labels":
["Accounts"],"properties":[],"edgeProviderNamesWhereSource":
["Transfers"],"edgeProviderNamesWhereDestination":
["Transfers"],"id":null,"links":null},"providerLabels":
["Accounts"],"entityKeyType":"integer","isIdentityKeyMapping":false,"vertexPr
operties":{},"vertexLabels":{"id":"04156FFE-
A3C1-4A6D-87E5-879A0895BBD4","links":[{"href":"https://localhost:7007/
core/v1/graphs/x-graph-id/properties/x-property-
name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"https://localhost:7007/core/v1/graphs/x-graph-id/properties/x-
property-name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":-1,"propertyId":"04156FFE-
A3C1-4A6D-87E5-879A0895BBD4","name":"__vertex_labels__","entityType":"vertex"
,"type":"ro_string_set","namespace":"2C17C639-3771-3E30-88AE-34D6B380C5EC","t
ransient":false},"transient":false}},"edgeTables":{"Transfers":
{"name":"Transfers","metaData":
{"name":"Transfers","idType":"long","directed":true,"labels":
["Transfers"],"properties":
[{"name":"AMOUNT","id":null,"propertyType":"float","dimension":0,"transient":
true,"links":null,"propertyId":"AF2A2D0A-9C8C-478F-
BD74-3444A7DD7339"}],"sourceVertexProviderName":"Accounts","destinationVertex
ProviderName":"Accounts","id":null,"links":null},"providerLabels":
["Transfers"],"entityKeyType":"long","isIdentityKeyMapping":true,"sourceVerte
```

```
xTableName":"Accounts","destinationVertexTableName":"Accounts","edgePro
perties":{"4046D845-D0C6-4231-A69B-F69D4963CD91":{"id":"4046D845-
D0C6-4231-A69B-F69D4963CD91","links":[{"href":"https://localhost:7007/
core/v1/graphs/x-graph-id/properties/x-property-
name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"https://localhost:7007/core/v1/graphs/x-graph-id/properties/x-
property-name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":0,"propertyId":"4046D845-D0C6-4231-A69B-
F69D4963CD91","name":"AMOUNT","entityType":"edge","type":"float","names
pace":"2C17C639-3771-3E30-88AE-34D6B380C5EC","transient":false}},"edgeL
abel":{"id":"9763546A-1860-49A4-9292-77D2AA04F4BB","links
06:29:03,836 DEBUG PgxSession - engine reports latest snapshot is
621849 milli-seconds old. Max age is 0 milli-seconds
06:29:03,836 DEBUG PgxSession - ==> try to check out newer snapshot
06:29:03,836 DEBUG RemoteUtils - create session cookie (session ID =
f5d029d7-2924-4cd4-86a9-6999c1ce5e3f)
06:29:03,836 DEBUG RemoteUtils - no value for the sticky cookie given
06:29:03,836 DEBUG RemoteUtils - create csrf token cookie (token =
36acbee2-6b78-4c13-b114-41040809833a)
06:29:03,836 DEBUG HttpRequestExecutor - Requesting POST https://
localhost:7007/core/v1/graphs/x-graph-id/refresh HTTP/1.1 with payload
{"blockIfFull":false,"_csrf_token":"36acbee2-6b78-4c13-
b114-41040809833a"}
06:29:03,878 DEBUG HttpRequestExecutor - received HTTP status 202
06:29:03,878 DEBUG HttpRequestExecutor -
{"futureId":"898d546e-583f-4d37-9ca9-d1e10134037f"}
06:29:04,135 DEBUG PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/status HTTP/1.1
06:29:04,828 DEBUG PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/value HTTP/1.1
06:29:04,858 DEBUG RemoteUtils - received HTTP status 201
06:29:04,859 DEBUG RemoteUtils - {"id":"BE960B34-E135-4CF8-AB2F-
E1A6E2D7DB60","links":[{"href":"https://localhost:7007/core/v1/
graphs/x-graph-id","rel":"self","method":"GET","interaction":["async-
polling"]},{"href":"https://localhost:7007/core/v1/graphs/x-graph-
id","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"graphName":"bank_graph","vertexTables":{"Accounts":
{"name":"Accounts","metaData":
{"name":"Accounts","idType":"integer","labels":
["Accounts"],"properties":[],"edgeProviderNamesWhereSource":
["Transfers"],"edgeProviderNamesWhereDestination":
["Transfers"],"id":null,"links":null},"providerLabels":
["Accounts"],"entityKeyType":"integer","isIdentityKeyMapping":false,"ve
rtexProperties":{},"vertexLabels":{"id":"19D95502-40D5-47F2-9F45-
B1CD09ECB989","links":[{"href":"https://localhost:7007/core/v1/
graphs/x-graph-id/properties/x-property-
name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"https://localhost:7007/core/v1/graphs/x-graph-id/properties/x-
property-name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":-1,"propertyId":"19D95502-40D5-47F2-9F45-
B1CD09ECB989","name":"__vertex_labels__","entityType":"vertex","type":"
ro_string_set","namespace":"2C17C639-3771-3E30-88AE-34D6B380C5EC","tran
sient":false},"transient":false}},"edgeTables":{"Transfers":
{"name":"Transfers","metaData":
{"name":"Transfers","idType":"long","directed":true,"labels":
```

```
["Transfers"],"properties":
[{"name":"AMOUNT","id":null,"propertyType":"float","dimension":0,"transient":
true,"links":null,"propertyId":"9A49BC0C-F8AA-465A-B8D6-
CA5A92BAE2C9"}],"sourceVertexProviderName":"Accounts","destinationVertexProvi
derName":"Accounts","id":null,"links":null},"providerLabels":
["Transfers"],"entityKeyType":"long","isIdentityKeyMapping":true,"sourceVerte
xTableName":"Accounts","destinationVertexTableName":"Accounts","edgePropertie
s":{"FED6FE43-D311-46B6-9A5A-E8DC0D7B56C6":{"id":"FED6FE43-D311-46B6-9A5A-
E8DC0D7B56C6","links":[{"href":"https://localhost:7007/core/v1/graphs/x-
graph-id/properties/x-property-
name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"https://localhost:7007/core/v1/graphs/x-graph-id/properties/x-
property-name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":0,"propertyId":"FED6FE43-D311-46B6-9A5A-
E8DC0D7B56C6","name":"AMOUNT","entityType":"edge","type":"float","namespace":
"2C17C639-3771-3E30-88AE-34D6B380C5EC","transient":false}},"edgeLabel":
{"id":"371D2AC6-4EC5-45AD-8885-B3590F56D944","links
$5 ==> PgxGraph[name=bank_graph,N=1000,E=5001,created=1621160944599]
```

Python

```
>>>setloglevel("oracle.pgx","DEBUG")
>>>session.read_graph_with_properties("/scratch/PG/data/
bank_graph_analytics.json")
10:37:46.308 [main] DEBUG oracle.pgx.vfs.CommonsVfsProvider - resolve /
scratch/PG/data/bank_graph_analytics.json
10:37:46.314 [main] DEBUG oracle.pgx.config.AbstractConfigFactory - parse
graph config from /scratch/PG/data/bank_graph_analytics.json (parent:
file:///scratch/PG/data)
10:37:46.464 [main] DEBUG oracle.pgx.client.RemoteUtils - create session
cookie (session ID = 786242ef-a430-4964-8379-662079514d2e)
10:37:46.465 [main] DEBUG oracle.pgx.client.RemoteUtils - no value for the
sticky cookie given
10:37:46.466 [main] DEBUG oracle.pgx.client.RemoteUtils - create csrf token
cookie (token = f02ccd16-56e1-4e61-8d17-d6122f5ea48f)
10:37:46.565 [main] DEBUG oracle.pgx.client.HttpRequestExecutor - Requesting
POST https://localhost:7007/core/v1/loadGraph HTTP/1.1 with payload
{"graphConfig":"TBpAV0ZGAB5yEUZcRkRQXERHDwJoTBtGU09tU1hVQFxaRghHfnwUHhZcBAtIQ
w4RcU5XVkNaWUsRGxtGU09tRE5JUBMORlsLQ11RV0YQSURBDlVXWUNTGwxPD1tBUlhZU2lZVU5mWF
BEFFsLUBoMRkZHABsBQ1BSRExWWEVRckxSVVVIaVhTXVIbDxN2JXwuaHl1cXtnKzJ+QxgRVkJGVFd
ADwIRRV1PW0UQHBVJR15EFxBfbEMURk1CAEQXQ11dREhTXEQWARpdVlRIFAwQeXMbSB1PRkYcR10U
CBZBERRED1MRHA9aWFtRDwIReXhgcxRPbUpkGRNRAFUAaEhEXUJbAQNfEhYJa1YWUlNNcltcW0xAW
BQIEl5dFx0WClMIUhoMEGBABAheB1FBQw8YG11RVGdHTklIFAwQXFhXUhMYRl4KVlxfXFMQXx0PAk
ZWUVlRZl1RVGdeVkldX1hVEg1fVF1HAU9JFVxTQUBbCwdZCFtdb1tRS0JRVWdDRVZbX1JXQhUDF3B
XB10QWUxFEBgQAQNeFV1dUVldVlhrTldfQlRDFAwQZHhmdHJ3MG0scxoaEFBTEQdPAEdWb1lVW1pR
clZSWlwPDBRwcXlyamVsKmFHGxpFXUFABgNyAltfRUBaGwwWa2p8emZsdXVmb359Fx0WAl0XWllCE
A4QFwJPDEcRHA9ES1lEXhoJbEIPQk9CVRUDF1dYC1MRFRQUXFVfAEQXQ3V+f3h6bRRJAUMRQ0BdUx
QIEkRNR1haAxBJFVZXX1EQX0RpJGdwYmRkbX97YxpOahUPRVlHQlRcakdRFkYAT2dGQFtEDAJIExY
JEmxXWllBQ0xAFURwGhRcUVpcFwsWBlMLXGdRQFVCDTlMD1VfSVldWkUWUDgzNzmCqX+4","graph
Name":null,"_csrf_token":"f02ccd16-56e1-4e61-8d17-d6122f5ea48f"}
10:37:47.082 [main] DEBUG oracle.pgx.client.HttpRequestExecutor - received
HTTP status 202
10:37:47.082 [main] DEBUG oracle.pgx.client.HttpRequestExecutor -
{"futureId":"aeae66b7-e1d6-46f3-b78f-1c0d9642d308"}
```

```
10:37:47.086 [pgx-client-thread-2] DEBUG
oracle.pgx.client.PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/status HTTP/1.1
10:37:50.434 [pgx-client-thread-2] DEBUG
oracle.pgx.client.PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/value HTTP/1.1
10:37:50.539 [pgx-client-thread-2] DEBUG oracle.pgx.client.RemoteUtils
- received HTTP status 201
10:37:50.539 [pgx-client-thread-2] DEBUG oracle.pgx.client.RemoteUtils
- {"id":"2EE6F933-5679-4387-B79B-A4AAD0814DC6","links":
[{"href":"https://localhost:7007/core/v1/graphs/x-graph-
id","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"https://localhost:7007/core/v1/graphs/x-graph-
id","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"graphName":"bank_graph_analytics","vertexTables":
{"Accounts":{"name":"Accounts","metaData":
{"name":"Accounts","idType":"integer","labels":
["Accounts"],"properties":
[{"name":"ID","id":null,"propertyType":"integer","dimension":0,"transie
nt":true,"links":null,"propertyId":"C933AB01-358B-4553-974D-0C54845719F
2"},
{"name":"NAME","id":null,"propertyType":"string","dimension":0,"transie
nt":true,"links":null,"propertyId":"E0EDF68C-5AFE-4886-
B3A0-385CE56F1814"}],"edgeProviderNamesWhereSource":
["Transfers"],"edgeProviderNamesWhereDestination":
["Transfers"],"id":null,"links":null},"providerLabels":
["Accounts"],"keyPropertyName":null,"entityKeyType":"integer","isIdenti
tyKeyMapping":false,"vertexProperties":{"F5023C5A-5294-4383-
BA4F-0109C67A020F":{"id":"F5023C5A-5294-4383-
BA4F-0109C67A020F","links":[{"href":"https://localhost:7007/core/v1/
graphs/x-graph-id/properties/x-property-
name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"https://localhost:7007/core/v1/graphs/x-graph-id/properties/x-
property-name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":0,"propertyId":"F5023C5A-5294-4383-
BA4F-0109C67A020F","name":"ID","entityType":"vertex","type":"integer","
namespace":"2C17C639-3771-3E30-88AE-34D6B380C5EC","transient":false},"C
588F89E-53EB-46DD-A83D-1078138C42C7":{"id":"C588F89E-53EB-46DD-
A83D-1078138C42C7","links":[{"href":"https://localhost:7007/core/v1/
graphs/x-graph-id/properties/x-property-
name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"https://localhost:7007/core/v1/graphs/x-graph-id/properties/x-
property-name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":0,"propertyId":"C588F89E-53EB-46DD-
A83D-1078138C42C7","name":"NAME","entityType":"vertex","type":"string",
"namespace":"2C17C639-3771-3E30-88AE-34D6B380C5EC","transient":false}},
"vertexLabels":{"id":"89FB1A38-BCDF-4FB0-9F8C-59471872BEA3","links":
[{"href":"https://localhost:7007/core/v1/graphs/x-graph-id/
properties/x-property-name","rel":"self","method":"GET","interaction":
["async-polling"]},{"href":"https://localhost:7007/core/v1/graphs/x-
graph-id/properties/x-property-name","rel":"canonical","method":"GET
10:37:50.655 [pgx-client-thread-2] DEBUG oracle.pgx.api.PgxSession -
engine reports latest snapshot is 0 milli-seconds old. Max age is 0
milli-seconds
10:37:50.655 [pgx-client-thread-2] DEBUG oracle.pgx.api.PgxSession -
```

```
==> within range. Return snapshot
PgxGraph(name: bank_graph_analytics, v: 1000, e: 5001, directed: True,
memory(Mb): 0)
```

13.2.2 Connecting with Java

You can obtain a connection to a remote graph server (PGX) instance by simply passing the base URL of the remote PGX instance to the `getInstance()` method. By doing this, your application automatically uses the PGX client libraries to connect to a remotely-located graph server (PGX).

You can specify the base URL when you initialize the graph server (PGX) instance using Java. An example is as follows. A URL to an graph server (PGX) is provided to the `getInMemAnalyst` API call.

```
import oracle.pgx.api.*;
import oracle.pg.rdbms.*;
ServerInstance instance = GraphServer.getInstance("https://
<hostname>:<port>","<username>","<password>".toCharArray());
PgxSession session = instance.createSession("my-session");
```

> **Note:**
>
> See Java API Reference for more information on the Java APIs.

- Starting and Stopping the PGX Engine

13.2.2.1 Starting and Stopping the PGX Engine

You can start the graph server (PGX) from the application by making a call to `instance.startEngine()` which takes a JSON object as an argument for PGX configuration.

> **Note:**
>
> - See Connecting with Java for more information about connecting to a graph server (PGX) instance and obtaining a `ServerInstance` object.
> - See Configuration Parameters for the Graph Server (PGX) Engine for the various configuration options for the graph server (PGX).

Stopping the PGX Engine

You can stop the PGX engine using one of the following APIs:

```
instance.shutdownEngineNow(); // cancels pending tasks, throws exception if
engine is not running
instance.shutdownEngineNowIfRunning(); // cancels pending tasks, only tries
```

```
to shut down if engine is running
if (instance.shutdownEngine(30, TimeUnit.SECONDS) == false) {
  // doesn't accept new tasks but finishes up remaining tasks
  // pending tasks didn't finish after 30 seconds
}
```

> **Note:**
>
> Shutting down the PGX engine keeps the Apache Tomcat server alive, but new sessions cannot be created. Also, all the current sessions and tasks will be cancelled and terminated.

13.2.3 Connecting with Python

You can connect to a remote graph server (PGX) instance in your Python program. You must first authenticate with the remote server before you can create a session as illustrated in the following example:

```
import pypgx
import opg4py
import opg4py.graph_server as graph_server
pgql_conn = opg4py.pgql.get_connection("<username>","<password>",
"<jdbc_url>")
pgql_statement = pgql_conn.create_statement()
pgql = """
        CREATE PROPERTY GRAPH bank_graph
        VERTEX TABLES (
          bank_accounts
            LABEL ACCOUNTS
            PROPERTIES (ID, NAME)
        )
        EDGE TABLES (
          bank_txns
            SOURCE KEY (from_acct_id) REFERENCES bank_accounts
            DESTINATION KEY (to_acct_id) REFERENCES bank_accounts
            LABEL TRANSFERS
            PROPERTIES (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT, DESCRIPTION)
        ) OPTIONS(PG_VIEW)
"""
pgql_statement.execute(pgql)
instance = graph_server.get_instance("<base_url>", "<username>",
"<password>")
session = instance.create_session("my_session")
graph = session.read_graph_by_name('BANK_GRAPH', 'pg_view')
analyst = session.create_analyst()
analyst.pagerank(graph)
rs = graph.query_pgql("SELECT id(x), x.pagerank FROM MATCH (x) LIMIT
5")
rs.print()
```

To execute, save the above program into a file named `program.py` and run the following command:

```
python3 program.py
```

You will see the following output:

```
+-----------------------------------------+
| id(x)              | pagerank           |
+-----------------------------------------+
| BANK_ACCOUNTS(2)   | 9.749447313256548E-4  |
| BANK_ACCOUNTS(4)   | 0.004584001759076056  |
| BANK_ACCOUNTS(6)   | 5.358461393401424E-4  |
| BANK_ACCOUNTS(8)   | 0.0013051552434930175 |
| BANK_ACCOUNTS(10)  | 0.0015040122009364232 |
+-----------------------------------------+
```

Converting PGQL result set into pandas dataframe

Additionally, you can also convert the PGQL result set to a `pandas.DataFrame` object using the `to_pandas()` method. This makes it easier to perform various data filtering operations on the result set and it can also be used in Lambda functions. For example,

```
example_query = (
    "SELECT n.name AS name, n.age AS age "
    "WHERE (n)"
)
result_set = sample_graph.query_pgql(example_query)
result_df = result_set.to_pandas()

result_df['age_bin'] = result_df['age'].apply(lambda x: int(x)/20) # create
age bins based on age ranges
```

Note:

To view the complete set of available Python APIs, see OPG4PY Python API Reference.

Part V
Using the Graph Server (PGX)

The graph server (PGX) of Oracle Graph supports a set of analytical functions.

> **Note:**
>
> You can only load property graph views into the graph server (PGX). Loading SQL property graphs into the graph server (PGX) is not supported.

This part describes the following:

- Developing Applications with Graph Analytics
  In order to run graph algorithms, the graph application connects to the graph server (PGX) in the middle tier, which in turn connects to the Oracle Database.
- Using the Machine Learning Library (PgxML) for Graphs
  The graph server (PGX) provides a machine learning library `oracle.pgx.api.mllib`, which supports graph-empowered machine learning algorithms.
- Executing PGQL Queries Against the Graph Server (PGX)
  This section describes the Java APIs that are used to execute PGQL queries in the graph server (PGX).
- REST Endpoints for the Graph Server

14 Developing Applications with Graph Analytics

In order to run graph algorithms, the graph application connects to the graph server (PGX) in the middle tier, which in turn connects to the Oracle Database.

Note:

You can only load property graph views into the graph server (PGX). Loading a SQL property graph into the graph server (PGX) is not supported.

- About Vertex and Edge IDs
  The graph server (PGX) enforces by default the existence of a unique identifier for each vertex and edge in a graph.
- Graph Management in the Graph Server (PGX)
  You can load a graph into the graph server (PGX) and perform different actions such as publish, store, or delete a graph.
- Keeping the Graph in Oracle Database Synchronized with the Graph Server
  You can use the `FlashbackSynchronizer` API to automatically apply changes made to graph in the database to the corresponding `PgxGraph` object in memory, thus keeping both synchronized.
- Optimizing Graphs for Read Versus Updates in the Graph Server (PGX)
  The graph server (PGX) can store an optimized graph for other reads or updates. This is only relevant when the updates are made directly to a graph instance in the graph server.
- Executing Built-in Algorithms
  The graph server (PGX) contains a set of built-in algorithms that are available as Java APIs.
- Using Custom PGX Graph Algorithms
  A custom PGX graph algorithm allows you to write a graph algorithm in Java syntax and have it automatically compiled to an efficient parallel implementation.
- Creating Subgraphs
  You can create subgraphs based on a graph that has been loaded into memory. You can use filter expressions or create bipartite subgraphs based on a vertex (node) collection that specifies the left set of the bipartite graph.
- Using Automatic Delta Refresh to Handle Database Changes
  You can automatically refresh (auto-refresh) graphs periodically to keep the in-memory graph synchronized with changes to the property graph stored in the property graph tables in Oracle Database (VT$ and GE$ tables).
- User-Defined Functions (UDFs) in PGX
  User-defined functions (UDFs) allow users of PGX to add custom logic to their PGQL queries or custom graph algorithms, to complement built-in functions with custom requirements.

- Using the Graph Server (PGX) as a Library
  When you utilize PGX as a library in your application, the graph server (PGX) instance runs in the same JVM as the Java application and all requests are translated into direct function calls instead of remote procedure invocations.

14.1 About Vertex and Edge IDs

The graph server (PGX) enforces by default the existence of a unique identifier for each vertex and edge in a graph.

When loading a graph into the graph server(PGX), you can retrieve these unique vertex and edge IDs using `PgxGraph.getVertex(ID id)` and `PgxGraph.getEdge(ID id)`, or by PGQL queries using the built-in `id()` method.
The following supported ID generation strategies can be selected through the configuration parameters `vertex_id_strategy` and `edge_id_strategy`:

- `keys_as_ids`: This is the default strategy to generate vertex IDs.
- `partitioned_ids`: This is the recommended strategy for partitioned graphs.
- `unstable_generated_ids`: This results in system generated vertex or edge IDs.
- `no_ids`: This strategy disables vertex or edge IDs and therefore prevents you from calling APIs using vertex or edge IDs.

Using keys to generate IDs

The default strategy to generate the vertex IDs is to use the keys provided during loading of the graph (`keys_as_ids`). In that case, each vertex should have a vertex key that is unique across all providers.

For edges, by default no keys are required in the edge data, and edge IDs will be automatically generated by PGX (`unstable_generated_ids`). This automatic ID generation can be applied for vertex IDs also. Note that the generation of vertex or edge IDs is not guaranteed to be deterministic. If required, it is also possible to load edge keys as IDs.

The `partitioned_ids` strategy requires keys to be unique only *within* a vertex or edge provider (data source). The keys do not have to be globally unique. Globally unique IDs are derived from a combination of the provider name and the key inside the provider, as <provider_name>(<unique_key_within_provider>). For example, `Account(1)`.

The `partititioned_ids` strategy can be set through the configuration fields `vertex_id_strategy` and `edge_id_strategy`. For example,

```
{
  "name": "bank_graph_analytics",
  "optimized_for": "updates",
  "vertex_id_strategy" : "partitioned_ids",
  "edge_id_strategy" : "partitioned_ids",
  "vertex_providers": [
    {
      "name": "Accounts",
      "format": "rdbms",
      "database_table_name": "BANK_ACCOUNTS",
      "key_column": "ID",
```

```
        "key_type": "integer",
        "props": [
          {
            "name": "ID",
            "type": "integer"
          },
          {
            "name": "NAME",
            "type": "string"
          }
        ],
        "loading": {
          "create_key_mapping" : true
        }
      }
    ],
    "edge_providers": [
      {
        "name": "Transfers",
        "format": "rdbms",
        "database_table_name": "BANK_TXNS",
        "key_column": "ID",
        "source_column": "FROM_ACCT_ID",
        "destination_column": "TO_ACCT_ID",
        "source_vertex_provider": "Accounts",
        "destination_vertex_provider": "Accounts",
        "props": [
           {
            "name": "ID",
            "type": "integer"
          },
          {
            "name": "AMOUNT",
            "type": "double"
          }
        ],
        "loading": {
          "create_key_mapping" : true
        }
      }
    ]
}
```

> **Note:**
>
> All available key types are supported in combination with partitioned IDs.

After the graph is loaded, PGX maintains information about which property of a provider corresponds to the key of the provider. In the preceding example, the vertex property `ID` happens to correspond to the vertex key and also the edge property `ID` happens to correspond to the edge key. Each provider can have at most one such "key property" and the property can have any name.

Key properties are used for internal optimizations as well as for providing keys for the vertex or edge or both when inserting new entities. Key properties are currently non-updatable. Trying to update a key property will result in an error. For example,

```
vertex key property ID cannot be updated
```

Using an auto-incrementer to generate partitioned IDs

It is recommended to always set `create_key_mapping` to `true` to benefit from performance optimizations. But if there are no single-column keys for edges, `create_key_mapping` can be set to `false`. Similarly, `create_key_mapping` can be set to `false` for vertex providers also. IDs will be generated via an auto-incrementer, for example `Accounts(1)`, `Accounts(2)`, `Accounts(3)`.

See PGQL Queries with Partitioned IDs for more information on executing PGQL queries with partitioned IDs.

14.2 Graph Management in the Graph Server (PGX)

You can load a graph into the graph server (PGX) and perform different actions such as publish, store, or delete a graph.

- Reading Graphs from Oracle Database into the Graph Server (PGX)
  Once logged into the graph server (PGX), you can read graphs from the database into the graph server.
- Storing a Graph Snapshot on Disk
  After reading a graph into memory, you can make any changes to the graph (such as running the PageRank algorithm and storing the values as vertex properties), and then store this snapshot of the graph on disk.
- Publishing a Graph
  You can publish a graph that can be referenced by other sessions.
- Deleting a Graph
  In order to reduce the memory usage of the graph server (PGX), the session must drop the unused graph objects created through the `getGraph()` method, by invoking the `destroy()` method.

14.2.1 Reading Graphs from Oracle Database into the Graph Server (PGX)

Once logged into the graph server (PGX), you can read graphs from the database into the graph server.

Your database user must exist and have read access on the graph data in the database.

There are several ways to load a property graph view into the graph server (PGX) from Oracle Database:

- Using the `readGraphByName` API - see Loading a PG View Using the readGraphByName API for more details.
- Using the PGQL `CREATE PROPERTY GRAPH` statement - see Creating a Property Graph Using PGQL for more details.

- Using the `PgViewSubgraphReader#fromPgView` API to create and load a subgraph - see Loading a Subgraph from Property Graph Views for more details.
- Using a PGX graph configuration file in JSON format - see Loading a Graph Using a JSON Configuration File for more details.
- Using the GraphConfigBuilder class to create Oracle RDBMS graph configurations programmatically through Java methods - see Loading a Graph by Defining a Graph Configuration Object for more details.
- Reading Entity Providers at the Same SCN
  If you have a graph which consists of multiple vertex or edge tables or both, then you can read all the vertices and edges at the same System Change Number (SCN).
- Progress Reporting and Estimation for Graph Loading
  Loading a large graph into the graph server(PGX) can be a long running operation. However, if you load the graph using an asynchronous action, then you can monitor the progress of the graph loading operation.
- API for Loading Graphs into Memory
  Learn about the APIs used for loading a graph using a JSON configuration file or graph configuration object.
- Graph Configuration Options
  Learn about the graph configuration options.
- Data Loading Security Best Practices
  Loading a graph from the database requires authentication and it is therefore important to adhere to certain security guidelines when configuring access to this kind of data source.
- Data Format Support Matrix
  Learn about the different data formats supported in the graph server (PGX).
- Immutability of Loaded Graphs
  Once the graph is loaded into the graph server (PGX), the graph and its properties are automatically marked as immutable.

14.2.1.1 Reading Entity Providers at the Same SCN

If you have a graph which consists of multiple vertex or edge tables or both, then you can read all the vertices and edges at the same System Change Number (SCN).

This helps to overcome issues such as reading edge providers at a later SCN than the SCN at which the vertices were read, as some edges may reference missing vertices.

Note that reading a graph from the database is still possible even if Flashback is not enabled on Oracle Database. In case of multiple databases, SCN can be used to maintain consistency for entity providers belonging to the same database only.

You can use the `as_of` flag in the graph configuration to specify at what SCN an entity provider must be read. The valid values for the `as_of` flag are as follows:

Table 14-1 Valid values for "as_of" Key in Graph Configuration

Value	Description
A positive `long` value	This is a parseable SCN value.
`"<current-scn>"`	The current SCN is determined at the beginning of the graph loading.

Table 14-1 (Cont.) Valid values for "as_of" Key in Graph Configuration

Value	Description
`"<no-scn>"`	This is to disable SCN at the time of graph loading.
`null`	This defaults to `"<current-scn>"` behavior.

If `"as_of"` is omitted for a vertex or an edge provider in the graph configuration file, then this follows the same behavior as `"as_of": null`.

Example 14-1 Graph Configuration Using `"as_of"` for Vertex and Edge Providers in the Same Database

The following example configuration has three vertex providers and one edge provider pointing to the same database.

```
{
  "name": "employee_graph",
  "vertex_providers": [
    {
      "name": "Department",
      "as_of": "<current-scn>",
      "format": "rdbms",
      "database_table_name": "DEPARTMENTS",
      "key_column": "DEPARTMENT_ID",
      "props": [
        {
          "name": "DEPARTMENT_NAME",
          "type": "string"
        }
      ]
    },
    {
      "name": "Location",
      "as_of": "28924323",
      "format": "rdbms",
      "database_table_name": "LOCATIONS",
      "key_column": "LOCATION_ID",
      "props": [
        {
          "name": "CITY",
          "type": "string"
        }
      ]
    },
    {
      "name": "Region",
      "as_of": "<no-scn>",
      "format": "rdbms",
      "database_table_name": "REGIONS",
      "key_column": "REGION_ID",
      "props": [
        {
```

```
          "name": "REGION_NAME",
          "type": "string"
        }
      ]
    }
  ],
  "edge_providers": [
    {
      "name": "LocatedAt",
      "format": "rdbms",
      "database_table_name": "DEPARTMENTS",
      "key_column": "DEPARTMENT_ID",
      "source_column": "DEPARTMENT_ID",
      "destination_column": "LOCATION_ID",
      "source_vertex_provider": "Department",
      "destination_vertex_provider": "Location"
    }
  ]
}
```

When reading the `employee_graph` using the preceding configuration file, the graph is read at the same SCN for the `Department` and `LocatedAt` entity providers. This is explained in the following table:

Table 14-2 Example Scenario Using "as_of"

Entity Provider	"as_of"	SCN Value
`Department`	`"<current-scn>"`	SCN determined automatically
`Location`	`"28924323"`	`"28924323"` used as SCN
`Region`	`"<no-scn>"`	No SCN used
`LocatedAt`	`"as_of"` flag is omitted	SCN determined automatically

The current SCN value of the database can be determined using one of the following options:

- Querying `V$DATABASE` view:

  ```
  SELECT CURRENT_SCN FROM V$DATABASE;
  ```

- Using `DBMS_FLASHBACK` package:

  ```
  SELECT DBMS_FLASHBACK.GET_SYSTEM_CHANGE_NUMBER FROM DUAL;
  ```

If you do not have the required privileges to perform either of the preceding operations, then you can use:

```
SELECT TIMESTAMP_TO_SCN(SYSDATE) FROM DUAL;
```

However, note that this option is less precise than the earlier two options.

You can then read the graph into the graph server using the JSON configuration file as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var g = session.readGraphWithProperties("employee_graph.json")
```

Java

```
PgxGraph g = session.readGraphWithProperties("employee_graph.json");
```

Python

```
g = session.read_graph_with_properties("employee_graph.json")
```

14.2.1.2 Progress Reporting and Estimation for Graph Loading

Loading a large graph into the graph server(PGX) can be a long running operation. However, if you load the graph using an asynchronous action, then you can monitor the progress of the graph loading operation.

The following table shows the asynchronous graph loading APIs supported for the following formats:

Table 14-3 Asynchronous Graph Loading APIs

Data Format	API
PG VIEWS	session.readGraphByNameAsync()
PG SCHEMA	session.readGraphWithPropertiesAsync()
CSV	session.readGraphFileAsync()

These supported APIs return a `PgxFuture` object.

You can then use the `PgxFuture.getProgress()` method to collect the following statistics:

- Report on the progress of the graph loading operation
- Estimate of the remaining vertices and edges that need to be loaded into memory

For example, the following code shows the steps to load a PG view graph asynchronously and subsequently obtain the `FutureProgress` object to report and estimate the loading progress. However, note that the graph loading estimate (for example, the number of loaded entities and providers or the number of total entities and providers) can be obtained only until the graph loading operation is in progress.

Also, the system internally computes the graph loading progress for every 10000 entries of entities that are loaded into the graph server (PGX).

- JShell
- Java

JShell

```
opg4j>  var graphLoadingFuture =
session.readGraphByNameAsync("BANK_GRAPH_VIEW", GraphSource.PG_VIEW)
readGraphFuture ==> oracle.pgx.api.PgxFuture@6106dfb6[Not completed]

opg4j> while (!graphLoadingFuture.isDone()) {
...>   var progress = graphLoadingFuture.getProgress();
...>   var graphLoadingProgress = progress.asGraphLoadingProgress();
...>   if (graphLoadingProgress.isPresent()) {
...>     var numLoadedVertices =
graphLoadingProgress.get().getNumLoadedVertices();
...>   }
...>   Thread.sleep(1000);
...> }

opg4j> var graph = graphLoadingFuture.get();
graph ==> PgxGraph[name=BANK_GRAPH_VIEW_3,N=999,E=4993,created=1664289985985]
```

Java

```
PgxFuture<PgxGraph> graphLoadingFuture =
session.readGraphByNameAsync("BANK_GRAPH_VIEW", GraphSource.PG_VIEW);
while (!graphLoadingFuture.isDone()) {
  FutureProgress progress = graphLoadingFuture.getProgress();
  Optional < GraphLoadingProgress > graphLoadingProgress =
progress.asGraphLoadingProgress();
  if (graphLoadingProgress.isPresent()) {
    long numLoadedVertices =
graphLoadingProgress.get().getNumLoadedVertices();
  }
  Thread.sleep(1000);
}
PgxGraph graph = graphLoadingFuture.get();
```

It is recommended that you do not use the `FutureProgress` object in a chain of asynchronous operations.

14.2.1.3 API for Loading Graphs into Memory

Learn about the APIs used for loading a graph using a JSON configuration file or graph configuration object.

The following methods in `PgxSession` can be used to load graphs into the graph server (PGX).

- Java
- Python

Java

```
PgxGraph readGraphWithProperties(String path)
PgxGraph readGraphWithProperties(String path, String newGraphName)
PgxGraph readGraphWithProperties(GraphConfig config)
PgxGraph readGraphWithProperties(GraphConfig config, String
newGraphName)
PgxGraph readGraphWithProperties(GraphConfig config, boolean
forceUpdateIfNotFresh)
PgxGraph readGraphWithProperties(GraphConfig config, boolean
forceUpdateIfNotFresh, String newGraphName)
PgxGraph readGraphWithProperties(GraphConfig config, long maxAge,
TimeUnit maxAgeTimeUnit)
PgxGraph readGraphWithProperties(GraphConfig config, long maxAge,
TimeUnit maxAgeTimeUnit, boolean blockIfFull, String newGraphName)
```

Python

```
read_graph_with_properties(self, config, max_age=9223372036854775807,
max_age_time_unit='days',
                                  block_if_full=False,
update_if_not_fresh=True, graph_name=None)
```

The first argument (`path` to a graph configuration file or a parsed `config` object) is the meta-data of the graph to be read. The meta-data includes the following information:

- Location of the graph data such as file location and name, DB location and connection information, and so on
- Format of the graph data such as plain text formats, XML-based formats, binary formats, and so on
- Types and Names of the properties to be loaded

The `forceUpdateIfNotFresh` and `maxAge` arguments can be used to fine-control the age of the snapshot to be read. The graph server (PGX) will return an existing graph snapshot if the given graph specification was already loaded into memory by a different session. So, the `maxAge` argument becomes important if reading from a database in which the data might change frequently. If no `forceUpdateIfNotFresh` or `maxAge` is specified, PGX will favor cached data over reading new snapshots into memory.

14.2.1.4 Graph Configuration Options

Learn about the graph configuration options.

The following table lists the JSON fields that are common to all graph configurations:

Table 14-4 Graph Config JSON Fields

Field	Type	Description	Default
name	string	Name of the graph.	Required
array_compaction_threshold	number	*[only relevant if the graph is optimized for updates]* Threshold used to determined when to compact the delta-logs into a new array. If lower than the engine min_array_compaction_threshold value, min_array_compaction_threshold will be used instead	0.2
attributes	object	Additional attributes needed to read and write the graph data.	null
data_source_id	string	Data source id to use to connect to an RDBMS instance.	null
edge_id_strategy	enum[no_ids, keys_as_ids, unstable_generated_ids]	Indicates what ID strategy should be used for the edges of this graph. If not specified (or set to null), the strategy will be determined during loading or using a default value.	null
edge_id_type	enum[long]	Type of the edge ID. Setting it to long requires the IDs in the edge providers to be unique across the graphs; those IDs will be used as global IDs. Setting it to null (or omitting it) will allow repeated IDs across different edge providers and PGX will automatically generate globally-unique IDs for the edges.	null
edge_providers	array of object	List of edge providers in this graph.	[]
error_handling	object	Error handling configuration.	null
external_stores	array of object	Specification of the external stores where external string properties reside.	[]
jdbc_url	string	JDBC URL pointing to an RDBMS instance	null
keystore_alias	string	Alias to the keystore to use when connecting to database.	null

Table 14-4 (Cont.) Graph Config JSON Fields

Field	Type	Description	Default
loading	object	Loading-specific configuration to use.	null
local_date_format	array of string	array of local_date formats to use when loading and storing local_date properties. See DateTimeFormatter for more details of the format string	[]
max_prefetched_rows	integer	Maximum number of rows prefetched during each round trip resultset-database.	10000
num_connections	integer	Number of connections to read and write data from or to the RDBMS table.	<no-of-cpus>
optimized_for	enum[read, updates]	Indicates if the graph should use data-structures optimized for read-intensive scenarios or for fast updates.	read
password	string	Password to use when connecting to database.	null
point2d	string	Longitude and latitude as floating point values separated by a space.	0.0 0.0
prepared_queries	array of object	An additional list of prepared queries with arguments, working in the same way as 'queries'. Data matching at least one those queries will also be loaded.	[]
queries	array of string	A list of queries used to determine which data to load from the database. Data matching at least one of the queries will be loaded. Not setting any query will load the entire graph.	[]
redaction_rules	array of object	Array of redaction rules.	[]
rules_mapping	array of object	Mapping for redaction rules to users and roles.	[]
schema	string	Schema to use when reading or writing RDBMS objects	null
source_name	string	Name of the database graph, if the graph is loaded from a database.	null
source_type	enum[pg_view]	Source type for database graphs.	null
time_format	array of string	The time format to use when loading and storing time properties. See DateTimeFormatter for a documentation of the format string.	[]

Table 14-4 (Cont.) Graph Config JSON Fields

Field	Type	Description	Default
`time_with_timezone_format`	`array of string`	The `time with timezone` format to use when loading and storing time with timezone properties. Please see DateTimeFormatter for more information of the format string.	`[]`
`timestamp_format`	`array of string`	The `timestamp` format to use when loading and storing timestamp properties. See DateTimeFormatter for more information of the format string.	`[]`
`timestamp_with_timezone_format`	`array of string`	The `timestamp with timezone` format to use when loading and storing `timestamp with timezone` properties. See DateTimeFormatter for more information of the format string.	`[]`
`username`	`string`	Username to use when connecting to an RDBMS instance.	`null`
`vector_component_delimiter`	`character`	Delimiter for the different components of vector properties.	`;`
`vertex_id_strategy`	`enum[no_ids, keys_as_ids, unstable_generated_ids]`	Indicates what ID strategy should be used for the vertices of this graph. If not specified (or set to `null`), the strategy will be automatically detected.	`null`
`vertex_id_type`	`enum[int, integer, long, string]`	Type of the vertex ID. For homogeneous graphs, if not specified (or set to `null`), it will default to a specific value (depending on the origin of the data).	`null`
`vertex_providers`	`array of object`	List of vertex providers in this graph.	`[]`

Note:

Database connection fields specified in the graph configuration will be used as default in case underlying data provider configuration does not specify them.

Provider Configuration JSON file Options

You can specify the meta-information about each provider's data using provider configurations. Provider configurations include the following information about the provider data:

- Location of the data: a file, multiple files or database providers
- Information about the properties: name and type of the property

Table 14-5 Provider Configuration JSON file Options

Field	Type	Description	Default
format	enum[pgb, csv, rdbms]	Provider format.	Required
name	string	Entity provider name.	Required
attributes	object	Additional attributes needed to read and write the graph data.	null
destination_vertex_provider	string	Name of the destination vertex provider to be used for this edge provider.	null
error_handling	object	Error handling configuration.	null
has_keys	boolean	Indicates if the provided entities data have keys.	true
key_type	enum[int, integer, long, string]	Type of the keys.	long
keystore_alias	string	Alias to the keystore to use when connecting to database.	null
label	string	label for the entities loaded from this provider.	null
loading	object	Loading-specific configuration.	null
local_date_format	array of string	Array of local_date formats to use when loading and storing local_date properties. See DateTimeFormatter for a documentation of the format string.	[]
password	string	Password to use when connecting to database.	null
point2d	string	Longitude and latitude as floating point values separated by a space.	0.0 0.0
props	array of object	Specification of the properties associated with this entity provider.	[]
source_vertex_provider	string	Name of the source vertex provider to be used for this edge provider.	null
time_format	array of string	The time format to use when loading and storing time properties. See DateTimeFormatter for a documentation of the format string.	[]
time_with_timezone_format	array of string	The time with timezone format to use when loading and storing time with timezone properties. See DateTimeFormatter for a documentation of the format string.	[]
timestamp_format	array of string	The timestamp format to use when loading and storing timestamp properties. See DateTimeFormatter for a documentation of the format string.	[]

Table 14-5 (Cont.) Provider Configuration JSON file Options

Field	Type	Description	Default
`timestamp_with_timezone_format`	`array of string`	The timestamp with timezone format to use when loading and storing timestamp with timezone properties. See DateTimeFormatter for a documentation of the format string.	`[]`
`vector_component_delimiter`	`character`	Delimiter for the different components of vector properties.	`;`

Provider Labels

The `label` field in the provider configuration can be used to set a label for the entities loaded from the provider. If no `label` is specified, all entities from the provider are labeled with the name of the provider. It is only possible to set the same label for two different providers if they have exactly the same properties (same names and same types).

Property Configuration

The `props` entry in the `Provider` configuration is an object with the following JSON fields:

Table 14-6 Property Configuration

Field	Type	Description	Default
`name`	`string`	Name of the property.	Required
`type`	`enum[boolean, integer, vertex, edge, float, long, double, string, date, local_date, time, timestamp, time_with_timezone, timestamp_with_timezone, point2d]`	Type of the property . **Note:** `date` is deprecated, use one of `local_date` / `time` / `timestamp` / `time_with_timezone` / `timestamp_with_timezone` instead). `vertex/edge` are place-holders for the type specified in `vertex_id_type`/`edge_id_type` fields.	Required

Table 14-6 (Cont.) Property Configuration

Field	Type	Description	Default
aggregate	enum[identity, group_key, min, max, avg, sum, concat, count]	[currently unsupported] which aggregation function to use, aggregation always happens by vertex key.	null
column	value	Name or index (starting from 0) of the column holding the property data. If it is not specified, the loader will try to use the property name as column name (for CSV format only).	null
default	value	Default value to be assigned to this property if datasource does not provide it. In case of date type: string is expected to be formatted with yyyy-MM-dd HH:mm:ss. If no default is present (null), non-existent properties will contain default Java types (primitives) or empty string (string) or 01.01.1970 00:00 (date).	null
dimension	integer	Dimension of property.	0
drop_after_loading	boolean	[currently unsupported] indicating helper properties only used for aggregation, which are dropped after loading	false
field	value	Name of the JSON field holding the property data. Nesting is denoted by dot - separation. Field names containing dots are possible, in this case the dots need to be escaped using backslashes to resolve ambiguities. Only the exactly specified object are loaded, if they are non existent, the default value is used.	null
format	array of string	Array of formats of property.	[]
group_key	string	[currently unsupported] can only be used if the property / key is part of the grouping expression.	null
max_distinct_strings_per_pool	integer	*[only relevant if string_pooling_strategy is indexed]* Amount of distinct strings per property after which to stop pooling. If the limit is reached an exception is thrown. If set to null, the default value from the global PGX configuration will be used.	null
stores	array of object	A list of storage identifiers that indicate where this property resides.	[]
string_pooling_strategy	enum[indexed, on_heap, none]	Indicates which string pooling strategy to use. If set to null, the default value from the global PGX configuration will be used.	null

Loading Configuration

The `loading` entry is a JSON object with the following fields:

Table 14-7 Loading Configuration

Field	Type	Description	Default
create_key_mapping	boolean	If `true`, a mapping between entity keys and internal IDs is prepared during loading.	true
filter	string	[currently unsupported] the filter expression	null
grouping_by	array of string	[currently unsupported] array of edge properties used for aggregator. For Vertices, only the ID can be used (default)	[]
load_labels	boolean	Whether or not to load the entity label if it is available.	false
strict_mode	boolean	If `true`, exceptions are thrown and logged with `ERROR` level whenever loader encounters problems with input file, such as invalid format, repeated keys, missing fields, mismatches and other potential errors. If `false`, loader may use less memory during loading phase, but behave unexpectedly with erratic input files.	true

Error Handling Configuration

The `error_handling` entry is a JSON object with the following fields:

Table 14-8 Error Handling Configuration

Field	Type	Description	Default
on_missed_prop_key	enum[silent, log_warn, log_warn_once, error]	Error handling for a missing property key.	log_warn_once
on_missing_vertex	enum[ignore_edge, ignore_edge_log, ignore_edge_log_once, create_vertex, create_vertex_log, create_vertex_log_once, error]	Error handling for a missing source or destination vertex of an edge in a vertex data source.	error
on_parsing_issue	enum[silent, log_warn, log_warn_once, error]	Error handling for incorrect data parsing. If set to silent, `log_warn` or `log_warn_once`, will attempt to continue loading. Some parsing issues may not be recoverable and provoke the end of loading.	error

Table 14-8 (Cont.) Error Handling Configuration

Field	Type	Description	Default
on_prop_conversion	enum[silent, log_warn, log_warn_once, error]	Error handling when encountering a different property type other than the one specified, but coercion is possible.	log_warn_once
on_type_mismatch	enum[silent, log_warn, log_warn_once, error]	Error handling when encountering a different property type other than the one specified, but coercion is *not* possible.	error
on_vector_length_mismatch	enum[silent, log_warn, log_warn_once, error]	Error handling for a vector property that does not have the correct dimension.	error

> **Note:**
>
> The only supported setting for the `on_missing_vertex` error handling configuration is `ignore_edge`.

14.2.1.5 Data Loading Security Best Practices

Loading a graph from the database requires authentication and it is therefore important to adhere to certain security guidelines when configuring access to this kind of data source.

The following guidelines are recommended:

- The user or role used to access the data should be a read-only account that only has access to the required graph data.
- The graph data should be marked as read-only, for example, with non-updateable views in the case of the database.

14.2.1.6 Data Format Support Matrix

Learn about the different data formats supported in the graph server (PGX).

The following table illustrates how the different data formats differ in the way IDs, labels and vector properties are handled.

> **Note:**
>
> The table refers to limitations of the PGX implementation of the format and not necessarily to limitations of the format itself.

Table 14-9 Data Format Support Matrix

Format	Vertex IDs	Edge IDs	Vertex Labels	Edge Labels	Vector properties
PGB	int, long, string	long	multiple	single	supported (vectors can be of type integer, long, float or double)
CSV	int, long, string	long	multiple	single	supported (vectors can be of type integer, long, float or double)
ADJ_LIST	int, long, string	Not supported	Not supported	Not supported	supported (vectors can be of type integer, long, float or double)
EDGE_LIST	int, long, string	Not supported	multiple	single	supported (vectors can be of type integer, long, float or double)
GRAPHML	int, long, string	Not supported	Not supported	Not supported	Not supported

14.2.1.7 Immutability of Loaded Graphs

Once the graph is loaded into the graph server (PGX), the graph and its properties are automatically marked as immutable.

The immutability of loaded graphs is due to the following design choices:

- Typical graph analyses happen on a snapshot of a graph instance, and therefore they do not require mutations of the graph instance.
- Immutability allows PGX to use an internal graph representation optimized for fast analysis.
- In remote mode, the graph instance might be shared among multiple clients.

However, the graph server (PGX) also provides methods to customize and mutate graph instances for the purpose of analysis. See Graph Mutation and Subgraphs for more information.

14.2.2 Storing a Graph Snapshot on Disk

After reading a graph into memory, you can make any changes to the graph (such as running the PageRank algorithm and storing the values as vertex properties), and then store this snapshot of the graph on disk.

If you want to save the state of the graph in memory, then a snapshot of a graph can be saved as a file in binary format (PGB file).

In general, if you must shut down the graph server, then it is recommended that you store all the graph queries and analytics APIs that have been run on the graph. Once the graph server (PGX) is restarted, you can reload the graph and rerun the APIs.

However, if you must save the state of the graph, then the following example explains how to store the graph snapshot on disk.

As a prerequisite for storing the graph snapshot, you need to explicitly authorize access to the corresponding directories by defining a directory object pointing to the directory (on the graph server) that contains the files to read or write.

```
CREATE OR REPLACE DIRECTORY pgx_file_location AS '<path_to_dir>';
GRANT READ, WRITE ON directory pgx_file_location to GRAPH_DEVELOPER;
```

Also, note the following:

- The directory in the `CREATE DIRECTORY` statement must exist on the graph server (PGX).
- The directory must be readable (and/or writable) at the OS level by the graph server (PGX).

The preceding code grants the privileges on the directory to the `GRAPH_DEVELOPER` role. However, you can also grant permissions to an individual user:

```
GRANT READ, WRITE ON DIRECTORY pgx_file_location TO <graph_user>;
```

You can then run the following code to load a property graph view into the graph server (PGX) and save the graph snapshot as a file. Note that multiple PGB files will be generated, one for each vertex and edge provider in the graph.

```
opg4j> var g = session.readGraphByName("BANK_GRAPH",
GraphSource.PG_VIEW)
g ==> PgxGraph[name=BANK_GRAPH_NEW,N=999,E=4993,created=1676021791568]

opg4j> analyst.pagerank(graph)
$8 ==> VertexProperty[name=pagerank,type=double,graph=BANK_GRAPH]

// Now save the state of this graph
opg4j>  var storedPgbConfig = graph.store(ProviderFormat.PGB,
"<path_to_dir>")
```

In a three-tier deployment, the file is written on the server-side file system. You must also ensure that the file location to write is specified in the graph server (PGX). (As explained in Three-Tier Deployments of Oracle Graph with Autonomous Database, in a three-tier deployment, access to the PGX server file system requires a list of allowed locations to be specified.)

14.2.3 Publishing a Graph

You can publish a graph that can be referenced by other sessions.

Publishing a Single Graph Snapshot

The `PgxGraph#publish()` method can be used to publish the current selected snapshot of the graph. The publish operation will move the graph name from the session-private namespace to the public namespace. If a graph with the same name has been already published, then the `publish()` method will fail with an exception. Graphs published with snapshots and single published snapshots share the same namespace.

Table 12-6 describes the grants required to publish a graph.

Note that calling the `publish()` method without arguments publishes the snapshot with its persistent properties only. However, if you want to publish specific transient properties, then you must list them within the `publish()` call as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var prop1 = graph.createVertexProperty(PropertyType.INTEGER, "prop1")
opg4j> prop1.fill(0)
opg4j> var cost = graph.createEdgeProperty(PropertyType.DOUBLE, "cost")
opg4j> cost.fill(0d)
opg4j> graph.publish(List.of(prop1), List.of(cost))
```

Java

```
VertexProperty<Integer, Integer> prop1 =
graph.createVertexProperty(PropertyType.INTEGER, "prop1");
prop1.fill(0);
EdgeProperty<Double> cost = graph.createEdgeProperty(PropertyType.DOUBLE,
"cost");
cost.fill(0d);
List<VertexProperty<Integer, Integer> vertexProps = Arrays.asList(prop);
List<EdgeProperty<Double>> edgeProps = Arrays.asList(cost);
graph.publish(vertexProps, edgeProps);
```

Python

```
prop = graph.create_vertex_property("integer", "prop1")
prop1.fill(0)
cost = graph.create_edge_property("double", "cost")
cost.fill(0d)
vertex_props = [prop]
edge_props = [cost]
graph.publish(vertex_props, edge_props)
```

Publishing a Graph with Snapshots

If you want to make all snapshots of the graph visible to other sessions, then use the `publishWithSnapshots()` method. When a graph is published with snapshots, the `GraphMetaData` information of each snapshot is also made available to the other sessions, with the exception of the graph configuration, which is `null`.

When calling the `publishWithSnapshots()` method, all the persistent properties of all the snapshots are published and made visible to the other sessions. Transient properties are session-private and therefore they must be published explicitly. Once published, all properties become read-only.

Similar to publishing a single graph snapshot, the `publishWithSnapshots()` method will move the graph name from the session-private namespace to the public namespace. If a graph with the same name has been already published, then the `publishWithSnapshots()` method will fail with an exception.

Also, note that the published properties, like the original transient properties, are associated to the specific snapshot on which they were created. Therefore, they are not visible on other snapshots.
If you want to publish specific transient properties, you should list them within the `publishWithSnapshots()` call, as in the following example:

- JShell
- Java
- Python

JShell

```
opg4j> var prop1 = graph.createVertexProperty(PropertyType.INTEGER,
"prop1")
opg4j> prop1.fill(0)
opg4j> var cost = graph.createEdgeProperty(PropertyType.DOUBLE, "cost")
opg4j> cost.fill(0d)
opg4j> graph.publishWithSnapshots(List.of(prop1), List.of(cost))
```

Java

```
VertexProperty<Integer, Integer> prop1 =
graph.createVertexProperty(PropertyType.INTEGER, "prop1");
prop1.fill(0);
EdgeProperty<Double> cost =
graph.createEdgeProperty(PropertyType.DOUBLE, "cost");
cost.fill(0d);
List<VertexProperty<Integer, Integer> vertexProps =
Arrays.asList(prop);
List<EdgeProperty<Double>> edgeProps = Arrays.asList(cost);
graph.publishWithSnapshots(vertexProps,edgeProps);
```

Python

```
VertexProperty<Integer, Integer> prop1 =
graph.createVertexProperty(PropertyType.INTEGER, "prop1")
prop1.fill(0)
EdgeProperty<Double> cost =
graph.createEdgeProperty(PropertyType.DOUBLE, "cost")
```

```
cost.fill(0d)
List<VertexProperty<Integer, Integer> vertexProps = Arrays.asList(prop)
List<EdgeProperty<Double>> edgeProps = Arrays.asList(cost)
graph.publishWithSnapshots(vertexProps,edgeProps)
```

Referencing a Published Graph from Another Session

You can reference a published graph by its name in another session, using the `PgxSession#getGraph()` method.

The following example references a published graph `myGraph` in a new session (`session2`):

- JShell
- Java
- Python

JShell

```
opg4j> var session2 = instance.createSession("session2")
opg4j> var graph2 = session2.getGraph(Namespace.PUBLIC, "myGraph")
```

Java

```
PgxSession session2 = instance.createSession("session2");
PgxGraph graph2 = session2.getGraph(Namespace.PUBLIC, "myGraph");
```

Python

```
session2 = pypgx.get_session("session2");
PgxGraph graph2 = session2.get_graph("myGraph")
```

`session2` can access only the published snapshot. If the graph has been published without snapshots, calling the `getAvailableSnapshots()` method will return an empty queue.

In case if the graph snapshots have been published, then the call to `getGraph()` returns the most recent available snapshot. `session2` can see all the available snapshots through the `getAvailableSnapshots()` method. You can then set a specific snapshot using the `PgxSession#setSnapshot()` method.

> **Note:**
>
> If a referenced graph is not required anymore, then it is important that you release the graph. See Deleting a Graph for more information.

Publishing a Property

After publishing (a single snapshot or all of them), you can still publish transient properties individually. Published properties are associated to a specific snapshot on which they are created, and hence visible only on that snapshot.

- JShell
- Java
- Python

JShell

```
opg4j> graph.getVertexProperty("prop1").publish()
opg4j> graph.getEdgeProperty("cost").publish()
```

Java

```
graph.getVertexProperty("prop1").publish();
graph.getEdgeProperty("cost").publish();
```

Python

```
graph.get_vertex_property("prop1").publish()
graph.get_edge_property("cost").publish()
```

Getting a Published Property in Another Session

Sessions referencing a published graph (with or without snapshots) can reference a published property through the `PgxGraph#getVertexProperty` and `PgxGraph#getEdgeProperty`.

- JShell
- Java
- Python

JShell

```
opg4j> var session2 = instance.createSession("session2")
opg4j> var graph2 = session2.getGraph(Namespace.PUBLIC, "myGraph")
opg4j> var vertexProperty = graph2.getVertexProperty("prop1")
opg4j> var edgeProperty = graph2.getEdgeProperty("cost")
```

Java

```
PgxSession session2 = instance.createSession("session2");
PgxGraph graph2 = session2.getGraph(Namespace.PUBLIC, "myGraph");
VertexProperty<Integer, Integer> vertexProperty =
graph2.getVertexProperty("prop1");
EdgeProperty<Double> edgeProperty = graph2.getEdgeProperty("cost");
```

Python

```
session2 = pypgx.get_session(session_name ="session2")
graph2 = session2.get_graph("myGraph")
vertex_property = graph2.get_vertex_property("prop1")
edge_property = graph2.get_edge_property("cost")
```

Pinning a Published Graph

You can pin a published graph so that it remains published even if no session uses it.

- JShell
- Java
- Python

JShell

```
opg4j> graph.pin()
```

Java

```
graph.pin();
```

Python

```
>>> graph.pin()
```

Unpinning a Published Graph

You can unpin a published graph that was earlier pinned. By doing this, you can remove the graph and all its snapshots, if no other session is using a snapshot of the graph.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.getGraph("bank_graph_analytics")
graph ==>
PgxGraph[name=bank_graph_analytics,N=999,E=4993,created=1660217577201]
opg4j> graph.unpin()
```

Java

```
PgxGraph graph = session.getGraph("bank_graph_analytics");
graph.unpin();
```

Python

```
>>> graph = session.get_graph("bank_graph_analytics")
>>> graph.unpin()
```

Related Topics

- Namespaces and Sharing
  The graph server (PGX) supports separate namespaces that help you to organize your entities.

14.2.4 Deleting a Graph

In order to reduce the memory usage of the graph server (PGX), the session must drop the unused graph objects created through the `getGraph()` method, by invoking the `destroy()` method.

Calling the `destroy()` method not only destroys the specified graph, but all of its associated properties, including transient properties as well. In addition, all of the collections related to the graph instance (for example, a `VertexSet`) are also destroyed automatically. If a session holds multiple `PgxGraph` objects referencing the same graph, invoking `destroy()` on any of them will invalidate all the `PgxGraph` objects referencing that graph, making any operation on those objects fail.

For example:

- JShell
- Java
- Python

JShell

```
opg4j> var graph1 = session.getGraph("myGraphName")
opg4j> var graph2 = session.getGraph("myGraphName")
opg4j> graph2.destroy()                                    // Delete graph2
opg4j> var properties = graph1.getVertexProperties() //throws an exception
as graph1 reference is not valid anymore
opg4j> properties = graph2.getVertexProperties()     //throws an exception
as graph2 reference is not valid anymore
```

Java

```
PgxGraph graph1 = session.getGraph("myGraphName");

// graph2 references the same graph of graph1
PgxGraph graph2 = session.getGraph("myGraphName");

// Delete graph2
graph2.destroy();

// Both the following calls throw an exception, as both references are not
valid anymore
Set<VertexProperty<?, ?>> properties = graph1.getVertexProperties();
properties = graph2.getVertexProperties();
```

Python

```
graph1 = session.get_graph("myGraphName")

# graph2 references the same graph of graph1
 graph2 = session.get_graph("myGraphName")

# Delete graph2
graph2.destroy()

# Both the following calls throw an exception, as both references are not
valid anymore
properties = graph1.get_vertex_properties()
properties = graph2.get_vertex_properties()
```

The same behavior occurs when multiple `PgxGraph` objects reference the same snapshot. Since a snapshot is effectively a graph, destroying a `PgxGraph` object referencing a certain snapshot invalidates all `PgxGraph` objects referencing the same snapshot, but does not invalidate those referencing other snapshots:

```
// Get a snapshot of "myGraphName"
PgxGraph graph1 = session.getGraph("myGraphName");

// graph2 and graph3 reference the same snapshot as graph1
PgxGraph graph2 = session.getGraph("myGraphName");
PgxGraph graph3 = session.getGraph("myGraphName");

// Assume another snapshot is created ...

// Make graph3 references the latest snapshot available
session.setSnapshot(graph3, PgxSession.LATEST_SNAPSHOT);
graph2.destroy();

// Both the following calls throw an exception, as both references are
not valid anymore
Set<VertexProperty<?, ?>> properties = graph1.getVertexProperties();
properties = graph2.getVertexProperties();

// graph3 is still valid, so the call succeeds
properties = graph3.getVertexProperties();
```

> **Note:**
>
> Even if a graph is destroyed by a session, the graph data may still remain in the server memory, if the graph is currently shared by other sessions. In such a case, the graph may still be visible among the available graphs through the `PgxSession.getGraphs()` method.

As a safe alternative to the manual removal of each graph, the PGX API supports some implicit resource management features which allow developers to safely omit the `destroy()` call. See Resource Management Considerations for more information.

14.3 Keeping the Graph in Oracle Database Synchronized with the Graph Server

You can use the `FlashbackSynchronizer` API to automatically apply changes made to graph in the database to the corresponding `PgxGraph` object in memory, thus keeping both synchronized.

This API uses Oracle's Flashback Technology to fetch the changes in the database since the last fetch and then push those changes into the graph server using the `ChangeSet` API. After the changes are applied, the usual snapshot semantics of the graph server apply: each delta fetch application creates a new in-memory snapshot. Any queries or algorithms that are executing concurrently to snapshot creation are unaffected by the changes until the corresponding session refreshes its `PgxGraph` object to the latest state by calling the `session.setSnapshot(graph, PgxSession.LATEST_SNAPSHOT)` procedure.

Also, if the changes from the previous fetch operation no longer exist, then the synchronizer will throw an exception. This occurs if the previous fetch duration is longer than the `UNDO_RETENTION` parameter setting in the database. To avoid this exception, ensure to fetch the changes at intervals less than the `UNDO_RETENTION` parameter value. The default setting for the `UNDO_RETENTION` parameter is `900` seconds. See *Oracle Database Reference* for more information.

Prerequisites for Synchronizing

The Oracle database must have Flashback enabled and the database user that you use to perform synchronization must have:

- Read access to all tables which need to be kept synchronized.
- Permission to use flashback APIs. For example:

```
GRANT EXECUTE ON DBMS_FLASHBACK TO <user>
```

The database must also be configured to retain changes for the amount of time needed by your use case.

Types of graphs that can be synchronized

Not all `PgxGraph` objects in PGX can be synchronized. The following limitations apply:

- Only the original creator of the graph can synchronize it. That is, the current user must have the MANAGE permission of the graph.
- Only graphs loaded from database tables (PG View graphs) can be synchronized. Graphs created from other formats or graphs created via the graph builder API or PG View graphs created from database views cannot be synchronized.
- Only the *latest snapshot* of a graph can be synchronized.

Types of changes that can be synchronized

The synchronizer supports keeping the in-memory graph snapshot in sync with the following database-side modifications:

- insertion of new vertices and edges
- removal of existing vertices and edges
- update of property values of any vertex or edge

The synchronizer does not support schema-level changes to the input graph, such as:

- alteration of the list of input vertex or edge tables
- alteration of any columns of any input tables (vertex or edge tables)

Furthermore, the synchronizer does not support updates to vertex and edge keys.

For a detailed example, see the following topic:

- Synchronizing a PG View Graph
  You can synchronize a graph loaded into the graph server (PGX) from a property graph view (PG View) with the changes made to the graph in the database.

- Synchronizing a Published Graph
  You can synchronize a published graph by configuring the Flashback Synchronizer with a `PartitionedGraphConfig` object containing the graph schema along with the database connection details.

14.3.1 Synchronizing a PG View Graph

You can synchronize a graph loaded into the graph server (PGX) from a property graph view (PG View) with the changes made to the graph in the database.

The following example shows the steps for synchronizing a PG View using the FlashbackSynchronizer API:

1. Load the PG View graph into the graph server (PGX) using the `readGraphByName()` API as shown:

   - JShell
   - Java
   - Python

   ### JShell

```
opg4j> var graph =
session.readGraphByName("BANK_GRAPH_VIEW",GraphSource.PG_VIEW,

ReadGraphOption.optimizeFor(GraphOptimizedFor.UPDATES),ReadGraphOpti
on.synchronizable())
graph ==>
PgxGraph[name=BANK_GRAPH_VIEW,N=999,E=4993,created=1660275936010]
```

   ### Java

```
PgxGraph graph =
session.readGraphByName("BANK_GRAPH_VIEW",GraphSource.PG_VIEW,

ReadGraphOption.optimizeFor(GraphOptimizedFor.UPDATES),ReadGraphOpti
on.synchronizable());
```

   ### Python

```
>>> graph = session.read_graph_by_name('BANK_GRAPH_VIEW','pg_view')
```

2. Open a new JDBC connection to the database and change the data in the underlying database tables for the PG View graph. For example, the following code updates the database value for one of the edge properties:

- JShell
- Java
- Python

JShell

```
opg4j> var conn = 
DriverManager.getConnection(<jdbcUrl>,<username>,<password>)
conn ==> oracle.jdbc.driver.T4CConnection@60f7261f
opg4j> var stmt = conn.createStatement()
stmt ==> oracle.jdbc.driver.OracleStatementWrapper@1a914a00
opg4j> stmt.executeQuery("UPDATE bank_txns SET amount=4000 WHERE 
txn_id=3")
$5 ==> oracle.jdbc.driver.ForwardOnlyResultSet@627d5f99
opg4j> conn.setAutoCommit(false)
opg4j> conn.commit()
```

Java

```
Connection conn = 
DriverManager.getConnection(<jdbcUrl>,<username>,<password>);
Statement stmt = conn.createStatement();
stmt.executeQuery("UPDATE bank_txns SET amount=4000 WHERE txn_id=3");
conn.setAutoCommit(false);
conn.commit();
```

Python

```
>>> conn = opg4py.pgql.get_connection(<username>,<password>,
<jdbcUrl>).get_jdbc_connection()
>>> conn.prepareStatement("UPDATE bank_txns SET amount=4000 WHERE 
txn_id=3").execute()
False
>>> conn.commit()
```

Committing the changes to the database causes the graph in the memory to go out of sync with the database source tables.

3. Synchronize the in-memory graph with the database by creating a new synchronizer object as shown in the following code:

```
Synchronizer synchronizer = new 
Synchronizer.Builder<FlashbackSynchronizer>()
    .setType(FlashbackSynchronizer.class)
    .setGraph(graph)
    .setConnection(conn)
    .build();
```

Internally, the graph server keeps track of the Oracle system change number (SCN) the current graph snapshot belongs to. The synchronizer is a client-side component which connects to the database, detects changes by comparing state of the original input tables using the current SCN via the flashback mechanism and then sends any changes to the graph server using the changeset API. In order to do so, the synchronizer needs to know how to connect to the database (`conn` parameter) as well as which graph to keep in sync (`graph` parameter).

Alternatively, you can use this equivalent shortcut as shown:

- JShell
- Java
- Python

JShell

```
opg4j>  var synchronizer =
graph.createSynchronizer(FlashbackSynchronizer.class, conn)
synchronizer ==> oracle.pgx.api.FlashbackSynchronizer@4ac2b4c6
```

Java

```
Synchronizer synchronizer =
graph.createSynchronizer(FlashbackSynchronizer.class, conn);
```

Python

```
>>> synchronizer =
graph.create_synchronizer(synchronizer_class='oracle.pgx.api.Flashba
ckSynchronizer', connection=conn)
```

4. Fetch and apply the database changes by calling the sync() function and create a new in-memory graph snapshot:

- JShell
- Java
- Python

JShell

```
opg4j> graph=synchronizer.sync()
g ==> PgxGraph[name=BANK_GRAPH_VIEW,N=999,E=4993,created=1660308128037]
```

Java

```
graph=synchronizer.sync();
```

Python

```
>>> graph = synchronizer.sync()
```

Splitting the Fetching and Applying of Changes

The `synchronizer.sync()` invocation in the preceding code, fetches the changes and applies them in one call. However, you can encode a more complex update logic by splitting this process into separate `fetch()` and `apply()` invocations. For example:

```
synchronizer.fetch(); // fetches changes from the database
if (synchronizer.getGraphDelta().getTotalNumberOfChanges() > 100) {  //
only create snapshot if there have been more than 100 changes
  synchronizer.apply();
}
```

5. Query the graph to verify the updates to the edge property.

- JShell
- Java
- Python

JShell

```
opg4j> graph.queryPgql("SELECT e.amount FROM MATCH (v1:Accounts)-
[e:Transfers]->(v2:Accounts) WHERE e.from_acct_id = 179 AND
e.to_acct_id=688").print()
```

Java

```
graph.queryPgql("SELECT e.amount FROM MATCH (v1:Accounts)-[e:Transfers]-
>(v2:Accounts) WHERE e.from_acct_id = 179 AND e.to_acct_id=688").print();
```

Python

```
>>> graph.query_pgql("SELECT e.amount FROM MATCH (v1:Accounts)-
[e:Transfers]->(v2:Accounts) WHERE e.from_acct_id = 179 AND
e.to_acct_id=688").print()
```

On execution, the preceding example produces the following output:

```
+--------+
| amount |
+--------+
| 4000.0 |
+--------+
```

14.3.2 Synchronizing a Published Graph

You can synchronize a published graph by configuring the Flashback Synchronizer with a `PartitionedGraphConfig` object containing the graph schema along with the database connection details.

The `PartitionedGraphConfig` object can be created either through the `PartitionedGraphConfigBuilder` API or by reading the graph configuration from a JSON file.
Though synchronization of graphs created via graph configuration objects is supported in general, the following few limitations apply:

- Only partitioned graph configurations with all providers being database tables are supported.
- Each edge or vertex provider or both must specify the owner of the table by setting the username field. For example, if user `SCOTT` owns the table, then set the user name accordingly for the providers.
- Snapshot source must be set to `CHANGE_SET`.
- It is highly recommended to optimize the graph for update operations in order to avoid memory exhaustion when creating many snapshots.

The following example shows the sample configuration for creating the `PartitionedGraphConfig` object:

- JSON Configuration
- GraphConfigBuilder API

JSON Configuration

```
{
  ...
  "optimized_for": "updates",
  "vertex_providers": [
```

```
        ...
        "username":"<username>",
        ...
    ],
    "edge_providers": [
        ...
        "username":"<username>",
        ...
    ],
    "loading": {
      "snapshots_source": "change_set"
    }
}
```

GraphConfigBuilder API

```
GraphConfig cfg = GraphConfigBuilder.forPartitioned()
                      …
                      .setUsername("<username>")
                      .setSnapshotsSource(SnapshotsSource.CHANGE_SET)
                      .setOptimizedFor(GraphOptimizedFor.UPDATES)
                      ...
                      .build();
```

As a prerequisite requirement, you must have a graph that is published in an earlier session. For example:

- JShell
- Java
- Python

JShell

```
opg4j> var graph =
session.readGraphWithProperties("<path_to_json_config_file>")
graph ==>
PgxGraph[name=bank_graph_analytics_fb,N=999,E=4993,created=1664310157103]
opg4j> graph.publishWithSnapshots()
```

Java

```
PgxGraph graph =
session.readGraphWithProperties("<path_to_json_config_file>");
graph.publishWithSnapshots();
```

Python

```
>>> graph =
session.read_graph_with_properties("<path_to_json_config_file>")
>>> graph.publish_with_snapshots()
```

You can now perform the following steps to synchronize the published graph using a graph configuration object which is built from a JSON file.

1. Get the published graph as shown:

   - JSonShell
   - Java
   - Python

   ## JShell

   ```
   opg4j> var graph = session.getGraph("bank_graph")
   graph ==>
   PgxGraph[name=bank_graph_analytics_fb,N=999,E=4993,created=166431015
   7103]
   ```

   ## Java

   ```
   PgxGraph graph = session.getGraph("bank_graph");
   ```

   ## Python

   ```
   >>> graph = session.get_graph("bank_graph")
   ```

2. Build the graph configuration object using a JSON file path as shown:

   - JShell
   - Java
   - Python

   ## JShell

   ```
   opg4j> var cfg =
   GraphConfigFactory.forPartitioned().fromFilePath("path_to_json_confi
   ```

```
g_file")
cfg ==> {"edge_providers":
[{"destination_vertex_provider":"Accounts","database_table_name":"BANK_TXN
S","name":"Transfers","key_type":"long",
"props":[{"type":"float","name":"AMOUNT"},
{"type":"string","name":"DESCRIPTION"}],"format":"rdbms","source_vertex_pr
ovider":"Accounts",
"source_column":"FROM_ACCT_ID","key_column":"TXN_ID","destination_column":
"TO_ACCT_ID","loading":{"create_key_mapping":true}}],
"loading":
{"snapshots_source":"CHANGE_SET"},"name":"bank_graph","vertex_providers":
[{"database_table_name":"BANK_ACCOUNTS",
"key_column":"ID","name":"Accounts","key_type":"integer","props":
[{"type":"integer","name":"ID"},{"type":"string","name":"NAME"}],
"loading":{"create_key_mapping":true},"format":"rdbms"}]}
```

Java

```
PartitionedGraphConfig cfg =
GraphConfigFactory.forPartitioned().fromFilePath("path_to_json_config_file
");
```

Python

```
>>> from pypgx.api import GraphConfigFactory
>>> cfg =
GraphConfigFactory.for_partitioned().from_file_path("path_to_json_config_f
ile")
```

Alternatively, you can also build the graph configuration object using the `GraphConfigBuilder` API as shown in Loading a Graph by Defining a Graph Configuration Object.

3. Change the data in the database table using the JDBC connection:

- JShell
- Java
- Python

JShell

```
opg4j> var conn =
DriverManager.getConnection(<jdbcUrl>,<username>,<password>)
conn ==> oracle.jdbc.driver.T4CConnection@60f7261f
opg4j> var stmt = conn.createStatement()
stmt ==> oracle.jdbc.driver.OracleStatementWrapper@1a914a00
opg4j> stmt.executeQuery("UPDATE bank_txns SET amount=9000 WHERE
```

```
txn_id=3")
$5 ==> oracle.jdbc.driver.ForwardOnlyResultSet@627d5f99
opg4j> conn.setAutoCommit(false)
opg4j> conn.commit()
```

Java

```
Connection conn =
DriverManager.getConnection(<jdbcUrl>,<username>,<password>);
Statement stmt = conn.createStatement();
stmt.executeQuery("UPDATE bank_txns SET amount=9000 WHERE
txn_id=3");
conn.setAutoCommit(false);
conn.commit();
```

Python

```
>>> conn = opg4py.pgql.get_connection("graphuser","graphuser",
"jdbc:oracle:thin:@localhost:1521/orclpdb").get_jdbc_connection()
>>> conn.prepareStatement("UPDATE bank_txns SET amount=9000 WHERE
txn_id=3").execute()
False
>>> conn.commit()
```

4. Configure the Flashback synchronizer using the graph configuration object and the connection details:

- JShell
- Java
- Python

JShell

```
opg4j> var synchronizer = new
Synchronizer.Builder<FlashbackSynchronizer>().
...>       setType(FlashbackSynchronizer.class).
...>       setGraph(graph).
...>       setConnection(conn).
...>       setGraphConfiguration(cfg).
...>       build()
synchronizer ==> oracle.pgx.api.FlashbackSynchronizer@1f122cbb
```

Java

```
Synchronizer synchronizer = new
Synchronizer.Builder<FlashbackSynchronizer>()
```

```
    .setType(FlashbackSynchronizer.class)
    .setGraph(graph)
    .setConnection(conn)
    .setGraphConfiguration(cfg)
    .build();
```

Python

```
>>> synchronizer =
graph.create_synchronizer(synchronizer_class='oracle.pgx.api.FlashbackSync
hronizer',
                          connection=conn, graph_config=cfg)
```

5. Synchronize the published graph as shown:

- JShell
- Java
- Python

JShell

```
opg4j> graph=synchronizer.sync()
graph ==> PgxGraph[name=bank_graph,N=999,E=4993,created=1664454171605]
```

Java

```
graph=synchronizer.sync();
```

Python

```
>>> graph = synchronizer.sync()
```

6. Query the graph to verify the updates to the edge property.

- JShell
- Java
- Python

JShell

```
opg4j> graph.queryPgql("SELECT e.amount FROM MATCH (v1:Accounts)-
[e:Transfers]->(v2:Accounts) WHERE v1.ID=179 and v2.ID=688").print()
```

Java

```
graph.queryPgql("SELECT e.amount FROM MATCH (v1:Accounts)-
[e:Transfers]->(v2:Accounts) WHERE v1.ID=179 and
v2.ID=688").print();
```

Python

```
graph.query_pgql("SELECT e.amount FROM MATCH (v1:Accounts)-
[e:Transfers]->(v2:Accounts) WHERE v1.ID=179 and
v2.ID=688").print();
```

On execution, the preceding example produces the following output:

```
+--------+
| amount |
+--------+
| 9000.0 |
+--------+
```

14.4 Optimizing Graphs for Read Versus Updates in the Graph Server (PGX)

The graph server (PGX) can store an optimized graph for other reads or updates. This is only relevant when the updates are made directly to a graph instance in the graph server.

Graph Optimized for Reads

Graphs optimized for reads will provide the best performance for graph analytics and PGQL queries. In this case there could be potentially higher latencies to update the graph (adding or removing vertex and edges or updating the property values of previously existing vertex or edges through `GraphChangeSet` API). There could also be higher memory consumption. When using graphs optimized for reads, each updated graph or graph snapshot consumes memory proportional to the size of the graph in terms of vertices and edges.

The `optimized_for` configuration property can be set to `reads` when loading the graph into the graph server (PGX) to create a graph instance that is optimized for reads.

Graph Optimized for Updates

Graphs optimized for updates use a representation enabling low-latency update of graphs. With this representation, the graph server can reach millisecond-scale latencies when updating graphs with millions of vertices and edges (this is indicative and will vary depending on the hardware configuration).

To achieve faster update operations, graph server avoids as much as possible doing a full duplication of the previous graph (snapshot) to create a new graph (snapshot). This also improves the memory consumption (in typical scenarios). New snapshots (or new graphs) will only consume additional memory proportional to the memory required for the changes applied.

In this representation, there could be lower performance of graph queries and analytics.

The `optimized_for` configuration property can be set to `updates` when loading the graph into the graph server (PGX) to create a graph instance that is optimized for reads.

14.5 Executing Built-in Algorithms

The graph server (PGX) contains a set of built-in algorithms that are available as Java APIs.

The following table provides an overview of the available algorithms, grouped by category. Note that these algorithms can be invoked through the Analyst Class.

> **Note:**
>
> See the supported Built-In Algorithms on GitHub for more details.

Table 14-10 Overview of Built-In Algorithms

Category	Algorithms
Classic graph algorithms	Prim's Algorithm
Community detection	Conductance Minimization (Soman and Narang Algorithm), Infomap, Label Propagation, Louvain
Connected components	Strongly Connected Components, Weakly Connected Components (WCC)
Link predition	WTF (Whom To Follow) Algorithm
Matrix factorization	Matrix Factorization
Other	Graph Traversal Algorithms
Path finding	All Vertices and Edges on Filtered Path, Bellman-Ford Algorithms, Bidirectional Dijkstra Algorithms, Compute Distance Index, Compute High-Degree Vertices, Dijkstra Algorithms, Enumerate Simple Paths, Fast Path Finding, Fattest Path, Filtered Fast Path Finding, Hop Distance Algorithms
Ranking and walking	Closeness Centrality Algorithms, Degree Centrality Algorithms, Eigenvector Centrality, Hyperlink-Induced Topic Search (HITS), PageRank Algorithms, Random Walk with Restart, Stochastic Approach for Link-Structure Analysis (SALSA) Algorithms, Vertex Betweenness Centrality Algorithms
Structure evaluation	Adamic-Adar index, Bipartite Check, Conductance, Cycle Detection Algorithms, Degree Distribution Algorithms, Eccentricity Algorithms, K-Core, Local Clustering Coefficient (LCC), Modularity, Partition Conductance, Reachability Algorithms, Topological Ordering Algorithms, Triangle Counting Algorithms

This following topics describe the use of the graph server (PGX) using Triangle Counting and PageRank analytics as examples.

- About Built-In Algorithms in the Graph Server (PGX)
- Running the Triangle Counting Algorithm
- Running the PageRank Algorithm

14.5.1 About Built-In Algorithms in the Graph Server (PGX)

The graph server (PGX) contains a set of built-in algorithms that are available as Java APIs. The details of the APIs are documented in the Javadoc that is included in the product documentation library. Specifically, see the `BuiltinAlgorithms` interface Method Summary for a list of the supported in-memory analyst methods.

For example, this is the PageRank procedure signature:

```
/**
   * Classic pagerank algorithm. Time complexity: O(E * K) with E =
number of edges, K is a given constant (max
   * iterations)
   *
   * @param graph
   *          graph
   * @param e
   *          maximum error for terminating the iteration
   * @param d
   *          damping factor
   * @param max
   *          maximum number of iterations
   * @return Vertex Property holding the result as a double
   */
  public <ID extends Comparable<ID>> VertexProperty<ID, Double>
pagerank(PgxGraph graph, double e, double d, int max);
```

14.5.2 Running the Triangle Counting Algorithm

For triangle counting, the `sortByDegree` boolean parameter of `countTriangles()` allows you to control whether the graph should first be sorted by degree (`true`) or not (`false`). If `true`, more memory will be used, but the algorithm will run faster; however, if your graph is very large, you might want to turn this optimization off to avoid running out of memory.

- JShell
- Java

JShell

```
opg4j> analyst.countTriangles(graph, true)
==> 1
```

Java

```
import oracle.pgx.api.*;

Analyst analyst = session.createAnalyst();
long triangles = analyst.countTriangles(graph, true);
```

The algorithm finds one triangle in the sample graph.

> **Tip:**
>
> When using the graph shell, you can increase the amount of log output during execution by changing the logging level. See information about the `:loglevel` command with `:h :loglevel`.

14.5.3 Running the PageRank Algorithm

PageRank computes a rank value between `0` and `1` for each vertex (node) in the graph and stores the values in a `double` property. The algorithm therefore creates a *vertex property* of type `double` for the output.

In the graph server (PGX), there are two types of vertex and edge properties:

- **Persistent Properties**: Properties that are loaded with the graph from a data source are fixed, in-memory copies of the data on disk, and are therefore persistent. Persistent properties are read-only, immutable and shared between sessions.
- **Transient Properties**: Values can only be written to transient properties, which are private to a session. You can create transient properties by calling `createVertexProperty` and `createEdgeProperty` on `PgxGraph` objects, or by copying existing properties using `clone()` on Property objects.

  Transient properties hold the results of computation by algorithms. For example, the PageRank algorithm computes a rank value between 0 and 1 for each vertex in the graph and stores these values in a transient property named `pg_rank`. Transient properties are destroyed when the Analyst object is destroyed.

This example obtains the top three vertices with the highest PageRank values. It uses a transient vertex property of type `double` to hold the computed PageRank values. The PageRank algorithm uses the following default values for the input parameters: error (tolerance = 0.001), damping factor = 0.85, and maximum number of iterations = 100.

- JShell
- Java

JShell

```
opg4j> rank = analyst.pagerank(graph, 0.001, 0.85, 100);
==> ...
```

```
opg4j> rank.getTopKValues(3)
==> 128=0.1402019732468347
==> 333=0.12002296283541904
==> 99=0.09708583862990475
```

Java

```
import java.util.Map.Entry;
import oracle.pgx.api.*;

Analyst analyst = session.createAnalyst();
VertexProperty<Integer, Double> rank = analyst.pagerank(graph, 0.001,
0.85, 100);
for (Entry<Integer, Double> entry : rank.getTopKValues(3)) {
 System.out.println(entry.getKey() + "=" + entry.getValue());
}
```

14.6 Using Custom PGX Graph Algorithms

A custom PGX graph algorithm allows you to write a graph algorithm in Java syntax and have it automatically compiled to an efficient parallel implementation.

- Writing a Custom PGX Algorithm
- Compiling and Running a Custom PGX Algorithm
- Example Custom PGX Algorithm: PageRank

14.6.1 Writing a Custom PGX Algorithm

A PGX algorithm is a regular .java file with a single class definition that is annotated with `@GraphAlgorithm`. For example:

```
import oracle.pgx.algorithm.annotations.GraphAlgorithm;

@GraphAlgorithm
public class MyAlgorithm {
    ...
}
```

A PGX algorithm class must contain exactly one public method which will be used as entry point. The class may contain any number of private methods.

For example:

```
import oracle.pgx.algorithm.PgxGraph;
import oracle.pgx.algorithm.VertexProperty;
import oracle.pgx.algorithm.annotations.GraphAlgorithm;
import oracle.pgx.algorithm.annotations.Out;

@GraphAlgorithm
```

```
public class MyAlgorithm {
    public int myAlgorithm(PgxGraph g, @Out VertexProperty<Integer>
distance) {
        System.out.println("My first PGX Algorithm program!");

        return 42;
    }
}
```

As with normal Java methods, a PGX algorithm method only supports primitive data types as return values (an integer in this example). More interesting is the `@Out` annotation, which marks the vertex property `distance` as output parameter. The caller passes output parameters by reference. This way, the caller has a reference to the modified property after the algorithm terminates.

- Collections
- Iteration
- Reductions

14.6.1.1 Collections

To create a collection you call the .create() function. For example, a VertexProperty<Integer> is created as follows:

```
VertexProperty<Integer> distance = VertexProperty.create();
```

To get the value of a property at a certain vertex `v`:

```
distance.get(v);
```

Similarly, to set the property of a certain vertex `v` to a value `e`:

```
distance.set(v, e);
```

You can even create properties of collections:

```
VertexProperty<VertexSequence> path = VertexProperty.create();
```

However, PGX Algorithm assignments are always *by value* (as opposed to *by reference*). To make this explicit, you *must* call `.clone()` when assigning a collection:

```
VertexSequence sequence = path.get(v).clone();
```

Another consequence of values being passed *by value* is that you can check for equality using the `==` operator instead of the Java method `.equals()`. For example:

```
PgxVertex v1 = G.getRandomVertex();
PgxVertex v2 = G.getRandomVertex();
System.out.println(v1 == v2);
```

14.6.1.2 Iteration

The most common operations in PGX algorithms are iterations (such as looping over all vertices, and looping over a vertex's neighbors) and graph traversal (such as breath-first/depth-first). All collections expose a `forEach` and `forSequential` method by which you can iterate over the collection in parallel and in sequence, respectively.

For example:

- To iterate over a graph's vertices in parallel:

  ```
  G.getVertices().forEach(v -> {
      ...
  });
  ```

- To iterate over a graph's vertices in sequence:

  ```
  G.getVertices().forSequential(v -> {
      ...
  });
  ```

- To traverse a graph's vertices from `r` in breadth-first order:

  ```
  import oracle.pgx.algorithm.Traversal;

  Traversal.inBFS(G, r).forward(n -> {
      ...
  });
  ```

  Inside the `forward` (or `backward`) lambda you can access the current level of the BFS (or DFS) traversal by `calling currentLevel()`.

14.6.1.3 Reductions

Within these parallel blocks it is common to atomically update, or reduce to, a variable defined outside the lambda. These atomic reductions are available as methods on `Scalar<T>: reduceAdd, reduceMul, reduceAnd`, and so on. For example, to count the number of vertices in a graph:

```
public int countVertices() {
    Scalar<Integer> count = Scalar.create(0);

    G.getVertices().forEach(n -> {
        count.reduceAdd(1);
    });

    return count.get();
}
```

Sometimes you want to update multiple values atomically. For example, you might want to find the smallest property value as well as the vertex whose property value attains this smallest value. Due to the parallel execution, two separate reduction statements might get you in an inconsistent state.

To solve this problem the `Reductions` class provides `argMin` and `argMax` functions. The first argument to `argMin` is the current value and the second argument is the potential new minimum. Additionally, you can chain `andUpdate` calls on the `ArgMinMax` object to indicate other variables and the values that they should be updated to (atomically). For example:

```
VertexProperty<Integer> rank = VertexProperty.create();
int minRank = Integer.MAX_VALUE;
PgxVertex minVertex = PgxVertex.NONE;

G.getVertices().forEach(n ->
    argMin(minRank, rank.get(n)).andUpdate(minVertex, n)
);
```

14.6.2 Compiling and Running a Custom PGX Algorithm

To be able to compile and run a custom PGX algorithm, you must perform the following actions:

> **Note:**
>
> Compiling a custom PGX Algorithm using the PGX Algorithm API is not supported on Oracle JDK 17.

1. Set the following two configuration parameters in the `conf/pgx.conf` file:
   - Set the `graph_algorithm_language` option to `JAVA`.
   - Set the `java_home_dir` option to the path to your Java home (use `<system-java-home-dir>` to have PGX infer Java home from the system properties).

   ```
   {
     "graph_algorithm_language": "JAVA",
     "java_home_dir": "<system-java-home-dir>"
   }
   ```

2. Create a session.

   - JShell
   - Java
   - Python

   ### JShell

   ```
   cd /opt/oracle/graph
   ./bin/opg4j
   ```

Java

```
import oracle.pgx.algorithm.*;
PgxSession session = Pgx.createSession("my-session");
```

Python

```
session = instance.create_session("my-session")
```

3. Compile a PGX Algorithm. For example:

- JShell
- Java
- Python

JShell

```
opg4j> var myAlgorithm = session.compileProgram("/path/to/
MyAlgorithm.java")
myAlgorithm ==> CompiledProgram[name=MyAlgorithm]
```

Java

```
import oracle.pgx.algorithm.CompiledProgram;
CompiledProgram myAlgorithm = session.compileProgram("/path/to/
MyAlgorithm.java");
```

Python

```
my_algorithm = session.compile_program("/path/to/MyAlgorithm.java")
```

4. Run the algorithm. For example:

- JShell
- Java
- Python

JShell

```
opg4j> var graph =session.readGraphWithProperties("/path/to/
bank_graph_analytics.json")
graph ==>
PgxGraph[name=bank_graph_analytics,N=1000,E=5001,created=1633504705054]
opg4j> var property = graph.createVertexProperty(PropertyType.INTEGER)
property ==>
VertexProperty[name=vertex_prop_integer_9,type=integer,graph=bank_graph_an
alytics]
opg4j> myAlgorithm.run(graph, property)
$6 ==> {
  "success" : true,
  "canceled" : false,
  "exception" : null,
  "returnValue" : 42,
  "executionTimeMs" : 0
}
```

Java

```
import oracle.pgx.algorithm.VertexProperty;
PgxGraph graph = session.readGraphWithProperties("/path/to/
bank_graph_analytics.json");
VertexProperty property =
graph.createVertexProperty(PropertyType.INTEGER);
myAlgorithm.run(graph, property);
```

Python

```
graph = session.read_graph_with_properties("/path/to/
bank_graph_analytics.json")
property = graph.create_vertex_property("integer")
my_algorithm.run(graph, property)
{'success': True, 'canceled': False, 'exception': None, 'return_value':
42, 'execution_time(ms)': 1}
```

14.6.3 Example Custom PGX Algorithm: PageRank

The following is an implementation of `pagerank` as a PGX algorithm:

```
import oracle.pgx.algorithm.PgxGraph;
import oracle.pgx.algorithm.Scalar;
import oracle.pgx.algorithm.VertexProperty;
import oracle.pgx.algorithm.annotations.GraphAlgorithm;
import oracle.pgx.algorithm.annotations.Out;

@GraphAlgorithm
public class Pagerank {
  public void pagerank(PgxGraph G, double tol, double damp, int max_iter,
```

```
boolean norm, @Out VertexProperty<Double> rank) {
    Scalar<Double> diff = Scalar.create();
    int cnt = 0;
    double N = G.getNumVertices();

    rank.setAll(1 / N);
    do {
      diff.set(0.0);
      Scalar<Double> dangling_factor = Scalar.create(0d);

      if (norm) {
        dangling_factor.set(damp / N * G.getVertices().filter(v ->
v.getOutDegree() == 0).sum(rank::get));
      }

      G.getVertices().forEach(t -> {
        double in_sum = t.getInNeighbors().sum(w -> rank.get(w) /
w.getOutDegree());
        double val = (1 - damp) / N + damp * in_sum +
dangling_factor.get();
        diff.reduceAdd(Math.abs(val - rank.get(t)));
        rank.setDeferred(t, val);
      });
      cnt++;
    } while (diff.get() > tol && cnt < max_iter);
  }
}
```

14.7 Creating Subgraphs

You can create subgraphs based on a graph that has been loaded into memory. You can use filter expressions or create bipartite subgraphs based on a vertex (node) collection that specifies the left set of the bipartite graph.

> **Note:**
>
> Starting from Graph Server and Client Release 22.3, creating subgraphs using filter expressions is deprecated. It is recommended that you load a subgraph from property graph views. See Loading a Subgraph from Property Graph Views for more information.

For information about reading a graph into memory, see Reading Graphs from Oracle Database into the Graph Server (PGX) for the various methods to load a graph into the graph server (PGX).

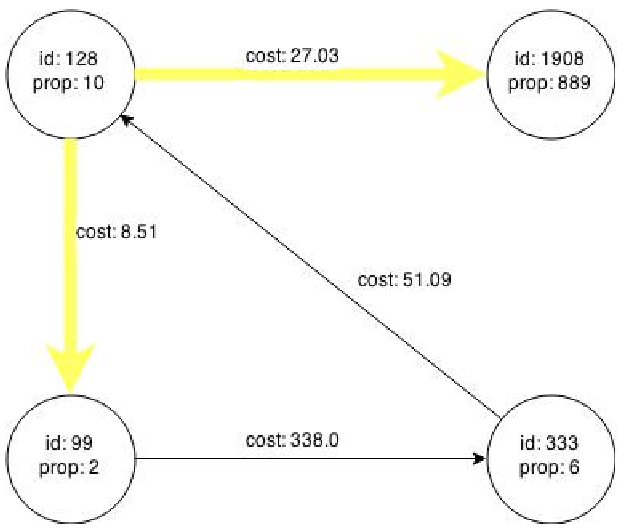
- About Filter Expressions
- Using a Simple Filter to Create a Subgraph
- Using a Complex Filter to Create a Subgraph
- Using a Vertex Set to Create a Bipartite Subgraph

14.7.1 About Filter Expressions

Filter expressions are expressions that are evaluated for each vertex or edge. The expression can define predicates that a vertex or an edge must fulfil in order to be contained in the result, in this case a subgraph.

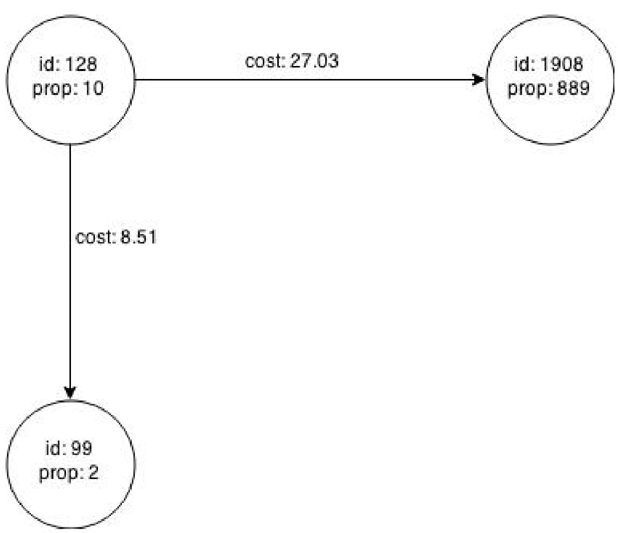
Consider an example graph that consists of four vertices (nodes) and four edges. For an edge to match the filter expression `src.prop == 10`, the source vertex `prop` property must equal 10. Two edges match that filter expression, as shown in the following figure.

Figure 14-1 Edges Matching src.prop == 10



The following figure shows the graph that results when the filter is applied.

Figure 14-2 Graph Created by the Simple Filter



The vertex filter `src.prop == 10` filters out the edges associated with vertex 333 and the vertex itself.

14.7.2 Using a Simple Filter to Create a Subgraph

The following examples create the subgraph described in About Filter Expressions.

- JShell
- Java

JShell

```
var subgraph = graph.filter(new VertexFilter("vertex.prop == 10"))
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.filter.*;

PgxGraph graph = session.readGraphWithProperties(...);
PgxGraph subgraph = graph.filter(new VertexFilter("vertex.prop ==
10"));
```

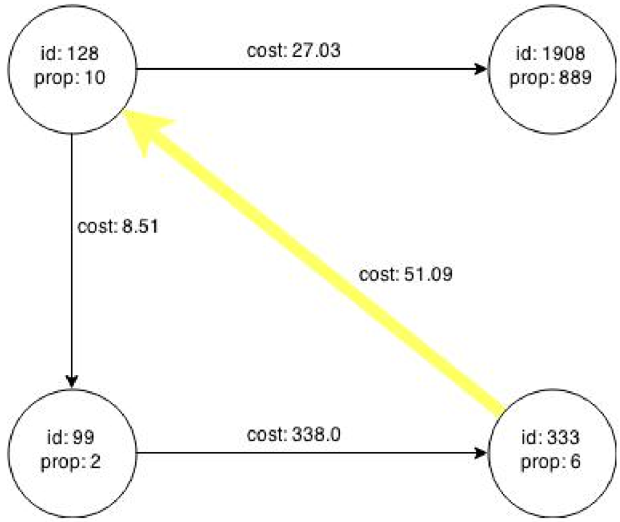
14.7.3 Using a Complex Filter to Create a Subgraph

This example uses a slightly more complex filter. It uses the `outDegree` function, which calculates the number of outgoing edges for an identifier (source `src` or destination `dst`). The following filter expression matches all edges with a `cost` property value greater than 50 and a destination vertex (node) with an `outDegree` greater than 1.

```
dst.outDegree() > 1 && edge.cost > 50
```

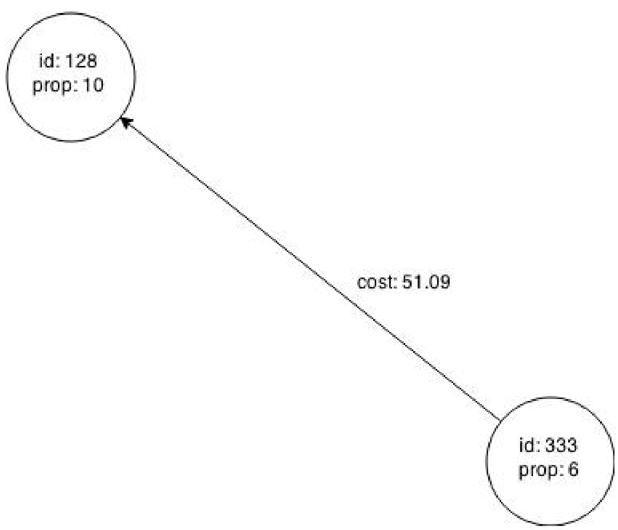
One edge in the sample graph matches this filter expression, as shown in the following figure.

Figure 14-3 Edges Matching the outDegree Filter



The following figure shows the graph that results when the filter is applied. The filter excludes the edges associated with the vertices 99 and 1908, and so excludes those vertices also.

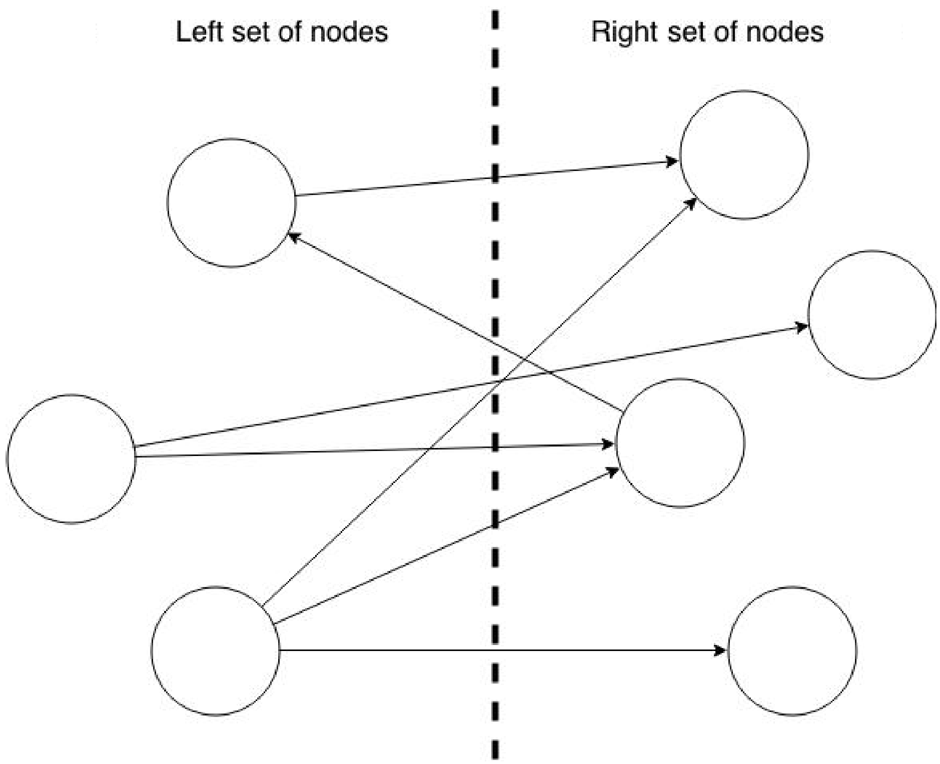
Figure 14-4 Graph Created by the outDegree Filter



14.7.4 Using a Vertex Set to Create a Bipartite Subgraph

You can create a bipartite subgraph by specifying a set of vertices (nodes), which are used as the left side. A bipartite subgraph has edges only between the left set of vertices and the right set of vertices. There are no edges within those sets, such as between two nodes on the left side. In the graph server (PGX), vertices that are isolated because all incoming and outgoing edges were deleted are not part of the bipartite subgraph.

The following figure shows a bipartite subgraph. No properties are shown.



The following examples create a bipartite subgraph from a simple graph consisting of four vertices and four edges. The vertex ID values for the four vertices are `99`, `128`, `1908` and `333` respectively. See Figure 14-1 in About Filter Expressions for more information on the vertex and edge property values including the edge direction between the vertices.

You must first create a vertex collection and fill it with the vertices for the left side. In the example shown, vertices with vertex ID values `333` and `99` are added to the left side of the vertex collection.

Using the Shell to Create a Bipartite Subgraph

```
opg4j> s = graph.createVertexSet()
==> ...
opg4j> s.addAll([graph.getVertex(333), graph.getVertex(99)])
==> ...
opg4j> s.size()
==> 2
opg4j> bGraph = graph.bipartiteSubGraphFromLeftSet(s)
==> PGX Bipartite Graph named sample-sub-graph-4
```

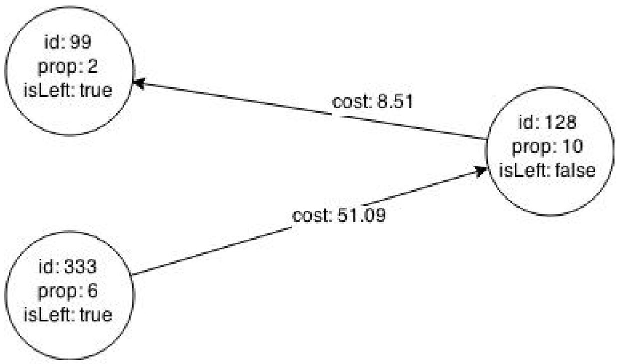
Using Java to Create a Bipartite Subgraph

```
import oracle.pgx.api.*;

VertexSet<Integer> s = graph.createVertexSet();
s.addAll(graph.getVertex(333), graph.getVertex(99));
BipartiteGraph bGraph = graph.bipartiteSubGraphFromLeftSet(s);
```

When you create a subgraph, the graph server (PGX) automatically creates a Boolean vertex (node) property that indicates whether the vertex is on the left side. You can specify a unique name for the property.

The resulting bipartite subgraph looks like this:



Vertex with ID `1908` is excluded from the bipartite subgraph. The only edge that connected that vertex extended from `128` to `1908`. The edge was removed, because it violated the bipartite properties of the subgraph. Vertex `1908` had no other edges, and so was removed as well. Moreover, the edge from the vertex with the ID `128` to the vertex with ID `99` is not present in the bipartite subgraph, because edges are only allowed to go from left to right (and not from right to left).

14.8 Using Automatic Delta Refresh to Handle Database Changes

You can automatically refresh (auto-refresh) graphs periodically to keep the in-memory graph synchronized with changes to the property graph stored in the property graph tables in Oracle Database (VT$ and GE$ tables).

Note that the auto-refresh feature is not supported when loading a graph into PGX in memory directly from relational tables.

- Configuring the Graph Server (PGX) for Auto-Refresh
- Configuring Basic Auto-Refresh
- Reading the Graph Using the Graph Server (PGX) or a Java Application
- Checking Out a Specific Snapshot of the Graph
- Advanced Auto-Refresh Configuration
- Special Considerations When Using Auto-Refresh

14.8.1 Configuring the Graph Server (PGX) for Auto-Refresh

Because auto-refresh can create many snapshots and therefore may lead to a high memory usage, by default the option to enable auto-refresh for graphs is available only to administrators.

To allow all users to auto-refresh graphs, you must include the following line into the graph server (PGX) configuration file (located in `/etc/oracle/graph/pgx.conf`):

```
{
  "allow_user_auto_refresh": true
}
```

14.8.2 Configuring Basic Auto-Refresh

Auto-refresh is configured in the loading section of the graph configuration. The example in this topic sets up auto-refresh to check for updates every minute, and to create a new snapshot when the data source has changed.

The following block (JSON format) enables the auto-refresh feature in the configuration file of the sample graph:

```
{
  "format": "pg",
  "jdbc_url": "jdbc:oracle:thin:@mydatabaseserver:1521/dbName",
  "username": "scott",
  "password": "<password>",
  "name": "my_graph",
  "vertex_props": [{
    "name": "prop",
    "type": "integer"
  }],
  "edge_props": [{
    "name": "cost",
    "type": "double"
  }],
  "separator": " ",
  "loading": {
    "auto_refresh": true,
    "update_interval_sec": 60
  },
}
```

Notice the additional `loading` section containing the auto-refresh settings. You can also use the Java APIs to construct the same graph configuration programmatically:

```
GraphConfig config = GraphConfigBuilder.forPropertyGraphRdbms()
  .setJdbcUrl("jdbc:oracle:thin:@mydatabaseserver:1521/dbName")
  .setUsername("scott")
  .setPassword("<password>")
  .setName("my_graph")
  .addVertexProperty("prop", PropertyType.INTEGER)
  .addEdgeProperty("cost", PropertyType.DOUBLE)
  .setAutoRefresh(true)
  .setUpdateIntervalSec(60)
  .build();
```

14.8.3 Reading the Graph Using the Graph Server (PGX) or a Java Application

After creating the graph configuration, you can load the graph into the graph server (PGX) using the regular APIs.

```
opg4j> G = session.readGraphWithProperties("graphs/my-config.pg.json")
```

After the graph is loaded, a background task is started automatically, and it periodically checks the data source for updates.

14.8.4 Checking Out a Specific Snapshot of the Graph

The database is queried every minute for updates. If the graph has changed in the database after the time interval passed, the graph is reloaded and a new snapshot is created in-memory automatically.

You can "check out" (move a pointer to a different version of) the available in-memory snapshots of the graph using the `getAvailableSnapshots()` method of `PgxSession`. Example output is as follows:

```
opg4j> session.getAvailableSnapshots(G)
==> GraphMetaData [getNumVertices()=4, getNumEdges()=4, memoryMb=0,
dataSourceVersion=1453315103000, creationRequestTimestamp=1453315122669
(2016-01-20 10:38:42.669), creationTimestamp=1453315122685 (2016-01-20
10:38:42.685), vertexIdType=integer, edgeIdType=long]
==> GraphMetaData [getNumVertices()=5, getNumEdges()=5, memoryMb=3,
dataSourceVersion=1452083654000, creationRequestTimestamp=1453314938744
(2016-01-20 10:35:38.744), creationTimestamp=1453314938833 (2016-01-20
10:35:38.833), vertexIdType=integer, edgeIdType=long]
```

The preceding example output contains two entries, one for the originally loaded graph with 4 vertices and 4 edges, and one for the graph created by auto-refresh with 5 vertices and 5 edges.

To check out out a specific snapshot of the graph, use the setSnapshot() methods of PgxSession and give it the creationTimestamp of the snapshot you want to load.

For example, if G is pointing to the newer graph with 5 vertices and 5 edges, but you want to analyze the older version of the graph, you need to set the snapshot to 1453315122685. In the graph shell:

```
opg4j> G.getNumVertices()
==> 5
opg4j> G.getNumEdges()
==> 5

opg4j> session.setSnapshot( G, 1453315122685 )
==> null

opg4j> G.getNumVertices()
==> 4
```

```
opg4j> G.getNumEdges()
==> 4
```

You can also load a specific snapshot of a graph directly using the `readGraphAsOf()` method of `PgxSession`. This is a shortcut for loading a graph with `readGraphWithProperty()` followed by a `setSnapshot()`. For example:

```
opg4j> G = session.readGraphAsOf( config, 1453315122685 )
```

If you do not know or care about what snapshots are currently available in-memory, you can also specify a time span of how “old” a snapshot is acceptable by specifying a maximum allowed age. For example, to specify a maximum snapshot age of 60 minutes, you can use the following:

```
opg4j> G = session.readGraphWithProperties( config, 60l,
TimeUnit.MINUTES )
```

If there are one or more snapshots in memory younger (newer) than the specified maximum age, the youngest (newest) of those snapshots will be returned. If all the available snapshots are older than the specified maximum age, or if there is no snapshot available at all, then a new snapshot will be created automatically.

14.8.5 Advanced Auto-Refresh Configuration

You can specify advanced options for auto-refresh configuration.

Internally, the graph server (PGX) fetches the changes since the last check from the database and creates a new snapshot by applying the delta (changes) to the previous snapshot. There are two timers: one for fetching and caching the deltas from the database, the other for actually applying the deltas and creating a new snapshot.

Additionally, you can specify a threshold for the number of cached deltas. If the number of cached changes grows above this threshold, a new snapshot is created automatically. The number of cached changes is a simple sum of the number of vertex changes plus the number of edge changes.

The deltas are fetched periodically and cached on the graph server (PGX) for two reasons:

- To speed up the actual snapshot creation process
- To account for the case that the database can "forget" changes after a while

You can specify both a threshold and an update timer, which means that both conditions will be checked before new snapshot is created. At least one of these parameters (threshold or update timer) must be specified to prevent the delta cache from becoming too large. The interval at which the source is queried for changes must not be omitted.

The following parameters show a configuration where the data source is queried for new deltas every 5 minutes. New snapshots are created every 20 minutes or if the cached deltas reach a size of 1000 changes.

```
{
  "format": "pg",
```

```
  "jdbc_url": "jdbc:oracle:thin:@mydatabaseserver:1521/dbName",
  "username": "scott",
  "password": "<your_password>",
  "name": "my_graph",

  "loading": {
    "auto_refresh": true,
    "fetch_interval_sec": 300,
    "update_interval_sec": 1200,
    "update_threshold": 1000,
    "create_edge_id_index": true,
    "create_edge_id_mapping": true
  }
}
```

14.8.6 Special Considerations When Using Auto-Refresh

This section explains a few special considerations when you enable auto-refresh for graphs in the graph server (PGX):

- If you call `graph.destroy()`, auto-refresh does not immediately stop. It only stops once the graph is actually freed from the server memory.

  This happens when all the following conditions are true:

  1. No other session is referencing that graph.
  2. PGX consumes more than `release_memory_threshold` memory. `release_memory_threshold` is a `pgx.conf` option that defaults to 85% of available system memory.
  3. The PGX "garbage collector" has been run. `memory_cleanup_interval` is a `pgx.conf` option which defaults to once every 10 minutes.
- If you configure the graph to be loaded with auto-refresh, you cannot omit the `jdbc url`, `username` and `keystore` parameters from the graph configuration file since auto-refreshed graphs are not "user bound". You cannot obtain the connection settings from the user who initiated it.

14.9 User-Defined Functions (UDFs) in PGX

User-defined functions (UDFs) allow users of PGX to add custom logic to their PGQL queries or custom graph algorithms, to complement built-in functions with custom requirements.

> **Caution:**
>
> UDFs enable running arbitrary code in the PGX server, possibly accessing sensitive data. Additionally, any PGX session can invoke any of the UDFs that are enabled on the PGX server. The application administrator who enables UDFs is responsible for checking the following:
>
> - All the UDF code can be trusted.
> - The UDFs are stored in a secure location that cannot be tampered with.
>
> Furthermore, PGX assumes UDFs to be state-less and side-effect free.

PGX supports two types of UDFs:

- Java UDFs
- JavaScript UDFs

How to Use Java UDFs

The following simple example shows how to register a Java UDF at the PGX server and invoke it.

1. Create a class with a public static method. For example:

```
package my.udfs;

public class MyUdfs {
  public static String concat(String a, String b) {
    return a + b;
  }
}
```

2. Compile the class and compress into a JAR file. For example:

```
mkdir ./target
javac -d ./target *.java
cd target
jar cvf MyUdfs.jar *
```

3. Copy the JAR file into `/opt/oracle/graph/pgx/server/lib`.
4. Create a UDF JSON configuration file. For example, assume that `/path/to/my/udfs/dir/my_udfs.json` contains the following:

```
{
  "user_defined_functions": [
    {
      "namespace": "my",
      "language": "java",
      "implementation_reference": "my.udfs.MyUdfs",
      "function_name": "concat",
      "return_type": "string",
      "arguments": [
```

```
            {
              "name": "a",
              "type": "string"
            },
            {
              "name": "b",
              "type": "string"
            }
          ]
       }
     ]
   }
```

5. Point to the directory containing the UDF configuration file in `/etc/oracle/graph/pgx.conf`. For example:

```
"udf_config_directory": "/path/to/my/udfs/dir/"
```

6. Restart the PGX server. For example:

```
sudo systemctl restart pgx
```

7. Try to invoke the UDF from within a PGQL query. For example:

```
graph.queryPgql("SELECT my.concat(my.concat(n.firstName, ' '), 
n.lastName) FROM MATCH (n:Person)")
```

8. Try to invoke the UDF from within a PGX algorithm. For example:

> **Note:**
>
> For each UDF you want to use, you need to create an abstract method with the same schema that gets annotated with the `@Udf` annotation.

```
import oracle.pgx.algorithm.annotations.Udf;
....

@GraphAlgorithm
public class MyAlogrithm {
  public void bomAlgorithm(PgxGraph g, VertexProperty<String> firstName, 
VertexProperty<String> lastName, @Out VertexProperty<String> fullName) {


  ... fullName.set(v, concat(firstName.get(v), lastName.get(v))); ...

  }

  @Udf(namespace = "my")
  abstract String concat(String a, String b);
}
```

JavaScript UDFs

The requirements for a JavaScript UDF is as follows:

- The JavaScript source must contain all dependencies.
- The source must contain at least one valid export.
- The `language` parameter must be set to `javascript` in the UDF configuration file.

For example, consider a JavaScript source file `format.js` as shown:

```
//format.js
const fun = function(name, country) {
  if (country == null) return name;
  else return name + " (" + country + ")";
}

module.exports = {stringFormat: fun};
```

In order to load the UDF from `format.js`, the UDF configuration file will appear as follows:

```
{
  "namespace": "my",
  "function_name": "format",
  "language": "javascript",
  "source_location": "format.js",
  "source_function_name": "stringFormat",
  "return_type": "string",
  "arguments": [
    {
      "name": "name",
      "type": "string"
    },
    {
      "name": "country",
      "type": "string"
    }
  ]
}
```

Note:

In this case, since the name of the UDF and the implementing method differ, you need to set the name of the UDF in the `source_function_name` field. Also, you can provide the path of the source code file in the `source_location` field.

UDF Configuration File Information

A UDF configuration file is a JSON file containing an array of `user_defined_functions`. (An example of such a file is in the step to "Create a UDF JSON configuration file" in the preceding How to Use Java UDFs subsection.)

Each user-defined function supports the fields shown in the following table.

Table 14-11 Fields for Each UDF

Field	Data Type	Description	Required?
function_name	string	Name of the function used as identifier in PGX	Required
language	enum[java, javascript]	Source language for he function (`java` or `javascript`)	Required
return_type	enum[boolean, integer, long, float, double, string]	Return type of the function	Required
arguments	array of object	Array of arguments. For each argument: type, argument name, required?	[]
implementation_reference	string	Reference to the function name on the classpath	null
namespace	string	Namespace of the function in PGX	null
source_code	string	Source code of the function provided inline	null
source_function_name	string	Name of the function in the source language	null
source_location	string	Local file path to the function's source code	null

All configured UDFs must be unique with regard to the combination of the following fields:

- namespace
- function_name
- arguments

14.10 Using the Graph Server (PGX) as a Library

When you utilize PGX as a library in your application, the graph server (PGX) instance runs in the same JVM as the Java application and all requests are translated into direct function calls instead of remote procedure invocations.

In this case, you must install the graph server (PGX) using `RPM` in the same machine as the client applications. The shell executables provided by the graph server installation helps you to launch the Java or the Python shell in an embedded server mode. See Installing Oracle Graph Server for more information.

You can now start the Java shell without any parameters as shown:

```
cd /opt/oracle/graph
./bin/opg4j
```

The local PGX instance will try to load a PGX configuration file from:

```
/etc/oracle/graph/pgx.conf
```

You can change the location of the configuration file by passing the `--pgx_conf` command-line option followed by the path to the configuration file:

```
# start local PGX instance with custom config
./bin/opg4j --pgx_conf <path_to_pgx.conf>
```

You can also start the Python shell without any parameters as shown:

```
cd /opt/oracle/graph/
./bin/opg4py
```

When using Java, you can obtain a reference to the local PGX instance as shown:

```
import oracle.pg.rdbms.*;
import oracle.pgx.api.*;
...
ServerInstance instance = GraphServer.getEmbeddedInstance();
```

In a Python application, you can obtain a reference to the local PGX instance as shown:

```
import os
os.environ["PGX_CLASSPATH"] = "/opt/oracle/graph/lib/*"
import opg4py.graph_server as graph_server
...
instance = graph_server.get_embedded_instance()
```

Starting the PGX Engine

PGX provides a convenience mechanism to start the PGX Engine when using the graph server (PGX) as a library. That is, the graph server (PGX) is automatically initialized and starts up automatically when `ServerInstance.createSession()` is called the first time. This is provided that the engine is not already running at that time.

For this implicit initialization, PGX will configure itself with the PGX configuration file at the default locations. If the PGX configuration file is not found, PGX will configure itself using default parameter values as shown in Configuration Parameters for the Graph Server (PGX) Engine.

Stopping the PGX Engine

When using the graph server (PGX) as a library, the `shutdownEngine()` method will be called automatically via a JVM shutdown hook on exit. Specifically, the shutdown hook is invoked once all the non-daemon threads of the application exit.

It is recommended that you do not terminate your PGX application forcibly with `kill -9`, as it will not clear the `temp` directory. See `tmp_dir` in Configuration Parameters for the Graph Server (PGX) Engine.

15
Using the Machine Learning Library (PgxML) for Graphs

The graph server (PGX) provides a machine learning library `oracle.pgx.api.mllib`, which supports graph-empowered machine learning algorithms.

The following machine learning algorithms are currently supported:

- Using the DeepWalk Algorithm
  DeepWalk is a widely employed vertex representation learning algorithm used in industry.
- Using the Supervised GraphWise Algorithm (Vertex Embeddings and Classification)
  Supervised GraphWise is an inductive vertex representation learning algorithm which is able to leverage vertex feature information. It can be applied to a wide variety of tasks, including vertex classification and link prediction.
- Using the Unsupervised GraphWise Algorithm
  Unsupervised GraphWise is an unsupervised inductive vertex representation learning algorithm which is able to leverage vertex information. The learned embeddings can be used in various downstream tasks including vertex classification, vertex clustering and similar vertex search.
- Using the Supervised EdgeWise Algorithm (Edge Embeddings and Classification)
  `SupervisedEdgeWise` is an inductive edge representation learning algorithm which is able to leverage vertex and edge feature information. It can be applied to a wide variety of tasks, including edge classification and link prediction.
- Using the Pg2vec Algorithm
  Pg2vec learns representations of graphlets (partitions inside a graph) by employing edges as the principal learning units and thereby packing more information in each learning unit (as compared to employing vertices as learning units) for the representation learning task.
- Model Repository and Model Stores
  A model store can be used to persist the trained graph server (PGX) machine learning models along with a model name (a unique identifier of the model in a particular model store) and a description.

> **See Also:**
>
> Model Repository and Model Stores for information on model store management and how models can be persisted in a model store.

15.1 Using the DeepWalk Algorithm

DeepWalk is a widely employed vertex representation learning algorithm used in industry.

It consists of two main steps:

1. First, the random walk generation step computes random walks for each vertex (with a pre-defined walk length and a pre-defined number of walks per vertex).
2. Second, these generated walks are fed to a **Word2vec** algorithm to generate the vector representation for each vertex (which is the word in the input provided to the Word2vec algorithm). See KDD paper for more details on DeepWalk algorithm.

DeepWalk creates vertex embeddings for a specific graph and cannot be updated to incorporate modifications on the graph. Instead, a new DeepWalk model should be trained on this modified graph. Lastly, it is important to note that the memory consumption of the DeepWalk model is `O(2n*d)` where `n` is the number of vertices in the graph and `d` is the embedding length.

The following describes the usage of the main functionalities of DeepWalk in PGX using DBpedia graph as an example with `8,637,721` vertices and `165,049,964` edges:

- Loading a Graph
- Building a Minimal DeepWalk Model
- Building a Customized DeepWalk Model
- Training a DeepWalk Model
- Getting the Loss Value For a DeepWalk Model
- Computing Similar Vertices for a Given Vertex
- Computing Similar Vertices for a Vertex Batch
- Getting All Trained Vertex Vectors
- Storing a Trained DeepWalk Model
- Loading a Pre-Trained DeepWalk Model
- Destroying a DeepWalk Model

15.1.1 Loading a Graph

The following describes the steps for loading a graph:

1. Create a **Session** and an **Analyst**.

- JShell
- Java
- Python

JShell

```
cd /opt/oracle/graph/
./bin/opg4j
// starting the shell will create an implicit session and analyst
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.mllib.DeepWalkModel;
import oracle.pgx.api.frames.*;
...
PgxSession session = Pgx.createSession("my-session");
Analyst analyst = session.createAnalyst();
```

Python

```
session = pypgx.get_session(session_name="my-session")
analyst = session.create_analyst()
```

2. Load the **graph**.

> **Note:**
>
> Though the DeepWalk algorithm implementation can be applied to directed or undirected graphs, currently only undirected random walks are considered.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphWithProperties("<path>/<graph.json>")
```

Java

```
PgxGraph graph = session.readGraphWithProperties("<path>/<graph.json>");
```

Python

```
graph = session.read_graph_with_properties("<path>/<graph.json>")
```

15.1.2 Building a Minimal DeepWalk Model

You can build a DeepWalk model using the minimal configuration and default hyper-parameters as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.deepWalkModelBuilder().
                setWindowSize(3).
                setWalksPerVertex(6).
                setWalkLength(4).
                build()
```

Java

```
DeepWalkModel model = analyst.deepWalkModelBuilder()
    .setWindowSize(3)
    .setWalksPerVertex(6)
    .setWalkLength(4)
    .build();
```

Python

```
model =
analyst.deepwalk_builder(window_size=3,walks_per_vertex=6,walk_length=4
)
```

15.1.3 Building a Customized DeepWalk Model

You can build a DeepWalk model using customized hyper-parameters as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.deepWalkModelBuilder().
                setMinWordFrequency(1).
                setBatchSize(512).
                setNumEpochs(1).
                setLayerSize(100).
```

```
                setLearningRate(0.05).
                setMinLearningRate(0.0001).
                setWindowSize(3).
                setWalksPerVertex(6).
                setWalkLength(4).
                setSampleRate(0.00001).
                setNegativeSample(2).
                setValidationFraction(0.01).
                build()
```

Java

```
DeepWalkModel model= analyst.deepWalkModelBuilder()
    .setMinWordFrequency(1)
    .setBatchSize(512)
    .setNumEpochs(1)
    .setLayerSize(100)
    .setLearningRate(0.05)
    .setMinLearningRate(0.0001)
    .setWindowSize(3)
    .setWalksPerVertex(6)
    .setWalkLength(4)
    .setSampleRate(0.00001)
    .setNegativeSample(2)
    .setValidationFraction(0.01)
    .build();
```

Python

```
model = analyst.deepwalk_builder(min_word_frequency=1,
                                 batch_size=512,num_epochs=1,
                                 layer_size=100,
                                 learning_rate=0.05,
                                 min_learning_rate=0.0001,
                                 window_size=3,
                                 walks_per_vertex=6,
                                 walk_length=4,
                                 sample_rate=0.00001,
                                 negative_sample=2,
                                 validation_fraction=0.01)
```

See DeepWalkModelBuilder in Javadoc for more explanation for each builder operation along with the default values.

15.1.4 Training a DeepWalk Model

You can train a DeepWalk model with the specified default or customized settings as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(graph)
```

Java

```
model.fit(graph);
```

Python

```
model.fit(graph)
```

15.1.5 Getting the Loss Value For a DeepWalk Model

You can fetch the loss value on a specified fraction of training data, that is set in builder using `setValidationFraction` as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var loss = model.getLoss()
```

Java

```
double loss = model.getLoss();
```

Python

```
loss = model.loss
```

15.1.6 Computing Similar Vertices for a Given Vertex

You can fetch the `k` most similar vertices for a given vertex as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var similars = model.computeSimilars("Albert_Einstein", 10)
opg4j> similars.print()
```

Java

```
PgxFrame similars = model.computeSimilars("Albert_Einstein", 10);
similars.print();
```

Python

```
similars = model.compute_similars("Albert_Einstein",10)
similars.print()
```

Searching for similar vertices for Albert_Einstein using the trained model, will result in the following output:

```
+-----------------------------------------+
| dstVertex          | similarity         |
+-----------------------------------------+
| Albert_Einstein    | 1.0000001192092896 |
| Physics            | 0.8664291501045227 |
| Werner_Heisenberg  | 0.8625140190124512 |
| Richard_Feynman    | 0.8496938943862915 |
| List_of_physicists | 0.8415523767471313 |
| Physicist          | 0.8384397625923157 |
| Max_Planck         | 0.8370327353477478 |
| Niels_Bohr         | 0.8340970873832703 |
| Quantum_mechanics  | 0.8331197500228882 |
| Special_relativity | 0.8280861973762512 |
+-----------------------------------------+
```

15.1.7 Computing Similar Vertices for a Vertex Batch

You can fetch the k most similar vertices for a list of input vertices as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var vertices = new ArrayList()
opg4j> vertices.add("Machine_learning")
opg4j> vertices.add("Albert_Einstein")
opg4j> batchedSimilars = model.computeSimilars(vertices, 10)
opg4j> batchedSimilars.print()
```

Java

```
List vertices = Arrays.asList("Machine_learning","Albert_Einstein");
PgxFrame batchedSimilars = model.computeSimilars(vertices,10);
batchedSimilars.print();
```

Python

```
vertices = ["Machine_learning","Albert_Einstein"]
batched_similars = model.compute_similars(vertices,10)
batched_similars.print()
```

The following describes the output result:

```
+-------------------------------------------------------------------+
| srcVertex        | dstVertex                  | similarity         |
+-------------------------------------------------------------------+
| Machine_learning | Machine_learning           | 1.0000001192092896 |
| Machine_learning | Data_mining                | 0.9070799350738525 |
| Machine_learning | Computer_science           | 0.8963605165481567 |
| Machine_learning | Unsupervised_learning      | 0.8828719854354858 |
| Machine_learning | R_(programming_language)   | 0.8821185827255249 |
| Machine_learning | Algorithm                  | 0.8819515705108643 |
| Machine_learning | Artificial_neural_network  | 0.8773092031478882 |
| Machine_learning | Data_analysis              | 0.8758628368377686 |
| Machine_learning | List_of_algorithms         | 0.8737979531288147 |
| Machine_learning | K-means_clustering         | 0.8715602159500122 |
```

```
| Albert_Einstein  | Albert_Einstein             | 1.0000001192092896 |
| Albert_Einstein  | Physics                     | 0.8664291501045227 |
| Albert_Einstein  | Werner_Heisenberg           | 0.8625140190124512 |
| Albert_Einstein  | Richard_Feynman             | 0.8496938943862915 |
| Albert_Einstein  | List_of_physicists          | 0.8415523767471313 |
| Albert_Einstein  | Physicist                   | 0.8384397625923157 |
| Albert_Einstein  | Max_Planck                  | 0.8370327353477478 |
| Albert_Einstein  | Niels_Bohr                  | 0.8340970873832703 |
| Albert_Einstein  | Quantum_mechanics           | 0.8331197500228882 |
| Albert_Einstein  | Special_relativity          | 0.8280861973762512 |
+--------------------------------------------------------------------+
```

15.1.8 Getting All Trained Vertex Vectors

You can retrieve the trained vertex vectors for the current DeepWalk model and store it in the database as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var vertexVectors = model.getTrainedVertexVectors().flattenAll()
opg4j> vertexVectors.write().db().name("vertex
vectors").tablename("vertexVectors").overwrite(true).store()
```

Java

```
PgxFrame vertexVectors = model.getTrainedVertexVectors().flattenAll();
vertexVectors.write()
    .db()
    .name("vertex vectors")
    .tablename("vertexVectors")
    .overwrite(true)
    .store();
```

Python

```
vertex_vectors = model.trained_vectors.flatten_all()
vertex_vectors.write().db().table_name("table_name").name("vertex_vectors").o
verwrite(True).store()
```

15.1.9 Storing a Trained DeepWalk Model

You can store models in database. The models get stored as a row inside a model store table.

The following code shows how to store a trained DeepWalk model in database in a specific model store table:

- JShell
- Java
- Python

JShell

```
opg4j> model.export().db().
              modelstore("modelstoretablename").  // name of the model
store table
              modelname("model").                 // model name
(primary key of model store table)
              description("a model description"). // description to
store alongside the model
              store()
```

Java

```
model.export().db()
    .modelstore("modelstoretablename")  // name of the model store
table
    .modelname("model")                 // model name (primary key of
model store table)
    .description("a model description") // description to store
alongside the model
    .store();
```

Python

```
model.export().db(model_store="modeltablename",            # name of
the model store table
                  model_name="model",                      # model
name (primary key of model store table)
                  model_description="a model description") #
description to store alongside the model
```

> **Note:**
>
> All the preceding examples assume that you are storing the model in the current logged in database. If you must store the model in a different database then refer to the examples in Storing a Trained Model in Another Database.

- Storing a Trained Model in Another Database

15.1.9.1 Storing a Trained Model in Another Database

You can store models in a different database other than the one used for login.

The following code shows how to store a trained model in a different database:

- JSHell
- Java
- Python

JShell

```
opg4j> model.export().db().
              username("user").                   // DB user to use for
storing the model
              password("password").               // password of the DB user
              jdbcUrl("jdbcUrl").                 // jdbc url to the DB
              modelstore("modelstoretablename").  // name of the model store
table
              modelname("model").                 // model name (primary key
of model store table)
              description("a model description"). // description to store
alongside the model
              store()
```

Java

```
model.export().db()
    .username("user")                    // DB user to use for storing the
model
    .password("password")                // password of the DB user
    .jdbcUrl("jdbcUrl")                  // jdbc url to the DB
    .modelstore("modelstoretablename")   // name of the model store table
    .modelname("model")                  // model name (primary key of model
store table)
    .description("a model description") // description to store alongside
the model
    .store();
```

Python

```
model.export().db(username="user",                          # DB user
to use for storing the model
                  password="password",                      # password
of the DB user
                  jdbc_url="jdbc_url",                      # jdbc url
to the DB
                  model_store="modelstoretablename",        # name of
the model store table
                  model_name="model",                       # model
name (primary key of model store table)
                  model_description="a model description") #
description to store alongside the model
```

15.1.10 Loading a Pre-Trained DeepWalk Model

You can load models from a database.

You can load a pre-trained DeepWalk model from a model store table in database as described in the following code:

Loading a Pre-Trained DeepWalk Model Using JShell

```
opg4j> var model = analyst.loadDeepWalkModel().db()
                .modelstore("modeltablename") // name of the model
store table
                .modelname("model")           // model name (primary
key of model store table)
                .load();
```

Loading a Pre-Trained DeepWalk Model Using Java

```
DeepWalkModelmodel = analyst.loadDeepWalkModel().db()
     .modelstore("modeltablename") // name of the model store table
     .modelname("model")           // model name (primary key of model
store table)
     .load();
```

Loading a Pre-Trained DeepWalk Model Using Python

```
analyst.get_deepwalk_model_loader().db(model_store="modelstoretablename
",
                                       model_name="model")
```

> **Note:**
>
> All the preceding examples assume that you are loading the model from the current logged in database. If you must load the model from a different database then refer to the examples in Loading a Pre-Trained Model From Another Database.

- Loading a Pre-Trained Model From Another Database

15.1.10.1 Loading a Pre-Trained Model From Another Database

You can load models from a different database other than the one used for login.

You can load a pre-trained model from a model store table in database as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.<modelLoader>.db().
                username("user").             // DB user to use for storing
the model
                password("password").         // password of the DB user
                jdbcUrl("jdbcUrl").           // jdbc url to the DB
                modelstore("modeltablename"). // name of the model store
table
                modelname("model").           // model name (primary key of
model store table)
                load()
```

where <modelLoader> applies as follows:

- `loadDeepWalkModel()`: Loads a Deepwalk model
- `loadSupervisedGraphWiseModel()`: Loads a Supervised GraphWise model
- `loadUnsupervisedGraphWiseModel()`: Loads an Unsupervised GraphWise model
- `loadSupervisedEdgeWiseModel()`: Loads a Supervised EdgeWise model
- `loadPg2vecModel()`: Loads a Pg2vec model

Java

```
<modeltype> model = analyst.<modelLoader>.db()
     .username("user")              // DB user to use for storing the model
     .password("password")          // password of the DB user
     .jdbcUrl("jdbcUrl")            // jdbc url to the DB
```

```
      .modelstore("modeltablename") // name of the model store table
      .modelname("model")           // model name (primary key of model
store table)
      .load();
```

where <*modeltype*> can have the following values based on the model to be loaded:

- `DeepWalkModel`: represents a Deepwalk model
- `SupervisedGraphWiseModel`: represents a Supervised GraphWise model
- `UnsupervisedGraphWiseModel`: represents an Unsupervised GraphWise model
- `SupervisedEdgeWiseModel`: represents a Supervised EdgeWise model
- `Pg2vecModel`: represents a Pg2vec model

where <*modelLoader*> applies as follows:

- `loadDeepWalkModel()`: Loads a Deepwalk model
- `loadSupervisedGraphWiseModel()`: Loads a Supervised GraphWise model
- `loadUnsupervisedGraphWiseModel()`: Loads an Unsupervised GraphWise model
- `loadSupervisedEdgeWiseModel()`: Loads a Supervised EdgeWise model
- `loadPg2vecModel()`: Loads a Pg2vec model

Python

```
model = analyst.<modelLoader>.db(username="user",     # DB user to use
for storing the model
                  password="password",                # password of
the DB user
                  jdbc_url="jdbc_url",                # jdbc url to
the DB
                  model_store="modelstoretablename",  # name of the
model store table
                  model_name="model")                 # model name
(primary key of model store table)
```

where <modelLoader> applies as follows:

- `get_deepwalk_model_loader()`: Loads a Deepwalk model
- `get_supervised_graphwise_model_loader()`: Loads a Supervised GraphWise model
- `get_unsupervised_graphwise_model_loader()`: Loads an Unsupervised GraphWise model
- `get_supervised_edgewise_model_loader()`: Loads a Supervised EdgeWise model
- `get_pg2vec_model_loader()`: Loads a Pg2vec model

15.1.11 Destroying a DeepWalk Model

You can destroy a DeepWalk model as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.destroy()
```

Java

```
model.destroy();
```

Python

```
model.destroy()
```

15.2 Using the Supervised GraphWise Algorithm (Vertex Embeddings and Classification)

Supervised GraphWise is an inductive vertex representation learning algorithm which is able to leverage vertex feature information. It can be applied to a wide variety of tasks, including vertex classification and link prediction.

Supervised GraphWise is based on GraphSAGE by Hamilton et al.

Model Structure

A Supervised GraphWise model consists of graph convolutional layers followed by several prediction layers.

The forward pass through a convolutional layer for a vertex proceeds as follows:

1. A set of neighbors of the vertex is sampled.
2. The previous layer representations of the neighbors are mean-aggregated, and the aggregated features are concatenated with the previous layer representation of the vertex.
3. This concatenated vector is multiplied with weights, and a bias vector is added.
4. The result is normalized to such that the layer output has unit norm.

The prediction layers are standard neural network layers.

The following describes the usage of the main functionalities of the implementation of **GraphSAGE** in PGX using the Cora graph as an example:

- Loading a Graph
- Building a Minimal GraphWise Model
- Advanced Hyperparameter Customization
- Building a GraphWise Model Using Heterogeneous Graphs
- Classification Versus Regression Models on Supervised GraphWise Models
- Setting a Custom Loss Function and Batch Generator (for Anomaly Detection)
- Training a Supervised GraphWise Model
- Getting the Loss Value For a Supervised GraphWise Model
- Inferring the Vertex Labels for a Supervised GraphWise Model
- Evaluating the Supervised GraphWise Model Performance
- Inferring Embeddings for a Supervised GraphWise Model
- Storing a Trained Supervised GraphWise Model
- Loading a Pre-Trained Supervised GraphWise Model
- Destroying a Supervised GraphWise Model
- Explaining a Prediction of a Supervised GraphWise Model

15.2.1 Loading a Graph

The following describes the steps for loading a graph:

1. Create a **Session** and an **Analyst**.

   - JShell
   - Java
   - Python

   ### JShell

```
cd /opt/oracle/graph/
./bin/opg4j
// starting the shell will create an implicit session and analyst
opg4j> import oracle.pgx.config.mllib.ActivationFunction
opg4j> import oracle.pgx.config.mllib.WeightInitScheme
opg4j> PgxSession session = Pgx.createSession("my-session")
opg4j> Analyst analyst = session.createAnalyst()
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.mllib.SupervisedGraphWiseModel;
import oracle.pgx.api.filter.VertexFilter;
import oracle.pgx.api.frames.*;
import oracle.pgx.config.mllib.ActivationFunction;
import oracle.pgx.config.mllib.GraphWiseConvLayerConfig;
import oracle.pgx.config.mllib.GraphWisePredictionLayerConfig;
import oracle.pgx.config.mllib.SupervisedGraphWiseModelConfig;
import oracle.pgx.config.mllib.WeightInitScheme;
PgxSession session = Pgx.createSession("my-session");
Analyst analyst = session.createAnalyst();
```

Python

```
session = pypgx.get_session(session_name="my-session")
analyst = session.create_analyst()
```

2. Load the **graph**.

- JShell
- Java
- Python

JShell

```
opg4j> var fullGraph = session.readGraphWithProperties("<path>/
<cora_full_graph.json>")
opg4j> var filter =
VertexFilter.fromPgqlResultSet(session.queryPgql("SELECT v FROM cora
MATCH (v) WHERE ID(v) % 4 > 0"), "v")
opg4j> var trainGraph = fullGraph.filter(filter)
opg4j> var testVertices = fullGraph.getVertices().
                 stream().
                 filter(v -> !trainGraph.hasVertex(v.getId())).
                 collect(Collectors.toList())
```

Java

```
PgxGraph fullGraph = session.readGraphWithProperties("<path>/
<cora_full_graph.json>");
VertexFilterfilter =
VertexFilter.fromPgqlResultSet(session.queryPgql("SELECT v FROM cora
MATCH (v) WHERE ID(v) % 4 >
0"),"v");PgxGraphtrainGraph=fullGraph.filter(filter);
PgxGraph trainGraph = fullGraph.filter(filter);
```

```
List<PgxVertex> testVertices = fullGraph.getVertices()
    .stream()
    .filter(v->!trainGraph.hasVertex(v.getId()))
    .collect(Collectors.toList());
```

Python

```
from pypgx.api.filters import VertexFilter
full_graph = session.read_graph_with_properties("<path>/
<cora_full_graph.json>")
vertex_filter =
VertexFilter.from_pgql_result_set(session.query_pgql("SELECT v FROM
cora MATCH (v) WHERE ID(v) % 4 > 0"),"v")
train_graph = full_graph.filter(vertex_filter)
test_vertices = []
train_vertices = train_graph.get_vertices()
for v in full_graph.get_vertices():
    if(not train_vertices.contains(v)):
        test_vertices.append(v)
```

15.2.2 Building a Minimal GraphWise Model

You can build a GraphWise model using the minimal configuration and default hyper-parameters as described in the following code. You can create a model with one of the following options:

- only vertex properties
- only edge properties
- both vertex and edge properties

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.supervisedGraphWiseModelBuilder().
                setVertexInputPropertyNames("features").
                setVertexTargetPropertyName("label").
                setEdgeInputPropertyNames("cost").
                build()
```

Java

```
SupervisedGraphWiseModel model = analyst.supervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("features")
    .setVertexTargetPropertyName("labels")
    .setEdgeInputPropertyNames("cost")
    .build();
```

Python

```
params = dict(vertex_target_property_name="label",
              edge_input_property_names=["cost"],
              vertex_input_property_names=["features"])

model = analyst.supervised_graphwise_builder(**params)
```

> **Note:**
>
> Even though only one vertex and one edge property is specified in the preceding example, you can specify a list of vertex or edge properties.

15.2.3 Advanced Hyperparameter Customization

You can build a GraphWise model using rich hyperparameter customization.

This is done through the following two sub-config classes:

1. `GraphWiseConvLayerConfig`
2. `GraphWisePredictionLayerConfig`

You can create a model with one of the following options:

- only vertex properties
- only edge properties
- both vertex and edge properties

The following code describes the implementation of the configuration using the preceding classes in GraphWise model. The example also specifies a weight decay parameter of `0.001` and dropout with dropping probability `0.5` for the GraphWise model to counteract overfitting.

- JShell
- Java
- Python

JShell

```
opg4j> var weightProperty = analyst.pagerank(trainGraph).getName();
opg4j> var convLayerConfig = analyst.graphWiseConvLayerConfigBuilder().
                setNumSampledNeighbors(25).
                setActivationFunction(ActivationFunction.TANH).
                setWeightInitScheme(WeightInitScheme.XAVIER).
                setWeightedAggregationProperty(weightProperty).
                setDropoutRate(0.5).
                build()
opg4j> var predictionLayerConfig = 
analyst.graphWisePredictionLayerConfigBuilder().
                setHiddenDimension(32).
                setActivationFunction(ActivationFunction.RELU).
                setWeightInitScheme(WeightInitScheme.HE).
                setDropoutRate(0.5).
                build()
opg4j> var model = analyst.supervisedGraphWiseModelBuilder().
                setVertexInputPropertyNames("vertex_features").
                setEdgeInputPropertyNames("edge_features").
                setVertexTargetPropertyName("labels").
                setConvLayerConfigs(convLayerConfig).
                setPredictionLayerConfigs(predictionLayerConfig).
                setWeightDecay(0.001).
                setNormalize(false).
                setEmbeddingDim(256).
                setLearningRate(0.05).
                setNumEpochs(30).
                setSeed(42).
                setShuffle(false).
                setStandardize(true).
                setBatchSize(64).
                build()
```

Java

```
String weightProperty = analyst.pagerank(trainGraph).getName();
GraphWiseConvLayerConfig convLayerConfig = 
analyst.graphWiseConvLayerConfigBuilder()
    .setNumSampledNeighbors(25)
    .setActivationFunction(ActivationFunction.TANH)
    .setWeightInitScheme(WeightInitScheme.XAVIER)
    .setWeightedAggregationProperty(weightProperty)
    .setDropoutRate(0.5)
    .build();

GraphWisePredictionLayerConfig predictionLayerConfig = 
analyst.graphWisePredictionLayerConfigBuilder()
    .setHiddenDimension(32)
    .setActivationFunction(ActivationFunction.RELU)
    .setWeightInitScheme(WeightInitScheme.HE)
    .setDropoutRate(0.5)
    .build();
```

```
SupervisedGraphWiseModel model = analyst.supervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setVertexTargetPropertyName("labels")
    .setConvLayerConfigs(convLayerConfig)
    .setPredictionLayerConfigs(predictionLayerConfig)
    .setWeightDecay(0.001)
    .setNormalize(false)
    .setEmbeddingDim(256)
    .setLearningRate(0.05)
    .setNumEpochs(30)
    .setSeed(42)
    .setShuffle(false)
    .setStandardize(true)
    .setBatchSize(64)
    .build();
```

Python

```
weightProperty = analyst.pagerank(train_graph).name

conv_layer_config = dict(num_sampled_neighbors=25,
                         activation_fn='tanh',
                         weight_init_scheme='xavier',
                         neighbor_weight_property_name=weightProperty,
                         dropout_rate=0.5)

conv_layer = analyst.graphwise_conv_layer_config(**conv_layer_config)

pred_layer_config = dict(hidden_dim=32,
                         activation_fn='relu',
                         weight_init_scheme='he',
                         dropout_rate=0.5)

pred_layer = analyst.graphwise_pred_layer_config(**pred_layer_config)

params = dict(vertex_target_property_name="labels",
              conv_layer_config=[conv_layer],
              pred_layer_config=[pred_layer],
              vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              seed=17,
              weight_decay=0.001,
              normalize=false,
              layer_size=256,
              learning_rate=0.05,
              num_epochs=30,
              seed=42,
              standardize=true,
              batch_size=64
)

model = analyst.supervised_graphwise_builder(**params)
```

See SupervisedGraphWiseModelBuilder, GraphWiseConvLayerConfigBuilder and GraphWisePredictionLayerConfigBuilder in Javadoc for a full description of all available hyperparameters and their default values.

15.2.4 Building a GraphWise Model Using Heterogeneous Graphs

You can build a GraphWise model using partitioned graphs which have different providers and features.

- JShell
- Java
- Python

JShell

```
opg4j> analyst.supervisedGraphWiseModelBuilder().
        setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
        setEdgeInputPropertyNames("edge_provider_features").
        setVertexTargetPropertyName("target_property").
        build()
```

Java

```
SupervisedGraphWiseModel model =
analyst.supervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .setEdgeInputPropertyNames("edge_provider_features")
    .setVertexTargetPropertyName("target_property")
    .build();
```

Python

```
params = dict(vertex_target_property_name="target_property",

vertex_input_property_names=["vertex_provider1_features",
"vertex_provider2_features"],
              edge_input_property_names=["edge_provider_features"])
model = analyst.supervised_graphwise_builder(**params)
```

Also, you can select the providers as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.supervisedGraphWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
         setEdgeInputPropertyNames("edge_provider_features").
         setVertexTargetPropertyName("target_property").
         setTargetVertexLabels("provider1").
         build()
```

Java

```
SupervisedGraphWiseModel model = analyst.supervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .setEdgeInputPropertyNames("edge_provider_features")
    .setVertexTargetPropertyName("target_property")
    .setTargetVertexLabels("provider1")
    .build();
```

Python

```
params = dict(vertex_target_property_name="target_property",
              vertex_input_property_names=["vertex_provider1_features",
"vertex_provider2_features"],
              edge_input_property_names=["edge_provider_features"],
              target_vertex_labels=["provider1"])
model = analyst.supervised_graphwise_builder(**params)
```

If you wish to control the flow of the embeddings at each layer, you can enable or disable the required connections. By default, all the connections are enabled.

- JShell
- Java
- Python

JShell

```
opg4j> var convLayerConfig = analyst.graphWiseConvLayerConfigBuilder().
         setNumSampledNeighbors(25).
         useVertexToVertexConnection(true).
         useEdgeToVertexConnection(true).
         useEdgeToEdgeConnection(false).
         useVertexToEdgeConnection(false).
         build()
opg4j> var model = analyst.supervisedGraphWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
         setEdgeInputPropertyNames("edge_provider_features").
         setVertexTargetPropertyName("target_property").
         setTargetVertexLabels("provider1").
         build()
```

Java

```
GraphWiseConvLayerConfig convLayerConfig =
analyst.graphWiseConvLayerConfigBuilder()
    .setNumSampledNeighbors(10)
    .useVertexToVertexConnection(true)
    .useEdgeToVertexConnection(true)
    .useEdgeToEdgeConnection(false)
    .useVertexToEdgeConnection(false)
    .build();

SupervisedGraphWiseModel model =
analyst.supervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .setEdgeInputPropertyNames("edge_provider_features")
    .setVertexTargetPropertyName("target_property")
    .setTargetVertexLabels("provider1")
    .setConvLayerConfigs(convLayerConfig)
    .build();
```

Python

```
conv_layer_config = dict(num_sampled_neighbors=25,
                         activation_fn='tanh',
                         weight_init_scheme='xavier',
                         neighbor_weight_property_name=weightProperty,
                         vertex_to_vertex_connection=True,
                         edge_to_vertex_connection=True,
                         vertex_to_edge_connection=False,
                         edge_to_edge_connection=False)

conv_layer = analyst.graphwise_conv_layer_config(**conv_layer_config)

params = dict(vertex_target_property_name="target_property",
```

```
vertex_input_property_names=["vertex_provider1_features",
"vertex_provider2_features"],
              edge_input_property_names=["edge_provider_features"],
              target_vertex_labels=["provider1"],
              conv_layer_config=[conv_layer])

model = analyst.supervised_graphwise_builder(**params)
```

15.2.5 Classification Versus Regression Models on Supervised GraphWise Models

When predicting a property, the loss function defines if the model will perform classification tasks or regression tasks.

For classification tasks, the Supervised GraphWise model will infer labels. Even if the property is a number, the model will assign one label for each value found and classify on it. The possible losses for classification tasks are `softmax cross entropy`, `sigmoid cross entropy`, and `DevNet loss`.

For regression tasks, the Supervised GraphWise model will infer values for the property. The loss for regression tasks is the `MSE` loss.

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.loss.LossFunctions
opg4j> var model = analyst.supervisedGraphWiseModelBuilder().
     setVertexInputPropertyNames("vertex_features").
     setEdgeInputPropertyNames("edge_features").
     setVertexTargetPropertyName("scores").
     setConvLayerConfigs(convLayerConfig).
     setPredictionLayerConfigs(predictionLayerConfig).
     setLossFunction(LossFunctions.MSELoss()).
     setBatchGenerator(BatchGenerators.STRATIFIED_OVERSAMPLING).
     build()
```

Java

```
import oracle.pgx.config.mllib.loss.LossFunctions;

SupervisedGraphWiseModel model = analyst.supervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
```

```
    .setVertexTargetPropertyName("scores")
    .setConvLayerConfigs(convLayerConfig)
    .setPredictionLayerConfigs(predictionLayerConfig)
    .setLossFunction(LossFunctions.MSELoss())
    .setBatchGenerator(BatchGenerators.STRATIFIED_OVERSAMPLING)
    .build();
```

Python

```
from pypgx.api.mllib import MSELoss

params = dict(edge_target_property_name="scores",
              conv_layer_config=[conv_layer],
              pred_layer_config=[pred_layer],
              vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              batch_gen='Stratified_Oversampling',
              loss_fn=MSELoss())

model = analyst.supervised_graphwise_builder(**params)
```

15.2.6 Setting a Custom Loss Function and Batch Generator (for Anomaly Detection)

It is possible to select different loss functions for the supervised model by providing a `LossFunction` object, and different batch generators by providing a `BatchGenerator` object. This is useful for applications such as Anomaly Detection, which can be cast into the standard supervised framework but require different loss functions and batch generators.

SupervisedGraphWise model can use the `DevNetLoss` and the `StratifiedOversamplingBatchGenerator`. The `DevNetLoss` takes confidence margin and the value the anomaly takes in the target property as the two parameters.

The following example assumes that the `convLayerConfig` has already been defined:

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.loss.LossFunctions
opg4j> import oracle.pgx.config.mllib.batchgenerator.BatchGenerators
opg4j> var predictionLayerConfig =
analyst.graphWisePredictionLayerConfigBuilder().
```

```
         setHiddenDimension(32).
         setActivationFunction(ActivationFunction.LINEAR).
         build()
opg4j> var model = analyst.supervisedGraphWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         setVertexTargetPropertyName("labels").
         setConvLayerConfigs(convLayerConfig).
         setPredictionLayerConfigs(predictionLayerConfig).
         setLossFunction(LossFunctions.devNetLoss(5.0, true)).
         setBatchGenerator(BatchGenerators.STRATIFIED_OVERSAMPLING).
         build()
```

Java

```
import oracle.pgx.config.mllib.loss.LossFunctions;
import oracle.pgx.config.mllib.batchgenerator.BatchGenerators;

GraphWisePredictionLayerConfig predictionLayerConfig =
analyst.graphWisePredictionLayerConfigBuilder()
    .setHiddenDimension(32)
    .setActivationFunction(ActivationFunction.LINEAR)
    .build();

SupervisedGraphWiseModel model = analyst.supervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setVertexTargetPropertyName("labels")
    .setConvLayerConfigs(convLayerConfig)
    .setPredictionLayerConfigs(predictionLayerConfig)
    .setLossFunction(LossFunctions.devNetLoss(5.0, true))
    .setBatchGenerator(BatchGenerators.STRATIFIED_OVERSAMPLING)
    .build();
```

Python

```
from pypgx.api.mllib import DevNetLoss

pred_layer_config = dict(hidden_dim=32,
                         activation_fn='LINEAR')

pred_layer = analyst.graphwise_pred_layer_config(**pred_layer_config)

params = dict(vertex_target_property_name="labels",
              conv_layer_config=[conv_layer],
              pred_layer_config=[pred_layer],
              vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              loss_fn=DevNetLoss(5.0, True),
              batch_gen='Stratified_Oversampling',
              seed=17)

model = analyst.supervised_graphwise_builder(**params)
```

15.2.7 Training a Supervised GraphWise Model

You can train a Supervised GraphWise model on a graph as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(trainGraph)
```

Java

```
model.fit(trainGraph);
```

Python

```
model.fit(train_graph)
```

15.2.8 Getting the Loss Value For a Supervised GraphWise Model

You can fetch the training loss value as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var loss = model.getTrainingLoss()
```

Java

```
double loss = model.getTrainingLoss();
```

Python

```
loss = model.get_training_loss()
```

15.2.9 Inferring the Vertex Labels for a Supervised GraphWise Model

You can infer the labels for vertices on any graph (including vertices or graphs that were not seen during training) as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var labels = model.inferLabels(fullGraph, testVertices)
opg4j> labels.head().print()
```

Java

```
PgxFrame labels = model.inferLabels(fullGraph,testVertices);
labels.head().print();
```

Python

```
labels = model.infer_labels(full_graph, test_vertices)
labels.print()
```

The output will be similar to the following example output:

```
+----------------------------------+
| vertexId | label                 |
+----------------------------------+
| 2        | Neural Networks       |
| 6        | Theory                |
| 7        | Case Based            |
| 22       | Rule Learning         |
| 30       | Theory                |
| 34       | Neural Networks       |
| 47       | Case Based            |
| 48       | Probabalistic Methods |
```

```
| 50       | Theory                   |
| 52       | Theory                   |
+---------------------------------+
```

Similarly, you can also get the model confidence for each class by inferring the prediction logits as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var logits = model.inferLogits(fullGraph, testVertices)
opg4j> labels.head().print()
```

Java

```
PgxFrame logits = model.inferLogits(fullGraph,testVertices);
logits.head().print();
```

Python

```
logits = model.infer_logits(full_graph, test_vertices)
logits.print()
```

15.2.10 Evaluating the Supervised GraphWise Model Performance

You can evaluate various classification metrics for the model using the `evaluateLabels` method as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.evaluateLabels(fullGraph, testVertices).print()
```

Java

```
model.evaluateLabels(fullGraph,testVertices).print();
```

Python

```
model.evaluate_labels(full_graph, test_vertices).print()
```

The output will be similar to the following example output:

```
+------------------------------------------+
| Accuracy | Precision | Recall | F1-Score |
+------------------------------------------+
| 0.8488   | 0.8523    | 0.831  | 0.8367   |
+------------------------------------------+
```

15.2.11 Inferring Embeddings for a Supervised GraphWise Model

You can use a trained model to infer embeddings for unseen nodes and store in the database as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var vertexVectors = model.inferEmbeddings(fullGraph,
testVertices).flattenAll()
opg4j> vertexVectors.write().
    db().
    name("vertex vectors").
    tablename("vertexVectors").
    overwrite(true).
    store()
```

Java

```
PgxFrame vertexVectors =
model.inferEmbeddings(fullGraph,testVertices).flattenAll();
vertexVectors.write()
    .db()
    .name("vertex vectors")
    .tablename("vertexVectors")
```

```
     .overwrite(true)
     .store();
```

Python

```
vertex_vectors = model.infer_embeddings(full_graph,
test_vertices).flatten_all()
vertex_vectors.write().db().table_name("table_name").name("vertex_vecto
rs").overwrite(True).store()
```

The schema for the `vertexVectors` will be as follows without flattening (`flattenAll` splits the vector column into separate double-valued columns):

```
+----------------------------------------------------------------+
| vertexId                                  | embedding          |
+----------------------------------------------------------------+
```

> **Note:**
>
> All the preceding examples assume that you are inferring the embeddings for a model in the current logged in database. If you must infer embeddings for the model in a different database then refer to the examples in Inferring Embeddings for a Model in Another Database.

- Inferring Embeddings for a Model in Another Database

15.2.11.1 Inferring Embeddings for a Model in Another Database

You can infer embeddings on a trained model and store in a different database other than the one used for login.

The following code shows how to infer embeddings and store in a different database:

- JShell
- Java
- Python

JShell

```
opg-jshell> var vertexVectors = model.inferEmbeddings(fullGraph,
testVertices).flattenAll()
opg-jshell> vertexVectors.write().
     db().
     username("user").                   // DB user to use for storing
```

```
the model
     password("password").              // password of the DB user
     jdbcUrl("jdbcUrl").                // jdbc url to the DB
     name("vertex vectors").
     tablename("vertexVectors").        // indicates the name of the table
in which the data should be stored
     overwrite(true).
     store()
```

Java

```
PgxFrame vertexVectors =
model.inferEmbeddings(fullGraph,testVertices).flattenAll();
vertexVectors.write()
    .db()
    .username("user")                   // DB user to use for storing the
model
    .password("password")               // password of the DB user
    .jdbcUrl("jdbcUrl")                 // jdbc url to the DB
    .name("vertex vectors")
    .tablename("vertexVectors")         // indicates the name of the table
in which the data should be stored
    .overwrite(true)
    .store();
```

Python

```
vertex_vectors = model.infer_embeddings(fullGraph,test_vertices).flattenAll()
vertex_vectors.write().db().username("user") \
                           .password("password") \
                           .jdbc_url("jdbcUrl") \
                           .table_name("table_name") \
                           .name("vertex vectors") \
                           .overwrite(True) \
                           .store()
```

15.2.12 Storing a Trained Supervised GraphWise Model

You can store models in database. The models get stored as a row inside a model store table.

The following code shows how to store a trained Supervised GraphWise model in database in a specific model store table:

- JShell
- Java

- Python

JShell

```
opg4j> model.export().db().
              modelstore("modelstoretablename").  // name of the model
store table
              modelname("model").                 // model name
(primary key of model store table)
              description("a model description"). // description to
store alongside the model
              store()
```

Java

```
model.export().db()
    .modelstore("modelstoretablename")  // name of the model store
table
    .modelname("model")                 // model name (primary key of
model store table)
    .description("a model description") // description to store
alongside the model
    .store();
```

Python

```
model.export().db(model_store="modeltablename",            # name of
the model store table
                  model_name="model",                      # model
name (primary key of model store table)
                  model_description="a model description") #
description to store alongside the model
```

Note:

All the preceding examples assume that you are storing the model in the current logged in database. If you must store the model in a different database then refer to the examples in Storing a Trained Model in Another Database.

15.2.13 Loading a Pre-Trained Supervised GraphWise Model

You can load models from a database.

You can load a pre-trained Supervised GraphWise model from a model store table in database as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.loadSupervisedGraphWiseModel().db().
                modelstore("modeltablename"). // name of the model store 
table
                modelname("model").           // model name (primary key of 
model store table)
                load();
```

Java

```
SupervisedGraphWiseModel model = analyst.loadSupervisedGraphWiseModel().db()
     .modelstore("modeltablename") // name of the model store table
     .modelname("model")           // model name (primary key of model store 
table)
     .load();
```

Python

```
model = analyst.get_supervised_graphwise_model_loader(). \
                 db(model_store="modelstoretablename",  # name of the model 
store table
                    model_name="model")                 # model name 
(primary key of model store table)
```

> **Note:**
>
> All the preceding examples assume that you are loading the model from the current logged in database. If you must load the model from a different database then refer to the examples in Loading a Pre-Trained Model From Another Database.

15.2.14 Destroying a Supervised GraphWise Model

You can destroy a GraphWise model as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.destroy()
```

Java

```
model.destroy();
```

Python

```
model.destroy()
```

15.2.15 Explaining a Prediction of a Supervised GraphWise Model

In order to understand which features and vertices are important for a prediction of the Supervised GraphWise model, you can generate a `SupervisedGnnExplanation` using a technique similar to the `GNNExplainer` by Ying et al.

The explanation holds information related to:

- **Graph structure**: An importance score for each vertex
- **Features**: An importance score for each graph property

> **Note:**
>
> The vertex being explained is always assigned importance 1. Further, the feature importances are scaled such that the most important feature has importance 1.

Additionally, an `SupervisedGnnExplanation` contains the inferred embeddings, logits, and label. You can get explanations for a model's predictions by using the `SupervisedGnnExplainer` object. The object can be obtained using the `gnnExplainer` method. After obtaining the `SupervisedGnnExplainer` object, you can use the `inferAndExplain` method to request an explanation for a vertex.

The parameters of the explainer can be configured while the explainer is being created or afterwards using the relevant setter functions. The configurable parameters for the `SupervisedGnnExplainer` are as follows:

- **`numOptimizationSteps`:** Number of optimization steps used by the explainer.
- **`learningRate`:** Learning rate of the explainer.
- **`marginalize`:** Determines if the explainer loss is marginalized over features. This can help in cases where there are important features that take values close to zero. Without marginalization the explainer can learn to mask such features out even if they are important. Marginalization solves this by learning a mask for the deviation from the estimated input distribution.

Note that, in order to achieve best results, the features should be centered around 0.

For example, assume a simple graph that contains a feature that correlates with the label and another feature that does not. It is therefore expected that the importance of the features to differ significantly (with the feature correlating with the label being more important), while structural importance does not play a big role. In this case, you can generate an explanation as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var simpleGraph = session.createGraphBuilder().
                          addVertex(0).setProperty("label_feature",
0.5).setProperty("const_feature", 0.5).
                          setProperty("label", true).
                          addVertex(1).setProperty("label_feature",
-0.5).setProperty("const_feature", 0.5).
                          setProperty("label", false).
                          addEdge(0, 1).build()

// build and train a Supervised GraphWise model as explained in Advanced
Hyperparameter Customization

// obtain and configure GnnExplainer
var explainer = model.gnnExplainer().learningRate(0.05)
explainer.numOptimizationSteps(200)

// explain prediction of vertex 0
opg4j> var explanation = explainer.inferAndExplain(simpleGraph,
simpleGraph.getVertex(0))
// if you used the devNet loss, you can add the decision threshold as an
extra parameter:
// var explanation = explainer.inferAndExplain(simpleGraph,
simpleGraph.getVertex(0), 6f)

opg4j> var constProperty = simpleGraph.getVertexProperty("const_feature")
opg4j> var labelProperty = simpleGraph.getVertexProperty("label_feature")

// retrieve feature importances
opg4j> var featureImportances = explanation.getVertexFeatureImportance()
opg4j> var importanceConstProp = featureImportances.get(constProperty) //
small as unimportant
opg4j> var importanceLabelProp = featureImportances.get(labelProperty) //
large (1) as important

// retrieve computation graph with importances
opg4j> var importanceGraph = explanation.getImportanceGraph()
```

```
// retrieve importance of vertices
opg4j> var importanceProperty =
explanation.getVertexImportanceProperty()
opg4j> var importanceVertex0 = importanceProperty.get(0) // has
importance 1
opg4j> var importanceVertex1 = importanceProperty.get(1) // available
if vertex 1 part of computation
```

Java

```
PgxGraph simpleGraph = session.createGraphBuilder()
    .addVertex(0).setProperty("label_feature",
0.5).setProperty("const_feature", 0.5)
    .setProperty("label", true)
    .addVertex(1).setProperty("label_feature",
-0.5).setProperty("const_feature", 0.5)
    .setProperty("label", false)
    .addEdge(0, 1).build();

// build and train a Supervised GraphWise model as explained in Advanced
Hyperparameter Customization

// obtain and configure the explainer
SupervisedGnnExplainerexplainer=model.gnnExplainer().learningRate(0.05)
;
explainer.numOptimizationSteps(200);

// explain prediction of vertex 0
SupervisedGnnExplanation<Integer> explanation =
explainer.inferAndExplain(simpleGraph,
    simpleGraph.getVertex(0));

// if we used the devNet loss, we can add the decision threshold as an
extra parameter:
// SupervisedGnnExplanation<Integer> explanation =
explainer.inferAndExplain(simpleGraph, simpleGraph.getVertex(0), 6f);

VertexProperty<Integer, Float> constProperty =
simpleGraph.getVertexProperty("const_feature");
VertexProperty<Integer, Float> labelProperty =
simpleGraph.getVertexProperty("label_feature");

// retrieve feature importances
Map<VertexProperty<Integer, ?>, Float> featureImportances =
explanation.getVertexFeatureImportance();
float importanceConstProp = featureImportances.get(constProperty); //
small as unimportant
float importanceLabelProp = featureImportances.get(labelProperty); //
large (1) as important

// retrieve computation graph with importances
PgxGraph importanceGraph = explanation.getImportanceGraph();
```

```
// retrieve importance of vertices
VertexProperty<Integer, Float> importanceProperty =
explanation.getVertexImportanceProperty();
float importanceVertex0 = importanceProperty.get(0); // has importance 1
float importanceVertex1 = importanceProperty.get(1); // available if vertex
1 part of computation
```

Python

```
simple_graph = session.create_graph_builder()
    .add_vertex(0).set_property("label_feature",
0.5).set_property("const_feature", 0.5)
    .set_property("label", true)
    .add_vertex(1).set_property("label_feature",
-0.5).set_property("const_feature", 0.5)
    .set_property("label", false)
    .add_edge(0, 1).build()

# build and train a Supervised GraphWise model as explained in Advanced
Hyperparameter Customization

# obtain the explainer
explainer = model.gnn_explainer(learning_rate=0.05)
explainer.num_optimization_steps=200

# explain prediction of vertex 0
explanation =
explainer.inferAndExplain(simple_graph,simple_graph.get_vertex(0))
# if we used the devNet loss, we can add the decision threshold as an extra
parameter:
# explanation = explainer.inferAndExplain(simple_graph,
simple_graph.get_vertex(0), 6)

const_property = simple_graph.get_vertex_property("const_feature")
label_property = simple_graph.get_vertex_property("label_feature")

# retrieve feature importances
feature_importances = explanation.get_vertex_feature_importance()
importance_const_prop = feature_importances[const_property]
importance_label_prop = feature_importances[label_property]

# retrieve computation graph with importances
importance_graph = explanation.get_importance_graph()

# retrieve importance of vertices
importance_property = explanation.get_vertex_importance_property()
importance_vertex_0 = importance_property[0]
importance_vertex_1 = importance_property[1]
```

See Also:

- Building a Minimal GraphWise Model
- Training a Supervised GraphWise Model

15.3 Using the Unsupervised GraphWise Algorithm

Unsupervised GraphWise is an unsupervised inductive vertex representation learning algorithm which is able to leverage vertex information. The learned embeddings can be used in various downstream tasks including vertex classification, vertex clustering and similar vertex search.

Unsupervised GraphWise is based on Deep Graph Infomax (DGI) by Velickovic et al.

Model Structure

A Unsupervised GraphWise model consists of graph convolutional layers followed by a DGI Layer.

The forward pass through a convolutional layer for a vertex proceeds as follows:

1. A set of neighbors of the vertex is sampled.
2. The previous layer representations of the neighbors are mean-aggregated, and the aggregated features are concatenated with the previous layer representation of the vertex.
3. This concatenated vector is multiplied with weights, and a bias vector is added.
4. The result is normalized to such that the layer output has unit norm.

The DGI Layer consists of three parts enabling unsupervised learning using embeddings produced by the convolution layers.

1. **Corruption function:** Shuffles the node features while preserving the graph structure to produce negative embedding samples using the convolution layers.
2. **Readout function:** Sigmoid activated mean of embeddings, used as summary of a graph.
3. **Discriminator:** Measures the similarity of positive (unshuffled) embeddings with the summary as well as the similarity of negative samples with the summary from which the loss function is computed.

Since none of these contains mutable hyperparameters, the default DGI layer is always used and cannot be adjusted.

The following describes the usage of the main functionalities of the implementation of `DGI` in PGX using the Cora graph as an example:

- Loading a Graph
- Building a Minimal Unsupervised GraphWise Model
- Advanced Hyperparameter Customization
- Building an Unsupervised GraphWise Model Using Heterogeneous Graphs
- Training an Unsupervised GraphWise Model

15.3.1 Loading a Graph

The following describes the steps for loading a graph:

1. Create a **Session** and an **Analyst**.

- JShell
- Java
- Python

JShell

```
cd /opt/oracle/graph/
./bin/opg4j
// starting the shell will create an implicit session and analyst
opg4j> import oracle.pgx.config.mllib.ActivationFunction
opg4j> import oracle.pgx.config.mllib.WeightInitScheme
opg4j> PgxSession session = Pgx.createSession("my-session")
opg4j> Analyst analyst = session.createAnalyst()
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.mllib.UnsupervisedGraphWiseModel;
import oracle.pgx.api.frames.*;
import oracle.pgx.config.mllib.ActivationFunction;
import oracle.pgx.config.mllib.GraphWiseConvLayerConfig;
import oracle.pgx.config.mllib.UnsupervisedGraphWiseModelConfig;
import oracle.pgx.config.mllib.WeightInitScheme;

PgxSession session = Pgx.createSession("my-session");
Analyst analyst = session.createAnalyst();
```

Python

```
session = pypgx.get_session()
analyst = session.analyst
```

2. Load the **graph**.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphWithProperties("<path/to/
graph_config.json>")
```

Java

```
PgxGraph graph = session.readGraphWithProperties("<path/to/
graph_config.json>");
```

Python

```
graph = session.read_graph_with_properties("<path/to/
graph_config.json>")
```

You do not need to use a test graph or test vertices, since the model is trained to be unsupervised.

15.3.2 Building a Minimal Unsupervised GraphWise Model

You can build an Unsupervised GraphWise model with only vertex properties, or only edge properties or both using the minimal configuration and default hyper-parameters.

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.unsupervisedGraphWiseModelBuilder().
                setVertexInputPropertyNames("features").
                build()
```

Java

```
UnsupervisedGraphWiseModel model =
analyst.unsupervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("features")
    .build();
```

Python

```
model =
analyst.unsupervised_graphwise_builder(vertex_input_property_names=["features
"])
```

15.3.3 Advanced Hyperparameter Customization

You can build an Unsupervised GraphWise model with only vertex properties or only edge properties or both using rich hyperparameter customization.
This is implemented using the sub-config class, `GraphWiseConvLayerConfig`.

The following code describes the implementation of the configuration in a Unsupervised GraphWise model. The example also specifies a weight decay parameter of `0.001` and dropout with dropping probability `0.5` for the model to counteract overfitting.

- JShell
- Java
- Python

JShell

```
opg4j> var weightProperty = analyst.pagerank(trainGraph).getName()
opg4j> var convLayerConfig = analyst.graphWiseConvLayerConfigBuilder().
                setNumSampledNeighbors(25).
                setActivationFunction(ActivationFunction.TANH).
                setWeightInitScheme(WeightInitScheme.XAVIER).
                setWeightedAggregationProperty(weightProperty).
                setDropoutRate(0.5).
                build()
opg4j> var dgiLayerConfig = analyst.graphWiseDgiLayerConfigBuilder().
                setCorruptionFunction(new PermutationCorruption()).

setDiscriminator(GraphWiseDgiLayerConfig.Discriminator.BILINEAR).

setReadoutFunction(GraphWiseDgiLayerConfig.ReadoutFunction.MEAN).
                build()
opg4j> var model = analyst.unsupervisedGraphWiseModelBuilder().
                setVertexInputPropertyNames("vertex_features").
                setEdgeInputPropertyNames("edge_features").
```

```
                setConvLayerConfigs(convLayerConfig).
                setDgiLayerConfig(dgiLayerConfig).

setLossFunction(UnsupervisedGraphWiseModelConfig.LossFunction.SIGMOID_C
ROSS_ENTROPY).
                setEmbeddingDim(256).
                setLearningRate(0.05).
                setNumEpochs(30).
                setSeed(42).
                setShuffle(false).
                setStandardize(true).
                setBatchSize(64).
                build()
```

Java

```
String weightProperty = analyst.pagerank(trainGraph).getName();
GraphWiseConvLayerConfig convLayerConfig =
analyst.graphWiseConvLayerConfigBuilder()
    .setNumSampledNeighbors(25)
    .setActivationFunction(ActivationFunction.TANH)
    .setWeightInitScheme(WeightInitScheme.XAVIER)
    .setWeightedAggregationProperty(weightProperty)
    .setDropoutRate(0.5)
    .build();

GraphWiseDgiLayerConfig dgiLayerConfig =
analyst.graphWiseDgiLayerConfigBuilder()
    .setCorruptionFunction(new PermutationCorruption())
    .setDiscriminator(GraphWiseDgiLayerConfig.Discriminator.BILINEAR)
    .setReadoutFunction(GraphWiseDgiLayerConfig.ReadoutFunction.MEAN)
    .build();

UnsupervisedGraphWiseModel model =
analyst.unsupervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setDgiLayerConfig(dgiLayerConfig)
    .setLossFunction(UnsupervisedGraphWiseModelConfig.LossFunction.SIGM
OID_CROSS_ENTROPY)
    .setConvLayerConfigs(convLayerConfig)
    .setWeightDecay(0.001)
    .setEmbeddingDim(256)
    .setLearningRate(0.05)
    .setNumEpochs(30)
    .setSeed(42)
    .setShuffle(false)
    .setStandardize(true)
    .setBatchSize(64)
    .build();
```

Python

```
weightProperty = analyst.pagerank(train_graph).name

conv_layer_config = dict(num_sampled_neighbors=25,
                         activation_fn='tanh',
                         weight_init_scheme='xavier',
                         neighbor_weight_property_name=weightProperty,
                         dropout_rate=0.5)
conv_layer = analyst.graphwise_conv_layer_config(**conv_layer_config)

dgi_layer_config = dict(corruption_function=None,
                        readout_function="mean",
                        discriminator="bilinear")
dgi_layer = analyst.graphwise_dgi_layer_config(**dgi_layer_config)

params = dict(conv_layer_config=[conv_layer],
              dgi_layer_config=dgi_layer,
              loss_fn="sigmoid_cross_entropy",
              vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              weight_decay=0.001,
              layer_size=256,
              learning_rate=0.05,
              num_epochs=30,
              seed=42,
              standardize=true,
              batch_size=64
)

model = analyst.unsupervised_graphwise_builder(**params)
```

See UnsupervisedGraphWiseModelBuilder and GraphWiseConvLayerConfigBuilder in Javadoc for full description of all available hyperparameters and their default values.

15.3.4 Building an Unsupervised GraphWise Model Using Heterogeneous Graphs

You can build an Unsupervised GraphWise model using partitioned graphs which have different providers and features.

- JShell
- Java
- Python

JShell

```
opg4j> analyst.unsupervisedGraphWiseModelBuilder().
        setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
        setEdgeInputPropertyNames("edge_provider_features").
        setVertexTargetPropertyName("target_property").
        build()
```

Java

```
UnsupervisedGraphWiseModel model =
analyst.unsupervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .setEdgeInputPropertyNames("edge_provider_features")
    .setVertexTargetPropertyName("target_property")
    .build();
```

Python

```
params =
dict(vertex_input_property_names=["vertex_provider1_features",
"vertex_provider2_features"],
              edge_input_property_names=["edge_provider_features"])
model = analyst.unsupervised_graphwise_builder(**params)
```

Also, you can select specific providers as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.unsupervisedGraphWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
         setEdgeInputPropertyNames("edge_provider_features").
         setTargetVertexLabels("provider1").
         build()
```

Java

```
UnsupervisedGraphWiseModel model =
analyst.unsupervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .setEdgeInputPropertyNames("edge_provider_features")
    .setTargetVertexLabels("provider1")
    .build();
```

Python

```
params = dict(vertex_input_property_names=["vertex_provider1_features",
"vertex_provider2_features"],
              edge_input_property_names=["edge_provider_features"],
              target_vertex_labels=["provider1"])
model = analyst.unsupervised_graphwise_builder(**params)
```

If you wish to control the flow of the embeddings at each layer, you can enable or disable the required connections. By default, all the connections are enabled.

- JShell
- Java
- Python

JShell

```
opg4j> var convLayerConfig = analyst.graphWiseConvLayerConfigBuilder().
         setNumSampledNeighbors(25).
         useVertexToVertexConnection(true).
         useEdgeToVertexConnection(true).
         useEdgeToEdgeConnection(false).
         useVertexToEdgeConnection(false).
         build()
opg4j> var model = analyst.unsupervisedGraphWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
         setEdgeInputPropertyNames("edge_provider_features").
         setTargetVertexLabels("provider1").
         build()
```

Java

```
GraphWiseConvLayerConfig convLayerConfig =
analyst.graphWiseConvLayerConfigBuilder()
    .setNumSampledNeighbors(10)
```

```
    .useVertexToVertexConnection(true)
    .useEdgeToVertexConnection(true)
    .useEdgeToEdgeConnection(false)
    .useVertexToEdgeConnection(false)
    .build();

UnsupervisedGraphWiseModel model =
analyst.unsupervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .setEdgeInputPropertyNames("edge_provider_features")
    .setTargetVertexLabels("provider1")
    .setConvLayerConfigs(convLayerConfig)
    .build();
```

Python

```
conv_layer_config = dict(num_sampled_neighbors=25,
                         activation_fn='tanh',
                         weight_init_scheme='xavier',
                         neighbor_weight_property_name=weightProperty,
                         vertex_to_vertex_connection=True,
                         edge_to_vertex_connection=True,
                         vertex_to_edge_connection=False,
                         edge_to_edge_connection=False)

conv_layer = analyst.graphwise_conv_layer_config(**conv_layer_config)

params =
dict(vertex_input_property_names=["vertex_provider1_features",
"vertex_provider2_features"],
              edge_input_property_names=["edge_provider_features"],
              target_vertex_labels=["provider1"],
              conv_layer_config=[conv_layer])

model = analyst.unsupervised_graphwise_builder(**params)
```

15.3.5 Training an Unsupervised GraphWise Model

You can train an Unsupervised GraphWise model on a graph as shown:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(trainGraph)
```

Java

```
model.fit(trainGraph);
```

Python

```
model.fit(train_graph)
```

15.3.6 Getting the Loss Value for an Unsupervised GraphWise Model

You can fetch the training loss value for an Unsupervised GraphWise Model as shown in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var loss = model.getTrainingLoss()
```

Java

```
double loss = model.getTrainingLoss();
```

Python

```
loss = model.get_training_loss()
```

15.3.7 Inferring Embeddings for an Unsupervised GraphWise Model

You can use a trained model to infer embeddings for unseen nodes and store them in the database as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var vertexVectors = model.inferEmbeddings(fullGraph,
fullGraph.getVertices()).flattenAll()
opg4j> vertexVectors.write().
    db().
    name("vertex vectors").
    tablename("vertexVectors").
    overwrite(true).
    store()
```

Java

```
PgxFrame vertexVectors =
model.inferEmbeddings(fullGraph,fullGraph.getVertices()).flattenAll();
vertexVectors.write()
    .db()
    .name("vertex vectors")
    .tablename("vertexVectors")
    .overwrite(true)
    .store();
```

Python

```
vertex_vectors =
model.infer_embeddings(full_Graph,full_Graph.get_vertices()).flattenAl
l()
vertex_vectors.write().db().table_name("table_name").name("vertex_vecto
rs").overwrite(True).store()
```

The schema for the `vertexVectors` will be as follows without flattening (`flattenAll` splits the vector column into separate double-valued columns):

```
+-----------------------------------------------------------------+
| vertexId                                | embedding             |
+-----------------------------------------------------------------+
```

Note:

All the preceding examples assume that you are inferring the embeddings for a model in the current logged in database. If you must infer embeddings for the model in a different database then refer to the examples in Inferring Embeddings for a Model in Another Database.

15.3.8 Storing an Unsupervised GraphWise Model

You can store models in database. The models get stored as a row inside a model store table.

- JShell
- Java
- Python

JShell

```
opg4j> model.export().db().
              modelstore("modelstoretablename").  // name of the model store
table
              modelname("model").                 // model name (primary key
of model store table)
              description("a model description"). // description to store
alongside the model
              store()
```

Java

```
model.export().db()
    .modelstore("modelstoretablename")  // name of the model store table
    .modelname("model")                 // model name (primary key of model
store table)
    .description("a model description") // description to store alongside
the model
    .store();
```

Python

```
model.export().db(model_store="modeltablename",            # name of the
model store table
                  model_name="model",                        # model name
(primary key of model store table)
                  model_description="a model description") # description to
store alongside the model
```

> **Note:**
>
> All the preceding examples assume that you are storing the model in the current logged in database. If you must store the model in a different database then refer to the examples in Storing a Trained Model in Another Database.

15.3.9 Loading a Pre-Trained Unsupervised GraphWise Model

You can load models from a database.

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.loadUnsupervisedGraphWiseModel().db().
                modelstore("modeltablename"). // name of the model
store table
                modelname("model").          // model name (primary
key of model store table)
                load()
```

Java

```
UnsupervisedGraphWiseModel model =
analyst.loadUnsupervisedGraphWiseModel().db()
     .modelstore("modeltablename") // name of the model store table
     .modelname("model")           // model name (primary key of model
store table)
     .load();
```

Python

```
model = analyst.get_unsupervised_graphwise_model_loader(). \
                 db(model_store="modelstoretablename",  # name of the
model store table
                    model_name="model")                 # model name
(primary key of model store table)
```

Note:

All the preceding examples assume that you are loading the model from the current logged in database. If you must load the model from a different database then refer to the examples in Loading a Pre-Trained Model From Another Database.

15.3.10 Destroying an Unsupervised GraphWise Model

You can destroy an Unsupervised GraphWise model as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.destroy()
```

Java

```
model.destroy();
```

Python

```
model.destroy()
```

15.3.11 Explaining a Prediction for an Unsupervised GraphWise Model

In order to understand which features and vertices are important for a prediction of the Unsupervised GraphWise model, you can generate an `UnsupervisedGnnExplanation` using a technique similar to the `GNNExplainer` by Ying et al.

The explanation holds information related to:

- **Graph structure**: An importance score for each vertex
- **Features**: An importance score for each graph property

Note:

The vertex being explained is always assigned importance 1. Further, the feature importances are scaled such that the most important feature has importance 1.

Additionally, an `UnsupervisedGnnExplanation` contains the inferred embedding. You can get explanations for a model's predictions by using the `UnsupervisedGnnExplainer` object. The object can be obtained using the `gnnExplainer` method. After obtaining the `UnsupervisedGnnExplainer` object, you can use the `inferAndExplain` method to request an explanation for a vertex.

The parameters of the explainer can be configured while the explainer is being created or afterwards using the relevant setter functions. The configurable parameters for the `UnsupervisedGnnExplainer` are as follows:

- **`numOptimizationSteps`:** Number of optimization steps used by the explainer.
- **`learningRate`:** Learning rate of the explainer.
- **`marginalize`:** Determines if the explainer loss is marginalized over features. This can help in cases where there are important features that take values close to zero. Without marginalization the explainer can learn to mask such features out even if they are important. Marginalization solves this by learning a mask for the deviation from the estimated input distribution.
- **`numClusters`:** Number of clusters to use in the explainer loss. The unsupervised explainer uses k-means clustering to compute the explainer loss that is optimized. If the approximate number of components in the graph is known, it is a good idea to set the number of clusters to this number.
- **`numSamples`:** Number of vertex samples to use to optimize the explainer. For the sake of performance, the explainer computes the loss on this number of randomly sampled vertices. Using more samples will be more accurate but will take longer and use more resources.

Note that, in order to achieve best results, the features should be centered around 0.

For example, assume a simple graph, `componentGraph` which contains `k` densely connect *components*, that is, there are many edges between vertices of the same component and few edges between any two components. By training an Unsupervised GraphWise model on this graph, you can expect a model that produces similar embeddings for vertices in a densely connected component.

The following example shows how to generate an explanation on an inference `componentGraph`. It is expected that vertices from the same component to have a higher importance than vertices from a different component. Note that the feature importances are not relevant in this example.

- JShell
- Java
- Python

JShell

```
opg4j> var componentGraph =
session.readGraphWithProperties("<path_to_component_graph.json>")
// explain prediction of vertex 0
opg4j> var feat1Property = componentGraph.getVertexProperty("feat1")
opg4j> var feat2Property = componentGraph.getVertexProperty("feat2")
```

```
// build and train an Unsupervised GraphWise model as explained in Advanced
Hyperparameter Customization

// obtain and configure the explainer
// setting the numClusters argument to the expected number of clusters may
improve
// explanation results as the explainer optimization will try to cluster
samples into
// this number of clusters
opg4j> var explainer = model.gnnExplainer().numClusters(50)
// set the number of samples to compute the loss over during explainer
optimization
opg4j> explainer.numSamples(10000)

// explain prediction of vertex 0
opg4j> var explanation = explainer.inferAndExplain(componentGraph,
componentGraph.getVertex(0), 10)

// retrieve computation graph with importance
opg4j> var importanceGraph = explanation.getImportanceGraph()

// retrieve importance of vertices
// vertex 1 is in the same densely connected component as vertex 0
// vertex 2 is in a different component
opg4j> var importanceProperty = explanation.getVertexImportanceProperty()
opg4j> var importanceVertex0 = importanceProperty.get(0)  // has importance 1
opg4j> var importanceVertex1 = importanceProperty.get(1)  // high importance
opg4j> var importanceVertex2 = importanceProperty.get(2)  // low importance

opg4j> var featureImportances = explanation.getVertexFeatureImportance()
opg4j> var importanceConstProp = featureImportances.get(constProperty) //
small as unimportant
opg4j> var importanceLabelProp = featureImportances.get(labelProperty) //
large (1) as important

// optionally retrieve feature importance
opg4j> var featureImportances = explanation.getVertexFeatureImportance()
opg4j> var importanceFeat1Prop = featureImportances.get(feat1Property)
opg4j> var importanceFeat2Prop = featureImportances.get(feat2Property)
```

Java

```
PgxGraph componentGraph =
session.readGraphWithProperties("<path_to_component_graph.json>") // load
component graph
VertexProperty<Integer, Float> feat1Property =
componentGraph.getVertexProperty("feat1");
VertexProperty<Integer, Float> feat2Property =
componentGraph.getVertexProperty("feat2");

// build and train an Unsupervised GraphWise model as explained in Advanced
Hyperparameter Customization
```

```
// obtain and configure the explainer
// setting the numClusters argument to the expected number of clusters
may improve
// explanation results as the explainer optimization will try to
cluster samples into
// this number of clusters
UnsupervisedGnnExplainer explainer =
model.gnnExplainer().numClusters(50);
// set the number of samples to compute the loss over during explainer
optimization
explainer.numSamples(10000);

// explain prediction of vertex 0
UnsupervisedGnnExplanation<Integer> explanation =
explainer.inferAndExplain(componentGraph, componentGraph.getVertex(0));

// retrieve computation graph with importances
PgxGraph importanceGraph = explanation.getImportanceGraph();

// retrieve importance of vertices
// vertex 1 is in the same densely connected component as vertex 0
// vertex 2 is in a different component
VertexProperty<Integer, Float> importanceProperty =
explanation.getVertexImportanceProperty();
float importanceVertex0 = importanceProperty.get(0);  // has
importance 1
float importanceVertex1 = importanceProperty.get(1);  // high
importance
float importanceVertex2 = importanceProperty.get(2);  // low importance

// retrieve feature importance (not relevant for this example)
Map<VertexProperty<Integer, ?>, Float> featureImportances =
explanation.getVertexFeatureImportance();
float importanceFeat1Prop = featureImportances.get(feat1Property);
float importanceFeat2Prop = featureImportances.get(feat2Property);
```

Python

```
# load 'component_graph' with vertex features 'feat1' and 'feat2'
feat1_property = component_graph.get_vertex_property("feat1")
feat2_property = component_graph.get_vertex_property("feat2")

# build and train an Unsupervised GraphWise model as explained in
Advanced Hyperparameter Customization

# obtain and configure the explainer
# setting the num_clusters argument to the expected number of clusters
may improve
# explanation results as the explainer optimization will try to
cluster samples into
# this number of clusters
explainer = model.gnn_explainer(num_clusters=50)
# set the number of samples to compute the loss over during explainer
```

```
optimization
explainer.num_samples = 10000

# explain prediction of vertex 0
explanation = explainer.infer_and_explain(
    graph=component_graph,
    vertex=component_graph.get_vertex(0)
)

# retrieve computation graph with importances
importance_graph = explanation.get_importance_graph()

# retrieve importance of vertices
# vertex 1 is in the same densely connected component as vertex 0
# vertex 2 is in a different component
importance_property = explanation.get_vertex_importance_property()
importance_vertex_0 = importance_property[0]  # has importance 1
importance_vertex_1 = importance_property[1]  # high importance
importance_vertex_2 = importance_property[2]  # low importance

# retrieve feature importance (not relevant for this example)
feature_importances = explanation.get_vertex_feature_importance()
importance_feat1_prop = feature_importances[feat1_property]
importance_feat2_prop = feature_importances[feat2_property]
```

See Also:

- Building a Minimal Unsupervised GraphWise Model
- Training an Unsupervised GraphWise Model

15.4 Using the Supervised EdgeWise Algorithm (Edge Embeddings and Classification)

`SupervisedEdgeWise` is an inductive edge representation learning algorithm which is able to leverage vertex and edge feature information. It can be applied to a wide variety of tasks, including edge classification and link prediction.

`SupervisedEdgeWise` is based on top of the `GraphWise` model, leveraging the source vertex embedding and the destination vertex embedding generated by the `GraphWise` model to generate inductive edge embeddings.

Model Structure

A `SupervisedEdgeWise` model consists of graph convolutional layers followed by several prediction layers.

First, the source and destination vertices of the target edge are processed through the convolutional layers. The forward pass through a convolutional layer for a vertex proceeds as follows:

1. A set of neighbors of the vertex is sampled.
2. The previous layer representations of the neighbors are mean-aggregated, and the aggregated features are concatenated with the previous layer representation of the vertex.
3. This concatenated vector is multiplied with weights, and a bias vector is added.
4. The result is normalized such that the layer output has unit norm.

The edge embedding layer concatenates the source vertex embedding, the edge features and the destination vertex embedding, and then forwards it through a linear layer to get the edge embedding.

The prediction layers are standard neural network layers.

- Loading a Graph
- Building a Minimal Supervised EdgeWise Model
- Advanced Hyperparameter Customization
- Applying EdgeWise for Partitioned Graphs
- Classification Versus Regression on Supervised EdgeWise Models
- Setting a Custom Loss Function and Batch Generator (for Anomaly Detection)
- Setting the Edge Embedding Production Method
- Training the Supervised EdgeWise Model
- Getting the Loss Value for a Supervised EdgeWise Model
- Inferring Edge Labels for a Supervised EdgeWise Model
- Evaluating Model Performance
- Inferring Embeddings for a Supervised EdgeWise Model
- Storing a Supervised EdgeWise Model
- Loading a Pre-Trained Supervised EdgeWise Model
- Destroying a Supervised EdgeWise Model
- Example: Predicting Ratings on the Movielens Dataset

15.4.1 Loading a Graph

The following describes the steps for loading a graph:

1. Create a **Session** and an **Analyst**.

   - JShell
   - Java
   - Python

JShell

```
cd /opt/oracle/graph/
./bin/opg4j
// starting the shell will create an implicit session and analyst
opg4j> import oracle.pgx.config.mllib.ActivationFunction
opg4j> import oracle.pgx.config.mllib.WeightInitScheme
opg4j> var session = Pgx.createSession("my-session")
opg4j> var analyst = session.createAnalyst()
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.mllib.SupervisedEdgeWiseModel;
import oracle.pgx.api.filter.EdgeFilter;
import oracle.pgx.api.frames.*;
import oracle.pgx.config.mllib.ActivationFunction;
import oracle.pgx.config.mllib.GraphWiseConvLayerConfig;
import oracle.pgx.config.mllib.GraphWisePredictionLayerConfig;
import oracle.pgx.config.mllib.SupervisedEdgeWiseModelConfig;
import oracle.pgx.config.mllib.WeightInitScheme;
PgxSession session = Pgx.createSession("my-session");
Analyst analyst = session.createAnalyst();
```

Python

```
session = pypgx.get_session(session_name="my-session")
analyst = session.create_analyst()
```

2. Load the **graph**.

- JShell
- Java
- Python

JShell

```
opg4j> var fullGraph =
session.readGraphWithProperties("<path_to_movielens.json>")
opg4j> var filter =
EdgeFilter.fromPgqlResultSet(session.queryPgql("SELECT e FROM movielens
MATCH (v1) -[e]-> (v2) WHERE ID(e) % 4 > 0"), "e")
opg4j> var trainGraph = fullGraph.filter(filter)
opg4j> var testEdges = fullGraph.getEdges().
                     stream().
```

```
                    filter(e -> !trainGraph.hasEdge(e.getId())).
                    collect(Collectors.toList())
```

Java

```
PgxGraph fullGraph =
session.readGraphWithProperties("<path_to_movielens.json>");
EdgeFilter filter =
EdgeFilter.fromPgqlResultSet(session.queryPgql("SELECT e FROM
movielens MATCH (v1) -[e]-> (v2) WHERE ID(e) % 4 > 0"), "e");
PgxGraph trainGraph = fullGraph.filter(filter);
List<PgxEdge> testEdges = fullGraph.getEdges()
                            .stream()
                            .filter(e -> !
trainGraph.hasEdge(e.getId()))
                            .collect(Collectors.toList());
```

Python

```
from pypgx.api.filters import EdgeFilter
full_graph =
session.read_graph_with_properties("<path_to_movielens.json>")
edge_filter = EdgeFilter.from_pgql_result_set(
    session.query_pgql("SELECT e FROM movielens MATCH (v1) -[e]->
(v2) WHERE ID(e) % 4 > 0"), "e"
)
train_graph = full_graph.filter(edge_filter)
test_edges = []
train_edges = train_graph.get_edges()
for e in full_graph.get_edges():
    if(not train_edges.contains(e)):
        test_vertices.append(e)
```

15.4.2 Building a Minimal Supervised EdgeWise Model

You can build an `EdgeWise` model using the minimal configuration and default hyper-parameters as described in the following code. Note that even though only one feature property is needed (either on vertices with `setVertexInputPropertyNames` or edges with `setEdgeInputPropertyNames`) for the model to work, you can specify as many as required.

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         setEdgeTargetPropertyName("label").
         build()
```

Java

```
SupervisedEdgeWiseModel model = analyst.supervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setEdgeTargetPropertyName("labels")
    .build();
```

Python

```
params = dict(edge_target_property_name="label",
              vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"])

model = analyst.supervised_edgewise_builder(**params)
```

15.4.3 Advanced Hyperparameter Customization

You can build a Supervised EdgeWise model using rich hyperparameter customization. This is implemented using the sub-config classes:

- `GraphWiseConvLayerConfig`
- `GraphWisePredictionLayerConfig`

The following code describes the implementation of the configuration in a Supervised EdgeWise model. The example also specifies a weight decay parameter of `0.001` and dropout with dropping probability `0.5` to counteract overfitting.

- JShell
- Java
- Python

JShell

```
opg4j> var weightProperty = analyst.pagerank(trainGraph).getName()
opg4j> var convLayerConfig = analyst.graphWiseConvLayerConfigBuilder().
                setNumSampledNeighbors(25).
                setActivationFunction(ActivationFunction.TANH).
```

```
                setWeightInitScheme(WeightInitScheme.XAVIER).
                setWeightedAggregationProperty(weightProperty).
                setDropoutRate(0.5).
                build()
opg4j> var predictionLayerConfig = 
analyst.graphWisePredictionLayerConfigBuilder().
         setHiddenDimension(32).
         setActivationFunction(ActivationFunction.RELU).
         setWeightInitScheme(WeightInitScheme.HE).
         setDropoutRate(0.5).
         build()
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         setEdgeTargetPropertyName("labels").
         setConvLayerConfigs(convLayerConfig).
         setPredictionLayerConfigs(predictionLayerConfig).
         setWeightDecay(0.001).
         build()
```

Java

```
String weightProperty = analyst.pagerank(trainGraph).getName();
GraphWiseConvLayerConfig convLayerConfig = 
analyst.graphWiseConvLayerConfigBuilder()
    .setNumSampledNeighbors(25)
    .setActivationFunction(ActivationFunction.TANH)
    .setWeightInitScheme(WeightInitScheme.XAVIER)
    .setWeightedAggregationProperty(weightProperty)
    .setDropoutRate(0.5)
    .build();

GraphWisePredictionLayerConfig predictionLayerConfig = 
analyst.graphWisePredictionLayerConfigBuilder()
    .setHiddenDimension(32)
    .setActivationFunction(ActivationFunction.RELU)
    .setWeightInitScheme(WeightInitScheme.HE)
    .setDropoutRate(0.5)
    .build();

SupervisedEdgeWiseModel model = 
analyst.supervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setEdgeTargetPropertyName("labels")
    .setConvLayerConfigs(convLayerConfig)
    .setPredictionLayerConfigs(predictionLayerConfig)
    .setWeightDecay(0.001)
    .build();
```

Python

```
weightProperty = analyst.pagerank(train_graph).name

conv_layer_config = dict(num_sampled_neighbors=25,
                         activation_fn='tanh',
                         weight_init_scheme='xavier',
                         neighbor_weight_property_name=weightProperty,
                         dropout_rate=0.5)

conv_layer = analyst.graphwise_conv_layer_config(**conv_layer_config)

pred_layer_config = dict(hidden_dim=32,
                         activation_fn='relu',
                         weight_init_scheme='he',
                         dropout_rate=0.5)

pred_layer = analyst.graphwise_pred_layer_config(**pred_layer_config)

params = dict(edge_target_property_name="labels",
              conv_layer_config=[conv_layer],
              pred_layer_config=[pred_layer],
              vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              seed=17,
              weight_decay=0.001)

model = analyst.supervised_edgewise_builder(**params)
```

15.4.4 Applying EdgeWise for Partitioned Graphs

You can apply EdgeWise on partitioned graphs, where you have different providers and different features.

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider_features").
         setEdgeInputPropertyNames("edge_provider1_features",
"edge_provider2_features").
         setEdgeTargetPropertyName("target_property").
         build()
```

Java

```
SupervisedEdgeWiseModel model =
analyst.supervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider_features")
    .setEdgeInputPropertyNames("edge_provider1_features",
"edge_provider2_features")
    .setEdgeTargetPropertyName("target_property")
    .build();
```

Python

```
params = dict(edge_target_property_name="target_property",
              vertex_input_property_names=["vertex_provider_features"],
              edge_input_property_names=["edge_provider1_features",
"edge_provider2_features"])

model = analyst.supervised_edgewise_builder(**params)
```

You can select which providers you want to train or infer on:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider_features").
         setEdgeInputPropertyNames("edge_provider1_features",
"edge_provider2_features").
         setEdgeTargetPropertyName("target_property").
         setTargetEdgeLabels("provider1").
         build()
```

Java

```
SupervisedEdgeWiseModel model =
analyst.supervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider_features")
    .setEdgeInputPropertyNames("edge_provider1_features",
"edge_provider2_features")
    .setEdgeTargetPropertyName("target_property")
    .setTargetEdgeLabels("provider1")
    .build();
```

Python

```
params = dict(edge_target_property_name="target_property",
              vertex_input_property_names=["vertex_provider_features"],
              edge_input_property_names=["edge_provider1_features",
"edge_provider2_features"],
              target_edge_labels=["provider1"])

model = analyst.supervised_edgewise_builder(**params)
```

If you wish to control the flow of the embeddings at each graph convolutional layer of the underlying Graphwise model, then you can enable or disable the connections of interest. By default, all the connections are enabled.

- JShell
- Java
- Python

JShell

```
opg4j> var convLayerConfig = analyst.graphWiseConvLayerConfigBuilder().
         setNumSampledNeighbors(25).
         useVertexToVertexConnection(true).
         useEdgeToVertexConnection(true).
         useEdgeToEdgeConnection(false).
         useVertexToEdgeConnection(false).
         build()
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
         setEdgeInputPropertyNames("edge_provider_features").
         setEdgeTargetPropertyName("target_property").
         setTargetEdgeLabels("provider1").
         build()
```

Java

```
GraphWiseConvLayerConfig convLayerConfig =
analyst.graphWiseConvLayerConfigBuilder()
    .setNumSampledNeighbors(10)
    .useVertexToVertexConnection(true)
    .useEdgeToVertexConnection(true)
    .useEdgeToEdgeConnection(false)
    .useVertexToEdgeConnection(false)
    .build();

SupervisedEdgeWiseModel model = analyst.supervisedEdgeWiseModelBuilder()
```

```
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .setEdgeInputPropertyNames("edge_provider_features")
    .setEdgeTargetPropertyName("target_property")
    .setTargetEdgeLabels("provider1")
    .setConvLayerConfigs(convLayerConfig)
    .build();
```

Python

```
conv_layer_config = dict(num_sampled_neighbors=25,
                         activation_fn='tanh',
                         weight_init_scheme='xavier',
                         neighbor_weight_property_name=weightProperty,
                         vertex_to_vertex_connection=True,
                         edge_to_vertex_connection=True,
                         vertex_to_edge_connection=False,
                         edge_to_edge_connection=False)

conv_layer = analyst.graphwise_conv_layer_config(**conv_layer_config)

params = dict(edge_target_property_name="target_property",

vertex_input_property_names=["vertex_provider1_features",
"vertex_provider2_features"],
              edge_input_property_names=["edge_provider_features"],
              target_edge_labels=["provider1"],
              conv_layer_config=[conv_layer])

model = analyst.supervised_edgewise_builder(**params)
```

15.4.5 Classification Versus Regression on Supervised EdgeWise Models

When predicting a property, the loss function defines if the model will perform classification tasks or regression tasks.

For classification tasks, the Supervised EdgeWise model will infer labels. Even if this property is a number, the model will assign one label for each value found and classify on it. The possible losses for classification tasks are `softmax cross entropy`, `sigmoid cross entropy`, and `DevNet loss`.

For regression tasks, the Supervised EdgeWise model will infer values for the property. The loss for regression tasks is the `MSE` loss.

It is possible to select different loss functions for the supervised model by providing a `LossFunction` object.

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.loss.LossFunctions;
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         setEdgeTargetPropertyName("labels").
         setLossFunction(LossFunctions.MSE_LOSS).
         build()
```

Java

```
import oracle.pgx.config.mllib.loss.LossFunctions;

SupervisedEdgeWiseModel model = analyst.supervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setEdgeTargetPropertyName("labels")
    .setLossFunction(LossFunctions.MSE_LOSS)
    .build();
```

Python

```
from pypgx.api.mllib import MSELoss

params = dict(edge_target_property_name="labels",
              vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              loss_fn=MSELoss())

model = analyst.supervised_edgewise_builder(**params)
```

15.4.6 Setting a Custom Loss Function and Batch Generator (for Anomaly Detection)

In addition to different loss functions, it is also possible to select different batch generators by providing a batch generator type. This is useful for applications such as Anomaly Detection, which can be cast into the standard supervised framework but require different loss functions and batch generators.

SupervisedEdgeWise model can use the DevNetLoss and the `StratifiedOversamplingBatchGenerator`. `DevNetLoss` takes confidence margin and the value the anomaly takes in the target property as the two parameters.

The following example assumes that the `convLayerConfig` has already been defined:

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.loss.LossFunctions
opg4j> import oracle.pgx.config.mllib.batchgenerator.BatchGenerators
opg4j> var predictionLayerConfig = 
analyst.graphWisePredictionLayerConfigBuilder().
         setHiddenDimension(32).
         setActivationFunction(ActivationFunction.LINEAR).
         build()
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         setEdgeTargetPropertyName("labels").
         setConvLayerConfigs(convLayerConfig).
         setPredictionLayerConfigs(predictionLayerConfig).
         setLossFunction(LossFunctions.devNetLoss(5.0, true)).
         setBatchGenerator(BatchGenerators.STRATIFIED_OVERSAMPLING).
         build()
```

Java

```
import oracle.pgx.config.mllib.loss.LossFunctions;
import oracle.pgx.config.mllib.batchgenerator.BatchGenerators;

GraphWisePredictionLayerConfig predictionLayerConfig = 
analyst.graphWisePredictionLayerConfigBuilder()
    .setHiddenDimension(32)
    .setActivationFunction(ActivationFunction.LINEAR)
    .build();

SupervisedEdgeWiseModel model = 
analyst.supervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setEdgeTargetPropertyName("labels")
    .setConvLayerConfigs(convLayerConfig)
    .setPredictionLayerConfigs(predictionLayerConfig)
    .setLossFunction(LossFunctions.devNetLoss(5.0, true))
    .setBatchGenerator(BatchGenerators.STRATIFIED_OVERSAMPLING)
    .build();
```

Python

```
from pypgx.api.mllib import DevNetLoss

pred_layer_config = dict(hidden_dim=32,
                         activation_fn='linear')

pred_layer = analyst.graphwise_pred_layer_config(**pred_layer_config)

params = dict(edge_target_property_name="labels",
              conv_layer_config=[conv_layer],
              pred_layer_config=[pred_layer],
              vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              loss_fn=DevNetLoss(5.0, True),
              batch_gen='Stratified_Oversampling',
              seed=17)

model = analyst.supervised_edgewise_builder(**params)
```

15.4.7 Setting the Edge Embedding Production Method

By default, the edge embedding is computed by combining the source vertex embedding, the destination vertex embedding and the edge features. You can manually set these by setting the `EdgeCombinationMethod` with booleans parameters:

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.edgecombination.EdgeCombinationMethods

opg4j> var method =
EdgeCombinationMethods.concatEdgeCombinationMethod(useSourceVertex,
useDestinationVertex, useEdge)
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         setEdgeTargetPropertyName("labels").
         setEdgeCombinationMethod(method).
         build()
```

Java

```
import oracle.pgx.config.mllib.edgecombination.EdgeCombinationMethod;
import oracle.pgx.config.mllib.edgecombination.EdgeCombinationMethods;

EdgeCombinationMethod method =
EdgeCombinationMethods.concatEdgeCombinationMethod(useSourceVertex,
useDestinationVertex, useEdge);

SupervisedEdgeWiseModel model =
analyst.supervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setEdgeTargetPropertyName("labels")
    .setEdgeCombinationMethod(method)
    .build();
```

Python

```
from pypgx.api.mllib import ConcatEdgeCombinationMethod

method_config = dict(use_source_vertex=True,
    use_destination_vertex=False,
    use_edge=True)

method = ConcatEdgeCombinationMethod(**method_config)

params = dict(edge_target_property_name="labels",
              vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              edge_combination_method=method,
              seed=17)

model = analyst.supervised_edgewise_builder(**params)
```

15.4.8 Training the Supervised EdgeWise Model

You can train a `SupervisedEdgeWiseModel` on a graph as shown:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(trainGraph)
```

Java

```
model.fit(trainGraph);
```

Python

```
model.fit(train_graph)
```

15.4.9 Getting the Loss Value for a Supervised EdgeWise Model

You can fetch the training loss value for a Supervised EdgeWise Model as shown in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var loss = model.getTrainingLoss()
```

Java

```
double loss = model.getTrainingLoss();
```

Python

```
loss = model.get_training_loss()
```

15.4.10 Inferring Edge Labels for a Supervised EdgeWise Model

You can infer the edge labels on any graph (including edges or graphs that were not seen during training):

- JShell
- Java
- Python

JShell

```
opg4j> var labels = model.infer(fullGraph, testEdges)
opg4j> labels.head().print()
```

Java

```
PgxFrame labels = model.infer(fullGraph, testEdges);
labels.head().print();
```

Python

```
labels = model.infer(full_graph,test_edges)
labels.print()
```

If the loss is `SigmoidCrossEntropy` or `DevNetLoss`, then it is also possible to set the decision threshold applied to the logits by adding it as an extra parameter, which is by default 0:

- JShell
- Java
- Python

JShell

```
opg4j> var labels = model.infer(fullGraph, testEdges, 6f)
opg4j> labels.head().print()
```

Java

```
PgxFrame labels = model.infer(fullGraph,testEdges,6f);
labels.head().print();
```

Python

```
labels = model.infer(full_graph, full_graph.get_edges(), 6)
labels.print()
```

The output will be similar to the following example output:

```
+-----------------------------+
| edgeId | value              |
+-----------------------------+
| 68472  | 2.2346956729888916 |
| 53436  | 2.1515913009643555 |
| 73364  | 1.9499346017837524 |
| 12096  | 2.1704165935516357 |
| 78740  | 2.1174447536468506 |
| 27664  | 2.1041007041931152 |
| 34844  | 2.148571491241455  |
| 74224  | 2.089123010635376  |
| 33744  | 2.0866644382476807 |
| 32812  | 2.0604987144470215 |
+-----------------------------+
```

Similarly, if the task is a classification task, you can get the model confidence for each class by inferring the prediction logits:

- JShell
- Java
- Python

JShell

```
opg4j> var logits = model.inferLogits(fullGraph, testEdges)
opg4j> logits.head().print()
```

Java

```
PgxFrame logits = model.inferLogits(fullGraph,testEdges);
logits.head().print();
```

Python

```
logits = model.infer_logits(full_graph, test_edges)
logits.print()
```

If the model is a classification model, the `inferLabels` method is also available and it is equivalent to the `infer` method.

15.4.11 Evaluating Model Performance

You can use the `evaluate` convenience method to evaluate various metrics for the model:

- JShell
- Java
- Python

JShell

```
opg4j> model.evaluate(fullGraph, testEdges).print()
```

Java

```
model.evaluate(fullGraph,testEdges).print();
```

Python

```
model.evaluate(full_graph,test_edges).print()
```

Similar to inferring labels, if the task is a classification task, you can add the decision threshold as an extra parameter:

- JShell
- Java
- Python

JShell

```
opg4j> model.evaluate(fullGraph, testEdges, 6f).print()
```

Java

```
model.evaluate(fullGraph,testEdges, 6f).print();
```

Python

```
model.evaluate(full_graph,test_edges, 6).print()
```

For a classification model, the output will be similar to the following:

```
+------------------------------------------+
| Accuracy | Precision | Recall | F1-Score |
+------------------------------------------+
| 0.8488   | 0.8523    | 0.831  | 0.8367   |
+------------------------------------------+
```

For a regression model, the output will be similar to the following:

```
+--------------------+
| MSE                |
+--------------------+
| 0.9573243436116953 |
+--------------------+
```

Note that for a classification model, the `evaluateLabels` method is also available and this is equivalent to the `evaluate` method.

15.4.12 Inferring Embeddings for a Supervised EdgeWise Model

You can use a trained model to infer embeddings for unseen nodes and store them in the database as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var edgeVectors = model.inferEmbeddings(fullGraph,
testEdges).flattenAll()
opg4j> edgeVectors.write().
         db().
         name("edge vectors").
         tablename("edgeVectors").
         overwrite(true).
         store()
```

Java

```
PgxFrame edgeVectors = model.inferEmbeddings(fullGraph,
testEdges).flattenAll();
edgeVectors.write()
    .db()
    .name("edge vectors")
    .tablename("edgeVectors")
```

```
    .overwrite(true)
    .store();
```

Python

```
edge_vectors = model.infer_embeddings(full_Graph,
test_edges).flatten_all()
edge_vectors.write().db().table_name("table_name").name("edge_vectors")
.overwrite(True).store()
```

The schema for the `edgeVectors` will be as follows without flattening (`flattenAll` splits the vector column into separate double-valued columns):

```
+----------------------------------------------------------------+
| edgeId                                  | embedding            |
+----------------------------------------------------------------+
```

All the preceding examples assume that you are inferring the embeddings for a model in the current logged in database. If you must infer embeddings for the model in a different database, then you must additionally provide the database credentials such as username, password and JDBC URL to the `inferEmbeddings` method. Refer to Inferring Embeddings for a Model in Another Database for an example.

15.4.13 Storing a Supervised EdgeWise Model

You can store models in the database. The models get stored as a row inside a model store table.
The following shows how to store a trained `SupervisedEdgeWise` model in the database in a specific model store table:

- JShell
- Java
- Python

JShell

```
opg4j> model.export().db().
              modelstore("modelstoretablename").  // name of the model
store table
              modelname("model").                 // model name
(primary key of model store table)
              description("a model description"). // description to
store alongside the model
              store()
```

Java

```
model.export().db()
     .modelstore("modelstoretablename")  // name of the model store table
     .modelname("model")                 // model name (primary key of model
store table)
     .description("a model description") // description to store alongside
the model
     .store();
```

Python

```
model.export().db(model_store="modeltablename",            # name of the
model store table
                      model_name="model",                     # model name
(primary key of model store table)
                      model_description="a model description") # description to
store alongside the model
```

Note:

All the preceding examples assume that you are storing the model in the current logged in database. If you must store the model in a different database then refer to the examples in Storing a Trained Model in Another Database.

15.4.14 Loading a Pre-Trained Supervised EdgeWise Model

You can load a pre-trained `SupervisedEdgeWise` model from a model store table in the database as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.loadSupervisedEdgeWiseModel().db().
                   modelstore("modeltablename"). // name of the model store
table
                   modelname("model").           // model name (primary key of
model store table)
                   load()
```

Java

```
SupervisedEdgeWiseModel model =
analyst.loadSupervisedEdgeWiseModel().db()
     .modelstore("modeltablename") // name of the model store table
     .modelname("model")           // model name (primary key of model
store table)
     .load();
```

Python

```
model = analyst.get_supervised_edgewise_model_loader(). \
                 db(model_store="modelstoretablename",  # name of the
model store table
                    model_name="model")                 # model name
(primary key of model store table)
```

> **Note:**
>
> All the preceding examples assume that you are loading the model from the current logged in database. If you must load the model from a different database then refer to the examples in Loading a Pre-Trained Model From Another Database.

15.4.15 Destroying a Supervised EdgeWise Model

You can destroy a Supervised EdgeWise model as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.destroy()
```

Java

```
model.destroy();
```

Python

```
model.destroy()
```

15.4.16 Example: Predicting Ratings on the Movielens Dataset

This section describes the usage of `SupervisedEdgeWise` in the graph server (PGX) using the Movielens graph as an example.
This data set consists of 100,000 ratings (1-5) from 943 users on 1682 movies, with simple demographic information for the users (age, gender, occupation) and movies (year, aggravating, genre). Users and movies are vertices, while ratings of users to movies are edges with a rating feature.

The following example predicts the ratings using the `SupervisedEdgeWise` model. The model is first built and it is then fit on the `trainGraph`.

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.loss.LossFunctions
opg4j> var convLayer = analyst.graphWiseConvLayerConfigBuilder().
        setNumSampledNeighbors(10).
        build()
opg4j> var predictionLayer = analyst.graphWisePredictionLayerConfigBuilder().
        setHiddenDimension(16).
        build()
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
        setVertexInputPropertyNames("movie_year", "avg_rating",
"movie_genres", // Movies features
            "user_occupation_label", "user_gender", "raw_user_age"). //
Users features
        setEdgeTargetPropertyName("user_rating").
        setConvLayerConfigs(convLayer).
        setPredictionLayerConfigs(predictionLayer).
        setNumEpochs(10).
        setEmbeddingDim(32).
        setLearningRate(0.003).
        setStandardize(true).
        setNormalize(true).
        setSeed(0).
        setLossFunction(LossFunctions.MSE_LOSS).
        build()
opg4j> model.fit(trainGraph)
```

Java

```
import oracle.pgx.config.mllib.loss.LossFunctions;
GraphWiseConvLayerConfig convLayer =
analyst.graphWiseConvLayerConfigBuilder()
        .setNumSampledNeighbors(10)
        .build();

GraphWisePredictionLayerConfig predictionLayer =
analyst.graphWisePredictionLayerConfigBuilder()
      .setHiddenDimension(16)
      .build();

SupervisedEdgeWiseModel model =
analyst.supervisedEdgeWiseModelBuilder()
        .setVertexInputPropertyNames("movie_year", "avg_rating",
"movie_genres", // Movies features
            "user_occupation_label", "user_gender", "raw_user_age") //
Users features
        .setEdgeTargetPropertyName("user_rating")
        .setConvLayerConfigs(convLayer)
        .setPredictionLayerConfigs(predictionLayer)
        .setNumEpochs(10)
        .setEmbeddingDim(32)
        .setLearningRate(0.003)
        .setStandardize(true)
        .setNormalize(true)
        .setSeed(0)
        .setLossFunction(LossFunctions.MSE_LOSS)
        .build();

model.fit(trainGraph);
```

Python

```
from pypgx.api.mllib import MSELoss
conv_layer_config = dict(num_sampled_neighbors=10)

conv_layer = analyst.graphwise_conv_layer_config(**conv_layer_config)

pred_layer_config = dict(hidden_dim=16)

pred_layer = analyst.graphwise_pred_layer_config(**pred_layer_config)

params = dict(edge_target_property_name="labels",
              conv_layer_config=[conv_layer],
              pred_layer_config=[pred_layer],
              vertex_input_property_names=["movie_year", "avg_rating",
"movie_genres",
                "user_occupation_label", "user_gender",
"raw_user_age"],
              edge_input_property_names=["user_rating"],
              num_epochs=10,
              layer_size=32,
```

```
              learning_rate=0.003,
              normalize=true,
              loss_fn=MSELoss(),
              seed=0)

model = analyst.supervised_edgewise_builder(**params)

model.fit(train_graph)
```

Since `EdgeWise` is inductive, you can infer the ratings for unseen edges:

- JShell
- Java
- Python

JShell

```
opg4j> var labels = model.infer(fullGraph, testEdges)
opg4j> labels.head().print()
```

Java

```
PgxFrame labels = model.infer(fullGraph, testEdges);
labels.head().print();
```

Python

```
labels = model.infer(full_graph, test_edges)
labels.print()
```

This returns the rating prediction for any edge as:

```
+------------------------------+
| edgeId | value               |
+------------------------------+
| 68472  | 3.844510078430176   |
| 53436  | 3.5453758239746094 |
| 73364  | 3.688265085220337   |
| 12096  | 3.8873679637908936 |
| 78740  | 3.3845553398132324 |
| 27664  | 2.6601722240448     |
| 34844  | 4.108948230743408   |
| 74224  | 3.7714107036590576 |
```

```
| 33744  | 3.2331383228302    |
| 32812  | 3.8763082027435303 |
+-----------------------------+
```

You can also evaluate the performance of the model:

- JShell
- Java
- Python

JShell

```
opg4j> model.evaluate(fullGraph, testEdges).print()
```

Java

```
model.evaluate(fullGraph,testEdges).print();
```

Python

```
model.evaluate(full_graph,test_edges).print()
```

This returns the following output:

```
+--------------------+
| MSE                |
+--------------------+
| 0.9573243436116953 |
+--------------------+
```

15.5 Using the Pg2vec Algorithm

Pg2vec learns representations of graphlets (partitions inside a graph) by employing edges as the principal learning units and thereby packing more information in each learning unit (as compared to employing vertices as learning units) for the representation learning task.

It consists of three main steps:

1. Random walks for each vertex (with pre-defined length per walk and pre-defined number of walks per vertex) are generated.
2. Each edge in this random walk is mapped as a `property.edge-word` in the created document (with the document label as the graph-id) where the `property.edge-`

word is defined as the concatenation of the properties of the source and destination vertices.

3. The generated documents (with their attached document labels) are fed to a doc2vec algorithm which generates the vector representation for each document, which is a graph in this case.

Pg2vec creates graphlet embeddings for a specific set of graphlets and cannot be updated to incorporate modifications on these graphlets. Instead, a new Pg2vec model should be trained on these modified graphlets.

The following represents the memory consumption of Pg2vec model.

```
O(2(n+m)*d)
```

where:

- n: is the number of vertices in the graph
- m: is the number of graphlets in the graph
- d: is the embedding length

The following describes the usage of the main functionalities of the implementation of Pg2vec in PGX using NCI109 dataset as an example with 4127 graphs in it:

- Loading a Graph
- Building a Minimal Pg2vec Model
- Building a Customized Pg2vec Model
- Training a Pg2vec Model
- Getting the Loss Value For a Pg2vec Model
- Computing Similar Graphlets for a Given Graphlet
- Computing Similars for a Graphlet Batch
- Inferring a Graphlet Vector
- Inferring Vectors for a Graphlet Batch
- Storing a Trained Pg2vec Model
- Loading a Pre-Trained Pg2vec Model
- Destroying a Pg2vec Model

15.5.1 Loading a Graph

The following describes the steps for loading a graph:

1. Create a **Session** and an **Analyst**.

   - JShell
   - Java
   - Python

JShell

```
cd /opt/oracle/graph/
./bin/opg4j
// starting the shell will create an implicit session and analyst
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.mllib.Pg2vecModel;
import oracle.pgx.api.frames.*;
...
PgxSession session = Pgx.createSession("my-session");
Analyst analyst = session.createAnalyst();
```

Python

```
session = pypgx.get_session(session_name="my-session")
analyst = session.create_analyst()
```

2. Load the **graph**.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphWithProperties("<path>/
<graph.json>")
```

Java

```
PgxGraph graph = session.readGraphWithProperties("<path>/
<graph.json>");
```

Python

```
graph = session.read_graph_with_properties("<path>/<graph.json>")
```

15.5.2 Building a Minimal Pg2vec Model

You can build a Pg2vec model using the minimal configuration and default hyper-parameters as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.pg2vecModelBuilder().
                setGraphLetIdPropertyName("graph_id").
                setVertexPropertyNames(Arrays.asList("category")).
                setWindowSize(4).
                setWalksPerVertex(5).
                setWalkLength(8).
                build()
```

Java

```
Pg2vecModel model = analyst.pg2vecModelBuilder()
    .setGraphLetIdPropertyName("graph_id")
    .setVertexPropertyNames(Arrays.asList("category"))
    .setWindowSize(4)
    .setWalksPerVertex(5)
    .setWalkLength(8)
    .build();
```

Python

```
model = analyst.pg2vec_builder(
    graphlet_id_property_name="graph_id",
    vertex_property_names=["category"],
    window_size=4,
    walks_per_vertex=5,
    walk_length=8)
```

You can specify the property name to determine each graphlet using the `Pg2vecModelBuilder#setGraphLetIdPropertyName` operation and also employ the vertex properties in Pg2vec which are specified using the `Pg2vecModelBuilder#setVertexPropertyNames` operation.

You can also use the weakly connected component (WCC) functionality in PGX to determine the graphlets in a given graph.

15.5.3 Building a Customized Pg2vec Model

You can build a Pg2vec model using customized hyper-parameters as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.pg2vecModelBuilder().
                setGraphLetIdPropertyName("graph_id").
                setVertexPropertyNames(Arrays.asList("category")).
                setMinWordFrequency(1).
                setBatchSize(128).
                setNumEpochs(5).
                setLayerSize(200).
                setLearningRate(0.04).
                setMinLearningRate(0.0001).
                setWindowSize(4).
                setWalksPerVertex(5).
                setWalkLength(8).
                setUseGraphletSize(true).
                setValidationFraction(0.05).
                setGraphletSizePropertyName("<propertyName>").
                build()
```

Java

```
Pg2vecModel model= analyst.pg2vecModelBuilder()
    .setGraphLetIdPropertyName("graph_id")
    .setVertexPropertyNames(Arrays.asList("category"))
    .setMinWordFrequency(1)
    .setBatchSize(128)
    .setNumEpochs(5)
    .setLayerSize(200)
    .setLearningRate(0.04)
    .setMinLearningRate(0.0001)
    .setWindowSize(4)
    .setWalksPerVertex(5)
    .setWalkLength(8)
    .setUseGraphletSize(true)
    .setValidationFraction(0.05)
    .setGraphletSizePropertyName("<propertyName>")
    .build();
```

Python

```
model = analyst.pg2vec_builder(
    graphlet_id_property_name="graph_id",
    vertex_property_names=["category"],
    min_word_frequency=1,
    batch_size=128,
    num_epochs=5,
    layer_size=200,
    learning_rate=0.04,
    min_learning_rate=0.0001,
    window_size=4,
    walks_per_vertex=5,
    walk_length=8,
    use_graphlet_size=true,
    graphlet_size_property_name="<property_name>",
    validation_fraction=0.05)
```

See Pg2vecModelBuilder in Javadoc for more explanation for each builder operation along with the default values.

15.5.4 Training a Pg2vec Model

You can train a Pg2vec model with the specified default or customized settings as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(graph)
```

Java

```
model.fit(graph);
```

Python

```
model.fit(graph)
```

15.5.5 Getting the Loss Value For a Pg2vec Model

You can fetch the training loss value on a specified fraction of training data (set in builder using `setValidationFraction`) as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var loss = model.getLoss()
```

Java

```
double loss = model.getLoss();
```

Python

```
loss = model.loss
```

15.5.6 Computing Similar Graphlets for a Given Graphlet

You can fetch the `k` most similar graphlets for a given graphlet as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var similars = model.computeSimilars(52, 10)
```

Java

```
PgxFrame similars = model.computeSimilars(52, 10);
```

Python

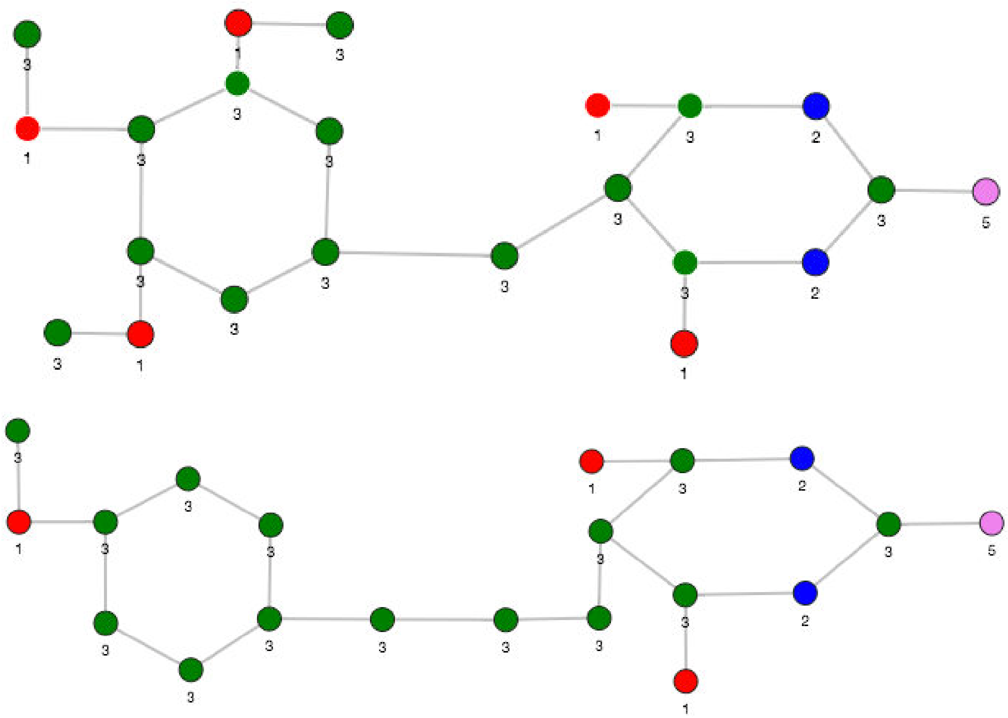
```
similars = model.compute_similars(52, 10)
```

Searching for similar vertices for graphlet with `ID = 52` using the trained model and printing it with `similars.print()`, will result in the following output:

```
+----------------------------------+
| dstGraphlet | similarity         |
+----------------------------------+
| 52          | 1.0                |
| 10          | 0.8748674392700195 |
| 23          | 0.8551455140113831 |
| 26          | 0.8493421673774719 |
| 47          | 0.8411962985992432 |
| 25          | 0.8281504511833191 |
| 43          | 0.8202780485153198 |
| 24          | 0.8179885745048523 |
| 8           | 0.796689510345459  |
| 9           | 0.7947834134101868 |
+----------------------------------+
```

The following depicts the visualization of two similar graphlets (top: `ID = 52` and bottom: `ID = 10`):

Figure 15-1 Pg2vec - Visualization of Two Similar Graphlets



15.5.7 Computing Similars for a Graphlet Batch

You can fetch the `k` most similar graphlets for a batch of input graphlets as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var graphlets = new ArrayList()
opg4j> graphlets.add(52)
opg4j> graphlets.add(41)
opg4j> var batchedSimilars = model.computeSimilars(graphlets, 10)
```

Java

```
List graphlets = Arrays.asList(52,41);
PgxFrame batchedSimilars = model.computeSimilars(graphlets,10);
```

Python

```
batched_similars = model.compute_similars([52,41],10)
```

Searching for similar vertices for graphlet with `ID = 52` and `ID = 41` using the trained model and printing it with `batched_similars.print()`, will result in the following output:

```
+-----------------------------------------------+
| srcGraphlet | dstGraphlet | similarity        |
+-----------------------------------------------+
| 52          | 52          | 1.0               |
| 52          | 10          | 0.8748674392700195 |
| 52          | 23          | 0.8551455140113831 |
| 52          | 26          | 0.8493421673774719 |
| 52          | 47          | 0.8411962985992432 |
| 52          | 25          | 0.8281504511833191 |
| 52          | 43          | 0.8202780485153198 |
| 52          | 24          | 0.8179885745048523 |
| 52          | 8           | 0.796689510345459  |
| 52          | 9           | 0.7947834134101868 |
| 41          | 41          | 1.0               |
| 41          | 197         | 0.9653506875038147 |
| 41          | 84          | 0.9552277326583862 |
| 41          | 157         | 0.9465565085411072 |
| 41          | 65          | 0.9287481307983398 |
| 41          | 248         | 0.9177336096763611 |
| 41          | 315         | 0.9043129086494446 |
| 41          | 92          | 0.8998928070068359 |
| 41          | 297         | 0.8897411227226257 |
| 41          | 50          | 0.8810243010520935 |
+-----------------------------------------------+
```

15.5.8 Inferring a Graphlet Vector

You can infer the vector representation for a given new graphlet as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var graphlet = session.readGraphWithProperties("<path>/
<graphletConfig.json>")
```

```
opg4j> var inferredVector = model.inferGraphletVector(graphlet)
opg4j> inferredVector.print()
```

Java

```
PgxGraph graphlet = session.readGraphWithProperties("<path>/
<graphletConfig.json>");
PgxFrame inferredVector = model.inferGraphletVector(graphlet);
inferredVector.print();
```

Python

```
graphlet = session.read_graph_with_properties("<path>/
<graphletConfig.json>")
inferred_vector = model.infer_graphlet_vector(graphlet)
inferred_vector.print()
```

The schema for the `inferredVector` will be similar to the following output:

```
+---------------------------------------------------------------+
| graphlet                                  | embedding         |
+---------------------------------------------------------------+
```

15.5.9 Inferring Vectors for a Graphlet Batch

You can infer the vector representations for multiple graphlets (specified with different graph-ids in a graph) as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var graphlet = session.readGraphWithProperties("<path>/
<graphletConfig.json>")
opg4j> var inferredVectorBatched =
model.inferGraphletVectorBatched(graphlets)
opg4j> inferredVectorBatched.print()
```

Java

```
PgxGraph graphlet = session.readGraphWithProperties("<path>/
<graphletConfig.json>");
```

```
PgxFrame inferredVectorBatched = model.inferGraphletVectorBatched(graphlets);
inferredVector.print();
```

Python

```
graphlets = session.read_graph_with_properties("<path>/
<graphletConfig.json>")
inferred_vector_batched = model.infer_graphlet_vector_batched(graphlets)
inferred_vector_batched.print()
```

The schema is same as for `inferGraphletVector` but with more rows corresponding to the input graphlets.

15.5.10 Storing a Trained Pg2vec Model

You can store models in database. The models get stored as a row inside a model store table.

The following code shows how to store a trained Pg2vec model in database in a specific model store table:

- JShell
- Java
- Python

JShell

```
opg4j> model.export().db().
              modelstore("modelstoretablename").  // name of the model store
table
              modelname("model").                 // model name (primary key
of model store table)
              description("a model description"). // description to store
alongside the model
              store()
```

Java

```
model.export().db()
    .modelstore("modelstoretablename")  // name of the model store table
    .modelname("model")                 // model name (primary key of model
store table)
    .description("a model description") // description to store alongside
the model
    .store();
```

Python

```
model.export().db(model_store="modeltablename",            # name of
the model store table
                  model_name="model",                      # model
name (primary key of model store table)
                  model_description="a model description") #
description to store alongside the model
```

> **Note:**
>
> All the preceding examples assume that you are storing the model in the current logged in database. If you must store the model in a different database then refer to the examples in Storing a Trained Model in Another Database.

15.5.11 Loading a Pre-Trained Pg2vec Model

You can load models from a database.

You can load a pre-trained Pg2vec model from a model store table in database as described in the following:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.loadPg2vecModel().db().
                modelstore("modeltablename"). // name of the model
store table
                modelname("model").           // model name (primary
key of model store table)
                load()
```

Java

```
Pg2vecModel model = analyst.loadPg2vecModel().db()
     .modelstore("modeltablename") // name of the model store table
     .modelname("model")           // model name (primary key of model
store table)
     .load();
```

Python

```
model = analyst.get_pg2vec_model_loader(). \
                 db(model_store="modelstoretablename",  # name of the model
store table
                    model_name="model")                 # model name
(primary key of model store table)
```

> **Note:**
>
> All the preceding examples assume that you are loading the model from the current logged in database. If you must load the model from a different database then refer to the examples in Loading a Pre-Trained Model From Another Database.

15.5.12 Destroying a Pg2vec Model

You can destroy a Pg2vec model as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.destroy()
```

Java

```
model.destroy();
```

Python

```
model.destroy()
```

15.6 Model Repository and Model Stores

A model store can be used to persist the trained graph server (PGX) machine learning models along with a model name (a unique identifier of the model in a particular model store) and a description.

The model repository API provides the following capabilities:

- Create a new model store
- List all the available model stores in the model repository
- Store a model in the model store
- List all the models in a given model store
- Load a model from the model store
- Get the model description for a model that is stored in the given model store
- Delete a model from the given model store
- Delete the existing model stores
- Database-Backed Model Repository

15.6.1 Database-Backed Model Repository

In a database-backed model repository, each model store corresponds to a table in the database. Internally, the tables are prefixed by 'GMLS_'.
The following steps describe the usage of the model repository API with code examples.

1. Create a model repository object as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var mr = analyst.modelRepository().db().open()
mr ==> oracle.pgx.api.mllib.DbModelRepository@5aac6f9f
```

Java

```
DbModelRepository mr = analyst.modelRepository().db().open();
```

Python

```
>>> mr = analyst.model_repository().db()
>>> mr
<pypgx.api.mllib._model_repo.ModelRepository object at
0x7f637496df60>
```

The preceding example assumes that you are creating the model repository from the current logged in database. If you must create the repository in a different database, then refer to the following example:

- JShell
- Java
- Python

JShell

```
opg4j> var mr = analyst.modelRepository().db().
...>                          username("<username>").   // DB user to use 
for storing the model
...>                          password("<password>").   // password of 
the DB user
...>                          jdbcUrl("<jdbcUrl>").     // jdbc url to 
the DB
...>                          open()
```

Java

```
DbModelRepository mr = analyst.modelRepository().db()
                               .username("<username>")   // DB user to 
use for storing the model
                               .password("<password>")  // password of 
the DB user
                               .jdbcUrl("<jdbcUrl>")   // jdbc url to the 
DB
                               .open();
```

Python

```
>>> mr = analyst.model_repository().db(username = "<username>", # DB user 
to use for storing the model
...                                  password = "<password>", # password of 
the DB user
...                                  jdbc_url = "<jdbc_url>") # jdbc url to 
the DB
```

2. Create a model store as shown:

- JShell
- Java

- Python

JShell

```
opg4j> var modelstore = "modelstore"
modelstore ==> "modelstore"
opg4j> mr.create(modelstore)
```

Java

```
String modelstore = "modelstore";
mr.create(modelstore);
```

Python

```
>>> mr.create("modelstore")
```

3. List the model store as shown and verify that the model store is empty:

- JShell
- Java
- Python

JShell

```
opg4j> mr.listModelStoresNames()
$4 ==> [DW, deepwalk_model, modelstore, modelstoretablename]
opg4j> mr.listModelStoresNamesMatching(modelstore)
$5 ==> [modelstore, modelstoretablename]
opg4j> mr.listModels(modelstore)
$6 ==> []
```

Java

```
mr.listModelStoresNames();
mr.listModelStoresNamesMatching(modelstore);
mr.listModels(modelstore);
```

Python

```
>>> mr.list_model_stores_names()
>>> mr.list_model_stores_names_matching("modelstore")
>>> mr.list_models("modelstore")
```

4. Create and fit a DeepWalk model as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var walkLength = 5
opg4j> var walksPerVertex = 4
opg4j> var embeddingSize = 20
opg4j> var batchSize = 128
opg4j> var model = analyst.deepWalkModelBuilder()
                           .setLayerSize(embeddingSize)
                           .setWalkLength(walkLength)
                           .setWalksPerVertex(walksPerVertex)
                           .setValidationFraction(1)
                           .setBatchSize(batchSize).build()
model ==> oracle.pgx.api.mllib.DeepWalkModel@34be7efb
opg4j> var smallGraphDeepWalk =
session.readGraphByName("<graph_name>",GraphSource.PG_VIEW)
smallGraphDeepWalk ==>
PgxGraph[name=BANK_GRAPH_VIEW_2,N=1000,E=5001,created=1649075718843]
opg4j> model.fit(smallGraphDeepWalk)
```

Java

```
import oracle.pgx.api.mllib.DeepWalkModel;
int walkLength = 5;
int walksPerVertex = 4;
int embeddingSize = 20;
int batchSize = 128;
DeepWalkModel model = analyst.deepWalkModelBuilder()
                           .setLayerSize(embeddingSize)
                           .setWalkLength(walkLength)
                           .setWalksPerVertex(walksPerVertex)
                           .setValidationFraction(1)
                           .setBatchSize(batchSize).build();
PgxGraph smallGraphDeepWalk =
session.readGraphByName("<graph_name>",GraphSource.PG_VIEW);
model.fit(smallGraphDeepWalk);
```

Python

```
>>> model =
analyst.deepwalk_builder(window_size=3,walks_per_vertex=6,walk_length=4)
```

```
graph = session.read_graph_by_name("<graph_name>", 'pg_view')
>>> model.fit(graph)
```

5. Store the trained model in the model store as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var modelName = "DeepWalkModel"
opg4j> var modelStorer = model.export().db()
modelStorer ==> oracle.pgx.api.mllib.DbModelStorer@1e86b2d1
opg4j> modelStorer.modelstore(modelstore)
                  .overwrite(true).modelname(modelName)
                  .description("DeepWalk: model desc")
                  .store()
```

Java

```
import oracle.pgx.api.mllib.DbModelStorer;
import oracle.pgx.api.mllib.DbModelLoader;

String modelName = "DeepWalkModel";
DbModelStorer<DeepWalkModel> modelStorer = model.export().db();
modelStorer.modelstore(modelstore)
           .overwrite(true).modelname(modelName)
           .description("DeepWalk: model desc")
           .store();
```

Python

```
>>> model.export().db(model_store = "modelstore", model_name =
"DeepWalkModel",
...                   model_description = "DeepWalk model description")
```

6. Verify that the model is now stored in the model store as shown:

- JShell
- Java

- Python

JShell

```
opg4j> mr.listModels(modelstore)
$11 ==> [DeepWalkModel]
```

Java

```
mr.listModels(modelstore);
```

Python

```
>>> mr.list_models("modelstore")
```

7. Load the model from the model store as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var modelLoader = analyst.loadDeepWalkModel().db()
opg4j> var reloadedModel = modelLoader.
                                 modelstore(modelstore).
                                 modelname(modelName).
                                 load()
reloadedModel ==> oracle.pgx.api.mllib.DeepWalkModel@4248608d
```

Java

```
DbModelLoader<DeepWalkModel> modelLoader =
analyst.loadDeepWalkModel().db();
DeepWalkModel reloadedModel = modelLoader.modelstore(modelstore)
                                         .modelname(modelName)
                                         .load();
```

Python

```
>>> analyst.get_deepwalk_model_loader().db(model_store = "modelstore",
                                   model_name = "DeepWalkModel")
DeepWalkModel
```

The preceding example assumes that you are loading the model from the current logged in database. If you must load the model from a different database then refer to the example in Loading a Pre-Trained Model From Another Database.

8. Get the model description from the model store as shown:

- JShell
- Java
- Python

JShell

```
opg4j> mr.getModelDescription(modelstore,modelName)
$14 ==> "DeepWalk: model desc"
```

Java

```
mr.getModelDescription(modelstore,modelName);
```

Python

```
>>> mr.get_model_description("modelstore","DeepWalkModel")
'DeepWalk model description'
```

9. Delete the model from the model store as shown:

- JShell
- Java
- Python

JShell

```
opg4j> mr.deleteModel(modelstore,modelName)
```

Java

```
mr.deleteModel(modelstore,modelName);
```

Python

```
>>> mr.delete_model("modelstore","DeepWalkModel")
```

10. Delete the model store as shown:

- JShell
- Java
- Python

JShell

```
opg4j> mr.deleteModelStore(modelstore)
```

Java

```
mr.deleteModelStore(modelstore);
```

Python

```
>>>      ("modelstore")
```

16 Executing PGQL Queries Against the Graph Server (PGX)

This section describes the Java APIs that are used to execute PGQL queries in the graph server (PGX).

16.1 Getting Started with PGQL

This section provides an example on how to get started with PGQL. It assumes a database realm that has been previously set up (follow the steps in Prepare the Graph Server for Database Authentication). It also assumes that the user has `read` access to the HR schema.

First, create a graph with employees, departments, and `employee works at department`, by executing a `CREATE PROPERTY GRAPH` statement.

Example 16-1 Creating a graph in the graph server (PGX)

The following statement creates a graph in the graph server (PGX)

```
String statement =
      "CREATE PROPERTY GRAPH hr_simplified "
    + "  VERTEX TABLES ( "
    + "    hr.employees LABEL employee "
    + "      PROPERTIES ARE ALL COLUMNS EXCEPT ( job_id, manager_id,
```

```
department_id ), "
    + "    hr.departments LABEL department "
    + "      PROPERTIES ( department_id, department_name ) "
    + "  ) "
    + "  EDGE TABLES ( "
    + "    hr.employees AS works_at "
    + "      SOURCE KEY ( employee_id ) REFERENCES employees
(employee_id) "
    + "      DESTINATION departments "
    + "      PROPERTIES ( employee_id ) "
    + "  )";
session.executePgql(statement);

/**
 * To get a handle to the graph, execute:
 */
PgxGraph g = session.getGraph("HR_SIMPLIFIED");

/**
 * You can use this handle to run PGQL queries on this graph.
 * For example, to find the department that “Nandita Sarchand” works
for, execute:
 */
String query =
    "SELECT dep.department_name "
  + "FROM MATCH (emp:Employee) -[:works_at]-> (dep:Department) "
  + "WHERE emp.first_name = 'Nandita' AND emp.last_name = 'Sarchand' "
  + "ORDER BY 1";
PgqlResultSet resultSet = g.queryPgql(query);
resultSet.print();
+-----------------+
| department_name |
+-----------------+
| Shipping        |
+-----------------+

/**
 * To get an overview of the types of vertices and their frequencies,
execute:
 */
String query =
      "SELECT label(n), COUNT(*) "
    + "FROM MATCH (n) "
    + "GROUP BY label(n) "
    + "ORDER BY COUNT(*) DESC";
PgqlResultSet resultSet = g.queryPgql(query);
resultSet.print();

+-----------------------+
| label(n)   | COUNT(*) |
+-----------------------+
| EMPLOYEE   | 107      |
| DEPARTMENT | 27       |
+-----------------------+
```

```
/**
  *To get an overview of the types of edges and their frequencies, execute:
  */
 String query =
    "SELECT label(n) AS srcLbl, label(e) AS edgeLbl, label(m) AS dstLbl,
COUNT(*) "
  + "FROM MATCH (n) -[e]-> (m) "
  + "GROUP BY srcLbl, edgeLbl, dstLbl "
  + "ORDER BY COUNT(*) DESC";
PgqlResultSet resultSet = g.queryPgql(query);
resultSet.print();

+---------------------------------------------+
| srcLbl   | edgeLbl  | dstLbl     | COUNT(*) |
+---------------------------------------------+
| EMPLOYEE | WORKS_AT | DEPARTMENT | 106      |
+---------------------------------------------+
```

16.2 Creating Property Graphs Using Options

Using the **OPTIONS** clause in the `CREATE PROPERTY GRAPH` statement, you can specify any of the options explained in the following sections:

Using Graph Optimization Options

You can load a graph for querying and analytics or for performing update operations. Depending on your requirement, you can optimize the read or update performance using the **OPTIONS** clause in the `CREATE PROPERTY GRAPH` statement.

The following table describes the valid options that are supported in the `OPTIONS` clause:

Table 16-1 Graph Optimization Options

OPTIONS	Description
`OPTIMIZED_FOR_READ`	This can be used for read-intensive scenarios.
`OPTIMIZED_FOR_UPDATES`	This is the default option and can be used for fast updates.
`SYNCHRONIZABLE`	This assures that the graph can be synchronized via Flashback Technology. However, exceptions are thrown if one of the edge keys is either composite or non-numeric. In these cases, the graph can normally still be loaded, but PGX generates a new (numeric and non-composite) edge key. Such edges can therefore not be synchronized with the database.

For example, the following graph is set using `OPTIMIZED_FOR_UPDATES` and `SYNCHRONIZABLE` options:

```
CREATE PROPERTY GRAPH hr
VERTEX TABLES (
employees LABEL employee, departments LABEL department
)
EDGE TABLES (
departments AS managed_by
```

```
SOURCE KEY ( department_id ) REFERENCES departments (department_id)
DESTINATION employees
NO PROPERTIES
) OPTIONS (OPTIMIZED_FOR_UPDATES, SYNCHRONIZABLE)
```

> **Note:**
>
> - `SYNCHRONIZABLE` option can be used in combination with `OPTIMIZED_FOR_UPDATES` and `OPTIMIZED_FOR_READ`. But, `OPTIMIZED_FOR_UPDATES` and `OPTIMIZED_FOR_READ` cannot be used together and in such a case an exception will be thrown.
> - If you are creating a synchronizable graph, then ensure that the vertex and edge keys are numeric and non-composite.

Using Options to Handle Edges with Missing Vertices

If either the source or destination vertex or both are missing for an edge, then you can configure one of the following values in the **OPTIONS** clause in the `CREATE PROPERTY GRAPH` statement:

- `IGNORE EDGE ON MISSING VERTEX`: Specifies that the edge for a missing vertex must be ignored.
- `IGNORE EDGE AND LOG ON MISSING VERTEX`: Specifies that the edge for a missing vertex must be ignored and all ignored edges must be logged.
- `IGNORE EDGE AND LOG ONCE ON MISSING VERTEX`: Specifies that the edge for a missing vertex must be ignored and only the first ignored edge must be logged.
- `ERROR ON MISSING VERTEX` (default): Specifies that an error must be thrown for edges with missing vertices.

For example, the following graph is set using `ERROR ON MISSING VERTEX` option:

```
CREATE PROPERTY GRAPH region_graph
VERTEX TABLES (
regions KEY (region_id),
countries KEY (country_id)
)
EDGE TABLES (
countries AS countries_regions
SOURCE KEY ( country_id ) REFERENCES countries(country_id)
DESTINATION KEY (region_id) REFERENCES regions(region_id)
NO PROPERTIES
) OPTIONS ( ERROR ON MISSING VERTEX)
```

On execution, the following error response is shown:

```
unknown vertex ID received in destination 4 of edge 5
```

When using `IGNORE EDGE AND LOG ON MISSING VERTEX` or `IGNORE EDGE AND LOG ONCE ON MISSING VERTEX` option, you must update the default Logback configuration file in `/etc/oracle/graph/logback.xml` and the graph server (PGX) logger configuration file in `/etc/oracle/graph/logback-server.xml` to log the DEBUG logs. Only then you can view the ignored edges in `/var/opt/log/pgx-server.log` file.

16.3 Supported PGQL Features and Limitations on the Graph Server (PGX)

The following table provides the complete list of supported and unsupported PGQL functionalities for the graph server (PGX):

Table 16-2 Supported PGQL Functionalities and Limitations on the Graph Server (PGX)

Features	PGQL on the Graph Server (PGX)
`CREATE PROPERTY GRAPH`	Supported Limitations: • No composite keys for vertices
`DROP PROPERTY GRAPH`	Not Supported
Fixed-length pattern matching	Supported
Variable-length pattern matching goals	Supported: • Reachability • `ANY` • `ANY SHORTEST` • `TOP k SHORTEST` • `ALL SHORTEST` • `ANY CHEAPEST` • `TOP k CHEAPEST` • `ALL`
Variable-length pattern matching quantifiers	Supported: • * • + • ? • { n } • { n, } • { n, m } • { , m } Limitations: • ? is only supported for reachability • In case of `ANY CHEAPEST` and `TOP k CHEAPEST`, only * is supported
Variable-length path unnesting	Supported: • `ONE ROW PER VERTEX` • `ONE ROW PER STEP` Limitation: • * quantifier is not supported
`GROUP BY`	Supported
`HAVING`	Supported

Table 16-2 (Cont.) Supported PGQL Functionalities and Limitations on the Graph Server (PGX)

Features	PGQL on the Graph Server (PGX)
Aggregations	Supported: • `COUNT` • `MIN`, `MAX`, `AVG`, `SUM` • `LISTAGG` • `ARRAY_AGG` Limitations: • `ARRAY_AGG` is only supported as horizontal aggregation (in combination with variable-length path) but not in combination with vertical aggregation
`DISTINCT` • `SELECT DISTINCT` • Aggregation with `DISTINCT` (such as, `COUNT(DISTINCT e.prop)`)	Supported
`SELECT v.*`	Supported
`ORDER BY (+ASC/DESC), LIMIT, OFFSET`	Supported
Data Types	Supported: • `INTEGER (32-bit)` • `LONG (64-bit)` • `FLOAT (32-bit)` • `DOUBLE (64-bit)` • `STRING` (no maximum length) • `BOOLEAN` • `DATE` • `TIME` • `TIME WITH TIME ZONE` • `TIMESTAMP` • `TIMESTAMP WITH TIME ZONE`
JSON	No built-in JSON support. However, JSON values can be stored as `STRING` and manipulated or queried through user-defined functions (UDFs) written in Java or JavaScript.
Operators	Supported: • Relational: +, -, *, /, %, - (unary minus) • Arithmetic: =, <>, <, >, <=, >= • Logical: `AND`, `OR`, `NOT` • String: `||` (concat)

Table 16-2 (Cont.) Supported PGQL Functionalities and Limitations on the Graph Server (PGX)

Features	PGQL on the Graph Server (PGX)
Functions and predicates	Supported: • IS NULL, IS NOT NULL • JAVA_REGEXP_LIKE (based on CONTAINS) • LOWER, UPPER • SUBSTRING • ABS, CEIL/CEILING, FLOOR, ROUND • EXTRACT • ID • LABEL, LABELS, HAS_LABEL • ALL_DIFFERENT • IN_DEGREE, OUT_DEGREE • CAST • CASE • IN and NOT IN • MATCH_NUMBER • ELEMENT_NUMBER
User-defined functions	Supported: • Java UDFs • JavaScript UDFs
Subqueries: • Scalar subqueries • EXISTS and NOT EXISTS subqueries	Supported
INSERT/UPDATE/DELETE	Supported
INTERVAL literals and operations	Supported literals: • SECOND • MINUTE • HOUR • DAY • MONTH • YEAR Supported operations: • Add INTERVAL to datetime (+) • Subtract INTERVAL from datetime (-)

Also, the following explains certain supported and unsupported PGQL features:

- Support for Selecting All Properties
- Unnesting of Variable-Length Path Queries
- Using INTERVAL Literals in PGQL Queries
- Limitations on Quantifiers
- Limitations on WHERE and COST Clauses in Quantified Patterns

16.3.1 Support for Selecting All Properties

You can use `SELECT v.*` to select all properties of the vertices or edges that bind to the variable `v`. For example:

```
SELECT label(n), n.* FROM MATCH (n) ORDER BY "number", "name"
```

On execution, the query output is as shown:

```
+-----------------------------+
| label(n) | number | name     |
+-----------------------------+
| Account  | 1001   | <null>   |
| Account  | 2090   | <null>   |
| Account  | 8021   | <null>   |
| Account  | 10039  | <null>   |
| Person   | <null> | Camille  |
| Person   | <null> | Liam     |
| Person   | <null> | Nikita   |
| Company  | <null> | Oracle   |
+-----------------------------+
```

You can use label expressions to select properties that belong to the specified vertex or edge labels. For example:

```
SELECT label(n), n.* FROM MATCH (n:Person) ORDER BY "name"
```

The preceding query retrieves all the properties for the specified `Person` label:

```
+--------------------+
| label(n) | name     |
+--------------------+
| Person   | Camille |
| Person   | Liam    |
| Person   | Nikita  |
+--------------------+
```

You can also specify a `PREFIX` to avoid duplicate column names in cases where you select all properties using multiple variables. For example:

```
SELECT n.* PREFIX 'n_', e.* PREFIX 'e_', m.* PREFIX 'm_'
FROM MATCH (n:Account) -[e:transaction]-> (m:Account)
ORDER BY "e_amount"
```

The query output is as shown:

```
+--------------------------------+
| n_number | e_amount | m_number |
+--------------------------------+
| 10039    | 1000.0   | 8021     |
```

```
| 8021      | 1500.3   | 1001      |
| 8021      | 3000.7   | 1001      |
| 2090      | 9900.0   | 10039     |
| 1001      | 9999.5   | 2090      |
+----------------------------------+
```

16.3.2 Unnesting of Variable-Length Path Queries

Unnesting of variable-length path queries (such as, `SHORTEST` or `CHEAPEST` paths) to obtain a separate row for each vertex or edge along a path is supported.

You can unnest a path aggregation using one of the following options:

- `ONE ROW PER MATCH` (default option)
- `ONE ROW PER VERTEX(`*`vertex_variable`*`)`
- `ONE ROW PER STEP(`*`edge_source_variable`*`,`*`edge_variable`*`,`*`edge_destination_variable`*`)`

For example, the following PGQL query uses the `ONE ROW PER STEP` option:

```
SELECT  v1.ACCT_ID AS src_no, k.TXN_AMOUNT, v2.ACCT_ID AS dest_no
FROM MATCH ALL SHORTEST (a:Accounts) -[e:transfers]->+ (b:Accounts)
ONE ROW PER STEP( v1,k,v2 )
WHERE a.ACCT_ID = 284 AND b.ACCT_ID = 616
```

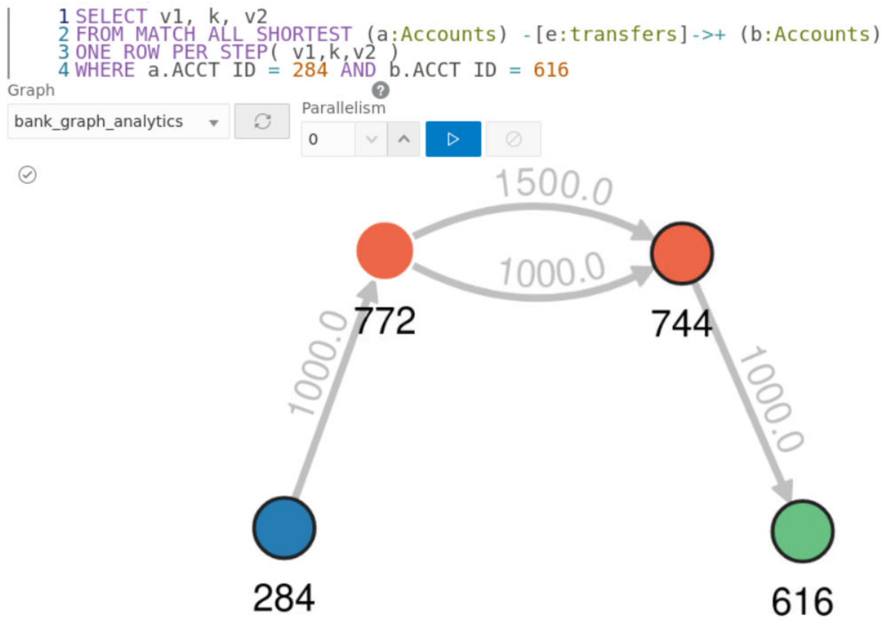
It is important to note that the `ONE ROW PER STEP` option only supports paths with a minimal hop greater than 0 and hence * quantifier is not supported with this option.

On execution, the preceding query retrieves one row for every edge on the path that is bound by the corresponding source and destination vertices:

```
+--------------------------------+
| src_no | TXN_AMOUNT | dest_no |
+--------------------------------+
| 744    | 1000.0     | 616     |
| 772    | 1000.0     | 744     |
| 284    | 1000.0     | 772     |
| 744    | 1000.0     | 616     |
| 772    | 1500.0     | 744     |
| 284    | 1000.0     | 772     |
+--------------------------------+
```

You can also use the Graph Visualization tool to visualize edges using `ONE ROW PER STEP` along a path:

Figure 16-1 Visualizing Unnesting of Variable-Length Path Queries



An example for a query with the `ONE ROW PER VERTEX` option is as follows:

```
SELECT k.acct_id AS id, k.acct_name AS name
FROM MATCH ANY SHORTEST (a:Accounts) ((src:Accounts)-[e:transfers]->)
{1,3}(b:Accounts)
ONE ROW PER VERTEX(k)
WHERE a.acct_id=284 AND b.acct_id=616
```

On execution, the preceding query retrieves one row per vertex along a path:

```
+-----------------+
| id  | name      |
+-----------------+
| 616 | Account4 |
| 744 | Account3 |
| 772 | Account2 |
| 284 | Account1 |
+----------------+
```

Built-in Function Support for Recursive Path Unnesting Queries

PGQL supports the following two built-in functions, which can be used in combination with any of the path unnesting option (`ONE ROW PER VERTEX`, `ONE ROW PER STEP` or `ONE ROW PER MATCH`):

- **`MATCH_NUMBER(k)`:** Returns a unique per-path identifier for each unnested path (that is, if two rows come from the same path, they have the same `MATCH_NUMBER(k)`).

- **`ELEMENT_NUMBER(k)`:** Returns the element number of a vertex or an edge along a path. Vertices are numbered with odd numbers, the leftmost vertex is numbered `1`, the second `3`, then `5` and so on. Edges are assigned with even numbers, starting with `2` for the leftmost edge, `4` for the next one, and so on.

For example, the following PGQL query uses the `MATCH_NUMBER(k)` and `ELEMENT_NUMBER(k)` functions with `ONE ROW PER VERTEX` option:

```
SELECT k.*, match_number(k), element_number(k)
FROM MATCH ANY SHORTEST (a:Accounts) -[e:transfers]->* (b:Accounts) ONE ROW
PER VERTEX ( k )
WHERE a.acct_id = 284 AND b.acct_id = 616
```

The preceding query produces the following output on execution. Note that the `element_number(k)` returned for the vertices are odd numbered values. Since the preceding query uses `ANY` path pattern, there is only one arbitrary path displayed in the output. Therefore `match_number(k)` is the same for all the rows in the path.

```
+-----------------------------------------------------------+
| ACCT_ID | ACCT_NAME | match_number(k) | element_number(k) |
+-----------------------------------------------------------+
| 616     | Account   | 0               | 7                 |
| 744     | Account   | 0               | 5                 |
| 772     | Account   | 0               | 3                 |
| 284     | Account   | 0               | 1                 |
+-----------------------------------------------------------+
```

The following example shows a PGQL query using `MATCH_NUMBER(k)` and `ELEMENT_NUMBER(k)` functions with `ONE ROW PER STEP` option:

```
SELECT v1.acct_id AS src_no,k.txn_amount,v2.acct_id AS dest_no,
match_number(k), element_number(k)
FROM MATCH ALL SHORTEST (a:Accounts) -[e:transfers]->+ (b:Accounts)
ONE ROW PER STEP( v1,k,v2 )
WHERE a.acct_id = 284 AND b.acct_id = 616
```

The preceding query output is as shown. Note that there are two paths identified by `match_number(k)` and the edges are displayed with even numbered `element_number(k)` values.

```
+---------------------------------------------------------------------+
| src_no | txn_amount | dest_no | match_number(k) | element_number(k) |
+---------------------------------------------------------------------+
| 744    | 1000.0     | 616     | 0               | 6                 |
| 772    | 1000.0     | 744     | 0               | 4                 |
| 284    | 1000.0     | 772     | 0               | 2                 |
| 744    | 1000.0     | 616     | 1               | 6                 |
| 772    | 1500.0     | 744     | 1               | 4                 |
| 284    | 1000.0     | 772     | 1               | 2                 |
+---------------------------------------------------------------------+
```

16.3.3 Using INTERVAL Literals in PGQL Queries

You can use `INTERVAL` literals in PGQL queries to add or subtract intervals to or from PGQL temporal data types respectively.

See the PGQL 1.5 Specification for the supported temporal data types.
An `INTERVAL` type is a period of time, which consists of the keyword "`INTERVAL`" followed by a numeral and a temporal unit. For example, `INTERVAL '1' DAY`.

The following table shows the valid temporal units that are supported in `INTERVAL` values:

Table 16-3 Valid values for fields in `INTERVAL` values

Keyword	Supported Valid Values
`YEAR`	Unconstrained except by <interval leading field precision>
`MONTH`	Months (within years) (0-11)
`DAY`	Unconstrained except by <interval leading field precision>
`HOUR`	Hours (within days) (0-23)
`MINUTE`	Minutes (within hours) (0-59)
`SECOND`	Seconds (within minutes) (0-59.999...)

The following `INTERVAL` operations are supported on a temporal data type:

- `TEMPORAL TYPE + INTERVAL`
- `INTERVAL + TEMPORAL TYPE`
- `TEMPORAL TYPE - INTERVAL`

For example, the following PGQL query retrieves persons where `n.birthdate + INTERVAL '20' YEAR > TIMESTAMP '2000-01-01 00:00:00'`:

- JShell
- Java
- Python

JShell

```
opg4j> graph.queryPgql("SELECT n.name, n.birthdate FROM MATCH
(n:Person) WHERE n.birthdate + INTERVAL '20' YEAR > TIMESTAMP
'2000-01-01 00:00:00'").print()
```

Java

```
graph.queryPgql("SELECT n.name, n.birthdate FROM MATCH (n:Person) WHERE
n.birthdate + INTERVAL '20' YEAR > TIMESTAMP '2000-01-01 00:00:00'").print();
```

Python

```
graph.query_pgql("SELECT n.name, n.birthdate FROM MATCH (n:Person) WHERE
n.birthdate + INTERVAL '20' YEAR > TIMESTAMP '2000-01-01 00:00:00'").print()
```

On execution, the query output is as shown:

```
+--------------------------+
| name  | birthdate        |
+--------------------------+
| Mary  | 1982-09-25T00:00 |
| Alice | 1987-02-01T00:00 |
+--------------------------+
```

16.3.4 Limitations on Quantifiers

Although all quantifiers such as `*`, `+`, and `{1,4}` are supported for reachability and shortest path patterns, the only quantifier that is supported for cheapest path patterns is `*` (zero or more).

16.3.5 Limitations on WHERE and COST Clauses in Quantified Patterns

The `WHERE` and `COST` clauses in quantified patterns, such as reachability patterns or shortest and cheapest path patterns, are limited to referencing a single variable only.

The following are examples of queries that are not supported because the `WHERE` or `COST` clauses reference two variables `e` and `x` instead of `zero` or `one`:

```
... PATH p AS (n) -[e]-> (m) WHERE e.prop > m.prop ...
... SHORTEST ( (n) (-[e]-> (x) WHERE e.prop + x.prop > 10)* (m) ) ...
... CHEAPEST ( (n) (-[e]-> (x) COST e.prop + x.prop )* (m) ) ...
```

The following query is supported because the subquery only references a single variable `a` from the outer scope, while the variable `c` does not count since it is newly introduced in the subquery:

```
... PATH p AS (a) -> (b)
      WHERE EXISTS ( SELECT * FROM MATCH (a) -> (c) ) ...
```

16.4 Java APIs for Executing CREATE PROPERTY GRAPH Statements

The easiest way to execute a `CREATE PROPERTY GRAPH` statement is through the `PgxSession.executePgql(String statement)` method.

Example 16-2 Executing a CREATE PROPERTY GRAPH statement

```
String statement =
      "CREATE PROPERTY GRAPH hr_simplified "
    + "  VERTEX TABLES ( "
    + "    hr.employees LABEL employee "
    + "      PROPERTIES ARE ALL COLUMNS EXCEPT ( job_id, manager_id, 
department_id ), "
    + "    hr.departments LABEL department "
    + "      PROPERTIES ( department_id, department_name ) "
    + "  ) "
    + "  EDGE TABLES ( "
    + "    hr.employees AS works_at "
    + "      SOURCE KEY ( employee_id ) REFERENCES employees
(employee_id) "
    + "      DESTINATION departments "
    + "      PROPERTIES ( employee_id ) "
    + "  )";
session.executePgql(statement);
PgxGraph g = session.getGraph("HR_SIMPLIFIED");

/**
 * Alternatively, one can use the prepared statement API, for example:
 */

PgxPreparedStatement stmnt = session.preparePgql(statement);
stmnt.execute();
stmnt.close();
PgxGraph g = session.getGraph("HR_SIMPLIFIED");
```

16.5 Python APIs for Executing CREATE PROPERTY GRAPH Statements

You can create a property graph by executing the `CREATE PROPERTY GRAPH` statement through the Python API.

Creating a Property Graph Using the Python Client

- Launch the Python client:

  ```
  ./bin/opg4py --base_url https://localhost:7007 --user customer_360
  ```

- Define and execute the `CREATE PROPERTY GRAPH` statement as shown:

```
statement = (
       "CREATE PROPERTY GRAPH "+ "<graph_name>" + " " +
       "VERTEX TABLES ( " +
       "bank_accounts " +
       "KEY(acct_id) " +
       "LABEL Account PROPERTIES (acct_id) " +
       ")" +
       "EDGE TABLES ( " +
       "bank_txns " +
       "KEY (txn_id) " +
       "SOURCE KEY (from_acct_id) REFERENCES bank_accounts (acct_id) " +
       "DESTINATION KEY (to_acct_id) REFERENCES bank_accounts (acct_id) "
+
       "LABEL Transfer PROPERTIES(amount) " +
       ")")
>>> session.prepare_pgql(statement).execute()
```

  where *<graph_name>* is the name of the graph.

  The graph gets created and you can verify through the `get_graph` method:

```
>>> graph = session.get_graph("<graph_name>")
>>> graph
PgxGraph(name:<graph_variable>, v: 1000, e: 5001, directed: True,
memory(Mb): 0)
```

16.6 Java APIs for Executing SELECT Queries

This section describes the APIs to execute `SELECT` queries in the graph server (PGX).

- Executing SELECT Queries Against a Graph in the Graph Server (PGX)
  The `PgxGraph.queryPgql(String query)` method executes the query in the current session. The method returns a `PgqlResultSet`.
- Executing SELECT Queries Against a PGX Session
  The `PgxSession.queryPgql(String query)` method executes the given query in the session and returns a `PgqlResultSet`.
- Iterating Through a Result Set
  There are two ways to iterate through a result set: in a JDBC-like manner or using the Java Iterator interface.
- Printing a Result Set
  The following methods of `PgqlResultSet (package oracle.pgx.api)` are used to print a result set:

16.6.1 Executing SELECT Queries Against a Graph in the Graph Server (PGX)

The `PgxGraph.queryPgql(String query)` method executes the query in the current session. The method returns a `PgqlResultSet`.

The `ON` clauses inside the `MATCH` clauses can be omitted since the query is executed directly against a PGX graph. For the same reason, the `INTO` clauses inside the `INSERT` clauses can be omitted. However, if you want to explicitly specify graph names in the `ON` and `INTO` clauses, then those graph names have to match the actual name of the graph (`PgxGraph.getName()`).

16.6.2 Executing SELECT Queries Against a PGX Session

The `PgxSession.queryPgql(String query)` method executes the given query in the session and returns a `PgqlResultSet`.

The `ON` clauses inside the `MATCH` clauses, and the `INTO` clauses inside the `INSERT` clauses, must be specified and cannot be omitted. At this moment, all the `ON` and `INTO` clauses of a query need to reference the same graph since joining data from multiple graphs in a single query is not yet supported.

16.6.3 Iterating Through a Result Set

There are two ways to iterate through a result set: in a JDBC-like manner or using the Java Iterator interface.

For JDBC-like iterations, the methods in `PgqlResultSet` (package `oracle.pgx.api`) are similar to the ones in `java.sql.ResultSet`. A noteworthy difference is that PGQL's result set interface is based on the new date and time library that was introduced in Java 8, while `java.sql.ResultSet` is based on the legacy `java.util.Date`. To bridge the gap, PGQL's result set provides `getLegacyDate(..)` for applications that still use `java.util.Date`.

A `PgqlResultSet` has a `cursor` that is initially set before the first row. Then, the following methods are available to reposition the cursor:

- `next() : boolean`
- `previous() : boolean`
- `beforeFirst()`
- `afterLast()`
- `first() : boolean`
- `last() : boolean`
- `absolute(long row) : boolean`
- `relative(long rows) : boolean`

After the cursor is positioned at the desired row, the following getters are used to obtain values:

- `getObject(int columnIdx) : Object`
- `getObject(String columnName) : Object`
- `getString(int columnIdx) : String`
- `getString(String columnName) : String`
- `getInteger(int columnIdx) : Integer`
- `getInteger(String columnName) : Integer`

- `getLong(int columnIdx) : Long`
- `getLong(String columnName) : Long`
- `getFloat(int columnIdx) : Float`
- `getFloat(String columnName) : Float`
- `getDouble(int columnIdx) : Double`
- `getDouble(String columnName) : Double`
- `getBoolean(int columnIdx) : Boolean`
- `getBoolean(String columnName) : Boolean`
- `getVertexLabels(int columnIdx) : Set<String>`
- `getVertexLabels(String columnName) : Set<String>`
- `getDate(int columnIdx) : LocalDate`
- `getDate(String columnName) : LocalDate`
- `getTime(int columnIdx) : LocalTime`
- `getTime(String columnName) : LocalTime`
- `getTimestamp(int columnIdx) : LocalDateTime`
- `getTimestamp(String columnName) : LocalDateTime`
- `getTimeWithTimezone(int columnIdx) : OffsetTime`
- `getTimeWithTimezone(String columnName) : OffsetTime`
- `getTimestampWithTimezone(int columnIdx) : OffsetDateTime`
- `getTimestampWithTimezone(String columnName) : OffsetDateTime`
- `getLegacyDate(int columnIdx) : java.util.Date`
- `getLegacyDate(String columnName) : java.util.Date`
- `getVertex(int columnIdx) : PgxVertex<ID>`
- `getVertex(String columnName) : PgxVertex<ID>`
- `getEdge(int columnIdx) : PgxEdge`
- `getEdge(String columnName) : PgxEdge`

See the Java Documentation for more details.

Finally, there is a `PgqlResultSet.close()` which releases the result set's resources, and there is a `PgqlResultSet.getMetaData()` through which the column names and column count can be retrieved.

An example for result set iteration is as follows:

```
PgqlResultSet resultSet = g.queryPgql(
    "   SELECT owner.name AS account_holder, SUM(t.amount) AS 
total_transacted_with_Nikita "
  + "     FROM MATCH (p:Person) -[:ownerOf]-> (account1:Account) "
  + "        , MATCH (account1) -[t:transaction]- (account2) "
  + "        , MATCH (account2:Account) <-[:ownerOf]- (owner:Person|Company) 
"
```

```
  + "    WHERE p.name = 'Nikita' "
  + " GROUP BY owner");

while (resultSet.next()) {
  String accountHolder = resultSet.getString(1);
  long totalTransacted = resultSet.getLong(2);
  System.out.println(accountHolder + ": " + totalTransacted);
}

resultSet.close();
```

The output of the above example will look like:

```
Oracle: 4501
Camille: 1000
```

In addition, the `PgqlResultSet` is also iterable via the Java Iterator interface. An example of a “for each loop” over the result set is as follows:

```
for (PgxResult result : resultSet) {
  String accountHolder = result.getString(1);
  long totalTransacted = result.getLong(2);
  System.out.println(accountHolder + ": " + totalTransacted);
}
```

The output of the above example will look like:

```
Oracle: 4501
Camille: 1000
```

Note that the same getters that are available for `PgqlResultSet` are also available for `PgxResult`.

16.6.4 Printing a Result Set

The following methods of `PgqlResultSet (package oracle.pgx.api)` are used to print a result set:

- `print() : PgqlResultSet`
- `print(long numResults) : PgqlResultSet`
- `print(long numResults, int from) : PgqlResultSet`
- `print(PrintStream printStream, long numResults, int from) : PgqlResultSet`

For example:

```
g.queryPgql("SELECT COUNT(*) AS numPersons FROM MATCH
(n:Person)").print().close()
+------------+
| numPersons |
+------------+
```

```
| 3           |
+------------+
```

Another example:

```
PgqlResultSet resultSet = g.queryPgql(
    "   SELECT owner.name AS account_holder, SUM(t.amount) AS
total_transacted_with_Nikita "
  + "     FROM MATCH (p:Person) -[:ownerOf]-> (account1:Account) "
  + "        , MATCH (account1) -[t:transaction]- (account2) "
  + "        , MATCH (account2:Account) <-[:ownerOf]- (owner:Person|Company)
"
  + "    WHERE p.name = 'Nikita' "
  + " GROUP BY owner")

resultSet.print().close()
+------------------------------------------------+
| account_holder | total_transacted_with_Nikita |
+------------------------------------------------+
| Camille        | 1000.0                       |
| Oracle         | 4501.0                       |
+------------------------------------------------+
```

16.7 Java APIs for Executing UPDATE Queries

The `UPDATE` queries make changes to existing graphs using the `INSERT`, `UPDATE`, and `DELETE` operations as detailed in the section Graph Modification of the PGQL 1.3 specification.

Note that `INSERT` allows you to insert new vertices and edges into a graph, `UPDATE` allows you to update existing vertices and edges by setting their properties to new values, and `DELETE` allows you to delete vertices and edges from a graph.

- Updatability of Graphs Through PGQL
  Graph data that is loaded from the Oracle RDBMS or from CSV files into the PGX is not updatable through PGQL right away.
- Executing UPDATE Queries Against a Graph in the Graph Server (PGX)
  To execute `UPDATE` queries against a graph, use the `PgxGraph.executePgql(String query)` method.
- Executing UPDATE Queries Against a PGX Session
  For now, there is no support for executing `UPDATE` queries against a `PgxSession` and therefore, updates always have to be executed against a PgxGraph. To obtain a graph from a session, use the `PgxSession.getGraph(String graphName)` method.
- Altering the Underlying Schema of a Graph
  The `INSERT` operations can only insert vertices and edges with known labels and properties. Similarly, `UPDATE` operations can only set values of known properties. Thus, new data must always conform to the existing schema of the graph.

16.7.1 Updatability of Graphs Through PGQL

Graph data that is loaded from the Oracle RDBMS or from CSV files into the PGX is not updatable through PGQL right away.

First, you need to create a copy of the data through the `PgxGraph.clone()` method. The resulting graph is fully updatable.

Consider the following example:

```
// load a graph from the RDBMS or from CSV
PgxGraph g1 = session.readGraphWithProperties("path/to/
graph_config.json");

// create an updatable copy of the graph
PgxGraph g2 = g1.clone("new_graph_name");

// insert an additional vertex into the graph
g2.executePgql("INSERT VERTEX v " +
               "         LABELS ( Person ) " +
               "         PROPERTIES ( v.firstName = 'Camille', " +
               "                      v.lastName = ' Mullins')");
```

Additionally, there is also a `PgxGraph.cloneAndExecutePgql(String query, String graphName)` method that combines the last two steps from above example into a single step:

```
// create an updatable copy of the graph while inserting a new vertex
PgxGraph g2_copy = g1.cloneAndExecutePgql(
                     "INSERT VERTEX v " +
                     "         LABELS ( Person ) " +
                     "         PROPERTIES ( v.firstName = 'Camille', "
+
                     "                      v.lastName = ' Mullins') "
                   , "new_graph_name");
```

Note that graphs that are created through `PgxGraph.clone()` are local to the session. However, they can be shared with other sessions through the `PgxGraph.publish(..)` methods but then they are no longer updatable through PGQL. Only session-local graphs are updatable but persistent graphs are not.

16.7.2 Executing UPDATE Queries Against a Graph in the Graph Server (PGX)

To execute `UPDATE` queries against a graph, use the `PgxGraph.executePgql(String query)` method.

The following is an example of `INSERT` query:

```
g.executePgql("INSERT VERTEX v " +
              "         LABELS ( Person ) " +
              "         PROPERTIES ( v.firstName = 'Camille', " +
              "                      v.lastName = ' Mullins' ) ");
```

Note that the `INTO` clause of the `INSERT` can be omitted. If you use an `INTO` clause, the graph name in the `INTO` clause must correspond to the name of the PGX graph (`PgxGraph.getName()`) that the query is executed against.

The following is an example of `UPDATE` query:

```
// set the date of birth of Camille to 2014-11-15
g.executePgql("UPDATE v SET ( v.dob = DATE '2014-11-14' ) " +
              "FROM MATCH (v:Person) " +
              "WHERE v.firstName = 'Camille' AND v.lastName = ' Mullins' ");
```

The following is an example of `DELETE` query:

```
// delete Camille from the graph
g.executePgql("DELETE v " +
              "FROM MATCH (v:Person) " +
              "WHERE v.firstName = 'Camille' AND v.lastName = 'Mullins' ");
```

16.7.3 Executing UPDATE Queries Against a PGX Session

For now, there is no support for executing `UPDATE` queries against a `PgxSession` and therefore, updates always have to be executed against a PgxGraph. To obtain a graph from a session, use the `PgxSession.getGraph(String graphName)` method.

16.7.4 Altering the Underlying Schema of a Graph

The `INSERT` operations can only insert vertices and edges with known labels and properties. Similarly, `UPDATE` operations can only set values of known properties. Thus, new data must always conform to the existing schema of the graph.

However, some PGX APIs exist for updating the schema of a graph: while no APIs exist for adding new labels, new properties can be added through the `PgxGraph.createVertexProperty(PropertyType type, String name)` and `PgxGraph.createEdgeProperty(PropertyType type, String name)` methods. The new properties are attached to each vertex/edge in the graph, irrespective of their labels. Initially the properties are assigned a default value but then the values can be updated through the `UPDATE` statements.

Consider the following example:

```
// load a graph from the RDBMS or from CSV
PgxGraph g = session.readGraphWithProperties("path/to/graph_config.json");

// add a new property to the graph
g.createVertexProperty(PropertyType.LOCAL_DATE, "dob");

// set the date of birth of Camille to 2014-11-15
g.executePgql("UPDATE v SET ( v.dob = DATE '2014-11-14' ) " +
              "FROM MATCH (v:Person) " +
              "WHERE v.firstName = 'Camille' AND v.lastName = ' Mullins' ");
```

16.8 PGQL Queries with Partitioned IDs

You can retrieve partitioned IDs using the `id()` function in PGQL.

PGQL SELECT Queries

The following are a few examples to retrieve partitioned IDs using PGQL `SELECT` queries:

```
g.queryPgql("SELECT id(n) FROM MATCH(n)").print().close()
```

This prints an output similar to:

```
+-------------+
| id(n)       |
+-------------+
| Accounts(2) |
| Accounts(4) |
| Accounts(6) |
+-------------+
```

```
g.queryPgql("SELECT n.name FROM MATCH(n) WHERE id(n) =
'Accounts(1)'").print().close()
```

The output is printed as shown:

```
+-------+
| name  |
+-------+
| User1 |
+-------+
```

```
g.queryPgql("SELECT LABEL(n), n.name from MATCH(n) WHERE n.id =
1").print().close()
```

The output is printed as shown:

```
+------------------+
| label(n) | name  |
+------------------+
| Accounts | User1 |
+------------------+
```

PGX automatically creates a unique index for keys so that queries with predicates such as `WHERE id(n) = 'Accounts(1)'` and `WHERE n.id = 1` can be efficiently processed by retrieving the vertex in constant time.

Using Bind Variables

Partitioned IDs can also be passed as bind values into a `PgxPreparedStatement`.

For example:

```
PgxPreparedStatement statement = g.preparePgql("SELECT n.name FROM MATCH (n)
WHERE id(n)= ?")
statement.setString(1, "Accounts(1)")
statement.executeQuery().print().close()
```

This prints the output as shown:

```
+-------+
| name  |
+-------+
| User1 |
+-------+
```

PGQL INSERT Queries

In `INSERT` queries, you must provide a value for the key property if a key property exists. The value is then used for the vertex or edge key.

For example you can execute an `INSERT` as shown:

```
g.executePgql("INSERT VERTEX v LABELS (Accounts) PROPERTIES (v.id = 1001,
v.name = 'User1001')")
```

The inserted values can be verified as shown:

```
g.queryPgql("SELECT id(n), n.name FROM MATCH(n) WHERE n.id =
1001").print().close()
```

This prints the output:

```
+---------------------------+
| id(n)          | name     |
+---------------------------+
| Accounts(1001) | User1001 |
+---------------------------+
```

16.9 Security Tools for Executing PGQL Queries

To safeguard against query injection, bind variables can be used in place of literals while `printIdentifier(String identifier)` can be used in place of identifiers like graph names, labels, and property names.

- Using Bind Variables
  There are two reasons for using bind variables:

- Using Identifiers in a Safe Manner
  When you create a query through string concatenation, not only literals in queries pose a security risk, but also identifiers like graph names, labels, and property names do. The only problem is that bind variables are not supported for such identifier. Therefore, if these identifiers are variable from the application's perspective, then it is recommended to protect against query injection by passing the identifier through the `oracle.pgql.lang.ir.PgqlUtils.printIdentifier(String identifier)` method.

16.9.1 Using Bind Variables

There are two reasons for using bind variables:

- It protects against query injection.
- It speeds up query execution because the same bind variables can be set multiple times without requiring recompilation of the query.

To create a prepared statement, use one of the following two methods:

- `PgxGraph.preparePgql(String query) : PgxPreparedStatement`
- `PgxSession.preparePgql(String query) : PgxPreparedStatement`

The `PgxPreparedStatement (package oracle.pgx.api)` returned from these methods have setter methods for binding the bind variables to values of the designated data type.

```
PreparedStatement stmnt = g.preparePgql(
  "SELECT v.id, v.dob " +
  "FROM MATCH (v) " +
  "WHERE v.firstName = ? AND v.lastName = ?");
stmnt.setString(1, "Camille");
stmnt.setString(2, "Mullins");
ResultSet rs = stmnt.executeQuery();
```

Each bind variable in the query needs to be set to a value using one of the following setters of `PgxPreparedStatement`:

- `setBoolean(int parameterIndex, boolean x)`
- `setDouble(int parameterIndex, double x)`
- `setFloat(int parameterIndex, float x)`
- `setInt(int parameterIndex, int x)`
- `setLong(int parameterIndex, long x)`
- `setDate(int parameterIndex, LocalDate x)`
- `setTime(int parameterIndex, LocalTime x)`
- `setTimestamp(int parameterIndex, LocalDateTime x)`
- `setTimeWithTimezone(int parameterIndex, OffsetTime x)`
- `setTimestampWithTimezone(int parameterIndex, OffsetDateTime x)`

- `setArray(int parameterIndex, List<?> x)`

Once all the bind variables are set, the statement can be executed through:

- `PgxPreparedStatement.executeQuery()`
  - For `SELECT` queries only
  - Returns a ResultSet
- `PgxPreparedStatement.execute()`
  - For any type of statement
  - Returns a Boolean to indicate the form of the result: true in case of a `SELECT` query, false otherwise
  - In case of `SELECT`, the ResultSet can afterwards be accessed through `PgxPreparedStatement.getResultSet()`

In PGQL, bind variables can be used in place of literals of any data type, including array literals. An example query with a bind variable to is set to an instance of a String array is:

```
List<String> countryNames = new ArrayList<String>();
countryNames.add("Scotland");
countryNames.add("Tanzania");
countryNames.add("Serbia");

PreparedStatement stmnt = g.preparePgql(
  "SELECT n.name, n.population " +
  "FROM MATCH (c:Country) " +
  "WHERE c.name IN ?");

ResultSet rs = stmnt.executeQuery();
```

Finally, if a prepared statement is no longer needed, it is closed through `PgxPreparedStatement.close()` to free up resources.

16.9.2 Using Identifiers in a Safe Manner

When you create a query through string concatenation, not only literals in queries pose a security risk, but also identifiers like graph names, labels, and property names do. The only problem is that bind variables are not supported for such identifier. Therefore, if these identifiers are variable from the application's perspective, then it is recommended to protect against query injection by passing the identifier through the `oracle.pgql.lang.ir.PgqlUtils.printIdentifier(String identifier)` method.

Given an identifier string, the method automatically adds double quotes to the start and end of the identifier and escapes the characters in the identifier appropriately.

Consider the following example:

```
String graphNamePrinted = printIdentifier("my graph name with \" special %
characters ");
PreparedStatement stmnt = g.preparePgql(
  "SELECT COUNT(*) AS numVertices FROM MATCH (v) ON " + graphNamePrinted);
```

16.10 Best Practices for Tuning PGQL Queries

This section describes best practices regarding memory allocation, parallelism, and query planning.

- Memory Allocation
  The graph server (PGX) has `on-heap` and `off-heap` memory, the earlier being the standard JVM heap while the latter being a separate heap that is managed by PGX. Just like graph data, intermediate and final results of PGQL queries are partially stored on-heap and partially off-heap. Therefore, both heaps are needed.
- Parallelism
  By default, all available processor threads are used to process PGQL queries. However, if needed, the number of threads can be limited by setting the `parallelism` option of the graph server (PGX).
- Query Plan Explaining
  The `PgxGraph.explainPgql(String query)` method is used to get insight into the query plan of the query. The method returns an instance of `Operation (package oracle.pgx.api)` which has the following methods:

16.10.1 Memory Allocation

The graph server (PGX) has `on-heap` and `off-heap` memory, the earlier being the standard JVM heap while the latter being a separate heap that is managed by PGX. Just like graph data, intermediate and final results of PGQL queries are partially stored on-heap and partially off-heap. Therefore, both heaps are needed.

In case of the on-heap memory, the default maximum is chosen upon startup of the JVM, but it can be overwritten through the `-Xmx` option.

In case of the off-heap, there is no maximum set by default and the off-heap memory usage, therefore, keeps increasing automatically until it depletes the system resources, in which case the operation is canceled, it's memory is released, and an appropriate exception is passed to the user. If needed, a maximum off-heap size can be configured through the `max_off_heap_size` option in the graph server (PGX).

A ratio of 1:1 for on-heap versus off-heap is recommended as a good starting point to allow for the largest possible graphs to be loaded and queried. See Configuring On-Heap Limits for the steps to configure the on-heap memory size.

16.10.2 Parallelism

By default, all available processor threads are used to process PGQL queries. However, if needed, the number of threads can be limited by setting the `parallelism` option of the graph server (PGX).

See Configuration Parameters for the Graph Server (PGX) Engine for more information on the graph server configuration parameters.

16.10.3 Query Plan Explaining

The `PgxGraph.explainPgql(String query)` method is used to get insight into the query plan of the query. The method returns an instance of `Operation (package oracle.pgx.api)` which has the following methods:

- `print()`: for printing the operation and its child operations
- `getOperationType()`: for getting the type of the operation
- `getPatternInfo()`: for getting a string representation of the operation
- `getCostEstimate()`: for getting the cost of the operation
- `getTotalCostEstimate()`: for getting the cost of the operations and its child operations
- `getCardinatlityEstimate()`: for getting the expected number of result rows
- `getChildren()`: for accessing the child operations

Consider the following example:

```
g.explainPgql("SELECT COUNT(*) FROM MATCH (n) -[e1]-> (m) -[e2]->
(o)").print()
\--- GROUP BY  GroupBy {"cardinality":"42", "cost":"42",
"accumulatedCost":"58.1"}
     \--- (m) -[e2]-> (o) NeighborMatch {"cardinality":"3.12",
"cost":"3.12", "accumulatedCost":"16.1"}
          \--- (n) -[e1]-> (m) NeighborMatch {"cardinality":"5", "cost":"5",
"accumulatedCost":"13"}
               \--- (n) RootVertexMatch {"cardinality":"8", "cost":"8",
"accumulatedCost":"8"}
```

In the above example, the `print()` method is used to print the query plan.

If a query plan is not optimal, it is often possible to rewrite the query to improve its performance. For example, a `SELECT` query may be split into an `UPDATE` and a `SELECT` query as a way to improve the total runtime.

Note that the graph server (PGX) does not provide a hint mechanism.

Also, printing the query plan shows the filters used in the query. For example:

```
g.explainPgql("SELECT id(n) FROM MATCH (n)-[e]->(m) WHERE " +
...> "id(n) > 500 " +
...> "AND id(n) < 510 " +
...> "AND id(n) <> 509 " +
...> "AND id(n) <> 507 ").print()
\--- Projection {"cardinality":"146", "cost":"0", "accumulatedCost":"175"}
     \--- (n) -[e]-> (m) NeighborMatch {"cardinality":"146", "cost":"146",
"accumulatedCost":"175"}
          \--- (n) RootVertexMatch {"cardinality":"29.2", "cost":"29.2",
"accumulatedCost":"29.2"}
                WHERE $filter1
filter1: (id(n) <> 509) AND
         (id(n) <> 507) AND
```

```
          (id(n) > 500) AND
          (id(n) < 510)
```

In the preceding example, since the query has filters that spans more than three lines, the filters are shown displayed below the query plan. If the filters are less than three lines, then the filters are shown directly within the query plan tree as shown:

```
g.explainPgql("SELECT id(n) FROM MATCH (n)-[e]->(m) WHERE " +
...> "id(n) > 500 " +
...> "AND id(n) < 510 ").print()
\--- Projection {"cardinality":"162", "cost":"0",
"accumulatedCost":"194"}
     \--- (n) -[e]-> (m) NeighborMatch {"cardinality":"162",
"cost":"162", "accumulatedCost":"194"}
          \--- (n) RootVertexMatch {"cardinality":"32.4",
"cost":"32.4", "accumulatedCost":"32.4"}
                WHERE (id(n) > 500) AND
                      (id(n) < 510)
```

17

REST Endpoints for the Graph Server

This section explains the Graph Server REST endpoints:

The following are the available REST endpoints:

> **Note:**
>
> The examples shown in the REST endpoints assume that:
>
> - The PGX server is up and running on `https://localhost:7007`.
> - Linux with `cURL` is installed. `cURL` is used to demonstrate how to access the `graph.publish` API using the CA certificate for verifying the graph server.

- Login
- List Graphs
- Run a PGQL Query
- Get User
- Logout
- Asynchronous REST Endpoints

17.1 Login

HTTP Request: `POST https://localhost:7007/ui/v1/login/`

Authentication: Uses cookie-based authentication.

Table 17-1 Parameters

Parameter	Parameter Type	Value	Required
`Content-type`	Header	`application/json`	Yes
`username`	Body	`<username>`	Yes
`password`	Body	`<password>`	Yes

Table 17-1 (Cont.) Parameters

Parameter	Parameter Type	Value	Required
`baseUrl`	Body	`<baseUrl>` to point to the graph server (PGX) or the database	Optional. If empty, the `pgx.base_url` parameter value in the `web.xml` file will be used. See Table 18-1 for the location of the `web.xml` file.
`pgqlDriver`	Body	Valid PGQL driver configuration values are: • `pgxDriver` : for PGQL on the graph server (PGX) • `pgqlDriver`: for PGQL on Oracle Database	Yes
`sessionId`	Body	`sessionId` from graph server (PGX)	Optional

Request

The following `curl` command signs the user in to the graph server:

```
curl --cacert /etc/oracle/graph/ca_certificate.pem -c cookie.txt -X
POST -H "Content-Type: application/json" -d '{"username":
"<username>", "password": "<password>", "pgqlDriver":
"<pgqlDriver>","baseUrl": "<baseUrl>", "sessionId": "<sessionId>" }'
https://localhost:7007/ui/v1/login/
```

Response: The `username` used for the login. For example:

```
"oracle"
```

On successful login, the server session cookie is stored in a cookie file, `cookie.txt`. Use this cookie file, in the subsequent calls to the API.

17.2 List Graphs

GET /v2/graphs

HTTP Request: `GET https://localhost:7007/ui/v2/graphs`

Request

The following `curl` command lists all the graphs to which the user has access along with the schema information:

```
curl --cacert /etc/oracle/graph/ca_certificate.pem -b cookie.txt
'https://localhost:7007/ui/v2/graphs'
```

Response: The list of graphs available for the current user along with the schema details. For example:

```
[
  {
    "schema": "HR",
    "graphName": "MY_GRAPH"
  }
]
```

Also, note that the `schema` parameter will be `NULL` for graphs created in the graph server (PGX).

GET /v1/graphs

> **Note:**
>
> The `/v1/graphs` endpoint may be deprecated in a future release of Graph Server and Client. Therefore, it is recommended that you use the `/v2/graphs` endpoint to list all the graphs for a user.

HTTP Request: `GET https://localhost:7007/ui/v1/graphs`
Request

The following `curl` command lists all the graphs that belong to the user:

```
curl --cacert /etc/oracle/graph/ca_certificate.pem -b cookie.txt 'https://
localhost:7007/ui/v1/graphs'
```

Response: The list of graphs available for the current user. For example:

```
["hr", "bank_graph_analytics"]
```

17.3 Run a PGQL Query

HTTP Request: `GET https://localhost:7007/ui/v1/query?pgql=<PGQL_query>&graph=<graph_name>&parallelism=<parallelism_value>&size=<size_value>&formatter=<formatter_value>`

Table 17-2 Query Parameters

Parameter	Description	Values	Required
`pgql`	PGQL query string	`<PGQL_query>`	Yes
`graph`	Name of the graph	`<graph_name>`	Optional, only if the `pgql` query parameter contains the graph name. Otherwise, it is required.

Table 17-2 (Cont.) Query Parameters

Parameter	Description	Values	Required
`parallelism`	Degree of Parallelism	<parallelism_value>	Optional. Default value depends on the PGQL driver configuration: • `pgxDriver`: <number-of-cpus> See `parallelism` in Table 20-1. • `pgqlDriver`: `1`
`size`	Fetch size (= the number of rows) of the query result	<size_value>	Optional. Default size value is `100`.
`formatter`	Formatter of the graph	<formatter_value>	Optional. Supported formatter options are: • `datastudio` • `gvt` Default value is `datastudio`.

Request

The following `curl` command executes PGQL Query on a property graph:

```
curl --cacert /etc/oracle/graph/ca_certificate.pem -b cookie.txt
'https://localhost:7007/ui/v1/query?pgql=SELECT%20e%0AMATCH%20()-
%5Be%5D-%3E()%0ALIMIT%205&graph=hr&size=100'
```

Response: The PGQL query result in JSON format.

```
{
  "name": "bank_graph_analytics_2",
  "resultSetId": "pgql_14",
  "graph": {
    "idType": "number",
    "vertices": [
      {
        "_id": "1",
        "p": [],
        "l": [
          "Accounts"
        ],
        "g": [
          "anonymous_1"
        ]
      },
      {
        "_id": "418",
        "p": [],
        "l": [
          "Accounts"
        ],
```

```
        "g": [
          "anonymous_2"
        ]
      },
      {
        "_id": "259",
        "p": [],
        "l": [
          "Accounts"
        ],
        "g": [
          "anonymous_2"
        ]
      }
    ],
    "edges": [
      {
        "_id": "0",
        "p": [
          {
            "n": "AMOUNT",
            "v": "1000.0",
            "s": false
          }
        ],
        "l": [
          "Transfers"
        ],
        "g": [
          "e"
        ],
        "s": "1",
        "d": "259",
        "u": false
      },
      {
        "_id": "1",
        "p": [
          {
            "n": "AMOUNT",
            "v": "1000.0",
            "s": false
          }
        ],
        "l": [
          "Transfers"
        ],
        "g": [
          "e"
        ],
        "s": "1",
        "d": "418",
        "u": false
      }
    ],
```

```
    "paths": [],
    "totalNumResults": 2
  },
  "table":
"e\nPgxEdge[provider=Transfers,ID=0]\nPgxEdge[provider=Transfers,ID=1]"
}
```

17.4 Get User

HTTP Request: `GET https://localhost:7007/ui/v1/user`

Request

The following `curl` command gets the name of the current user:

```
curl --cacert /etc/oracle/graph/ca_certificate.pem -b cookie.txt
'https://localhost:7007/ui/v1/user'
```

Response: The name of the current user. For example:

```
"oracle"
```

17.5 Logout

HTTP Request: `POST https://localhost:7007/ui/v1/logout/`

Request

The following `curl` command is to successfully log out from the Graph Visualization application:

```
curl --cacert /etc/oracle/graph/ca_certificate.pem -b cookie.txt -X
POST 'https://localhost:7007/ui/v1/logout/'
```

Response: None

On successful logout, the server returns `HTTP` status code `200` and the session token from the `cookie.txt` file will no longer be valid.

17.6 Asynchronous REST Endpoints

The graph server REST endpoints support cancellation of queries.

In order to be able to cancel queries, you need to send the query using the following asynchronous REST endpoints:

- Run a PGQL Query Asynchronously
- Check a Query Completion
- Cancel a Query Execution
- Retrieve a Query Result

17.6.1 Run a PGQL Query Asynchronously

HTTP Request: `GET https://localhost:7007/ui/v1/async-query?pgql=<PGQL query>&graph=<graph>&parallelism=<value>&size=<size value>`

See Table 17-2 for more information on query parameters.

Request

The following `curl` command executes a PGQL query asynchronously on a property graph:

```
curl --cacert /etc/oracle/graph/ca_certificate.pem -b cookie.txt 'https://
localhost:7007/ui/v1/async-query?pgql=SELECT%20e%0AMATCH%20()-%5Be%5D-%3E()
%0ALIMIT%205&graph=hr&parallelism=&size=100'
```

Response: None.

> **Note:**
>
> An error message will be returned in case the query is malformed or if the graph does not exist.

17.6.2 Check a Query Completion

HTTP Request: `GET https://localhost:7007/ui/v1/async-query-complete`

Request

The following `curl` command checks if the PGQL query execution is completed:

```
curl --cacert /etc/oracle/graph/ca_certificate.pem -b cookie.txt 'https://
localhost:7007/ui/v1/async-query-complete'
```

Response: A boolean that indicates if the query execution is completed. For example,

```
true
```

> **Note:**
>
> You do not have to specify any request `ID`, as the currently executing query is attached to your HTTP session. You can only have one query executing per session. For concurrent query execution, create multiple HTTP sessions by logging in multiple times.

17.6.3 Cancel a Query Execution

HTTP Request: `DELETE https://localhost:7007/ui/v1/async-query`

Request

The following `curl` command cancels a currently executing PGQL Query on a property graph:

```
curl -X DELETE --cacert /etc/oracle/graph/ca_certificate.pem -b
cookie.txt 'https://localhost:7007/ui/v1/async-query'
```

Response: Confirmation of the cancellation or an error message if the query has already completed execution.

17.6.4 Retrieve a Query Result

HTTP Request: `GET https://localhost:7007/ui/v1/async-result`

> **Note:**
>
> The endpoint, `GET https://localhost:7007/ui/v1/async-result?pgql=<PGQL query>&graph=<graph>&parallelism=<value>&size=<size value>`, to retrieve a query result is deprecated:
>
> ```
> curl --cacert /etc/oracle/graph/ca_certificate.pem -b
> cookie.txt 'https://localhost:7007/ui/v1/async-result?
> pgql=SELECT%20e%0AMATCH%20()-%5Be%5D-%3E()
> %0ALIMIT%205&graph=hr&parallelism=&size=100'
> ```

Request

The following `curl` command retrieves the result of a successfully completed query:

```
curl --cacert /etc/oracle/graph/ca_certificate.pem -b cookie.txt
'https://localhost:7007/ui/v1/async-result'
```

Response: The PGQL query result in JSON format.


```
{
  "name": "bank_graph_analytics_2",
  "resultSetId": "pgql_14",
  "graph": {
    "idType": "number",
    "vertices": [
      {
        "_id": "1",
        "p": [],
        "l": [
          "Accounts"
        ],
        "g": [
          "anonymous_1"
        ]
```

```
      },
      {
        "_id": "418",
        "p": [],
        "l": [
          "Accounts"
        ],
        "g": [
          "anonymous_2"
        ]
      },
      {
        "_id": "259",
        "p": [],
        "l": [
          "Accounts"
        ],
        "g": [
          "anonymous_2"
        ]
      }
    ],
    "edges": [
      {
        "_id": "0",
        "p": [
          {
            "n": "AMOUNT",
            "v": "1000.0",
            "s": false
          }
        ],
        "l": [
          "Transfers"
        ],
        "g": [
          "e"
        ],
        "s": "1",
        "d": "259",
        "u": false
      },
      {
        "_id": "1",
        "p": [
          {
            "n": "AMOUNT",
            "v": "1000.0",
            "s": false
          }
        ],
        "l": [
          "Transfers"
        ],
        "g": [
```

```
          "e"
        ],
        "s": "1",
        "d": "418",
        "u": false
      }
    ],
    "paths": [],
    "totalNumResults": 2
  },
  "table":
"e\nPgxEdge[provider=Transfers,ID=0]\nPgxEdge[provider=Transfers,ID=1]"
}
```

Part VI
Graph Visualization Application

The Graph Visualization application enables interactive exploration and visualization of property graphs. It can also visualize graphs stored in the database.

- About the Graph Visualization Application
  The Graph Visualization application is a single-page web application that works with the graph server (PGX).
- Using the Graph Visualization Application
  Depending on the PGQL driver selected at the time of logging in, the Graph Visualization application is either connected to the database or to the graph server (PGX).

18 About the Graph Visualization Application

The Graph Visualization application is a single-page web application that works with the graph server (PGX).

The graph server can be deployed in embedded mode or in Apache Tomcat or Oracle WebLogic Server. Graph Visualization application takes PGQL queries as an input and renders the result visually. A rich set of client-side exploration and visualization features can reveal new insights into your graph data.

Graph Visualization application works with the graph server (PGX). It can visualize graphs that are have been loaded into the graph server (PGX), either preloaded when the graph server is started, or loaded at run-time by a client application and made available through the `graph.publish()` API.

- How does the Graph Visualization Application Work
  The Graph Visualization application exposes its own web interface and REST endpoint and can execute PGQL queries against the graph server (PGX) or the Oracle Database (PGQL on RDBMS).
- Kerberos Enabled Authentication for the Graph Visualization Application
  The Graph Visualization application can authenticate users with Kerberos authentication enabled.
- Embedding the Graph Visualization Library in a Web Application
  You can integrate the graph visualization component in a web application to visualize graph data.

18.1 How does the Graph Visualization Application Work

The Graph Visualization application exposes its own web interface and REST endpoint and can execute PGQL queries against the graph server (PGX) or the Oracle Database (PGQL on RDBMS).

By default, it uses PGX and therefore requires a running PGX server to function. Alternatively, you can configure Graph Visualization application to directly talk to the database via PGQL on RDBMS. Graph Visualization application does not have any UI to create graphs, it can only visualize graphs which are already loaded into PGX or Oracle Database. See REST Endpoints for the Graph Server for more information on the graph visualization REST endpoints.

See Running the Graph Visualization Application in Standalone Mode for more information on starting the Graph Visualization application.

18.2 Kerberos Enabled Authentication for the Graph Visualization Application

The Graph Visualization application can authenticate users with Kerberos authentication enabled.

Graph Visualization provides two different drivers to log in:

- **Graph Server (PGX) Driver:** To send your credentials (Kerberos ticket) to Graph Server.
- **Database Driver:** To send your credentials (Kerberos ticket) directly to the database.

- Prerequisite Requirements for Kerberos Authentication
- Preparing the Graph Visualization Application for Kerberos Authentication

> **See Also:**
>
> Kerberos Enabled Authentication for the Graph Server (PGX)

18.2.1 Prerequisite Requirements for Kerberos Authentication

The system requirements for the respective PGQL drivers are as follows:

- **Graph Server (PGX) Driver:** See Prerequisite Requirements for enabling Kerberos authentication on the graph server (PGX).
- **Database Driver:**
  - The database must have Kerberos authentication enabled. See Configuring Kerberos Authentication for more information.
  - Both the database and the Kerberos Authentication Server need to be reachable from the host where the Graph Visualization application is running.
  - The database must be prepared for graph server authentication. That is, relevant graph roles have been granted to users who will log into the Graph Visualization application.

18.2.2 Preparing the Graph Visualization Application for Kerberos Authentication

In order to use Kerberos authentication, you must enter your Active Directory credentials in the Graph Visualization application login page.
To enable Kerberos authentication for the Graph Visualization application, follow the steps shown:

1. Locate the `web.xml` file for your installation.

   You can locate the `WEB-INF/web.xml` inside the Graph Visualization `WAR` file for your installation as shown in the following table:

Table 18-1 Location of `WEB-INF/web.xml` file

Type of Installation	WAR file	Location
Standalone installation (RPM)	`graphviz-<version>-pgviz<graphviz-version>.war`	`/opt/oracle/graph/graphviz`
Apache Tomcat Deployment:	`graphviz-<version>-pgviz<graphviz-version>-tomcat.war` *<version>* denotes the downloaded Oracle Graph Server and Client version.	a. Download `oracle-graph-webapps-<version>.zip` from Oracle Software Delivery Cloud b. Unzip the file into a directory of your choice. c. Locate the `.war` file for deploying the Graph Visualization application to Tomcat. It follows the naming pattern: `graphviz-<version>-pgviz<graphviz-version>-tomcat.war`
Oracle WebLogic Server Deployment	`graphviz-<version>-pgviz<graphviz-version>-wls.war` *<version>* denotes the downloaded Oracle Graph Server and Client version.	a. Download `oracle-graph-webapps-<version>.zip` from Oracle Software Delivery Cloud b. Unzip the file into a directory of your choice. c. Locate the `.war` file for deploying the Graph Visualization application to Oracle WebLogic Server. It follows the naming pattern: `graphviz-<version>-pgviz<graphviz-version>-wls.war`

2. Extract the appropriate `WAR` file to a directory of your choice by executing the following command:

```
unzip graphviz-*.war -d <war-file-extraction-path>
```

3. Locate and open the `WEB-INF/web.xml` file for update using any file editor of your choice. For example:

```
cd <war-file-extraction-path>
vi WEB-INF/web.xml
```

4. Enable the `graphviz.driver.auth.kerberos` parameter as shown:

```
<context-param>
        <param-name>graphviz.driver.auth.kerberos</param-name>
        <param-value>true</param-value>
</context-param>
```

Setting this flag **true** initiates the Graph Visualization application to install its own `okinit` package.

5. Optionally. set the cache directory that will be used by the Graph Visualization application to temporarily store Kerberos tickets given by clients as shown

```
<context-param>
        <param-name>graphviz.driver.auth.kerberos.cache_dir</param-
name>
        <param-value>/dev/shm/graph_cache</param-value>
</context-param>
```

The default value is */dev/shm/graph_cache*. If the directory does not exist, it will be automatically created upon server startup.

6. Optionally, set the maximum amount of concurrent Kerberos active sessions in the Graph Visualization application.

```
<context-param>
        <param-name>graphviz.driver.auth.kerberos.max_cache_size</
param-name>
        <param-value>64</param-value>
</context-param>
```

7. Optionally, modify the directory where `okinit` package will be installed, by updating the following parameter:

```
<context-param>
    <param-name>graphviz.driver.auth.kerberos.okinit-directory</
param-name>
    <param-value>/tmp</param-value>
</context-param>
```

> **Note:**
>
> The default value is */tmp* and you must have executable permission for the directory.

8. Optionally, set the following parameter if there is a location for an existing `okinit` package on your machine. In this case, the GraphVisualization application will not install its own `okinit` package.

```
<context-param>
        <param-
name>graphviz.driver.auth.kerberos.graphviz.driver.auth.okinit-
location</param-name>
        <param-value></param-value>
</context-param>
```

> **Note:**
>
> The GraphVisualization application must have executable permission for the directory location.

9. Finally, after all the preceding updates, repackage the `WAR` file by executing the following commands:

```
cd <war-file-extraction-path>
jar -cvf <war-file-name> *
```

10. Redeploy the `WAR` file to the appropriate directory for your installation.

    Kerberos authentication is enabled for the Graph Visualization Application.

18.3 Embedding the Graph Visualization Library in a Web Application

You can integrate the graph visualization component in a web application to visualize graph data.

The Oracle Graph Server and Client deployment contains a JavaScript library for the Graph Visualization component in the `oracle-graph-visualization-library-23.1.0.zip` file.

The Graph Visualization interface in the library supports:

- Custom vertex and edge styling based on its properties
- Interactive actions for graph exploration
- Tooltip with vertex and edge details
- Automatic legend
- Multiple graph layouts

See the Graph JavaScript API Reference for Property Graph Visualization for more information.

You can download the `oracle-graph-visualization-library-23.1.0.zip` file from Oracle Software Delivery Cloud and integrate the library in you web application.

See the demo application on GitHub for an example.

19 Using the Graph Visualization Application

Depending on the PGQL driver selected at the time of logging in, the Graph Visualization application is either connected to the database or to the graph server (PGX).

In both cases, the principal points of entry for the Graph Visualization application are the query editor and the graph list which displays the list of graphs existing either in the graph server (PGX) or in the database.

The following sections explain the application user interface and running PGQL queries for visualization in detail:

- Visualizing PGQL Queries on Graphs Loaded Into the Graph Server (PGX)
  To run PGQL queries on a graph loaded into the graph server (PGX), you must login to the Graph Visualization application by selecting the **Graph Server** advanced option in the login screen.
- Visualizing PGQL and SQL Graph Queries on Graphs in the Database
  To run PGQL or SQL graph queries on graphs in the database, you must login to the Graph Visualization application by selecting the **Database** advanced option in the login screen.
- Graph Visualization Modes
  The buttons on the right let you switch between two modes: Graph Manipulation and Zoom/Move.
- Graph Visualization Settings
  You can click the **Settings** gear icon to display the Graph Visualization settings window.
- Using the Geographical Layout
  The Graph Visualization application offers a choice of layouts for rendering graphs. One of them is the Geographical layout that will show the graph (vertices and edges) on a global map.
- Using Live Search
  Live Search lets you to search the displayed graph and add live fuzzy search score to each item, so you can create a Highlight which visually shows the results of the search in the graph immediately.
- Using URL Parameters to Control the Graph Visualization Application
  You can provide the Graph Visualization application input data through URL parameters instead of using the form fields of the user interface.

19.1 Visualizing PGQL Queries on Graphs Loaded Into the Graph Server (PGX)

To run PGQL queries on a graph loaded into the graph server (PGX), you must login to the Graph Visualization application by selecting the **Graph Server** advanced option in the login screen.

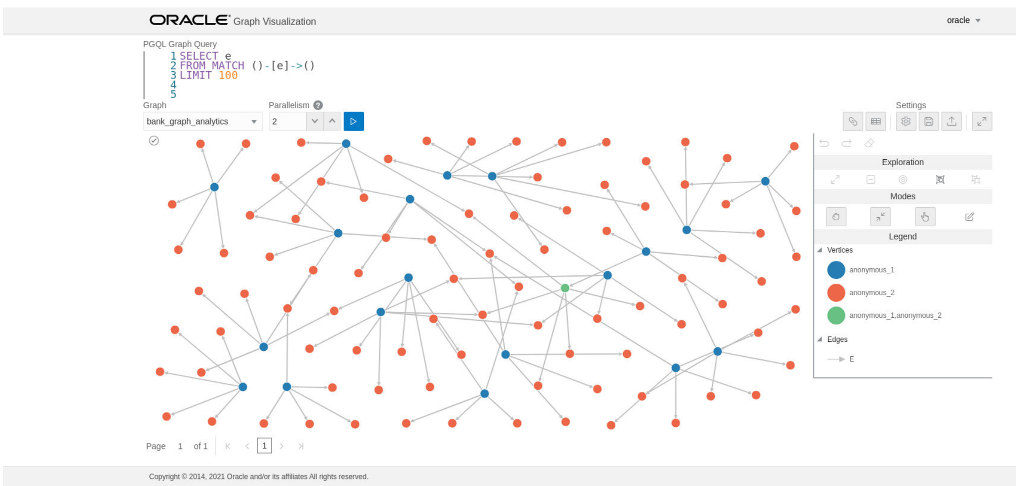
See Configuring the Graph Visualization Application for PGQL on Graph Server (PGX) for more information.

To run queries against a graph, select that graph. The query editor lets you write PGQL queries that can be visualized. (PGQL is the SQL-like query language supported by the Graph Visualization application.)

> **Note:**
>
> For graphs loaded into the graph server (PGX), the graph visualization application supports only PGQL `SELECT` queries. Modifying a graph using a PGQL `INSERT`, `UPDATE` or `DELETE` query is not supported.

Once the query is ready and the desired graph is selected, click the **Run** icon to execute the query. The following figure shows a query visualization identifying all edges that are directed edges from any vertex in the graph to any other vertex.

Figure 19-1   Query Visualization



When a query is successful, the graph visualization is displayed, including nodes and their connections. You can right-click a node or connection to display tooltip information, and you can drag the nodes around.

19.2 Visualizing PGQL and SQL Graph Queries on Graphs in the Database

To run PGQL or SQL graph queries on graphs in the database, you must login to the Graph Visualization application by selecting the **Database** advanced option in the login screen.

See Configuring the Graph Visualization Application for PGQL on Database for more information.

The user interface for the Graph Visualization application can vary depending on the database version you are using.

For Oracle Database 23c: The following two tab options are displayed:

- **PGQL**: To run PGQL queries on property graph views. See Graph Pattern Matching queries in the PGQL specification for more details.
- **SQL/PGQ**: To run SQL graph queries on SQL property graphs. See SQL GRAPH_TABLE Queries for more details.

For Oracle Database 21c or earlier: Only the **PGQL** option in the preceding list is supported.

- Visualizing PGQL Queries on PG Views
  You can create, query, modify and visualize property graph views (PG Views) in the database using the Graph Visualization application.
- Visualizing Graph Queries on SQL Property Graphs
  You can query and visualize a SQL property graph in the database using the Graph Visualization application.

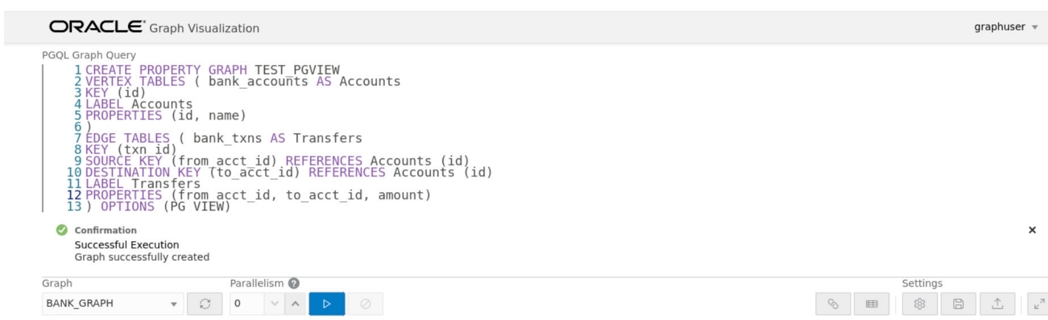
19.2.1 Visualizing PGQL Queries on PG Views

You can create, query, modify and visualize property graph views (PG Views) in the database using the Graph Visualization application.

When connected to the database, you can run the following PGQL queries in the **PGQL** tab of the application.

- `CREATE PROPERTY GRAPH`: To create a new property graph as shown:

Figure 19-2 Creating a PG View



- `INSERT`, `UPDATE` and `DELETE`: To modify an existing graph. For example:

Figure 19-3 Updating an Edge in a PG View

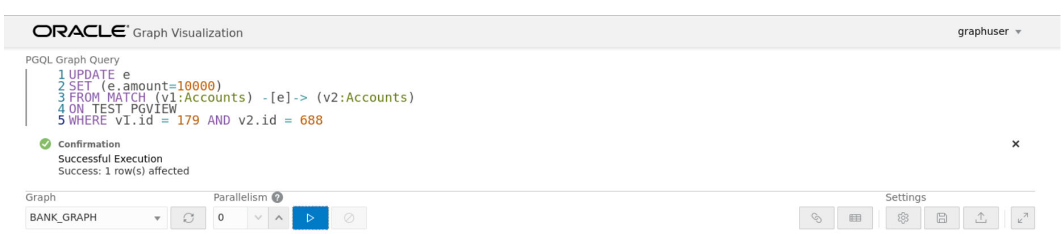
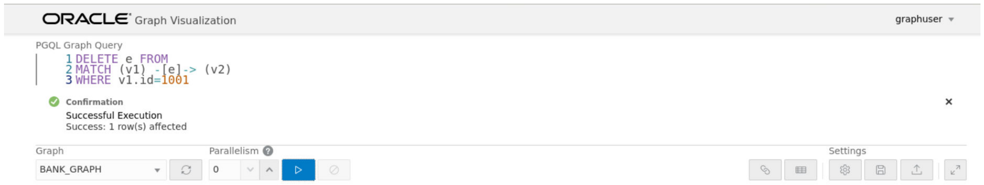
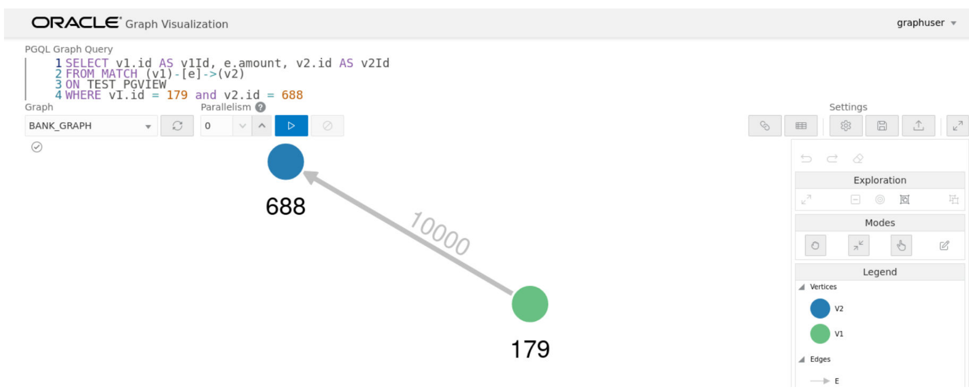


Figure 19-4 Deleting an Edge in a PG View



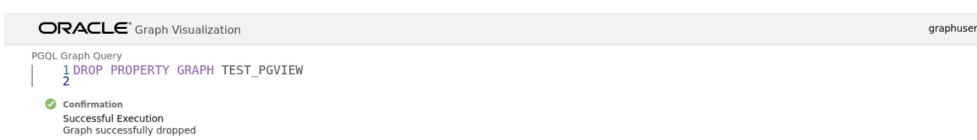
- `SELECT`: To query a property graph as shown:

Figure 19-5 Querying a PG View



- `DROP PROPERTY GRAPH`: To delete a property graph as shown:

Figure 19-6 Dropping a PG View



19.2.2 Visualizing Graph Queries on SQL Property Graphs

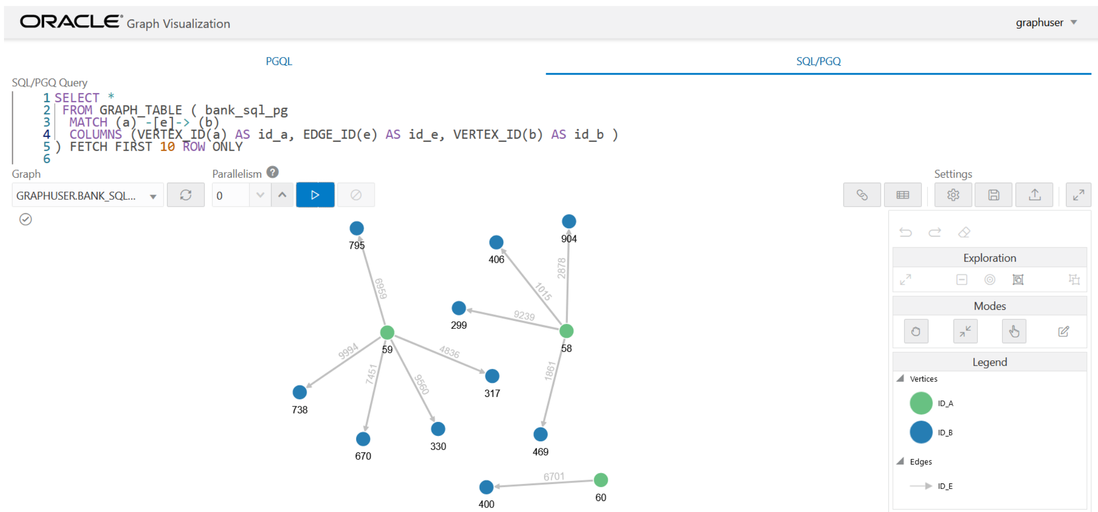
You can query and visualize a SQL property graph in the database using the Graph Visualization application.

However, in order to visualize the vertices and edges of a `GRAPH_TABLE` query together with their IDs and all their labels and properties, the query must return the vertex ID, or edge ID, or both.

For example, the following figure shows the visualization of a SQL `GRAPH_TABLE` query on a SQL property graph. Note that the `COLUMNS` clause in the query uses the `VERTEX_ID` and `EDGE_ID` operators.

> **Note:**
>
> In addition to the privileges mentioned in Privileges to Query a SQL Property Graph, you must also have the `CREATE VIEW` and `CREATE MATERIALIZED VIEW` privileges to query and visualize a SQL property graph in the Graph Visualization application.

Figure 19-7 GRAPH_TABLE Query on SQL Property Graph



In the preceding example, note that the name of the graph is provided in the `GRAPH_TABLE` query.

> **See Also:**
>
> SQL GRAPH_TABLE Queries for more information

19.3 Graph Visualization Modes

The buttons on the right let you switch between two modes: Graph Manipulation and Zoom/ Move.

- **Graph Manipulation** mode lets you execute actions that modify the visualization. These actions include:
  - **Drop** removes selected vertices from visualization. Can also be executed from the tooltip.
  - **Group** selects multiple vertices and collapses them into a single one.
  - **Ungroup** selects a group of collapsed vertices and ungroups them.
  - **Expand** retrieves a configurable number of neighbors (hops) of selected vertices. Can also be executed from the tooltip.

  - **Focus**, like Expand, retrieves a configurable number of neighbors, but also drops all other vertices. Can also be executed from the tooltip.
  - **Undo** undoes the last action.
  - **Redo** redoes the last action.
  - **Reset** resets the visualization to the original state after the query.
- **Zoom/Move** mode lets you zoom in and out, as well as to move to another part of the visualization. The **Pan to Center** button resets the zoom and returns the view to the original one.

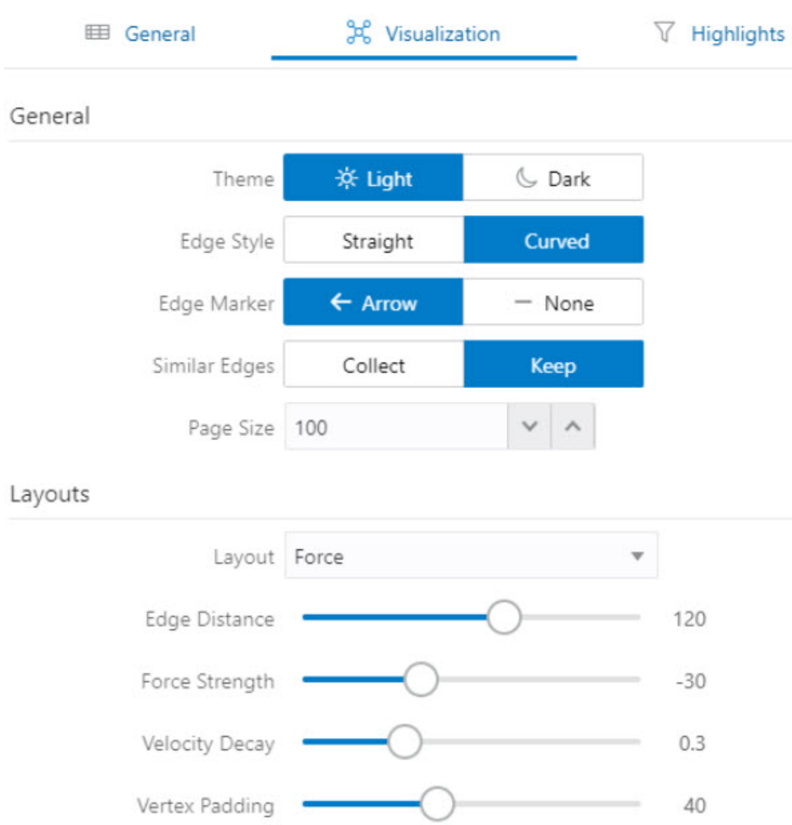
An additional mode, called **Sticky** mode, lets you cancel the action of dragging the nodes around.

19.4 Graph Visualization Settings

You can click the **Settings** gear icon to display the Graph Visualization settings window.

The settings window lets you modify some parameters for the visualization, and it has tabs for General, Visualization, and Highlights. The following figure shows this window, with the Visualization tab selected.

Figure 19-8 Graph Visualization Settings Window



The **General tab** includes the following:

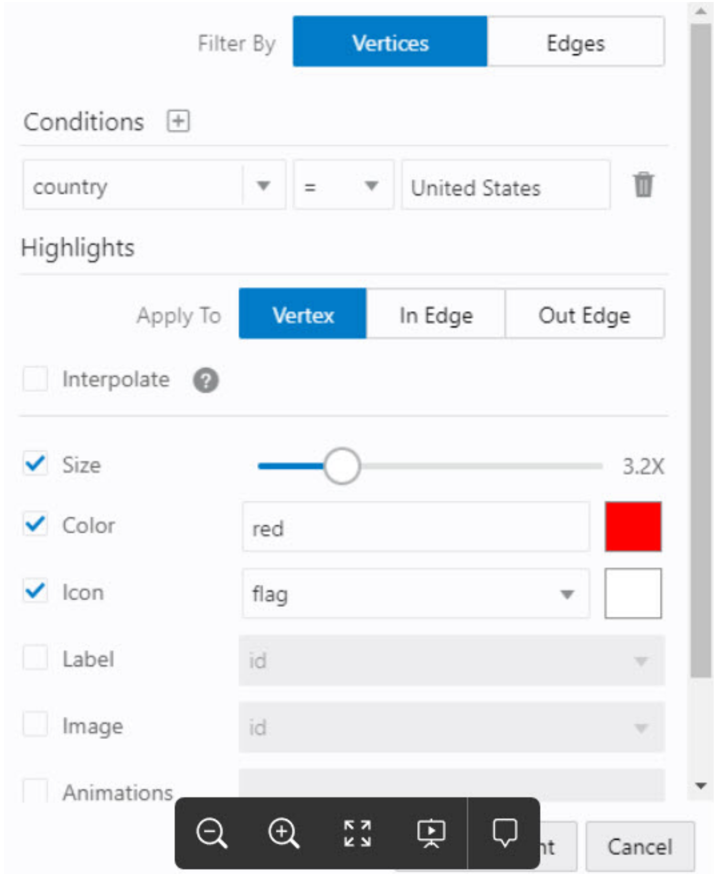
- **Number of hops**: The configurable number of hops for the expand and focus actions.
- **Truncate label**: Truncates the label if it exceeds the maximum length.
- **Max. visible label length**: Maximum length before truncating.
- **Show Label On Hover**: Controls whether the label is shown on hover.
- **Display the graph legend**: Controls whether the legend is displayed.

The **Visualization tab** includes the following:

- **Theme**: Select a light or dark mode.
- **Edge Style**: Select straight or curved edges.
- **Edge Marker**: Select arrows or no edge marker. This only applies to directed edges.
- **Similar Edges**: Select keep or collect.
- **Page Size**: Specify how many vertices and edges are displayed per page.
- **Layouts**: Select between different layouts (random, grid, circle, concentric, ...).
- **Vertex Label**: Select which property to use as the vertex label.
- **Vertex Label Orientation**: Select the relative position of the vertex label.
- **Edge Label**: Select which property to use as the edge label.

The **Highlights tab** includes customization options that let you modify the appearance of edges and vertices. Highlighting can be applied based on conditions (filters) on single or multiple elements. The following figure shows a condition (`country = United States`) and visual highlight options for vertices.

Figure 19-9   Highlights Options for Vertices



A filter for highlights can contain multiple conditions on any property of the element. The following conditions are supported.

- = (equal to)
- < (less than)
- <= (less than or equal to)
- > (greater than)
- >= (greater than or equal to)
- != (not equal to)
- ~ (filter is a regular expression)
- * (any: like a wildcard, can match to anything)

The visual highlight customization options include:

- Edges:
  - Width
  - Color
  - Label

  - Style
  - Animations
- Vertices:
  - Size
  - Color
  - Icon
  - Label
  - Image
  - Animations

You can export and import highlight options by clicking the Save and Import buttons in the main window. **Save** lets you persist the highlight options, and **Load** lets you apply previously saved highlight options.

When you click **Save**, a file is saved containing a JSON object with the highlights configuration. Later, you can load that file to restore the highlights of the saved session.

19.5 Using the Geographical Layout

The Graph Visualization application offers a choice of layouts for rendering graphs. One of them is the Geographical layout that will show the graph (vertices and edges) on a global map.

The following figure shows a graph rendered on a geographical layout in the Graph Visualization application:

Figure 19-10 Geographical Layout

In order to view your vertices on a map, they must include a geographical location, in the form of a pair of properties that contain the longitude and latitude coordinates for that vertex. For example:

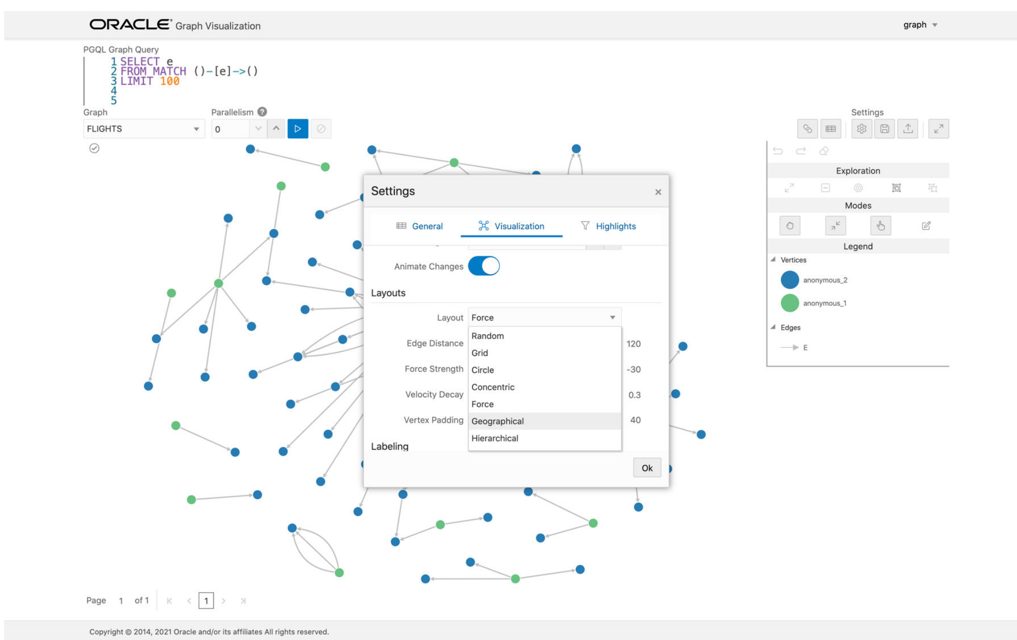
```
+-----------------------------------------------+
| iata | city        | longitude    | latitude    |
+-----------------------------------------------+
| SIN  | Singapore   | 103.994003   | 1.35019     |
| LAX  | Los Angeles | -118.4079971 | 33.94250107 |
| MUC  | Munich      | 11.7861      | 48.353802   |
| CDG  | Paris       | 2.55         | 49.012798   |
| LHR  | London      | -0.461941    | 51.4706     |
+-----------------------------------------------+
```

Note:

You can use any name for the longitude and latitude properties (such as X and Y, or long and lat). But, you must ensure that the longitude/latitude pair are in the WGS84 system (GPS coordinates), and the coordinates are expressed in decimal degrees.

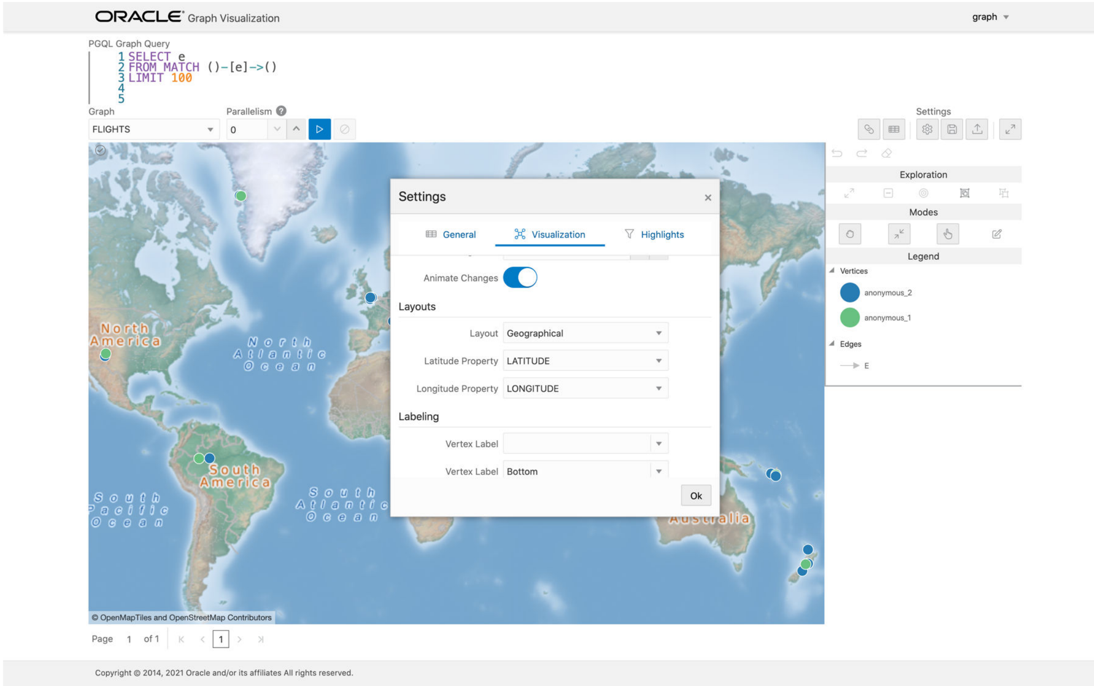
You can select the geographical layout in the Graph Visualization settings window as shown:

Figure 19-11 Setting Geographical Layout



Then, select the properties in your vertices that contain the geographical coordinates as shown:

Figure 19-12 Selecting the Coordinates for the Geographical layout



You can now move around the map and zoom in/out using your mouse or trackpad. From now on, whenever you enter a new PGQL query, the map will automatically center and zoom the vertices returned by the query.

19.6 Using Live Search

Live Search lets you to search the displayed graph and add live fuzzy search score to each item, so you can create a Highlight which visually shows the results of the search in the graph immediately.

If you run a query, and a graph is displayed, you can add the live search, which is on the settings dialog. On the bottom of the General tab, you will see these options.

- **Enable Live Search:** Enables the Live Search feature, adds the search input to the visualization, and lets you further customize the search.
- **Enable Search In:** You can select whether you want to search the properties of Vertices, Edges, or both.
- **Properties To Search:** Based on what you selected for Enable Search In, you can set one or more properties to search in. For example, if you disable the search for edges but you had a property from edges selected, it will be stored and added back when you enable search for the edges again. (This also works for vertices.)
- **Advanced Settings:** You can fine-tune the search even more. Each of the advanced options is documented with context help, visible upon enabling.
  - **Location:** Determines approximately where in the text the pattern is expected to be found.

- **Distance:** Determines how close the match must be to the fuzzy location (specified by location). An exact letter match which is distance characters away from the fuzzy location would score as a complete mismatch. A distance of 0 requires the match be at the exact location specified, a distance of 1000 would require a perfect match to be within 800 characters of the location to be found using a threshold of 0.8.
- **Maximum Pattern Length:** The maximum length of the pattern. The longer the pattern (that is, the search query), the more intensive the search operation will be. Whenever the pattern exceeds this value, an error will be thrown.
- **Min Char Match:** The minimum length of the pattern. Whenever the pattern length is below this value, an error will be thrown.

When the search is enabled, the input will be displayed in the top left part of the Graph Visualization component. If you start typing, the search will add a score to every vertex or edge, based on the settings and the search match.

To be able to see the results visually, you have to add a **Highlight** with interpolation set to a **Live Search** score and other settings based on the desired visual change.

19.7 Using URL Parameters to Control the Graph Visualization Application

You can provide the Graph Visualization application input data through URL parameters instead of using the form fields of the user interface.

If you supply the parameters in the URL, the Graph Visualization application automatically executes the specified query and hides the input form fields from the screen, so only the resulting visualization output is visible. This feature is useful if you want to embed the resulting graph visualization into an existing application, such as through an iframe. However, it is important to note that the application must run on the same domain as the graph visualization application.

The following table specifies the available URL parameters:

Table 19-1 Available URL Parameters

Parameter Name	Value (must be URL encoded)	Type	Optional?
graph	Graph name	string	No
parallelism	Degree of parallelism desired	number	Yes (defaults to server-side default parallelism)
query	PQL query	string	No

The following URL shows an example of visualizing the PGQL query `SELECT v, e MATCH (v) -[e]-> () LIMIT 10` on graph `myGraph` with parallelism 4:

```
https://myhost:7007/ui/?query=SELECT%20v%2C%20e%20MATCH%20%28v%29%20-
%5Be%5D-%3E%20%28%29%20LIMIT%2010&graph=myGraph&parallelism=4
```

Part VII

Graph Server (PGX) Advanced User Guide

Part II provides in-depth information on using the graph server (PGX) for advanced users.

Part II contains the following chapters:

- Configuring the Graph Server (PGX) and the Graph Client
  This chapter explains the configuration options for the graph server (PGX) and the graph client.
- Deploying Oracle Graph Server Behind a Load Balancer
  You can deploy multiple graph servers (PGX) behind a load balancer and connect clients to the servers through the load balancer.
- Namespaces and Sharing
  The graph server (PGX) supports separate namespaces that help you to organize your entities.
- PGX Programming Guides
  You can avail all the PGX functionalities through asynchronous Java APIs. Each asynchronous method has a synchronous equivalent, which blocks the caller thread until the server produces a response.
- Working with Files Using the Graph Server (PGX)
  This chapter describes in detail about working with different file formats to perform various actions like loading, storing, or exporting a graph using the Graph Server (PGX).
- Log Management in the Graph Server (PGX)
  The graph server (PGX) internally uses the SLF4J interface with Logback as the default logger implementation.

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Configuring the Graph Server (PGX) and the Graph Client

This chapter explains the configuration options for the graph server (PGX) and the graph client.

- Configuration Parameters for the Graph Server (PGX) Engine
  You can configure the graph server (PGX) engine and the PGX run-time library by assigning a single JSON file to the graph server (PGX) at start up.
- Configuration Parameters for Connecting to the Graph Server (PGX)
  You can configure the graph server (PGX) to use the required options at startup.
- Configuration Parameters for the Graph Client
  You can configure the PGX graph client. All the parameters are available as command-line options also.

20.1 Configuration Parameters for the Graph Server (PGX) Engine

You can configure the graph server (PGX) engine and the PGX run-time library by assigning a single JSON file to the graph server (PGX) at start up.

To pass the PGX engine configuration file to the graph server (PGX), see Passing the Configuration File to the Graph Server (PGX).

The PGX engine parameters are shown in the following table:

Table 20-1 Configuration Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
`admin_request_cache_timeout`	`integer`	After how many seconds admin request results get removed from the cache. Requests which are not done or not yet consumed are excluded from this timeout. Note: This is only relevant if PGX is deployed as a webapp.	`60`
`allow_idle_timeout_overwrite`	`boolean`	If true, sessions can overwrite the default idle timeout.	`true`
`allow_override_scheduling_information`	`boolean`	If true, allow all users to override scheduling information like task weight, task priority, and number of threads	`true`
`allow_task_timeout_overwrite`	`boolean`	If true, sessions can overwrite the default task timeout.	`true`

Table 20-1 (Cont.) Configuration Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
allow_user_auto_refresh	boolean	If true, users may enable auto refresh for graphs they load. If false, only graphs mentioned in preload_graphs can have auto refresh enabled.	false
allowed_remote_loading_locations	array of string	Allow loading graphs into the PGX engine from remote locations (http, https, ftp, ftps, s3, hdfs). If empty, as by default, no remote location is allowed. If "*" is specified in the array, all remote locations are allowed. Only the value "*" is currently supported. Note that pre-loaded graphs are loaded from any location, regardless of the value of this setting. Note that this parameter reduces security and therefore use it only when needed.	[]
basic_scheduler_config	object	Configuration parameters for the fork join pool backend.	null
bfs_iterate_que_task_size	integer	Task size for BFS iterate QUE phase.	128
bfs_threshold_parent_read_based	number	Threshold of BFS traversal level items to switch to parent-read-based visiting strategy.	0.05
bfs_threshold_read_based	integer	Threshold of BFS traversal level items to switch to read-based visiting strategy.	1024
bfs_threshold_single_threaded	integer	Until what number of BFS traversal level items vertices are visited single-threaded.	128
character_set	string	Standard character set to use throughout PGX. UTF-8 is the default. Note: Some formats may not be compatible.	utf-8
cni_diff_factor_default	integer	Default diff factor value used in the common neighbor iterator implementations.	8
cni_small_default	integer	Default value used in the common neighbor iterator implementations, to indicate below which threshold a subarray is considered small.	128
cni_stop_recursion_default	integer	Default value used in the common neighbor iterator implementations, to indicate the minimum size where the binary search approach is applied.	96

Table 20-1 (Cont.) Configuration Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
`dfs_threshold_large`	`integer`	Value that determines at which number of visited vertices the DFS implementation will switch to data structures that are optimized for larger numbers of vertices.	`4096`
`enable_csrf_token_checks`	`boolean`	If true, the PGX webapp will verify the Cross-Site Request Forgery (CSRF) token cookie and request parameters sent by the client exist and match. This is to prevent CSRF attacks.	`true`
`enable_gm_compiler`	`boolean`	If `true`, enable dynamic compilation of PGX Algorithm API (or Green-Marl code) during runtime.	`true`
`enable_shutdown_cleanup_hook`	`boolean`	If true, PGX will add a JVM shutdown hook that will automatically shutdown PGX at JVM shutdown. Notice: Having the shutdown hook deactivated and not explicitly shutting down PGX may result in pollution of your temp directory.	`true`
`enterprise_scheduler_config`	`object`	Configuration parameters for the enterprise scheduler.	`null`
`enterprise_scheduler_flags`	`object`	*[relevant for enterprise_scheduler]* Enterprise scheduler-specific settings.	`null`
`explicit_spin_locks`	`boolean`	`true` means spin explicitly in a loop until lock becomes available. `false` means using JDK locks which rely on the JVM to decide whether to context switch or spin. Setting this value to `true` usually results in better performance.	`true`
`file_locations`	`array of object`	The file locations that can be used in the authorization-config.	`[]`
`graph_algorithm_language`	`enum[GM_LEGACY, GM, JAVA]`	Front-end compiler to use.	`JAVA`
`graph_validation_level`	`enum[low, high]`	Level of validation performed on newly loaded or created graphs.	`low`
`ignore_incompatible_backend_operations`	`boolean`	If `true`, only log when encountering incompatible operations and configuration values in RTS or FJ pool. If `false`, throw exceptions.	`false`

Table 20-1 (Cont.) Configuration Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
in_place_update_consistency_model	enum[ALLLOW_INCONSISTENCIES, CANCEL_TASKS]	Consistency model used when in-place updates occur. Only relevant if in-place updates are enabled. Currently updates are only applied in place if the updates are not structural (Only modifies properties). Two models are currently implemented, one only delays new tasks when an update occurs, the other also delays running tasks.	ALLOW_INCONSISTENCIES
init_pgql_on_startup	boolean	If true PGQL is directly initialized on start-up of PGX. Otherwise, it is initialized during the first use of PGQL.	true
interval_to_poll_max	integer	Exponential backoff upper bound (in ms) to which -once reached, the job status polling interval is fixed	1000
java_home_dir	string	The path to Java's home directory. If set to <system-java-home-dir>, use the java.home system property.	<system-java-home-dir>
large_array_threshold	integer	Threshold when the size of an array is too big to use a normal Java array. This depends on the used JVM. (Defaults to Integer.MAX_VALUE - 3)	2147483644
max_active_sessions	integer	Maximum number of sessions allowed to be active at a time.	1024
max_distinct_strings_per_pool	integer	*[only relevant if string_pooling_strategy is indexed]* Number of distinct strings per property after which to stop pooling. If the limit is reached, an exception is thrown.	65536
max_http_client_request_size	long	Maximum size in bytes of any http request sent to the PGX server over the REST API. Setting it to -1 allows requests of any size.	10485760

Table 20-1 (Cont.) Configuration Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
`max_off_heap_size`	`integer`	Maximum amount of off-heap memory (in megabytes) that PGX is allowed to allocate before an OutOfMemoryError will be thrown. Note that this limit is not guaranteed to never be exceeded, because of rounding and synchronization trade-offs. It only serves as threshold when PGX starts to reject new memory allocation requests.	`<available-physical-memory>`
`max_queue_size_per_session`	`integer`	The maximum number of pending tasks allowed to be in the queue, per session. If a session reaches the maximum, new incoming requests of that sesssion get rejected. A negative value means infinity or unlimited..	`-1`
`max_snapshot_count`	`integer`	Number of snapshots that may be loaded in the engine at the same time. New snapshots can be created via auto or forced update. If the number of snapshots of a graph reaches this threshold, no more auto-updates will be performed, and a forced update will result in an exception until one or more snapshots are removed from memory. A value of zero indicates to support an unlimited amount of snapshots.	`0`
`memory_allocator`	`enum[basic_allocator, enterprise_allocator]`	The memory allocator to use.	`basic_allocator`
`memory_cleanup_interval`	`integer`	Memory cleanup interval in seconds.	`5`
`min_array_compaction_threshold`	`number`	Minimum value (*only relevant for graphs optimized for updates*) that can be used for the `array_compaction_threshold` value in graph configuration. If a graph configuration attemps to use a value lower than the one specified by `min_array_compaction_threshold`, it will use `min_array_compaction_threshold` instead.	`0.2`

Table 20-1 (Cont.) Configuration Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
min_fetch_interval_sec	integer	For delta-refresh (*only relevant if the graph format supports delta updates*), the lowest interval at which a graph source is queried for changes. You can tune this value to prevent PGX from hanging due to too frequent graph delta-refreshing.	2
min_update_interval_sec	integer	For auto-refresh, the lowest interval after which a new snapshot is created, either by reloading the entire graph or if the format supports delta-updates, out of the cached changes *(only relevant if the format supports delta updates)*. You can tune this value to prevent PGX from hanging due to too frequent graph auto-refreshing.	2
ms_bfs_frontier_type_strategy	enum[auto_grow, short, int]	The type strategy to use for MS-BFS frontiers.	auto_grow
num_spin_locks	integer	Number of spin locks each generated app will create at instantiation. Trade-off: a small number implies less memory consumption; a large number implies faster execution (if algorithm uses spin locks).	1024
parallelism	integer	Number of worker threads to be used in thread pool. Note: If the caller thread is part of another thread-pool, this value is ignored and the parallelism of the parent pool is used.	<number-of-cpus>
pattern_matching_supernode_cache_threshold	integer	Minimum number of a node's neighbor to be a supernode. This is for the pattern matching engine.	1000
pgx_realm	object	Configuration parameters for the realm.	null
pgx_server_base_url	string	This is used when deploying the graph server behind a load balancer to make clients before 21.3 backward compatible. The value should be set to the load balancer address.	null

Table 20-1 (Cont.) Configuration Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
pooling_factor	number	*[only relevant if string_pooling_strategy is on_heap]* This value prevents the string pool to grow as big as the property size, which could render the pooling ineffective.	0.25
preload_graphs	array of object	List of graph configs to be registered at start-up. Each item includes path to a graph config, the name of the graph and whether it should be published.	[]
random_generator_strategy	enum[non_deterministic, deterministic]	Method of generating random numbers in PGX.	non_deterministic
random_seed	long	*[relevant for deterministic random number generator only]* Seed for the deterministic random number generator used in pgx. The default is -24466691093057031.	-24466691093057031
readiness_memory_usage_ratio	number	Memory limit ratio that should be considered to detect if PGX server is ready. This is used by `isReady` API and the default value is 1.0	1.0
release_memory_threshold	number	Threshold percentage (decimal fraction) of used memory after which the engine starts freeing unused graphs. Examples: A value of 0.0 means graphs get freed as soon as their reference count becomes zero. That is, all sessions which loaded that graph were destroyed/timed out. A value of 1.0 means graphs never get freed, and the engine will throw OutOfMemoryErrors as soon as a graph is needed which does not fit in memory anymore. A value of 0.7 means the engine keeps all graphs in memory as long as total memory consumption is below 70% of total available memory, even if there is currently no session using them. When consumption exceeds 70% and another graph needs to get loaded, unused graphs get freed until memory consumption is below 70% again.	0.0
revisit_threshold	integer	Maximum number of matched results from a node to be cached.	4096

Table 20-1 (Cont.) Configuration Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
running_memory_usage_ratio	number	Memory limit ratio that should be considered to detect if PGX server is running. This is used by isRunning API and the default value is 1.0	1.0
scheduler	enum[basic_scheduler, enterprise_scheduler, low_latency_scheduler]	The scheduler to use. • basic_scheduler: uses a scheduler with basic features • enterprise_scheduler: uses a scheduler with advanced enterprise features for running multiple tasks concurrently and providing better performance • low_latency_scheduler: uses a scheduler that privileges latency of tasks over throughput or fairness across multiple sessions. The low_latency_scheduler is only available in embedded mode.	enterprise_scheduler
session_idle_timeout_secs	integer	Timeout of idling sessions in seconds. Zero (0) means infinity or no timeout.	14400
session_task_timeout_secs	integer	Timeout in seconds to interrupt long-running tasks submitted by sessions (algorithms, I/O tasks). Zero (0) means infinity or no timeout.	0
small_task_length	integer	Task length if the total amount of work is smaller than default task length (only relevant for task-stealing strategies).	128
strict_mode	boolean	If true, exceptions are thrown and logged with ERROR level whenever the engine encounters configuration problems, such as invalid keys, mismatches, and other potential errors. If false, the engine logs problems with ERROR/WARN level (depending on severity) and makes best guesses and uses sensible defaults instead of throwing exceptions.	true
string_pooling_strategy	enum[indexed, on_heap, none]	The string pooling strategy to use.	on_heap

Table 20-1 (Cont.) Configuration Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
task_length	integer	Default task length (only relevant for task-stealing strategies). Should be between 100 and 10000. Trade-off: a small number implies more fine-grained tasks are generated, higher stealing throughput; a large number implies less memory consumption and GC activity.	4096
tmp_dir	string	Temporary directory to store compilation artifacts and other temporary data. If set to <system-tmp-dir>, uses the standard tmp directory of the underlying system (/tmp on Linux).	"/tmp"
udf_config_directory	string	Directory path containing UDF config files.	null
use_index_for_reachability_queries	enum[auto, off]	Create index for reachability queries.	auto
use_memory_mapper_for_reading_pgb	boolean	If true, use memory mapped files for reading graphs in PGB format if possible; if false, always use a stream-based implementation.	true
use_memory_mapper_for_storing_pgb	boolean	If true, use memory mapped files for storing graphs in PGB format if possible; if false, always use a stream-based implementation.	true

The default values of the runtime configuration fields are optimized to deliver the best performance across a wide set of algorithms. Depending on your workload you may be able to improve performance further by experimenting with different strategies, sizes, and thresholds.

Enterprise Scheduler Parameters

The following parameters are relevant only if the advanced scheduler is used. (They are ignored if the basic scheduler is used.)

Parameter	Type	Description	Default
`analysis_task_config`	`object`	Configuration for analysis tasks	**weight** `<no-of-CPUs>` **priority** `MEDIUM` **max_threads** `<no-of-CPUs>`
`fast_analysis_task_config`	`object`	Configuration for fast analysis tasks	**weight** `1` **priority** `HIGH` **max_threads** `<no-of-CPUs>`
`max_num_concurrent_io_tasks`	`integer`	Maximum number of concurrent I/O tasks at a time	`3`
`num_io_threads_per_task`	`integer`	Number of I/O threads to use per task	`<no-of-cpus>`

Basic Scheduler Parameters

The following parameters are relevant only if the basic scheduler is used. (They are ignored if the advanced scheduler is used.)

Field	Type	Description	Default
`num_workers_analysis`	`integer`	This specifies how many worker threads to use for analysis tasks.	`<no-of-cpus>`
`num_workers_fast_track_analysis`	`integer`	This specifies how many worker threads to use for fast-track analysis tasks.	`1`

Field	Type	Description	Default
`num_workers_io`	`integer`	This specifies how many worker threads to use for I/O tasks (load/refresh/write from/to disk). This value does not impact file-based loaders, as they are always single-threaded. Database loaders will open a new connection for each I/O worker.	`<no-of-cpus>`

Example 20-1 Minimal Graph Server (PGX) Configuration

The following example causes the graph server (PGX) to initialize its analysis thread pool with 32 workers. (Default values are used for all other parameters.)

```
{
  "enterprise_scheduler_config": {
    "analysis_task_config": {
      "max_threads": 32
    }
  }
}
```

Example 20-2 Two Pre-loaded Graphs

This example sets more fields and specifies two fixed graphs for loading into memory during the graph server (PGX) startup.

```
{
  "enterprise_scheduler_config": {
    "analysis_task_config": {
      "max_threads": 32
    },
    "fast_analysis_task_config": {
      "max_threads": 32
    }
  },
  "memory_cleanup_interval": 600,
  "max_active_sessions": 1,
  "release_memory_threshold": 0.2,
  "preload_graphs": [
    {
      "path": "graph-configs/my-graph.bin.json",
      "name": "my-graph"
    },
    {
      "path": "graph-configs/my-other-graph.adj.json",
      "name": "my-other-graph",
      "publish": false
    }
```

```
    ],
    "authorization": [{
      "pgx_role": "GRAPH_DEVELOPER",
      "pgx_permissions": [{
        "preloaded_graph": "my-graph",
        "grant": "read"
      },
      {
        "preloaded_graph": "my-other-graph",
        "grant": "read"
      }]
    },
      ....
    ]
  }
```

Relative paths in parameter values are always resolved relative to the parent directory of the configuration file in which they are specified. For example, if the preceding JSON is in `/pgx/conf/pgx.conf`, then the file path `graph-configs/my-graph.bin.json` inside that file would be resolved to `/pgx/conf/graph-configs/my-graph.bin.json`.

- Configuration of the Graph Server (PGX) Run-Time Parameters
- Passing the Configuration File to the Graph Server (PGX)
- Memory Consumption by the Graph Server (PGX)
  The graph server (PGX) loads the graph into main memory in order to carry out analysis on the graph and its properties.

20.1.1 Configuration of the Graph Server (PGX) Run-Time Parameters

You can configure the following graph server (PGX) run-time fields.

Table 20-2 Graph Server (PGX) Run-Time Parameters

Parameter	Type	Description	Default
bfs_iterate_que_task_size	integer	Task size for BFS iterate QUE phase.	128
bfs_threshold_parent_read_based	number	Threshold of BFS traversal level items above which to switch to parent-read-based visiting strategy.	0.05
bfs_threshold_read_based	integer	Threshold of BFS traversal level items above which to switch to read-based visiting strategy.	1024
bfs_threshold_single_threaded	integer	Number until which BFS traversal level items vertices are visited single-threaded.	128
character_set	string	Standard charset to use throughout PGX, UTF-8 will be used as default. Note: Some formats may not be compatible.	utf-8
cni_diff_factor_default	integer	Default diff factor value used in the common neighbor iterator implementations.	8
cni_small_default	integer	Default value used in the common neighbor iterator implementations, to indicate below which threshold a subarray is considered small.	128

Table 20-2 (Cont.) Graph Server (PGX) Run-Time Parameters

Parameter	Type	Description	Default
`cni_stop_recursion_default`	`integer`	Default value used in the common neighbor iterator implementations, to indicate the minimum size where the binary search approach is applied.	`96`
`dfs_threshold_large`	`integer`	Value that determines at which number of visited vertices, the DFS implementation will switch to data-structures that are more optimized for larger numbers of vertices.	`4096`
`enterprise_scheduler_flags`	`object`	*[relevant for `enterprise_scheduler`]* Enterprise scheduler specific settings.	`null`
`explicit_spin_locks`	`boolean`	`true` means spin explicitly in a loop until lock becomes available. `false` means using JDK locks which rely on the JVM to decide whether to context switch or spin. Our experiments showed that setting this value to `true` results in better performance.	`true`
`graph_validation_level`	`enum[low, high]`	Level of validation performed on newly loaded or created graphs.	`low`
`max_distinct_strings_per_pool`	`integer`	*[only relevant if `string_pooling_strategy` is `indexed`]* Amount of distinct strings per property after which to stop pooling. If the limit is reached an exception is thrown.	`65536`
`max_off_heap_size`	`integer`	Maximum amount of off-heap memory PGX is allowed to allocate in megabytes, before an OutOfMemoryError will be thrown. **Note:** This limit is not guaranteed to never be exceeded because of rounding and synchronization trade-offs. It only serves as threshold when PGX starts to reject new memory allocation requests.	`<available-physical-memory>`
`memory_allocator`	`enum[basic_allocator, enterprise_allocator]`	Denotes which memory allocator to use.	`basic_allocator`

Table 20-2 (Cont.) Graph Server (PGX) Run-Time Parameters

Parameter	Type	Description	Default
ms_bfs_frontier_type_strategy	enum[auto_grow, short, int]	The type strategy to use for MS-BFS frontiers.	auto_grow
num_spin_locks	integer	Number of spin locks each generated app will create at instantiation. Trade-off: small number implies less memory consumption. Big number implies faster execution (if algorithm uses spin locks).	1024
pattern_matching_supernode_cache_threshold	integer	Minimum number of a node's neighbor to be a supernode. This is for pattern matching engine.	1000
pooling_factor	number	*[only relevant if string_pooling_strategy is on_heap]* This value prevents the string pool to grow as big as the property size which could render the pooling ineffective.	0.25
random_generator_strategy	enum[non_deterministic, deterministic]	Method of generating random numbers in PGX.	non_deterministic
random_seed	long	*[relevant for deterministic random number generator only]* Seed for the deterministic random number generator used in PGX. The default is -24466691093057031.	-24466691093057031
revisit_threshold	integer	Maximum number of matched results from a node to be cached.	4096
scheduler	enum[basic_scheduler, enterprise_scheduler, low_latency_scheduler]	Denotes which scheduler to use. • basic_scheduler: use scheduler with basic features. • enterprise_scheduler: use scheduler with advanced, enterprise features for running multiple tasks concurrently and increased performance. • low_latency_scheduler: use scheduler that privileges latency of tasks over throughput or fairness across multiple sessions. The low_latency_scheduler is only available in embedded mode	enterprise_scheduler
small_task_length	integer	Task length, if total amount of work is small than default task length (only relevant for task-stealing strategies).	128
string_pooling_strategy	enum[indexed, on_heap, none]	Denotes which string pooling strategy to use.	on_heap

Table 20-2 (Cont.) Graph Server (PGX) Run-Time Parameters

Parameter	Type	Description	Default
task_length	integer	Default task length (only relevant for task-stealing strategies). F/J pool documentation says this value should be between 100 and 10000. Trade-off: small number implies more fine-grained tasks are generated, higher stealing throughput. High number implies less memory consumption and GC activity.	4096
use_index_for_reachability_queries	enum[auto, off]	Create index for reachability queries.	auto
use_memory_mapper_for_reading_pgb	boolean	If true, use memory mapped files for reading graphs in PGB format if possible; false always use s stream based implementation.	true
use_memory_mapper_for_storing_pgb	boolean	If true, use memory mapped files for storing in PGB format if possible; if false always use a stream based implementation.	true

20.1.2 Passing the Configuration File to the Graph Server (PGX)

The PGX engine configuration file is parsed by the graph server at startup-time whenever `ServerInstance#startEngine` (or any of its variants) is called. You can pass the path to your configuration file to the graph server (PGX) or perform it programmatically. This topic explains the different ways to pass the configuration file to the graph server (PGX):

Programmatically

All configuration fields exist as Java enums. Example:

```
Map<PgxConfig.Field, Object> pgxCfg = new HashMap<>();
pgxCfg.put(PgxConfig.Field.MEMORY_CLEANUP_INTERVAL, 600);

ServerInstance instance = ...
instance.startEngine(pgxCfg);
```

All parameters not explicitly set will get default values.

Explicitly Using a File

Instead of a map, you can pass the graph server (PGX) configuration JSON file from the local filesystem or from the classpath:

```
instance.startEngine("path/to/pgx.conf"); // file on local filesystem
instance.startEngine("classpath:/path/to/pgx.conf"); // file on current
classpath
```

For all other protocols, you can directly pass the JSON file as an input stream:

```
InputStream is = ...
instance.startEngine(is);
```

Implicitly Using a File

If `startEngine()` is called without an argument, then the graph server (PGX) looks for a configuration file at the following places and stops when it finds the file:

- File path found in the Java system property `pgx_conf`. Example: `java -Dpgx_conf=conf/my.pgx.config.json ...`
- A file named `pgx.conf` in the root directory of the current classpath
- A file named `pgx.conf` in the root directory relative to the current `System.getProperty("user.dir")` directory

Note: Providing a configuration is optional. A default value for each field will be used if the field cannot be found in the given configuration file, or if no configuration file is provided.

Using the Shell in Embedded Mode

To change how the shell configures the embedded (local) graph server (PGX) instance, edit `etc/oracle/graph/conf/pgx.conf`. Changes will be reflected the next time you invoke the OPG4J shell CLI.

You can also change the location of the configuration file as in the following example:

```
./bin/opg4j --pgx_conf path/to/my/other/pgx.conf
```

Setting System Properties

Any graph server (PGX) engine or runtime parameter can be set using Java system properties by writing `-Dpgx.<FIELD>=<VALUE>` arguments to the JVM that the graph server (PGX) is running on. Note that setting system properties will overwrite any other configuration. The following example sets the maximum off-heap size to 256 GB, regardless of what any other configuration says:

```
java -Dpgx.max_off_heap_size=256000 ...
```

You can also set nested configuration fields, as used for the enterprise scheduler configuration using system properties. The `<FIELD>` is formed as `<CONFIG_FIELD1>__<CONFIG_FIELD2>`.

Setting Environment Variables

Also, any graph server (PGX) engine or runtime parameter can be set using environment variables by adding 'PGX_' to the graph server (PGX) JVM environment. Note that setting environment variables will overwrite any other configuration. However, if both system property and an environment variable are set for the same parameter, then the system property value is used. The following example sets the maximum off-heap size to 256 GB using an environment variable:

```
PGX_MAX_OFF_HEAP_SIZE=256000 java ...
```

20.1.3 Memory Consumption by the Graph Server (PGX)

The graph server (PGX) loads the graph into main memory in order to carry out analysis on the graph and its properties.

The memory consumed by the graph server for a graph is split between the memory to store the topology of the graph (the information to indicate what are the vertices and edges in the graph without their attached properties), and the memory for the properties attached to the vertices and edges. Internally, the graph server (PGX) stores the graph topology in compressed sparse row (CSR) format, a data structure which has minimal memory footprint while providing very fast read access.

- Memory Management

20.1.3.1 Memory Management

The graph server (PGX) requires both on-heap and off-heap memory to store graph data.

The allocation of memory for the graph data is as shown:

- Graph indexes and graph topology are stored off-heap.
- All primitive properties (integer, long, double, float, boolean, date, local_date, timestamp, time, point2d) are stored off-heap.
- String properties are stored on-heap.

Default Configuration of Memory Limits

You can configure both on-heap and off-heap memory limits. In case of the on-heap, if you don't explicitly set a maximum then it will default to the maximum on-heap size determined by Java Hotspot, which is based on various factors, including the total amount of physical memory available. In case of the off-heap, if you don't explicitly set a maximum then it will default to the total physical available memory on the machine.

- Configuring On-Heap Limits
- Configuring Off-Heap Limits

20.1.3.1.1 Configuring On-Heap Limits

The on-heap memory limits for the graph server (PGX) can be configured by updating the `systemd` configuration file for the PGX service. However, there is a risk of losing the updates to the configuration file, the next time you upgrade the graph server (PGX). Therefore, it is recommended that you provide the on-heap memory configuration in a drop-in file. All directives in the drop-in file are dynamically merged with the directives in the main configuration file (`/etc/systemd/system/pgx.service`) during the graph server (PGX) startup.
You can perform the following steps to create a drop-in file and configure the on-heap memory size:

1. Navigate to the `/etc/systemd/system/pgx.service.d` directory. If the `pgx.service.d` directory does not exist in the file path, then create one.
2. Create a drop-in file (`.conf` file) with any name in `/etc/systemd/system/pgx.service.d`. Skip this step, if one already exists.

3. Edit the drop-in file as a `root` user or with `sudo` command and add the on-heap memory option in the `[Service]` section as shown:

   ```
   sudo vi /etc/systemd/system/pgx.service.d/setup.conf
   ```

   The following example displays the added on-heap memory setting in the `setup.conf` file:

   ```
   [Service]
   # Java on-heap memory setting
   Environment="JAVA_TOOL_OPTIONS=-Xms1G -Xmx2G"
   ```

   This option sets the initial heap space to 1GB and allows it to grow up to 2GB.

   The supported options for configuring the on-heap memory are:

   - `-Xmx`: to set the maximum on-heap size of the JVM.
   - `-Xms`: to set the initial on-heap size of the JVM.
   - `-XX:NewSize`: to set the initial size of the young generation
   - `-XX:MaxNewSize`: to set the maximum size of the young generation

   See the `java` command documentation for more information on these options.

4. Add the `JAVA_HOME` environment variable to ensure that the graph server (PGX) is using the appropriate JDK.

   ```
   [Service]
   # JAVA_HOME variable
   Environment=JAVA_HOME=/usr/java/jdk-15.0.1/
   # Java on-heap memory setting
   Environment="JAVA_TOOL_OPTIONS=-Xms1G -Xmx2G"
   ```

   Note that the comments begin with `#` and you can optionally comment any specific option in order to test your configuration.

5. Reload the PGX service to use the updated settings by running the following command:

   ```
   sudo systemctl daemon-reload
   ```

6. Restart the graph server (PGX):

   ```
   sudo systemctl restart pgx
   ```

7. Verify that the new memory setting is correctly passed to the graph server (PGX):

   ```
   sudo systemctl show pgx -p Environment
   Environment=PGX_SERVER_KEYSTORE_PASSWORD=changeit JAVA_HOME=/usr/
   java/jdk-15.0.1/ JAVA_TOOL_OPTIONS=-Xms1G\x20-Xmx2G
   ```

8. Verify that the new memory setting is used by the graph server (PGX):

   ```
   $ sudo journalctl -u pgx -n 50 | grep JAVA_TOOL_OPTIONS
   Sep 26 10:52:46 localvm.localdomain bash[25206]: Picked up
   JAVA_TOOL_OPTIONS: -Xms1G -Xmx2G
   ```

9. Finally, use the server-state REST endpoint to confirm the new memory usage. For example:

```
$ BASE_URL=https://localhost:7007
$ USERNAME=graph
$ PASSWORD=graph
$ PGX_RESPONSE=`curl -s -k -X POST -H 'Content-Type: application/json' -d
'{"username": "'"${USERNAME}"'", "password": "'"${PASSWORD}"'"}' $
{BASE_URL}/auth/token`
$ PGX_ACCESS_TOKEN=`echo $PGX_RESPONSE | jq -r '.access_token'`
$ echo `curl -s -k -H 'Authorization: Bearer '"$
{PGX_ACCESS_TOKEN}" $BASE_URL/control/v1/serverState|jq '.entity.memory'`
|jq
{
  "localvm.localdomain": [
    {
      "free_heap_mb": 830,
      "current_heap_mb": 989,
      "used_heap_mb": 159,
      "maximum_heap_mb": 1979,
      "type": "java_heap"
    },
    {
      "used_off_heap_mb": 0,
      "maximum_off_heap_mb": 1741,
      "current_off_heap_mb": 1741,
      "free_off_heap_mb": 1741,
      "type": "unmanaged"
    }
  ]
}
```

20.1.3.1.2 Configuring Off-Heap Limits

You can specify the off-heap limit by setting the `max_off_heap_size` field in the graph server (PGX) configuration. See Configuration Parameters for the Graph Server (PGX) Engine for more information on the `max_off_heap_size` parameter. Note that the off-heap limit is not guaranteed to never be exceeded because of rounding and synchronization trade-offs.

20.2 Configuration Parameters for Connecting to the Graph Server (PGX)

You can configure the graph server (PGX) to use the required options at startup.

See Configuring the Graph Server (PGX)

20.3 Configuration Parameters for the Graph Client

You can configure the PGX graph client. All the parameters are available as command-line options also.

Table 20-3 Configuration Parameters for the Graph Client

Parameter	Type	Description	Default
access_token	string	The authentication token.	null
base_url	string	The base url in the format host [: port][/path] of the PGX server REST end-point. If the base_url is null, the default will be used which points to embedded PGX instance.	null
cctrace_out	string	*[relevant for enable_cctrace]* When cctrace is enabled, this option specifies a path to a file where cctrace should log to. If null it will use the default PGX logger on level TRACE. If it is the special value :stderr: it will log to stderr.	null
cctrace_print_stacktraces	boolean	*[relevant for enable_cctrace]* When cctrace is enabled, this flag prints the stacktrace for each request and result.	false
client_server_interaction_mode	enum[async_polling, blocking]	If async_polling the PGX client would poll the status of the future until it is completed. If blocking, the PGX client would send a request to directly get the value of the future and the server would block until the future result is ready.	async_polling
enable_cctrace	boolean	If true log every call to a Control or Core interface.	false
keystore	string	The path to the keystore to use for client connections. The keystore is used to authenticate this client at the PGX server if two-way SSL/TLS is enabled.	null
max_client_http_connections	integer	Maximum number of connections to open to the PGX server.	2
password	string	Keystore password only.	null
prefetch_size	integer	Number of items to be prefetched in remote iterators.	2048
realm_client_config	object	Implementation dependent configuration options for the realm client.	null
remote_future_pending_retry_interval	integer	Number of milliseconds to wait before sending another request in case a GET request for a PgxRemoteFuture receives a 202 - Accepted response.	500

Table 20-3 (Cont.) Configuration Parameters for the Graph Client

Parameter	Type	Description	Default
remote_future_timeout	integer	Time that a GET request for a PgxRemoteFuture will be alive, until it times out and tries again. Time in milliseconds, set it to zero for an infinite timeout. See HTTP Client SO_TIMEOUT for more details.	300000
tls_version	string	TLS version to be used by the client. For example, TLSv1.2.	tlsv1.2
truststore	string	Path to the truststore to use for client connections. The truststore is used to validate the server certificate if communicating over SSL/TLS.	null
upload_batch_size	integer	Number of items to be uploaded in a batch. This is used in Core#addAllToCollection() and Core#setProperty().	65536
username	string	Name of the user.	null

Example 20-3 Configure the Graph Client Using the Graph PGX Shell

This following is an example to configure the graph client:

```
cd /opt/oracle/graph
./bin/opg-jshell --base_url https://myhost:8080/pgx --username scott --prefetch_size
1024 --upload_batch_size 5000 --remote_future_timeout 20000 --pending_retry_interval
800
```

Example 20-4 Configure the Graph Client Using the Java API

The following is an example to configure the graph client programatically using the Pgx.getInstance methods:

```
public static ServerInstance getInstance(String baseUrl, String username,
String password, Integer prefetchSize,
  Integer uploadBatchSize, Integer remoteFutureTimeout, Integer
remoteFuturePendingRetryInterval)
```

To specify key store and trust store for SSL connections use the standard JDK system properties:

```
System.setProperty("javax.net.ssl.trustStore","<truststore>");
System.setProperty("javax.net.ssl.keyStore","<keystore>");
System.setProperty("javax.net.ssl.keyStorePassword","<password>");
```

21 Deploying Oracle Graph Server Behind a Load Balancer

You can deploy multiple graph servers (PGX) behind a load balancer and connect clients to the servers through the load balancer.

Using Session Persistence with a Load Balancer

You can use the Load Balancer sticky cookie feature since the graph server (PGX) is not stateless. This implies that when you configure load balancer cookie stickiness, the load balancer inserts a cookie to identify the server and the client requests are always directed to the same backend server.

The graph client supports all sessions that belong to a `serverInstance` to be sent to the same server. You must set the cookie name as `PGX_INSTANCE_STICKY_COOKIE`.

You can use one of the following options to deploy different graph servers behind a load balancer:

- Using HAProxy for PGX Load Balancing and High Availability
  HAProxy is a high-performance TCP/HTTP load balancer and proxy server that allows multiplexing incoming requests across multiple web servers.
- Deploying Graph Server (PGX) Using OCI Load Balancer
  You can deploy multiple graph servers (PGX) behind a load balancer using Oracle Cloud Infrastructure (OCI) Load Balancing Service.
- Health Check in the Load Balancer

21.1 Using HAProxy for PGX Load Balancing and High Availability

HAProxy is a high-performance TCP/HTTP load balancer and proxy server that allows multiplexing incoming requests across multiple web servers.

You can use HAProxy with multiple instances of the graph server (PGX) for high availability. The following example uses the OPG4J shell to connect to PGX.

The following instructions assume you have already installed and configured the graph server (PGX), as explained in Starting the Graph Server (PGX).

1. If HAProxy is not already installed on Big Data Appliance or your Oracle Linux distribution, run this command:

   ```
   yum install haproxy
   ```

2. Start the graph server instances.
   For example, if you want to load balance PGX across 4 nodes (such as bda02, bda03, bda04, and bda05) in the Big Data Appliance, start PGX on each of these nodes. Configure PGX to listen for connections on port 7007.

3. Configure HAProxy:
   a. Locate the `haproxy.cfg` file in `/etc/haproxy` directory on the host where you installed HAProxy.
   b. Add a frontend section with the following parameters:
      - **`bind`:** to set the listening IP address and port
      - **`mode`:** `http` or `https`
      - **`default_backend`:** to set the name of the backend to be used

      For example, the following frontend configuration receives `HTTP` traffic on all IP addresses assigned to the server at port `7008`:

```
frontend graph_server_front
  bind *:7008
  mode http
  default_backend graph_server
```

   c. Add a backend section with the following parameters:
      - **`mode`:** `http` or `https`
      - **`cookie`:** name of the cookie to be used for session persistence
      - **`server`:** list of servers running behind the load balancer

      For example, the following backend configuration uses the `PGX_INSTANCE_STICKY_COOKIE`:

```
backend graph_server
  mode http
  cookie PGX_INSTANCE_STICKY_COOKIE insert indirect nocache
  server graph_server_1 host_name_graph_server_1:port check
cookie graph_server_1 # Notice that the name at the end must be
the same as the server name
  server graph_server_2 host_name_graph_server_2:port check
cookie graph_server_2
  option httpchk GET /isReady
  http-check expect string true
```

      In the preceding configuration file, the `option httpchk` clause instructs the load balancer to check the readiness of the server. The `http-check` clause specifies that the load balancer must expect a `true` response in order to determine that the server is healthy and capable of handling more requests. See Health Check in the Load Balancer for supported health check endpoints.
4. Start the load balancer.
   Start HAProxy using `systemctl`:

```
sudo systemctl start haproxy
```

5. Test the load balancer.

From any host you can test connectivity to the HAProxy server by passing in the host and port of the server running HAProxy as the `base_url` parameter to the graph client shell CLI. For example:

```
cd /opt/oracle/graph
./bin/opg4j --base_url http://localhost:7008 -u <username>
```

> **Note:**
>
> The PGX in-memory state is lost if the server goes down. HAProxy will route commands to another server, but the client must reload all graph data.

It is recommended that you run a series of PGX commands to test routing. Stop the server and restart the graph shell CLI to confirm that HAProxy redirects the request to a new server.

21.2 Deploying Graph Server (PGX) Using OCI Load Balancer

You can deploy multiple graph servers (PGX) behind a load balancer using Oracle Cloud Infrastructure (OCI) Load Balancing Service.

You can enable cookie-based session persistence with a load balancer to direct all requests from a single client to a specific backend server.
You can you perform the following steps to deploy multiple graph servers using the OCI load balancer.

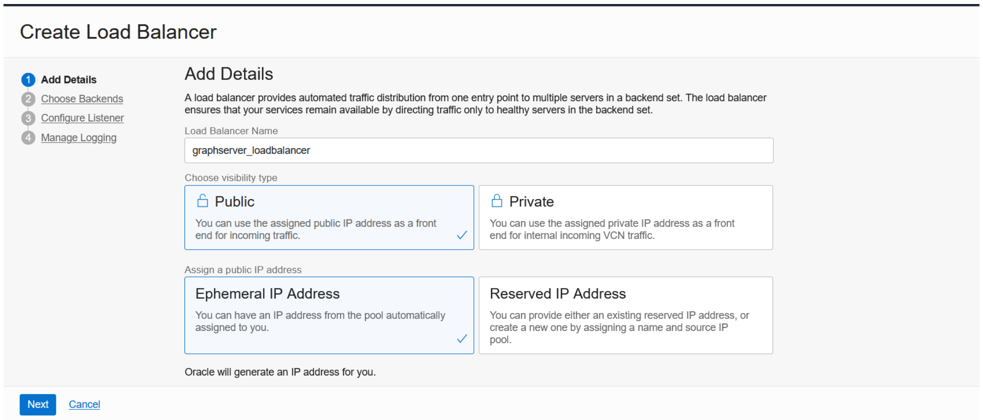
As a prerequisite requirement, you must ensure that two or more graph servers are running on different machines on the same port (7007 by default).

1. Sign in to OCI console using your Oracle Cloud Account.
2. Open the navigation menu, click **Networking** and then **Load Balancers**.
3. Click **Create Load Balancer**.

   The **Select Load Balancer Type** window opens.
4. Select **Load Balancer** and click **Create Load Balancer**.

   The **Add Details** page opens as shown:

Figure 21-1 Configuring Load Balancer Details

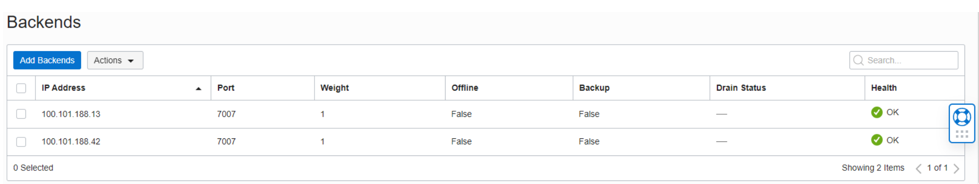


5. Optionally, edit the following details:
   - **Load Balancer Name**
   - **Choose visibility type**
   - **Choose IP address type**
6. Under **Choose Networking** section, select the **Virtual Cloud Network** where the graph server instances are running.
7. Accept the default values for all other fields and click **Next**.

   The **Choose Backends** page opens.
8. Select **Weighted Round Robin** as the Load Balancing Policy.
9. Click **Add Backends** to add the backend servers.

   The **Add Backends** slider opens as shown.

Figure 21-2 Adding Backends to Load Balancer



10. Select as many backend graph server instances as available and click **Add Selected Backends**.

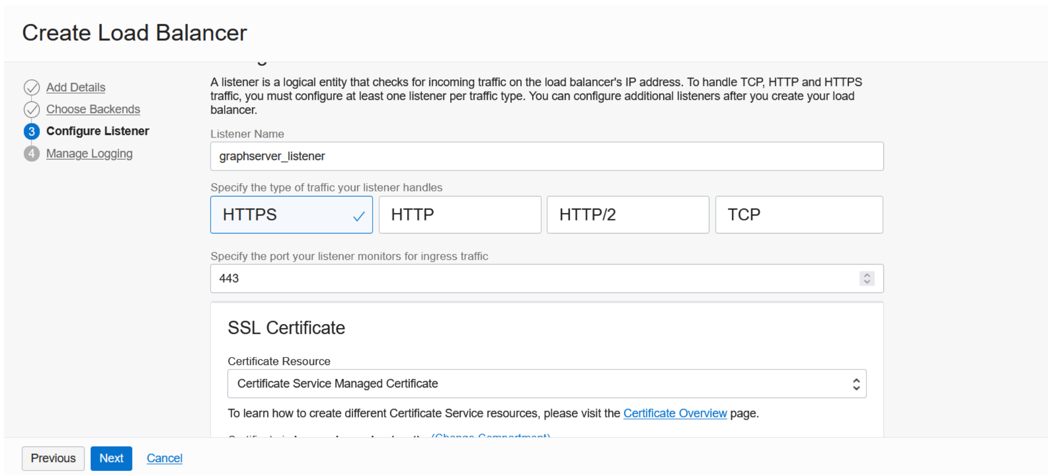
    The selected backend set appear in the **Select Backend Servers** table.
11. Specify the following values for the parameters under **Specify Health Check Policy**:
    - **Protocol:** HTTP
    - **Port:** backend port used by all the graph servers
    - **Interval in milliseconds:** default value
    - **Timeout in milliseconds:** default value
    - **Number of Retries:** default value

- **Status Code:** 200
- **URL Path:** `/isReady`
  See Health Check in the Load Balancer for supported health check endpoints.
- **Response Body RegEx:** `true`

12. Click **Next**.

    The **Configure Listener** page opens as shown:

Figure 21-3 Configuring a Listener for the Load Balancer



13. Optionally, edit the **Listener Name**.
14. Specify **HTTPS** or **HTTP** as the type of traffic handled by the listener.
15. Specify the listener port value to either **443** or **80**.
16. Upload **SSL Certificate** if you specified **HTTPS** communication.
17. Click **Next**.

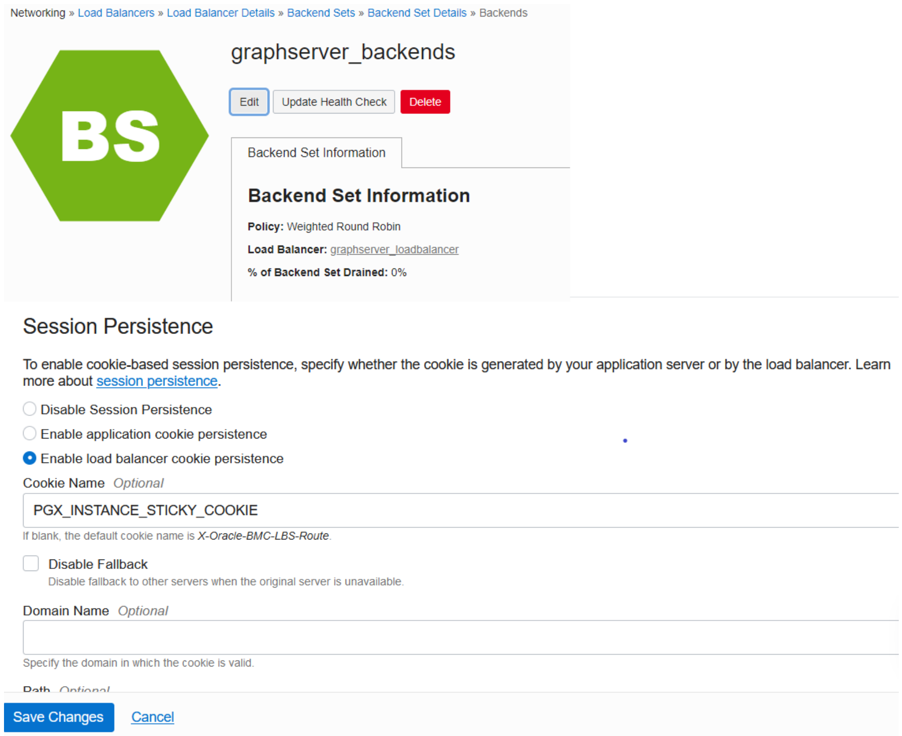
    The **Manage Logging** page opens as shown.
18. Accept all the default values on this page and click **Submit**.

    The load balancer is provisioned and it appears on the table in the **Load Balancers** page.
19. Click on the provisioned load balancer to view the **Load Balancer Details**.
20. Click **Backend Sets** under **Resources**.
21. Click the backend set you want to edit.

    The **Backend Set Details** page opens.
22. Click **Edit**.

    The **Edit Backend Set** dialog opens as shown:

Figure 21-4 Enabling Session Persistence



23. Select **Enable load balancer cookie persistence**.
24. Set the **Cookie Name** to `PGX_INSTANCE_STICKY_COOKIE` and click **Save Changes**.

    Your work request gets submitted.

You can now send requests to the load balancer and your session will be persisted on the respective server to which you are logged in.

21.3 Health Check in the Load Balancer

To configure health check in the load balancer, the graph server(PGX) exposes the `isReady` and `isRunning` endpoints.

> **Note:**
>
> By default, the `isReady` and `isRunning` endpoints are unprotected. See Public Health Endpoint Security to enable protection for the health check API.

The load balancer can check the following health status of the graph servers:

- **Readiness of the graph server:** The `isReady` endpoint detects if the graph server (PGX) is capable of handling more requests. See the `readiness_memory_usage_ratio` system parameter in Configuration Parameters for the Graph Server (PGX) Engine for more details.

- **Liveness of the graph server:** The `isRunning` endpoint detects if the graph server (PGX) is running and alive. See the `running_memory_usage_ratio` system parameter in Configuration Parameters for the Graph Server (PGX) Engine for more details.

By default, both the endpoints do not require authentication. If the server is running or ready, they return `true` in the HTTP body with `HTTP` status code `200`. If the server is **not** running or ready, they return `false` with `HTTP` status code `200`.

22
Namespaces and Sharing

The graph server (PGX) supports separate namespaces that help you to organize your entities.

Each client session has its own session-private namespace and can choose any name without affecting other sessions. There is also a public namespace for published graphs (for example, published via the `publishWithSnapshots()` or the `publish()` methods).

Similarly, each published graph defines a public namespace for published properties as well as a private namespace per session. So different sessions can create properties with the same name on a published graph.

- Defining Graph Names
- Retrieving Graphs by Name
- Checking Used Names
- Property Name Resolution and Graph Mutations

22.1 Defining Graph Names

Graphs that are created in a session either through loading (for example, calling readGraphWithProperties()) or through mutations will take up a name in the session-private namespace. A graph will be placed in the public namespace only through publishing (that is, when calling the `publishWithSnapshots()` or the publish() methods). Publishing a graph will move its name from the session-private namespace to the public namespace.

There can only be one graph with a given name in a given namespace, but a name can be used in different namespaces to refer to different graphs. An operation that creates a new graph (for example, `readGraphWithProperties()`) will fail if the chosen name of the new graph already exists in the session-private namespace. Publishing a graph fails if there is already a graph in the public namespace with the same name.

22.2 Retrieving Graphs by Name

You can retrieve a graph by name by the following two ways:

- getGraph(Namespace, String): with explicitly mentioning the namespace
- getGraph(String): without explicitly mentioning the namespace

With getGraph(Namespace, String), you need to provide the namespace (either session private or public). In this case, the graph will be looked up in the given namespace only.

With getGraph(String), the provided name will be first looked up in the private namespace. If no graph with the given name is found there, then the graph name will be looked up in the public namespace. In other words, if a graph with the same name is defined in both the public and the private namespaces, getGraph(String) will return the private graph and you need to use `getGraph(Namespace, String)` to get hold of the public graph with that name.

22.3 Checking Used Names

To see the currently used names in a namespace you can use the PgxSession.getGraphs(Namespace) method, which will list all the names in the given namespace. The names in the returned collection can be used in a getGraph(Namespace, String) call to retrieve the corresponding `PgxGraph`.

22.4 Property Name Resolution and Graph Mutations

Property names behave in a similar way as graph names. All property names of a non-published graph are in the session-private namespace. Once a graph is published with PgxGraph.publishWithSnapshots() or the PgxGraph.publish() methods, its properties are published as well and their names move into the public namespace.

Once a graph is published, newly created properties will still be private to the session and their names will be in the private namespace. Those properties can be published individually with the Property.publish() method, as long as no other property with the same name is already published for that graph.

Additionally, new private properties can be created with the same name of an already-published properties (since the names are part of separate namespaces). To handle such situations and retrieve the correct property, the PGX API offers the getVertexProperty(Namespace, String) and the getEdgeProperty(Namespace, String) methods, which allow specifying the namespace where the property name should be looked up.

Similar to graphs, if you search a property without specifying the namespace, the private namespace is searched first and if the property is not found, the search proceeds to the public namespace. This case applies for getVertexProperty(String) or the getEdgeProperty(String) methods and for PGQL queries.

Likewise, when a mutation on a graph reads or writes a property referred to by name and two properties exist with the same name, the property in the private namespace is selected. To override the default selection, some mutation mechanisms accept a collection of specific Property objects to be copied into the mutated graph. For example, such mechanism is supported for filter expressions. See Creating Subgraphs for more details.

23

PGX Programming Guides

You can avail all the PGX functionalities through asynchronous Java APIs. Each asynchronous method has a synchronous equivalent, which blocks the caller thread until the server produces a response.

These APIs may perform one or any combination of:

- Complex, non-blocking Java applications on top of PGX
- Simple, sequential Java scripts executed by JShell
- ShellPerforming interactive graph analysis in the JShell

Layers of PGX API

The PGX API is composed of a few different Java interfaces. Each interface provides a distinct layer of abstraction for PGX, as shown in the following table:

Table 23-1 PGX API Interface

Interface	Description
`ServerInstance`	The `ServerInstance` class encapsulates access to a PGX server instance and can be used to create sessions, start and stop the PGX engine, monitor the engine status and perform other administrative tasks. If the instance points to a remote instance, access to the administrative functions requires special authorization on the HTTP level by default.
`PgxSession`	A `PgxSession` represents an active user currently connected to an instance. Each session gets its own workspace on the server side which can be used to read graphs, create in-memory data structures, hold analysis results and custom algorithms. The `PgxSession` class provides various methods to create new transient data (currently collections). If a session is idling for too long, the PGX engine will automatically destroy it to ensure no resources are wasted.
`PgxGraph`	A `PgxGraph` represents a client-side handle to the graph data managed by the PGX server. A graph may contain an arbitrary amount of properties of type `VertexProperty` and/or `EdgeProperty`. **Note:** The PGX currently only supports non-partitioned graphs, meaning every vertex/edge has the same properties with the same names and types as all the other vertices/edges. `PgxGraph` class provides various methods to create new transient data (including maps and collections) as well as graph mutation operations, such as undirecting, sorting and filtering.

Table 23-1 (Cont.) PGX API Interface

Interface	Description
`Analyst`	The `Analyst` API contains all of the built-in algorithms PGX provides. `Analyst` objects keep track of all the transient data they created during algorithm invocations to hold analysis results. Once an `Analyst` gets destroyed, all the results it created get freed on the server-side automatically.
`CompiledProgram`	The `CompiledProgram` class (PGX Algorithm API) encapsulates runtime-compiled custom algorithms and allows invocation of those algorithms using PGX data objects, such as `PgxGraph` or `VertexProperty`, as arguments.

Please see the `oracle.pgx.api` package in the Javadoc for more details.

- Design of the Graph Server (PGX) API
  This guide focuses on the design of the graph server (PGX) API.
- Data Types and Collections in the Graph Server (PGX)
  This guide provides you the list of the supported data types and collections in the graph server (PGX).
- Handling Asynchronous Requests in Graph Server (PGX)
  This guide explains in detail the asynchronous methods supported by the PGX API.
- Graph Client Sessions
  The graph server (PGX) assumes there may be multiple concurrent clients, and each client submits request to the shared PGX server independently.
- Graph Mutation and Subgraphs
  This guide discusses the several methods provided by the graph server (PGX) for mutating graph instances.
- Graph Builder and Graph Change Set
- Managing Transient Data
  This guide discusses how to handle transient properties and collections.
- Graph Versioning
  This guide describes the different ways to work with graph snapshots.
- Labels and Properties
  You can perform various actions on the graph property and label values by executing PGQL queries.
- Filter Expressions
  This guide explains the usage of filter expressions.
- Advanced Task Scheduling Using Execution Environments
  This guide shows how you can use the advanced scheduling features of the enterprise scheduler.
- Admin API
  This guide shows how to use the graph server (PGX) Admin API to inspect the server state including sessions, graphs, tasks, memory and thread pools.
- PgxFrames Tabular Data-Structure

23.1 Design of the Graph Server (PGX) API

This guide focuses on the design of the graph server (PGX) API.

The design of the PGX API reflects consideration of the following situations:

- Multiple clients may concurrently be accessing a single running instance of PGX, sharing its resources. Each client needs to maintain its own isolated workspace (session).
- Graph and property data can be large in size and therefore that data only resides on the server side.
- Some graph analysis may take a significant amount of time.
- Clients may not reside in the same address space (JVM) as PGX. Actually, clients may not even be Java applications.

Client Sessions

In PGX, each client maintains its own session, an isolated, private workspace. Therefore, clients first have to obtain a `PgxSession` object from a PGX `ServerInstance` before they can perform any analysis.

Asynchronous Execution

The PGX API is designed for asynchronous execution. That means that each computationally intensive method in the PGX API *immediately* returns a `PgxFuture` object without waiting for the request to finish. The `PgxFuture` class implements the Future interface, which can be used to retrieve the result of a computation at some point in the future.

> **Note:**
>
> The asynchronous execution aspect of this design facilitates multiple (remote) clients submitting requests to a single server. A request from one client may be queued up to wait until PGX resources become available. The asynchronous API allows the client (or calling thread) to work on other tasks until PGX completes the request.

No Direct References

The PGX API does not return objects with direct reference to PGX internal objects (such as the graph or its properties) to the client. This is because:

- The client might not be in the same JVM as the server
- The graph instance might be shared by multiple clients

Instead, the PGX API only returns lightweight, stateless pointer objects to those objects. These pointer objects only holds the `ID(name)` of the server-side object to which they are pointing.

Resource Management Considerations

The graph server (PGX), being an *in-memory* analytic engine, might allocate large amounts of memory to hold the graph data of clients. Therefore, it is important that client sessions clean up their resources once they have ended. The PGX API supports several features to make this easier:

- Every object returned by the PGX API pointing to a server-side resource implements the `Destroyable` interface, which means all memory-consuming client-side objects can be destroyed the same way. For example:

```
PgxGraph myGraph = ...
myGraph.destroyAsync(); // request destruction of myGraph, don't
wait for response
try {
  myGraph.destroy();   // blocks caller thread until destruction
was done
} catch (ExecutionException e) {
  // destruction failed
}
```

- `Destroyable` extends AutoClosable, so users can leverage Java's built-in resource management syntax:

```
try (PgxGraph myGraph = session.readGraphWithProperties(config)) {
  // do something with myGraph
}
// myGraph is destroyed
```

- Session time out. In some cases, the PGX server will remove the session and all its data automatically. This can occur when a client fails to destroy either the data or its session, or if it does not hear from the session after a configurable timeout. See Configuration Parameters for the Graph Server (PGX) Engine for more information to configure timeout parameters.

23.2 Data Types and Collections in the Graph Server (PGX)

This guide provides you the list of the supported data types and collections in the graph server (PGX).

Primitive Data Types

The following section explains the primitive data types supported by the graph server (PGX) and their limitations.

PGX supports the following primitive data types.:

- **Numeric Types**: `integer`, `long`, `float`, and `double`. These types have the same size, range and precision of the corresponding Java primitive data type.
- **Boolean Type**: The `boolean` data type has only two possible values, `true` and `false`. As with Java and C++, its size is not precisely defined.
- **String**: `String` is a primitive data type in PGX. PGX follows the Java conventions for String representation.
- **Datetime Types**: `date`, `time`, `timestamp`, `time with time zone`, and `timestamp with time zone`. These types correspond to the Java types shown in Table 23-2 from the standard library package `java.util.time`.

- **Vertex** and **Edge**: The type `vertex` or `edge` of the graph itself is a proper type in PGX.

> **Note:**
>
> - `vertex` and `edge` is itself a valid primitive data type. For instance, in a path-finding algorithm, each `vertex` can have a temporary property `predecessor` that stores which incoming neighbor is the predecessor vertex in the path. Such a property would have the type `vertex`.
> - `local_date` must be used instead of `date` in the graph configuration file. See Using Datetime Data Types for more examples on usage of datetime data types.

All properties and scalar variables must be one of the above preceding data types. See Managing Transient Data for more information on handling transient properties and scalar variables.

The following table presents the overview of the supported data types, their integration in different languages and APIs and their minimum and maximum value limitations.

> **Note:**
>
> - For float and double types, the smallest absolute value is included in the table, the minimum value is the negative of maximum value for these types.
> - For string values, PGX supports arbitrary long strings.

Table 23-2 Overview of Data types

Data Type	Loading & Storing	PGX Java API	PGQL and Filter Expression	Minimum Value Limitation	Maximum Value Limitation
string	string	String	STRING	-	-
int/integer	int/integer	int	INT/INTEGER	-2147483648	2147483647
long	long	long	LONG	-9223372036854775808	-9223372036854775807
float	float	float	FLOAT	1.4E-45	3.4028235e+38
double	double	double	DOUBLE	4.9E-324	1.7976931348623157E308
boolean	boolean	boolean	BOOLEAN	-	-
date	local_date	LocalDate	DATE	-5877641-06-23	5881580-07-11
time	time	LocalTime	TIME	00:00:00.000	23:59:59.999
timestamp	timestamp	LocalDateTime	TIMESTAMP	-292275055-05-17 00:00:00.000	292278994-08-17 07:12:55.807
time with time zone	time_with_timezone	OffsetTime	TIME WITH TIME ZONE	00:00:00.000+18:00	23:59:59.999-18:00

Table 23-2 (Cont.) Overview of Data types

Data Type	Loading & Storing	PGX Java API	PGQL and Filter Expression	Minimum Value Limitation	Maximum Value Limitation
timestamp with time zone	timestamp_with_timezone	OffsetDateTime	TIMESTAMP WITH TIME ZONE	-292275055-05-17 00:00:00.000+18:00	292278994-08-17 07:12:55.807-18:00
vertex	-	PgxVertex	-	-	-
edge	-	PgxEdge	-	-	-

Collections

The graph server (PGX) supports three different collection types: `sequence`, `set` and `order`. All of these collections can contain values of the `vertex` type, but each has different semantics regarding uniqueness and preserving the order of its elements:

- **Sequence**: a `sequence` works basically like a list. It preserves the order of the elements added to it, and the same element can appear multiple times.
- **Set**: a `set` can contain the same value once at the most. Adding a value that is already in the `set` will have no effect. `set` does not preserve the order of the elements it contains.
- **Order**: just like the `set`, the `order` collection will contain each element once at the most. But the `order` preserves the order of the elements inserted into it (that is, it is a FIFO data structure).

See Collection Data Types for examples on creation and usage of the different collections.

Immutable Collections

Some operations, like PgxGraph.getVertices() and PgxGraph.getEdges() return immutable collections. These collections behave like normal collections, but cannot be modified by operations like `addAll` or `removeAll` and `clear`.

An immutable collection can be transformed into a mutable collection by using the `toMutable` method, which returns a mutable copy of the collection. If `toMutable` is called on a collection that is already mutable, the method has the same result as the method `clone`.

To check if a collection is mutable, use the `isMutable` method.

Maps

PGX provides the following two kinds of maps:

- Graph-bound maps can hold mappings between types in `PropertyType`. This is the kind of maps to use if the key or value types are graph-related like `VERTEX` and `EDGE` otherwise using session-bound maps is recommended.
- Session-bound maps can map between non graph-related types and are directly bound to the session.

See Map Data Types for examples on creation and usage of maps.

- Using Collections and Maps
- Using Datetime Data Types

23.2.1 Using Collections and Maps

This section explains with examples, the creation and usages of collections and maps.

You must first create a session before getting started with the collection and map data types.

- JShell
- Java
- Python

JShell

```
cd /opt/oracle/graph/
./bin/opg-jshell // starting the shell will create an implicit session
```

Java

```
import oracle.pgx.api.*;
...
PgxSession session=Pgx.createSession("<session_name>");
```

Python

```
from pypgx import get_session
session = get_session(session_name="<session_name>")
```

- Collection Data Types
- Map Data Types

23.2.1.1 Collection Data Types

The graph server (PGX) defines two types of collections:

- **Graph-bound collections**: such as vertex and edge collections. These collections belong to the graph.
- **Session-bound collections**: belong to the session.
- Graph-Bound Collections
- Session-Bound Collections

23.2.1.1.1 Graph-Bound Collections

The following describes the usage of graph-bound collections.

You must first load the graph to work with vertex and edge collections as shown in Reading Graphs from Oracle Database into the Graph Server (PGX).

Vertex Collections

You can create a vertex collection as shown in the following code:

- JShell
- Java
- Python

JShell

```
v0 = graph.getVertex(100) // 'graph' is the loaded graph object. '100'
-> '103' are vertex ids that supposedly
v1 = graph.getVertex(101) // exist in the graph
v2 = graph.getVertex(102)
v3 = graph.getVertex(103)

myVertexSet = graph.createVertexSet("myVertexSet")  // A name is
automatically generated if none given
myVertexSet.add(v0)                                  // Adds vertex
'v0' to the set
myVertexSet.addAll([v1, v2, v3])                     // Supports
variadic parameter as well: myVertexSet.addAll(v1, v2, v3)
```

Java

```
import java.util.Arrays;
import oracle.pgx.api.*;
...
PgxVertex v0 = graph.getVertex(100);
PgxVertex v1 = graph.getVertex(101);
PgxVertex v2 = graph.getVertex(102);
PgxVertex v3 = graph.getVertex(103);

VertexSet myVertexSet = graph.createVertexSet("myVertexSet");  // A
name is automatically generated if none given
myVertexSet.add(v0);
myVertexSet.addAll(Arrays.asList(v1, v2, v3));
```

Python

```
...
v0 = graph.get_vertex(100)
v1 = graph.get_vertex(101)
v2 = graph.get_vertex(102)
v3 = graph.get_vertex(103)

my_vertex_set = graph.create_vertex_set("myVertexSet")
my_vertex_set.add(v0)
my_vertex_set.add_all([v1,v2,v3])
```

Edge Collections

You can create an edge collection as shown in the following code:

- JShell
- Java
- Python

JShell

```
e0 = graph.getEdge(100) // 'graph' is the loaded graph object. '100' ->
'103' are edge ids that supposedly
e1 = graph.getEdge(101) // exist in the graph
e2 = graph.getEdge(102)
e3 = graph.getEdge(103)

myEdgeSequence = graph.createEdgeSequence("myEdgeSequence")
myEdgeSequence.add(e0)
myEdgeSequence.addAll([e1, e2, e3])
```

Java

```
import java.util.Arrays;
import oracle.pgx.api.*;
...
PgxEdge e0 = graph.getEdge(100);
PgxEdge e1 = graph.getEdge(101);
PgxEdge e2 = graph.getEdge(102);
PgxEdge e3 = graph.getEdge(103);

EdgeSequence myEdgeSequence = graph.createEdgeSequence("myEdgeSequence");
myEdgeSequence.add(e0);
myEdgeSequence.addAll(Arrays.asList(e1, e2, e3));
```

Python

```
e0 = graph.get_edge(100)
e1 = graph.get_edge(101)
e2 = graph.get_edge(102)
e3 = graph.get_edge(103)

my_edge_sequence = graph.create_edge_sequence("my_edge_sequence")
my_edge_sequence.add(e0)
my_edge_sequence.add_all([e1, e2, e3])
```

23.2.1.1.2 Session-Bound Collections

You can create and manipulate collections directly in the session without the need for a graph. Session-bound collections can be further passed as parameters to graph algorithms or used like any other collection object. The following sub-sections describe the currently supported types for these collections.

Scalar Collections

Scalar collections contain simple data types like `Integer`, `Long`, `Float`, `Double` and `Boolean`. They can be managed by the `PgxSession` APIs:

Creation of a Scalar Collection

You can use `createSet()` and `createSequence()` methods to create a scalar collection as shown in the following code:

- JShell
- Java

JShell

```
myIntSet = session.createSet(PropertyType.INTEGER, "myIntSet")
myDoubleSequence = session.createSequence(PropertyType.DOUBLE)  // A
name will be automatically generated if none is provided.
println myDoubleSequence.getName()                              //
Display the generated name.
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.common.types.*;
...
ScalarSet myIntSet = session.createSet(PropertyType.INTEGER,
"myIntSet");
ScalarSequence myDoubleSequence =
```

```
session.createSequence(PropertyType.DOUBLE);
System.out.println(myDoubleSequence.getName());
```

Run Operations on a Scalar Collection

You can run several operations on a scalar collection as shown in the following code:

- JShell
- Java

JShell

```
myIntSet.add(10)
myIntSet.addAll([0, 1, 2, 3, 4, 5, 6, 7, 8, 9])
myIntSet.addAll([0,1,2])                // Element uniqueness. This
operation has no effect on the set.
println myIntSet

myIntSet.contains(1)                   // Checks the presence of an element.
This code returns `true`.
myIntSet.remove(10)
myIntSet.removeAll([4, 5, 6, 7, 8, 9]) // Leaves only elements `0, 1, 2, 3`.
println  myIntSet
```

Java

```
import java.util.Arrays;
import oracle.pgx.api.*;
...
myIntSet.add(10);
myIntSet.addAll(Arrays.asList(0, 1, 2, 3, 4, 5, 6, 7, 8, 9));
myIntSet.addAll(Arrays.asList(0, 1, 2));

myIntSet.contains(1);  // Returns `true`.
myIntSet.remove(10);
myIntSet.removeAll(Arrays.asList(4, 5, 6, 7, 8, 9));
```

Traversal of a Scalar Collection

You can traverse a scalar collection either using an iterator or using the new Stream API. You can add elements of a sequence to a set, traverse a sequence and filter out elements not required, and then add the rest to another scalar collection.

- JShell
- Java

JShell

```
myIntSet.forEach({x -> print x + "\n"})
myIntSet.stream().filter({x -> x % 2 == 0}).forEach({x ->
myDoubleSequence.add(x)})
println myDoubleSequence
```

Java

```
import java.util.Iterator;
import java.util.stream.Stream;
import oracle.pgx.api.*;
...
myIntSet.forEach(x -> System.out.println(x));
myIntSet.stream().filter(x -> x % 2 ==
0).forEach(myDoubleSequence::add);
```

23.2.1.2 Map Data Types

The graph server (PGX) defines two types of maps:

- **Graph-bound maps**: These maps support any key or value type and are created using a graph object.
- **Session-bound maps**: Keys or values in these maps are of any type except from graph-related types (that is, vertices or edges). These maps belong to the session.

- Graph-Bound Maps
- Session-Bound Maps

23.2.1.2.1 Graph-Bound Maps

Some data types like `VERTEX` or `EDGE` depend on the graph. Consequently, mappings involving these data types also depend on the graph. PGX provides `PgxGraph` and `PgxMap` APIs to manage such maps.

The following describes the usage of graph-bound maps.

You must first load the graph to work with vertex and edge maps.

You can create a graph-bound map using vertices as keys as shown in the following code:

- JShell
- Java

* Python

JShell

```
v0 = graph.getVertex(100)
v1 = graph.getVertex(101)
v2 = graph.getVertex(102)
v3 = graph.getVertex(103)

vertexToLongMap = graph.createMap(PropertyType.VERTEX, PropertyType.LONG,
"vertexToLongMap")
vertexToLongMap.put(v0, v0.getDegreeAsync().get())
vertexToLongMap.put(v1, v1.getDegreeAsync().get())
vertexToLongMap.put(v2, v2.getDegreeAsync().get())
vertexToLongMap.put(v3, v3.getDegreeAsync().get())
```

Java

```
import java.util.Arrays;
import oracle.pgx.api.*;
...
PgxVertex v0 = graph.getVertex(100);
PgxVertex v1 = graph.getVertex(101);
PgxVertex v2 = graph.getVertex(102);
PgxVertex v3 = graph.getVertex(103);

PgxMap<PgxVertex, Long> vertexToLongMap =
graph.createMap(PropertyType.VERTEX, PropertyType.LONG, "vertexToLongMap");
vertexToLongMap.put(v0, v0.getDegree());
vertexToLongMap.put(v1, v1.getDegree());
vertexToLongMap.put(v2, v2.getDegree());
vertexToLongMap.put(v3, v3.getDegree());
```

Python

```
v0 = graph.get_vertex(100)
v1 = graph.get_vertex(101)
v2 = graph.get_vertex(102)
v3 = graph.get_vertex(103)

vertex_to_long_map = graph.create_map("vertex", "long", "vertex_to_long_map")
vertex_to_long_map.put(v0, v0.degree)
vertex_to_long_map.put(v1, v1.degree)
vertex_to_long_map.put(v2, v2.degree)
vertex_to_long_map.put(v3, v3.degree)
```

You can create graph-bound maps using edges as keys as shown in the following code:

- JShell
- Java
- Python

JShell

```
e0 = graph.getEdge(100)
e1 = graph.getEdge(101)
e2 = graph.getEdge(102)
e3 = graph.getEdge(103)

edgeToVertexMap = graph.createMap(PropertyType.EDGE,
PropertyType.VERTEX, "edgeToVertexMap")
edgeToVertexMap.put(e0, e0.getSource())
edgeToVertexMap.put(e1, e1.getSource())
edgeToVertexMap.put(e2, e2.getSource())
edgeToVertexMap.put(e3, e3.getSource())
```

Java

```
import java.util.Arrays;
import oracle.pgx.api.*;
...
PgxEdge e0 = graph.getEdge(100);
PgxEdge e1 = graph.getEdge(101);
PgxEdge e2 = graph.getEdge(102);
PgxEdge e3 = graph.getEdge(103);

PgxMap<PgxEdge, PgxVertex> edgeToVertexMap =
graph.createMap(PropertyType.EDGE, PropertyType.VERTEX,
"edgeToVertexMap");
edgeToVertexMap.put(e0, e0.getSource());
edgeToVertexMap.put(e1, e1.getSource());
edgeToVertexMap.put(e2, e2.getSource());
edgeToVertexMap.put(e3, e3.getSource());
```

Python

```
e0 = graph.get_edge(100)
e1 = graph.get_edge(101)
e2 = graph.get_edge(102)
e3 = graph.get_edge(103)

edge_to_long_map = graph.create_map("edge", "long",
"edge_to_long_map")
edge_to_long_map.put(e0, e0.source)
edge_to_long_map.put(e1, e1.source)
edge_to_long_map.put(e2, e2.source)
edge_to_long_map.put(e3, e3.source)
```

Note:

If you destroy the graph you will lose the map. Consider using a session-bound maps instead if your map does not involve any graph-related key or value type.

23.2.1.2.2 Session-Bound Maps

You can directly create maps in the session. But, you cannot use any graph-related data type as the map key or value type. Session-bound maps can be further passed as parameters to graph algorithms or used like any other map object. They are managed by `PgxSession` and `PgxMaps` APIs.

Scalar collections contain simple data types like `Integer`, `Long`, `Float`, `Double` and `Boolean`. They can be managed by the `PgxSession` APIs.

Creation of a Session-bound Map

You can use `createMap()` method and its overloads to create a session-bound map.

- JShell
- Java

JShell

```
intToDouble = session.createMap(PropertyType.INTEGER, PropertyType.DOUBLE,
"intToDouble")
intToTime = session.createMap(PropertyType.INTEGER, PropertyType.TIME)  // A
name will be automatically generated.
println intToTime.getName()
println intToTime.getSessionId()
println intToTime.getGraph()                                           //
`null`: Not bound to a graph.
println intToTime.getKeyType()
println intToTime.getValueType()
```

Java

```
import java.time.LocalTime;
import oracle.pgx.api.*;
import oracle.pgx.common.types.*;
...
PgxMap<Integer, Double> intToDouble =
session.createMap(PropertyType.INTEGER, PropertyType.DOUBLE, "intToDouble");
PgxMap<Integer, LocalTime> intToTime =
session.createSequence(PropertyType.INTEGER, PropertyType.TIME);
System.out.println(intToTime.getName());
System.out.println(intToTime.getSessionId());
```

```
System.out.println(intToTime.getGraph());  // `null`: Not bound to a
graph.
System.out.println(intToTime.getKeyType());
System.out.println(intToTime.getValueType());
```

Run Operations on a Session-bound Map

You can run important operations such as setting, removing and checking existence of entries on a session-bound map as shown in the following code:

- JShell
- Java

JShell

```
intToDouble.put(0, 0.314)
intToDouble.put(1, 3.14)
intToDouble.put(2, 31.4)
intToDouble.put(3, 314)

println intToDouble.size()           // 4
println intToDouble.get(1)
println intToDouble.get(3)
println intToDouble.get(10)          // null

println intToDouble.containsKey(0)   // `true`
intToDouble.remove(0)
println intToDouble.containsKey(0)   // `false`
println intToDouble.containsKey(10)  // `false`
intToDouble.remove(10)
println intToDouble.containsKey(10)  // `false`

println intToDouble.put(1, 999)      //  previous mapped value
(`3.14`) is replaced by `999`
intToDouble.destroy()
```

Java

```
import java.util.Arrays;
import oracle.pgx.api.*;

...

intToDouble.put(0, 0.314);
intToDouble.put(1, 3.14);
intToDouble.put(2, 31.4);
intToDouble.put(3, 314);
```

```
System.out.println(inToDouble.size());              // 4
System.out.println(intToDouble.get(1));
System.out.println(intToDouble.get(3));
System.out.println(intToDouble.get(10));            // null

System.out.println(intToDouble.containsKey(0));    // `true`
intToDouble.remove(0);
System.out.println(intToDouble.containsKey(0));    // `false`
System.out.println(intToDouble.containsKey(10));   // `false`
intToDouble.remove(10);
System.out.println(intToDouble.containsKey(10));   // `false`

System.out.println(intToDouble.put(1, 999));       //  previous mapped value
(`3.14`) is replaced by `999`
intToDouble.destroy();
```

Traversal of a Session-bound Map

You can traverse a session-bound map, using `entries()` method to get an iterable of map entries and `keys()` method to get an iterable of map keys.

- JShell
- Java

JShell

```
intToDouble.entries().forEach {it -> println (it)}
intToDouble.keys().forEach {it -> println (it)}
```

Java

```
import java.util.Iterable;
import java.util.stream.Stream;
import oracle.pgx.api.*;
...
Iterable<Map.Entry> entries = intToDouble.entries();
entries.forEach(System.out::println);
Iterable<Map.Entry> keys = intToDouble.keys();
keys.forEach(System.out::println);
```

23.2.2 Using Datetime Data Types

This section explains in detail working of `datetime` data types such as `date`, `time` and `timestamp`.

Overview of Datetime Data Types in Graph Server (PGX)

Table 23-3 presents the overview of the five `datetime` data types supported by PGX along with example values.

> **Note:**
>
> PGX also supports custom format specification when loading data into PGX.

Table 23-3 Overview of Datetime Data Types in PGX

Data Type	Loading and Storing	PGX Java API	PGQL and Filter Expression	Example Value-1	Example Value-1
date	local_date	LocalDate	DATE	2001-01-29	2018-10-08
time	time	LocalTime	TIME	10:15	10:30:01.000
timestamp	timestamp	LocalDateTime	TIMESTAMP	2001-01-29 10:15	2018-10-08 10:30:01.000
time with time zone	time_with_timezone	OffsetTime	TIME WITH TIME ZONE	10:15+01:00	10:30:01.000-08:00
timestamp with time zone	timestamp_with_timezone	OffsetDateTime	TIMESTAMP WITH TIME ZONE	2001-01-29 10:15+01:00	2018-10-08 10:30:01.000-08:00

- Loading Datetime Data
- Specifying Custom Datetime Formats
- APIs for Accessing Datetime Data
- Querying Datetime Data Using PGQL
- Accessing Datetimes from PGQL Result Sets

23.2.2.1 Loading Datetime Data

You must first load a graph to work with datetime data. See Reading Graphs from Oracle Database into the Graph Server (PGX) for more information on graph loading.

The following example shows how to load a graph that has three vertices representing persons and zero edges.

Example 23-1 Loading Datetime Data

1. Create an `EDGE_LIST` file `persons.edge_list` as shown:

```
1*Judy,1989-01-15,1989-01-15 10:15-08:00
2*Klara,2001-01-29,2001-01-29 21:30-08:00
3*Pete,1995-08-01,1995-08-01 03:00-08:00
```

2. Create a corresponding graph configuration file `persons.edge_list.json` as shown:

```
{
    "format":"edge_list",
    "uri":"persons.edge_list",
    "vertex_id_type":"long",
    "vertex_props":[
        {
            "name":"name",
            "type":"string"
        },
        {
            "name":"date_of_birth",
            "type":"local_date"
        },
        {
            "name":"timestamp_of_birth",
            "type":"timestamp_with_timezone",
            "format":["yyyy-MM-dd H[H]:m[m][:s[s]][XXX]"]
        }
    ],
    "edge_props":[
    ],
    "separator":","
}
```

3. You can now load the data as shown in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphWithProperties("persons.edge_list.json",
"people_graph")
```

Java

```
import oracle.pgx.api.*;
...
PgxGraph graph =
session.readGraphWithProperties("persons.edge_list.json","people_graph");
```

Python

```
graph =
session.read_graph_with_properties("persons.edge_list.json",graph_name=
"people_graph")
```

23.2.2.2 Specifying Custom Datetime Formats

You can also manually specify the datetime format(s) of your data.

By default, PGX tries to parse datetime values using a set of predefined formats. If this fails, an exception like the following is thrown:

```
property timestamp_of_birth: could not parse value at line 1 for
property of temporal type OffsetDateTime using any of the given formats
```

In such a case, you can custom format the datetime data.

There are two ways of specifying datetime formats:

- on a *per-property* basis
- on a *per-type* basis

Property-Specific Datetime format:

You can custom format the property `timestamp_of_birth` used in Example 23-1 to the format `yyyy-MM-dd H[H]:m[m][:s[s]][XXX]` as shown:

Example 23-2 Specifying Property-Specific Datetime format:

```
{
    "name":"timestamp_of_birth",
    "type":"timestamp_with_timezone",
    "format":["yyyy-MM-dd H[H]:m[m][:s[s]][XXX]"]
}
```

where `yyyy-MM-dd H[H]:m[m][:s[s]][XXX]` specifies that the timestamp values consist of:

- a four-digit year
- a hyphen followed by a two-digit month
- a hyphen followed by a two-digit day
- a space
- an hour, specified as either one or two digits
- a colon followed by a minute, specified as either one or two digits
- an *optional* part that consists of a colon followed by a second that is specified as either one or two digits
- an *optional* timezone

> **Note:**
>
> - `H[H]:m[m]` allows the value `01:15` as well as the value `1:15`.
> - `yyyy-MM-dd` allows the value `1989-01-15` but not the value `1989-1-15`. However, if two-digit months and days are needed, a format like `yyyy-M[M]-d[d]` can be used.

Also the format specification takes a *list* of formats. In the preceding example, the list contains only a single format, but you may specify any number of formats. If more than one format is specified, then when parsing the datetime data, the formats are tried from left to right until parsing succeeds. In this way, you can even load data that contains a mixture of values in different formats.

Type-Specific Datetime format:

You can also specify datetime formats on a *per-type* basis. This is useful in cases when there are multiple properties that have the same type as well as the same format because you will only need to specify the datetime format only once.

In case of the per-type specification, the format is used for each vertex or edge property that has the particular type.

The following example shows two type-specific formats (`local_date_format` and `timestamp_with_timezone_format`):

Example 23-3 Specifying Type-Specific Datetime format:

```
...
    "edge_props":[
    ],
    "separator":",",
    "local_date_format":["yyyy-MM-dd"],
    "timestamp_with_timezone_format":["yyyy-MM-dd H[H]:m[m][:s[s]][XXX]"]
}
```

In the example, properties of type date (`local_date`) have the format `yyyy-MM-dd` while properties of type timestamp with time zone (`timestamp_with_timezone`) have the format `yyyy-MM-dd H[H]:m[m][:s[s]][XXX]`.

> **Note:**
>
> Property-specific formats always overrides type-specific formats. If you specify a type-specific format, and the property of the particular type also has a property-specific format, then only the property-specific format is used to parse the datetime data.

23.2.2.3 APIs for Accessing Datetime Data

The graph server (PGX) uses the new Java 8 temporal data types for accessing datetime data through the Java API:

- `date` in PGX maps to `LocalDate` in Java
- `time` in PGX maps to `LocalTime` in Java
- `timestamp` in PGX maps to `LocalDateTime` in Java
- `time with time zone` in PGX maps to `OffsetTime` in Java
- `timestamp with time zone` in PGX maps to `OffsetDateTime` in Java

You can retrieve a date as shown in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var dateOfBirthProperty =
graph.getVertexProperty("date_of_birth")
opg4j> var birthdayOfJudy = dateOfBirthProperty.get(1)
```

Java

```
import java.time.LocalDate;
import oracle.pgx.api.*;
...
VertexProperty<LocalDate> dateOfBirthProperty =
graph.getVertexProperty("date_of_birth");
LocalDate birthdayOfJudy = dateOfBirthProperty.get(1);
```

Python

```
date_of_birth_property = graph.get_vertex_property("date_of_birth")
birthday_of_judy = date_of_birth_property.get(1)
```

23.2.2.4 Querying Datetime Data Using PGQL

You can perform various operations such as *extracting* values from datetimes, *comparing* datetime values, and, *converting* between different datetime types. on datetime data using PGQL.

The following are example PGQL queries that show different operations that involve datetime data:

Retrieving Datetime Properties

The following query retrieves the `date_of_birth` and `timestamp_of_birth` properties from the all the persons in the graph.

```
  SELECT n.name AS name, n.date_of_birth AS birthday, n.timestamp_of_birth
AS timestamp
    FROM MATCH (n) ON people_graph
ORDER BY birthday
```

The result of the query is as follows:

```
+----------------------------------------------+
| name  | birthday   | timestamp               |
+----------------------------------------------+
| Judy  | 1989-01-15 | 1989-01-15T10:15-08:00 |
| Pete  | 1995-08-01 | 1995-08-01T03:00-08:00 |
| Klara | 2001-01-29 | 2001-01-29T21:30-08:00 |
+----------------------------------------------+
```

Comparing Datetime Values

The following query provides an overview of persons who are older than other persons in the graph:

```
SELECT n.name AS person1, 'is older than' AS relation, m.name AS person2
    FROM MATCH (n) ON people_graph, (m) ON people_graph
   WHERE n.date_of_birth > m.date_of_birth
ORDER BY person1, person2
```

The result of the query is as follows:

```
+------------------------------------+
| person1 | relation      | person2 |
+------------------------------------+
| Klara   | is older than | Judy    |
| Klara   | is older than | Pete    |
| Pete    | is older than | Judy    |
+------------------------------------+
```

Extracting Values from Datetimes

The following query extracts the year, month, and day from the `date_of_birth` values:

```
SELECT n.name AS name
       , n.date_of_birth AS dob
       , EXTRACT(YEAR FROM n.date_of_birth) AS year
       , EXTRACT(MONTH FROM n.date_of_birth) AS month
       , EXTRACT(DAY FROM n.date_of_birth) AS day
    FROM MATCH (n) ON people_graph
ORDER BY name
```

The result of the query is as follows:

```
+----------------------------------------+
| name  | dob        | year | month | day |
+----------------------------------------+
| Judy  | 1989-01-15 | 1989 | 1     | 15  |
| Klara | 2001-01-29 | 2001 | 1     | 29  |
| Pete  | 1995-08-01 | 1995 | 8     | 1   |
+----------------------------------------+
```

Converting Between Different Types of Datetime Values

The following query converts the `timestamp_of_birth` property into values of the following three datetime types:

- a timestamp (without time zone)
- a time with time zone
- a time (without time zone)

```
SELECT n.name AS name
       , n.timestamp_of_birth AS original_timestamp
       , CAST(n.timestamp_of_birth AS TIMESTAMP) AS utc_timestamp
       , CAST(n.timestamp_of_birth AS TIME WITH TIME ZONE) AS
timezoned_time
       , CAST(n.timestamp_of_birth AS TIME) AS utc_time
    FROM MATCH (n) ON people_graph
ORDER BY original_timestamp
```

The result of the query is as follows:

```
+----------------------------------------------------------------------
---------+
| name  | original_timestamp     | utc_timestamp    | timezoned_time |
utc_time |
+----------------------------------------------------------------------
---------+
| Judy  | 1989-01-15T10:15-08:00 | 1989-01-15T18:15 | 10:15-08:00    |
18:15    |
| Pete  | 1995-08-01T03:00-08:00 | 1995-08-01T11:00 | 03:00-08:00    |
11:00    |
| Klara | 2001-01-29T21:30-08:00 | 2001-01-30T05:30 | 21:30-08:00    |
05:30    |
+----------------------------------------------------------------------
---------+
```

23.2.2.5 Accessing Datetimes from PGQL Result Sets

You can use the following APIs for retrieving datetime values from PGQL result sets.

```
LocalDate getDate(int elementIdx)
LocalDate getDate(String variableName)
LocalTime getTime(int elementIdx)
```

```
LocalTime getTime(String variableName)
LocalDateTime getTimestamp(int elementIdx)
LocalDateTime getTimestamp(String variableName)
OffsetTime getTimeWithTimezone(int elementIdx)
OffsetTime getTimeWithTimezone(String variableName)
OffsetDateTime getTimestampWithTimezone(int elementIdx)
OffsetDateTime getTimestampWithTimezone(String variableName)
```

The following example prints the birthdays of all the persons in the graph is as follows:

- JShell
- Java

JShell

```
opg4j> var resultSet = session.queryPgql("""
  SELECT n.name, n.date_of_birth
    FROM MATCH (n) ON people_graph
ORDER BY n.name
""")
opg4j> while (resultSet.next()) {
...>  System.out.println(resultSet.getString(1) + " has birthday " +
resultSet.getDate(2));
...> }
opg4j> resultSet.close()
```

Java

```
import java.time.LocalDate;
import oracle.pgx.api.*;
...
PgqlResultSet resultSet = session.queryPgql(
  "  SELECT n.name, n.date_of_birth\n" +
  "    FROM MATCH (n) ON people_graph\n" +
  "ORDER BY n.name");

while (resultSet.next()) {
  System.out.println(resultSet.getString(1) + " has birthday " +
resultSet.getDate(2));
}

resultSet.close();
```

The result of the query is as follows:

```
Judy has birthday 1989-01-15
Klara has birthday 2001-01-29
Pete has birthday 1995-08-01
```

In addition to the Java types from the new `java.time` package, the legacy `java.util.Date` is also supported through the following APIs:

```
Date getLegacyDate(int elementIdx)
Date getLegacyDate(String variableName)
```

> **Note:**
>
> The legacy `java.util.Date` can store dates, times, as well as timestamps, so these two APIs can be used for accessing values of any of the five datetime types.

23.3 Handling Asynchronous Requests in Graph Server (PGX)

This guide explains in detail the asynchronous methods supported by the PGX API.

The PGX API is designed to be asynchronous. This means that all of its core methods ending with *Async* **do not** block the caller thread until the request is completed. Instead, a `PgxFuture` object is instantly returned.

You can perform the following three actions on the returned `PgxFuture` object:

- Block
- Chain
- Cancel

- Blocking Operation
- Chaining Operation
- Cancelling Operation
- Handling Concurrent Asynchronus Operations

23.3.1 Blocking Operation

You can easily get the result by calling the `get()` method on the `PgxFuture`. The `get()` blocks the caller thread until the result is available:

```
PgxFuture<PgxSession> sessionPromise = instance.createSessionAsync("my-
session");
try {
    // block caller thread
    PgxSession session = sessionPromise.get();
```

```
    // do something with session
    ...
} catch (InterruptedException e) {
    // caller thread was interrupted while waiting for result
} catch (ExecutionException e) {
    // an exception was thrown during asynchronous computation
    Throwable cause = e.getCause(); // the actual exception is nested
}
```

PGX provides blocking convenience methods for every *Async* method, which calls the `get()` method. Typically, those methods have the same name as the asynchronous method they wrap, but without the *Async* suffix. For example, the preceding code snippet is equal to:

```
try {
    // block caller thread
    PgxSession session = instance.createSession("my-session");
    // do something with session
    ...
} catch (InterruptedException e) {
    // caller thread was interrupted while waiting for result
} catch (ExecutionException e) {
    // an exception was thrown during asynchronous computation
    Throwable cause = e.getCause(); // the actual exception is nested
}
```

23.3.2 Chaining Operation

The graph server (PGX) ships a version of Java 8's `CompletableFuture` named `PgxFuture`, a monadic enhancement of the `Future` interface.

The `CompletableFuture` allows chaining of asynchronous computations without polling or the need of deeply nested callbacks (also known as callback hell). All `PgxFuture` instances returned by PGX APIs are instances of `CompletableFuture` and can be chained without the need of Java 8.

```
import java.util.concurrent.CompletableFuture

...

final GraphConfig graphConfig = ...
instance.createSessionAsync("my-session")
  .thenCompose(new Fun<PgxSession, CompletableFuture<PgxGraph>>() {
  @Override
  public CompletableFuture<PgxGraph> apply(PgxSession session) {
    return session.readGraphWithPropertiesAsync(graphConfig);
  }
}).thenAccept(new Action<PgxGraph>() {
  @Override
  public void accept(PgxGraph graph) {
    // do something with loaded graph
  }
});
```

The asynchronous chaining in the preceding example is explained as follows:

- The first line in the code makes an asynchronous call to `createSessionAsync()` to create a session.
  Once the promise is resolved, it returns a `PgxFuture` object, which is the newly created `PgxSession`.
- The code then calls the `.thenCompose()` handler by passing a function which takes the `PgxSession` object as an argument.
  Inside the function, there is another asynchronous `readGraphWithPropertiesAsync()` request which return another `PgxFuture` object.

  The outer `PgxFuture` object returned by `.thenCompose()` gets resolved when the `readGraphWithPropertiesAsync()` request completes.
- This is followed by the `.thenAccept()` handler. The function that is passed to `.thenAccept()` does not return anything. Therefore, the `future` return type of `.thenAccept()` is `PgxFuture<Void>`.

Blocking Versus Chaining

For most use cases, you can block the caller thread. However, blocking can quickly lead to poor performance or deadlocks once things get more complex. As a rule, use blocking to quickly analyze selected graphs in a sequential manner, for example, in shell scripts or during interactive analysis using the interactive PGX shell.

Use chaining for applications built on top of PGX.

23.3.3 Cancelling Operation

You can cancel a pending request by invoking the `cancel` method of the returned `PgxFuture` instance.

For example:

```
PgxFuture<Object> promise=...
// do something else
promise.cancel(); // will cancel computation
```

Any subsequent calls to `promise.get()` will result in a CancellationException being thrown.

> **Note:**
>
> Due to Java's cooperative threading model, it might take some time before PGX actually stops the computation.

23.3.4 Handling Concurrent Asynchronous Operations

Using the `PgxSession#runConcurrently` API provided by the graph server (PGX), you can submit a list of suppliers of asynchronous APIs to run concurrently in the PGX server.

For example:

```
import oracle.pgx.api.*;

    Supplier<PgxFuture<?>> asyncRequest1 = () ->
session.readGraphWithPropertiesAsync(...);
    Supplier<PgxFuture<?>> asyncRequest2 = () ->
session.getAvailableSnapshotsAsync(...);

    List<Supplier<PgxFuture<?>>> supplierList = Arrays.asList(asyncRequest1,
asyncRequest2);

    //executing the async requests with the enabled optimization feature
    List<?> results = session.runConcurrently(supplierList);

    //the supplied requests are mapped to their results and orderly collected
    PgxGraph graph = (PgxGraph) results.get(0);
    Deque<GraphMetaData> metaData = (Deque<GraphMetaData>) results.get(1);
```

23.4 Graph Client Sessions

The graph server (PGX) assumes there may be multiple concurrent clients, and each client submits request to the shared PGX server independently.

Each session has its own workspace in PGX and is isolated from other sessions.

You can share graphs or properties among sessions.

Creating Sessions

The following methods in the `ServerInstance` class are used to create sessions:

- Java
- Python

Java

```
PgxSession createSession(String source)
PgxSession createSession(String source, long idleTimeout, long taskTimeout,
TimeUnit unit)
```

The preceding methods accept the following arguments:

- `source` is any arbitrary string that describes the client. Currently, this string is only used for logging purposes.
- The user can specify the idle timeout (`idleTimeout`) and task timeout (`taskTimeout`) when creating a new session. If these values are not specified, default values are used. See Configuration Parameters for the Graph Server (PGX) Engine for more information on graph server (PGX) configuration options.

Python

```
import pypgx
session = pypgx.get_session()
```

Destroying Sessions

To destroy a session, simply call:

- JShell
- Java
- Python

JShell

```
session.destroyAsync();
```

Java

```
session.destroy();
```

Python

```
session.destroy()
```

Administrators can destroy sessions by ID using the following code:

```
instance.killSession(sessionId);
```

> **Note:**
>
> Calling administrative methods by default requires special authorization in client/server mode.

When a session is destroyed, PGX reclaims all of the resources associated with the session. Specifically, all transient data is destroyed immediately. See Managing Transient Data for more information on transient data.

However, PGX may choose to keep the loaded graph instance in memory for caching purposes, especially if a graph instance is shared by multiple clients. In summary, every graph remains in memory until no client is using it.

> **Note:**
>
> A session can be destroyed automatically via the session time-out mechanism. See Configuration Parameters for the Graph Server (PGX) Engine for more information on graph server (PGX) configuration options.

23.5 Graph Mutation and Subgraphs

This guide discusses the several methods provided by the graph server (PGX) for mutating graph instances.

You can use the mutation and subgraph methods that are defined in the `PgxGraph` class, to mutate a graph.

> **Note:**
>
> All of the mutating methods create a new graph or snapshot instance as the mutated version of the original graph, rather than mutating the original graph directly.

- Altering Graphs
- Simplifying and Copying Graphs
- Transposing Graphs
- Undirecting Graphs
- Advanced Multi-Edge Handling
- Creating a Subgraph
- Creating a Bipartite Subgraph
- Creating a Sparsified Subgraph

23.5.1 Altering Graphs

This section explains the graph alteration mutation used to add or remove vertex and edge providers of a graph.

You can add or remove vertex and edge providers in a graph that has been loaded or created previously. Providers can be added from existing datasources, or new empty providers can be created. The mutation can either create a new independent graph, or create a new snapshot for the graph.

The following topics explain in detail on adding and removing vertex and edge providers:

You must first create a graph-alteration builder to start altering an existing graph. For example, the following code shows how to start a graph alteration on a graph that is stored in a variable `graph`:

- JShell
- Java
- Python

JShell

```
opg-jshell> var alterationBuilder = graph.alterGraph()
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.graphalteration.GraphAlterationBuilder;

GraphAlterationBuilder alterationBuilder = graph.alterGraph();
```

Python

```
alteration_builder = graph.alter_graph()
```

- Loading Or Removing Additional Vertex or Edge Providers

23.5.1.1 Loading Or Removing Additional Vertex or Edge Providers

You can alter your graph by adding or removing vertex or edge providers from a specific datasource. Alternatively you can also add empty vertex or edge providers.

Keys in Additionally Loaded Providers

The vertex and edge providers that are loaded must provide the respective keys in accordance with the vertex ID and edge ID strategy of the graph being altered. If the ID strategy is `KEYS_AS_IDS`, the provider must create a key mapping. But, if the ID strategy is `UNSTABLE_GENERATED_IDS`, it must not create the key mapping.

- Loading Vertex Providers
- Loading Edge Providers
- Adding Additional Empty Vertex or Edge Providers
- Removing Vertex or Edge Providers
- Applying the Alteration and Building a Graph or Snapshot

23.5.1.1.1 Loading Vertex Providers

You can add a vertex provider by calling `alterationBuilder.addVertexProvider(EntityProviderConfig vertexProviderConfig)`.

`vertexProviderConfig` is a vertex provider configuration and it provides configuration details such as:

- location of the datasource to load from
- the stored format
- properties of the vertex provider

Adding a Vertex Provider from a JSON Configuration

You can add the provider by calling `alterationBuilder.addVertexProvider(String pathToVertexProviderConfig)` where `pathToVertexProviderConfig` points to a file accessible from the client that contains a JSON representation of a vertex provider configuration.

For example, a vertex provider configuration can be stored in a JSON file as shown:

```
{
  "name": "Accounts",
  "format": "rdbms",
  "database_table_name": "BANK_ACCOUNTS",
  "key_column": "ID",
  "key_type": "integer",
  "props": [
    {
      "name": "ID",
      "type": "integer"
    },
    {
      "name": "NAME",
      "type": "string"
    }
  ]
}
```

You can then add the vertex provider as shown in the following example:

- JShell
- Java
- Python

JShell

```
// Loading by indicating the path to the JSON file
opg4j> alterationBuilder.addVertexProvider("<path-to-vertex-provider-
configuration>")
$9 ==>
oracle.pgx.api.graphalteration.internal.GraphAlterationBuilderImpl@48d464cf

// Or by first loading the content of a JSON file into an
EntityProviderConfig object
opg4j> var vertexProviderConfig = new
AnyFormatEntityProviderConfigFactory().fromPath("<path-to-vertex-provider-
configuration>")
```

```
vertexProviderConfig ==>
{"format":"rdbms","name":"Accounts","database_table_name":"BANK_ACCOUNT
S","loading":{"create_key_mapping":true},"key_type":"integer","props":
[{"type":"integer","name":"ID"},
{"type":"string","name":"NAME"}],"key_column":"ID"}
opg4j> alterationBuilder.addVertexProvider(vertexProviderConfig)
$15 ==>
oracle.pgx.api.graphalteration.internal.GraphAlterationBuilderImpl@77e2
a5d3
```

Java

```
// Loading by indicating the path to the JSON file
alterationBuilder.addVertexProvider("<path-to-vertex-provider-
configuration>");

// Or by first loading the content of a JSON file into an
EntityProviderConfig object
EntityProviderConfig vertexProviderConfig = new
AnyFormatEntityProviderConfigFactory().fromPath("<path-to-vertex-
provider-configuration>");
alterationBuilder.addVertexProvider(vertexProviderConfig);
```

Python

```
# Loading by indicating the path to the JSON file
alterationBuilder.add_vertex_provider("<path-to-vertex-provider-
configuration>");
```

Adding a Vertex Provider Programmatically Using an API

Alternatively, the vertex provider configuration can be built programmatically:

- JShell
- Java

JShell

```
opg4j> var vertexProviderConfigBuilder = new
RdbmsEntityProviderConfigBuilder().
...>       setName("Accounts").
...>       setKeyColumn("ID").
...>       setDatabaseTableName("BANK_ACCOUNTS").
...>       addProperty("ID", PropertyType.INTEGER)
vertexProviderConfigBuilder ==>
oracle.pgx.config.RdbmsEntityProviderConfigBuilder@8ff4d2b
```

```
opg4j> var vertexProviderConfig = vertexProviderConfigBuilder.build()
vertexProviderConfig ==> {"error_handling":
{},"format":"rdbms","name":"Accounts","database_table_name":"BANK_ACCOUNTS","
loading":{"create_key_mapping":true},"attributes":
{},"key_type":"long","props":
[{"dimension":0,"type":"integer","name":"ID"}],"key_column":"ID"}

opg4j> alterationBuilder.addVertexProvider(vertexProviderConfig)
$24 ==>
oracle.pgx.api.graphalteration.internal.GraphAlterationBuilderImpl@7b303608
```

Java

```
RdbmsEntityProviderConfigBuilder vertexProviderConfigBuilder = new
RdbmsEntityProviderConfigBuilder()
  .setName("Accounts")
  .setKeyColumn("ID")
  .setDatabaseTableName("BANK_ACCOUNTS")
  .addProperty("ID", PropertyType.INTEGER);
EntityProviderConfig vertexProviderConfig =
vertexProviderConfigBuilder.build();
alterationBuilder.addVertexProvider(vertexProviderConfig);
```

23.5.1.1.2 Loading Edge Providers

You can add an edge provider by calling `alterationBuilder.addEdgeProvider(EntityProviderConfig edgeProviderConfig) where edgeProviderConfig`. `edgeProviderConfig` is an edge provider configuration and it provides configuration details such as:

- location of the datasource to load from
- the stored format
- properties of the edge provider

The source and destination vertex providers to which it is linked must either be already in the base graph (and not removed in the alteration), or added with the alteration.

Adding an Edge Provider from a JSON Configuration

You can also add the provider by calling `alterationBuilder.addEdgeProvider(String pathToEdgeProviderConfig)` where `pathToEdgeProviderConfig` points to a file accessible from the client that contains a JSON representation of an edge provider configuration.

For example, an edge provider configuration can be stored in a JSON file as shown:

```
{
  "name": "Transfers",
  "format": "rdbms",
  "database_table_name": "BANK_EDGES_AMT",
  "key_column": "ID",
  "source_column": "SRC_ID",
```

```
  "destination_column": "DEST_ID",
  "source_vertex_provider": "Accounts",
  "destination_vertex_provider": "Accounts",
  "props": [
    {
      "name": "AMOUNT",
      "type": "float"
    }
  ]
}
```

You can then add the edge provider as shown in the following example:

- JShell
- Java
- Python

JShell

```
// Loading by indicating the path to the JSON file
opg4j> alterationBuilder.addEdgeProvider("<path-to-edge-provider-
configuration>")
$10 ==>
oracle.pgx.api.graphalteration.internal.GraphAlterationBuilderImpl@48d4
64cf

// Or by first loading the content of a JSON file into an
EntityProviderConfig object
opg4j> EntityProviderConfig edgeProviderConfig = new
AnyFormatEntityProviderConfigFactory().fromPath("<path-to-edge-
provider-configuration>")
edgeProviderConfig ==>
{"format":"rdbms","source_vertex_provider":"Accounts","name":"Transfers
","database_table_name":"BANK_EDGES_AMT","loading":
{"create_key_mapping":false},"source_column":"SRC_ID","destination_colu
mn":
"DEST_ID","key_type":"long","destination_vertex_provider":"Accounts","p
rops":[{"type":"float","name":"AMOUNT"}],"key_column":"ID"}

opg4j> alterationBuilder.addEdgeProvider(edgeProviderConfig)
$26 ==>
oracle.pgx.api.graphalteration.internal.GraphAlterationBuilderImpl@7b30
3608
```

Java

```
// Loading by indicating the path to the JSON file
alterationBuilder.addEdgeProvider("<path-to-edge-provider-
configuration>");
```

```
// Or by first loading the content of a JSON file into an
EntityProviderConfig object
EntityProviderConfig edgeProviderConfig = new
AnyFormatEntityProviderConfigFactory().fromPath("<path-to-edge-provider-
configuration>");
alterationBuilder.addEdgeProvider(edgeProviderConfig);
```

Python

```
# Loading by indicating the path to the JSON file
alterationBuilder.add_edge_provider("<path-to-edge-provider-configuration>");
```

Adding an Edge Provider Programmatically Using an API

Alternatively, the edge provider configuration can be built programmatically:

- JShell
- Java

JShell

```
opg4j> RdbmsEntityProviderConfigBuilder edgeProviderConfigBuilder = new
RdbmsEntityProviderConfigBuilder().
...>                                               setName("Transfers").
...>                                               setKeyColumn("id").
...>                                               setSourceColumn("src_id").
...>
setDestinationColumn("dest_id").
...>
setSourceVertexProvider("Accounts").
...>
setDestinationVertexProvider("Accounts").
...>                                               createKeyMapping(true).
...>
setDatabaseTableName("bank_txns").
...>
addProperty("from_acct_id", PropertyType.LONG).
...>                                               addProperty("to_acct_id",
PropertyType.LONG).
...>                                               addProperty("amount",
PropertyType.LONG)
edgeProviderConfigBuilder ==>
oracle.pgx.config.RdbmsEntityProviderConfigBuilder@5a5f65b9

opg4j> EntityProviderConfig edgeProviderConfig =
edgeProviderConfigBuilder.build()
edgeProviderConfig ==> {"error_handling":
```

```
{},"attributes{},"destination_column":"dest_id","key_type":"long","dest
ination_vertex_provider":"Accounts","key_column":"id","format":"rdbms",
"source_vertex_provider":
"Accounts","name":"Transfers","database_table_name":"bank_txns","loadin
g":{"create_key_mapping":true},"source_column":"src_id","props":
[{"dimension":0,"type":"long","name":"from_acct_id"},
{"dimension":0,"type":"long",
"name":"to_acct_id"},{"dimension":0,"type":"long","name":"amount"}]}

opg4j> alterationBuilder.addEdgeProvider(edgeProviderConfig)
$30 ==>
oracle.pgx.api.graphalteration.internal.GraphAlterationBuilderImpl@441c
cfd7
```

Java

```
RdbmsEntityProviderConfigBuilder edgeProviderConfigBuilder = new
RdbmsEntityProviderConfigBuilder()
.setName("Transfers")
.setKeyColumn("id")
.setSourceColumn("src_id")
.setDestinationColumn("dest_id").
.setSourceVertexProvider("Accounts")
.setDestinationVertexProvider("Accounts")
.createKeyMapping(true)
.setDatabaseTableName("bank_txns")
.addProperty("from_acct_id", PropertyType.LONG)
.addProperty("to_acct_id", PropertyType.LONG)
.addProperty("amount", PropertyType.LONG);

EntityProviderConfig edgeProviderConfig =
edgeProviderConfigBuilder.build();
alterationBuilder.addEdgeProvider(edgeProviderConfig);
```

23.5.1.1.3 Adding Additional Empty Vertex or Edge Providers

You can also add empty vertex or edge providers, without having the providers connected to any specific datasource.

The names and types of the properties of each empty provider can be specified programmatically. Similarly, you can also specify if a key mapping for the providers needs to be created.

Adding Additional Empty Vertex Providers

You can add an empty vertex provider by calling `alterationBuilder.addEmptyVertexProvider(String vertexProviderName)`. You can then add properties, specify the key column, create the key mapping programmatically as shown in the following example.

See the **GraphAlterationEmptyVertexProviderBuilder** Interface in the Javadoc for more details.

- JShell
- Java

JShell

```
opg4j> alterationBuilder.addEmptyVertexProvider("AccountsProvider").
...>         setLabel("Accounts").
...>         createKeyMapping(true).
...>         addProperty("NAME", PropertyType.STRING)
$14 ==>
oracle.pgx.api.graphalteration.internal.GraphAlterationEmptyVertexProviderBui
lderImpl@4b3ea082
```

Java

```
alterationBuilder.addEmptyVertexProvider("AccountsProvider")
        .setLabel("Accounts")
        .createKeyMapping(true)
        .addProperty("NAME", PropertyType.STRING);
```

Adding Additional Empty Edge Providers

You can add an empty edge provider by calling `alterationBuilder.addEmptyEdgeProvider(String providerName, String sourceProvider, String destProvider)`. You can then add properties, specify the key column, create the key mapping programmatically as shown in the following example.

See the **GraphAlterationEmptyEdgeProviderBuilder** Interface in the Javadoc for more details.

- JShell
- Java

JShell

```
opg4j> alterationBuilder.addEmptyEdgeProvider("TransactionProvider",
"Accounts", "Accounts").
...>         setLabel("Transfers").
...>         createKeyMapping(false). // set to false if no keys are needed
...>         addProperty("Description", PropertyType.STRING)
$26 ==>
oracle.pgx.api.graphalteration.internal.GraphAlterationEmptyEdgeProviderBuild
erImpl@54720caf
```

Java

```
alterationBuilder.addEmptyEdgeProvider("TransactionProvider",
"Accounts", "Accounts")
.setLabel("Transfers")
.createKeyMapping(false)
.addProperty("Description", PropertyType.STRING);
```

23.5.1.1.4 Removing Vertex or Edge Providers

You can remove an edge provider by calling `alterationBuilder.removeEdgeProvider(String edgeProviderName)`, where `edgeProviderName` is the name of the edge provider to be removed from the graph.

Similarly, calling `alterationBuilder.removeVertexProvider(String vertexProviderName)` will result in the graph to not contain that specific vertex provider. If that vertex provider was the source or destination provider for some edge providers in the base graph, those edge providers should also be removed before the application of the alteration or an exception will be thrown.

It is possible to indicate that the edge providers associated to a removed vertex provider should be automatically removed by calling `alterationBuilder.cascadeEdgeProviderRemovals(boolean cascadeEdgeProviderRemovals)` with `cascadeEdgeProviderRemovals` set to `true`.

23.5.1.1.5 Applying the Alteration and Building a Graph or Snapshot

You must call `alterationBuilder.build()`, once the different vertex and edge providers have been added or removed in the alteration to actually apply the operation. By calling `alterationBuilder.build()`, a new graph is created and that graph contains all the providers of the base graph excluding the removed providers, and the additionally loaded providers.

You can also call `alterationBuilder.buildNewSnapshot()`, in which case, a new snapshot for the base graph is created and that snapshot contains all the providers of the base graph excluding the removed providers, and the additionally loaded providers.

23.5.2 Simplifying and Copying Graphs

You can create a simplified version of the graph by calling the `simplify()` method.

- Java
- Python

Java

```
PgxGraph simplify(Collection<VertexProperty<?, ?>> vertexProps,
        Collection<EdgeProperty<?>> edgeProps, MultiEdges multiEdges,
```

```
        SelfEdges selfEdges, TrivialVertices trivialVertices,
        Mode mode, String newGraphName)
```

Python

```
simplify(self, vertex_properties=True, edge_properties=True, keep_multi_edges=False,
                 keep_self_edges=False, keep_trivial_vertices=False, in_place=False,
name=None)
```

The first two arguments (`vertexProps` and `edgeProps`) list which properties will be copied into the newly created simplified graph instance. PGX provides convenience constants `VertexProperty.ALL`, `EdgeProperty.ALL` and `VertexProperty.NONE`, `EdgeProperty.NONE` to specify all properties or none properties to be stored, respectively.

The next three arguments determine which operations will be performed to simplify the graph.

- `multiEdges`: if `MultiEdges.REMOVE_MULTI_EDGES`, eliminate multiple edges between a source vertex and a destination vertex, that is, leave at most one edge between two vertices. `MultiEdges.KEEP_MULTI_EDGES` indicates to keep them. By default, PGX picks one edge out of the multi-edges and takes its properties. See Advanced Multi-Edge Handling for more fine-grained control over the edge properties during simplification.
- `selfEdges`: if `SelfEdges.REMOVE_SELF_EDGES`, eliminate every edge whose source and destination are the same vertex. `SelfEdges.KEEP_MULTI_EDGES` indicates to keep them.
- `trivialVertices`: if `TrivialVertices.REMOVE_TRIVIAL_VERTICES`, eliminate all the vertices that have neither incoming edges nor outgoing edges. `TrivialVertices.KEEP_TRIVIAL_VERTICES` indicates to keep them.

The `mode` argument, if set to `Mode.MUTATE_IN_PLACE` , requests that the mutation occurs directly on the specified graph instance without creating a new one. If set to `Mode.CREATE_COPY`, the method will create a new graph instance with the new name in `newGraphName`. If `newGraphName` is omitted (or `null`), PGX will generate a unique graph name.

The return value of this method is the simplified `PgxGraph` instance.

The `Mode.MUTATE_IN_PLACE` option is only applicable if the graph is marked as mutable. Every graph is immutable by default when loaded into PGX. To make a `PgxGraph` mutable, the client should create a private copy of the graph first, using one of the following methods:

- Java
- Python

Java

```
PgxGraph clone()
PgxGraph clone(String newGraphName)
PgxGraph clone(Collection<VertexProperty<?, ?>> vertexProps,
Collection<EdgeProperty<?>> edgeProps, String newGraphName)
```

Python

```
clone(self, vertex_properties=True, edge_properties=True, name=None)
```

As with `simplify()`, the user can specify optional properties of the graph to copy with `vertexProps` and `edgeProps`. If no properties are specified, all of the original graph's properties will be copied into the new graph instance. The user can specify the name of the newly created graph instance with `newGraphName`.

23.5.3 Transposing Graphs

You can create a transposed version of the graph.

- Java
- Python

Java

```
PgxGraph transpose(Collection<VertexProperty<?, ?>> vertexProps,
                     Collection<EdgeProperty<?>> edgeProps,
                     Map<String, String> edgeLabelMapping,
                     Mode mode, String newGraphName)
```

Python

```
transpose(self, vertex_properties=True, edge_properties=True,
edge_label_mapping=None, in_place=False,
                  name=None)
```

The `edgeLabelMapping` argument can be used to rename edge labels. If any key in the given map does not exist as an edge label, it will be ignored.

`edgeLabelMapping` argument can also be an empty Map or null.

- `null`: if argument is `null`, edge labels from source graph will be removed on transposed graph. (default behavior when using convenience methods).
- `empty Map`: if argument is an empty Map, edge labels from source graph will be neither removed or renamed. Instead, it will be kept as it is in source graph.

See Simplifying and Copying Graphs for the meaning of the other parameters.

Additionally, the graph server (PGX) provides the following convenience methods from the `PgxGraph` class for the common operation of copying all vertex and edge properties into the transposed graph instance:

- `transpose(Mode mode, String newGraphName)`
- `transpose(String newGraphName)`
- `transpose(Mode mode)`

23.5.4 Undirecting Graphs

The following methods create the undirected version of a graph instance:

- Java
- Python

Java

```
PgxGraph undirect()
PgxGraph undirect(String newGraphName)
PgxGraph undirect(MultiEdges multiEdges, SelfEdges selfEdges,
TrivialVertices trivialVertices, Mode mode, String newGraphName)
PgxGraph undirect(Collection<VertexProperty<?, ?>> vertexProps,
Collection<EdgeProperty<?>> edgeProps, MultiEdges multiEdges, SelfEdges
selfEdges, Mode mode, String newGraphName)
```

Python

```
undirect(self, vertex_properties=True, edge_properties=True,
keep_multi_edges=True, keep_self_edges=True,
                 keep_trivial_vertices=True, in_place=False, name=None)
```

The first two methods create an undirected version of the graph while copying all of the vertex properties. `newGraphName` is an optional argument to specify the name of the newly created graph instance.

In contrast, the third and fourth methods concurrently perform *undirecting* and *simplifying* of a graph. See Simplifying and Copying Graphs for the meaning of each parameter.

All methods return an object of the undirected `PgxGraph` type.

An undirected graph has some restrictions. Some algorithms are only supported on directed graphs or are not yet supported for undirected graphs. Further, PGX does not support to store undirected graphs nor reading from undirected formats. Since the edges do not have a direction anymore, the behavior of `pgxEdge.getSource()` or `pgxEdge.getDestination()` can be ambiguous. In order to provide deterministic results, PGX will always return the vertex with the smaller internal id as source and the other as destination vertex.

23.5.5 Advanced Multi-Edge Handling

Both `simplify()` and `undirect()` support the removal of multi-edges using `MultiEdges.REMOVE_MULTI_EDGES`. If this parameter is set, all multi-edges in this graph are removed, that is, collapsed. Whenever several multi-edges with edge properties are collapsed into one edge, you can choose one of the following two strategies supported by the graph server (PGX) to decide how to treat the corresponding properties:

- Picking
- Merging

If you choose picking, the graph server (PGX) picks one edge out of every set of multi-edges and copies all its properties including the edge label and key into the new graph. In the case of merging, the graph server (PGX) creates a completely new edge out for every set of multi-edges. PGX determines the properties of these new edges by applying a `MergingFunction` on every property of the multi-edges.

If there are no multi-edges between two vertices, that is, zero or only one edge, the chosen strategy does not have an effect on the outcome. The edge is kept with all its properties as it is.

- Picking
- Merging
- StrategyBuilder in General

23.5.5.1 Picking

This strategy can be used to pick an edge out of multi-edges. The graph server (PGX) allows the user to define several picking criteria. You can pick by:

- Property
- Label
- Edge-ID

Every picking criteria has to be combined with a `PickingStrategyFunction`. PGX supports either `PickingStrategyFunction.MIN` and `PickingStrategyFunction.MAX`, which picks the edge whose property/label/id is either minimal or maximal. If one does not specify a picking criteria, PGX will non-deterministically pick an edge out of the multi-edges.

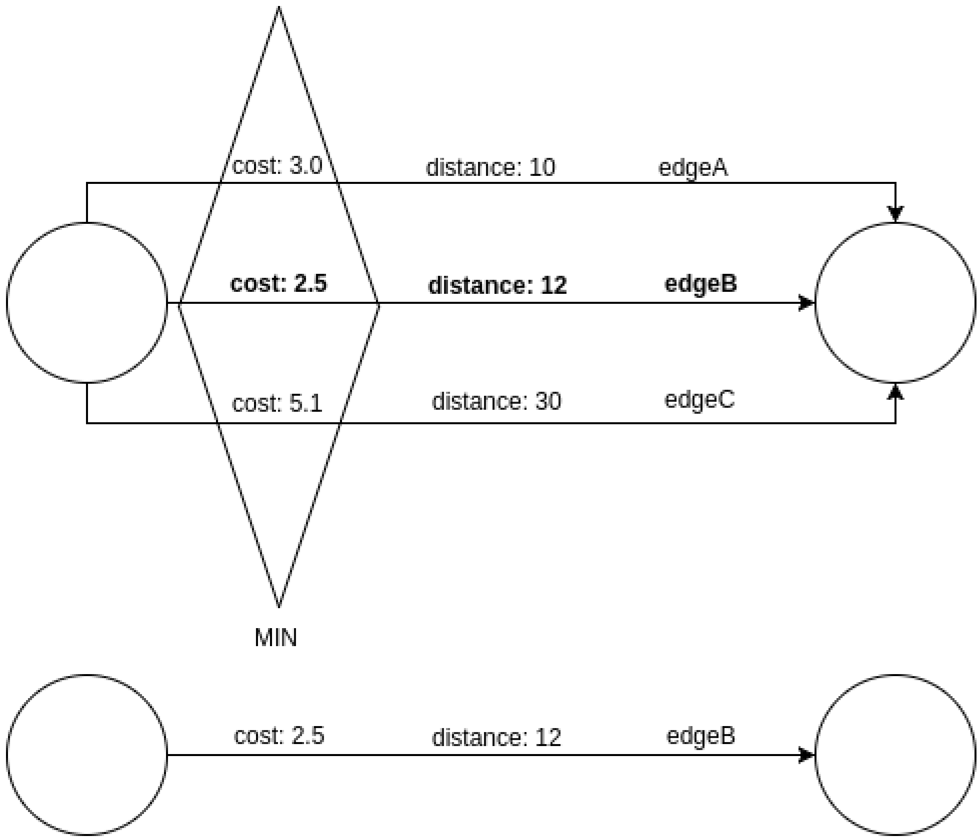
A PickingStrategy can be created using a `PickingStrategyBuilder`, which can be retrieved by calling `createPickingStrategyBuilder()` on the target graph.

You can call one of the following functions as per your chosen picking criteria:

```
PickingStrategyBuilder setPickByEdgeId(PickingStrategyFunction
pickingStrategyFunction)
PickingStrategyBuilder setPickByLabel(PickingStrategyFunction
pickingStrategyFunction)
PickingStrategyBuilder setPickByProperty(EdgeProperty edgeProperty,
PickingStrategyFunction pickingStrategyFunction)
PickingStrategyBuilder setPickByProperty(String propertyName,
PickingStrategyFunction pickingStrategyFunction)
```

The following figure shows how PGX picks the edge with the *minimal* cost and takes all its properties.

Figure 23-1 Picking Strategy



23.5.5.2 Merging

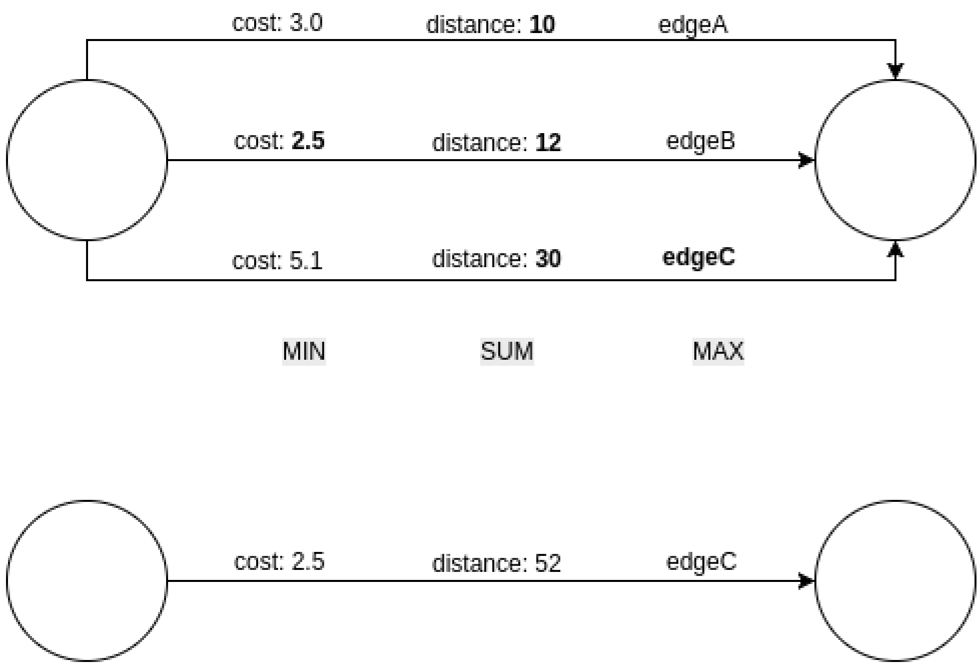
This strategy can be used to merge the properties of multi-edges. The graph server (PGX) allows the user to define a `MergingFunction` for every property. Currently, PGX supports the following functions:

- `MergingFunction.MIN`
- `MergingFunction.MAX`
- `MergingFunction.SUM`

> **Note:**
>
> SUM is only defined on numeric properties.

The following figure shows how the graph server (PGX) merges the different edge properties and labels. It takes the *minimal* cost, the *sum* of distances and the *maximal* edge label.

Figure 23-2 Merging Strategy



23.5.5.3 StrategyBuilder in General

By default, both the StrategyBuilders use the same values as in the convenience methods of `simplify()` and `undirect()`. This includes that all properties are kept by default. If one wants to drop specific properties, one can either use the `dropVertexProperty()` or `dropEdgeProperty()` functions.

```
MutationStrategyBuilder setNewGraphName(String newGraphName)
MutationStrategyBuilder setCopyMode(Mode mode)
MutationStrategyBuilder setTrivialVertices(TrivialVertices
trivialVertices)
MutationStrategyBuilder setSelfEdges(SelfEdges selfEdges)
MutationStrategyBuilder setMultiEdges(MultiEdges multiEdges)
MutationStrategyBuilder
dropVertexProperties(Collection<VertexProperty<?, ?>> vertexProperty)
MutationStrategyBuilder dropEdgeProperties(Collection<EdgeProperty<?>>
edgeProperty)
MutationStrategyBuilder dropVertexProperty(VertexProperty<?, ?>
vertexProperty)
MutationStrategyBuilder dropEdgeProperty(EdgeProperty<?> edgeProperty)
MutationStrategy build()
```

`Simplify()` and `undirect()` can be called using a `MutationStrategy` as follows:

```
MutationStrategy strategy = strategyBuilder.build()
PgxGraph simplifiedGraph graph.simplify(strategy)
//OR
PgxGraph undirectedGraph graph.undirect(strategy)
```

23.5.6 Creating a Subgraph

PGX provides the following methods for creating subgraphs via a filter (see Filter Expressions for more information) expression:

- Java
- Python

Java

```
PgxGraph filter(GraphFilter graphFilter)
PgxGraph filter(GraphFilter graphFilter, String newGraphName)
PgxGraph filter(Collection<VertexProperty<?, ?>> vertexProps,
Collection<EdgeProperty<?>> edgeProps, GraphFilter graphFilter, String
newGraphName)
```

Python

```
filter(self, graph_filter, vertex_properties=True, edge_properties=True,
name=None)
```

As in the other graph mutating methods, the user has the option to specify the name of the subgraph with the `newGraphName` parameter and of choosing the vertex and edge properties to be copied into the subgraph (`vertexProps` and `edgeProps`). All of the preceding methods return a `PgxGraph` object which represents the created subgraph.

All filter methods require a `GraphFilter` argument containing a filter expression. Fundamentally, the filter expression is a Boolean expression that is evaluated for every vertex and edge in the original graph (in parallel). If the expression is evaluated as `true` for the vertex or edge, then that vertex or edge is included in the subgraph.

See Creating Subgraphs for more information on how to create subgraphs from graphs loaded into memory.

23.5.7 Creating a Bipartite Subgraph

The graph server (PGX) enables the client to create a bipartite subgraph. The following methods return the created `BipartiteGraph` instance:

- Java
- Python

Java

```
BipartiteGraph bipartiteSubGraphFromLeftSet(VertexSet<?> vertexSet)
BipartiteGraph bipartiteSubGraphFromLeftSet(VertexSet<?> vertexSet,
String newGraphName)
BipartiteGraph
bipartiteSubGraphFromLeftSet(Collection<VertexProperty<?, ?>>
vertexProps, Collection<EdgeProperty<?>> edgeProps, VertexSet<?>
vertexSet, String newGraphName)
BipartiteGraph
bipartiteSubGraphFromLeftSet(Collection<VertexProperty<?, ?>>
vertexProps, Collection<EdgeProperty<?>> edgeProps, VertexSet<?>
vertexSet, String newGraphName, String isLeftPropName)
```

Python

```
bipartite_sub_graph_from_left_set(self, vset, vertex_properties=True,
edge_properties=True, name=None, is_left_name=None)
```

These methods require an additional argument `vertexSet`, which points to a set of vertices (see Using Collections and Maps for more information) whose elements (vertices) would contain the left vertices (that is, vertices on the left side of the bipartite graph that have only edges to vertices on the right side) in the resulting bipartite graph.

When creating the bipartite subgraph, PGX automatically inserts an additional `boolean` vertex property `isLeft`. The value of this property is set `true` for the left vertices and `false` for the right vertices in the bipartite subgraph. The name of the `isLeft` vertex property can be obtained with `getIsLeftPropertyAsync()` on the returned `BipartiteGraph` object.

The user has the option to specify a name for the newly created graph (`newGraphName`) as well as a custom name for the Boolean left-vertex indicating property (`isLeftPropName`). The user can also specify the vertex and edge properties to be copied into the newly created graph instance (`vertexProps` and `edgeProps`).

23.5.8 Creating a Sparsified Subgraph

The graph server (PGX) supports creating a sparsified subgraph of a graph:

- Java
- Python

Java

```
PgxGraph sparsify(double e)
PgxGraph sparsify(double e, String newGraphName)
```

```
PgxGraph sparsify(Collection<VertexProperty<?, ?>> vertexProps,
Collection<EdgeProperty<?>> edgeProps, double e, String newGraphName)
```

Python

```
sparsify(self, sparsification, vertex_properties=True, edge_properties=True,
name=None)
```

The `double` argument `e` is the sparsification coefficient with a value between `0.0` and `1.0`.

The user again has the option to specify the name for the newly created graph (`newGraphName`) as well as the vertex and edge properties to be copied into the newly created graph instance (`vertexProps` and `edgeProps`).

The returned `PgxGraph` object represents a sparsified subgraph which has fewer edges than the original graph.

23.6 Graph Builder and Graph Change Set

This guide explains the `GraphBuilder` API used for creating graphs and the `GraphChangeSet` interface used for modifying loaded graphs.

- Building Graphs Using GraphBuilder Interface
- Modifying Loaded Graphs Using ChangeSet

23.6.1 Building Graphs Using GraphBuilder Interface

Using the `GraphBuilder` interface, you can create graphs programmatically.

The basic work flow for creating graphs from scratch is:

1. Acquire a modifiable graph builder to accumulate all the new vertices and edges
2. Add vertices and edges to the graph builder
3. Create a `PgxGraph` out of the accumulated changes

- Creating a Simple Graph
- Adding a Vertex Property
- Using Strings as Vertex Identifiers
- Referencing a Vertex for Creating Edges
- Adding an Edge Property and a Label
- Using Graph Builder with Implicit IDs

23.6.1.1 Creating a Simple Graph

This section shows an example of creating a simple graph using the `createGraphBuilder()` method .

- JShell
- Java
- Python

JShell

```
opg4j> var builder = session.createGraphBuilder()
builder ==> GraphBuilderImpl[session=cd201ac9-e73f-447c-9cec-
cd929293acc3,vertexChanges=0,edgeChanges=0]

opg4j> builder.addEdge(1, 2)
opg4j> builder.addEdge(2, 3)
opg4j> builder.addEdge(2, 4)
opg4j> builder.addEdge(3, 4)
opg4j> builder.addEdge(4, 2)

opg4j> var graph = builder.build()
graph ==>
PgxGraph[name=anonymous_graph_16,N=4,E=5,created=1629805890550]
```

Java

```
import oracle.pgx.api.*;

PgxSession session = Pgx.createSession("example");
GraphBuilder<Integer> builder = session.createGraphBuilder();

builder.addEdge(1, 2);
builder.addEdge(2, 3);
builder.addEdge(2, 4);
builder.addEdge(3, 4);
builder.addEdge(4, 2);

PgxGraph graph = builder.build();
```

Python

```
from pypgx import get_session

session = get_session(session_name="example")
builder = session.create_graph_builder()
builder.add_edge(1, 2)
builder.add_edge(2, 3)
builder.add_edge(2, 4)
builder.add_edge(3, 4)
builder.add_edge(4, 2)
graph = builder.build()
```

Also, note that the following:

- A call to `addEdge` consists of the new unique edge ID, the source vertex ID and the destination vertex ID.
- No graph configuration is required.
- When adding edges, all vertices that do not already exist are created on the fly as edges are created.
- `GraphBuilder` supports only the following two generation strategies for creating vertices and edge IDs:
  - USER_IDS (the default value)
  - AUTO_GENERATED

23.6.1.2 Adding a Vertex Property

You can also add vertices separately and assign property values to them.

The following example shows how to add a vertex property using the `GraphBuilder` interface.

- JShell
- Java
- Python

JShell

```
opg4j> var builder = session.createGraphBuilder()
opg4j> builder.addVertex(1).setProperty("double-prop", 0.1)
opg4j> builder.addVertex(2).setProperty("double-prop", 2.0)
opg4j> builder.addVertex(3).setProperty("double-prop", 0.3)
opg4j> builder.addVertex(4).setProperty("double-prop", 4.56789)
opg4j> builder.addEdge(1, 2)
opg4j> builder.addEdge(2, 3)
opg4j> builder.addEdge(2, 4)
opg4j> builder.addEdge(3, 4)
opg4j> builder.addEdge(4, 2)
opg4j> var graph = builder.build()
```

Java

```
import oracle.pgx.api.*;

PgxSession session = Pgx.createSession("example");
GraphBuilder<Integer> builder = session.createGraphBuilder();

builder.addVertex(1).setProperty("double-prop", 0.1);
builder.addVertex(2).setProperty("double-prop", 2.0);
```

```
builder.addVertex(3).setProperty("double-prop", 0.3);
builder.addVertex(4).setProperty("double-prop", 4.56789);

builder.addEdge(1, 2);
builder.addEdge(2, 3);
builder.addEdge(2, 4);
builder.addEdge(3, 4);
builder.addEdge(4, 2);

PgxGraph graph = builder.build();
```

Python

```
from pypgx import get_session

session = get_session(session_name="example")
builder = session.create_graph_builder()

builder.add_vertex(1).set_property("double-prop", 0.1)
builder.add_vertex(2).set_property("double-prop", 2.0)
builder.add_vertex(3).set_property("double-prop", 0.3)
builder.add_vertex(4).set_property("double-prop", 4.56789)

builder.add_edge(1, 2)
builder.add_edge(2, 3)
builder.add_edge(2, 4)
builder.add_edge(3, 4)
builder.add_edge(4, 2)

graph=builder.build()
```

If the value for a property is missing for a vertex or an edge, a default value is assumed as shown:

Table 23-4 Default Property Values

Properties	Default Values
Numeric	`0` (or the respective equivalent)
Boolean	`false`
Date	`1.1.1970 00:00:00`
String	`null`

> **Tip:**
>
> Multiple calls to `setProperty` can be chained to set multiple property values at once.

23.6.1.3 Using Strings as Vertex Identifiers

By default, `integer` vertex IDs are used to identify a vertex. But, the type of the vertex ID can also be a `long` or a `string`.

In order to implement this, you must specify the vertex ID type when creating the graph using the `GraphBuilder` as shown:

- JShell
- Java
- Python

JShell

```
opg4j> GraphBuilder<String> builder =
session.createGraphBuilder(IdType.STRING)
opg4j> builder.addVertex("vertex 1").setProperty("double-prop", 0.1)
opg4j> builder.addVertex("vertex 2").setProperty("double-prop", 2.0)
opg4j> builder.addVertex("vertex 3").setProperty("double-prop", 0.3)
opg4j> builder.addVertex("vertex 4").setProperty("double-prop", 4.56789)
opg4j> builder.addEdge("vertex 1", "vertex 2")
opg4j> builder.addEdge("vertex 2", "vertex 3")
opg4j> builder.addEdge("vertex 2", "vertex 4")
opg4j> builder.addEdge("vertex 3", "vertex 4")
opg4j> builder.addEdge("vertex 4", "vertex 2")

opg4j> var graph = builder.build()
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.common.types.IdType;

PgxSession session = Pgx.createSession("example");
GraphBuilder<String> builder = session.createGraphBuilder(IdType.STRING);

builder.addVertex("vertex 1").setProperty("double-prop", 0.1);
builder.addVertex("vertex 2").setProperty("double-prop", 2.0);
builder.addVertex("vertex 3").setProperty("double-prop", 0.3);
builder.addVertex("vertex 4").setProperty("double-prop", 4.56789);

builder.addEdge("vertex 1", "vertex 2");
builder.addEdge("vertex 2", "vertex 3");
builder.addEdge("vertex 2", "vertex 4");
builder.addEdge("vertex 3", "vertex 4");
builder.addEdge("vertex 4", "vertex 2");

PgxGraph graph = builder.build();
```

Python

```
from pypgx import get_session

session = get_session(session_name="example")
builder = session.create_graph_builder(id_type='string')
builder.add_vertex("vertex 1").set_property("double-prop", 0.1)
builder.add_vertex("vertex 2").set_property("double-prop", 2.0)
builder.add_vertex("vertex 3").set_property("double-prop", 0.3)
builder.add_vertex("vertex 4").set_property("double-prop", 4.56789)

builder.add_edge("vertex 1", "vertex 2")
builder.add_edge("vertex 2", "vertex 3")
builder.add_edge("vertex 2", "vertex 4")
builder.add_edge("vertex 3", "vertex 4")
builder.add_edge("vertex 4", "vertex 2")

graph = builder.build()
```

23.6.1.4 Referencing a Vertex for Creating Edges

You can also avoid entering the full vertex ID when adding an edge. For this, you must obtain a reference to the vertex that is created, which can be later used in the `addEdge` statement.

- JShell
- Java
- Python

JShell

```
opg4j> GraphBuilder<String> builder =
session.createGraphBuilder(IdType.STRING)

opg4j> var v1 = builder.addVertex("vertex 1").setProperty("double-
prop", 0.1)
opg4j> var v2 = builder.addVertex("vertex 2").setProperty("double-
prop", 2.0)
opg4j> var v3 = builder.addVertex("vertex 3").setProperty("double-
prop", 0.3)
opg4j> var v4 = builder.addVertex("vertex 4").setProperty("double-
prop", 4.56789)

opg4j> builder.addEdge(v1, v2)
opg4j> builder.addEdge(v2, v3)
opg4j> builder.addEdge(v2, v4)
opg4j> builder.addEdge(v3, v4)
```

```
opg4j> builder.addEdge(v4, v2)

opg4j> var graph = builder.build()
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.common.types.IdType;

PgxSession session = Pgx.createSession("example");
GraphBuilder<String> builder = session.createGraphBuilder(IdType.STRING);

VertexBuilder<String> v1 = builder.addVertex("vertex 1").setProperty("double-
prop", 0.1);
VertexBuilder<String> v2 = builder.addVertex("vertex 2").setProperty("double-
prop", 2.0);
VertexBuilder<String> v3 = builder.addVertex("vertex 3").setProperty("double-
prop", 0.3);
VertexBuilder<String> v4 = builder.addVertex("vertex 4").setProperty("double-
prop", 4.56789);

builder.addEdge(v1, v2);
builder.addEdge(v2, v3);
builder.addEdge(v2, v4);
builder.addEdge(v3, v4);
builder.addEdge(v4, v2);

PgxGraph graph = builder.build();
```

Python

```
from pypgx import get_session

session = get_session(session_name="example")
builder = session.create_graph_builder(id_type='string')

v1 = builder.add_vertex("vertex 1").set_property("double-prop", 0.1)
v2 = builder.add_vertex("vertex 2").set_property("double-prop", 2.0)
v3 = builder.add_vertex("vertex 3").set_property("double-prop", 0.3)
v4 = builder.add_vertex("vertex 4").set_property("double-prop", 4.56789)

builder.add_edge(v1, v2)
builder.add_edge(v2, v3)
builder.add_edge(v2, v4)
builder.add_edge(v3, v4)
builder.add_edge(v4, v2)

graph = builder.build()
```

23.6.1.5 Adding an Edge Property and a Label

The following examples show how to add an edge property and a label to a graph.

- JShell
- Java
- Python

JShell

```
opg4j> var builder = session.createGraphBuilder(IdType.STRING)

opg4j> var v1 = builder.addVertex("vertex 1").setProperty("double-
prop", 0.1)
opg4j> var v2 = builder.addVertex("vertex 2").setProperty("double-
prop", 2.0)
opg4j> var v3 = builder.addVertex("vertex 3").setProperty("double-
prop", 0.3)
opg4j> var v4 = builder.addVertex("vertex 4").setProperty("double-
prop", 4.56789)

opg4j> builder.addEdge(v1, v2).setProperty("edge-prop",
"edge_prop_1_2").setLabel("label")
opg4j> builder.addEdge(v2, v3).setProperty("edge-prop",
"edge_prop_2_3").setLabel("label")
opg4j> builder.addEdge(v2, v4).setProperty("edge-prop",
"edge_prop_2_4").setLabel("label")
opg4j> builder.addEdge(v3, v4).setProperty("edge-prop",
"edge_prop_3_4").setLabel("label")
opg4j> builder.addEdge(v4, v2).setProperty("edge-prop",
"edge_prop_4_2").setLabel("label")

opg4j> var graph = builder.build()
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.common.types.IdType;

PgxSession session = Pgx.createSession("example");
GraphBuilder<String> builder =
session.createGraphBuilder(IdType.STRING);

VertexBuilder<String> v1 = builder.addVertex("vertex
1").setProperty("double-prop", 0.1);
VertexBuilder<String> v2 = builder.addVertex("vertex
2").setProperty("double-prop", 2.0);
VertexBuilder<String> v3 = builder.addVertex("vertex
3").setProperty("double-prop", 0.3);
```

```
VertexBuilder<String> v4 = builder.addVertex("vertex 4").setProperty("double-
prop", 4.56789);

builder.addEdge(v1, v2).setProperty("edge-prop",
"edge_prop_1_2").setLabel("label");
builder.addEdge(v2, v3).setProperty("edge-prop",
"edge_prop_2_3").setLabel("label");
builder.addEdge(v2, v4).setProperty("edge-prop",
"edge_prop_2_4").setLabel("label");
builder.addEdge(v3, v4).setProperty("edge-prop",
"edge_prop_3_4").setLabel("label");
builder.addEdge(v4, v2).setProperty("edge-prop",
"edge_prop_4_2").setLabel("label");

PgxGraph graph = builder.build();
```

Python

```
from pypgx import get_session

session = get_session(session_name="example")
builder = session.create_graph_builder(id_type='string')

v1 = builder.add_vertex("vertex 1").set_property("double-prop", 0.1)
v2 = builder.add_vertex("vertex 2").set_property("double-prop", 2.0)
v3 = builder.add_vertex("vertex 3").set_property("double-prop", 0.3)
v4 = builder.add_vertex("vertex 4").set_property("double-prop", 4.56789)

builder.add_edge(v1, v2).set_property("edge-prop",
"edge_prop_1_2").set_label("label")
builder.add_edge(v2, v3).set_property("edge-prop",
"edge_prop_2_3").set_label("label")
builder.add_edge(v2, v4).set_property("edge-prop",
"edge_prop_2_4").set_label("label")
builder.add_edge(v3, v4).set_property("edge-prop",
"edge_prop_3_4").set_label("label")
builder.add_edge(v4, v2).set_property("edge-prop",
"edge_prop_4_2").set_label("label")

graph = builder.build()
```

23.6.1.6 Using Graph Builder with Implicit IDs

The `GraphBuilder` supports an `AUTO_GENERATED` generation strategy that allows to omit the edge or vertex IDs.

In this generation strategy, the graph server (PGX) will automatically assign IDs to the entities being added to the changeset. `PgxSession` supports `createGraphBuilder(IdGenerationStrategy vertexIdGenerationStrategy, IdGenerationStrategy edgeIdGenerationStrategy)` and `createGraphBuilder(IdType`

`idType, IdGenerationStrategy vertexIdGenerationStrategy, IdGenerationStrategy edgeIdGenerationStrategy)` to specify the `IdGenerationStrategy`.

The following example illustrates creating a graph with three vertices and three edges using the `GraphBuilder` interface.

- JShell
- Java
- Python

JShell

```
opg4j> var builder =
session.createGraphBuilder(IdGenerationStrategy.AUTO_GENERATED,
IdGenerationStrategy.AUTO_GENERATED)

opg4j> var v1 = builder.addVertex()
opg4j> var v2 = builder.addVertex()
opg4j> var v3 = builder.addVertex()
opg4j> builder.addEdge(v1, v2)
opg4j> builder.addEdge(v1, v3)
opg4j> builder.addEdge(v3, v2)
opg4j> var graph = builder.build()
```

Java

```
import oracle.pgx.api.*;

PgxSession session = Pgx.createSession("example");
GraphBuilder<Integer> builder =
session.createGraphBuilder(IdGenerationStrategy.AUTO_GENERATED,
IdGenerationStrategy.AUTO_GENERATED);

VertexBuilder<Integer> v1 = builder.addVertex();
VertexBuilder<Integer> v2 = builder.addVertex();
VertexBuilder<Integer> v3 = builder.addVertex();
builder.addEdge(v1, v2);
builder.addEdge(v1, v3);
builder.addEdge(v3, v2);

PgxGraph graph = builder.build();
```

Python

```
>>> builder =
session.create_graph_builder(vertex_id_generation_strategy='auto_genera
ted', edge_id_generation_strategy='auto_generated')
>>> v1 = builder.add_vertex()
```

```
>>> v2 = builder.add_vertex()
>>> v3 = builder.add_vertex()
>>> builder.add_edge(v1, v2)
>>> builder.add_edge(v1, v3)
>>> builder.add_edge(v3, v2)
>>> graph = builder.build()
```

23.6.2 Modifying Loaded Graphs Using ChangeSet

This guide explains how to add and remove vertices and edges from already loaded graphs.

As a prerequisite, you must have a graph already loaded into the graph server (PGX). See Reading Graphs from Oracle Database into the Graph Server (PGX) for more information.

You can now use the `GraphChangeSet` interface to modify the loaded graphs.

> **Note:**
>
> Modifying undirected graphs is not supported in graph server (PGX) 21.3.

- Modifying Vertices
- Adding Edges
- GraphChangeSet with Partitioned IDs
- Error Handling when Using a ChangeSet

23.6.2.1 Modifying Vertices

You can add, remove and modify vertices using the `GraphChangeSet` object.

- JShell
- Java
- Python

JShell

```
opg4j> var changeSet = graph.<Integer>createChangeSet()

opg4j> changeSet.addVertex(42).setProperty("prop", 23)
opg4j> changeSet.updateVertex(128).setProperty("prop", 5)
opg4j> changeSet.removeVertex(1908)

opg4j> var updatedGraph = changeSet.build()
```

```
opg4j> updatedGraph.hasVertex(42) // Evaluates to: true
opg4j> updatedGraph.hasVertex(1908) // Evaluates to: false
```

Java

```
import oracle.pgx.api.*;

GraphChangeSet<Integer> changeSet = graph.createChangeSet();

changeSet.addVertex(42).setProperty("prop", 23);
changeSet.updateVertex(128).setProperty("prop", 5);
changeSet.removeVertex(1908);

PgxGraph updatedGraph = changeSet.build();
```

Python

```
from pypgx.api import *

change_set = graph.create_change_set()

change_set.add_vertex(42).set_property("prop", 23)
changeSet.update_vertex(128).set_property("prop", 5)
changeSet.remove_vertex(1908)

updated_graph = change_set.build()
```

23.6.2.2 Adding Edges

You can also add edges to a graph using `GraphChangeSet`.

- JShell
- Java
- Python

JShell

```
opg4j> var changeSet2 = updatedGraph.<Integer>createChangeSet()

opg4j> changeSet2.addEdge(333, 42).setProperty("cost", 42.3)
opg4j> changeSet2.addEdge(42, 99)

opg4j> var updatedGraph2 = changeSet2.build()
```

Java

```
import oracle.pgx.api.*;

GraphChangeSet<Integer> changeSet2 = graph.createChangeSet();

changeSet2.addEdge(333, 42).setProperty("cost", 42.42);
changeSet2.addEdge(42, 99);

PgxGraph updatedGraph2 = changeSet2.build();
```

Python

```
from pypgx.api import *

change_set_2 = graph.create_change_set()
changeSet2.add_edge(333, 42).set_property("cost", 42.42)
changeSet2.add_edge(42, 99)
updated_graph_2 = change_set_2.build()
```

Note that by calling `changeSet2.build()`, you created a brand new graph with a unique name assigned by the graph server (PGX). If need be, you can specify a name argument to the `build()` method.

Additionally, you can create a new snapshot on top of the current graph with the `buildNewSnapshot()` method. See Creating a Snapshot via ChangeSet for more information.

23.6.2.3 GraphChangeSet with Partitioned IDs

You can use the `GraphChangeSet` API with graph with partitioned IDs. Ensure to set both the vertex ID generation strategy as well as the edge ID generation strategy to `IdGenerationStrategy.USER_IDS`. Furthermore, make sure to set the vertex ID type to `String`. An edge ID type does not need to be specified.

You can add, update and remove vertices and edges as shown in the following examples:

- Java
- Python

Java

```
GraphChangeSet<String> changeSet =
g.createChangeSet(IdGenerationStrategy.USER_IDS,
IdGenerationStrategy.USER_IDS);
changeSet.addVertex("Accounts(1002)").setProperty("NAME","User1002");
changeSet.updateVertex("Accounts(4)").setProperty("NAME","User4");
changeSet.removeVertex("Accounts(3)");
changeSet.addEdge("Transfers(5002)", "Accounts(5)",
```

```
"Accounts(6)").setProperty("AMOUNT", 12.50);
changeSet.updateEdge("Transfers(5)").setProperty("DESCRIPTION",
'Transfer from User');
changeSet.removeEdge("Transfers(5001)");
PgxGraph g1 = changeSet.build();
```

Python

```
change_set = graph.create_change_set(vertex_id_generation_strategy =
'user_ids', edge_id_generation_strategy = 'user_ids')
change_set.add_vertex("Accounts(1002)").set_property("NAME",
"User1002")
change_set.update_vertex("Accounts(4)").set_property("NAME", "User4")
change_set.remove_vertex("Accounts(3)")
change_set.remove_edge("Transfers(5001)")
PgxGraph g1 = change_set.build()
```

Note:

You cannot use the `setLabel()` API when IDs are partitioned. The vertex or edge will be labelled automatically based on the label attached to the provider (for which the name is provided as part of the ID). Similarly, you cannot set the vertex or edge key properties through the `setProperty()` API as the value is already extracted from the vertex or edge ID.

23.6.2.4 Error Handling when Using a ChangeSet

Error handling while populating a `ChangeSet` or while applying a `ChangeSet` to the existing graph can be configured by setting the `InvalidChangePolicy`. The options are:

- `OnInvalidChange.ERROR`: throws an exception (This is the default configuration)
- `OnInvalidChange.IGNORE`: ignores the issue and continues
- `OnInvalidChange.IGNORE_AND_LOG`: ignores the issue, logs in `DEBUG` log level and continues
- `OnInvalidChange.IGNORE_AND_LOG_ONCE`: only logs the first occurrence of each issue type

Issues that can be ignored with `InvalidChangePolicy` include trying to remove a vertex or an edge that does not exist in the graph, property type mismatch, updates to non existing properties, providing a vertex ID with wrong type or invalid vertex or edge providers.

The following example, tries to remove vertex `9032` which does not exist in the graph. By configuring `IGNORE_AND_LOG`, this action will be ignored while the property value update for vertex `99` will be applied successfully.

- JShell
- Java

JShell

```
opg4j> var changeSet3 = updatedGraph2.<Integer>createChangeSet()
opg4j> changeSet3.setInvalidChangePolicy(OnInvalidChange.IGNORE_AND_LOG)

opg4j> changeSet3.removeVertex(9032)
opg4j> changeSet3.updateVertex(99).setProperty("prop1", 17)
opg4j> var updatedGraph3 = changeSet3.build() // will log that a vertex
removal was ignored

opg4j> var prop1Val = updatedGraph3.getVertex(99).getProperty("prop1") //
evaluates to 17
```

Java

```
import oracle.pgx.api.*;

GraphChangeSet<Integer> changeSet3 = graph.createChangeSet();
changeSet3.setInvalidChangePolicy(OnInvalidChange.IGNORE_AND_LOG);
changeSet3.removeVertex(9032);
changeSet3.updateVertex(99).setProperty("prop1", 17);
PgxGraph updatedGraph3 = changeSet3.build(); // will log that a vertex
removal was ignored

int prop1Val = updatedGraph3.getVertex(99).getProperty("prop1"); //
evaluates to 17
```

Note:

When connecting to a remote graph server (PGX), error handling log messages will not be relayed to the client. In such a case, you need access to the server logs to determine which issues have been ignored. For this, you must update the default Logback configuration file in `/etc/oracle/graph/logback.xml` and the graph server (PGX) logger configuration file in `/etc/oracle/graph/logback-server.xml` to log the DEBUG logs. You can then view the ignored issues in `/var/opt/log/pgx-server.log` file.

Add Existing Edges and Vertices

The error handling for adding a vertex or an edge where its ID is already used in the graph or in an incompatible ChangeSet action can be configured with `AddExistingVertexPolicy` and `AddExistingEdgePolicy`.

> **Note:**
>
> The default setting for `AddExistingVertexPolicy` and `AddExistingEdgePolicy` is `IGNORE`. This is different from `InvalidChangePolicy` where the default is `ERROR`.

23.7 Managing Transient Data

This guide discusses how to handle transient properties and collections.

The graph server (PGX) allows each client to maintain its own isolated workspace, called session. Clients may create additional data objects in their own session, which they can then use for analysis.

- Managing Transient Properties
- Managing Collections and Scalars

23.7.1 Managing Transient Properties

The graph server (PGX) adopts the Property Graph data model. Once a graph is loaded into PGX, the graph instance itself and its original properties are set as immutable. However, the client can create and attach additional properties to the graph dynamically. These extra properties are referred to as *transient* properties and are mutable by the client

The methods for creating transient properties are available in `PgxGraph`:

- Java
- Python

Java

```
VertexProperty<ID, V> createVertexPropertyAsync(PropertyType type)
VertexProperty<ID, V> createVertexPropertyAsync(PropertyType type,
String name)
EdgeProperty<V> createEdgePropertyAsync(PropertyType type)
EdgeProperty<V> createEdgePropertyAsync(PropertyType type, String name)
```

In the preceding code:

- `PropertyType`: is an `enum` for the data type of the property, which must be one of the primitive types supported by PGX.
- `name`: is an optional argument to assign a unique name to the newly created property. If no name is specified, PGX will assign one to the client.

> **Note:**
>
> Names must be unique. There cannot be two different vertex or edge properties for the same graph and with the same name.

Python

```
create_vertex_property(self,data_type,name=None)
```

All methods return a `Property` object, which represent the newly created transient property. Both of the underlying classes, `VertexProperty<ID, V>` and `EdgeProperty<V>`, are parametrized with the value type `V` the property holds. `V` matches the given `PropertyType`. `VertexProperty<ID, V>` is additionally parametrized with the vertex ID type. This is due to PGX support of several types of vertex identifiers. See our graph configuration chapter on how to specify the vertex ID type of a graph. `EdgeProperty<V>` is not parametrized with the edge ID type, because PGX only supports edge identifiers of type `long`.

- Java
- Python

Java

```
GraphConfig config = GraphConfigBuilder.forFileFormats(...)
    ...
    .setVertexIdType(IdType.LONG)
    ...
    .build();

PgxGraph G = session.readGraphWithProperties(config);
VertexProperty<Long, String> p1 =
G.createVertexProperty(PropertyType.STRING);
EdgeProperty<Double> p2 = G.createEdgeProperty(PropertyType.DOUBLE);
```

Python

```
G = session.read_graph_with_properties(config)
p1 = G.create_vertex_property("string")
p2 = G.create_edge_property("double")
```

To delete a transient property from the session, call `destroyAsync()` (or `destroy()`) on the property object.

23.7.2 Managing Collections and Scalars

The client can create graph-bound vertex and edge collections to use during the analysis with the following methods in `PgxGraph`:

- Java
- Python

Java

```
VertexSequence<E> createVertexSequence()
VertexSequence<E> createVertexSequence(String name)
VertexSet<E> createVertexSet()
VertexSet<E> createVertexSet(String name)
EdgeSequence createEdgeSequence()
EdgeSequence createEdgeSequence(String name)
EdgeSet createEdgeSet()
EdgeSet createEdgeSet(String name)
```

Python

```
create_edge_sequence(self, name=None)
create_vertex_sequence(self, name=None)
create_edge_set(self, name=None)
create_edge_sequence(self, name=None)
```

PGX also supports scalar collections such as `set` and `sequence`. Each of these collections can hold elements of various primitive data types like `INTEGER`, `LONG`, `FLOAT`, `DOUBLE` or `BOOLEAN`. Scalar collections are session-bound and can be created with the following methods in `PgxSession`:

```
ScalarSet<T> createSet(PropertyType contentType, String name)
ScalarSequence<T> createSequence(PropertyType contentType, String name)
ScalarSet<T> createSet(PropertyType contentType)
ScalarSequence<T> createSequence(PropertyType contentType)
```

In the preceding code, the optional argument (`name`) specifies the name of the newly created collection. If omitted, PGX chooses a name for the client. As with properties, the collections holding vertices are parametrized with the `ID` type of the vertices. Refer to graph configuration chapter to learn how to specify the vertex ID type of a graph.

The return value is the collection object which points to the newly created empty collection.

To drop a collection from the session, call `destroy()` on the collection object.

To check which collections are currently allocated for a graph you can use the following method:

- Java
- Python

Java

```
Map<String, PgxCollection<? extends PgxEntity<?>, ?>> getCollections()
```

Python

```
get_collections(self)
```

The returned map contains the names of the collections as keys and the collections as values. The collections can be casted to the matching collection subclass.

PGX supports special `Map` collection types and allows users to map between different data types (`oracle.pgx.common.types.PropertyType`). Maps can be created using `PgxGraph` or `PgxSession` APIs, the difference is that the latter supports only non graph-related types, and that the created maps directly depend on the session:

```
PgxMap<K, V> createMap(PropertyType keyType, PropertyType valType)
PgxMap<K, V> createMap(PropertyType keyType, PropertyType valType, String
mapName)
```

Similarly, scalar variables can be created in the client session using the following methods:

- Java
- Python

Java

```
Scalar<T> createScalar(PropertyType type, String newScalarName)
Scalar<T> createScalar(PropertyType type)
```

Python

```
create_scalar(self,data_type,name=None)
```

These collections and scalar variables can then be passed as arguments to graph algorithms. See Using Custom PGX Graph Algorithms for more information.

23.8 Graph Versioning

This guide describes the different ways to work with graph snapshots.

A graph can have multiple snapshots associated with it, reflecting different versions of the graph. All snapshots of a graph have the same graph configuration associated.

The following topics explains the various operations you can perform on graph snapshots:

- Configuring the Snapshots Source
- Creating a Snapshot via Refreshing
- Creating a Snapshot via ChangeSet
- Checking Out the Latest Snapshots of a Graph
- Checking Out Different Snapshots of a Graph
- Directly Loading a Specific Snapshot of a Graph

23.8.1 Configuring the Snapshots Source

Snapshots can be created from two sources: **Refreshing** and **ChangeSet**.

Refreshing is available for graphs that are read from a persistent data source, that is, a file. When the data source has changed with respect to the version stored in the graph server (PGX), it can be read again manually by calling the `PgxSession.readGraphWithProperties()` method. Similarly, if auto-refresh is set for the graph, the graph server (PGX) automatically reads the data source and creates new snapshots when the data source has changed.

Instead, a `ChangeSet` is a set of changes to a graph that the user creates and populates via the PGX `ChangeSet` API. Once a `ChangeSet` is created and populated with the desired changes, the user can simply call `GraphChangeSet.buildNewSnapshot()` to create a new snapshot for the graph. In this way, you are empowered to integrate changes coming from any source into the graph and build snapshots out of them.

Only one source of snapshots is allowed for a single graph and is chosen during graph configuration via the `snapshots_source` option, which can be set to either `REFRESH` or `CHANGE_SET`. In case the `snapshots_source` option is not explicitly set by the user, the following default settings apply:

- If the graph is from a persistent data source, the default value is `REFRESH`, so that snapshots can be created only by calling `PgxSession.readGraphWithProperties()` (or via auto-refresh, if configured).
- If the graph is transient, that is, built from a graph builder, the default value is `CHANGE_SET`, since the graph is not backed by a persistent data source from which changes can be read. It is for this reason, `CHANGE_SET` is the only admissible value for transient graphs.

Additionally, the following restrictions apply:

- If auto-refresh is enabled, then snapshots come from reading the backing data source and hence only `REFRESH` is admissible for the `snapshots_source` option.
- If the user attempts to create snapshots in a way that is different from the configuration (for example, by calling `GraphChangeSet.buildNewSnapshot()` when the graph's `snapshots_source` is `REFRESH`), the operation is invalid and an exception is thrown.

23.8.2 Creating a Snapshot via Refreshing

You can create a snapshot via refreshing by performing the following steps:

1. Create a session and load the graph into memory.
2. Check the available snapshots of the graph with `PgxSession.getAvailableSnapshots()` method.

- JShell
- Java
- Python

JShell

```
opg4j> session.getAvailableSnapshots(G)
==> GraphMetaData [getNumVertices()=4, getNumEdges()=4, memoryMb=0,
dataSourceVersion=1453315103000, creationRequestTimestamp=1453315122669
(2016-01-20 10:38:42.669), creationTimestamp=1453315122685 (2016-01-20
10:38:42.685), vertexIdType=integer, edgeIdType=long]
```

Java

```
Deque<GraphMetaData> snapshots = session.getAvailableSnapshots(G);
for( GraphMetaData metaData : snapshots ) {
  System.out.println( metaData );
}
```

Python

```
snapshots = session.get_available_snapshots(G)
for metadata in snapshots:
    print(metadata)
```

3. Edit the source file to contain an additional vertex and an additional edge or insert two rows in the database.
4. Reload the updated graph within the same session as you loaded the original graph. A new snapshot is created.

- JShell
- Java
- Python

JShell

```
opg4j> var G = session.readGraphWithProperties( G.getConfig(),
true )
==> PGX Graph named 'sample_2' bound to PGX session
'a1744e86-65fb-4bd1-b2dc-5458b20954a9' registered at PGX Server
Instance running in embedded mode
opg4j> session.getAvailableSnapshots(G)
==> GraphMetaData [getNumVertices()=4, getNumEdges()=4, memoryMb=0,
dataSourceVersion=1453315103000,
creationRequestTimestamp=1453315122669 (2016-01-20 10:38:42.669),
creationTimestamp=1453315122685 (2016-01-20 10:38:42.685),
vertexIdType=integer, edgeIdType=long]
==> GraphMetaData [getNumVertices()=5, getNumEdges()=5, memoryMb=3,
dataSourceVersion=1452083654000,
creationRequestTimestamp=1453314938744 (2016-01-20 10:35:38.744),
creationTimestamp=1453314938833 (2016-01-20 10:35:38.833),
vertexIdType=integer, edgeIdType=long]
```

Java

```
G = session.readGraphWithProperties( G.getConfig(), true );

Deque<GraphMetaData> snapshots = session.getAvailableSnapshots( G );
```

Python

```
G =
session.read_graph_with_properties(G.config,update_if_not_fresh=True
)
```

Note that there are two `GraphMetaData` objects in the call for available snapshots, one with 4 vertices and 4 edges and one with 5 vertices and 5 edges.

5. Verify that the graph variable points to the newly loaded graph using `getNumVertices()` and `getNumEdges()` methods.

- JShell
- Java
- Python

JShell

```
opg4j> G.getNumVertices()
==> 5
opg4j> G.geNumEdges()
==> 5
```

Java

```
int vertices = G.getNumVertices();
long edges = G.getNumEdges();
```

Python

```
vertices = G.num_vertices
edges = G.num_edges
```

23.8.3 Creating a Snapshot via ChangeSet

You can create a graph snapshot with ChangeSet via the PGX Java API. When you want to create the graph from a persistent data source, you can use `PgxSession.readGraphWithProperties()` with the `snapshots_source` configuration option set to `CHANGE_SET`.
You can create a snapshot via `ChangeSet` by performing the following steps:

1. Create a snapshot of a transient graph from database:

- JShell
- Java
- Python

JShell

```
opg4j> var builder = session.createGraphBuilder()
opg4j> builder.addEdge(1, 2)
opg4j> builder.addEdge(2, 3)
opg4j> builder.addEdge(2, 4)
opg4j> builder.addEdge(3, 4)
opg4j> builder.addEdge(4, 2)
opg4j> var graph = builder.build()
```

Java

```
import oracle.pgx.api.*;
```

```
GraphBuilder<Integer> builder = session.createGraphBuilder();

builder.addEdge(1, 2);
builder.addEdge(2, 3);
builder.addEdge(2, 4);
builder.addEdge(3, 4);
builder.addEdge(4, 2);

PgxGraph graph = builder.build();
```

Python

```
builder = session.create_graph_builder();

builder.add_edge(1, 2)
builder.add_edge(2, 3)
builder.add_edge(2, 4)
builder.add_edge(3, 4)
builder.add_edge(4, 2)

graph = builder.build()
```

2. Create a ChangeSet from `graph` and populate it. The following example shows adding a new edge between vertices 1 and 4:

- JShell
- Java
- Python

JShell

```
opg4j> var changeSet = graph.<Integer>createChangeSet()
opg4j> changeSet.addEdge(6, 1, 4)
```

Java

```
import oracle.pgx.api.*;
GraphChangeSet<Integer> changeSet = graph.createChangeSet();
changeSet.addEdge(6, 1, 4);
```

Python

```
changeSet = graph.create_change_set()changeSet.add_edge(1,4,6)
```

3. Create a second snapshot using `GraphChangeSet.buildNewSnapshot()` as shown in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var secondSnapshot = changeSet.buildNewSnapshot()
opg4j> session.getAvailableSnapshots(secondSnapshot).size()
==> 2
```

Java

```
PgxGraph secondSnapshot = changeSet.buildNewSnapshot();
System.out.println( session.getAvailableSnapshots(secondSnapshot).size() )
;
```

Python

```
second_snapshot = change_set.build_new_snapshot()
print(len(session,get_available_snapshots()))
```

Thus two snapshots, referenced via the variables `graph` and `secondSnapshot` are created.

23.8.4 Checking Out the Latest Snapshots of a Graph

With multiple snapshots of a graph being available and regardless of their source, you can check out a specific snapshot using the `PgxSession.setSnapshot()` method. You can use the `LATEST_SNAPSHOT` constant of `PgxSession` to easily check out the latest available snapshot, as shown in the following example:

- JShell
- Java

JShell

```
opg4j> session.setSnapshot( G, PgxSession.LATEST_SNAPSHOT )
==> null
```

```
opg4j> session.getCreationTimestamp()
==> 1453315122685
```

Java

```
session.setSnapshot( G, PgxSession.LATEST_SNAPSHOT );
System.out.println(session.getCreationTimestamp());
```

See the printed timestamp to verify the most recent snapshot.

23.8.5 Checking Out Different Snapshots of a Graph

You can also check out a specific snapshot, again using the `PgxSession.setSnapshot()`.

For example, consider the following two snapshots of a graph:

```
==> GraphMetaData [getNumVertices()=4, getNumEdges()=4, memoryMb=0,
dataSourceVersion=1453315103000,
creationRequestTimestamp=1453315122669 (2016-01-20 10:38:42.669),
creationTimestamp=1453315122685 (2016-01-20 10:38:42.685),
vertexIdType=integer, edgeIdType=long]
==> GraphMetaData [getNumVertices()=5, getNumEdges()=5, memoryMb=3,
dataSourceVersion=1452083654000,
creationRequestTimestamp=1453314938744 (2016-01-20 10:35:38.744),
creationTimestamp=1453314938833 (2016-01-20 10:35:38.833),
vertexIdType=integer, edgeIdType=long]
```

To check out a specific snapshot of the graph, you must pass the `creationTimestamp` of the snapshot you want to load to `setSnapshot()`.

For example, if `G` is pointing to the newest graph with `5` vertices and `5` edges, but you want to analyze the older graph, you need to set the snapshot to `1453315122685`.

- JShell
- Java
- Python

JShell

```
opg4j> G.getNumVertices()
==> 5
opg4j> G.getNumEdges()
==> 5
opg4j> session.setSnapshot( G, 1453315122685 )
==> null
```

```
opg4j> G.getNumVertices()
==> 4
opg4j> G.getNumEdges()
==> 4
```

Java

```
session.setSnapshot(G,1453315122685);
```

Python

```
session.set_snapshot(G,1453315122685)
```

Note that setting the snapshot, changes the number of vertices and edges from 5 to 4.

Alternatively, you can also retrieve the creation timestamp of each snapshot from its associated `GraphMetaData` object via the `GraphMetaData.getCreationTimestamp()` method. The easiest way to get the `GraphMetaData` information of all the snapshots is to use the `PgxSession.getAvailableSnapshots()` method, which returns a collection of `GraphMetaData` information of each snapshot ordered by creation timestamp from the most recent to the oldest.

23.8.6 Directly Loading a Specific Snapshot of a Graph

You can also load a specific snapshot of a graph directly using the `PgxSession.readGraphAsOf()` method. This is a shortcut for loading a graph with `readGraphWithProperties()` followed by a `setSnapshot()`.
Consider two snapshots of a graph that are already loaded into the PGX session. The following example shows how to get a reference to a specific snapshot:

1. Get a graph configuration for the graph:

- JShell
- Java
- Python

JShell

```
opg4j> var config =
GraphConfigFactory.forAnyFormat().fromPath("<path_to_json>")
==> {"format":"adj_list", ... }
```

Java

```
GraphConfig config =
GraphConfigFactory.forAnyFormat().fromPath("<path_to_json>");
```

Python

```
config =
GraphConfigFactory.for_any_format().from_path("<path_to_json>")
```

2. Check the loaded snapshots for this graph config using `getAvailableSnapshots()`:

- JShell
- Java
- Python

JShell

```
opg4j> session.getAvailableSnapshots(G)
==> GraphMetaData [getNumVertices()=4, getNumEdges()=4, memoryMb=0,
dataSourceVersion=1453315103000,
creationRequestTimestamp=1453315122669 (2016-01-20 10:38:42.669),
creationTimestamp=1453315122685 (2016-01-20 10:38:42.685),
vertexIdType=integer, edgeIdType=long]
==> GraphMetaData [getNumVertices()=5, getNumEdges()=5, memoryMb=3,
dataSourceVersion=1452083654000,
creationRequestTimestamp=1453314938744 (2016-01-20 10:35:38.744),
creationTimestamp=1453314938833 (2016-01-20 10:35:38.833),
vertexIdType=integer, edgeIdType=long]
```

Java

```
Deque<GraphMetaData> snapshots = session.getAvailableSnapshots(G);
```

Python

```
session.get_available_snapshots(G)
```

3. Check out the snapshot of the graph which has 4 vertices and 4 edges and having the timestamp `1453315122685`:

- JShell
- Java
- Python

JShell

```
opg4j> var G = session.readGraphAsOf( config, 1453315122685 )
==> PGX Graph named 'sample' bound to PGX session 'a1744e86-65fb-4bd1-
b2dc-5458b20954a9' registered at PGX Server Instance running in embedded
mode
opg4j> G.getNumVertices()
==> 4
opg4j> G.getNumEdges()
==> 4
```

Java

```
PgxGraph G = session.readGraphAsOf( config, 1453315122685 );
```

Python

```
G = read_graph_as_of(config, creation_timestamp=1453315122685)
```

23.9 Labels and Properties

You can perform various actions on the graph property and label values by executing PGQL queries.

- Setting and Getting Property Values
- Getting Label Values

23.9.1 Setting and Getting Property Values

Getting Property Values

You can obtain the vertex or edge property values by executing a `SELECT` PGQL query on the graph.

For example:

- JShell
- Java

JShell

```
opg4j> session.queryPgql("SELECT e.src_id, e.dest_id, e.amount FROM
MATCH (n:Account) -[e:Transfers]-> (m:Account) on bank_graph").print()
```

Java

```
...
...
PgxGraph g = session.getGraph("bank_graph");
String query =
    "SELECT e.src_id, e.dest_id, e.amount FROM MATCH (n:Account) -
[e:Transfers]-> (m:Account)";
g.queryPgql(query).print();
```

The resulting property values may appear as:

```
+---------------------------+
| src_id | dest_id | amount |
+---------------------------+
| 1      | 259     | 1000   |
| 1      | 418     | 1000   |
| 1      | 584     | 1000   |
| 1      | 644     | 1000   |
| 1      | 672     | 1000   |
| 2      | 493     | 1000   |
| 2      | 546     | 1000   |
| 2      | 693     | 1000   |
| 2      | 833     | 1000   |
| 2      | 840     | 1000   |
+---------------------------+
```

Setting Property Values

You can set the vertex or edge property values by executing insert or update PGQL queries on the graph.

For example, to set a new vertex account ID on a graph using `INSERT` query:

- JShell
- Java

JShell

```
opg4j> PgxGraph g = session.getGraph("bank_graph_analytics")
g ==>
PgxGraph[name=bank_graph_analytics,N=1000,E=5001,created=1616312153556]
opg4j> PgxGraph g_mutable = g.clone("bank_graph_analytics_copy")
```

```
g_mutable ==>
PgxGraph[name=bank_graph_analytics_copy,N=1000,E=5001,created=1616312413799]
opg4j> g_mutable.executePgql("INSERT VERTEX v LABELS (Accounts) PROPERTIES
( v.id = 1001)")
```

Java

```
...
...
PgxGraph g1 = session.readGraphWithProperties("bank_graph_analytics.json");
PgxGraph g2 = g1.clone("bank_graph_analytics_copy");
g2.executePgql("INSERT VERTEX v " +
               "         LABELS ( Accounts ) " +
               "         PROPERTIES ( v.id = 1001 )");
```

23.9.2 Getting Label Values

You can retrieve the vertex or edge label values of a graph as shown:

```
PgxGraph g = session.getGraph("bank_graph_analytics");
String query =
      "SELECT LABEL(v), COUNT(*) "
    + "FROM MATCH (v) "
    + "GROUP BY LABEL(v) "
    + "ORDER BY COUNT(v) DESC";
PgqlResultSet resultSet = g.queryPgql(query);
resultSet.print();
```

The result may appear as shown:

```
+-----------------------+
| LABEL(n)    | COUNT(*) |
+-----------------------+
|  ACCOUNT    | 1000     |
+-----------------------+
```

23.10 Filter Expressions

This guide explains the usage of filter expressions.

Filter expressions are applied in the following scenarios:

- **Path-Finding:** Include only specific vertices and edges in a path
- **Sub-Graphs:** Include only specific vertices and edges in a subgraph
- **Set creation:** Create a vertex or edge set and include only specific vertices or edges

There are two types of filter expressions:

- **Vertex filters:**: Evaluated on each vertex

- **Edge filters:** Evaluated on each edge, including the two vertices it connects.

These filter expressions will evaluate to `true` if the current edge or vertex matches the expression or to `false` if it does not. Filter expressions are stateless and side-effect free.

The following short example below will evaluate to `true` for all edges where the source vertex's string property name is "PGX".

```
src.name="PGX"
```

- Syntax
- Type System
- Path Finding Filters
- Subgraph Filters
- Operations on Filter Expressions

23.10.1 Syntax

Trivial Expressions

Always evaluates to `true`:

```
true
```

Always evaluates to `false`:

```
false
```

Constants

Legal constants are integer, long and floating point numbers of single and double precision as well as strings literals and `true` and `false`. Long constants need to be suffixed with `l` or `L`. Floating point numbers are treated as double precision numbers by default. To force a certain precision you can use `f` or `F` for single precision and `d` or `D` for double precision floating point numbers. String literals are UTF-8 character sequences, surrounded by single or double quotation marks.

```
25
4294967296L
0.62f
0.33d
"Double quoted string"
'Single quoted string'
```

Vertex and Edge Identifiers

Depending on the filter type, different identifiers are valid.

Vertex Filter

Vertex filter expressions have only one keyword that addresses the vertex in the current context.

`vertex` denotes the vertex that is currently being evaluated by the filter expression.

```
vertex
```

Edge Filter

Edge filter expressions have several keywords that addresses the edge or its vertices in the current context.

`edge` denotes the edge that is currently being evaluated by the filter expression.

```
edge
```

`dst` denotes the destination vertex of the current edge. `dst` is only valid in the subgraph context.

```
dst
```

`src` denotes the source vertex of the current edge. `src` is only valid in the subgraph context.

```
src
```

Properties

Filter expressions can access the values of vertex and edge properties.

```
<id>.<property>
```

where:

- `<id>`: is any vertex or edge identifier (that is, `src`, `dst`, `vertex`, `edge`).
- `<property>`: is the name of a vertex or edge property.

> **Note:**
>
> This has to be the name of an edge property if the identifier is `edge`. Otherwise it has to be a vertex property.

If the property name is a reserved name in the filter expression syntax or contains spaces, it must be quoted in single or double quotes.

The following code accesses the 'cost' property of the source vertex.

```
src.cost
```

Temporal properties support values comparison (constants and property values) using special constructors. The default temporal formats are shown in the following table:

Table 23-5 Default Temporal Formats

Property Type	Constructor
DATE	date ('yyyy-MM-dd HH:mm:ss')
LOCAL_DATE	date 'yyyy-MM-dd'

Table 23-5 (Cont.) Default Temporal Formats

Property Type	Constructor
`TIME`	`time 'HH:mm:ss'`
`TIME_WITH_TIMEZONE`	`time 'HH:mm:ss+/-XXX'`
`TIMESTAMP`	`timestamp 'yyyy-MM-dd HH:mm:ss'`
`TIMESTAMP_WITH_TIMEZONE`	`timestamp 'yyyy-MM-dd HH:mm:ss+/-XXX'`

The following expression accesses the property '`timestamp_withTZ`' of an edge and checks if it is equal to `3/27/2007 06:00+01:00`.

```
edge.timestamp_withTZ = timestamp'2007-03-2706:00:00+01:00'
```

> **Note:**
>
> *Properties* of type *date* can only be checked for equality. *date* type usage is deprecated since version 2.5, instead use *local date* or *timestamp* types that support all operations.

Methods

Filter expressions support the following functions:

Degree Functions

1. `outDegree()` returns the number of outgoing edges of the vertex identifier. `degree()` is a synonym for `outDegree`.

   ```
   int <id>.degree()
   int <id>.outDegree()
   ```

   The following example determines whether the `out-degree` of the source vertex is greater than three:

   ```
   src.degree() > 3
   ```

2. `inDegree()` returns the number of incoming edges of the vertex identifier.

   ```
   int <id>.inDegree()
   ```

Label Functions

1. `hasLabel()` checks if a vertex has a label.

   ```
   boolean <id>.hasLabel('<label>')
   ```

   The following example determines whether a vertex has the label "`city`":

   ```
   vertex.hasLabel('city')
   ```

2. `label()` returns the label of an edge.

   ```
   string <id>.label()
   ```

   The following expression checks whether the label of an edge is "`clicked_by`":

   ```
   edge.label() = 'clicked_by'
   ```

Relational Expressions

To compare values (e.g., property values or constants), filter expressions provide the comparison operators listed below. Note: Both == and = are synonyms.

```
==
=
!=
<
<=
>
>=
```

The following example checks whether the "cost" property of the source vertex is lower than or equals to 1.23.

```
src.cost <= 1.23
```

Vertex ID Comparison

It is also possible to filter for vertices with a specific vertex ID.

```
<id> = <vertex_id>
```

The following example determines whether the source vertex of an edge has the vertex ID "San Francisco"

```
src = "San Francisco"
```

Regular Expressions

Strings can be matched using regular expressions.

```
<string expression> =~ '<regularexpression>'
```

The following example checks if the edge label starts with a lowercase letter and ends with a number:

```
edge.label() =~ '^[a-z].*[0-9]$'
```

> **Note:**
>
> The syntax followed for the pattern on the right-hand side, is Java REGEX.

Type Conversions

The following syntax allows converting the type of <expression> to <type>.

```
(<type>) <expression>
```

The following example converts the value of the 'cost' property of the source vertex to an integer value:

```
(int) src.cost
```

Boolean Expressions

Filter expressions can be composed to form other filter expressions. This can be done using the Boolean operators && (and), || (or) and ! (not).

> **Note:**
>
> Only boolean operands can be composed.

```
(! true) || false
edge.cost < INF && dst.visited = false
src.degree() < 10 || !(dst.visited)
```

Arithmetic Expressions

Any numeric expression can be combined using arithmetic expressions. The available arithmetic operators are: `+`, `-`, `*`, `/`, `%`.

> **Note:**
>
> These operators only work on numeric operands.

```
1 + 5
-vertex.degree()
edge.cost * 2 > 5
src.value * 2.5 = (dst.inDegree() + 5) / dst.outDegree()
```

Operator Precedence

Operator precedences are shown in the following list, from highest precedence to the lowest. An operator on a higher level is evaluated before an operator on a lower level.

1. `+` (unary plus), `-` (unary minus)
2. `*`,`/`, `%`
3. `+`, `-`
4. `=`,`!=`, `<`, `>`, `<=`, `>=`, `=~`
5. `NOT`
6. `AND`
7. `OR`

Syntactic Sugar

`both` and `any` denote the source and destination vertex of the current edge. They can be used to express a condition that should be `true` for both or at least either one of the two vertices. These keywords are only valid in an edge filter expression. To use them in a vertex filter results in a runtime type-checking exception.

```
both
any
```

The filter expressions inside the following examples are equivalent:

```
both.property = 1
src.property = 1 && dst.property = 1

any.degree() > 1
src.degree() > 1 || dst.degree() > 1
```

23.10.2 Type System

Filter expressions are a very simple type system. There are only the following 13 types:

1. `integer` (can be abbreviated in expressions with `int`)
2. `long`
3. `float`
4. `double`
5. `boolean`
6. `string`
7. `date`
8. `time`
9. `time with timezone`
10. `timestamp`
11. `timestamp with timezone`
12. `vertex`
13. `edge`

Conversions are only allowed from one numeric type to another numeric type (i.e. `integer`, `float`, `double`, `long`).

Comparisons require both sides to be of the same (or convertible) type.

23.10.3 Path Finding Filters

Filters can be used to limit the analyzed edges when searching for a shortest path between a source and destination vertex in a graph.

An edge filter expression is evaluated against each edge that is visited during the traversal of the graph. If the filter evaluates to `false` on an edge, this edge will be ignored and will not appear in the resulting shortest path.

It is also possible to use a vertex filter for path finding.

A vertex filter expression is evaluated against each vertex that is visited during the traversal of the graph, except for the source and destination vertex.

If the filter evaluates to `false` on a vertex, the edge to this vertex and all outgoing edges of the vertex will be ignored. The vertex will not appear in the resulting shortest path.

The source and destination vertex can be any vertex in the graph and the filter is not evaluated for them.

23.10.4 Subgraph Filters

Edge Filters

An edge filter expression is evaluated for each edge in the graph. The edge filter has access to the source and destination vertex of each edge and all of its properties.

If the filter expression evaluates to true, the edge and both the source and destination vertex will appear in the subgraph.

Vertex Filters

A vertex filter expression is evaluated for every vertex in the graph.

Every vertex for which the filter expression evaluates to true will appear in the subgraph.

Every edge connecting two vertices for which the expression evaluates to true will also appear in the subgraph.

Result Set Filters

Result set edge and vertex filters allow the creation of edge and vertex sets out of a given PGQL result set.

Vertex and Edge Collection Filters

Vertex and edge collection filters allow the creation of edge and vertex filters out of a given vertex and edge collection.

23.10.5 Operations on Filter Expressions

This section explains the various operations that you can perform on filter expressions.

- Defining Filter Expressions
- Defining Result Set Filters
- Creating a Subgraph from PGQL Result Set
- Defining Collection Filters
- Creating a Subgraph from Collection Filters
- Combining Filter Expressions
- Creating a Subgraph Using Filter Expressions with Partitioned IDs

23.10.5.1 Defining Filter Expressions

You can define a new vertex filter, as shown in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var vertexFilter = VertexFilter.fromExpression("vertex.name =
'PGX'")
```

Java

```
VertexFilter vertexFilter = VertexFilter.fromExpression("vertex.name =
'PGX'");
```

Python

```
vertex_filter = VertexFilter("vertex.name = 'PGX'")
```

You can define a new edge filter, as shown in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var edgeFilter = EdgeFilter.fromExpression("edge.cost > 5")
```

Java

```
EdgeFilter edgeFilter = EdgeFilter.fromExpression("edge.cost > 5");
```

Python

```
vertex_filter = EdgeFilter("edge.cost > 5")
```

23.10.5.2 Defining Result Set Filters

You can define a result set vertex filter, as shown in the following code:

- JShell
- Java

JShell

```
// Evaluates query on graph g to obtain a result set
opg4j> var resultSet = g.queryPgql("SELECT x FROM MATCH (x) WHERE x.age >
```

```
24")
// Define a filter on the result set for the column "x"
opg4j> var vertexFilter = VertexFilter.fromPgqlResultSet(resultSet,
"x")
// Obtain a vertex set
opg4j> var vertexSet = g.getVertices(vertexFilter)
```

Java

```
// Evaluates query on graph g to obtain result set
PgqlResultSet resultSet = g.queryPgql("SELECT x FROM MATCH (x) WHERE
x.age > 24");
// Define a filter on the result set for the column "x"
VertexFilter vertexFilter = VertexFilter.fromPgqlResultSet(resultSet,
"x");
// Obtain a vertex set
VertexSet vertexSet = g.getVertices(vertexFilter);
```

You can define a result set edge filter, as shown in the following code:

- JShell
- Java

JShell

```
// Evaluates query on graph g to obtain result set
opg4j> var resultSet = g.queryPgql("SELECT e FROM MATCH ()-[e]->()
WHERE e.weight >= 8")
// Define a filter on the result set for the column "e"
opg4j> var edgeFilter = EdgeFilter.fromPgqlResultSet(resultSet, "e")
// Obtain an edge set
opg4j> var edgeSet = g.getEdges(edgeFilter)
```

Java

```
// Evaluates query on graph g to obtain result set
PgqlResultSet resultSet = g.queryPgql("SELECT e FROM MATCH ()-[e]->()
WHERE e.weight >= 8");
// Define a filter on the result set for the column "e"
EdgeFilter edgeFilter = EdgeFilter.fromPgqlResultSet(resultSet, "e");
// Obtain an edge set
EdgeSet edgeSet = g.getEdges(edgeFilter);
```

23.10.5.3 Creating a Subgraph from PGQL Result Set

A subgraph can be obtained from a PGQL result set using result set filters.

You can create a subgraph from a result set vertex filter, as shown in the following code:

- JShell
- Java

JShell

```
// Evaluates query on graph g to obtain result set
opg4j> var resultSet = g.queryPgql("SELECT x FROM MATCH (x) WHERE x.age > 
24")
// Define a filter on the result set for the column "x"
opg4j> var resultSetVertexFilter = VertexFilter.fromPgqlResultSet(resultSet, 
"x")
// Create a subgraph of g containing the matched vertices in the resultSet 
and the edges that connect them if any.
opg4j> var newGraph = g.filter(resultSetVertexFilter)
```

Java

```
// Evaluates query on graph g to obtain result set
PgqlResultSet resultSet = g.queryPgql("SELECT x MATCH (x) WHERE x.age > 24");
// Define a filter on the result set for the column "x"
VertexFilter resultSetVertexFilter = 
VertexFilter.fromPgqlResultSet(resultSet, "x");
// Create a subgraph of g containing the matched vertices in the resultSet 
and the edges that connect them if any.
PgxGraph newGraph = g.filter(resultSetVertexFilter);
```

You can create a subgraph from a result set edge filter, as shown in the following code:

- JShell
- Java

JShell

```
// Evaluates query on graph g to obtain result set
opg4j> var resultSet = g.queryPgql("SELECT e FROM MATCH ()-[e]->() WHERE 
e.cost < 100")
// Define a filter on the result set for the column "e"
```

```
opg4j> var resultSetEdgeFilter =
EdgeFilter.fromPgqlResultSet(resultSet, "e")
// Create a subgraph of g containing the matched edges in the
resultSet and their corresponding source and destination vertices.
opg4j> var newGraph = g.filter(resultSetEdgeFilter)
```

Java

```
// Evaluates query on graph g to obtain result set
PgqlResultSet resultSet = g.queryPgql("SELECT e FROM MATCH ()-[e]->()
WHERE e.cost < 100");
// Define a filter on the result set for the column "e"
EdgeFilter resultSetEdgeFilter =
EdgeFilter.fromPgqlResultSet(resultSet, "e");
// Create a subgraph of g containing the matched edges in the
resultSet and their corresponding source and destination vertices.
PgxGraph newGraph = g.filter(resultSetEdgeFilter);
```

23.10.5.4 Defining Collection Filters

You can define a vetex collection filter, as shown in the following code:

- JShell
- Java

JShell

```
// Obtain a vertex collection from an algorithm, query execution or
any other way
opg4j> VertexCollection<?> vertexCollection = ...
// Define a filter from the collection
opg4j> var vertexFilter = VertexFilter.fromCollection(vertexCollection)
```

Java

```
// Obtain a vertex collection from an algorithm, query execution or
any other way
VertexCollection<?> vertexCollection = ...
// Define a filter from the collection
VertexFilter vertexFilter =
VertexFilter.fromCollection(vertexCollection);
```

You can define a edge collection filter, as shown in the following code:

- JShell
- Java

JShell

```
// Obtain an edge collection from an algorithm, query execution or any other
way
opg4j> EdgeCollection edgeCollection = ...
// Define a filter from the collection
opg4j> var edgeFilter = EdgeFilter.fromCollection(edgeCollection)
```

Java

```
// Obtain an edge collection from an algorithm, query execution or any other
way
EdgeCollection edgeCollection = ...
// Define a filter from the collection
EdgeFilter edgeFilter = EdgeFilter.fromCollection(edgeCollection);
```

23.10.5.5 Creating a Subgraph from Collection Filters

A subgraph can be obtained by using vertex or edge collection filters.

You can create a subgraph from vertex collection filter, as shown in the following code:

- JShell
- Java

JShell

```
// Obtain a vertex collection from an algorithm, query execution or any
other way
opg4j> VertexCollection<?> vertexCollection = ...
// Define a filter from the collection
opg4j> var vertexFilter = VertexFilter.fromCollection(vertexCollection)
// Create a subgraph of g containing the matched vertices in the vertex
collection and the edges that connect them if any.
opg4j> var newGraph = g.filter(vertexFilter)
```

Java

```
// Obtain a vertex collection from an algorithm, query execution or any
other way
VertexCollection<?> vertexCollection = ...
```

```
// Define a filter from the collection
VertexFilter vertexFilter =
VertexFilter.fromCollection(vertexCollection);
// Create a subgraph of g containing the matched vertices in the
vertex collection and the edges that connect them if any.
PgxGraph newGraph = g.filter(vertexFilter);
```

You can create a subgraph from edge collection filter, as shown in the following code:

- JShell
- Java

JShell

```
// Obtain an edge collection from an algorithm, query execution or any
other way
opg4j> EdgeCollection edgeCollection = ...
// Define a filter from the collection
opg4j> var edgeFilter = EdgeFilter.fromCollection(edgeCollection)
// Create a subgraph of g containing the matched edges in the
collection and their corresponding source and destination vertices.
opg4j> var newGraph = g.filter(edgeFilter)
```

Java

```
// Obtain an edge collection from an algorithm, query execution or any
other way
EdgeCollection edgeCollection = ...
// Define a filter from the collection
EdgeFilter edgeFilter = EdgeFilter.fromCollection(edgeCollection);
// Create a subgraph of g containing the matched edges in the
collection and their corresponding source and destination vertices.
PgxGraph newGraph = g.filter(edgeFilter);
```

23.10.5.6 Combining Filter Expressions

Any filter expression used for subgraph filtering, can be combined with any other filter expression to form a new filter expression.

Filters can be combined using the following operations:

- intersection
- union

The intersection of two filters will only keep a vertex or edge, if both filters would accept it.

> **Note:**
>
> The intersection of two filters will not behave as an `AND` in the filter expression.

The union of two filters will keep a vertex or edge, if one of the filters would accept it.

> **Note:**
>
> The union of filters will not behave as an `OR` in the filter expression.

In the following example an edge filter is intersected with a vertex filter. The resulting subgraph will only include vertices that have the name '`PGX`' and will only include edges that have a cost greater than `5`.

- JShell
- Java
- Python

JShell

```
opg4j> var edgeFilter = EdgeFilter.fromExpression("edge.cost > 5")
opg4j> var vertexFilter = VertexFilter.fromExpression("vertex.name = 'PGX'")
opg4j> var combinedFilter = edgeFilter.intersect(vertexFilter)
```

Java

```
EdgeFilter edgeFilter = EdgeFilter.fromExpression("edge.cost > 5");
VertexFilter vertexFilter = VertexFilter.fromExpression("vertex.name =
'PGX'");
GraphFilter combinedFilter = edgeFilter.intersect(vertexFilter);
```

Python

```
edge_filter = EdgeFilter("edge.cost > 5")
vertex_filter = VertexFilter("vertex.name = 'PGX'")
combined_filter = edge_filter.intersect(vertex_filter)
```

In contrast, the subgraph created by the union of those filters will include vertices that either have the name `'PGX`' or that has an incoming or outgoing edge with a cost greater than `5`. It will also include edges with a cost greater than 5, as well as edges for which the source and destination vertex have the name 'PGX'.

23.10.5.7 Creating a Subgraph Using Filter Expressions with Partitioned IDs

You can create a subgraph using filter expressions with partitioned IDs.

For example, the following creates a subgraph that contains only a single vertex with ID Account(1):

- JShell
- Java
- Python

JShell

```
opg4j> PgxGraph subgraph =
g.filter(VertexFilter.fromExpression("vertex = 'Accounts(1)'"))
subgraph ==> PgxGraph[name=sub-graph_26,N=1,E=0,created=1630414040396]
```

Java

```
PgxGraph subgraph = g.filter(VertexFilter.fromExpression("vertex =
'Accounts(1)'"));
```

Python

```
subgraph = graph.filter(VertexFilter.from_expression("vertex =
'Accounts(1)'"))
```

The following example creates a subgraph that contains only a single edge with ID Transfers(1), and two accompanying vertices:

- JShell
- Java
- Python

JShell

```
opg4j> PgxGraph subgraph = g.filter(EdgeFilter.fromExpression("edge =
'Transfers(1)'"))
subgraph ==> PgxGraph[name=sub-graph_27,N=2,E=1,created=1630414144529]
```

Java

```
PgxGraph subgraph = g.filter(EdgeFilter.fromExpression("edge =
'Transfers(1)'"));
```

Python

```
subgraph = graph.filter(EdgeFilter.from_expression("edge = 'Transfers(1)'"))
```

23.11 Advanced Task Scheduling Using Execution Environments

This guide shows how you can use the advanced scheduling features of the enterprise scheduler.

The enterprise scheduler features of the graph server (PGX) are currently only available for Linux (x86_64), macOS (x86_64) and Solaris (x86_64, sparc).

The following topics provide more detailed information on enabling and scheduling tasks using the execution environment:

- Enterprise Scheduler Configuration Guide
- Enabling Enterprise Scheduler Features
- Retrieving and Inspecting the Execution Environment
- Modifying and Submitting Tasks Under an Updated Environment
- Using Lambda Syntax

23.11.1 Enterprise Scheduler Configuration Guide

This chapter describes the extra configuration options for the enterprise scheduler.

> **Note:**
>
> These configuration options are only available if the `scheduler` configuration variable is set to `enterprise_scheduler` in Configuration Parameters for the Graph Server (PGX) Engine.

The configuration is divided into the following two parts:

1. `enteprise_scheduler_config`: for setting details about how tasks should be scheduled
2. `enterprise_scheduler_flags`: where you can configure the enterprise scheduler in more detail

Enterprise Scheduler Fields

Field	Type	Description	Default
`analysis_task_config`	`object`	Configuration for analysis tasks.	**weight** `<no-of-CPUs>` **priority** `medium` **max_threads** `<no-of-CPUs>`
`fast_analysis_task_config`	`object`	Configuration for fast analysis tasks.	**weight** `1` **priority** `high` **max_threads** `<no-of-CPUs>`
`max_num_concurrent_io_tasks`	`integer`	Maximum number of concurrent io tasks at a time.	`3`
`num_io_threads_per_task`	`integer`	Number of io threads to use per task.	`<no-of-cpus>`

Analysis Task Config Fields

Field	Type	Description	Default
`max_threads`	`integer`	A hard limit on the number of threads to use for a task.	*required*
`priority`	`enum[high, medium, low]`	The priority of the task. Threads are given to the task with the highest priority at the moment of execution. If there are more threads that have the highest priority, threads are given to the tasks according to their weight	*required*
`weight`	`integer`	The weight of the task. Threads are given to tasks proportionally to their weight. Tasks with higher weight will get more threads than tasks with lower weight. Tasks with the same weight will get the same amount of threads.	*required*

Enterprise Scheduler Flags

Field	Type	Description	Default
show_allocations	boolean	If true show memory allocation information.	false
show_environment	boolean	If true show version numbers and main environment settings at startup.	false
show_logging	boolean	If true enable summary logging. This is available even in non-debug builds and includes information such as the machine hardware information obtained at start-up, and per-job / per-loop information about the workload.	false
show_profiling	boolean	If true show profiling information.	false
show_scheduler_state	boolean	If true dump scheduler state on each update.	false
show_warnings	boolean	If true enable warnings. These are non-fatal errors. For example, if a NUMA-aware allocation cannot be placed on the intended socket.	true

Example 23-4 Custom Enterprise Scheduler Configuration

This configuration sets the number of io threads per task to 16, increases the maximum number of concurrent io tasks to 5. It also sets the configuration for fast analysis tasks to have a weight of 1, priority of "high" and sets a limit to the maximum number of threads used to 1.

```
{
  "enterprise_scheduler_config": {
    "num_io_threads_per_task": 16,
    "max_num_concurrent_io_tasks": 5,
    "fast_analysis_task_config": {
      "weight": 1,
      "priority": "high",
      "max_threads": 1
    }
  }
}
```

Example 23-5 Using the Enterprise Scheduler Flags

This configuration enables extra logging output from the enterprise scheduler.

```
{
  "enterprise_scheduler_flags": {
    "show_logging": true
  }
}
```

23.11.2 Enabling Enterprise Scheduler Features

You can enable the enterprise scheduler features, by setting the flag `allow_override_scheduling_information` of the the graph server (PGX) configuration file to `true`:

```
{"allow_override_scheduling_information":true}
```

See Configuration Parameters for the Graph Server (PGX) Engine for all configuration options of the graph server (PGX).

23.11.3 Retrieving and Inspecting the Execution Environment

Execution environments are bound to a session. You can retrieve the execution environment for a session by calling `getExecutionEnvironment()` on a `PgxSession`:

- JShell
- Java

JShell

```
opg4j> execEnv.getValues()
==> [analysis-pool.max_num_threads=4, analysis-pool.weight=4, analysis-pool.priority=MEDIUM, io-pool.num_threads_per_task=4, fast-track-analysis-pool.max_num_threads=4, fast-track-analysis-pool.weight=1, fast-track-analysis-pool.priority=HIGH]
```

Java

```
import oracle.pgx.api.*;
import java.util.List;
import java.util.Map.Entry;

List<Entry<String, Object>> currentValues = execEnv.getValues();
for (Entry<String, Object> value : currentValues) {
  System.out.println(value.getKey() + " = " + value.getValue());
}
```

See Enterprise Scheduler Configuration Guide for the values of an unmodified execution environment.

To retrieve the sub-environments use the `getIoEnvironment()`, `getAnalysisEnvironment()` and `getFastAnalysisEnvironment()` methods. Each sub-environment has their own `getValues()` method for retrieving the configuration of the sub-environment.

- JShell
- Java

JShell

```
opg4j> var ioEnv = execEnv.getIoEnvironment()
ioEnv ==> IoEnvironment[pool=io-pool]
opg4j> ioEnv.getValues()
$5 ==> {num_threads_per_task=4}

opg4j> var analysisEnv = execEnv.getAnalysisEnvironment()
analysisEnv ==> CpuEnvironment[pool=analysis-pool]
opg4j> analysisEnv.getValues()
$7 ==> {max_num_threads=4, weight=4, priority=MEDIUM}

opg4j> var fastAnalysisEnv = execEnv.getFastAnalysisEnvironment()
fastAnalysisEnv ==> CpuEnvironment[pool=fast-track-analysis-pool]
opg4j> fastAnalysisEnv.getValues()
$9 ==> {max_num_threads=4, weight=1, priority=HIGH}
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.executionenvironment.*;
import java.util.Map;

IoEnvironment ioEnv = execEnv.getIoEnvironment();
CpuEnvironment analysisEnv = execEnv.getAnalysisEnvironment();
CpuEnvironment fastAnalysisEnv = execEnv.getFastAnalysisEnvironment();

for (Entry<String, Object> value : ioEnv.getValues().getEntrySet()) {
  System.out.println(value.getKey() + " = " + value.getValue());
}

for (Entry<String, Object> value : analysisEnv.getValues().getEntrySet()) {
  System.out.println(value.getKey() + " = " + value.getValue());
}

for (Entry<String, Object> value :
fastAnalysisEnv.getValues().getEntrySet()) {
  System.out.println(value.getKey() + " = " + value.getValue());
}
```

23.11.4 Modifying and Submitting Tasks Under an Updated Environment

You can modify an Input/Output (IO) environment in the number of threads by using the `setNumThreadsPerTask()` method of the `IoEnvironment`. The value is updated immediately and all tasks that are submitted after updating it are executed with the updated value.

- JShell
- Java

JShell

```
opg4j> ioEnv.setNumThreadsPerTask(8)
opg4j> var g = session.readGraphWithProperties(...)
==> PgxGraph[name=graph,N=3,E=6,created=0]
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.executionenvironment.*;

ioEnv.setNumThreadsPerTask(8);
PgxGraph g = session.readGraphWithProperties(...);
```

You can reset an environment to their initial values by calling the `ioEnv.reset()` method. Additionally, you can reset all environments at once by calling `execEnv.reset()` on the `ExecutionEnvironment` class.

You can modify CPU environments in their weight, priority and maximum number of threads using the `setWeight()`, `setPriority()` and `setMaxThreads()` methods:

- JShell
- Java

JShell

```
opg4j> analysisEnv.setWeight(50)
opg4j> fastAnalysisEnv.setMaxNumThreads(1)
opg4j> var rank = analyst.pagerank(g)
rank ==> VertexProperty[name=pagerank,type=double,graph=my-graph]
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.executionenvironment.*;

analysisEnv.setWeight(50);
fastAnalysisEnv.setMaxThreads(1);
Analyst analyst = session.createAnalyst();
VertexProperty rank = analyst.pagerank(g);
```

23.11.5 Using Lambda Syntax

Generally you can perform the following actions in the environment:

1. Set up the execution environment
2. Execute task
3. Reset execution environment

All these actions can be combined and performed in a single step using the `set` method. For each `set` method there is a method using the `with` prefix which takes the updated value and a lambda which should be executed using the updated value.

For example, use `withNumThreadsPerTask()` instead of `setNumThreadsPerTask()` as shown:

- JShell
- Java

JShell

```
opg4j> var g = ioEnv.withNumThreadsPerTask(8, () ->
session.readGraphWithProperties(...))
==> PgxGraph[name=graph,N=3,E=6,created=0]
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.executionenvironment.*;

PgxGraph g = ioEnv.withNumThreadsPerTask(8, () ->
session.readGraphWithProperties(...));
```

The preceding code execution is equivalent to the following sequence of actions:

```
var oldValue = ioEnv.getNumThreadsPerTask()
ioEnv.setNumThreadsPerTask(currentValue)
var g = session.readGraphWithProperties(...)
ioEnv.setNumThreadsPerTask(oldValue)
```

23.12 Admin API

This guide shows how to use the graph server (PGX) Admin API to inspect the server state including sessions, graphs, tasks, memory and thread pools.

- Get a Server Instance
- Get Inspection Data
- Get Active Sessions
- Get Cached Graphs
- Get Published Graphs
- Get Currently Loading Graphs
- Get Tasks
- Get Available Memories

23.12.1 Get a Server Instance

You can get a PGX `Instance` as shown in the following code:

- Java
- Python

Java

```
import oracle.pgx.api.*;
ServerInstance instance = Pgx.getInstance(Pgx.EMBEDDED_URL);
```

Python

```
instance = pypgx.get_session(base_url = "url")
```

23.12.2 Get Inspection Data

Inspection data is information about the server state.

You can get the inspection data using the following code. Note that you must the `PGX_SERVER_GET_INFO` permission to access the server state data.

- JShell
- Java
- Python

JShell

```
var serverState = instance.getServerState()
```

Java

```
JsonNode serverState = instance.getServerState();
```

Python

```
server_state = instance.get_server_state()
```

This returns a `JsonNode` which contains all the administration information, such as number of graphs loaded, number of sessions, memory usage for graphs, properties, and so on.

```
{
    "cached_graphs": [],
    "published_graphs": [],
    "graphs_currently_loading": [],
    "sessions": [],
    "tasks": [],
    "pools": [],
    "memory": {}
}
```

Note that the `sessions` parameter lists all the sessions and the memory used by the sessions along with the user information for each session.

```
{
  "session_id": "530b5f9a-75c4-4838-9cc3-44df44b035c5",
  "source": "testServerState",
  "user": "user1",    // session user information
   ...
}
```

23.12.3 Get Active Sessions

`serverState.get("sessions")` returns an array of current active sessions. Each entry contains information about a session.

```
{
   "session_id":"530b5f9a-75c4-4838-9cc3-44df44b035c5",
   "source":"testServerState",
   "user":"user1",
   "task_timeout_ms":0,
   "idle_timeout_ms":0,
   "alive_ms":237,
   "total_analysis_time_ms":115,
   "state":"RELEASED",
   "private_graphs":[
      {
         "name":"anonymous_graph_1",
         "creation_timestamp":1589317879755,
         "is_transient":true,
         "memory":{
            "topology_bytes":46,
            "key_mapping_bytes":30,
            "persistent_property_mem_bytes":0,
            "transient_property_mem_bytes":0
         },
         "vertices_num":1,
         "edges_num":0,
         "persistent_vertex_properties":[

         ],
         "persistent_edge_properties":[

         ],
         "transient_vertex_properties":[

         ],
         "transient_edge_properties":[

         ]
      }
   ],
   "published_graphs":[
      {
         "name":"multigraph",
         "creation_timestamp":1589317879593,
         "is_transient":false,
         "memory":{
            "topology_bytes":110,
            "key_mapping_bytes":56,
            "persistent_property_mem_bytes":64,
            "transient_property_mem_bytes":0
         },
         "vertices_num":2,
```

```
          "edges_num":6,
          "persistent_vertex_properties":[
             {
                "loaded":true,
                "mem_size_bytes":16,
                "name":"tProp",
                "type":"string"
             }
          ],
          "persistent_edge_properties":[
             {
                "loaded":true,
                "mem_size_bytes":48,
                "name":"cost",
                "type":"double"
             }
          ],
          "transient_vertex_properties":[

          ],
          "transient_edge_properties":[

          ]
       }
    ]
}
```

The following table explains session information fields:

Table 23-6 Session Information Options

Field	Description
`sessionID`	Session ID generated by the graph server (PGX)
`source`	Descriptive string identifying the client session
`user`	Session owner
`task_timeout_ms`	Timeout to interrupt long-running tasks submitted by sessions (algorithms, I/O tasks) in milliseconds. Set to zero for infinity/no timeout.
`idle_timeout_ms`	Timeout of idling sessions in milliseconds. Set to zero for infinity/no timeout.
`alive_ms`	Session's age in milliseconds
`total_analysis_time_ms`	Total session's executing time in milliseconds
`state`	Current session of the session can be `Idle`, `Submitted`, `Released` or `Terminating`
`private_graphs`	Session bounded graphs
`published_graphs`	Published graphs pointed to from the session

Note:

The `is_transient` field indicates if the graph is transient. A graph is transient if it is not loaded from an external source.

23.12.4 Get Cached Graphs

The server state contains also cached graph information `serverState.get("cached_graphs")` which returns a collection of graphs cached in memory. Each entry contains information about a graph as shown:

```
{
   "name":"sf-1589317879394",
   "creation_timestamp":1589317879394,
   "vertex_properties":[
      {
         "loaded":true,
         "mem_size_bytes":478504,
         "name":"prop1",
         "type":"double"
      }
   ],
   "edge_properties":[
      {
         "loaded":true,
         "mem_size_bytes":1197720,
         "name":"cost",
         "type":"double"
      },
      {
         "loaded":true,
         "mem_size_bytes":598860,
         "name":"0",
         "type":"integer"
      }
   ],
   "memory":{
      "topology_bytes":3921814,
      "key_mapping_bytes":1407466,
      "property_mem_bytes":2275084
   },
   "vertices_num":59813,
   "edges_num":149715
}
```

The following table explains graph information fields:

Table 23-7 Graph Information

Field	Description
`name`	Name of the graph.

Table 23-7 (Cont.) Graph Information

Field	Description
creation_timestamp	Creation timestamp of the graph.
vertex_properties	List of vertex properties, each entry contains the name, type, memory size used by the property, and a boolean flag to indicate if the property is loaded into memory.
edge_properties	List of edges properties, similar to vertex properties.
memory	Memory size used by the whole graph (topology, key mappings and properties).
vertices_num	Number of vertices.
edges_num	Number of edges.

23.12.5 Get Published Graphs

`serverState.get("published_graphs")` returns a list of published graphs.

Each graph entry contains information about the published graph, similar to cached_graphs.

23.12.6 Get Currently Loading Graphs

`serverState.get("graphs_currently_loading")` returns progress information about graphs which are currently loading.

Each entry, corresponding to one graph, is shown as follows:

```
{
    "name": "anonymous_graph_1",
    "session_id": "530b5f9a-75c4-4838-9cc3-44df44b035c5",
    "start_loading_timestamp": 1605468453030,
    "elapsed_loading_time_ms": 281742,
    "num_vertices_read": 10000000,
    "num_edges_read": 196500000,
    "num_edge_providers_loaded": 1,
    "num_edge_providers_remaining": 9,
    "num_vertex_providers_loaded": 1,
    "num_vertex_providers_remaining": 0,
    "loading_phase": "reading edges",
    "loading_phase_start_timestamp": 1605468453085,
    "loading_phase_elapsed_time_ms": 281687,
    "loading_phase_state": "current vertex provider index: 1, number of
vertices read for prorvider: 0, current edge provider index: 1, number of
edges read for prorvider: 76,500,000"
}
```

The `name` field contains a temporary name of the graph. It may not be equal to the name that is assigned to graph after loading.

Fields indicating the number of read vertices and edges are updated in regular intervals of 10,000 entities.

The field `loading_phase` indicates the current phase during graph loading. Valid values are "`reading edges`" or "`building graph indices`". For some loading phases, the field `loading_phase_state` contains a string with additional information on the phase. However, not all loading phases provide this additional information.

> **Note:**
>
> `graphs_currently_loading` is supported for data formats `CSV`, `ADJ_LIST`, `EDGE_LIST`, `TWO_TABLES` and `PG (FLAT_FILE)` for homogeneous graphs and for formats `CSV` and `RDBMS` for partitioned graphs.

23.12.7 Get Tasks

`serverState.get("tasks")` returns the last 100 queued tasks.

Each task has a type, the pool to be executed on (the task might be already executed) and other status fields ({`Queued`|`Started`|`Done`} `time`), and a `sessionid` if the task belongs to a session.

23.12.8 Get Available Memories

This section contains a map of available memories, the key is the hostname and the value is a list of current available memories (managed and unmanaged). Each entry contains how much memory is free, used and the maximum available memory.

23.13 PgxFrames Tabular Data-Structure

`PgxFrame` is a data-structure to load, store and manipulate tabular data. It contains rows and columns. A `PgxFrame` can contain multiple columns where each column consist of elements of the same data type, and has a name. The list of the columns with their names and data types defines the schema of the frame. (The number of rows in the `PgxFrame` is not part of the schema of the frame.)

`PgxFrame` provides some operations that also output `PgxFrames` (described later in the tutorial). Those operations can be performed in-place (meaning that the frame is mutated during the operation) in order to save memory. In place operations should be used whenever possible. However, we provide out-place variants, i.e., a new frame is created during the operation.

The following table lists all the in-place operations along with the respective out-place operations:

Table 23-8 Mapping between In-Place and Out-Place Operations

In-place operations	Out-place operations
`headInPlace`	`head`
`tailInPlace`	`tail`
`flattenAllInPlace`	`flattenAll`
`renameColumnInPlace`	`renameColumn`
`renameColumnsInPlace`	`renameColumns`

Table 23-8 (Cont.) Mapping between In-Place and Out-Place Operations

In-place operations	Out-place operations
`selectInPlace`	`select`

- Converting PgqlResultSet to a PgxFrame
- Storing a PgxFrame to a Database
- Storing a PgxFrame to a CSV File
- Union of PGX Frames
- Joining PGX Frames
- Printing the Content of a PgxFrame
- Destroying a PgxFrame
- Loading and Storing Vector Properties
- Flattening Vector Properties
- PgxFrame Helpers
- Converting a PgxFrame to PgqlResultSet
- PgxFrame to Pandas DataFrame Conversions
- Loading a PgxFrame from a Database
- Loading a PgxFrame from a CSV File
- Loading a PgxFrame from Client-Side Data
- Creating a Graph from Multiple PgxFrame Objects

23.13.1 Converting PgqlResultSet to a PgxFrame

The following example describes how to save the `PgqlResultSet` to a `PgxFrame`.

- JShell
- Java
- Python

JShell

```
opg4j> var pg = session.readGraphByName("BANK_GRAPH_NEW",GraphSource.PG_VIEW)
opg4j> var rs = pg.queryPgql("SELECT e.* FROM MATCH (v1:Accounts)-
[e:Transfers]->(v2:Accounts) LIMIT 5")
opg4j> var rsFrame = rs.toFrame()
opg4j> rsFrame.print()
+------------------------------------------------+
| FROM_ACCT_ID | TO_ACCT_ID | AMOUNT | DESCRIPTION |
+------------------------------------------------+
| 999          | 934        | 1000.0 | transfer    |
```

```
| 999          | 71         | 1000.0 | transfer    |
| 999          | 839        | 1000.0 | transfer    |
| 999          | 891        | 1000.0 | transfer    |
| 999          | 919        | 1000.0 | transfer    |
+---------------------------------------------------+
$4 ==> oracle.pgx.api.frames.internal.PgxFrameImpl@39a1c200
```

Java

```
import oracle.pgx.api.frames.*;

PgxGraph pg =
session.readGraphByName("BANK_GRAPH_NEW",GraphSource.PG_VIEW);
PgqlResultSet rs = pg.queryPgql("SELECT e.* FROM MATCH (v1:Accounts)-
[e:Transfers]->(v2:Accounts) LIMIT 5");
PgxFrame rsFrame = rs.toFrame();
rsFrame.print();
```

Python

```
>>> pg = session.read_graph_by_name('BANK_GRAPH_NEW','pg_view')
>>> rs = pg.query_pgql("SELECT e.* FROM MATCH (v1:Accounts)-
[e:Transfers]->(v2:Accounts) LIMIT 5")
>>> rs_frame = rs.to_frame()
>>> rs_frame.print()
+---------------------------------------------------+
| FROM_ACCT_ID | TO_ACCT_ID | AMOUNT | DESCRIPTION |
+---------------------------------------------------+
| 1            | 418        | 1000.0 | transfer    |
| 1            | 584        | 1000.0 | transfer    |
| 1            | 644        | 1000.0 | transfer    |
| 1            | 672        | 1000.0 | transfer    |
| 1            | 259        | 1000.0 | transfer    |
+---------------------------------------------------+
```

Converting PgqlResultSet to pandas DataFrame

You can also save the `PgqlResultSet` to `pandas DataFrame` as shown in the following example:

```
>>> rs.to_pandas()
   FROM_ACCT_ID  TO_ACCT_ID  AMOUNT DESCRIPTION
0           999         934  1000.0    transfer
1           999          71  1000.0    transfer
2           999         839  1000.0    transfer
3           999         891  1000.0    transfer
4           999         919  1000.0    transfer
```

23.13.2 Storing a PgxFrame to a Database

When storing a `PgxFrame` to a database, the frame is stored as a table, where the columns correspond to the columns of the `PgxFrame` and the rows correspond to the rows of the `PgxFrame`. Note that the column order preservation may or may not happen when storing a `PgxFrame` in the database.

The following example shows how to store the `PgxFrame` in the database. The example assumes that you are storing the `PgxFrame` in the current logged in schema.

- JShell
- Java
- Python

JShell

```
opg4j> rsFrame.write().
           db().                     // select the "format" to be relational
db
           name("F1").               // name of the frame
           tablename("T1").          // name of the table in which the data
must be stored
           overwrite(true).          // indicates that if there is a table
with the same name, it will be overwritten (truncated)
           connections(16).          // indicates that 16 connections can be
used to store in parallel
           store()
```

Java

```
rsFrame.write()
    .db()
    .name("F1")
    .tablename("T1")
    .overwrite(true)
    .connections(16)
    .store();
```

Python

```
>>> rs_frame.write().db().\
...     table_name('T1').\
...     overwrite(True).\
...     store()
```

Alternatively, you can also store the `PgxFrame` in a different schema as shown in the following example. Ensure that you have `CREATE TABLE` privilege when writing to a different schema:

- JShell
- Java
- Python

JShell

```
// store as table in the database using jdbc + username + password
opg4j> rsFrame.write().
           db().                        // select the "format" to be
relational db
           name("framename").           // name of the frame
           tablename("tablename").      // name of the table in which the
data must be stored
           overwrite(true).             // indicates that if there is a
table with the same name, it will be overwritten (truncated)
           connections(16).             // indicates that 16 connections
can be used to store in parallel
           jdbcUrl("<jdbcUrl>").
           username("<db_username>").
           password("<password>").
           store()
```

Java

```
rsFrame.write()
    .db()                         // select the "format" to be relational
db
    .name("framename")            // name of the frame
    .tablename("tablename")       // name of the table in which the data
must be stored
    .overwrite(true)              // indicates that if there is a table
with the same name, it will be overwritten (truncated)
    .connections(16)              // indicates that 16 connections can be
used to store in parallel
    .jdbcUrl("<jdbcUrl>")
    .username("<db_username>")
    .password("<password>")
    .store();
```

Python

```
>>> rs_frame.write().db().\
...     table_name('T1').\
...     overwrite(True).\
...     jdbc_url("<jdbcUrl>").\
```

```
...     username("<db_username>").\
...     password("<password>").\
...     store()
```

23.13.3 Storing a PgxFrame to a CSV File

In order to write a `PgxFrame` to a CSV file, you first need to explicitly authorize access to the corresponding directories by defining a directory object pointing to the directory (on the graph server) where the file needs to be written.

```
CREATE OR REPLACE DIRECTORY graph_files AS '/tmp';
GRANT READ, WRITE ON DIRECTORY graph_files TO GRAPH_DEVELOPER;
```

Also, note the following:

- The directory in the `CREATE DIRECTORY` statement must exist **on the graph server (PGX)**.
- The directory must be writable at the OS level by the graph server (PGX).

The preceding code grants the privileges on the directory to the `GRAPH_DEVELOPER` role. However, you can also grant permissions to an individual user:

```
GRANT WRITE ON DIRECTORY graph_files TO <graph_user>;
```

You can then save a `PgxFrame` to a CSV file as shown in the following example:

- JShell
- Java
- Python

JShell

```
opg4j> rsFrame.write().overwrite(true).csv("/tmp/Transfers.csv")
```

Java

```
rsFrame.write().overwrite(true).csv("/tmp/Transfers.csv");
```

Python

```
>>> rs_frame.store("/tmp/Transfers.csv")
```

23.13.4 Union of PGX Frames

You can join two `PgxFrame`s that have compatible columns (that is, same type and order).

- JShell
- Java
- Python

JShell

```
opg4j> <first-frame>.union(<secondframe>).print()
```

Java

```
<first-frame>.union(<first-frame>).print();
```

Python

```
<first-frame>.union(<first-frame>).print()
```

The rows of the resulting `PgxFrame` are the union of the rows from the two original frames.

Note that the union operation does not remove duplicate rows that resulted by joining the two frames.

23.13.5 Joining PGX Frames

You can join two frames whose rows are correlated through one of the columns using the `join` functionality. This allows us to combine frames by checking for equality between rows for a specific column.

The following example shows joining two PgxFrames `exampleFrame` and `moreInfoFrame` on the `name` column by calling the `join` method.

- JShell
- Java
- Java

JShell

```
opg4j> exampleFrame.join(moreInfoFrame, "name", "leftFrame",
"rightFrame").print()
```

Java

```
exampleFrame.join(moreInfoFrame, "name", "leftFrame", "rightFrame").print();
```

Java

```
example_frame.join(moreInfoFrame, "name", "leftFrame", "rightFrame").print()
```

The result may appear as shown:

```
+-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
---------------------------------------------+
| leftFrame_name | leftFrame_age | leftFrame_salary | leftFrame_married |
leftFrame_tax_rate | leftFrame_random | leftFrame_date_of_birth |
rightFrame_name | rightFrame_title               | rightFrame_reports |
+-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
------------------------------------------------------+
| John           | 27            | 4133300.0        | true              |
11.0               | 123456782        | 1985-10-18              |
John            | Software Engineering Manager | 5                  |
| Albert         | 23            | 5813000.5        | false             |
12.0               | 124343142        | 2000-01-14              |
Albert          | Sales Manager                | 10                 |
| Emily          | 24            | 9380080.5        | false             |
13.0               | 128973221        | 1910-07-30              |
Emily           | Operations Manager           | 20                 |
+-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
------------------------------------------------------+
```

The joined frame contains the columns of the two frames involved in the operation for the rows with the same `name`.

> **Note:**
>
> The column prefixes specified in the join() call, `leftFrame` and `rightFrame`.

23.13.6 Printing the Content of a PgxFrame

You can observe the contents of a frame using the `print` functionality as shown:

- JShell
- Java
- Python

JShell

```
opg4j> exampleFrame.print()
```

Java

```
exampleFrame.print();
```

Python

```
example_frame.print()
```

The output appears as follows:

```
+---------------------------------------------------+
| FROM_ACCT_ID | TO_ACCT_ID | AMOUNT | DESCRIPTION |
+---------------------------------------------------+
| 2            | 546        | 1000.0 | transfer    |
| 2            | 840        | 1000.0 | transfer    |
| 2            | 493        | 1000.0 | transfer    |
| 2            | 693        | 1000.0 | transfer    |
| 2            | 833        | 1000.0 | transfer    |
+---------------------------------------------------+
```

23.13.7 Destroying a PgxFrame

`PgxFrame`s consumes a lot of memory on the graph server (PGX) if they have a lot of rows or columns. Hence, it is necessary to close them with the `close()` operation. After this operation, the content of the `PgxFrame` is not available anymore.

You can close a frame as shown:

- JShell
- Java
- Python

JShell

```
opg4j> exampleFrame.close()
```

Java

```
exampleFrame.close();
```

Python

```
example_frame.close()
```

23.13.8 Loading and Storing Vector Properties

You can load or store vector properties which are fundamental for PgxML functionality in the graph server (PGX) using PgxFrames.
In order to load a `PgxFrame` with vector properties, follow the steps as shown:

1. Create the `PgxFrame` schema, defining the columns as shown:

   - JShell
   - Java

   ### JShell

   ```
   opg4j> var vecFrameSchema = List.of(
     columnDescriptor("intProp", DataTypes.INTEGER_TYPE),
     columnDescriptor("intProp2", DataTypes.INTEGER_TYPE),
     columnDescriptor("vectProp", DataTypes.vector(DataTypes.FLOAT_TYPE, 3)),
     columnDescriptor("stringProp", DataTypes.STRING_TYPE),
     columnDescriptor("vectProp2", DataTypes.vector(DataTypes.FLOAT_TYPE, 2))
   ).toArray(new ColumnDescriptor[0])
   ```

   ### Java

   ```
   ColumnDescriptor[] vecFrameSchema = {
       columnDescriptor("intProp", DataTypes.INTEGER_TYPE),
       columnDescriptor("intProp2", DataTypes.INTEGER_TYPE),
       columnDescriptor("vectProp", DataTypes.vector(DataTypes.FLOAT_TYPE,
   3)),
       columnDescriptor("stringProp", DataTypes.STRING_TYPE),
       columnDescriptor("vectProp2", DataTypes.vector(DataTypes.FLOAT_TYPE,
   2))
   };
   ```

2. Load the `PgxFrame` with the given schema from the specified path:

- JShell
- Java

JShell

```
opg4j> var vecFrame = session.readFrame().
    db().
    name("vector PgxFrame").
    tablename("tablename").      // name of the table from where
the data must be loaded
    jdbcUrl("jdbcUrl").
    username("user").
    owner("owner").              // necessary if the table is owned
by another user
    connections(16).             // indicates that 16 connections
can be used to load in parallel
    columns(vecFrameSchema).     // columns to load
    load()
```

Java

```
PgxFrame vecFrame = session.readFrame()
    .db()
    .name("vector PgxFrame")
    .tablename("tablename")      // name of the table from where
the data must be loaded
    .jdbcUrl("jdbcUrl")
    .username("user")
    .owner("owner")              // necessary if the table is owned
by another user
    .connections(16)             // indicates that 16 connections
can be used to load in parallel
    .columns(vecFrameSchema)     // columns to load
    .load();
```

The final result in the `PgxFrame` may appear as follows:

```
+------------------------------------------------------------+
| intProp | intProp2 | vectProp    | stringProp | vectProp2 |
+------------------------------------------------------------+
| 0       | 2        | 0.1;0.2;0.3 | testProp0  | 0.1;0.2   |
| 1       | 1        | 0.1;0.2;0.3 | testProp10 | 0.1;0.2   |
| 1       | 2        | 0.1;0.2;0.3 | testProp20 | 0.1;0.2   |
| 2       | 3        | 0.1;0.2;0.3 | testProp30 | 0.1;0.2   |
```

```
| 3        | 1         | 0.1;0.2;0.3 | testProp40 | 0.1;0.2    |
+------------------------------------------------------------+
```

23.13.9 Flattening Vector Properties

You can split the vector properties into multiple columns using the `flattenAll()` operation.

For example, you can flatten the vector properties for the example explained in Loading and Storing Vector Properties as shown:

- JShell
- Java

JShell

```
opg4j> vecFrame.flattenAll()
```

Java

```
vecFrame.flattenAll();
```

The resulting flattened `PgxFrame` may appear as shown:

```
+-----------------------------------------------------------------------------
------------------------+
| intProp | intProp2 | vectProp_0 | vectProp_1 | vectProp_2 | stringProp |
vectProp2_0 | vectProp2_1 |
+-----------------------------------------------------------------------------
------------------------+
| 0       | 2        | 0.1        | 0.2        | 0.3        | testProp0   |
0.1          | 0.2          |
| 1       | 1        | 0.1        | 0.2        | 0.3        | testProp10 |
0.1          | 0.2          |
| 1       | 2        | 0.1        | 0.2        | 0.3        | testProp20 |
0.1          | 0.2          |
| 2       | 3        | 0.1        | 0.2        | 0.3        | testProp30 |
0.1          | 0.2          |
| 3       | 1        | 0.1        | 0.2        | 0.3        | testProp40 |
0.1          | 0.2          |
+-----------------------------------------------------------------------------
------------------------+
```

23.13.10 PgxFrame Helpers

`PgxFrame` supports the following operations:

- `head`
- `tail`
- `select`
- `renameColumns`

Head Operation

The `head` operation can be used to only keep the first rows of a `PgxFrame`. (The result is deterministic only for ordered `PgxFrame`.)

- JShell
- Java

JShell

```
opg4j> vecFrame.head(2).print()
```

Java

```
vecFrame.head(2).print();
```

The output appears as follows:

```
+----------------------------------------------------------+
| intProp | intProp2 | vectProp    | stringProp | vectProp2 |
+----------------------------------------------------------+
| 0       | 2        | 0.1;0.2;0.3 | testProp0  | 0.1;0.2   |
| 1       | 1        | 0.1;0.2;0.3 | testProp10 | 0.1;0.2   |
+----------------------------------------------------------+
```

Tail Operation

The `tail` operation can be used to only keep the last rows of a `PgxFrame`. (The result is deterministic only for ordered `PgxFrame`).

- JShell
- Java

JShell

```
opg4j> vecFrame.tail(2).print()
```

Java

```
vecFrame.tail(2).print();
```

The output appears as follows:

```
+-----------------------------------------------------------+
| intProp | intProp2 | vectProp    | stringProp | vectProp2 |
+-----------------------------------------------------------+
| 2       | 3        | 0.1;0.2;0.3 | testProp30 | 0.1;0.2   |
| 3       | 1        | 0.1;0.2;0.3 | testProp40 | 0.1;0.2   |
+-----------------------------------------------------------+
```

Select Operation

The `select` operation can be used to keep only a specified list of columns of an input `PgxFrame`.

- JShell
- Java
- Python

JShell

```
opg4j> var vecFrameSelected = vecFrame.select("vectProp2", "vectProp",
"stringProp")
```

Java

```
PgxFrame vecFrameSelected =
vecFrame.select("vectProp2","vectProp","stringProp");
```

Python

```
vec_frame_selected = vec_frame.select("vectProp2","vectProp","stringProp")
```

The result may appear as follows:

```
+---------------------------------------+
| vectProp2 | vectProp    | stringProp |
+---------------------------------------+
| 0.1;0.2   | 0.1;0.2;0.3 | testProp0  |
```

```
| 0.1;0.2    | 0.1;0.2;0.3 | testProp10 |
| 0.1;0.2    | 0.1;0.2;0.3 | testProp20 |
| 0.1;0.2    | 0.1;0.2;0.3 | testProp30 |
| 0.1;0.2    | 0.1;0.2;0.3 | testProp40 |
+---------------------------------------+
```

Rename PgxFrame Columns

You can rename the columns in a `PgxFrame` to customized names as follows:

- JShell
- Java

JShell

```
opg4j> var vecFrameRenamed = vecFrame.renameColumns(
  renaming("vectProp2", "vectProp2_renamed"),
  renaming("vectProp", "vectProp_renamed"),
  renaming("stringProp", "stringProp_renamed")
)
```

Java

```
vecFrameRenamed = vecFrame.renameColumns(renaming("vectProp2",
"vectProp2_renamed"),
                                            renaming("vectProp",
"vectProp_renamed"),
                                            renaming("stringProp",
"stringProp_renamed"));
```

The renamed `PgxFrame` appears as follows:

```
+----------------------------------------------------------------------
----------+
| intProp | intProp2 | vectProp_renamed | stringProp_renamed |
vectProp2_renamed |
+----------------------------------------------------------------------
----------+
| 0       | 2        | 0.1;0.2;0.3      | testProp0          |
0.1;0.2           |
| 1       | 1        | 0.1;0.2;0.3      | testProp10         |
0.1;0.2           |
| 1       | 2        | 0.1;0.2;0.3      | testProp20         |
0.1;0.2           |
| 2       | 3        | 0.1;0.2;0.3      | testProp30         |
0.1;0.2           |
| 3       | 1        | 0.1;0.2;0.3      | testProp40         |
```

```
0.1;0.2           |
+--------------------------------------------------------------------------
----+
```

23.13.11 Converting a PgxFrame to PgqlResultSet

You can convert a `PgxFrame` to `PgqlResultSet` as follows:

- JShell
- Java
- Python

JShell

```
opg4j> var resultSet = exampleFrame.toPgqlResultSet()
```

Java

```
PgqlResultSet resultSet = exampleFrame.toPgqlResultSet();
```

Python

```
result_set = example_frame.to_pgql_result_set()
```

You can view the content of the result set through the usual `PgqlResultSet` APIs. The output appears as follows:

```
+---------------------------------------------------+
| from_acct_id | to_acct_id | amount | description |
+---------------------------------------------------+
| 1            | 418        | 1000.0 | transfer    |
| 1            | 584        | 1000.0 | transfer    |
| 1            | 644        | 1000.0 | transfer    |
| 1            | 672        | 1000.0 | transfer    |
| 1            | 259        | 1000.0 | transfer    |
+---------------------------------------------------+
```

23.13.12 PgxFrame to Pandas DataFrame Conversions

You can save a `PgxFrame` to a pandas `DataFrame` as shown in the following example:

```
>>> pandas_data_frame =  example_frame.to_pandas()
```

Similarly, you can load a `PgxFrame` from a pandas `DataFrame` as shown in the following example:

```
>>> example_frame = session.pandas_to_pgx_frame(pandas_data_frame,
"example frame")
```

23.13.13 Loading a PgxFrame from a Database

You can load a `PgxFrame` from relational tables in an Oracle database. Each column of the relational table will correspond to a column in the loaded frame. When loading a `PgxFrame` from the database, the default behavior is to detect the table columns and load them all. If not specified explicitly, the connection details of the current user and session are used and the columns are detected automatically.
The following describes the steps to load a `PgxFrame` from a database table:

1. Create a **Session** and an **Analyst**:

- JShell
- Java
- Python

JShell

```
cd /opt/oracle/graph/
./bin/opg4j
// starting the shell will create an implicit session and analyst
opg4j> import static
oracle.pgx.api.frames.functions.ColumnRenaming.renaming
opg4j> import static
oracle.pgx.api.frames.schema.ColumnDescriptor.columnDescriptor
opg4j> import oracle.pgx.api.frames.schema.*
opg4j> import oracle.pgx.api.frames.schema.datatypes.*
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.frames.*;
import oracle.pgx.api.frames.functions.*;
import oracle.pgx.api.frames.schema.*;
import oracle.pgx.api.frames.schema.datatypes.*;
import static
oracle.pgx.api.frames.functions.ColumnRenaming.renaming;
import static
oracle.pgx.api.frames.schema.ColumnDescriptor.columnDescriptor;

PgxSession session = Pgx.createSession("my-session");
Analyst analyst = session.createAnalyst();
```

Python

```
session = pypgx.get_session(session_name="my-session")
analyst = session.create_analyst()
```

2. Load a `PgxFrame`. The example assumes that you are loading the `PgxFrame` from the current logged in schema.

- JShell
- Java
- Python

JShell

```
opg4j> var exampleFrame = session.readFrame().
...>       db().
...>       name("Transfers").      // name of the frame
...>       tablename("T1").        // name of the table from where the
data must be loaded
...>       connections(16).        // indicates that 16 connections can
be used to load in parallel
...>       load()
```

Java

```
PgxFrame exampleFrame = session.readFrame()
    .db()
    .name("Transfers")
    .tablename("T1")
    .connections(16)
    .load();
```

Python

```
>>> example_frame = session.read_frame() \
...     .name('Transfers') \
...     .db() \
...     .table_name('T1') \
...     .load()
```

3. If only a subset of the columns must be loaded, then you can specify the columns as shown in the following example. Note that the following example loads the `PgxFrame` from a different schema.

* JShell
* Java
* Python

JShell

```
opg4j> session.registerKeystore(<pathToKeystore>,
<keystorePassword>)
opg4j> var exampleFrame = session.readFrame().
...>        db().
...>        name("Transfers").
...>        tablename("T1").              // name of the table from
where the data must be loaded
...>        jdbcUrl("<jdbcUrl>").
...>        username("<username>").
...>        keystoreAlias("<keystore_alias>").
...>        connections(16).              // indicates that 16
connections can be used to load in parallel
...>        columns(
...>        columnDescriptor("FROM_ACCT_ID", DataTypes.INTEGER_TYPE),
...>        columnDescriptor("TO_ACCT_ID", DataTypes.INTEGER_TYPE)
...>        ).                            // columns to load
...>        load()
```

Java

```
session.registerKeystore(<pathToKeystore>, <keystorePassword>)
PgxFrame exampleFrame = session.readFrame()
    .db()
    .name("Transfers")
    .tablename("T1")              // name of the table from where
the data must be loaded
    .jdbcUrl("<jdbcUrl>")
    .username("<username>")
    .keystoreAlias("<keystore_alias>")
    .connections(16)             // indicates that 16 connections
can be used to load in parallel
    .columns(
              columnDescriptor("FROM_ACCT_ID",
DataTypes.INTEGER_TYPE),
              columnDescriptor("TO_ACCT_ID", DataTypes.INTEGER_TYPE)
            )                    // columns to load
    .load();
```

Python

```
>>> example_frame = session.read_frame() \
...             .name('Transfers1') \
...             .db() \
```

```
...             .table_name('T1') \
...             .jdbc_url('jdbc:oracle:thin:@localhost:1521/orclpdb') \
...             .username('graphuser') \
...             .keystore_alias('database3') \
...             .columns(
...             [
...               ('FROM_ACCT_ID', 'INTEGER_TYPE'),
...               ('TO_ACCT_ID', 'INTEGER_TYPE')
...             ]
...             )\
...             .load()
```

You can also create a graph from the `PgxFrame`(s). See Creating a Graph from Multiple PgxFrame Objects for more information.

23.13.14 Loading a PgxFrame from a CSV File

In order to load a `PgxFrame` from a CSV file, you first need to explicitly authorize access to the corresponding directories by defining a directory object pointing to the directory (on the graph server) where the file needs to be written.

```
CREATE OR REPLACE DIRECTORY graph_files AS '/tmp';
GRANT READ, WRITE ON DIRECTORY graph_files TO GRAPH_DEVELOPER;
```

Also, note the following:

- The directory in the `CREATE DIRECTORY` statement must exist **on the graph server (PGX)**.
- The directory must be readable at the OS level by the graph server (PGX).

The preceding code grants the privileges on the directory to the `GRAPH_DEVELOPER` role. However, you can also grant permissions to an individual user:

```
GRANT READ ON DIRECTORY graph_files TO <graph_user>;
```

You can then load a `PgxFrame` from a CSV file as shown in the following example:

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.api.frames.schema.datatypes.*
opg4j> import static
oracle.pgx.api.frames.schema.ColumnDescriptor.columnDescriptor
```

```
opg4j> var exampleFrame = session.readFrame().csv().
...>     name("transfersFrame").
...>     columns(
...>       columnDescriptor("from_acct_id", DataTypes.INTEGER_TYPE),
...>       columnDescriptor("to_acct_id", DataTypes.INTEGER_TYPE),
...>       columnDescriptor("amount", DataTypes.FLOAT_TYPE),
...>       columnDescriptor("description", DataTypes.STRING_TYPE)
...>     ).
...>     load("/tmp/Transfers.csv")
```

Java

```
import oracle.pgx.api.frames.schema.datatypes.*;
import static
oracle.pgx.api.frames.schema.ColumnDescriptor.columnDescriptor;

PgxFrame exampleFrame = session.readFrame().csv().
    name("transfersFrame").
    columns(
      columnDescriptor("from_acct_id", DataTypes.INTEGER_TYPE),
      columnDescriptor("to_acct_id", DataTypes.INTEGER_TYPE),
      columnDescriptor("amount", DataTypes.FLOAT_TYPE),
      columnDescriptor("description", DataTypes.STRING_TYPE)
    ).
    load("/tmp/Transfers.csv");
```

Python

```
>>> example_frame = session.read_frame(). \
...     csv(). \
...     name('transfers_frame'). \
...     columns([('from_acct_id', 'INTEGER_TYPE'),
...              ('to_acct_id', 'INTEGER_TYPE'),
...              ('amount', 'FLOAT_TYPE'),
...              ('description', 'STRING_TYPE')]). \
...     load('/tmp/Transfers.csv')
```

23.13.15 Loading a PgxFrame from Client-Side Data

You can also load `PgxFrame`(s) directly from client-side data.
The following describes the steps to load a `PgxFrame` from client-side data:

1. Create a **Session** and an **Analyst**:

   See step-1 in Loading a PgxFrame from a Database for the code examples.

2. Define a frame schema to load a `PgxFrame` from client side data. For example, the following shows a frame schema defined with various data types:

- JShell
- Java
- Python

JShell

```
opg4j> var exampleFrameSchema = List.of(
    columnDescriptor("name", DataTypes.STRING_TYPE),
    columnDescriptor("age", DataTypes.INTEGER_TYPE),
    columnDescriptor("salary", DataTypes.DOUBLE_TYPE),
    columnDescriptor("married", DataTypes.BOOLEAN_TYPE),
    columnDescriptor("tax_rate", DataTypes.FLOAT_TYPE),
    columnDescriptor("random", DataTypes.LONG_TYPE),
    columnDescriptor("date_of_birth", DataTypes.LOCAL_DATE_TYPE)
)
```

Java

```
List<ColumnDescriptor> exampleFrameSchema = Arrays.asList(
    columnDescriptor("name", DataTypes.STRING_TYPE),
    columnDescriptor("age", DataTypes.INTEGER_TYPE),
    columnDescriptor("salary", DataTypes.DOUBLE_TYPE),
    columnDescriptor("married", DataTypes.BOOLEAN_TYPE),
    columnDescriptor("tax_rate", DataTypes.FLOAT_TYPE),
    columnDescriptor("random", DataTypes.LONG_TYPE),
    columnDescriptor("date_of_birth", DataTypes.LOCAL_DATE_TYPE)
);
```

Python

```
example_frame_schema = [
    ("name", "STRING_TYPE"),
    ("age", "INTEGER_TYPE"),
    ("salary", "DOUBLE_TYPE"),
    ("married", "BOOLEAN_TYPE"),
    ("tax_rate", "FLOAT_TYPE"),
    ("random", "LONG_TYPE"),
    ("date_of_birth", "LOCAL_DATE_TYPE")
]
```

3. Define data as per the schema.

- JShell
- Java
- Python

JShell

```
opg4j> Map<String, Iterable<?>> exampleFrameData = Map.of(
    "name", Arrays.asList("Alice", "Bob", "Charlie"),
    "age", Arrays.asList(25, 27, 29),
    "salary", Arrays.asList(10000.0, 15000.0, 20000.0),
    "married", Arrays.asList(false, false, true),
    "tax_rate", Arrays.asList(0.21, 0.26, 0.32),
    "random", Arrays.asList(2394293898324L, 45640604960495L,
12312323409087654L),
    "date_of_birth", Arrays.asList(
        LocalDate.of(1990, 9, 15),
        LocalDate.of(1991, 11, 4),
        LocalDate.of(1993, 10, 4)
    )
)
```

Java

```
Map<String, Iterable<?>> exampleFrameData = new HashMap<>();
exampleFrameData.put("name", Arrays.asList("Alice", "Bob",
"Charlie"));
exampleFrameData.put("age", Arrays.asList(25, 27, 29));
exampleFrameData.put("salary", Arrays.asList(10000.0, 15000.0,
20000.0));
exampleFrameData.put("married", Arrays.asList(false, false, true));
exampleFrameData.put("tax_rate", Arrays.asList(0.21, 0.26, 0.32));
exampleFrameData.put("random", Arrays.asList(2394293898324L,
45640604960495L, 12312323409087654L));
exampleFrameData.put("date_of_birth",
    Arrays.asList(LocalDate.of(1990, 9, 15),
        LocalDate.of(1991, 11, 4),
        LocalDate.of(1993, 10, 4)
    )
);
```

Python

```
from datetime import date

example_frame_data = {
    "name": ["Alice", "Bob", "Charlie"],
    "age": [25, 27, 29],
    "salary": [10000.0, 15000.0, 20000.0],
    "married": [False, False, True],
    "tax_rate": [0.21, 0.26, 0.32],
    "random": [2394293898324, 45640604960495, 12312323409087654],
    "date_of_birth": [date(1990, 9, 15),
                      date(1991, 11, 4),
                      date(1993, 10, 4)]
}
```

4. Load the frame as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var exampleFrame = session.createFrame(exampleFrameSchema,
exampleFrameData, "example frame")
```

Java

```
PgxFrame exampleFrame = session.createFrame(exampleFrameSchema,
exampleFrameData, "example frame");
```

Python

```
example_frame=session.create_frame(example_frame_schema,example_frame_data
,'example frame')
```

5. You can also load the frame incrementally as you receive more data:

- JShell
- Java
- Python

JShell

```
opg4j> var exampleFrameBuilder =
session.createFrameBuilder(exampleFrameSchema);
opg4j> exampleFrameBuilder.addRows(exampleFrameData)
opg4j> Map<String, Iterable<?>> exampleFrameDataPart2 = Map.of(
    "name", Arrays.asList("Dave"),
    "age", Arrays.asList(26),
    "salary", Arrays.asList(18000.0),
    "married", Arrays.asList(true),
    "tax_rate", Arrays.asList(0.30),
    "random", Arrays.asList(456783423423L),
    "date_of_birth", Arrays.asList(LocalDate.of(1989, 9, 15))
)
```

```
opg4j> exampleFrameBuilder.addRows(exampleFrameDataPart2)
opg4j> var exampleFrame = exampleFrameBuilder.build("example frame")
```

Java

```
PgxFrameBuilder exampleFrameBuilder =
session.createFrameBuilder(exampleFrameSchema);
exampleFrameBuilder.addRows(exampleFrameData);
Map<String, Iterable<?>> exampleFrameDataPart2 = new HashMap<>();
exampleFrameDataPart2.put("name", Arrays.asList("Dave"));
exampleFrameDataPart2.put("age", Arrays.asList(26));
exampleFrameDataPart2.put("salary", Arrays.asList(18000.0));
exampleFrameDataPart2.put("married", Arrays.asList(true));
exampleFrameDataPart2.put("tax_rate", Arrays.asList(0.30));
exampleFrameDataPart2.put("random", Arrays.asList(456783423423L));
exampleFrameDataPart2.put("date_of_birth",
    Arrays.asList(LocalDate.of(1989, 9, 15))
);
exampleFrameBuilder.addRows(exampleFrameDataPart2);
PgxFrame exampleFrame = exampleFrameBuilder.build("example frame");
```

Python

```
example_frame_builder =
session.create_frame_builder(example_frame_schema)
example_frame_builder.add_rows(example_frame_data)
example_frame_data_part_2 = {
    "name": ["Dave"],
    "age": [26],
    "salary": [18000.0],
    "married": [True],
    "tax_rate": [0.30],
    "random": [456783423423],
    "date_of_birth": [date(1989, 9, 15)]
}
example_frame_builder.add_rows(example_frame_data_part_2)
example_frame = example_frame_builder.build("example frame")
```

6. Finally, you can also load a frame from a Pandas dataframe in Python as shown:

```
import pandas as pd
example_pandas_dataframe = pd.DataFrame(data=example_frame_data)
example_frame =
session.pandas_to_pgx_frame(example_pandas_dataframe, "example
frame")
```

You can also create a graph from the `PgxFrame`(s) . See Creating a Graph from Multiple PgxFrame Objects for more information.

23.13.16 Creating a Graph from Multiple PgxFrame Objects

You can create a `PgxGraph` with vertex `PgxFrame`(s) and edge `PgxFrame`(s).

Consider the following `PgxFrame` objects:

```
people
+---------------+
| id | name     |
+---------------+
| 1  | Alice    |
| 2  | Bob      |
| 3  | Charlie  |
+---------------+

houses
+---------------------------+
| identification | location |
+---------------------------+
| 1              | Road 1   |
| 2              | Street 5 |
| 3              | Avenue 4 |
+---------------------------+

knows
+------------+
| src | dst  |
+------------+
| 1   | 1    |
| 2   | 3    |
| 3   | 2    |
+------------+

lives
+------------------------+
| source | destination   |
+------------------------+
| 1      | 2             |
| 2      | 1             |
| 3      | 3             |
+------------------------+
```

You can now create a `PgxGraph` as shown in the following examples:

- JShell
- Java
- Python

JShell

```
opg4j> var graphFromFramesCreator =
session.createGraphFromFrames("example graph")
opg4j> graphFromFramesCreator.vertexProvider("people", people)
opg4j> graphFromFramesCreator.vertexProvider("houses",
houses).vertexKeyColumn("identification")
opg4j> graphFromFramesCreator.edgeProvider("knows", "people",
"people", knows)
opg4j> var edge_provider =
graphFromFramesCreator.edgeProvider("lives", "people", "houses", lives)
opg4j> edge_provider.sourceVertexKeyColumn("source")
opg4j> edge_provider.destinationVertexKeyColumn("destination")
opg4j> graphFromFramesCreator.partitioned(true)
opg4j> var graph = graphFromFramesCreator.create()
```

Java

```
PgxGraphFromFramesCreator graphFromFramesCreator =
session.createGraphFromFrames("example graph");
graphFromFramesCreator.vertexProvider("people", people);
graphFromFramesCreator.vertexProvider("houses",
houses).vertexKeyColumn("identification");
graphFromFramesCreator.edgeProvider("knows", "people", "people",
knows);
PgxEdgeProviderFromFramesCreator edgeProvider =
graphFromFramesCreator.edgeProvider("lives", "people", "houses",
lives);
edgeProvider.sourceVertexKeyColumn("source");
edgeProvider.destinationVertexKeyColumn("destination");
graphFromFramesCreator.partitioned(true);
PgxGraph graph = graphFromFramesCreator.create();
```

Python

```
vertex_providers_from_frames = [
    session.vertex_provider_from_frame("person",
                                       people),
    session.vertex_provider_from_frame("house",
                                       frame = houses,
                                       vertex_key_column =
"identification")
]
edge_providers_from_frames = [
    session.edge_provider_from_frame("person_knows_person",
                                     source_provider = "person",
                                     destination_provider = "person",
                                     frame = knows),
    session.edge_provider_from_frame("person_lives_at_house",
                                     source_provider = "person",
                                     destination_provider = "house",
                                     frame = lives,
                                     source_vertex_column="source",
```

```
                                     destination_vertex_column="destination")
]
graph = session.graph_from_frames("example graph",
vertex_providers_from_frames, edge_providers_from_frames, partitioned=True)
```

24 Working with Files Using the Graph Server (PGX)

This chapter describes in detail about working with different file formats to perform various actions like loading, storing, or exporting a graph using the Graph Server (PGX).

In order to read or write files, you need to explicitly authorize access to the corresponding directories by defining a directory object pointing to the directory (on the graph server) that contains the files to read or write.

```
CREATE OR REPLACE DIRECTORY graph_files AS '/data/graphs/my_graphs';
GRANT READ, WRITE ON DIRECTORY graph_files TO GRAPH_DEVELOPER;
```

Also, note the following:

- The directory in the `CREATE DIRECTORY` statement must exist **on the graph server (PGX)**.
- The directory must be readable (and/or writable) at the OS level by the graph server (PGX).

The preceding code grants the privileges on the directory to the `GRAPH_DEVELOPER` role. However, you can also grant permissions to an individual user:

```
GRANT READ ON DIRECTORY graph_files TO <graph_user>;
```

- Loading Graph Data from Files
- Loading Graph Data in Parallel from Multiple Files
- Exporting Graphs Into a File
- Exporting a Graph into Multiple Files

24.1 Loading Graph Data from Files

You can load graph data from files by either of the two ways:

- using the header format specified in the files
- by directly calling the graph builder API

Creating a graph using file header format

The graph server (PGX) uses the header of the files to determine the name and types of the properties to load. It also infers the column to be used as vertex ID, the columns that indicate the source and destination vertex ID for edges, and the column to be loaded as vertex or edge label.

Creating a graph using graph builder API

You can also use PgxSession.readGraphFiles() to load the graph. This method takes the following three arguments:

- path to the vertex file
- path to the edge file
- name of the graph to be created

- JShell
- Java
- Python

JShell

```
opg4j> var loadedGraph = session.readGraphFiles("<path/vertices.csv>",
"<path/edges.csv>", "<graph_name>")
```

Java

```
import oracle.pgx.api.PgxSession;
import oracle.pgx.api.PgxGraph;

PgxSession session = Pgx.createSession("NewSession");
PgxGraph loadedGraph = session.readGraphFiles("<path/vertices.csv>",
"<path/edges.csv>", "<graph_name>");
```

Python

```
session = pypgx.get_session(session_name="<session_name>")
loaded_graph = session.read_graph_files("<path/vertices.csv>", "<path/
edges.csv>", "<graph_name>")
```

The graph server (PGX) supports loading graph data from files for the following data formats

- Plain Text Formats
- XML File Formats
- Binary File Formats
- Graph Configuration for Loading from File
- Specifying the File Path
- Supported File Access Protocols

- Plain Text Formats
- XML File Formats
- Binary File Formats

24.1.1 Graph Configuration for Loading from File

The following table presents the graph configuration options to load graph data from all supported file formats to the graph server (PGX).

Table 24-1 Loading from File - Graph Configuration Options

Field	Type	Description	Default
array_compaction_threshold	number	*[only relevant if the graph is optimized for updates]* Threshold used to determined when to compact the delta-logs into a new array. If lower than the engine min_array_compaction_threshold value, min_array_compaction_threshold will be used instead.	0.2
attributes	object	Additional attributes needed to read and write the graph data.	null
detect_gzip	boolean	Enable or disable automatic gzip compression detection when loading graphs.	true
edge_id_strategy	enum[no_ids, keys_as_ids, unstable_generated_ids]	Indicates what ID strategy should be used for the edges of this graph. If not specified (or set to null), the strategy will be determined during loading or using a default value.	null
edge_id_type	enum[long]	Type of the edge ID. For homogeneous graphs, if not specified (or set to null), it will default to long.	null
edge_props	array of object	Specification of edge properties associated with graph.	[]
edge_uris	array of string	List of unified resource identifiers.	[]
error_handling	object	Error handling configuration.	null
external_stores	array of object	Specification of the external stores where external string properties reside.	[]
format	enum[pgb, edge_list, adj_list, graphml, pg, rdf, two_tables]	Graph format to be used.	null
header	boolean	First line of file is meant for headers. For example, 'EdgeId, SourceId, DestId, EdgeProp1, EdgeProp2'	false
keystore_alias	string	Alias to the keystore to use when connecting to the database.	null
loading	object	Loading-specific configuration.	null

Table 24-1 (Cont.) Loading from File - Graph Configuration Options

Field	Type	Description	Default
local_date_format	array of string	Array of local_date formats to use when loading and storing local_date properties. See DateTimeFormatter for documentation of the format string.	[]
optimized_for	enum[read, updates]	Indicates if the graph must use data-structures optimized for read-intensive scenarios or for fast updates.	read
partition_while_loading	enum[by_label, no]	Indicates if the graph must partitioned while loading.	null
password	string	Password to use when connecting to database.	null
point2d	string	Longitude and latitude as floating point values separated by a space.	0.0 0.0
separator	string	A series of single-character separators for tokenizing. The characters ", {, } and \n cannot be used as separators. Default value is "," for CSV files, and "\t " for other formats. The first character will be used as a separator when storing.	null
storing	object	Storing-specific configuration.	null
time_format	array of string	The time format to use when loading and storing time properties. See DateTimeFormatter for documentation of the format string.	[]
time_with_timezone_format	array of string	The time with timezone format to use when loading and storing time with timezone properties. See DateTimeFormatter for documentation of the format string.	[]
timestamp_format	array of string	The timestamp format to use when loading and storing timestamp properties. See DateTimeFormatter for documentation of the format string.	[]
timestamp_with_timezone_format	array of string	The timestamp with timezone format to use when loading and storing timestamp with timezone properties. See DateTimeFormatter for documentation of the format string.	[]
vector_component_delimiter	character	Delimiter for the different components of vector properties.	;
vertex_id_strategy	enum[no_ids, keys_as_ids, unstable_generated_ids]	Indicates what ID strategy should be used for the vertices of this graph. If not specified (or set to null), the strategy will be automatically detected.	null
vertex_id_type	enum[int, integer, long, string]	Type of the vertex ID. For homogeneous graphs, if not specified (or set to null), it will default to a specific value (depending on the origin of the data).	null
vertex_props	array of object	Specification of vertex properties associated with graph.	[]
vertex_uris	array of string	List of unified resource identifiers.	[]

In the CSV format, the columns used to specify the vertex ID column, vertex labels column, edge ID column, edge source ID column, edge destination ID column and the edge label column can be configured with the CSV specific fields as shown in the following table:

Table 24-2 CSV Specific Options

Field	Type	Description	Default
array_compaction_threshold	number	*[only relevant if the graph is optimized for updates]* Threshold used to determined when to compact the delta-logs into a new array. If lower than the engine min_array_compaction_threshold value, min_array_compaction_threshold will be used instead.	0.2
attributes	object	Additional attributes needed to read and write the graph data.	null
detect_gzip	boolean	Enable or disable automatic gzip compression detection when loading graphs.	true
edge_destination_column	value	Name or index (starting from 1) of column corresponding to edge destination (for CSV format only).	null
edge_id_column	value	Name or index (starting from 1) of column corresponding to edge id (for CSV format only).	null
edge_id_strategy	enum[no_ids, keys_as_ids, unstable_generated_ids]	Indicates what ID strategy should be used for the edges of this graph. If not specified (or set to null), the strategy will be determined during loading or using a default value.	null
edge_id_type	enum[long]	Type of the edge ID. For homogeneous graphs, if not specified (or set to null), it will default to long.	null
edge_label_column	value	Name or index (starting from 1) of column corresponding to edge label (for CSV format only).	null
edge_props	array of object	Specification of edge properties associated with graph.	[]
edge_source_column	value	Name or index (starting from 1) of column corresponding to edge source (for CSV format only).	null
error_handling	object	Error handling configuration.	null
external_stores	array of object	Specification of the external stores where external string properties reside.	[]
format	enum[pgb, edge_list, adj_list, graphml, pg, rdf, two_tables]	Graph format to be used.	null
header	boolean	First line of file is meant for headers. For example, 'EdgeId, SourceId, DestId, EdgeProp1, EdgeProp2'.	false

Table 24-2 (Cont.) CSV Specific Options

Field	Type	Description	Default
keystore_alias	string	Alias to the keystore to use when connecting to database.	null
loading	object	Loading-specific configuration.	null
local_date_format	array of string	array of local_date formats to use when loading and storing local_date properties. See DateTimeFormatter for documentation of the format string	[]
optimized_for	enum[read, updates]	Indicates if the graph should use data-structures optimized for read-intensive scenarios or for fast updates.	read
partition_while_loading	enum[by_label, no]	Indicates if the graph should be partitioned while loading.	null
password	string	Password to use when connecting to database.	null
point2d	string	Longitude and latitude as floating point values separated by a space.	0.0 0.0
separator	string	a series of single-character separators for tokenizing. The characters ", {, } and \n cannot be used as separators. Default value is "," for CSV files, and "\t " for other formats. The first character will be used as a separator when storing.	null
storing	object	Storing-specific configuration.	null
time_format	array of string	The time format to use when loading and storing time properties. See DateTimeFormatter for documentation of the format string	[]
time_with_timezone_format	array of string	The time with timezone format to use when loading and storing time with timezone properties. See DateTimeFormatter for documentation of the format string.	[]
timestamp_format	array of string	The timestamp format to use when loading and storing timestamp properties. See DateTimeFormatter for documentation of the format string.	[]
timestamp_with_timezone_format	array of string	The timestamp with timezone format to use when loading and storing timestamp with timezone properties. See DateTimeFormatter for documentation of the format string.	[]
vector_component_delimiter	character	Delimiter for the different components of vector properties.	;
vertex_id_column	value	Name or index (starting from 1) of column corresponding to vertex id (for CSV format only).	null
vertex_id_strategy	enum[no_ids, keys_as_ids, unstable_generated_ids]	Indicates what ID strategy should be used for the vertices of this graph. If not specified (or set to null), the strategy will be automatically detected.	null

Table 24-2 (Cont.) CSV Specific Options

Field	Type	Description	Default
vertex_id_type	enum[int, integer, long, string]	Type of the vertex ID. For homogeneous graphs, if not specified (or set to null), it will default to a specific value (depending on the origin of the data).	null
vertex_labels_column	value	Name or index (starting from 1) of column corresponding to vertex labels (for CSV format only).	null
vertex_props	array of object	Specification of vertex properties associated with graph.	[]

24.1.2 Specifying the File Path

The following examples show how to specify the file path for various file formats.

For formats that contain vertices and edges specified in one file (for example, EdgeList), use uris as shown in the following code:

```
{"uris":["path/to/file.format"]}
```

For formats that require separate files for edges and vertices (for example, FlatFile), use vertex_uris and edge_uris as shown in the following code:

```
{"vertex_uris":["vertices1.format","vertices2.format"],"edge_uris":
["edges1.format","edges2.format"]}
```

PGX will parse graphs in most of the plain text formats in parallel if the graph data is split into multiple files, as shown in the following code:

```
{"uris":["file1.format","file2.format",...,"fileN.format"]}
```

24.1.3 Supported File Access Protocols

The graph server (PGX) supports loading from graph configuration files and graph data files over various protocols and virtual file systems. The type of file system or protocol is determined by the scheme of the uniform resource identifier (URI):

- local file system (file:) - this is also the default if the given URI does not contain any scheme
- classpath (classpath: or res:)
- HDFS (hdfs:)
- HTTPS (https:)
- FTPS (ftps:)

- various archive formats (`zip:`, `jar:`, `tar:`, `tgz:`, `tbz2:`, `gz:` and `bz2:`). The URI format is `scheme://arch-file-uri[!absolute-path]` (if you would like to use the `!` as a literal file-name character it must be escaped using `%21`).
  For example, `jar:../lib/classes.jar!/META-INF/graph.json`.

  Paths may be nested as in `tar:gz:https://anyhost/dir/mytar.tar.gz!/mytar.tar!/path/in/tar/graph.data`.

> **Note:**
>
> Relative paths are always resolved relative to the parent directory of the configuration file.

24.1.4 Plain Text Formats

The graph server (PGX) supports the following plain-text formats:

- Comma-Separated Values (CSV)
- Adjacency List (ADJ_LIST)
- Edge List (EDGE_LIST)
- Two Tables (TWO_TABLES)
- Flat File (FLAT_FILE)

Parsing of Vertices

PGX supports three types of vertex identifies (id): `integer`, `long` and `string`. The type defaults to `integer`, but can be configured through the `vertex_id_type` option in the graph configuration.

Parsing of Edges

Of the various formats and protocols supported by graph server (PGX), only CSV and flat file parsing support edge identifiers. For all other data sources, the id of an edge is PGX's internal id, which is an integer from zero to `num_edges - 1`.

Parsing of Properties

`string` properties, spatial properties (currently only `point2d`) and temporal properties (`date`, `local_date`, `time`, `timestamp`, `time_with_timezone` and `timestamp_with_timezone`) must be quoted ("`<string>`") only if they contain a separator character (usually `,` for CSV and `' '` for Edge List and Adjacency List) or if they contain `"` or `\n`.

`date` properties are parsed using Java's SimpleDateFormat utility, instantiated with the format string `yyyy-MM-dd HH:mm:ss` unless specified otherwise in the graph configuration. All other types of temporal properties are parsed using Java's DateTimeFormatter utility.

`point2d` can be specified by its longitude followed by its latitude, separated by a space. Both longitude and latitude are doubles. For example, "`-74.0445 40.6892`" is the representation of a point2d instance representing the location of the Statue of Liberty.

Boolean values are interpreted as true if the value is `true` (ignoring case), `Y` (ignoring case) or `1`, false otherwise. The suggested notation for false is `false` (ignoring case), `N` (ignoring case) or `0`. All other types are parsed using the `parseXXX()` functions of its corresponding Java type, for example, `Integer.parseInt(...)` for integer types.

Vector properties are supported in the Adjacency List (ADJ_LIST), Comma-Separated Values (CSV), Edge List (EDGE_LIST), and Two Tables text (TWO_TABLES) formats. Vector properties with vector components of type `integer`, `long`, `float` and `double` can be loaded from these formats. In order to specify that a vertex or edge property is a vector property, the `dimension` field of the graph property configuration must be set to the dimension of the vector and be a strictly positive integer value. A vector value is represented in the supported text formats by the list of the vector components values separated by the vector component delimiter. By default the vector component delimiter is `;`, but this delimiter can be changed by changing the `vector_component_delimiter` graph configuration entry. Therefore a 3-dimensional vector of doubles could for example look like `0.1;0.0004;3.14` in the text file if the vector component delimiter is `;`.

Separators

When using single file formats, IDs and properties are separated with `tab` or one single space (`"\t "`) by default, for multiple file formats comma (`","`) is used instead. However, PGX allows to configure the separator string.

Parallel Loading

The following formats support parallel loading from multiple files:

- CSV (specify multiple files in vertex_uris and/or edge_uris)
- Adjacency List (specify multiple files in uris)
- Edge List (specify multiple files in uris)
- Two Tables (specify multiple files in vertex_uris and/or edge_uris)
- Flat File (specify multiple files in vertex_uris and/or edge_uris)

Legend

The following abbreviations are used to specify text formats:

- V = Vertex Key
- VG = Neighbor Vertex
- VL = Vertex Labels
- VP = Vertex Property
- VPK = Vertex Property Key
- VPT = Vertex Property Type
- EL = Edge Label
- EP = Edge Property
- EPK = Edge Property Key
- EPT = Edge Property Type

For example `<V-2, VG-4>` or `<V-2, VG-4>` denotes the 4th neighbor of the 2nd vertex.

- Comma-Separated Values (CSV)

- Adjacency List (ADJ_LIST)
- Edge List (EDGE_LIST)
- Two Tables (TWO_TABLES)

24.1.4.1 Comma-Separated Values (CSV)

The CSV format is a text file format with vertices and edges stored in different files. Each line of the files represents a vertex or an edge. The vertex key and labels, the edge key, source, destination and label, and the attached properties are stored in the order specified by the file header (first line) and the configuration.

A graph with V vertices, having N vertex properties and K neighbors each, and E edges, having M edge properties, would be represented in CSV as shown:

```
vertices.csv

<V-1>,<VL-1>,<V-1, NP-1>,...,<V-1, NP-N>
<V-2>,<VL-2>,<V-2, NP-1>,...,<V-2, NP-N>
...
<V-V>,<VL-N>,<V-V, NP-1>,...,<V-V, NP-N>

edges.csv

<E-1>,<V-1>,<V-1, VG-1>,<EL-1>,<E-1, EP-1>,...,<E-1, EP-M>
...
<E-K>,<V-1>,<V-1, VG-K>,<EL-N>,<E-K, EP-1>,...,<E-K, EP-M>
<E-K+1>,<V-2>,<V-2, VG-1>,<EL-N+1>,<E-K+1, EP-1>,...,<E-K+1, EP-M>
...
<E-V*K>,<V-V>,<V-V, VG-K>,<EL-V*K>,<E-V*K, EP-1>,...,<E-V*K, EP-M>
```

Example 24-1 Loading graph from a CSV file with header details

The following examples shows a graph configuration file for loading a graph with two vertices and two edges:

```
vertices.csv

key,integer_prop,string_prop
1,33,"Alice"
2,42,"Bob"


edges.csv

source,dest,integer_prop,string_prop
1,2,0,"baz"
2,2,-12,"bat"
```

The corresponding graph configuration file is as shown:

```
{
    "format": "csv",
    "header": true,
    "vertex_id_column": "key",
    "edge_source_column": "source",
    "edge_destination_column": "dest",
```

```
    "vertex_uris": ["vertices.csv"],
    "edge_uris": ["edges.csv"],
    "vertex_props": [
        {
            "name": "integer_prop",
            "type": "integer"
        },
        {
            "name": "string_prop",
            "type": "string"
        }
    ],
    "edge_props": [
        {
            "name": "integer_prop",
            "type": "integer"
        },
        {
            "name": "string_prop",
            "type": "string"
        }
    ]
}
```

Example 24-2 Loading graph from a CSV file without header details

The following examples shows a graph configuration file for loading a graph with two vertices and two edges:

```
vertices.csv

1,33,"Alice"
2,42,"Bob"
```

```
edges.csv

1,2,0,"baz"
2,2,-12,"bat"
```

The corresponding graph configuration file is as shown:

> **Note:**
>
> The column indices are given in place of the column names.

```
{
    "format": "csv",
    "header": false,
    "vertex_id_column": 1,
    "edge_source_column": 1,
    "edge_destination_column": 2,
```

```
    "vertex_uris": ["vertices.csv"],
    "edge_uris": ["edges.csv"],
    "vertex_props": [
        {
            "name": "integer_prop",
            "type": "integer",
            "column": 2
        },
        {
            "name": "string_prop",
            "type": "string",
            "column": 3
        }
    ],
    "edge_props": [
        {
            "name": "integer_prop",
            "type": "integer",
            "column": 3
        },
        {
            "name": "string_prop",
            "type": "string",
            "column": 4
        }
    ]
}
```

If no column indices are set in the configuration file, the columns are assumed to be in the following order:

- For vertex files: - Vertex ID - Vertex labels (if present) - Vertex properties in the order they are declared in the configuration
- For edge files: - Edge ID (if present) - Edge source - Edge destination - Edge label (if present) - Edge properties in the order they are declared in the configuration

Therefore the earlier configuration is equivalent to:

```
{
    "format": "csv",
    "header": false,
    "vertex_uris": ["vertices.csv"],
    "edge_uris": ["edges.csv"],
    "vertex_props": [
        {
            "name": "integer_prop",
            "type": "integer"
        },
        {
            "name": "string_prop",
            "type": "string"
        }
    ],
    "edge_props": [
        {
```

```
                "name": "integer_prop",
                "type": "integer"
            },
            {
                "name": "string_prop",
                "type": "string"
            }
        ]
    }
```

24.1.4.2 Adjacency List (ADJ_LIST)

The Adjacency List format is a text file format containing a list of neighbors from a vertex, per line. The format is extended to encode properties. The following shows a graph with V vertices, having N vertex properties and M edge properties:

```
<V-1> <V-1, VP-1> ... <V-1, VP-N> <V-1, VG-1> <EP-1> ... <EP-M> <V-1, VG-2> <EP-1> ...
<EP-M>
<V-2> <V-2, VP-1> ... <V-2, VP-N> <V-2, VG-1> <EP-1> ... <EP-M> <V-2, VG-2> <EP-1> ...
<EP-M>
...
<V-V> <V-V, VP-1> ... <V-V, VP-N> <V-V, VG-1> <EP-1> ... <EP-M> <V-V, VG-2> <EP-1> ...
<EP-M>
```

> **Note:**
>
> Trailing separators will be considered as errors. For example, if whitespace is used to separate the properties, any trailing whitespace will cause an exception to be raised.

Example 24-3 Graph in Adjacency List Format

This example shows a graph with 4 vertices (1, 2, 3 and 4), each having a double and a string property, and 3 edges, each having a boolean and a date property, encoded in Adjacency List format:

```
1 8.0 "foo"
2 4.3 "bar" 1 false "1985-10-18 10:00:00"
3 6.1 "bax" 2 true "1961-12-30 14:45:14" 4 false "2001-01-15 07:00:43"
4 17.78 "f00"
```

> **Note:**
>
> ADJ_LIST is more space efficient than EDGE_LIST. This is because vertices are first defined and then the edges are being created, indicating that we are repeating each vertex at least once.

24.1.4.3 Edge List (EDGE_LIST)

The Edge List format is a text file format starting with a section with one vertex per line, followed by a section with one edge per line. If a vertex does not have any labels or properties, it is possible to omit the vertex in the first section, but still specify edges for the vertex in the second section.

```
EdgeList      := {Vertex '\n'}* '\n' {Edge '\n'}*

Vertex        := VertexId '*' VertexLabels? PropertyValue*
VertexId      := Integer | Long | String
VertexLabels  := '{' String* '}'

Edge          := SrcVertex DstVertex EdgeLabel? PropertyValue*
SrcVertex     := VertexId
DstVertex     := VertexId
EdgeLabel     := String

PropertyValue := Integer | Long | Double | Float | Boolean | String | Date
```

The vertices start with an identifier (`VertexId`), followed by a `*`, an optional set of vertex labels (`VertexLabels?`) and the vertex properties (`PropertyValue*`). A vertex identifier is either an Integer, a Long, or a String. Furthermore, vertex labels are zero or more Strings between curly braces (`'{' String* '}'`).

The edges start with source and destination vertex identifiers (`SrcVertex DstVertex`), followed by optional edge label (`EdgeLabel?`) and the edge properties (`PropertyValue*`). The edge label is a `String`.

Example 24-4 Graph in Edge List format

This example shows a graph with two vertices and two edges, with labels and properties:

```
1 * { "Person" "Male" } "Mario" 15
2 * { "Person" "Male" } "Luigi" 14
1 2 "likes" 3.5
2 1 "likes" 2.1
```

The two vertices (lines 1-2) have identifiers 1 and 2 and both have the labels "Person" and "Male", a string property ("Mario" and "Luigi") and an integer property (15 and 14). There is an edge from vertex 1 to vertex 2 (line 3) with label "likes" and a double property with value 3.5, and another edge from vertex 2 to vertex 1 with label "likes" and a double property with value 2.1.

The following shows the corresponding graph configuration:

```
{
  "format":"edge_list",
  "uri":"example.edgelist",
  "vertex_id_type":"long",
  "vertex_labels":true,
  "edge_label":true,
  "vertex_props":[
    {
      "name":"name",
      "type":"string"
    },
    {
      "name":"age",
      "type":"int"
```

```
      }
    ],
    "edge_props":[
      {
        "name":"rating",
        "type":"double"
      }
    ],
    "loading_options": {
      "load_vertex_labels":true,
      "load_edge_label":true
    },
    "separator":" "
}
```

24.1.4.4 Two Tables (TWO_TABLES)

When configured to use `file` as datastore, the Two Tables format becomes a text file format similar to the Edge List format, with the only difference that the vertices and edges are stored in two different files. The vertices file contains vertex IDs followed by vertex properties. The edges file contains the source vertices and target vertices, followed by edge properties.

A graph with V vertices, having N vertex properties and M edge properties would be represented in two files as shown in the following:

```
vertices.ttt:

<V-1>  <V-1, NP-1> ... <V-1, NP-N>
<V-2>  <V-2, NP-1> ... <V-2, NP-N>
...
<V-V> <V-V, NP-1> ... <V-V, NP-N>

edges.ttt:

<V-1> <V-1, VG-1> <EP-1> ... <EP-M>
<V-1> <V-1, VG-2> <EP-1> ... <EP-M>
...
<V-V> <V-V, VG-1> <EP-1> ... <EP-M>
```

Example 24-5   Graph in Two Tables Text format

The following example shows the graph of 4 vertices (1, 2, 3 and 4), each having a `double` and a `string` property, and 3 edges, each having a `boolean` and a `date` property, encoded in Two Tables Text format:

```
vertices.ttt:

1 8.0 "foo"
2 4.3 "bar"
3 6.1 "bax"
4 17.78 "f00"

edges.ttt:

2 1 false "1985-10-18 10:00:00"
3 2 true "1961-12-30 14:45:14"
3 4 false "2001-01-15 07:00:43"
```

Note:

If you are planning on storing big graphs you must consider Two Tables Text format in order to save disk space.

24.1.5 XML File Formats

Graph ML

The graph server (PGX) supports loading graphs from files using the XML-based Graph ML format. Graphs already in memory may also be exported into GraphML files. See GraphML specification for a detailed description of the XML schema.

PGX GraphML Limitation

PGX does not support all features of the GraphML format. Some of the limitations are:

- If the graph is undirected (`edgedefault="undirected"`), then edge properties are not supported
- All vertices (edges) must have the same amount and type of vertex (edge) properties
- `port`, `default`, and `hyperedge` are not supported

Example 24-6

The following example graph consists of 3 vertices and 3 edges. Each vertex has an integer property named `number` and each edge has a string property named `label`. Note that the edges are directed and that the strings for the property do not have to be put in (double) quotation marks.

```
<?xml version="1.0" encoding="UTF-8"?>
<graphml xmlns="http://graphml.graphdrawing.org/xmlns">
    <key attr.name="number" attr.type="integer" for="node" 
id="number"/>
    <key attr.name="label" attr.type="string" for="edge" id="label"/>
    <graph edgedefault="directed">
        <node id="1">
            <data key="number">2</data>
        </node>
        <node id="2">
            <data key="number">45</data>
        </node>
        <node id="3">
            <data key="number">83</data>
        </node>
        <edge target="2" source="1">
            <data key="label">this graph</data>
        </edge>
        <edge source="3" target="2">
            <data key="label">forms a</data>
        </edge>
        <edge target="1" source="3">
            <data key="label">triangle</data>
```

```
        </edge>
    </graph>
</graphml>
```

> **Caution:**
>
> Due to the verbose nature of XML, the GraphML format comes with a large overhead compared to other file-based graph formats. You must use a different format if you want to consider the load or store performance and file size as important factors.

24.1.6 Binary File Formats

PGX Binary Format (PGB)

PGX binary format (`.pgb`) is the proprietary binary format for graph server (PGX), which allows fast and efficient file processing. Fundamentally, the file is a binary dump of the graph and property data. Bytes are written in network byte order (big endian).

Type Encoding

Table 24-3 Type Encoding

Value	Type	Size in bytes
0	Boolean	1
1	Integer	4
2	Long	8
3	Float	4
4	Double	8
7	String	varies
11	Vertex labels	varies
13	Local date	4
14	Time	4
15	Timestamp	8
16	Time with time zone	8
17	Timestamp with time zone	12
18	Vector property	variable: `<sizeof component-type> * <dimension>`

File Layout

Table 24-4 File Layout

Size in bytes	Description	Required	Comment
4	magic word	Yes	0x99191191

Table 24-4 (Cont.) File Layout

Size in bytes	Description	Required	Comment
4	vertex size	Yes	Allowed values are 4 and 8.
4	edge size	Yes	Allowed values are 4 and 8.
<vertex size>	number of vertices	Yes	
<edge size>	number of edges	Yes	
<edge size> * (<numVertices> + 1)	edge begin array	Yes	
<vertex size> * <numEdges>	destination vertex array	Yes	
1	component bitmap	Yes	• 0x0001: node keys • 0x0002: vertex labels • 0x0004: edge label • 0x0008: edge keys • other bits: reserved
4	vertexKey type	No	Only present if *component bitmap* & 0x0001 == 0x0001. See Table 24-3 for type encoding.
<vertex key layout>	vertex keys	No	Only present if *component bitmap* & 0x0001 == 0x0001.
4	edgeKey type	No	Only present if *component bitmap* & 0x0008 == 0x0008. See table Table 24-3 for type encoding
<numEdges> * 8	edge keys	No	Only present if *component bitmap* & 0x0008 == 0x0008.
4	number of vertex properties	Yes	
<num vertex properties> * <property layout>	property data	Yes	See Table 24-10.
4	number of edge properties	Yes	
<num edge properties> * <property layout>	property data	Y	See Edge Property Layout.
<vertex labels layout>	vertex labels	No	Only present if *component bit* & 0x0002 == 0x0002.
<edge labels layout>	edge label	No	Only present if *component bit* & 0x0004 == 0x0004.
4	number of shared pools	Yes	
<shared pools size>	shared pools	No	
<property names size>	property names	No	Only present if *component bit* & 0x0010 == 0x0010. See Table 24-19.

Vertex Key Layout

The layout of vertex keys depends on the vertexKey type. PGB supports `integer`, `long` and `string` vertex keys.

Table 24-5 Integer Vertex Keys

Size in bytes	Description	Required	Comment
`<numVertices> * 4`	key data	Yes	For each vertex, the corresponding integer key value.

Table 24-6 Long Vertex Keys

Size in bytes	Description	Required	Comment
`<numVertices> * 8`	key data	Yes	For each vertex, the corresponding long key value.

Table 24-7 String Vertex Keys

Size in bytes	Description	Required	Comment
`4`	compression scheme	Yes	reserved (must be `0`)
`8`	property size	Yes	size of each element in bytes in the following data
`<number of keys> * <string key element layout>`	string key data	Yes	content of the vertex keys (see Table 24-5)

Table 24-8 String Key Element Layout

Size in bytes	Description	Required	Comment
`4`	string length	Yes	length of the string in bytes
`<string length>`	string key data	Yes	content of the string as bytes, **No zero-character**

Property Layout

The following shows the special layout for string properties, and for vector properties:

Table 24-9 Primitive Type Layout

Size in bytes	Description	Required	Comment
`4`	property type	Yes	See Table 24-3 for type encoding.
`8`	property size	Yes	Size of the property data in bytes
`<property size>`	property data	Yes	Stored as `<numVertices/numEdges> * <type size>`

Table 24-10 Vector Property Layout

Size in bytes	Description	Comment
4	vector type mark	Always equal to 18.
8	size of vector property data and extra fields	dataSize = <sizeof component-type> * <dimension> + 8 (The 8 extra bytes are for the added following 2 extra fields in the vector property header.)
4	vector component data type	Valid types are integer, long, float, double. Encoded with the value specified in Table 24-3.
4	vector dimension	Number of components per vector value. Must be greater than 0 to be a valid vector property.
dataSize - 8	data	Stored as array of length * ` in which the value of the j-th component of the vector for the i-th entity is at position i * + j`.

Table 24-11 String Type Layout

Size in bytes	Description	Required	Comment
4	property type	Yes	Must be 7.
8	property size	Yes	Size of the following data in bytes.
1	reserved	Yes	Reserved (must be 0).
<dictionary layout>	dictionary	Yes	String dictionary used in the property
<numVertices/ numEdges> * 8	property content	Yes	Content of the string property, stored as IDs that refer to the strings in the dictionary.

Table 24-12 String Dictionary Layout

Size in bytes	Description	Required	Comment
1	reserved	Yes	Reserved (must be 0).
8	number of strings	Yes	Number of strings in the following dictionary.
<number of strings> * <dictionary element layout>	dictionary data	Yes	See Table 24-13.

Table 24-13 String Dictionary Element Layout

Size in bytes	Description	Required	Comment
8	string id	Yes	Unique ID of the string.

Table 24-13 (Cont.) String Dictionary Element Layout

Size in bytes	Description	Required	Comment
4	string length	Yes	Length of the string in bytes.
<string length>	string data	Yes	Content of the string as bytes, **No zero-character**

Vertex Labels Layout

Table 24-14 Vertex Labels Layout

Size in bytes	Description	Required	Comment
4	type	Yes	Must be 11.
8	size	Yes	Size of the following data in bytes.
<dictionary layout>	dictionary	Yes	String dictionary used in the vertex labels.
<numVertices + 1> * 8	string id begin array	Yes	<string ids> offset array for each vertex.
8	number of string ids	Yes	The number of string ids.
<number of string ids> * 8	string ids	Yes	Array of string ids in the string dictionary.

Edge Label Layout

The edge label layout follows the string type layout.

Shared Pools Layout

Table 24-15 Shared Pools Layout

Size in bytes	Description	Required	Comment
1	type	Yes	1: enum, 2: prefixed

Table 24-16 Type == Enum

Size in bytes	Description	Required	Comment
8	num strings	Yes	
<number of strings> * <string table layout>	dictionary data	Yes	See Table 24-18.

Table 24-17 Type == Prefix

Size in bytes	Description	Required	Comment
8	num prefixes	Yes	
<number of prefixes> * <string table layout>	dictionary data	Yes	See Table 24-18.
8	num suffixes	Yes	
<number of suffixes> * <string table layout>	dictionary data	Yes	See Table 24-18.

Table 24-18 String Table for Shared Pools

Size in bytes	Description	Required	Comment
8	string id	Yes	String can be literal (in case of enum) or prefix/suffix (in case of prefix).
4	string length	Yes	
<string length>	string data	Yes	

Property Names Layout

Table 24-19 Property Names Layout

Size in bytes	Description	Required	Comment
8	size	Yes	String can be literal (in case of enum) or prefix/suffix (in case of prefix).
<sum of size of vertex property names>	vertex property names	No	Follows the String Key Element Layout. See Table 24-8.
<sum of size of edge property names>	edge property names	No	Follows the String Key Element Layout. See Table 24-8.

24.2 Loading Graph Data in Parallel from Multiple Files

You can load a graph in parallel using multiple files.

The following example demonstrates how to load graph data from multiple files.

For example, consider a vertex file split into four partitions as shown:

```
vertex_file1

1,Color,1,red,,
2,Color,1,yellow,,


vertex_file2

3,Color,1,blue,,
4,Color,1,green,,


vertex_file3

5,Color,1,orange,,
6,Color,1,white,,


vertex_file4

7,Color,1,black,,
```

The edge file is split into two partitions as shown:

```
edge_file1

1,1,2,edge1,Weight,4,,1.0,
2,2,3,edge2,Weight,4,,2.0,
3,3,4,edge3,Weight,4,,3.0,


edge_file2

4,4,5,edge4,Weight,4,,4.0,
5,5,6,edge5,Weight,4,,5.0,
6,6,7,edge6,Weight,4,,6.0,
```

The following graph configuration can be used to load the graph data from four vertex files and two edge files into the same graph. Note that all the `uris` are specified inside the JSON graph configuration.

```
{
  "format": "flat_file",
  "vertex_uris": ["vertex_file1", "vertex_file2", "vertex_file3",
"vertex_file4"],
  "edge_uris": ["edge_file1", "edge_file2"],
  "separator": ",",
  "edge_props": [
    {
      "name": "Weight",
      "type": "double"
```

```
    }
  ],
  "vertex_props": [
    {
      "name": "Color",
      "type": "string"
    }
  ]
}
```

You can also create a graph configuration with multiple file partitions using Java as shown:

```
FileGraphConfig config = GraphConfigBuilder
   .forFileFormat(Format.FLAT_FILE)
   .setSeparator(",")
   .addVertexUri("vertex_file1")
   .addVertexUri("vertex_file2")
   .addVertexUri("vertex_file3")
   .addVertexUri("vertex_file4")
   .addEdgeUri("edge_file1")
   .addEdgeUri("edge_file2")
   .addVertexProperty("Color", PropertyType.STRING)
   .addEdgeProperty("Weight", PropertyType.DOUBLE)
   .build();
```

> **Note:**
>
> The graph configuration in the preceding codes include one double edge property named "Weight" and one string vertex property named "Color".

You can now load the graph data from the files as explained in Creating a graph using graph builder API.

The graph server (PGX) will automatically load the graph in parallel, using one thread for each file. This means that a graph can be loaded in parallel with as many threads as files are given depending on the configured parallelism for the graph server (PGX) instance.

> **Note:**
>
> Since the graph config will be used for all of the specified files, it is crucial to use the same format for all these files, that is, using the same separator, having the same defined properties, complying with the same format specification.

24.3 Exporting Graphs Into a File

The graph server (PGX) allows the client to export a currently loaded graph into a file.

Using the `store()` method on any PgxGraph object, the client can specify which file format to store the graph in. The client can also dynamically select the set of properties to be stored with the graph, that is, not all the properties need to be exported. The client can specify a CompressionScheme to use when storing as shown:

Table 24-20 Files CompressionScheme

CompressionScheme	Supported Formats
`NONE`	All formats
`GZIP`	`ADJ_LIST`, `EDGE_LIST`, `FLAT_FILE`, `TWO_TABLES` (`text`)

The client can export to multiple files as well.

When PGX exports the specified graph into a file, PGX also creates a graph config which the client receives as return value. This is to help loading the created graph instance later.

When exporting graph data into multiple files a `FileGraphStoringConfig` can be used which contains the following JSON fields:

Table 24-21 Graph Configuration when Exporting Graph into Multiple Files

Field	Type	Description	Default
`base_path`	`string`	Base path to use for storing a graph; file paths will be constructed using the following format _._, that is, `parent_path/my_graph_1.edges`.	`null`
`compression_scheme`	`enum[none, gzip]`	The scheme to use for compression, or none to disable compression.	`none`
`delimiter`	`character`	Delimiter character used as separator when storing. The characters `"`, `{`, `}` and `\n` cannot be used as delimiters.	`null`
`edge_extension`	`string`	The extension to use when creating edge file partitions.	`edges`
`initial_partition_index`	`integer`	The value used as initial partition index, that is, `initial_partition_index=1024 -> my_graph_1024.edges, my_graph_1025.edges.`	`1`
`num_partitions`	`integer`	The number of partitions that should be created, when exporting to multiple files.	`1`

Table 24-21 (Cont.) Graph Configuration when Exporting Graph into Multiple Files

Field	Type	Description	Default
`row_extension`	`string`	The extension to use when creating row file partitions.	`rows`
`vertex_extension`	`string`	The extension to use when creating vertex file partitions.	`nodes`

- Exporting a Graph to Disk

24.3.1 Exporting a Graph to Disk

You can save a graph loaded into memory to the disk in various formats. Therefore you can make sub-graphs and graph data computed at run time through analytics persistent, for future use. The resulting file can be used later as input for the graph server (PGX).

Consider the following example where a graph is loaded into memory and PageRank analysis is executed on the graph.

- JShell
- Java
- Python

JShell

```
var g = session.readGraphWithProperties("<path_to_json>")
var rank = analyst.pagerank(g, 0.001, 0.85, 100)
```

Java

```
PgxGraph g = session.readGraphWithProperties("<path_to_json>");
Analyst analyst = session.createAnalyst();
VertexProperty<Integer, Double> rank = analyst.pagerank(g, 0.001,
0.85, 100);
```

Python

```
g = session.read_graph_with_properties("<path_to_json>")
analyst = session.create_analyst()
rank = analyst.pagerank(g, 0.001, 0.85, 100)
```

You can now store the graph, together with the result of the PageRank analysis and all original edge properties, as a file in edge-list format, on disk. When a graph is stored, you need to specify the graph format, a path where the file should be stored, the properties to store and a flag that specifies whether or not a file should be overwritten should a file with the same name already exist.

- JShell
- Java
- Python

JShell

```
var config = g.store(Format.EDGE_LIST, "<file-path>", List.of(rank),
EdgeProperty.ALL, false)
```

Java

```
var config = g.store(Format.EDGE_LIST, "<file-path>", List.of(rank),
EdgeProperty.ALL, false);
```

Python

```
config = g.store('edge_list', "<file-path>", vertex_properties = [rank],
overwrite= False)
```

The graph data can now be found under the file path. The graph configuration returned by the `store` method can be used to load the new graph back into memory. To persist the graph configuration to disk as well, you can use the config's `toString` method to get a JSON representation:

- JShell
- Java
- Python

JShell

```
var path = Paths.get("<file-path>")
Files.writeString(path, config.toString())
```

Java

```
import apache.commons.io.*; // PGX contains a version of Apache
Commons IO
...
FileUtils.write(new File("<file-path>"), config.toString());
```

Python

```
with open("<file-path>","w"):
    f.write(str(config))
```

24.4 Exporting a Graph into Multiple Files

You can store a graph into multiple files using the `store` method. Most parameters are the same, as if storing to a single file. However, the main difference lies in specifying how to partition the data.

You can partition the data in either of the following two ways:

- specifying a `FileGraphStoringConfig` (see Table 24-21 for more information)
- specifying a base path and the number of partitions

Export into Multiple Files Using FileGraphStoringConfig

You can specify a more detailed way of creating the multiple partitions used to store the graph by using the `FileGraphStoringConfig`. You can create a `FileGraphStoringConfig` object using a `FileGraphStoringConfigBuilder`.

For example, the following code specifies that the storing should be done into four partitions using the specified base path and using zero as the initial index for the partitioning. It also contains the file extension to use for vertex files and for edge files and finally it sets comma as the delimiter to be used when storing the graph data:

```
FileGraphStoringConfig storingConfig = new
FileGraphStoringConfigBuilder(basePath) //
  .setNumPartitions(4) //
  .setInitialPartitionIndex(0) //
  .setVertexExtension(vertexExtension) //
  .setEdgeExtension(edgeExtension) //
  .setDelimiter(',') //
  .build();
```

You can also partition all tables equally using the `numPartitions` parameter. This implies that all tables are exported into the same number of files.

If you do not want to partition the tables equally, you can either create one `PartitionedGraphConfig` which contains for each provider a `FileGraphStoringConfig` (see Table 24-21) or we can use a version of `store()` that takes two maps of FileGraphStoringConfigs, one for the vertex tables and one for the edge tables.

For the first option, you can create for each vertex and edge table a `FileGraphStoringConfig` and put it into a `FileEntityProviderConfig` using `setStoringOptions` in the builder of `FileEntityProviderConfig`. The providers are then added to the `PartitionedGraphConfig` as edge and vertex providers using `addVertexProvider()` and `addEdgeProvider()` in the builder of `PartitionedGraphConfig`. Later you can use the `store()` method which takes the `PartitionedGraphConfig` as parameter.

The second option creates for every edge and vertex table a storing configuration, adds those into a vertex provider and an edge provider map and calls the corresponding `store()` method with these maps as parameters.

For example:

```
FileGraphStoringConfig vertexStoringConfig1 = new
FileGraphStoringConfigBuilder(basePath + "_vertexTable1") //
  .setNumPartitions(4) //
  .setInitialPartitionIndex(0) //
  .setVertexExtension(vertexExtension) //
  .setDelimiter(',') //
  .build();

FileGraphStoringConfig vertexStoringConfig2 = new
FileGraphStoringConfigBuilder(basePath + "_vertexTable2") //
  .setNumPartitions(4) //
  .setInitialPartitionIndex(0) //
  .setVertexExtension(vertexExtension) //
  .setDelimiter(',') //
  .build();

FileGraphStoringConfig edgeStoringConfig1 = new
FileGraphStoringConfigBuilder(basePath + "_edgeTable1") //
  .setNumPartitions(4) //
  .setInitialPartitionIndex(0) //
  .setEdgeExtension(edgeExtension) //
  .setDelimiter(',') //
  .build();

Map<String, FileGraphStoringConfig> vertexStoringConfigs = new HashMap<>();
vertexStoringConfigs.put("vertexTable1", vertexStoringConfig1);
vertexStoringConfigs.put("vertexTable2", vertexStoringConfig2);

Map<String, FileGraphStoringConfig> edgeStoringConfigs = new HashMap<>();
edgeStoringConfigs.put("edgeTable1", edgeStoringConfig);
```

Export into Multiple Files without FileGraphStoringConfig

If you only need to specify how many partitions are required and the base name to be used, it is simpler to use `store()` method by only specifying those parameters. Following this procedure, the graph server (PGX) will use defaults for the other fields. See Table 24-21 for more information on default values.

Export into Multiple Files Using a Graph Configuration Object

An alternate way for exporting into multiple files is by creating a `FileGraphStoringConfig` and putting it into a `Graph Configuration` object using `setStoringOptions` in its builder, and then using the corresponding version of the `store()` method.

25
Log Management in the Graph Server (PGX)

The graph server (PGX) internally uses the SLF4J interface with Logback as the default logger implementation.

- Configuring Logback Logging

25.1 Configuring Logback Logging

The default Logback logging configuration file is located in `/etc/oracle/graph/logback-server.xml`. This configuration file contains the target location for the logs in `/var/log/oracle/graph/`. Additionally, the rolling file appenders are also defined in this configuration file.

> **Note:**
>
> - Logback is configured to roll the log files based on both log size (250 MB) and date.
> - Log files are automatically saved in a compressed format in subdirectories, one directory per month. There can be multiple files on a given day.
> - Also, each startup of the graph server(PGX) triggers a new log file.

The Logback configuration file is picked up automatically by the the graph server(PGX). To use this configuration in your java application, you can set the `logback.configurationFile` system variable when launching the JVM:

```
java -Dlogback.configurationFile=$PGX_HOME/conf/logback.xml ...
```

Changing Logging Level During a JShell Session

When connected to the graph server using JShell, you can use the `loglevel(String loggerName, String levelName)` function to quickly change the logging level of any logger. For example:

```
loglevel("oracle.pgx", "debug")
loglevel("ROOT", "info")
loglevel("org.apache.hadoop", "off")
```

Logging in a Web Application Server

The `graph-server-<version>-pgx<version>.war` file in the `oracle-graph-webapps-<version>.zip` download package contains the `logback.xml`. This file determines what should be logged in the web application running on the application server of your choice. The file is located in the folder `WEB-INF/classes` inside the `graph-server-<version>-pgx<version>.war` file. By default, only errors are logged. But you can change this file if you want more logging in your web server. You must restart the web server after you change the file, for the change to take effect.

Part VIII

Supplementary Information for Property Graph Support

This document has the following appendixes.

- Using the Property Graph Schema
  This chapter provides conceptual and usage information about creating, storing, and working with property graph data in an Oracle Database environment.
- Mapping Graph Server Roles to Default Privileges
- Disabling Transport Layer Security (TLS) in Graph Server
- Migrating Property Graph Applications from Before Release 21c
  If you are migrating from a previous version of Oracle Spatial and Graph to Release 21c, you may need to make some changes to existing property graph-related applications.
- Upgrading From Graph Server and Client 20.4.x to 21.x
  If you are upgrading from Graph Server and Client 20.4.x to 21.x version, you may need to create new roles in database and migrate authorization rules from `pgx.conf` file to the database. Also, starting from Graph Server and Client Release 21.1, TLS is enforced at the time of the RPM file installation.
- Third-Party License Information for Oracle Graph Server and Client
  This appendix contains licensing information about third-party products included with Oracle Graph Server and Client.

A
Using the Property Graph Schema

This chapter provides conceptual and usage information about creating, storing, and working with property graph data in an Oracle Database environment.

You can create a property graph and store it in the property graph schema in Oracle Database in one of the following ways:

1. Use the `CREATE PROPERTY GRAPH` statement to create and populate these property graph schema objects.
2. Use OPG_APIS.CREATE_PG, to create the property graph schema objects. Then load data from the database tables into the schema objects using SQL or using the Data Access Layer APIs. The property graph schema provides a flexible schema option for storing your graph.

> **Note:**
>
> The original database tables remain as-is and the data is copied from the original tables into the property graph schema tables.

- Executing PGQL Queries Against Property Graph Schema Tables
  This topic explains how you can execute PGQL queries directly against the graph stored in property graph schema tables.
- OPG_APIS Package Subprograms
  The OPG_APIS package contains subprograms (functions and procedures) for working with property graphs in an Oracle database.
- OPG_GRAPHOP Package Subprograms
  The OPG_GRAPHOP package contains subprograms for various operations on property graphs in an Oracle database.

A.1 Property Graph Schema Objects for Oracle Database

The property graph PL/SQL and Java APIs use special Oracle Database schema objects.

This topic describes objects related to the property graph schema approach to working with graph data.

Oracle Spatial and Graph lets you store, query, manipulate, and query property graph data in Oracle Database. For example, to create a property graph named myGraph, you can use either the Java APIs (`oracle.pg.rdbms.OraclePropertyGraph`) or the PL/SQL APIs (MDSYS.OPG_APIS package).

With the PL/SQL API:

```
BEGIN
     opg_apis.create_pg(
           'myGraph',
           dop => 4,              -- degree of parallelism
           num_hash_ptns => 8,    -- number of hash partitions used to
store the graph
           tbs => 'USERS',        -- tablespace
           options => 'COMPRESS=T'
           );
END;
/
```

With the Java API:

```
  cfg = GraphConfigBuilder
            .forPropertyGraphRdbms()
            .setJdbcUrl("jdbc:oracle:thin:@127.0.0.1:1521:orcl")
            .setUsername("<your_user_name>")
            .setPassword("<your_password>")
            .setName("myGraph")
            .setMaxNumConnections(8)
            .setLoadEdgeLabel(false)
            .build();

  OraclePropertyGraph opg = OraclePropertyGraph.getInstance(cfg);
```

- Property Graph Tables (Detailed Information)

- Default Indexes on Vertex (VT$) and Edge (GE$) Tables
- Flexibility in the Property Graph Schema

A.1.1 Property Graph Tables (Detailed Information)

After a property graph is established in the database, several tables are created automatically in the user's schema, with the graph name as the prefix and VT$ or GE$ as the suffix. For example, for a graph named `myGraph`, table myGraphVT$ is created to store vertices and their properties (K/V pairs), and table myGraphGE$ is created to store edges and their properties.

Additional internal tables are created with IT$ and GT$ suffixes, to store text index metadata and graph skeleton (topological structure).

The definitions of tables myGraphVT$ and myGraphGE$ are as follows. They are important for SQL-based analytics and SQL-based property graph query. In both the VT$ and GE$ tables, VTS, VTE, and FE are reserved columns; column SL is for the security label; and columns K, T, V, VN, and VT together store all information about a property (K/V pair) of a graph element. In the VT$ table, VID is a long integer for storing the vertex ID. In the GE$ table, EID, SVID, and DVID are long integer columns for storing edge ID, source (from) vertex ID, and destination (to) vertex ID, respectively.

```
SQL> describe myGraphVT$
 Name                           Null?    Type
 ----------------------------------------- --------
----------------------------
 VID                           NOT NULL NUMBER
 K                                      NVARCHAR2(3100)
 T                                      NUMBER(38)
 V                                      NVARCHAR2(15000)
 VN                                     NUMBER
 VT                                     TIMESTAMP(6) WITH TIME ZONE
 SL                                     NUMBER
 VTS                                    DATE
 VTE                                    DATE
 FE                                     NVARCHAR2(4000)


SQL> describe myGraphGE$
 Name                           Null?    Type
 ----------------------------------------- --------
----------------------------
 EID                            NOT NULL NUMBER
 SVID                           NOT NULL NUMBER
 DVID                           NOT NULL NUMBER
 EL                                      NVARCHAR2(3100)
 K                                       NVARCHAR2(3100)
 T                                       NUMBER(38)
 V                                       NVARCHAR2(15000)
 VN                                      NUMBER
 VT                                      TIMESTAMP(6) WITH TIME ZONE
 SL                                      NUMBER
 VTS                                     DATE
```

```
VTE                                    DATE
FE                                     NVARCHAR2(4000)
```

For simplicity, only simple graph names are allowed, and they are case insensitive.

In both the VT$ and GE$ tables, Columns K, T, V, VN, VT together store all information about a property (K/V pair) of a graph element, while SL is used for security label, and VTS, VTE, FE are reserved columns.

In the property graph schema design, a property value is stored in the VN column if the value has numeric data type (long, int, double, float, and so on), in the VT column if the value is a timestamp, or in the V column for Strings, boolean and other serializable data types. For better Oracle Text query support, a literal representation of the property value is saved in the V column even if the data type is numeric or timestamp. To differentiate all the supported data types, an integer ID is saved in the T column.

The K column in both VT$ and GE$ tables stores the property key. Each edge must have a label of String type, and the labels are stored in the EL column of the GE$ table.

The T column in both VT$ and GE$ tables is a number representing the data type of the value of the property it describes. For example 1 means the value is a string, 2 means the value is an integer, and so on. Some T column possible values and associated data types are as follows:

- 1: STRING
- 2: INTEGER
- 3: FLOAT
- 4: DOUBLE
- 5: DATE
- 6: BOOLEAN
- 7: LONG
- 8: SHORT
- 9: BYTE
- 10: CHAR
- 20: Spatial data

The **VT$ table** schema for storing vertices contains these columns:

- VID, a long column denoting the ID of the vertex.
- VL, a string column denoting the label of the vertex.
- K, a string column denoting the name of the property. If there is no property associated to the vertex, the value of this column should be a whitespace.
- T, a long column denoting the type of the property.
- V, a string column denoting the value of the property as a String. If the property type is numeric, a String format version of the value is stored in this column. Similarly, if the property is timestamp based, a String format version of the value is stored.

- VN, a numeric column denoting the value of a numeric property. This column stores the property value only if the property type is numeric.
- VT, a timestamp with time zone column storing the value of a date time property. This column stores the property value only if the property type is timestamp based.
- SL, a numeric column reserved for the security label set using Oracle Label Security (for further details on using Security Labels, see Access Control for Property Graph Data (Graph-Level and OLS)).
- VTS, a timestamp with time zone column reserved for future extensions.
- VTE, a timestamp with time zone column reserved for future extensions.
- FE, a string column reserved for future extensions.

The following example inserts rows into a table named CONNECTIONSVT$. It includes T column values 1 through 10 (representing various data types).

```
INSERT INTO connectionsvt$(vid,k,t,v,vn,vt) VALUES (2001, '1-STRING', 1,
'Some String', NULL, NULL);
INSERT INTO connectionsvt$(vid,k,t,v,vn,vt) VALUES (2001, '2-INTEGER', 2,
NULL, 21, NULL);
INSERT INTO connectionsvt$(vid,k,t,v,vn,vt) VALUES (2001, '3-FLOAT', 3,
NULL, 21.5, NULL);
INSERT INTO connectionsvt$(vid,k,t,v,vn,vt) VALUES (2001, '4-DOUBLE', 4,
NULL, 21.5, NULL);
INSERT INTO connectionsvt$(vid,k,t,v,vn,vt) VALUES (2001, '5-DATE', 5, NULL,
NULL, timestamp'2018-07-20 15:32:53.991000');
INSERT INTO connectionsvt$(vid,k,t,v,vn,vt) VALUES (2001, '6-BOOLEAN', 6,
'Y', NULL, NULL);
INSERT INTO connectionsvt$(vid,k,t,v,vn,vt) VALUES (2001, '7-LONG', 7, NULL,
42, NULL);
INSERT INTO connectionsvt$(vid,k,t,v,vn,vt) VALUES (2001, '8-SHORT', 8,
NULL, 10, NULL);
INSERT INTO connectionsvt$(vid,k,t,v,vn,vt) VALUES (2001, '9-BYTE', 9, NULL,
10, NULL);
INSERT INTO connectionsvt$(vid,k,t,v,vn,vt) VALUES (2001, '10-CHAR', 10,
'A', NULL, NULL);
...
UPDATE connectionsVT$ SET V = coalesce(v,to_nchar(vn),to_nchar(vt)) WHERE
vid=2001;
COMMIT;
```

The **GE$ table** schema for storing edges contains these columns:

- EID, a long column denoting the ID of the edge.
- SVID, a long column denoting the ID of the outgoing (origin) vertex.
- DVID, a long column denoting the ID of the incoming (destination) vertex.
- EL, a string column denoting the label of the edge.
- K, a string column denoting the name of the property. If there is no property associated to the vertex, the value of this column should be a whitespace.
- T, a long column denoting the type of the property.

- V, a string column denoting the value of the property as a String. If the property type is numeric, a String format version of the value is stored in this column. Similarly, if the property is timestamp based, a String format version of the value is stored.
- VN, a numeric column denoting the value of a numeric property. This column stores the property value only if the property type is numeric.
- VT, a timestamp with time zone column storing the value of a date time property. This column stores the property value only if the property type is timestamp based.
- SL, a numeric column reserved for the security label set using Oracle Label Security (for further details on using Security Labels, see Access Control for Property Graph Data (Graph-Level and OLS)).
- VTS, a timestamp with time zone column column reserved for future extensions.
- VTE, a timestamp with time zone column reserved for future extensionss.
- FE, a string column reserved for future extensions.

In addition to the VT$ and GE$ tables, Oracle Spatial and Graph maintains other internal tables.

An internal graph skeleton table, defined with the **GT$ suffix**, is used to store the topological structure of a graph, and contains these columns:

- EID, a long column denoting the ID of the edge.
- EL, a string column denoting the label of the edge.
- SVID, a long column denoting the ID of the outgoing (origin) vertex.
- DVID, a long column denoting the ID of the incoming (destination) vertex.
- ELH, a raw column specifying the hash value of an edge label.
- ELS, a integer column specifying the edge label size with respect to total of characters.

An internal table, defined with the **SS$ suffix**, is created for Oracle internal use only.

A.1.2 Default Indexes on Vertex (VT$) and Edge (GE$) Tables

For query performance, several indexes on property graph tables are created by default. The index names follow the same convention as the table names, including using the graph name as the prefix. For example, for the property graph `myGraph`, the following local (partitioned) indexes are created:

- A unique index `myGraphXQV$ on myGraphVT$(VID, K)`
- A unique index `myGraphXQE$` on `myGraphGE$(EID, K)`
- An index `myGraphXSE$` on `myGraphGE$(SVID, DVID, EID, VN)`
- An index `myGraphXDE$` on `myGraphGE$(DVID, SVID, EID, VN)`

A.1.3 Flexibility in the Property Graph Schema

The property graph schema design does not use a catalog or centralized repository of any kind. Each property graph is separately stored and managed by a schema of user's choice. A user's schema may have one or more property graphs.

This design provides considerable flexibility to users. For example:

- Users can create additional indexes as desired.
- Different property graphs can have a different set of indexes or compression options for the base tables.
- Different property graphs can have different numbers of hash partitions.
- You can even drop the XSE$ or XDE$ index for a property graph; however, for integrity you should keep the unique constraints.

A.2 Data Access Layer

The data access layer provides a set of Java APIs that you can use to create and drop property graphs, add and remove vertices and edges, search for vertices and edges using key-value pairs, create text indexes, and perform other manipulations.

For more information, see:

- Using Java APIs for Property Graph Data
- Property Graph Schema Objects for Oracle Database (PL/SQL and Java APIs) and OPG_APIS Package Subprograms (PL/SQL API).

A.3 Getting Started with Property Graphs

Follow these steps to get started with property graphs.

1. The first time you use property graphs, ensure that the software is installed and operational.
2. Interact with a graph using one or more of the following options:
   - Use Java APIs in your Java application. The Java APIs can also be run in the JShell Command line interface for prototype and demo purposes.
   - Run PGQL queries:
     – In the Java application, or
     – In the Graph visualization interface, or
     – In the SQLcl client
   - Run PGQL queries and execute Java APIs in the Apache Zeppelin interpreter

- Required Privileges for Database Users
  The database schema that contains the graph tables (either Property Graph schema objects or relational tables that will be directly loaded as a graph in memory) requires certain privileges.

Related Topics

- Using Java APIs for Property Graph Data
  Creating a property graph involves using the Java APIs to create the property graph and objects in it.

A.3.1 Required Privileges for Database Users

The database schema that contains the graph tables (either Property Graph schema objects or relational tables that will be directly loaded as a graph in memory) requires certain privileges.

```
ALTER SESSION
CREATE PROCEDURE
CREATE SEQUENCE
CREATE SESSION
CREATE TABLE
CREATE TRIGGER
CREATE TYPE
CREATE VIEW
```

A.4 Using Java APIs for Property Graph Data

Creating a property graph involves using the Java APIs to create the property graph and objects in it.

- Overview of the Java APIs
- Parallel Retrieval of Graph Data
- Using an Element Filter Callback for Subgraph Extraction
- Using Optimization Flags on Reads over Property Graph Data
- Adding and Removing Attributes of a Property Graph Subgraph
- Getting Property Graph Metadata
- Merging New Data into an Existing Property Graph
- Opening and Closing a Property Graph Instance
- Creating Vertices
- Creating Edges
- Deleting Vertices and Edges
- Reading a Graph from a Database into an Embedded Graph Server (PGX)
- Specifying Labels for Vertices
- Building an In-Memory Graph
- Dropping a Property Graph
- Executing PGQL Queries

A.4.1 Overview of the Java APIs

The Java APIs that you can use for property graphs include the following:

- Oracle Graph Property Graph Java APIs
- Oracle Database Property Graph Java APIs

A.4.1.1 Oracle Graph Property Graph Java APIs

Oracle Graph property graph support provides database-specific APIs for Oracle Database.

To use the Oracle Spatial and Graph API, import the following classes into your Java program:

```
import oracle.pg.common.*;
import oracle.pg.text.*;
import oracle.pg.rdbms.*;
import oracle.pg.rdbms.pgql.*;
import oracle.pgx.config.*;
import oracle.pgx.common.types.*;
```

To compile and run your Java applications, set your classpath to include the jar files in `<client-install-dir>/lib/`.

For example:

```
javac -cp ".:<client-install-dir>/lib/*" Main.java
java -cp ".:<client-install-dir>/lib/*" Main
```

A.4.1.2 Oracle Database Property Graph Java APIs

The Oracle Database property graph Java APIs enable you to create and populate a property graph stored in Oracle Database.

To use these Java APIs, import the classes into your Java program. For example:

```
import oracle.pg.rdbms.*;
import java.sql.*;
```

A.4.2 Parallel Retrieval of Graph Data

The parallel property graph query provides a simple Java API to perform parallel scans on vertices (or edges). Parallel retrieval is an optimized solution taking advantage of the distribution of the data across table partitions, so each partition is queried using a separate database connection.

Parallel retrieval will produce an array where each element holds all the vertices (or edges) from a specific partition (split). The subset of shards queried will be separated by the given start split ID and the size of the connections array provided. This way, the subset will consider splits in the range of [start, start - 1 + size of connections array]. Note that an integer ID (in the range of [0, N - 1]) is assigned to all the splits in the vertex table with N splits.

The following code loads a property graph, opens an array of connections, and executes a parallel query to retrieve all vertices and edges using the opened connections. The number of calls to the `getVerticesPartitioned (getEdgesPartitioned)` method is controlled by the total number of splits and the number of connections used.

```
OraclePropertyGraph opg = OraclePropertyGraph.getInstance(args, szGraphName);

// Clear existing vertices/edges in the property graph
opg.clearRepository();
```

```
String szOPVFile = "../../data/connections.opv";
String szOPEFile = "../../data/connections.ope";

// This object will handle parallel data loading
OraclePropertyGraphDataLoader opgdl =
OraclePropertyGraphDataLoader.getInstance();
opgdl.loadData(opg, szOPVFile, szOPEFile, dop);

// Create connections used in parallel query
Oracle[] oracleConns = new Oracle[dop];
Connection[]   conns = new Connection[dop];
for (int i = 0; i < dop; i++) {
  oracleConns[i] = opg.getOracle().clone();
  conns[i] = oracleConns[i].getConnection();
}

long lCountV = 0;
// Iterate over all the vertices' partitionIDs to count all the
vertices
for (int partitionID = 0; partitionID <
opg.getVertexPartitionsNumber();
     partitionID += dop) {
  Iterable<Vertex>[] iterables
        = opg.getVerticesPartitioned(conns /* Connection array */,
                                     true /* skip store to cache */,
                                     partitionID /* starting partition
*/);
  lCountV += consumeIterables(iterables); /* consume iterables using
                                             threads */
}

// Count all vertices
System.out.println("Vertices found using parallel query: " + lCountV);

long lCountE = 0;
// Iterate over all the edges' partitionIDs to count all the edges
for (int partitionID = 0; partitionID <
opg.getEdgeTablePartitionIDs();
     partitionID += dop) {
  Iterable<Edge>[] iterables
          = opg.getEdgesPartitioned(conns /* Connection array */,
                                    true /* skip store to cache */,
                                    partitionID /* starting
partitionID */);
  lCountE += consumeIterables(iterables); /* consume iterables using
                                             threads */
}

// Count all edges
System.out.println("Edges found using parallel query: " + lCountE);

// Close the connections to the database after completed
for (int idx = 0; idx < conns.length; idx++) {
   conns[idx].close();
}
```

A.4.3 Using an Element Filter Callback for Subgraph Extraction

Oracle Spatial and Graph provides support for an easy subgraph extraction using user-defined element filter callbacks. An element filter callback defines a set of conditions that a vertex (or an edge) must meet in order to keep it in the subgraph. Users can define their own element filtering by implementing the `VertexFilterCallback` and `EdgeFilterCallback` API interfaces.

The following code fragment implements a `VertexFilterCallback` that validates if a vertex does not have a political role and its origin is the United States.

```
/**
* VertexFilterCallback to retrieve a vertex from the United States
* that does not have a political role
*/
private static class NonPoliticianFilterCallback
implements VertexFilterCallback
{
@Override
public boolean keepVertex(OracleVertexBase vertex)
{
String country = vertex.getProperty("country");
String role = vertex.getProperty("role");

if (country != null && country.equals("United States")) {
if (role == null || !role.toLowerCase().contains("political")) {
return true;
}
}

return false;
}

public static NonPoliticianFilterCallback getInstance()
{
return new NonPoliticianFilterCallback();
}
}
```

The following code fragment implements an `EdgeFilterCallback` that uses the `VertexFilterCallback` to keep only edges connected to the given input vertex, and whose connections are not politicians and come from the United States.

```
/**
 * EdgeFilterCallback to retrieve all edges connected to an input
 * vertex with "collaborates" label, and whose vertex is from the
 * United States with a role different than political
*/
private static class CollaboratorsFilterCallback
implements EdgeFilterCallback
{
private VertexFilterCallback m_vfc;
private Vertex m_startV;

public CollaboratorsFilterCallback(VertexFilterCallback vfc,
 Vertex v)
{
m_vfc = vfc;
m_startV = v;
```

```
}

@Override
public boolean keepEdge(OracleEdgeBase edge)
{
if ("collaborates".equals(edge.getLabel())) {
if (edge.getVertex(Direction.IN).equals(m_startV) &&
m_vfc.keepVertex((OracleVertex)
edge.getVertex(Direction.OUT))) {
return true;
}
else if (edge.getVertex(Direction.OUT).equals(m_startV) &&
 m_vfc.keepVertex((OracleVertex)
edge.getVertex(Direction.IN))) {
return true;
}
}

return false;
}

public static CollaboratorsFilterCallback
getInstance(VertexFilterCallback vfc, Vertex v)
{
return new CollaboratorsFilterCallback(vfc, v);
}

}
```

Using the filter callbacks previously defined, the following code fragment loads a property graph, creates an instance of the filter callbacks and later gets all of Robert Smith's collaborators who are not politicians and come from the United States.

```
OraclePropertyGraph opg = OraclePropertyGraph.getInstance(
 args, szGraphName);

// Clear existing vertices/edges in the property graph
opg.clearRepository();

String szOPVFile = "../../data/connections.opv";
String szOPEFile = "../../data/connections.ope";

// This object will handle parallel data loading
OraclePropertyGraphDataLoader opgdl =
OraclePropertyGraphDataLoader.getInstance();
opgdl.loadData(opg, szOPVFile, szOPEFile, dop);

// VertexFilterCallback to retrieve all people from the United States // who are
not politicians
NonPoliticianFilterCallback npvfc = NonPoliticianFilterCallback.getInstance();

// Initial vertex: Robert Smith
Vertex v = opg.getVertices("name", "Robert Smith").iterator().next();

// EdgeFilterCallback to retrieve all collaborators of Robert Smith
// from the United States who are not politicians
CollaboratorsFilterCallback cefc =
CollaboratorsFilterCallback.getInstance(npvfc, v);

Iterable<<Edge> smithCollabs = opg.getEdges((String[])null /* Match any
of the properties */,
```

```
cefc /* Match the
EdgeFilterCallback */
);
Iterator<<Edge> iter = smithCollabs.iterator();

System.out.println("\n\n--------Collaborators of Robert Smith from " +
 " the US and non-politician\n\n");
long countV = 0;
while (iter.hasNext()) {
Edge edge = iter.next(); // get the edge
// check if smith is the IN vertex
if (edge.getVertex(Direction.IN).equals(v)) {
 System.out.println(edge.getVertex(Direction.OUT) + "(Edge ID: " +
 edge.getId() + ")"); // get out vertex
}
else {
System.out.println(edge.getVertex(Direction.IN)+ "(Edge ID: " +
 edge.getId() + ")"); // get in vertex
}

countV++;
}
```

By default, all reading operations such as get all vertices, get all edges (and parallel approaches) will use the filter callbacks associated with the property graph using the methods `opg.setVertexFilterCallback(vfc)` and `opg.setEdgeFilterCallback(efc)`. If there is no filter callback set, then all the vertices (or edges) and edges will be retrieved.

The following code fragment uses the default edge filter callback set on the property graph to retrieve the edges.

```
// VertexFilterCallback to retrieve all people from the United States // who are not
politicians
NonPoliticianFilterCallback npvfc = NonPoliticianFilterCallback.getInstance();

// Initial vertex: Robert Smith
Vertex v = opg.getVertices("name", "Robert Smith").iterator().next();

// EdgeFilterCallback to retrieve all collaborators of Robert Smith
// from the United States who are not politicians
CollaboratorsFilterCallback cefc = CollaboratorsFilterCallback.getInstance(npvfc, v);

opg.setEdgeFilterCallback(cefc);

Iterable<Edge> smithCollabs = opg.getEdges();
Iterator<Edge> iter = smithCollabs.iterator();

System.out.println("\n\n--------Collaborators of Robert Smith from " +
 " the US and non-politician\n\n");
long countV = 0;
while (iter.hasNext()) {
Edge edge = iter.next(); // get the edge
// check if smith is the IN vertex
if (edge.getVertex(Direction.IN).equals(v)) {
 System.out.println(edge.getVertex(Direction.OUT) + "(Edge ID: " +
 edge.getId() + ")"); // get out vertex
}
else {
System.out.println(edge.getVertex(Direction.IN)+ "(Edge ID: " +
 edge.getId() + ")"); // get in vertex
}
```

```
countV++;
}
```

A.4.4 Using Optimization Flags on Reads over Property Graph Data

Oracle Spatial and Graph provides support for optimization flags to improve graph iteration performance. Optimization flags allow processing vertices (or edges) as objects with none or minimal information, such as ID, label, and/or incoming/outgoing vertices. This way, the time required to process each vertex (or edge) during iteration is reduced.

The following table shows the optimization flags available when processing vertices (or edges) in a property graph.

Optimization Flag	Description
DO_NOT_CREATE_OBJECT	Use a predefined constant object when processing vertices or edges.
JUST_EDGE_ID	Construct edge objects with ID only when processing edges.
JUST_LABEL_EDGE_ID	Construct edge objects with ID and label only when processing edges.
JUST_LABEL_VERTEX_EDGE_ID	Construct edge objects with ID, label, and in/out vertex IDs only when processing edges
JUST_VERTEX_EDGE_ID	Construct edge objects with just ID and in/out vertex IDs when processing edges.
JUST_VERTEX_ID	Construct vertex objects with ID only when processing vertices.

The following code fragment uses a set of optimization flags to retrieve only all the IDs from the vertices and edges in the property graph. The objects retrieved by reading all vertices and edges will include only the IDs and no Key/Value properties or additional information.

```
import oracle.pg.common.OraclePropertyGraphBase.OptimizationFlag;
OraclePropertyGraph opg = OraclePropertyGraph.getInstance(
 args, szGraphName);

// Clear existing vertices/edges in the property graph
opg.clearRepository();

String szOPVFile = "../../data/connections.opv";
String szOPEFile = "../../data/connections.ope";

// This object will handle parallel data loading
OraclePropertyGraphDataLoader opgdl =
OraclePropertyGraphDataLoader.getInstance();
opgdl.loadData(opg, szOPVFile, szOPEFile, dop);


// Optimization flag to retrieve only vertices IDs
OptimizationFlag optFlagVertex = OptimizationFlag.JUST_VERTEX_ID;

// Optimization flag to retrieve only edges IDs
OptimizationFlag optFlagEdge = OptimizationFlag.JUST_EDGE_ID;

// Print all vertices
Iterator<Vertex> vertices =
opg.getVertices((String[])null /* Match any of the
```

```
properties */,
null /* Match the VertexFilterCallback */,
optFlagVertex /* optimization flag */
).iterator();

System.out.println("----- Vertices IDs----");
long vCount = 0;
while (vertices.hasNext()) {
OracleVertex v = vertices.next();
System.out.println((Long) v.getId());
vCount++;
}
System.out.println("Vertices found: " + vCount);


// Print all edges
Iterator<Edge> edges =
opg.getEdges((String[])null /* Match any of the properties */,
null /* Match the EdgeFilterCallback */,
optFlagEdge /* optimization flag */
).iterator();

System.out.println("----- Edges ----");
long eCount = 0;
while (edges.hasNext()) {
Edge e = edges.next();
System.out.println((Long) e.getId());
eCount++;
}
System.out.println("Edges found: " + eCount);
```

By default, all reading operations such as get all vertices, get all edges (and parallel approaches) will use the optimization flag associated with the property graph using the method `opg.setDefaultVertexOptFlag(optFlagVertex)` and `opg.setDefaultEdgeOptFlag(optFlagEdge)`. If the optimization flags for processing vertices and edges are not defined, then all the information about the vertices and edges will be retrieved.

The following code fragment uses the default optimization flags set on the property graph to retrieve only all the IDs from its vertices and edges.

```
import oracle.pg.common.OraclePropertyGraphBase.OptimizationFlag;

// Optimization flag to retrieve only vertices IDs
OptimizationFlag optFlagVertex = OptimizationFlag.JUST_VERTEX_ID;

// Optimization flag to retrieve only edges IDs
OptimizationFlag optFlagEdge = OptimizationFlag.JUST_EDGE_ID;

opg.setDefaultVertexOptFlag(optFlagVertex);
opg.setDefaultEdgeOptFlag(optFlagEdge);

Iterator<Vertex> vertices = opg.getVertices().iterator();
System.out.println("----- Vertices IDs----");
long vCount = 0;
while (vertices.hasNext()) {
OracleVertex v = vertices.next();
System.out.println((Long) v.getId());
vCount++;
}
System.out.println("Vertices found: " + vCount);
```

```
// Print all edges
Iterator<Edge> edges = opg.getEdges().iterator();
System.out.println("----- Edges ----");
long eCount = 0;
while (edges.hasNext()) {
Edge e = edges.next();
System.out.println((Long) e.getId());
eCount++;
}
System.out.println("Edges found: " + eCount);
```

A.4.5 Adding and Removing Attributes of a Property Graph Subgraph

Oracle Spatial and Graph supports updating attributes (key/value pairs) to a subgraph of vertices and/or edges by using a user-customized operation callback. An operation callback defines a set of conditions that a vertex (or an edge) must meet in order to update it (either add or remove the given attribute and value).

You can define your own attribute operations by implementing the `VertexOpCallback` and `EdgeOpCallback` API interfaces. You must override the `needOp` method, which defines the conditions to be satisfied by the vertices (or edges) to be included in the update operation, as well as the `getAttributeKeyName` and `getAttributeKeyValue` methods, which return the key name and value, respectively, to be used when updating the elements.

The following code fragment implements a `VertexOpCallback` that operates over the `smithCollaborator` attribute associated only with Robert Smith collaborators. The value of this property is specified based on the role of the collaborators.

```
private static class CollaboratorsVertexOpCallback
implements VertexOpCallback
{
private OracleVertexBase m_smith;
private List<Vertex> m_smithCollaborators;

public CollaboratorsVertexOpCallback(OraclePropertyGraph opg)
{
// Get a list of Robert Smith'sCollaborators
m_smith = (OracleVertexBase) opg.getVertices("name",
 "Robert Smith")
.iterator().next();

Iterable<Vertex> iter = m_smith.getVertices(Direction.BOTH,
"collaborates");
m_smithCollaborators = OraclePropertyGraphUtils.listify(iter);
}

public static CollaboratorsVertexOpCallback
getInstance(OraclePropertyGraph opg)
{
return new CollaboratorsVertexOpCallback(opg);
}

/**
 * Add attribute if and only if the vertex is a collaborator of Robert
 * Smith
*/
```

```
@Override
public boolean needOp(OracleVertexBase v)
{
return m_smithCollaborators != null &&
 m_smithCollaborators.contains(v);
}

@Override
public String getAttributeKeyName(OracleVertexBase v)
{
return "smithCollaborator";
}

/**
 * Define the property's value based on the vertex role
 */
@Override
public Object getAttributeKeyValue(OracleVertexBase v)
{
String role = v.getProperty("role");
role = role.toLowerCase();
if (role.contains("political")) {
return "political";
}
else if (role.contains("actor") || role.contains("singer") ||
 role.contains("actress") || role.contains("writer") ||
 role.contains("producer") || role.contains("director")) {
return "arts";
}
else if (role.contains("player")) {
return "sports";
}
else if (role.contains("journalist")) {
return "journalism";
}
else if (role.contains("business") || role.contains("economist")) {
return "business";
}
else if (role.contains("philanthropist")) {
return "philanthropy";
}
return " ";
}
}
```

The following code fragment implements an `EdgeOpCallback` that operates over the `smithFeud` attribute associated only with Robert Smith feuds. The value of this property is specified based on the role of the collaborators.

```
private static class FeudsEdgeOpCallback
implements EdgeOpCallback
{
private OracleVertexBase m_smith;
private List<Edge> m_smithFeuds;

public FeudsEdgeOpCallback(OraclePropertyGraph opg)
{
// Get a list of Robert Smith's feuds
m_smith = (OracleVertexBase) opg.getVertices("name",
 "Robert Smith")
.iterator().next();
```

```
Iterable<Vertex> iter = m_smith.getVertices(Direction.BOTH,
"feuds");
m_smithFeuds = OraclePropertyGraphUtils.listify(iter);
}

public static FeudsEdgeOpCallback getInstance(OraclePropertyGraph opg)
{
return new FeudsEdgeOpCallback(opg);
}

/**
 * Add attribute if and only if the edge is in the list of Robert Smith's
 * feuds
*/
@Override
public boolean needOp(OracleEdgeBase e)
{
return m_smithFeuds != null && m_smithFeuds.contains(e);
}

@Override
public String getAttributeKeyName(OracleEdgeBase e)
{
return "smithFeud";
}

/**
 * Define the property's value based on the in/out vertex role
 */
@Override
public Object getAttributeKeyValue(OracleEdgeBase e)
{
OracleVertexBase v = (OracleVertexBase) e.getVertex(Direction.IN);
if (m_smith.equals(v)) {
v = (OracleVertexBase) e.getVertex(Direction.OUT);
}
String role = v.getProperty("role");
role = role.toLowerCase();

if (role.contains("political")) {
return "political";
}
else if (role.contains("actor") || role.contains("singer") ||
 role.contains("actress") || role.contains("writer") ||
 role.contains("producer") || role.contains("director")) {
return "arts";
}
else if (role.contains("journalist")) {
return "journalism";
}
else if (role.contains("player")) {
return "sports";
}
else if (role.contains("business") || role.contains("economist")) {
return "business";
}
else if (role.contains("philanthropist")) {
return "philanthropy";
}
return " ";
```

```
}
}
```

Using the operations callbacks defined previously, the following code fragment loads a property graph, creates an instance of the operation callbacks, and later adds the attributes into the pertinent vertices and edges using the `addAttributeToAllVertices` and `addAttributeToAllEdges` methods in `OraclePropertyGraph`.

```
OraclePropertyGraph opg = OraclePropertyGraph.getInstance(
 args, szGraphName);

// Clear existing vertices/edges in the property graph
opg.clearRepository();

String szOPVFile = "../../data/connections.opv";
String szOPEFile = "../../data/connections.ope";

// This object will handle parallel data loading
OraclePropertyGraphDataLoader opgdl = OraclePropertyGraphDataLoader.getInstance();
opgdl.loadData(opg, szOPVFile, szOPEFile, dop);

// Create the vertex operation callback
CollaboratorsVertexOpCallback cvoc = CollaboratorsVertexOpCallback.getInstance(opg);

// Add attribute to all people collaborating with Smith based on their role
opg.addAttributeToAllVertices(cvoc, true /** Skip store to Cache */, dop);

// Look up for all collaborators of Smith
Iterable<Vertex> collaborators = opg.getVertices("smithCollaborator", "political");
System.out.println("Political collaborators of Robert Smith " +
getVerticesAsString(collaborators));

collaborators = opg.getVertices("smithCollaborator", "business");
System.out.println("Business collaborators of Robert Smith " +
getVerticesAsString(collaborators));

// Add an attribute to all people having a feud with Robert Smith to set
// the type of relation they have
FeudsEdgeOpCallback feoc = FeudsEdgeOpCallback.getInstance(opg);
opg.addAttributeToAllEdges(feoc, true /** Skip store to Cache */, dop);

// Look up for all feuds of Smith
Iterable<Edge> feuds = opg.getEdges("smithFeud", "political");
System.out.println("\n\nPolitical feuds of Robert Smith " + getEdgesAsString(feuds));

feuds = opg.getEdges("smithFeud", "business");
System.out.println("Business feuds of Robert Smith " +
getEdgesAsString(feuds));
```

The following code fragment defines an implementation of `VertexOpCallback` that can be used to remove vertices having value philanthropy for attribute `smithCollaborator`, then call the API `removeAttributeFromAllVertices`; It also defines an implementation of `EdgeOpCallback` that can be used to remove edges having value business for attribute `smithFeud`, then call the API `removeAttributeFromAllEdges`.

```
System.out.println("\n\nRemove 'smithCollaborator' property from all the" +
 "philanthropy collaborators");
PhilanthropyCollaboratorsVertexOpCallback pvoc =
PhilanthropyCollaboratorsVertexOpCallback.getInstance();
```

```
opg.removeAttributeFromAllVertices(pvoc);

System.out.println("\n\nRemove 'smithFeud' property from all the" + "business
feuds");
BusinessFeudsEdgeOpCallback beoc = BusinessFeudsEdgeOpCallback.getInstance();

opg.removeAttributeFromAllEdges(beoc);

/**
 * Implementation of a EdgeOpCallback to remove the "smithCollaborators"
 * property from all people collaborating with Robert Smith that have a
 * philanthropy role
 */
private static class PhilanthropyCollaboratorsVertexOpCallback implements
VertexOpCallback
{
  public static PhilanthropyCollaboratorsVertexOpCallback getInstance()
  {
     return new PhilanthropyCollaboratorsVertexOpCallback();
  }

  /**
   * Remove attribute if and only if the property value for
   * smithCollaborator is Philanthropy
   */
  @Override
  public boolean needOp(OracleVertexBase v)
  {
    String type = v.getProperty("smithCollaborator");
    return type != null && type.equals("philanthropy");
  }

  @Override
  public String getAttributeKeyName(OracleVertexBase v)
  {
    return "smithCollaborator";
  }

  /**
   * Define the property's value. In this case can be empty
   */
  @Override
  public Object getAttributeKeyValue(OracleVertexBase v)
  {
    return " ";
  }
}

/**
 * Implementation of a EdgeOpCallback to remove the "smithFeud" property
 * from all connections in a feud with Robert Smith that have a business role
 */
private static class BusinessFeudsEdgeOpCallback implements EdgeOpCallback
{
  public static BusinessFeudsEdgeOpCallback getInstance()
  {
    return new BusinessFeudsEdgeOpCallback();
  }

  /**
   * Remove attribute if and only if the property value for smithFeud is
```

```
    * business
    */
   @Override
   public boolean needOp(OracleEdgeBase e)
   {
     String type = e.getProperty("smithFeud");
     return type != null && type.equals("business");
   }

  @Override
  public String getAttributeKeyName(OracleEdgeBase e)
  {
    return "smithFeud";
  }

  /**
   * Define the property's value. In this case can be empty
   */
   @Override
   public Object getAttributeKeyValue(OracleEdgeBase e)
   {
     return " ";
   }
}
```

A.4.6 Getting Property Graph Metadata

You can get graph metadata and statistics, such as all graph names in the database; for each graph, getting the minimum/maximum vertex ID, the minimum/maximum edge ID, vertex property names, edge property names, number of splits in graph vertex, and the edge table that supports parallel table scans.

The following code fragment gets the metadata and statistics of the existing property graphs stored in an Oracle database.

```
// Get all graph names in the database
List<String> graphNames = OraclePropertyGraphUtils.getGraphNames(dbArgs);

for (String graphName : graphNames) {
OraclePropertyGraph opg = OraclePropertyGraph.getInstance(args,
graphName);

System.err.println("\n Graph name: " + graphName);
System.err.println(" Total vertices: " +
 opg.countVertices(dop));

System.err.println(" Minimum Vertex ID: " +
 opg.getMinVertexID(dop));
System.err.println(" Maximum Vertex ID: " +
 opg.getMaxVertexID(dop));

Set<String> propertyNamesV = new HashSet<String>();
opg.getVertexPropertyNames(dop, 0 /* timeout,0 no timeout */,
 propertyNamesV);

System.err.println(" Vertices property names: " +
getPropertyNamesAsString(propertyNamesV));

System.err.println("\n\n Total edges: " + opg.countEdges(dop));
System.err.println(" Minimum Edge ID: " + opg.getMinEdgeID(dop));
```

```
System.err.println(" Maximum Edge ID: " + opg.getMaxEdgeID(dop));

Set<String> propertyNamesE = new HashSet<String>();
opg.getEdgePropertyNames(dop, 0 /* timeout,0 no timeout */,
 propertyNamesE);

System.err.println(" Edge property names: " +
getPropertyNamesAsString(propertyNamesE));

System.err.println("\n\n Table Information: ");
System.err.println("Vertex table number of splits: " +
 (opg.getVertexPartitionsNumber()));
System.err.println("Edge table number of splits: " +
 (opg.getEdgePartitionsNumber()));
}
```

A.4.7 Merging New Data into an Existing Property Graph

In addition to loading graph data into an empty property graph in Oracle Database, you can merge new graph data into an existing (empty or non-empty) graph. As with data loading, data merging splits the input vertices and edges into multiple chunks and merges them with the existing graph in database in parallel.

When doing the merging, the flows are different depends on whether there is an overlap between new graph data and existing graph data. *Overlap* here means that the same key of a graph element may have different values in the new and existing graph data. For example, key `weight` of the vertex with ID 1 may have value 0.8 in the new graph data and value 0.5 in the existing graph data. In this case, you must specify whether the new value or the existing value should be used for the key.

The following options are available for graph data merging: JDB-based, external table-based, and SQL loader-based merging.

- JDBC-Based Graph Data Merging
- External Table-Based Data Merging
- SQL Loader-Based Data Merging

JDBC-Based Graph Data Merging

JDBC-based data merging uses Java Database Connectivity (JDBC) APIs to load the new graph data into Oracle Database and then merge the new graph data into an existing graph.

The following example merges the new graph data from vertex and edge files szOPVFile and szOPEFile in Oracle-defined Flat-file format with an existing graph named opg, using a JDBC-based data merging with a DOP (degree of parallelism) of 48, batch size of 1000, and specified data merging options.

```
String szOPVFile = "../../data/connectionsNew.opv";
String szOPEFile = "../../data/connectionsNew.ope";
OraclePropertyGraphDataLoader opgdl =
OraclePropertyGraphDataLoader.getInstance();
opgdl.mergeData(opg, szOPVFile, szOPEFile,
     48 /*DOP*/,
     1000 /*Batch Size*/,
     true /*Rebuild index*/,
```

```
     "pdml=t, pddl=t, no_dup=t, use_new_val_for_dup_key=t" /*Merge
options*/);
```

To optimize the performance of the data merging operations, a set of flags and hints can be specified in the merging options parameter when calling the JDBC-based data merging. These hints include:

- **DOP:** The degree of parallelism to use when merging the data. This parameter determines the number of chunks to generate when splitting the file, as well as the number of loader threads to use when merging the data into the property graph VT$ and GE$ tables.
- **Batch Size:** An integer specifying the batch size to use for Oracle JDBC statements in batching mode.
- **Rebuild index:** If set to true, the data loader will disable all the indexes and constraints defined over the property graph into which the data will be loaded. After all the data is merged into the property graph, all the original indexes and constraints will be rebuilt and enabled.
- **Merge options:** An option (or multiple options separated by commas) to optimize the data merging operations. These options include:
  - PDML=T: enables parallel execution for DML operations for the database session used in the data loader. This hint is used to improve the performance of long-running batching jobs.
  - PDDL=T: enables parallel execution for DDL operations for the database session used in the data loader. This hint is used to improve the performance of long-running batching jobs.
  - NO_DUP=T: assumes the input new graph data does not have invalid duplicates. In a valid property graph, each vertex (or edge) can at most have one value for a given property key. In an invalid property graph, a vertex (or edge) may have two or more values for a particular key. As an example, a vertex, v, has two key/value pairs: name/"John" and name/"Johnny", and they share the same key.
  - OVERLAP=F: assumes there is no overlap between new graph data and existing graph data. That is, there is no key with multiple distinct values in the new and existing graph data.
  - USE_NEW_VAL_FOR_DUP_KEY=T: if there is overlap between new graph data and existing graph data, use the value in the new graph data; otherwise, use the value in the existing graph data.

External Table-Based Data Merging

External table-based data merging uses an external table to load new graph data into Oracle Database and then merge the new graph data into an existing graph.

External-table based data merging requires a directory object, where the files read by the external tables will be stored. This directory can be created using the following SQL*Plus statements:

```
create or replace directory tmp_dir as '/tmppath/';
grant read, write on directory tmp_dir to public;
```

The following example merges the new graph data from a vertex and edge files szOPVFile and szOPEFile in Oracle flat-file format with an existing graph opg using an external table-based data merging, a DOP (degree of parallelism) of 48, and specified merging options.

```
String szOPVFile = "../../data/connectionsNew.opv";
String szOPEFile = "../../data/connectionsNew.ope";
String szExtDir = "tmp_dir";
OraclePropertyGraphDataLoader opgdl =
OraclePropertyGraphDataLoader.getInstance();
opgdl.mergeDataWithExtTab(opg, szOPVFile, szOPEFile,
     48 /*DOP*/,
     true /*Use Named Pipe for splitting*/,
     szExtDir /*database directory object*/,
     true /*Rebuild index*/,
     "pdml=t, pddl=t, no_dup=t, use_new_val_for_dup_key=t" /*Merge
options*/);
```

SQL Loader-Based Data Merging

SQL loader-based data merging uses Oracle SQL*Loader to load the new graph data into Oracle Database and then merge the new graph data into an existing graph.

The following example merges the new graph data from a vertex and edge files szOPVFile and szOPEFile in Oracle Flat-file format with an existing graph opg using an SQL loader -based data merging with a DOP (degree of parallelism) of 48 and the specified merging options. To use the APIs, the path to the SQL*Loader needs to be specified.

```
String szUser = "username";
String szPassword = "password";
String szDbId = "db18c"; /*service name of the database*/
String szOPVFile = "../../data/connectionsNew.opv"; 0
String szOPEFile = "../../data/connectionsNew.ope";
String szSQLLoaderPath = "<YOUR_ORACLE_HOME>/bin/sqlldr";
OraclePropertyGraphDataLoader opgdl =
OraclePropertyGraphDataLoader.getInstance();
opgdl.mergeDataWithSqlLdr(opg, szUser, szPassword, szDbId, szOPVFile,
szOPEFile,
     48 /*DOP*/,
     true /*Use Named Pipe for splitting*/,
     szSQLLoaderPath /* SQL*Loader path: the path to bin/sqlldr */,
     true /*Rebuild index*/,
     "pdml=t, pddl=t, no_dup=t, use_new_val_for_dup_key=t" /*Merge
options*/);
```

A.4.8 Opening and Closing a Property Graph Instance

When describing a property graph, use these Oracle Property Graph classes to open and close the property graph instance properly:

- `OraclePropertyGraph.getInstance`: Opens an instance of an Oracle property graph. This method has two parameters, the connection information and the graph name.

- `OraclePropertyGraph.clearRepository`: Removes all vertices and edges from the property graph instance.
- `OraclePropertyGraph.shutdown`: Closes the graph instance.

For Oracle Database, the `OraclePropertyGraph.getInstance` method uses an Oracle instance to manage the database connection. `OraclePropertyGraph` has a set of constructors that let you set the graph name, number of hash partitions, degree of parallelism, tablespace, and options for storage (such as compression). For example:

```
import oracle.pg.rdbms.*;
Oracle oracle = new Oracle(jdbcURL, username, password);

OraclePropertyGraph opg = OraclePropertyGraph.getInstance(oracle, graphName);
opg.clearRepository();
//      .
//      .  Graph description
//      .
// Close the graph instance
opg.shutdown();
```

If the in-memory analyst functions are required for an application, you should use `GraphConfigBuilder` to create a graph for Oracle Database, and instantiate `OraclePropertyGraph` with that graph name as an argument. For example, the following code snippet constructs a graph `config`, gets an `OraclePropertyGraph` instance, loads some data into that graph, and gets an in-memory analyst.

```
import oracle.pgx.config.*;
import oracle.pgx.api.*;
import oracle.pgx.common.types.*;

...

PgNosqlGraphConfig cfg = GraphConfigBuilder. forPropertyGraphRdbms ()
       .setJdbcUrl("jdbc:oracle:thin:@<hostname>:1521:<sid>")
       .setUsername("<username>").setPassword("<password>")
       .setName(szGraphName)
       .setMaxNumConnections(8)
       .addEdgeProperty("lbl", PropertyType.STRING, "lbl")
       .addEdgeProperty("weight", PropertyType.DOUBLE, "1000000")
       .build();

  OraclePropertyGraph opg = OraclePropertyGraph.getInstance(cfg);

  String szOPVFile = "../../data/connections.opv";
  String szOPEFile = "../../data/connections.ope";

  // perform a parallel data load
  OraclePropertyGraphDataLoader opgdl =
OraclePropertyGraphDataLoader.getInstance();
  opgdl.loadData(opg, szOPVFile, szOPEFile, 2 /* dop */, 1000, true,
"PDML=T,PDDL=T,NO_DUP=T,");

  ...
  PgxSession session = Pgx.createSession("session-id-1");
```

```
PgxGraph g = session.readGraphWithProperties(cfg);

Analyst analyst = session.createAnalyst();
...
```

A.4.9 Creating Vertices

To create a vertex, use these Oracle Property Graph methods:

- `OraclePropertyGraph.addVertex`: Adds a vertex instance to a graph.
- `OracleVertex.setProperty`: Assigns a key-value property to a vertex.
- `OraclePropertyGraph.commit`: Saves all changes to the property graph instance.

The following code fragment creates two vertices named `V1` and `V2`, with properties for age, name, weight, height, and sex in the `opg` property graph instance. The `v1` properties set the data types explicitly.

```
// Create vertex v1 and assign it properties as key-value pairs
Vertex v1 = opg.addVertex(1l);
  v1.setProperty("age",  Integer.valueOf(31));
  v1.setProperty("name", "Alice");
  v1.setProperty("weight", Float.valueOf(135.0f));
  v1.setProperty("height", Double.valueOf(64.5d));
  v1.setProperty("female", Boolean.TRUE);

Vertex v2 = opg.addVertex(2l);
  v2.setProperty("age",  27);
  v2.setProperty("name", "Bob");
  v2.setProperty("weight", Float.valueOf(156.0f));
  v2.setProperty("height", Double.valueOf(69.5d));
  v2.setProperty("female", Boolean.FALSE);
```

A.4.10 Creating Edges

To create an edge, use these Oracle Property Graph methods:

- `OraclePropertyGraph.addEdge`: Adds an edge instance to a graph.
- `OracleEdge.setProperty`: Assigns a key-value property to an edge.

The following code fragment creates two vertices (`v1` and `v2`) and one edge (`e1`).

```
// Add vertices v1 and v2
Vertex v1 = opg.addVertex(1l);
v1.setProperty("name", "Alice");
v1.setProperty("age", 31);

Vertex v2 = opg.addVertex(2l);
v2.setProperty("name", "Bob");
v2.setProperty("age", 27);

// Add edge e1
Edge e1 = opg.addEdge(1l, v1, v2, "knows");
e1.setProperty("type", "friends");
```

A.4.11 Deleting Vertices and Edges

You can remove vertex and edge instances individually, or all of them simultaneously. Use these methods:

- `OraclePropertyGraph.removeEdge`: Removes the specified edge from the graph.
- `OraclePropertyGraph.removeVertex`: Removes the specified vertex from the graph.
- `OraclePropertyGraph.clearRepository`: Removes all vertices and edges from the property graph instance.

The following code fragment removes edge `e1` and vertex `v1` from the graph instance. The adjacent edges will also be deleted from the graph when removing a vertex. This is because every edge must have an beginning and ending vertex. After removing the beginning or ending vertex, the edge is no longer a valid edge.

```
// Remove edge e1
opg.removeEdge(e1);

// Remove vertex v1
opg.removeVertex(v1);
```

The `OraclePropertyGraph.clearRepository` method can be used to remove all contents from an `OraclePropertyGraph` instance. However, use it with care because this action cannot be reversed.

A.4.12 Reading a Graph from a Database into an Embedded Graph Server (PGX)

You can read a graph from Oracle Database into a graph server (PGX) that is embedded in the same client Java application (a single JVM). For the following example, a correct `java.io.tmpdir` setting is required.

```
int dop = 8;                    // need customization
Map<PgxConfig.Field, Object> confPgx = new HashMap<PgxConfig.Field,
Object>();
confPgx.put(PgxConfig.Field.ENABLE_GM_COMPILER, false);
confPgx.put(PgxConfig.Field.NUM_WORKERS_IO, dop);   //
confPgx.put(PgxConfig.Field.NUM_WORKERS_ANALYSIS, dop); // <= # of physical
cores
confPgx.put(PgxConfig.Field.NUM_WORKERS_FAST_TRACK_ANALYSIS, 2);
confPgx.put(PgxConfig.Field.SESSION_TASK_TIMEOUT_SECS, 0);  // no timeout set
confPgx.put(PgxConfig.Field.SESSION_IDLE_TIMEOUT_SECS, 0);  // no timeout set

PgRdbmsGraphConfig cfg =
GraphConfigBuilder.forPropertyGraphRdbms().setJdbcUrl("jdbc:oracle:thin:@<you
r_db_host>:<db_port>:<db_sid>")
     .setUsername("<username>")
     .setPassword("<password>")
     .setName("<graph_name>")
     .setMaxNumConnections(8)
     .setLoadEdgeLabel(false)
     .build();
```

```
OraclePropertyGraph opg = OraclePropertyGraph.getInstance(cfg);
ServerInstance localInstance = Pgx.getInstance();
localInstance.startEngine(confPgx);
PgxSession session = localInstance.createSession("session-id-1"); //
Put your session description here.

Analyst analyst = session.createAnalyst();

// The following call will trigger a read of graph data from the
database
PgxGraph pgxGraph = session.readGraphWithProperties(opg.getConfig());

long triangles = analyst.countTriangles(pgxGraph, false);
System.out.println("triangles " + triangles);

// Remove edge e1
opg.removeEdge(e1);

// Remove vertex v1
opg.removeVertex(v1);
```

A.4.13 Specifying Labels for Vertices

The database and data access layer do not provide labels for vertices; however, you can treat the value of a designated vertex property as one or more labels. Such a transformation is relevant only to the in-memory analyst.

In the following example, a property "`country`" is specified in a call to `setUseVertexPropertyValueAsLabel()`, and the comma delimiter "`,`" is specified in a call to `setPropertyValueDelimiter()`. These two together imply that values of the `country` vertex property will be treated as vertex labels separated by a comma. For example, if vertex X has a string value "`US`" for its country property, then its vertex label will be `US`; and if vertex Y has a string value "`UK,CN`", then it will have two labels: `UK` and `CN`.

```
GraphConfigBuilder.forPropertyGraph...
   .setName("<your_graph_name>")
   ...
  .setUseVertexPropertyValueAsLabel("country")
  .setPropertyValueDelimiter(",")
  .setLoadVertexLabels(true)
  .build();
```

A.4.14 Building an In-Memory Graph

In addition to Store the Database Password in a Keystore, you can create an in-memory graph programmatically. This can simplify development when the size of graph is small or when the content of the graph is highly dynamic. The key Java class is `GraphBuilder`, which can accumulate a set of vertices and edges added with the `addVertex` and `addEdge` APIs. After all changes are made, an in-memory graph instance (`PgxGraph`) can be created by the `GraphBuilder`.

The following Java code snippet illustrates a graph construction flow. Note that there are no explicit calls to `addVertex`, because any vertex that does not already exist will be added dynamically as its adjacent edges are created.

```
import oracle.pgx.api.*;

PgxSession session = Pgx.createSession("example");
GraphBuilder<Integer> builder = session.createGraphBuilder();

builder.addEdge(1, 2);
builder.addEdge(2, 3);
builder.addEdge(2, 4);
builder.addEdge(3, 4);
builder.addEdge(4, 2);

PgxGraph graph = builder.build();
```

To construct a graph with vertex properties, you can use `setProperty` against the vertex objects created.

```
PgxSession session = Pgx.createSession("example");
GraphBuilder<Integer> builder = session.createGraphBuilder();

builder.addVertex(1).setProperty("double-prop", 0.1);
builder.addVertex(2).setProperty("double-prop", 2.0);
builder.addVertex(3).setProperty("double-prop", 0.3);
builder.addVertex(4).setProperty("double-prop", 4.56789);

builder.addEdge(1, 2);
builder.addEdge(2, 3);
builder.addEdge(2, 4);
builder.addEdge(3, 4);
builder.addEdge(4, 2);

PgxGraph graph = builder.build();
```

To use long integers as vertex and edge identifiers, specify `IdType.LONG` when getting a new instance of `GraphBuilder`. For example:

```
import oracle.pgx.common.types.IdType;
GraphBuilder<Long> builder = session.createGraphBuilder(IdType.LONG);
```

During edge construction, you can directly use vertex objects that were previously created in a call to `addEdge`.

```
v1 = builder.addVertex(1).setProperty("double-prop", 0.5)
v2 = builder.addVertex(2).setProperty("double-prop", 2.0)

builder.addEdge(v1, v2)
```

As with vertices, edges can have properties. The following example sets the edge label by using `setLabel`:

```
builder.addEdge(v1, v2).setProperty("edge-prop",
"edge_prop_1_2").setLabel("label")
```

A.4.15 Dropping a Property Graph

To drop a property graph from the database, use the `OraclePropertyGraphUtils.dropPropertyGraph` method. This method has two parameters, the connection information and the graph name. For example:

```
// Drop the graph
Oracle oracle = new Oracle(jdbcUrl, username, password);
OraclePropertyGraphUtils.dropPropertyGraph(oracle, graphName);
```

You can also drop a property graph using the PL/SQL API. For example:

```
EXECUTE opg_apis.drop_pg('my_graph_name');
```

A.4.16 Executing PGQL Queries

You can execute PGQL queries directly against Oracle Database with the `PgqlStatement` and `PgqlPreparedStatement` interfaces. See Executing PGQL Queries Against Property Graph Schema Tables for details.

A.5 Access Control for Property Graph Data (Graph-Level and OLS)

Oracle Graph supports two access control and security models: graph level access control, and fine-grained security through integration with Oracle Label Security (OLS).

- Graph-level access control relies on grant/revoke to allow/disallow users other than the owner to access a property graph.
- OLS for property graph data allows sensitivity labels to be associated with individual vertex or edge stored in a property graph.

The default control of access to property graph data stored in an Oracle Database is at the graph level: the owner of a graph can grant read, insert, delete, update and select privileges on the graph to other users.

However, for applications with stringent security requirements, you can enforce a fine-grained access control mechanism by using the Oracle Label Security option of Oracle Database. With OLS, for each query, access to specific elements (vertices or edges) is granted by comparing their labels with the user's labels. (For information about using OLS, see *Oracle Label Security Administrator's Guide* .)

With Oracle Label Security enabled, elements (vertices or edges) may not be inserted in the graph if the same elements exist in the database with a stronger sensitivity label. For example, assume that you have a vertex with a very sensitive label, such as: `( Vertex ID 1 {name:str:v1} "SENSITIVE" )`. This actually prevents a low-privileged (PUBLIC) user from updating the vertex: `( Vertex ID 1 {name:str:v1} "PUBLIC" )`. On the other hand, if a high-privileged user overwrites a vertex or an edge that had been created with a low-level security label, the newer label with higher security will be assigned to the vertex or edge, and the low-privileged user will not be able to see it anymore.

- Applying Oracle Label Security (OLS) on Property Graph Data
  This topic presents an example illustrating how to apply OLS to property graph data.

A.5.1 Applying Oracle Label Security (OLS) on Property Graph Data

This topic presents an example illustrating how to apply OLS to property graph data.

Because the property graph is stored in regular relational tables, this example is no different from applying OLS on a regular relational table. The following shows how to configure and enable OLS, create a security policy with security labels, and apply it to a property graph. The code examples are very simplified, and do not necessarily reflect recommended practices regarding user names and passwords.

1. As SYSDBA, create database users named userP, userP2, userS, userTS, userTS2 and pgAdmin.

```
CONNECT / as sysdba;

CREATE USER userP IDENTIFIED BY userPpass;
GRANT connect, resource, create table, create view, create any index TO
userP;
GRANT unlimited TABLESPACE to userP;

CREATE USER userP2 IDENTIFIED BY userP2pass;
GRANT connect, resource, create table, create view, create any index TO
userP2;
GRANT unlimited TABLESPACE to userP2;

CREATE USER userS IDENTIFIED BY userSpass;
GRANT connect, resource, create table, create view, create any index TO
userS;
GRANT unlimited TABLESPACE to userS;

CREATE USER userTS IDENTIFIED BY userTSpass;
GRANT connect, resource, create table, create view, create any index TO
userTS;
GRANT unlimited TABLESPACE to userTS;

CREATE USER userTS2 IDENTIFIED BY userTS2pass;
GRANT connect, resource, create table, create view, create any index TO
userTS2;
GRANT unlimited TABLESPACE to userTS2;

CREATE USER pgAdmin IDENTIFIED BY pgAdminpass;
GRANT connect, resource, create table, create view, create any index TO
pgAdmin;
GRANT unlimited TABLESPACE to pgAdmin;
```

2. As SYSDBA, configure and enable Oracle Label Security.

```
ALTER USER lbacsys IDENTIFIED BY lbacsys ACCOUNT UNLOCK;
EXEC LBACSYS.CONFIGURE_OLS;
EXEC LBACSYS.OLS_ENFORCEMENT.ENABLE_OLS;
```

3. As SYSTEM, grant privileges to sec_admin and hr_sec.

```
CONNECT system/<system-password>
GRANT connect, create any index to sec_admin IDENTIFIED BY password;
GRANT connect, create user, drop user, create role, drop any role
TO hr_sec IDENTIFIED BY password;
```

4. As LBACSYS, create the security policy.

```
CONNECT lbacsys/<lbacsys-password>

BEGIN
SA_SYSDBA.CREATE_POLICY (
  policy_name => 'DEFENSE',
  column_name => 'SL',
  default_options => 'READ_CONTROL,LABEL_DEFAULT,HIDE');
END;
/
```

5. As LBACSYS , grant DEFENSE_DBA and execute to sec_admin and hr_sec users.

```
GRANT DEFENSE_DBA to sec_admin;
GRANT DEFENSE_DBA to hr_sec;

GRANT execute on SA_COMPONENTS to sec_admin;
GRANT execute on SA_USER_ADMIN to hr_sec;
```

6. As SEC_ADMIN, create three security levels (For simplicity, compartments and groups are omitted here.)

```
CONNECT sec_admin/<sec_admin-password>;

BEGIN
SA_COMPONENTS.CREATE_LEVEL (
  policy_name => 'DEFENSE',
  level_num => 1000,
  short_name => 'PUB',
  long_name => 'PUBLIC');
END;
/
EXECUTE
SA_COMPONENTS.CREATE_LEVEL('DEFENSE',2000,'CONF','CONFIDENTIAL');
EXECUTE
SA_COMPONENTS.CREATE_LEVEL('DEFENSE',3000,'SENS','SENSITIVE');
```

7. Create three labels.

```
EXECUTE SA_LABEL_ADMIN.CREATE_LABEL('DEFENSE',1000,'PUB');
EXECUTE SA_LABEL_ADMIN.CREATE_LABEL('DEFENSE',2000,'CONF');
EXECUTE SA_LABEL_ADMIN.CREATE_LABEL('DEFENSE',3000,'SENS');
```

8. As HR_SEC, assign labels and privileges.

```
CONNECT hr_sec/<hr_sec-password>;

BEGIN
SA_USER_ADMIN.SET_USER_LABELS (
  policy_name => 'DEFENSE',
  user_name => 'UT',
  max_read_label => 'SENS',
  max_write_label => 'SENS',
  min_write_label => 'CONF',
  def_label => 'SENS',
  row_label => 'SENS');
END;
/

EXECUTE SA_USER_ADMIN.SET_USER_LABELS('DEFENSE', 'userTS', 'SENS');
EXECUTE SA_USER_ADMIN.SET_USER_LABELS('DEFENSE','userTS2','SENS');
EXECUTE SA_USER_ADMIN.SET_USER_LABELS('DEFENSE', 'userS', 'CONF');
EXECUTE SA_USER_ADMIN.SET_USER_LABELS ('DEFENSE', userP', 'PUB', 'PUB',
'PUB', 'PUB', 'PUB');
EXECUTE SA_USER_ADMIN.SET_USER_LABELS ('DEFENSE', 'userP2', 'PUB', 'PUB',
'PUB', 'PUB', 'PUB');
EXECUTE SA_USER_ADMIN.SET_USER_PRIVS ('DEFENSE', 'pgAdmin', 'FULL');
```

9. As SEC_ADMIN, apply the security policies to the desired property graph. Assume a property graph with the name OLSEXAMPLE with userP as the graph owner. To apply OLS security, execute the following statements.

```
CONNECT sec_admin/<password>;

EXECUTE SA_POLICY_ADMIN.APPLY_TABLE_POLICY ('DEFENSE', 'userP',
'OLSEXAMPLEVT$');
EXECUTE SA_POLICY_ADMIN.APPLY_TABLE_POLICY ('DEFENSE', 'userP',
'OLSEXAMPLEGE$');
EXECUTE SA_POLICY_ADMIN.APPLY_TABLE_POLICY ('DEFENSE', 'userP',
'OLSEXAMPLEGT$');
EXECUTE SA_POLICY_ADMIN.APPLY_TABLE_POLICY ('DEFENSE', 'userP',
'OLSEXAMPLESS$');
```

Now Oracle Label Security has sensitivity labels to be associated with individual vertices or edges stored in the property graph.

The following example shows how to create a property graph with name OLSEXAMPLE, and an example flow to demonstrate the behavior when different users with different security labels create, read, and write graph elements.

```
// Create Oracle Property Graph
String graphName = "OLSEXAMPLE";
```

```
Oracle connPub = new Oracle("jdbc:oracle:thin:@host:port:SID",
"userP", "userPpass");
OraclePropertyGraph graphPub =
OraclePropertyGraph.getInstance(connPub, graphName, 48);

// Grant access to other users
graphPub.grantAccess("userP2",  "RSIUD"); // Read, Select, Insert,
Update, Delete (RSIUD)
graphPub.grantAccess("userS",   "RSIUD");
graphPub.grantAccess("userTS",  "RSIUD");
graphPub.grantAccess("userTS2", "RSIUD");

// Load data
OraclePropertyGraphDataLoader opgdl =
OraclePropertyGraphDataLoader.getInstance();
String vfile = "../../data/connections.opv";
String efile = "../../data/connections.ope";
graphPub.clearRepository();
opgdl.loadData(graphPub, vfile, efile, 48, 1000, true, null);
System.out.println("Vertices with user userP and PUBLIC LABEL: " +
graphPub.countVertices()); // 78
System.out.println("Vertices with user userP and PUBLIC LABEL: " +
graphPub.countEdges());  // 164

// Second user with a higher level
Oracle connTS = new Oracle("jdbc:oracle:thin:@host:port:SID",
"userTS", "userTpassS");
OraclePropertyGraph graphTS = OraclePropertyGraph.getInstance(connTS,
"USERP", graphName, 8, 48, null, null);
System.out.println("Vertices with user userTS and SENSITIVE LABEL: " +
graphTS.countVertices()); // 78
System.out.println("Vertices with user userTS and SENSITIVE LABEL: " +
graphTS.countEdges());  // 164

// Add vertices and edges with the second user
long lMaxVertexID = graphTS.getMaxVertexID();
long lMaxEdgeID = graphTS.getMaxEdgeID();
long size = 10;
System.out.println("\nAdd " + size + " vertices and edges with user
userTS and SENSITIVE LABEL\n");
for (long idx = 1; idx <= size; idx++) {
  Vertex v = graphTS.addVertex(idx + lMaxVertexID);
  v.setProperty("name", "v_" + (idx + lMaxVertexID));
  Edge e = graphTS.addEdge(idx + lMaxEdgeID, v,
graphTS.getVertex(idx), "edge_" + (idx + lMaxEdgeID));
}
graphTS.commit();

// User userP with a lower level only sees the original vertices and
edges, user userTS can see more
System.out.println("Vertices with user userP and PUBLIC LABEL: " +
graphPub.countVertices()); // 78
System.out.println("Vertices with user userP and PUBLIC LABEL: " +
graphPub.countEdges());  // 164
System.out.println("Vertices with user userTS and SENSITIVE LABEL: " +
```

```
graphTS.countVertices()); // 88
System.out.println("Vertices with user userTS and SENSITIVE LABEL: " +
graphTS.countEdges());  // 174

// Third user with a higher level
Oracle connTS2 = new Oracle("jdbc:oracle:thin:@host:port:SID", "userTS2",
"userTS2pass");
OraclePropertyGraph graphTS2 = OraclePropertyGraph.getInstance(connTS2,
"USERP", graphName, 8, 48, null, null);
System.out.println("Vertices with user userTS2 and SENSITIVE LABEL: " +
graphTS2.countVertices()); // 88
System.out.println("Vertices with user userTS2 and SENSITIVE LABEL: " +
graphTS2.countEdges());  // 174

// Fourth user with a intermediate level
Oracle connS = new Oracle("jdbc:oracle:thin:@host:port:SID", "userS",
"userSpass");
OraclePropertyGraph graphS = OraclePropertyGraph.getInstance(connS, "USERP",
graphName, 8, 48, null, null);
System.out.println("Vertices with user userS and CONFIDENTIAL LABEL: " +
graphS.countVertices()); // 78
System.out.println("Vertices with user userS and CONFIDENTIAL LABEL: " +
graphS.countEdges());  // 164

// Modify vertices with the fourth user
System.out.println("\nModify " + size + " vertices with user userS and
CONFIDENTIAL LABEL\n");
for (long idx = 1; idx <= size; idx++) {
  Vertex v = graphS.getVertex(idx);
  v.setProperty("security_label", "CONFIDENTIAL");
}
graphS.commit();

// User userP with a lower level that userS cannot see the new vertices
// Users userS and userTS can see them
System.out.println("Vertices with user userP with property security_label: "
+ OraclePropertyGraphUtils.size(graphPub.getVertices("security_label",
"CONFIDENTIAL"))); // 0
System.out.println("Vertices with user userS with property security_label: "
+ OraclePropertyGraphUtils.size(graphS.getVertices("security_label",
"CONFIDENTIAL"))); // 10
System.out.println("Vertices with user userTS with property security_label:
" + OraclePropertyGraphUtils.size(graphTS.getVertices("security_label",
"CONFIDENTIAL"))); // 10
System.out.println("Vertices with user userP and PUBLIC LABEL: " +
graphPub.countVertices()); // 68
System.out.println("Vertices with user userTS and SENSITIVE LABEL: " +
graphTS.countVertices()); // 88
```

The preceding example should produce the following output.

```
Vertices with user userP and PUBLIC LABEL: 78
Vertices with user userP and PUBLIC LABEL: 164
Vertices with user userTS and SENSITIVE LABEL: 78
Vertices with user userTS and SENSITIVE LABEL: 164
```

```
Add 10 vertices and edges with user userTS and SENSITIVE LABEL

Vertices with user userP and PUBLIC LABEL: 78
Vertices with user userP and PUBLIC LABEL: 164
Vertices with user userTS and SENSITIVE LABEL: 88
Vertices with user userTS and SENSITIVE LABEL: 174
Vertices with user userTS2 and SENSITIVE LABEL: 88
Vertices with user userTS2 and SENSITIVE LABEL: 174
Vertices with user userS and CONFIDENTIAL LABEL: 78
Vertices with user userS and CONFIDENTIAL LABEL: 164

Modify 10 vertices with user userS and CONFIDENTIAL LABEL

Vertices with user userP with property security_label: 0
Vertices with user userS with property security_label: 10
Vertices with user userTS with property security_label: 10
Vertices with user userP and PUBLIC LABEL: 68
Vertices with user userTS and SENSITIVE LABEL: 88
```

A.6 SQL-Based Property Graph Query and Analytics

You can use SQL to query property graph data in Oracle Spatial and Graph.

For the property graph support in Oracle Spatial and Graph, all the vertices and edges data are persisted in relational form in Oracle Database. For detailed information about the Oracle Spatial and Graph property graph schema objects, see Property Graph Schema Objects for Oracle Database.

This chapter provides examples of typical graph queries implemented using SQL. The audience includes DBAs as well as application developers who understand SQL syntax and property graph schema objects.

The benefits of querying directly property graph using SQL include:

- There is no need to bring data outside Oracle Database.
- You can leverage the industry-proven SQL engine provided by Oracle Database.
- You can easily join or integrate property graph data with other data types (relational, JSON, XML, and so on).
- You can take advantage of existing Oracle SQL tuning and database management tools and user interface.

The examples assume that there is a property graph named **`connections`** in the current schema. The SQL queries and example output are for illustration purpose only, and your output may be different depending on the data in your `connections` graph. In some examples, the output is reformatted for readability.

- Simple Property Graph Queries
  The examples in this topic query vertices, edges, and properties of the graph.
- Text Queries on Property Graphs
  If values of a property (vertex property or edge property) contain free text, then it might help performance to create an Oracle Text index on the V column.
- Navigation and Graph Pattern Matching
  A key benefit of using a graph data model is that you can easily navigate across entities (people, movies, products, services, events, and so on) that are modeled as vertices, following links and relationships modeled as edges. In addition, graph

matching templates can be defined to do such things as detect patterns, aggregate individuals, and analyze trends.

- Navigation Options: CONNECT BY and Parallel Recursion
  The CONNECT BY clause and parallel recursion provide options for advanced navigation and querying.
- Pivot
  The PIVOT clause lets you dynamically add columns to a table to create a new table.
- SQL-Based Property Graph Analytics
  In addition to the analytical functions offered by the graph server (PGX), the property graph feature in Oracle Spatial and Graph supports several native, SQL-based property graph analytics.

A.6.1 Simple Property Graph Queries

The examples in this topic query vertices, edges, and properties of the graph.

Example A-1 Find a Vertex with a Specified Vertex ID

This example find the vertex with vertex ID 1 in the `connections` graph.

```
SQL> select vid, k, v, vn, vt
      from connectionsVT$
      where vid=1;
```

The output might be as follows:

```
     1 country     United States
     1 name        Robert Smith
     1 occupation  CEO of Example Corporation
     ...
```

Example A-2 Find an Edge with a Specified Edge ID

This example find the edge with edge ID 100 in the `connections` graph.

```
SQL> select eid,svid,dvid,k,t,v,vn,vt
      from connectionsGE$
      where eid=1000;
```

The output might be as follows:

```
    1000   1 2 weight   3   1   1
```

In the preceding output, the K of the edge property is "weight" and the type ID of the value is 3, indicating a float value.

Example A-3 Perform Simple Counting

This example performs simple counting in the `connections` graph.

```
SQL> -- Get the total number of K/V pairs of all the vertices
SQL> select /*+ parallel */ count(1)
       from connectionsVT$;
```

```
    299

SQL> -- Get the total number of K/V pairs of all the edges
SQL> select /*+ parallel(8) */ count(1)
       from connectionsGE$;
    164

SQL> -- Get the total number of vertices
SQL> select /*+ parallel */ count(distinct vid)
       from connectionsVT$;

    78

SQL> -- Get the total number of edges
SQL> select /*+ parallel */ count(distinct eid)
       from connectionsGE$;

    164
```

Example A-4   Get the Set of Property Keys Used

This example gets the set of property keys used for the vertices n the `connections` graph.

```
SQL> select /*+ parallel */ distinct k
      from connectionsVT$;

company
show
occupation
type
team
religion
criminal charge
music genre
genre
name
role
political party
country

13 rows selected.

SQL> -- get the set of property keys used for edges
SQL> select /*+ parallel */ distinct k
       from connectionsGE$;

weight
```

Example A-5 Find Vertices with a Value

This example finds vertices with a value (of any property) that is of String type, and where and the value contains two adjacent occurrences of a, e, i, o, or u, regardless of case.n the `connections` graph.

```
SQL> select vid, t, k, v
       from connectionsVT$
      where t=1
        and regexp_like(v, '([aeiou])\1', 'i');

     6         1  name   Jordan Peele
     6         1  show   Key and Peele
    54         1  name   John Green
        ...
```

It is usually hard to leverage a B-Tree index for the preceding kind of query because it is difficult to know beforehand what kind of regular expression is going to be used. For the above query, you might get the following execution plan. Note that full table scan is chosen by the optimizer.

```
---------------------------------------------------------------------------------------
---------------------------------------------
| Id  | Operation             | Name            | Rows   | Bytes | Cost (%CPU)| Time
| Pstart| Pstop |    TQ  |IN-OUT| PQ Distrib |
---------------------------------------------------------------------------------------
---------------------------------------------
|   0 | SELECT STATEMENT      |                 |    15 |   795 |    28    (0)| 00:00:01
|       |       |        |      |            |
|   1 |  PX COORDINATOR       |                 |       |       |             |
|       |       |        |      |            |
|   2 |   PX SEND QC (RANDOM)| :TQ10000        |    15 |   795 |    28    (0)| 00:00:01
|       |       |  Q1,00 | P->S | QC (RAND)  |
|   3 |    PX BLOCK ITERATOR |                 |    15 |   795 |    28    (0)| 00:00:01
|     1 |     8 |  Q1,00 | PCWC |            |
|*  4 |     TABLE ACCESS FULL| CONNECTIONSVT$ |    15 |   795 |    28    (0)| 00:00:01
|     1 |     8 |  Q1,00 | PCWP |            |
---------------------------------------------------------------------------------------
---------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   4 - filter(INTERNAL_FUNCTION("V") AND  REGEXP_LIKE ("V",U'([aeiou])\005C1','i') AND
"T"=1 AND INTERNAL_FUNCTION("K"))
Note
-----
   - Degree of Parallelism is 2 because of table property
```

If the Oracle Database In-Memory option is available and memory is sufficient, it can help performance to place the table (full table or a set of relevant columns) in memory. One way to achieve that is as follows:

```
SQL> alter table connectionsVT$ inmemory;
Table altered.
```

Now, entering the same SQL containing the regular expression shows a plan that performs a "TABLE ACCESS INMEMORY FULL".

```
--------------------------------------------------------------------------------
-----------------------------------------------------------
| Id  | Operation                        | Name            | Rows  | Bytes | Cost
(%CPU)  | Time      | Pstart| Pstop |    TQ    |IN-OUT| PQ Distrib |
--------------------------------------------------------------------------------
------------------------------------------------------------
|   0 | SELECT STATEMENT                 |                 |    15 |   795 |
28      (0)| 00:00:01 |       |       |        |      |            |
|   1 |  PX COORDINATOR                  |                 |       |
|              |          |       |       |        |      |            |
|   2 |   PX SEND QC (RANDOM)            | :TQ10000        |    15 |   795 |
28      (0)| 00:00:01 |       |       |  Q1,00 | P->S | QC (RAND)  |
|   3 |    PX BLOCK ITERATOR             |                 |    15 |   795 |
28      (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWC |            |
|*  4 |     TABLE ACCESS INMEMORY FULL| CONNECTIONSVT$ |    15 |   795 |
28      (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWP |            |
--------------------------------------------------------------------------------
------------------------------------------------------------
Predicate Information (identified by operation id):
---------------------------------------------------
   4 - filter(INTERNAL_FUNCTION("V") AND  REGEXP_LIKE ("V",U'([aeiou])
\005C1','i') AND "T"=1 AND INTERNAL_FUNCTION("K"))
Note
-----
   - Degree of Parallelism is 2 because of table property
```

A.6.2 Text Queries on Property Graphs

If values of a property (vertex property or edge property) contain free text, then it might help performance to create an Oracle Text index on the V column.

Oracle Text can process text that is directly stored in the database. The text can be short strings (such as names or addresses), or it can be full-length documents. These documents can be in a variety of textual format.

The text can also be in many different languages. Oracle Text can handle any space-separated languages (including character sets such as Greek or Cyrillic). In addition, Oracle Text is able to handle the Chinese, Japanese and Korean pictographic languages)

Because the property graph feature uses NVARCHAR typed column for better support of Unicode, it is ***highly recommended*** that UTF8 (AL32UTF8) be used as the database character set.

To create an Oracle Text index on the vertices table (or edges table), the ALTER SESSION privilege is required. For example:

```
SQL> grant alter session to <YOUR_USER_SCHEMA_HERE>;
```

If customization is required, also grant the EXECUTE privilege on CTX_DDL:

```
SQL> grant execute on ctx_ddl to <YOUR_USER_SCHEMA_HERE>;
```

The following shows some example statements for granting these privileges to SCOTT.

```
SQL> conn / as sysdba
Connected.
SQL> -- This is a PDB setup --
SQL> alter session set container=orcl;
Session altered.

SQL> grant execute on ctx_ddl to scott;
Grant succeeded.

SQL> grant alter session to scott;
Grant succeeded.
```

Example A-6   Create a Text Index

This example creates an Oracle Text index on the vertices table (V column) of the connections graph in the SCOTT schema. Note that the Oracle Text index created here is for all property keys, not just one or a subset of property keys. In addition, if a new property is added to the graph and the property value is of String data type, then it will automatically be included in the same text index.

The example uses the OPG_AUTO_LEXER lexer owned by MDSYS.

```
SQL> execute opg_apis.create_vertices_text_idx('scott', 'connections',
pref_owner=>'MDSYS', lexer=>'OPG_AUTO_LEXER', dop=>2);
```

If customization is desired, you can use the ctx_ddl.create_preference API. For example:

```
SQL> -- The following requires access privilege to CTX_DDL
SQL> exec ctx_ddl.create_preference('SCOTT.OPG_AUTO_LEXER', 'AUTO_LEXER');

PL/SQL procedure successfully completed.

SQL> execute opg_apis.create_vertices_text_idx('scott', 'connections',
pref_owner=>'scott', lexer=>'OPG_AUTO_LEXER', dop=>2);

PL/SQL procedure successfully completed.
```

You can now use a rich set of functions provided by Oracle Text to perform queries against graph elements.

Note:

If you no longer need an Oracle Text index, you can use the drop_vertices_text_idx or opg_apis.drop_edges_text_idx API to drop it. The following statements drop the text indexes on the vertices and edges of a graph named `connections` owned by SCOTT:

```
SQL> exec opg_apis.drop_vertices_text_Idx('scott',
'connections');
SQL> exec opg_apis.drop_edges_text_Idx('scott', 'connections');
```

Example A-7 Find a Vertex that Has a Property Value

The following example find a vertex that has a property value (of string type) containing the keyword "Smith".

```
SQL> select vid, k, t, v
        from connectionsVT$
       where t=1
         and contains(v, 'Smith', 1) > 0
       order by score(1) desc
       ;
```

The output and SQL execution plan from the preceding statement may appear as follows. Note that DOMAIN INDEX appears as an operation in the execution plan.

```
     1  name     1  Robert Smith

Execution Plan
----------------------------------------------------------
Plan hash value: 1619508090

--------------------------------------------------------------------------------
-------------------------------------
| Id  | Operation                          | Name             | Rows  | Bytes |
Cost (%CPU) | Time     | Pstart| Pstop |
--------------------------------------------------------------------------------
-------------------------------------
|   0 | SELECT STATEMENT                   |                  |     1 |    56
|     5  (20) | 00:00:01 |       |       |
|   1 |  SORT ORDER BY                     |                  |     1 |    56
|     5  (20) | 00:00:01 |       |       |
|*  2 |   TABLE ACCESS BY GLOBAL INDEX ROWID| CONNECTIONSVT$  |     1 |    56
|     4    (0)| 00:00:01 | ROWID | ROWID |
|*  3 |    DOMAIN INDEX                    | CONNECTIONSXTV$ |       |
|     4    (0)| 00:00:01 |       |       |
--------------------------------------------------------------------------------
-------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   2 - filter("T"=1 AND INTERNAL_FUNCTION("K") AND INTERNAL_FUNCTION("V"))
   3 - access("CTXSYS"."CONTAINS"("V",'Smith',1)>0)
```

Example A-8 Fuzzy Match

The following example finds a vertex that has a property value (of string type) containing variants of "ameriian" (a deliberate misspelling for this example) Fuzzy match is used.

```
SQL> select vid, k, t, v
       from connectionsVT$
      where contains(v, 'fuzzy(ameriian,,,weight)', 1) > 0
      order by score(1) desc;
```

The output and SQL execution plan from the preceding statement may appear as follows.

```
     8 role       1  american business man
     9 role       1  american business man
     4 role       1  american economist
     6 role       1  american comedian actor
     7 role       1  american comedian actor
     1 occupation 1 44th president of United States of America

6 rows selected.

Execution Plan
----------------------------------------------------------
Plan hash value: 1619508090

-----------------------------------------------------------------------------------------
--------------------------------
| Id  | Operation                           | Name             | Rows  | Bytes | Cost
(%CPU)| Time      | Pstart| Pstop |
-----------------------------------------------------------------------------------------
--------------------------------
|   0 | SELECT STATEMENT                    |                  |     1 |    56 |     5
(20)| 00:00:01 |       |       |
|   1 |  SORT ORDER BY                      |                  |     1 |    56 |     5
(20)| 00:00:01 |       |       |
|*  2 |   TABLE ACCESS BY GLOBAL INDEX ROWID| CONNECTIONSVT$   |     1 |    56 |
4   (0)| 00:00:01 | ROWID | ROWID |
|*  3 |    DOMAIN INDEX                     | CONNECTIONSXTV$ |       |       |
4   (0)| 00:00:01 |       |       |
-----------------------------------------------------------------------------------------
--------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   2 - filter(INTERNAL_FUNCTION("K") AND INTERNAL_FUNCTION("V"))
```

Example A-9 Query Relaxation

The following example is a sophisticated Oracle Text query that implements **query relaxation**, which enables you to execute the most restrictive version of a query first, progressively relaxing the query until the required number of matches is obtained. Using query relaxation with queries that contain multiple strings, you can provide guidance for determining the “best” matches, so that these appear earlier in the results than other potential matches.

This example searchs for "american actor" with a query relaxation sequence.

```
SQL> select vid, k, t, v
       from connectionsVT$
      where CONTAINS (v,
 '<query>
   <textquery lang="ENGLISH" grammar="CONTEXT">
     <progression>
       <seq>{american} {actor}</seq>
       <seq>{american} NEAR {actor}</seq>
       <seq>{american} AND {actor}</seq>
       <seq>{american} ACCUM {actor}</seq>
     </progression>
   </textquery>
   <score datatype="INTEGER" algorithm="COUNT"/>
  </query>') > 0;
```

The output and SQL execution plan from the preceding statement may appear as follows.

```
     7 role       1 american comedian actor
     6 role       1 american comedian actor
    44 occupation 1 actor
     8 role       1 american business man
    53 occupation 1 actor film producer
    52 occupation 1 actor
     4 role       1 american economist
    47 occupation 1 actor
     9 role       1 american business man

9 rows selected.


Execution Plan
----------------------------------------------------------
Plan hash value: 2158361449

----------------------------------------------------------------------------------
-------------------------------------
| Id  | Operation                         | Name          | Rows   | Bytes | Cost
(%CPU)| Time      | Pstart| Pstop |
----------------------------------------------------------------------------------
-------------------------------------
|   0 | SELECT STATEMENT                  |                 |       1 |      56
|       4   (0)| 00:00:01 |         |         |
|*  1 |  TABLE ACCESS BY GLOBAL INDEX ROWID| CONNECTIONSVT$  |       1 |      56
|       4   (0)| 00:00:01 | ROWID | ROWID |
|*  2 |   DOMAIN INDEX                    | CONNECTIONSXTV$ |         |
|       4   (0)| 00:00:01 |         |         |
----------------------------------------------------------------------------------
-------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   1 - filter(INTERNAL_FUNCTION("K") AND INTERNAL_FUNCTION("V"))
   2 - access("CTXSYS"."CONTAINS"("V",'<query>      <textquery lang="ENGLISH"
grammar="CONTEXT">
          <progression>       <seq>{american} {actor}</seq>    <seq>{american}
```

```
NEAR {actor}</seq>
          <seq>{american} AND {actor}</seq>        <seq>{american} ACCUM {actor}</
seq>    </progression>
          </textquery>    <score datatype="INTEGER" algorithm="COUNT"/> </query>'))>0)
```

Example A-10 Find an Edge

Just as with vertices, you can create an Oracle Text index on the V column of the edges table (GE$) of a property graph. The following example uses the OPG_AUTO_LEXER lexer owned by MDSYS.

```
SQL> exec opg_apis.create_edges_text_idx('scott', 'connections',
pref_owner=>'mdsys', lexer=>'OPG_AUTO_LEXER', dop=>4);
```

If customization is required, use the ctx_ddl.create_preference API.

A.6.3 Navigation and Graph Pattern Matching

A key benefit of using a graph data model is that you can easily navigate across entities (people, movies, products, services, events, and so on) that are modeled as vertices, following links and relationships modeled as edges. In addition, graph matching templates can be defined to do such things as detect patterns, aggregate individuals, and analyze trends.

This topic provides graph navigation and pattern matching examples using the example property graph named connections. Most of the SQL statements are relatively simple, but they can be used as building blocks to implement requirements that are more sophisticated. It is generally best to start from something simple, and progressively add complexity.

Example A-11 Who Are a Person's Collaborators?

The following SQL ststement finds all entities that a vertex with ID 1 collaborates with. For simplicity, it considers **only** outgoing relationships.

```
SQL> select dvid, el, k, vn, v
       from connectionsGE$
      where svid=1
        and el='collaborates';
```

> **Note:**
>
> To find the specific vertex ID of interest, you can perform a text query on the property graph using keywords or fuzzy matching. (For details and examples, see Text Queries on Property Graphs.)

The preceding example's output and execution plan may be as follows.

```
 2 collaborates weight 1 1
21 collaborates weight 1 1
22 collaborates weight 1 1
  ....
26 collaborates weight 1 1
```

```
10 rows selected.


---------------------------------------------------------------------------------
---------------------------------------------------------------------------
| Id  | Operation                                       | Name             | Rows  |
Bytes | Cost (%CPU)| Time       | Pstart| Pstop |    TQ    |IN-OUT| PQ Distrib |
---------------------------------------------------------------------------------
---------------------------------------------------------------------------
|   0 | SELECT STATEMENT                                |                  |    10
|   460 |      2     (0)| 00:00:01 |       |       |        |      |         |
|   1 |  PX COORDINATOR                                 |                  |
|       |               |          |       |       |        |      |         |
|   2 |   PX SEND QC (RANDOM)                           | :TQ10000         |    10
|   460 |      2     (0)| 00:00:01 |       |       |  Q1,00 | P->S | QC (RAND)  |
|   3 |    PX PARTITION HASH ALL                        |                  |    10
|   460 |      2     (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWC |         |
|*  4 |     TABLE ACCESS BY LOCAL INDEX ROWID BATCHED| CONNECTIONSGE$   |    10
|   460 |      2     (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWP |         |
|*  5 |      INDEX RANGE SCAN                           | CONNECTIONSXSE$ |    20
|       |      1     (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWP |         |
---------------------------------------------------------------------------------
---------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   4 - filter(INTERNAL_FUNCTION("EL") AND "EL"=U'collaborates' AND
INTERNAL_FUNCTION("K") AND INTERNAL_FUNCTION("V"))
   5 - access("SVID"=1)
```

Example A-12 Who Are a Person's Collaborators and What are Their Occupations?

The following SQL statement finds collaborators of the vertex with ID 1, and the occupation of each collaborator. A join with the vertices table (VT$) is required.

```
SQL> select dvid, vertices.v
       from connectionsGE$, connectionsVT$ vertices
      where svid=1
        and el='collaborates'
        and dvid=vertices.vid
        and vertices.k='occupation';
```

The preceding example's output and execution plan may be as follows.

```
    21  67th United States Secretary of State
    22  68th United States Secretary of State
    23  chancellor
    28  7th president of Iran
    19  junior United States Senator from New York
...


---------------------------------------------------------------------------------
----------------------------------------------------------------------------
| Id  | Operation                                       | Name             | Rows
| Bytes | Cost (%CPU)| Time      | Pstart| Pstop |    TQ  |IN-OUT| PQ Distrib |
---------------------------------------------------------------------------------
```

```
------------------------------------------------------------------------------
|   0 | SELECT STATEMENT                                 |                 |     7 |
525 |     7   (0)| 00:00:01 |       |       |      |    |            |
|   1 |  PX COORDINATOR                                  |                 |
|       |            |          |       |       |      |    |            |
|   2 |   PX SEND QC (RANDOM)                            | :TQ10000        |     7 |
525 |     7   (0)| 00:00:01 |       |       |  Q1,00 | P->S | QC (RAND)  |
|   3 |    NESTED LOOPS                                  |                 |     7 |
525 |     7   (0)| 00:00:01 |       |       |  Q1,00 | PCWP |            |
|   4 |     PX PARTITION HASH ALL                        |                 |    10 |
250 |     2   (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWC |            |
|*  5 |      TABLE ACCESS BY LOCAL INDEX ROWID BATCHED| CONNECTIONSGE$  |    10 |
250 |     2   (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWP |            |
|*  6 |       INDEX RANGE SCAN                           | CONNECTIONSXSE$ |    20
|       |     1   (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWP |            |
|   7 |     PARTITION HASH ITERATOR                      |                 |     1
|       |     0   (0)| 00:00:01 |   KEY |   KEY |  Q1,00 | PCWP |            |
|*  8 |      TABLE ACCESS BY LOCAL INDEX ROWID           | CONNECTIONSVT$  |
|       |            |          |   KEY |   KEY |  Q1,00 | PCWP |            |
|*  9 |       INDEX UNIQUE SCAN                          | CONNECTIONSXQV$ |     1
|       |     0   (0)| 00:00:01 |   KEY |   KEY |  Q1,00 | PCWP |            |
--------------------------------------------------------------------------------------------
----------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   5 - filter(INTERNAL_FUNCTION("EL") AND "EL"=U'collaborates')
   6 - access("SVID"=1)
   8 - filter(INTERNAL_FUNCTION("VERTICES"."V"))
   9 - access("DVID"="VERTICES"."VID" AND "VERTICES"."K"=U'occupation')
       filter(INTERNAL_FUNCTION("VERTICES"."K"))
```

Example A-13 Find a Person's Enemies and Aggregate Them by Their Country

The following SQL statement finds enemies (that is, those with the `feuds` relationship) of the vertex with ID 1, and aggregates them by their countries. A join with the vertices table (VT$) is required.

```
SQL>   select vertices.v, count(1)
         from connectionsGE$, connectionsVT$ vertices
        where svid=1
          and el='feuds'
          and dvid=vertices.vid
          and vertices.k='country'
     group by vertices.v;
```

The example's output and execution plan may be as follows. In this case, the vertex with ID 1 has 3 enemies in the United States and 1 in Russia.

```
United States      3
Russia             1


--------------------------------------------------------------------------------------------
---------------------------------------------------------------------------
| Id  | Operation                                        | Name            | Rows    |
Bytes  | Cost (%CPU)| Time      | Pstart| Pstop |     TQ   |IN-OUT| PQ Distrib |
--------------------------------------------------------------------------------------------
```

```
--------------------------------------------------------------------------
|   0 | SELECT STATEMENT                                  |                 |      5
|    375 |        5  (20)| 00:00:01 |        |        |        |       |          |
|   1 |  PX COORDINATOR                                   |                 |
|        |               |          |        |        |        |       |          |
|   2 |   PX SEND QC (RANDOM)                             | :TQ10001        |      5
|    375 |        5  (20)| 00:00:01 |        |        |  Q1,01 | P->S | QC (RAND)
|
|   3 |    HASH GROUP BY                                  |                 |      5
|    375 |        5  (20)| 00:00:01 |        |        |  Q1,01 | PCWP |          |
|   4 |     PX RECEIVE                                    |                 |      5
|    375 |        5  (20)| 00:00:01 |        |        |  Q1,01 | PCWP |          |
|   5 |      PX SEND HASH                                 | :TQ10000        |      5
|    375 |        5  (20)| 00:00:01 |        |        |  Q1,00 | P->P | HASH     |
|   6 |       HASH GROUP BY                               |                 |      5
|    375 |        5  (20)| 00:00:01 |        |        |  Q1,00 | PCWP |          |
|   7 |        NESTED LOOPS                               |                 |      5
|    375 |        4   (0)| 00:00:01 |        |        |  Q1,00 | PCWP |          |
|   8 |      PX PARTITION HASH ALL                        |                 |      5
|    125 |        2   (0)| 00:00:01 |      1 |      8 |  Q1,00 | PCWC |          |
|*  9 |       TABLE ACCESS BY LOCAL INDEX ROWID BATCHED| CONNECTIONSGE$  |      5
|    125 |        2   (0)| 00:00:01 |      1 |      8 |  Q1,00 | PCWP |          |
|* 10 |        INDEX RANGE SCAN                           | CONNECTIONSXSE$ |     20
|        |        1   (0)| 00:00:01 |      1 |      8 |  Q1,00 | PCWP |          |
|  11 |      PARTITION HASH ITERATOR                      |                 |      1
|        |        0   (0)| 00:00:01 |    KEY |    KEY |  Q1,00 | PCWP |          |
|* 12 |       TABLE ACCESS BY LOCAL INDEX ROWID           | CONNECTIONSVT$  |
|        |               |          |    KEY |    KEY |  Q1,00 | PCWP |          |
|* 13 |        INDEX UNIQUE SCAN                          | CONNECTIONSXQV$ |      1
|        |        0   (0)| 00:00:01 |    KEY |    KEY |  Q1,00 | PCWP |          |
--------------------------------------------------------------------------------
--------------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   9 - filter(INTERNAL_FUNCTION("EL") AND "EL"=U'feuds')
  10 - access("SVID"=1)
  12 - filter(INTERNAL_FUNCTION("VERTICES"."V"))
  13 - access("DVID"="VERTICES"."VID" AND "VERTICES"."K"=U'country')
       filter(INTERNAL_FUNCTION("VERTICES"."K"))
```

Example A-14 Find a Person's Collaborators, and aggregate and sort them

The following SQL statement finds the collaborators of the vertex with ID 1, aggregates them by their country, and sorts them in ascending order.

```
SQL> select vertices.v, count(1)
      from connectionsGE$, connectionsVT$ vertices
     where svid=1
       and el='collaborates'
       and dvid=vertices.vid
       and vertices.k='country'
  group by vertices.v
  order by count(1) asc;
```

The example output and execution plan may be as follows. In this case, the vertex with ID 1 has the most collaborators in the United States.

```
Germany        1
Japan          1
Iran           1
United States  7


-------------------------------------------------------------------------------------
-----------------------------------------------------------------------------
| Id  | Operation                                    | Name            | Rows  |
Bytes | Cost (%CPU)| Time      | Pstart| Pstop |    TQ   |IN-OUT| PQ Distrib |
-------------------------------------------------------------------------------------
-----------------------------------------------------------------------------
|   0 | SELECT STATEMENT                             |                 |    10
|   750 |      9    (23)| 00:00:01 |       |       |        |      |          |
|   1 |  PX COORDINATOR                              |                 |
|       |              |          |       |       |        |      |          |
|   2 |   PX SEND QC (ORDER)                         | :TQ10002        |    10
|   750 |      9    (23)| 00:00:01 |       |       |  Q1,02 | P->S | QC (ORDER) |
|   3 |    SORT ORDER BY                             |                 |    10
|   750 |      9    (23)| 00:00:01 |       |       |  Q1,02 | PCWP |          |
|   4 |     PX RECEIVE                               |                 |    10
|   750 |      9    (23)| 00:00:01 |       |       |  Q1,02 | PCWP |          |
|   5 |      PX SEND RANGE                           | :TQ10001        |    10
|   750 |      9    (23)| 00:00:01 |       |       |  Q1,01 | P->P | RANGE    |
|   6 |       HASH GROUP BY                          |                 |    10
|   750 |      9    (23)| 00:00:01 |       |       |  Q1,01 | PCWP |          |
|   7 |        PX RECEIVE                            |                 |    10
|   750 |      9    (23)| 00:00:01 |       |       |  Q1,01 | PCWP |          |
|   8 |     PX SEND HASH                             | :TQ10000        |    10
|   750 |      9    (23)| 00:00:01 |       |       |  Q1,00 | P->P | HASH     |
|   9 |      HASH GROUP BY                           |                 |    10
|   750 |      9    (23)| 00:00:01 |       |       |  Q1,00 | PCWP |          |
|  10 |       NESTED LOOPS                           |                 |    10
|   750 |      7     (0)| 00:00:01 |       |       |  Q1,00 | PCWP |          |
|  11 |        PX PARTITION HASH ALL                 |                 |    10
|   250 |      2     (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWC |          |
|* 12 |         TABLE ACCESS BY LOCAL INDEX ROWID BATCHED | CONNECTIONSGE$  |    10
|   250 |      2     (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWP |          |
|* 13 |          INDEX RANGE SCAN                    | CONNECTIONSXSE$ |    20
|       |      1     (0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWP |          |
|  14 |        PARTITION HASH ITERATOR               |                 |     1
|       |      0     (0)| 00:00:01 |   KEY |   KEY |  Q1,00 | PCWP |          |
|* 15 |         TABLE ACCESS BY LOCAL INDEX ROWID    | CONNECTIONSVT$  |
|       |        |                 |   KEY |   KEY |  Q1,00 | PCWP |          |
|* 16 |          INDEX UNIQUE SCAN                   | CONNECTIONSXQV$ |     1
|       |      0     (0)| 00:00:01 |   KEY |   KEY |  Q1,00 | PCWP |          |
-------------------------------------------------------------------------------------
-----------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

  12 - filter(INTERNAL_FUNCTION("EL") AND "EL"=U'collaborates')
  13 - access("SVID"=1)
  15 - filter(INTERNAL_FUNCTION("VERTICES"."V"))
  16 - access("DVID"="VERTICES"."VID" AND "VERTICES"."K"=U'country')
       filter(INTERNAL_FUNCTION("VERTICES"."K"))
```

A.6.4 Navigation Options: CONNECT BY and Parallel Recursion

The CONNECT BY clause and parallel recursion provide options for advanced navigation and querying.

- CONNECT BY lets you navigate and find matches in a hierarchical order. To follow outgoing edges, you can use prior dvid = svid to guide the navigation.
- Parallel recursion lets you perform navigation up to a specified number of hops away.

The examples use a property graph named connections.

Example A-15 CONNECT WITH

The following SQL statement follows the outgoing edges by 1 hop.

```
SQL> select G.dvid
       from connectionsGE$ G
      start with svid = 1
    connect by nocycle prior dvid = svid and level <= 1;
```

The preceding example's output and execution plan may be as follows.

```
         2
         3
         4
         5
         6
         7
         8
         9
        10
        ...
---------------------------------------------------------------------------------
--------------------------------------------------------
| Id  | Operation                  | Name            | Rows  | Bytes | Cost
(%CPU)| Time      | Pstart| Pstop |    TQ  |IN-OUT| PQ Distrib |
---------------------------------------------------------------------------------
--------------------------------------------------------
|   0 | SELECT STATEMENT           |                 |     7 |   273 |     3
(67)| 00:00:01 |       |       |        |      |            |
|*  1 |  CONNECT BY WITH FILTERING|                 |       |       |
|          |       |       |        |      |            |
|   2 |   PX COORDINATOR           |                 |       |       |
|          |       |       |        |      |            |
|   3 |    PX SEND QC (RANDOM)     | :TQ10000        |     2 |    12 |     0
(0)| 00:00:01 |       |       |  Q1,00 | P->S | QC (RAND)  |
|   4 |     PX PARTITION HASH ALL |                 |     2 |    12 |     0
(0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWC |            |
|*  5 |      INDEX RANGE SCAN      | CONNECTIONSXSE$ |     2 |    12 |     0
(0)| 00:00:01 |     1 |     8 |  Q1,00 | PCWP |            |
|*  6 |   FILTER                   |                 |       |       |
|          |       |       |        |      |            |
|   7 |    NESTED LOOPS            |                 |     5 |    95 |     1
(0)| 00:00:01 |       |       |        |      |            |
|   8 |     CONNECT BY PUMP        |                 |       |       |
|          |       |       |        |      |            |
|   9 |     PARTITION HASH ALL     |                 |     2 |    12 |     0
```

```
(0)| 00:00:01 |      1 |      8 |         |       |            |
|* 10 |       INDEX RANGE SCAN      | CONNECTIONSXSE$ |      2 |     12 |      0   (0)|
00:00:01 |      1 |      8 |         |       |            |
---------------------------------------------------------------------------------------
--------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   1 - access("SVID"=PRIOR "DVID")
       filter(LEVEL<=2)
   5 - access("SVID"=1)
   6 - filter(LEVEL<=2)
  10 - access("connect$_by$_pump$_002"."prior dvid "="SVID")
```

To extend from 1 hop to multiple hops, change 1 in the preceding example to another integer. For example, to change it to 2 hops, specify: `level <= 2`

Example A-16   Parallel Recursion

The following SQL statement uses recursion within the WITH clause to perform navigation up to 4 hops away, a using recursively defined graph expansion: `g_exp` references `g_exp` in the query, and that defines the recursion. The example also uses the PARALLEL optimizer hint for parallel execution.

```
SQL> WITH g_exp(svid, dvid, depth) as
  (
    select svid as svid, dvid as dvid, 0 as depth
      from connectionsGE$
     where svid=1
   union all
     select g2.svid,  g1.dvid, g2.depth + 1
       from g_exp g2, connectionsGE$ g1
      where g2.dvid=g1.svid
        and g2.depth <= 3
  )
select  /*+ parallel(4) */ dvid, depth
  from  g_exp
 where svid=1
;
```

The example's output and execution plan may be as follows. Note that `CURSOR DURATION MEMORY` is chosen in the execution, which indicates the graph expansion stores the intermediate data in memory.

```
        22          4
        25          4
        24          4
         1          4

        23          4
        33          4
        22          4
        22          4
       ...        ...


Execution Plan
```

```
---------------------------------------------------------------------------------
---------------------------------------------------------------------------------
------
| Id  | Operation                                      |
Name                       | Rows  | Bytes | Cost (%CPU)| Time     | Pstart|
Pstop |    TQ  |IN-OUT| PQ Distrib |
---------------------------------------------------------------------------------
---------------------------------------------------------------------------------
------
|   0 | SELECT STATEMENT
|                            |   801 | 31239 |   147   (0)| 00:00:01 |
|       |        |      |            |
|   1 |  TEMP TABLE TRANSFORMATION
|                            |       |       |            |          |
|       |        |      |            |
|   2 |   LOAD AS SELECT (CURSOR DURATION MEMORY)      |
SYS_TEMP_0FD9D6614_11CB2D2 |       |       |            |          |
|       |        |      |            |
|   3 |    UNION ALL (RECURSIVE WITH) BREADTH FIRST
|                            |       |       |            |          |
|       |        |      |            |
|   4 |     PX COORDINATOR
|                            |       |       |            |          |
|       |        |      |            |
|   5 |      PX SEND QC (RANDOM)
| :TQ20000                   |     2 |    12 |     0   (0)| 00:00:01 |
|       |  Q2,00 | P->S | QC (RAND)  |
|   6 |       LOAD AS SELECT (CURSOR DURATION MEMORY)|
SYS_TEMP_0FD9D6614_11CB2D2 |       |       |            |          |
|       |  Q2,00 | PCWP |            |
|   7 |        PX PARTITION HASH ALL
|                            |     2 |    12 |     0   (0)| 00:00:01 |     1
|     8 |  Q2,00 | PCWC |            |
|*  8 |         INDEX RANGE SCAN                       |
CONNECTIONSXSE$            |     2 |    12 |     0   (0)| 00:00:01 |     1 |
8 |  Q2,00 | PCWP |            |
|   9 |     PX COORDINATOR
|                            |       |       |            |          |
|       |        |      |            |
|  10 |      PX SEND QC (RANDOM)
| :TQ10000                   |   799 |   12M|    12   (0)| 00:00:01 |
|       |  Q1,00 | P->S | QC (RAND)  |
|  11 |       LOAD AS SELECT (CURSOR DURATION MEMORY)|
SYS_TEMP_0FD9D6614_11CB2D2 |       |       |            |          |
|       |  Q1,00 | PCWP |            |
|* 12 |        HASH JOIN
|                            |   799 |   12M|    12   (0)| 00:00:01 |
|       |  Q1,00 | PCWP |            |
|  13 |         BUFFER SORT (REUSE)
|                            |       |       |            |          |
|       |  Q1,00 | PCWP |            |
|  14 |          PARTITION HASH ALL
|                            |   164 |   984 |     2   (0)| 00:00:01 |     1
|     8 |  Q1,00 | PCWC |            |
|  15 |           INDEX FAST FULL SCAN                 |
CONNECTIONSXDE$            |   164 |   984 |     2   (0)| 00:00:01 |     1 |
8 |  Q1,00 | PCWP |            |
|  16 |         PX BLOCK ITERATOR
|                            |       |       |            |          |
|       |  Q1,00 | PCWC |            |
|* 17 |          TABLE ACCESS FULL                     |
```

```
SYS_TEMP_0FD9D6614_11CB2D2 |       |       |            |          |       |       |
Q1,00 | PCWP |             |
|  18 |   PX COORDINATOR                               |
|       |       |            |          |       |       |        |      |            |
|  19 |    PX SEND QC (RANDOM)                         | :TQ30000                   |
801 | 31239 |    135   (0)| 00:00:01 |       |       |  Q3,00 | P->S | QC (RAND)  |
|* 20 |     VIEW                                       |                            |
801 | 31239 |    135   (0)| 00:00:01 |       |       |  Q3,00 | PCWP |            |
|  21 |      PX BLOCK ITERATOR                         |                            |
801 |    12M|    135   (0)| 00:00:01 |       |       |  Q3,00 | PCWC |            |
|  22 |       TABLE ACCESS FULL                        | SYS_TEMP_0FD9D6614_11CB2D2 |
801 |    12M|    135   (0)| 00:00:01 |       |       |  Q3,00 | PCWP |            |
---------------------------------------------------------------------------------------
---------------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   8 - access("SVID"=1)
  12 - access("G2"."DVID"="G1"."SVID")
  17 - filter("G2"."INTERNAL_ITERS$"=LEVEL AND "G2"."DEPTH"<=3)
  20 - filter("SVID"=1)
```

A.6.5 Pivot

The PIVOT clause lets you dynamically add columns to a table to create a new table.

The schema design (VT$ and GE$) of the property graph is narrow ("skinny") rather than wide ("fat"). This means that if a vertex or edge has multiple properties, those property keys, values, data types, and so on will be stored using multiple rows instead of multiple columns. Such a design is very flexible in the sense that you can add properties dynamically without having to worry about adding too many columns or even reaching the physical maximum limit of number of columns a table may have. However, for some applications you may prefer to have a wide table if the properties are somewhat homogeneous.

Example A-17 Pivot

The following CREATE TABLE ... AS SELECT statement uses PIVOT to add four columns: ‘company’,’ occupation’,’ name’, and ‘religion’.

```
SQL> CREATE TABLE table pg_wide
as
 with G AS (select vid, k, t, v
              from connectionsVT$
           )
 select *
   from G
  pivot (
    min(v) for k in ('company', 'occupation', 'name', 'religion')
  );

Table created.
```

The following DESCRIBE statement shows the definition of the new table, including the four added columns. (The output is reformatted for readability.)

```
SQL> DESCRIBE pg_wide;
 Name                                                    Null?    Type
 --------------------------------------------------- --------
--------------------
 VID                                                     NOT NULL NUMBER
 T
NUMBER(38)
 'company'
NVARCHAR2(15000)
 'occupation'
NVARCHAR2(15000)
 'name'
NVARCHAR2(15000)
 'religion'
NVARCHAR2(15000)
```

A.6.6 SQL-Based Property Graph Analytics

In addition to the analytical functions offered by the graph server (PGX), the property graph feature in Oracle Spatial and Graph supports several native, SQL-based property graph analytics.

The benefits of SQL-based analytics are:

- Easier analysis of larger graphs that do not fit in physical memory
- Cheaper analysis since no graph data is transferred outside the database
- Better analysis using the current state of a property graph database
- Simpler analysis by eliminating the step of synchronizing an in-memory graph with the latest updates from the graph database

However, when a graph (or a subgraph) fits in memory, then running analytics provided by the graph server (PGX) usually provides better performance than using SQL-based analytics.

Because many of the analytics implementation require using intermediate data structures, most SQL- (and PL/SQL-) based analytics APIs have parameters for working tables (wt). A typical flow has the following steps:

1. Prepare the working table or tables.
2. Perform analytics (one or multiple calls).
3. Perform cleanup

The following subtopics provide SQL-based examples of some popular types of property graph analytics.

- Shortest Path Examples
- Collaborative Filtering Overview and Examples

A.6.6.1 Shortest Path Examples

The following examples demonstrate SQL-based shortest path analytics.

Example A-18 Shortest Path Setup and Computation

Consider shortest path, for example. Internally, Oracle Database uses the bidirectional Dijkstra algorithm. The following code snippet shows an entire prepare, perform, and cleanup workflow.

```
set serveroutput on

DECLARE
  wt1 varchar2(100);  -- intermediate working tables
  n number;
  path    varchar2(1000);
  weights varchar2(1000);
BEGIN
  -- prepare
  opg_apis.find_sp_prep('connectionsGE$', wt1);
  dbms_output.put_line('working table name    ' || wt1);

  -- compute
  opg_apis.find_sp(
     'connectionsGE$',
      1,                            -- start vertex ID
      53,                           -- destination vertex ID
      wt1,                          -- working table (for Dijkstra expansion)
      dop => 1,                     -- degree of parallelism
      stats_freq=>1000,             -- frequency to collect statistics
      path_output => path,          -- shortest path (a sequence of vertices)
      weights_output => weights,    -- edge weights
      options => null
      );
  dbms_output.put_line('path    ' || path);
  dbms_output.put_line('weights ' || weights);

  -- cleanup (commented out here; see text after the example)
  -- opg_apis.find_sp_cleanup('connectionsGE$', wt1);
END;
/
```

This example may produce the following output. Note that if ***no*** working table name is provided, the preparation step will automatically generate a temporary table name and create it. Because the temporary working table name uses the session ID, your output will probably be different.

```
working table name    "CONNECTIONSGE$$TWFS12"
path    1 3    52 53
weights 4 3 1    1 1

PL/SQL procedure successfully completed.
```

If you want to know the definition of the working table or tables, then skip the cleanup phase (as shown in the preceding example that comments out the call to `find_sp_cleanup`). After the computation is done, you can describe the working table or tables.

```
SQL> describe "CONNECTIONSGE$$TWFS12"
 Name                    Null?     Type
 --------- -------- ----------------------------
 NID                                   NUMBER
 D2S                                   NUMBER
 P2S                                   NUMBER
 D2T                                   NUMBER
 P2T                                   NUMBER
 F                                   NUMBER(38)
 B                                   NUMBER(38)
```

For advanced users who want to try different table creation options, such as using in-memory or advanced compression, you can pre-create the preceding working table and pass the name in.

Example A-19 Shortest Path: Create Working Table and Perform Analytics

The following statements show some advanced options, first creating a working table with the same column structure and basic compression enabled, then passing it to the SQL-based computation. The code optimizes the intermediate table for computations with CREATE TABLE compression and in-memory options.

```
create table connections$MY_EXP(
 NID                                   NUMBER,
 D2S                                   NUMBER,
 P2S                                   NUMBER,
 D2T                                   NUMBER,
 P2T                                   NUMBER,
 F                                   NUMBER(38),
 B                                   NUMBER(38)
) compress nologging;


DECLARE
  wt1 varchar2(100) := 'connections$MY_EXP';
  n number;
  path    varchar2(1000);
  weights varchar2(1000);
BEGIN
  dbms_output.put_line('working table name    ' || wt1);

  -- compute
  opg_apis.find_sp(
     'connectionsGE$',
      1,
      53,
      wt1,
      dop => 1,
      stats_freq=>1000,
      path_output => path,
```

```
      weights_output => weights,
      options => null
      );
  dbms_output.put_line('path    ' || path);
  dbms_output.put_line('weights ' || weights);

  -- cleanup
  -- opg_apis.find_sp_cleanup('connectionsGE$', wt1);
END;
/
```

At the end of the computation, if the working table has not been dropped or truncated, you can check the content of the working table, as follows. Note that the working table structure may vary between releases.

```
SQL> select * from connections$MY_EXP;
       NID        D2S        P2S        D2T        P2T          F          B
---------- ---------- ---------- ---------- ---------- ---------- ----------
         1          0            1.000E+100                     1         -1
        53 1.000E+100                     0                    -1          1
        54 1.000E+100                     1         53         -1          1
        52 1.000E+100                     1         53         -1          1
         5          1          1 1.000E+100                     0         -1
        26          1          1 1.000E+100                     0         -1
         8       1000          1 1.000E+100                     0         -1
         3          1          1          2         52          0          0
        15          1          1 1.000E+100                     0         -1
        21          1          1 1.000E+100                     0         -1
        19          1          1 1.000E+100                     0         -1
       ...
```

Example A-20 Shortest Path: Perform Multiple Calls to Same Graph

To perform multiple calls to the same graph, only *a single call* to the preparation step is needed. The following shows an example of computing shortest path for multiple pairs of vertices in the same graph.

```
DECLARE
  wt1 varchar2(100);  -- intermediate working tables
  n number;
  path    varchar2(1000);
  weights varchar2(1000);
BEGIN
  -- prepare
  opg_apis.find_sp_prep('connectionsGE$', wt1);
  dbms_output.put_line('working table name    ' || wt1);

  -- find shortest path from vertex 1 to vertex 53
  opg_apis.find_sp( 'connectionsGE$', 1, 53,
      wt1, dop => 1, stats_freq=>1000, path_output => path, weights_output
=> weights, options => null);
  dbms_output.put_line('path    ' || path);
  dbms_output.put_line('weights ' || weights);
```

```
  -- find shortest path from vertex 2 to vertex 36
  opg_apis.find_sp( 'connectionsGE$', 2, 36,
      wt1, dop => 1, stats_freq=>1000, path_output => path,
weights_output => weights, options => null);
  dbms_output.put_line('path    ' || path);
  dbms_output.put_line('weights ' || weights);

  -- find shortest path from vertex 30 to vertex 4
  opg_apis.find_sp( 'connectionsGE$', 30, 4,
      wt1, dop => 1, stats_freq=>1000, path_output => path,
weights_output => weights, options => null);
  dbms_output.put_line('path    ' || path);
  dbms_output.put_line('weights ' || weights);

  -- cleanup
  opg_apis.find_sp_cleanup('connectionsGE$', wt1);
END;
/
```

The example's output may be as follows: three shortest paths have been found for the multiple pairs of vertices provided.

```
working table name    "CONNECTIONSGE$$TWFS12"
path    1 3    52 53
weights 4 3 1   1 1
path    2    36
weights 2 1   1
path    30 21    1 4
weights 4 3 1   1 1

PL/SQL procedure successfully completed.
```

A.6.6.2 Collaborative Filtering Overview and Examples

Collaborative filtering, also referred to as social filtering, filters information by using the recommendations of other people. Collaborative filtering is widely used in systems that recommend purchases based on purchases by others with similar preferences.

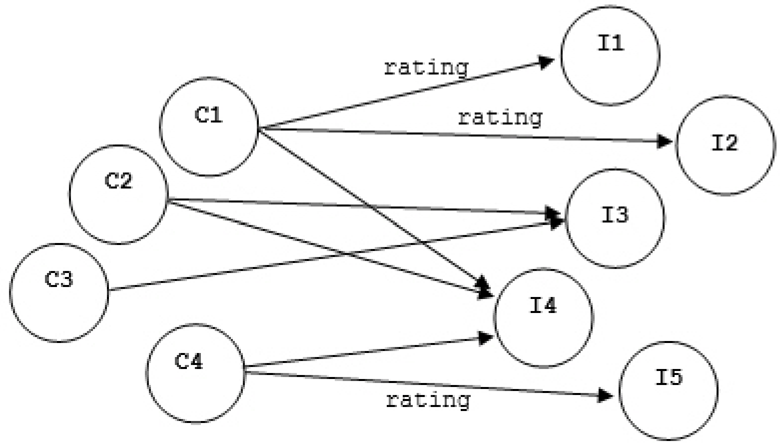
The following examples demonstrate SQL-based collaborative filtering analytics.

Example A-21   Collaborative Filtering Setup and Computation

This example shows how to use SQL-based collaborative filtering, specifically using matrix factorization to recommend telephone brands to customers. This example assumes there exists a graph called "PHONES" in the database. This example graph contains customer and item vertices, and edges with a 'rating' label linking some customer vertices to other some item vertices. The rating labels have a numeric value corresponding to the rating that a specific customer (edge OUT vertex) assigned to the specified product (edge IN vertex).

The following figure shows this graph.

Figure A-1 Phones Graph for Collaborative Filtering




```
set serveroutput on

DECLARE
  wt_l varchar2(32);  -- working tables
  wt_r varchar2(32);
  wt_l1 varchar2(32);
  wt_r1 varchar2(32);
  wt_i varchar2(32);
  wt_ld varchar2(32);
  wt_rd varchar2(32);
  edge_tab_name    varchar2(32) := 'phonesge$';
  edge_label       varchar2(32) := 'rating';
  rating_property  varchar2(32) := '';
  iterations       integer      := 100;
  min_error        number       := 0.001;
  k                integer      := 5;
  learning_rate    number       := 0.001;
  decrease_rate    number       := 0.95;
  regularization   number       := 0.02;
  dop              number       := 2;
  tablespace       varchar2(32) := null;
  options          varchar2(32) := null;
BEGIN

  -- prepare
  opg_apis.cf_prep(edge_tab_name,wt_l,wt_r,wt_l1,wt_r1,wt_i,wt_ld,wt_rd);
  dbms_output.put_line('working table wt_l ' || wt_l);
  dbms_output.put_line('working table wt_r ' || wt_r);
  dbms_output.put_line('working table wt_l1 ' || wt_l1);
  dbms_output.put_line('working table wt_r1 ' || wt_r1);
  dbms_output.put_line('working table wt_i ' || wt_i);
  dbms_output.put_line('working table wt_ld ' || wt_ld);
  dbms_output.put_line('working table wt_rd ' || wt_rd);

  -- compute
  opg_apis.cf(edge_tab_name,edge_label,rating_property,iterations,
```

```
min_error,k,learning_rate,decrease_rate,regularization,dop,

wt_l,wt_r,wt_l1,wt_r1,wt_i,wt_ld,wt_rd,tablespace,options);
END;
/
```

no

```
working table wt_l    "PHONESGE$$CFL57"
working table wt_r    "PHONESGE$$CFR57"
working table wt_l1    "PHONESGE$$CFL157"
working table wt_r1    "PHONESGE$$CFR157"
working table wt_i    "PHONESGE$$CFI57"
working table wt_ld    "PHONESGE$$CFLD57"
working table wt_rd    "PHONESGE$$CFRD57"

PL/SQL procedure successfully completed.
```

Example A-22   Collaborative Filtering: Validating the Intermediate Error

At the end of every computation, you can check the current error of the algorithm with the following query as long as the data in the working tables has not been already deleted. The following SQL query illustrates how to get the intermediate error of a current run of the collaborative filtering algorithm.

```
SELECT /*+ parallel(48) */ SQRT(SUM((w1-w2)*(w1-w2) +
              <regularization>/2 * (err_reg_l+err_reg_r))) AS err
  FROM <wt_i>;
```

Note that the regularization parameter and the working table name (parameter `wt_i`) should be replaced according to the values used when running the OPG_APIS.CF algorithm. In the preceding previous example, replace <regularization> with 0.02 and <wt_i> with "PHONESGE$$CFI149" as follows:

```
SELECT /*+ parallel(48) */ SQRT(SUM((w1-w2)*(w1-w2) + 0.02/2 *
(err_reg_l+err_reg_r))) AS err
  FROM "PHONESGE$$CFI149";
```

This query may produce the following output.

```
       ERR
----------
4.82163662
```

f the value of the current error is too high or if the predictions obtained from the matrix factorization results of the collaborative filtering are not yet useful, you can run more iterations of the algorithm, by reusing the working tables and the progress made so far. The following example shows how to make predictions using the SQL-based collaborative filtering.

Example A-23   Collaborative Filtering: Making Predictions

The result of the collaborative filtering algorithm is stored in the tables `wt_l` and `wt_r`, which are the two factors of a matrix product. These matrix factors should be used when making the predictions of the collaborative filtering.

In a typical flow of the algorithm, the two matrix factors can be used to make the predictions before calling the OPG_APIS.CF_CLEANUP procedure, or they can be copied and persisted into other tables for later use. The following example demonstrates the latter case:

```
DECLARE
  wt_l varchar2(32);  -- working tables
  wt_r varchar2(32);
  wt_l1 varchar2(32);
  wt_r1 varchar2(32);
  wt_i varchar2(32);
  wt_ld varchar2(32);
  wt_rd varchar2(32);
  edge_tab_name    varchar2(32) := 'phonesge$';
  edge_label       varchar2(32) := 'rating';
  rating_property  varchar2(32) := '';
  iterations       integer      := 100;
  min_error        number       := 0.001;
  k                integer      := 5;
  learning_rate    number       := 0.001;
  decrease_rate    number       := 0.95;
  regularization   number       := 0.02;
  dop              number       := 2;
  tablespace       varchar2(32) := null;
  options          varchar2(32) := null;
BEGIN

  -- prepare
  opg_apis.cf_prep(edge_tab_name,wt_l,wt_r,wt_l1,wt_r1,wt_i,wt_ld,wt_rd);

  -- compute
  opg_apis.cf(edge_tab_name,edge_label,rating_property,iterations,
              min_error,k,learning_rate,decrease_rate,regularization,dop,
              wt_l,wt_r,wt_l1,wt_r1,wt_i,wt_ld,wt_rd,tablespace,options);

  -- save only these two tables for later predictions
  EXECUTE IMMEDIATE 'CREATE TABLE customer_mat AS SELECT * FROM ' || wt_l;
  EXECUTE IMMEDIATE 'CREATE TABLE item_mat AS SELECT * FROM ' || wt_r;

  -- cleanup
  opg_apis.cf_cleanup('phonesge$',wt_l,wt_r,wt_l1,wt_r1,wt_i,wt_ld,wt_rd);
END;
/
```

This example will produce the only the following output.

```
PL/SQL procedure successfully completed.
```

Now that the matrix factors are saved in the tables customer_mat and item_mat, you can use the following query to check the "error" (difference) between the real values (those values that previously existed in the graph as 'ratings') and the estimated predictions (the result of the matrix multiplication in a certain customer row and item column).

Note that the following query is customized with a join on the vertex table in order return an NVARCHAR property of the vertices (for example, the name property) instead of a numeric

ID. This query will return all the predictions for every single customer vertex to every item vertex in the graph.

```
SELECT /*+ parallel(48) */ MIN(vertex1.v) AS customer,
                           MIN(vertex2.v) AS item,
                           MIN(edges.vn) AS real,
                           SUM(l.v * r.v) AS predicted
FROM PHONESGE$ edges,
      CUSTOMER_MAT l,
      ITEM_MAT r,
      PHONESVT$ vertex1,
      PHONESVT$ vertex2
WHERE l.k = r.k
  AND l.c = edges.svid(+)
  AND r.p = edges.dvid(+)
  AND l.c = vertex1.vid
  AND r.p = vertex2.vid
GROUP BY l.c, r.p
ORDER BY l.c, r.p  -- This order by clause is optional
;
```

This query may produce an output similar to the following (some rows are omitted for brevity).

```
CUSTOMER    ITEM        REAL    PREDICTED
------------------------------------------------
Adam        Apple          5    3.67375703
Adam        Blackberry        3.66079652
Adam        Danger            2.77049596
Adam        Ericsson        4.21764858
Adam        Figo            3.10631337
Adam        Google        4     4.42429022
Adam        Huawei        3    3.4289115
Ben        Apple                2.82127589
Ben        Blackberry    2    2.81132282
Ben        Danger        3    2.12761307
Ben        Ericsson    3        3.2389595
Ben        Figo                 2.38550534
Ben        Google              3.39765075
Ben        Huawei               2.63324582
...
Don        Apple               1.3777496
Don        Blackberry    1     1.37288909
Don        Danger        1     1.03900439
Don        Ericsson          1.58172236
Don        Figo        1    1.16494421
Don        Google            1.65921807
Don        Huawei        1    1.28592648
Erik        Apple        3    2.80809351
Erik        Blackberry    3    2.79818695
Erik        Danger            2.11767182
Erik        Ericsson    3     3.2238255
Erik        Figo            2.3743591
Erik        Google        3    3.38177526
Erik        Huawei        3    2.62094201
```

If you want to check only some rows to decide whether the prediction results are ready or more iterations of the algorithm should be run, the previous query can be wrapped in an outer query. The following example will select only the first 11 results.

```
SELECT /*+ parallel(48) */ * FROM (
SELECT /*+ parallel(48) */ MIN(vertex1.v) AS customer,
                           MIN(vertex2.v) AS item,
                           MIN(edges.vn) AS real,
                           SUM(l.v * r.v) AS predicted
FROM PHONESGE$ edges,
     CUSTOMER_MAT l,
     ITEM_MAT r,
     PHONESVT$ vertex1,
     PHONESVT$ vertex2
WHERE l.k = r.k
  AND l.c = edges.svid(+)
  AND r.p = edges.dvid(+)
  AND l.c = vertex1.vid
  AND r.p = vertex2.vid
GROUP BY l.c, r.p
ORDER BY l.c, r.p
) WHERE rownum <= 11;
```

This query may produce an output similar to the following.

```
CUSTOMER    ITEM        REAL    PREDICTED
-------------------------------------------------
Adam        Apple          5    3.67375703
Adam        Blackberry        3.66079652
Adam        Danger            2.77049596
Adam        Ericsson        4.21764858
Adam        Figo            3.10631337
Adam        Google       4     4.42429022
Adam        Huawei       3    3.4289115
Ben        Apple                 2.82127589
Ben        Blackberry    2    2.81132282
Ben        Danger        3    2.12761307
Ben        Ericsson    3       3.2389595
```

To get a prediction for a specific vertex (customer, item, or both) the query can be restricted with the desired ID values. For example, to get the predicted value of vertex 1 (customer) and vertex 105 (item), you can use the following query.

```
SELECT /*+ parallel(48) */ MIN(vertex1.v) AS customer,
                           MIN(vertex2.v) AS item,
                           MIN(edges.vn) AS real,
                           SUM(l.v * r.v) AS predicted
FROM PHONESGE$ edges,
     CUSTOMER_MAT l,
     ITEM_MAT r,
     PHONESVT$ vertex1,
     PHONESVT$ vertex2
WHERE l.k = r.k
  AND l.c = edges.svid(+)
  AND r.p = edges.dvid(+)
  AND l.c = vertex1.vid
```

```
  AND vertex1.vid = 1 /* Remove to get all predictions for item 105 */
  AND r.p = vertex2.vid
  AND vertex2.vid = 105 /* Remove to get all predictions for customer
1 */
                        /* Remove both lines to get all predictions */
GROUP BY l.c, r.p
ORDER BY l.c, r.p;
```

This query may produce an output similar to the following.

```
CUSTOMER    ITEM        REAL    PREDICTED
------------------------------------------------
Adam        Ericsson        4.21764858
```

A.7 Creating Property Graph Views on an RDF Graph

With Oracle Graph, you can view RDF data as a property graph to execute graph analytics operations by creating property graph views over an RDF graph stored in Oracle Database.

Given an RDF model (or a virtual model), the property graph feature creates two views, a <graph_name>VT$ view for vertices and a <graph_name>GE$ view for edges.

The `PGUtils.createPropertyGraphViewOnRDF` method lets you customize a property graph view over RDF data:

```
public static void createPropertyGraphViewOnRDF( Connection conn /* a Connection
instance to Oracle database */,
      String pgGraphName /* the name of the property graph to be created */,
      String rdfModelName /* the name of the RDF model */,
      boolean virtualModel /* a flag represents if the RDF model
                              is virtual model or not;
                              true - virtual mode, false - normal model*/,
      RDFPredicate[] predListForVertexAttrs /* an array of RDFPredicate objects
specifying how to create vertex view using these predicates; each RDFPredicate
includes two fields: an URL of the RDF predicate, the corresponding name of
vertex key in the Property Graph. The mapping from RDF predicates to vertex keys
will be created based on this parameter.  */,
      RDFPredicate[] predListForEdges /* an array of RDFPredicate specifying how
to create edge view using these predicates; each RDFPredicate includes two (or
three) fields: an URL of the RDF predicate, the edge label in the Property
Graph, the weight of the edge (optional). The mapping from RDF predicates to
edges will be created based on this parameter. */)
```

This operation requires the name of the property graph, the name of the RDF Model used to generate the Property Graph view, and a set of mappings determining how triples will be parsed into vertices or edges. The `createPropertyGraphViewOnRDF` method requires a *key/value mapping* array specifying how RDF predicates are mapped to Key/Value properties for vertices, and an *edge mapping* array specifying how RDF predicates are mapped to edges. The `PGUtils.RDFPredicate` API lets you create a map from RDF assertions to vertices/edges.

Vertices are created based on the triples matching at least one of the RDF predicates in the key/value mappings. Each triple satisfying one of the RDF predicates defined in the mapping array is parsed into a vertex with ID based on the internal RDF resource

ID of the subject of the triple, and a key/value pair whose key is defined by the mapping itself and whose value is obtained from the object of the triple.

The following example defines a key/value mapping of the RDF predicate URI `http://purl.org/dc/elements/1.1/title` to the key/value property with property name `title`.

```
String titleURL = "http://purl.org/dc/elements/1.1/title";
// create an RDFPredicate to specify how to map the RDF predicate to vertex keys
RDFPredicate titleRDFPredicate
              = RDFPredicate.getInstance(titleURL /* RDF Predicate URI */ ,
                                         "title" /* property name */);
```

Edges are created based on the triples matching at least one of the RDF predicates in the edge mapping array. Each triple satisfying the RDF predicate defined in the mapping array is parsed into an edge with ID based on the row number, an edge label defined by the mapping itself, a source vertex obtained from the RDF Resource ID of the subject of the triple, and a destination vertex obtained from the RDF Resource ID of the object of the triple. For each triple parsed here, two vertices will be created if they were not generated from the key/value mapping.

The following example defines an edge mapping of the RDF predicate URI `http://purl.org/dc/elements/1.1/reference` to an edge with a label *references* and a weight of 0.5d.

```
String referencesURL = "http://purl.org/dc/terms/references";
// create an RDFPredicate to specify how to map the RDF predicate to edges
RDFPredicate referencesRDFPredicate
                      = RDFPredicate.getInstance(referencesURL, "references", 0.5d);
```

The following example creates a property graph view over the RDF model `articles` describing different publications, their authors, and references. The generated property graph will include vertices with some key/value properties that may include `title` and `creator`. The edges in the property graph will be determined by the references among publications.

```
Oracle oracle = null;
Connection conn = null;
OraclePropertyGraph pggraph = null;
try {
  // create the connection instance to Oracle database
  OracleDataSource ds = new oracle.jdbc.pool.OracleDataSource();
  ds.setURL(jdbcUrl);
  conn = (OracleConnection) ds.getConnection(user, password);

  // define some string variables for RDF predicates
  String titleURL = "http://purl.org/dc/elements/1.1/title";
  String creatorURL = "http://purl.org/dc/elements/1.1/creator";
  String serialnumberURL = "http://purl.org/dc/elements/1.1/serialnumber";
  String widthURL = "http://purl.org/dc/elements/1.1/width";
  String weightURL = "http://purl.org/dc/elements/1.1/weight";
  String onsaleURL = "http://purl.org/dc/elements/1.1/onsale";
  String publicationDateURL = "http://purl.org/dc/elements/1.1/publicationDate";
  String publicationTimeURL = "http://purl.org/dc/elements/1.1/publicationTime";
  String referencesURL = "http://purl.org/dc/terms/references";

  // create RDFPredicate[] predsForVertexAttrs to specify how to map
  // RDF predicate to vertex keys
  RDFPredicate[] predsForVertexAttrs = new RDFPredicate[8];
  predsForVertexAttrs[0] = RDFPredicate.getInstance(titleURL, "title");
  predsForVertexAttrs[1] = RDFPredicate.getInstance(creatorURL, "creator");
  predsForVertexAttrs[2] = RDFPredicate.getInstance(serialnumberURL,
```

```
                                                    "serialnumber");
  predsForVertexAttrs[3] = RDFPredicate.getInstance(widthURL, "width");
  predsForVertexAttrs[4] = RDFPredicate.getInstance(weightURL, "weight");
  predsForVertexAttrs[5] = RDFPredicate.getInstance(onsaleURL, "onsale");
  predsForVertexAttrs[6] = RDFPredicate.getInstance(publicationDateURL,
                                                    "publicationDate");
  predsForVertexAttrs[7] = RDFPredicate.getInstance(publicationTimeURL,
                                                    "publicationTime");

  // create RDFPredicate[] predsForEdges to specify how to map RDF predicates to
  // edges
  RDFPredicate[] predsForEdges = new RDFPredicate[1];
  predsForEdges[0] = RDFPredicate.getInstance(referencesURL, "references", 0.5d);

  // create PG view on RDF model
  PGUtils.createPropertyGraphViewOnRDF(conn, "articles", "articles", false,
                                     predsForVertexAttrs, predsForEdges);

  // get the Property Graph instance
  oracle = new Oracle(jdbcUrl, user, password);
  pggraph = OraclePropertyGraph.getInstance(oracle, "articles", 24);

  System.err.println("------ Vertices from property graph view ------");
  pggraph.getVertices();
  System.err.println("------ Edges from property graph view ------");
  pggraph.getEdges();
}
finally {
  pggraph.shutdown();
  oracle.dispose();
  conn.close();
}
```

Given the following triples in the `articles` RDF model (11 triples), the output property graph will include two vertices, one for `<http://nature.example.com/Article1>` (v1) and another one for `<http://nature.example.com/Article2>` (v2). For vertex v1, it has eight properties, whose values are the same as their RDF predicates. For example, v1's title is *"All about XYZ".* Similarly for vertex v2, it has two properties: `title` and `creator`. The output property graph will include a single edge (eid:1) from vertex v1 to vertex v2 with an edge label *"references"* and a weight of 0.5d.

```
<http://nature.example.com/Article1> <http://purl.org/dc/elements/1.1/title>
"All about XYZ"^^xsd:string.
<http://nature.example.com/Article1> <http://purl.org/dc/elements/1.1/creator>
"Jane Smith"^^xsd:string.
<http://nature.example.com/Article1> <http://purl.org/dc/elements/1.1/
serialnumber> "123456"^^xsd:integer.
<http://nature.example.com/Article1> <http://purl.org/dc/elements/1.1/width>
"10.5"^^xsd:float.
<http://nature.example.com/Article1> <http://purl.org/dc/elements/1.1/weight>
"1.08"^^xsd:double.
<http://nature.example.com/Article1> <http://purl.org/dc/elements/1.1/onsale>
"false"^^xsd:boolean.
<http://nature.example.com/Article1> <http://purl.org/dc/elements/1.1/
publicationDate> "2016-03-08"^^xsd:date)
<http://nature.example.com/Article1> <http://purl.org/dc/elements/1.1/
publicationTime> "2016-03-08T10:10:10"^^xsd:dateTime)
<http://nature.example.com/Article2> <http://purl.org/dc/elements/1.1/title> "A
review of ABC"^^xsd:string.
<http://nature.example.com/Article2> <http://purl.org/dc/elements/1.1/creator>
```

```
"Joe Bloggs"^^xsd:string.
<http://nature.example.com/Article1> <http://purl.org/dc/terms/references> <http://
nature.example.com/Article2>.
```

The preceding code will produce an output similar as the following. Note that the internal RDF resource ID values may vary across different Oracle databases.

```
------ Vertices from property graph view ------
Vertex ID 7299961478807817799 {creator:str:Jane Smith, onsale:bol:false,
publicationDate:dat:Mon Mar 07 16:00:00 PST 2016, publicationTime:dat:Tue Mar 08
02:10:10 PST 2016, serialnumber:dbl:123456.0, title:str:All about XYZ,
weight:dbl:1.08, width:flo:10.5}
Vertex ID 7074365724528867041 {creator:str:Joe Bloggs, title:str:A review of ABC}
------ Edges from property graph view ------
Edge ID 1 from Vertex ID 7299961478807817799 {creator:str:Jane Smith,
onsale:bol:false, publicationDate:dat:Mon Mar 07 16:00:00 PST 2016,
publicationTime:dat:Tue Mar 08 02:10:10 PST 2016, serialnumber:dbl:123456.0,
title:str:All about XYZ, weight:dbl:1.08, width:flo:10.5} =[references]=> Vertex ID
7074365724528867041 {creator:str:Joe Bloggs, title:str:A review of ABC}
edgeKV[{weight:dbl:0.5}]
```

A.8 Quick Start: Interactively Analyze Graph Data Stored in Property Graph Schema Objects

This tutorial shows how you can quickly get started using property graph data and learn to execute PGQL queries and run graph algorithms on the data and display results.

The tutorials in this section are:

- Quick Start: Create and Query a Graph in the Database, Load into Graph Server (PGX) for Analytics
  This tutorial shows how you can get started using property graph data when you create a graph and persist it in the database. The graph can be queried in the database. This tutorial uses the JShell client.
- Quick Start: Create, Query, and Analyze a Graph in Graph Server (PGX)
  This tutorial shows how you can quickly get started using property graph data when using the graph server (PGX).

A.8.1 Quick Start: Create and Query a Graph in the Database, Load into Graph Server (PGX) for Analytics

This tutorial shows how you can get started using property graph data when you create a graph and persist it in the database. The graph can be queried in the database. This tutorial uses the JShell client.

See Create and Query a Graph in the Database for more information on creating and storing graphs in database.

- Convert existing relational data into a graph in the database.
- Query this graph using PGQL.

In Load the Graph into Memory and Run Graph Analytics, you will run graph algorithms after loading the graph into the graph server (PGX).

- Load the graph into the graph server (PGX), run graph algorithms on this graph, and visualize results.

Prerequisites for the following quickstart are:

- An installation of Oracle Graph server.

  See Oracle Graph Server and Client Installation for information to download Oracle Graph Server and Client.
- An installation of Oracle Graph client
- Java 11
  – The graph server can work with Java 8 or Java 11.
  – The JShell client used in this example requires Java 11.

  For Java downloads, see https://www.oracle.com/technetwork/java/javase/overview/index.html.
- Connection details for your Oracle Database. See Verifying Database Compatibility to identify any limitations. The Property Graph feature is supported for Oracle Database versions 12.2 and later.
- Basic knowledge about how to run commands on Oracle Database (for example, using `SQL*Plus` or `SQL Developer`).

Set up the example data

This example uses the HR (human resources) sample dataset.

- For instructions how to import that data into a user managed database, see: https://github.com/oracle/db-sample-schemas
- If you are using Autonomous Database, see: https://www.thatjeffsmith.com/archive/2019/07/creating-hr-in-oracle-autonomous-database-w-sql-developer-web/

Note that the database schema storing the graph must have the privileges listed in Required Privileges for Database Users.

- Create and Query a Graph in the Database
  In this section, you will use the Oracle Graph client to create a graph from relational tables and store it in the property graph schema in the database.
- Load the Graph into Memory and Run Graph Analytics

A.8.1.1 Create and Query a Graph in the Database

In this section, you will use the Oracle Graph client to create a graph from relational tables and store it in the property graph schema in the database.

Major tasks for this tutorial:

- Start the shell
- Open a JDBC database connection
- Create a PGQL connection
- Write and execute the graph creation statement
- Run a few PGQL queries

Start the shell

On the system where Oracle Graph client is installed, start the shell by as follows:

```
cd <client-install-dir>
./bin/opg4j --no_connect
```

The `--no_connect` option indicates that you are not connecting to the graph server (PGX). You will only be connecting to the database in this example.

Note that `JAVA_HOME` should be set to Java 11 before you start the shell. For example:

```
export JAVA_HOME=/usr/lib/jvm/java-11-oracle
```

See Interactive Graph Shell CLIs for details about the shell.

Open a JDBC database connection

Inside the shell prompt, use the standard JDBC Java API to obtain a database connection object. For example:

```
opg4j> var jdbcUrl = "<jdbc-url>" // for example:
jdbc:oracle:thin:@myhost:1521/myservice
opg4j> var user = "<db-user>" // for example: hr
opg4j> var pass = "<db-pass>"
opg4j> var conn = DriverManager.getConnection(jdbcUrl, user, pass)
conn ==> oracle.jdbc.driver.T4CConnection@57e6cb01
```

Connecting to an Autonomous Database works the same way: provide a JDBC URL that points to the local wallet. See Using Oracle Graph with the Autonomous Database for an example.

Create a PGQL connection

Convert the JDBC connection into a PGQL connection object. For example:

```
opg4j> conn.setAutoCommit(false)
opg4j> var pgql = PgqlConnection.getConnection(conn)
pgql ==> oracle.pg.rdbms.pgql.PgqlConnection@6fb3d3bb
```

Write and execute the graph creation statement

Using a text editor, write a CREATE PROPERTY GRAPH statement that describes how the HR sample data should be converted into a graph. Save this file as create.pgql at a location of your choice. For example:

```
CREATE PROPERTY GRAPH hr
  VERTEX TABLES (
    employees LABEL employee
      PROPERTIES ARE ALL COLUMNS EXCEPT ( job_id, manager_id,
department_id ),
    departments LABEL department
      PROPERTIES ( department_id, department_name ),
```

```
  jobs LABEL job
    PROPERTIES ARE ALL COLUMNS,
  job_history
    PROPERTIES ( start_date, end_date ),
  locations LABEL location
    PROPERTIES ARE ALL COLUMNS EXCEPT ( country_id ),
  countries LABEL country
    PROPERTIES ARE ALL COLUMNS EXCEPT ( region_id ),
  regions LABEL region
)
EDGE TABLES (
  employees AS works_for
    SOURCE employees
    DESTINATION KEY ( manager_id ) REFERENCES employees (employee_id)
    NO PROPERTIES,
  employees AS works_at
    SOURCE employees
    DESTINATION departments
    NO PROPERTIES,
  employees AS works_as
    SOURCE employees
    DESTINATION jobs
    NO PROPERTIES,
  departments AS managed_by
    SOURCE departments
    DESTINATION employees
    NO PROPERTIES,
  job_history AS for_employee
    SOURCE job_history
    DESTINATION employees
    LABEL for
    NO PROPERTIES,
  job_history AS for_department
    SOURCE job_history
    DESTINATION departments
    LABEL for
    NO PROPERTIES,
  job_history AS for_job
    SOURCE job_history
    DESTINATION jobs
    LABEL for
    NO PROPERTIES,
  departments AS department_located_in
    SOURCE departments
    DESTINATION locations
    LABEL located_in
    NO PROPERTIES,
  locations AS location_located_in
    SOURCE locations
    DESTINATION countries
    LABEL located_in
    NO PROPERTIES,
  countries AS country_located_in
    SOURCE countries
    DESTINATION regions
```

```
      LABEL located_in
      NO PROPERTIES
  )
```

Then, back in your graph shell, execute the CREATE `PROPERTY GRAPH` statement by sending it to your PGQL connection. Replace <path> with the path to the directory containing the `create.pgql` file:

```
opg4j> pgql.prepareStatement(Files.readString(Paths.get("<path>/
create.pgql"))).execute()
$16 ==> false
```

Run a few PGQL queries

Now that you have a graph named hr, you can use PGQL to run a few queries against it directly on the database. For example:

```
// define a little helper function that executes the query, prints the
results and properly closes the statement
opg4j> Consumer<String> query = q -> { try(var s = pgql.prepareStatement(q))
{ s.execute(); s.getResultSet().print(); } catch(Exception e) { throw new
RuntimeException(e); } }
query ==> $Lambda$605/0x0000000100ae6440@6c9e7af2

// print the number of vertices in the graph
opg4j> query.accept("SELECT COUNT(v) FROM MATCH (v) ON hr")
+----------+
| COUNT(v) |
+----------+
| 215      |
+----------+

// print the number of edges in the graph
opg4j> query.accept("SELECT COUNT(e) FROM MATCH ()-[e]->() ON hr")
+----------+
| count(e) |
+----------+
| 433      |
+----------+

// find the highest earning managers
opg4j> query.accept("SELECT DISTINCT m.FIRST_NAME, m.LAST_NAME, m.SALARY
FROM MATCH (v:EMPLOYEE)-[:WORKS_FOR]->(m:EMPLOYEE) ON hr ORDER BY m.SALARY
DESC")
+---------------------------------------+
| m.FIRST_NAME | m.LAST_NAME | m.SALARY |
+---------------------------------------+
| Steven       | King        | 24000.0  |
| Lex          | De Haan     | 17000.0  |
| Neena        | Kochhar     | 17000.0  |
| John         | Russell     | 14000.0  |
| Karen        | Partners    | 13500.0  |
| Michael      | Hartstein   | 13000.0  |
| Alberto      | Errazuriz   | 12000.0  |
```

```
| Shelley       | Higgins      | 12000.0   |
| Nancy         | Greenberg    | 12000.0   |
| Den           | Raphaely     | 11000.0   |
| Gerald        | Cambrault    | 11000.0   |
| Eleni         | Zlotkey      | 10500.0   |
| Alexander     | Hunold       | 9000.0    |
| Adam          | Fripp        | 8200.0    |
| Matthew       | Weiss        | 8000.0    |
| Payam         | Kaufling     | 7900.0    |
| Shanta        | Vollman      | 6500.0    |
| Kevin         | Mourgos      | 5800.0    |
+----------------------------------------+

// find the average salary of accountants in the Americas
opg4j> query.accept("SELECT AVG(e.SALARY) FROM MATCH (e:EMPLOYEE) -
[h:WORKS_AT]-> (d:DEPARTMENT) -[:LOCATED_IN]-> (:LOCATION) -
[:LOCATED_IN]-> (:COUNTRY) -[:LOCATED_IN]-> (r:REGION) ON hr WHERE
r.REGION_NAME = 'Americas' AND d.DEPARTMENT_NAME = 'Accounting'")
+----------------+
| avg(e.SALARY)  |
+----------------+
| 14500.0        |
+----------------+
```

A.8.1.2 Load the Graph into Memory and Run Graph Analytics

Major tasks for this tutorial:

- Load the graph from the property graph schema into memory
- Execute algorithms and query the algorithm results
- Share the Graph with Other Sessions

Load the graph from the property graph schema into memory

In this section of the quickstart, you will load the graph stored in the Property Graphs schema in the database into the graph server (PGX). This will enable you to run a variety of different built-in algorithms on the graph and will also improve query performance for larger graphs.

First, start the JShell client and connect to the graph server (PGX):

```
./bin/opg4j --base_url https://<graph server host>:7007 --username
<graphuser>
```

`<graphuser>` is the database user you will use to for the PGX server authentication. You will be prompted for the database password.

> **Note:**
>
> For demo purposes only, if you have set `enable_tls` to `false` in the `/etc/oracle/graph/server.conf` file you can use an `http` instead of `https` connection.

```
./bin/opg4j --base_url http://<graph server host>:7007 --username <graphuser>
```

This starts the shell and makes a connection to the graph server.

> **Note:**
>
> Always use low-privilege read-only database user accounts for PGX, as explained in Security Best Practices with Graph Data.

Next load the graph into memory in this server.

To load the graph into memory, create a PGX graph config object, using the PGX graph config builder API to do this directly in the shell.

The following example creates a PGX graph config object. It lists the properties to load into memory so that you can exclude other properties, thus reducing memory consumption.

```
Supplier<GraphConfig> pgxConfig = () -> { return
GraphConfigBuilder.forPropertyGraphRdbms()
.setName("hr")
 .addVertexProperty("COUNTRY_NAME", PropertyType.STRING)
 .addVertexProperty("DEPARTMENT_NAME", PropertyType.STRING)
 .addVertexProperty("FIRST_NAME", PropertyType.STRING)
 .addVertexProperty("LAST_NAME", PropertyType.STRING)
 .addVertexProperty("EMAIL", PropertyType.STRING)
 .addVertexProperty("PHONE_NUMBER", PropertyType.STRING)
 .addVertexProperty("SALARY", PropertyType.DOUBLE)
 .addVertexProperty("MIN_SALARY", PropertyType.DOUBLE)
 .addVertexProperty("MAX_SALARY", PropertyType.DOUBLE)
 .addVertexProperty("STREET_ADDRESS", PropertyType.STRING)
 .addVertexProperty("POSTAL_CODE", PropertyType.STRING)
 .addVertexProperty("CITY", PropertyType.STRING)
 .addVertexProperty("STATE_PROVINCE", PropertyType.STRING)
 .addVertexProperty("REGION_NAME", PropertyType.STRING)
 .setPartitionWhileLoading(PartitionWhileLoading.BY_LABEL)
 .setLoadVertexLabels(true)
 .setLoadEdgeLabel(true)
 .build(); }
```

Now that you have a graph config object, use the following API to read the graph into PGX:

```
opg4j> var graph = session.readGraphWithProperties(pgxConfig.get())
graph ==> PgxGraph[name=hr,N=215,E=433,created=1586996113457]
```

The session object is created for you automatically.

Execute algorithms and query the algorithm results

Now that you have the graph in memory, you can run any built-in algorithm using a single API invocation. For example, for `pagerank`:

```
opg4j> analyst.pagerank(graph)
$31==> VertexProperty[name=pagerank,type=double,graph=hr]
```

As you can see from the preceding outputs, each algorithm created a new vertex property on the graph holding the output of the algorithm. To print the most important people in the graph (according to pagerank), you can run the following query:

```
opg4j>  session.queryPgql("SELECT m.FIRST_NAME, m.LAST_NAME,
m.pagerank "
...> + "FROM MATCH (m:EMPLOYEE) ON hr ORDER BY m.pagerank DESC LIMIT
10").print().close()
+-----------------------------------------------------+
| m.FIRST_NAME | m.LAST_NAME | m.pagerank |
+-----------------------------------------------------+
| Adam | Fripp | 0.002959240305566317 |
| John | Russell | 0.0028810951120575284 |
| Michael | Hartstein | 0.002181365227465801 |
| Alexander | Hunold | 0.002082616009054747 |
| Den | Raphaely | 0.0020378615199327507 |
| Shelley | Higgins | 0.002028946863425767 |
| Nancy | Greenberg | 0.0017419394483596667 |
| Steven | King | 0.0016622985848193119 |
| Neena | Kochhar | 0.0015252785582170803 |
| Jennifer | Whalen | 0.0014263044976976823 |
+-----------------------------------------------------+
```

Share the Graph with Other Sessions

After you load the graph into the graph server, you can use the `publish()` API to make the graph visible to other sessions, such as the graph visualization session. For example:

```
opg4j> graph.publish(VertexProperty.ALL, EdgeProperty.ALL)
```

The published graph will include any new properties you add to the graph by calling functions, such as `pagerank`.

You can use the Graph Visualization Application by navigating to `<my-server-name>:7007/ui/` in your browser.

You can connect to a particular client session by providing the session ID when you log into the Graph Visualization Application. You will then be able to visualize all graphs in the session, even if they have not been published.

```
opg4j> session
session ==> PgxSession[ID=5adf83ab-31b1-4a0e-8c08-
d6a95ba63ee0,source=pgxShell]
```

The session id is `5adf83ab-31b1-4a0e-8c08-d6a95ba63ee0`.

> **Note:**
>
> You must create a server certificate to connect to the graph server (PGX) from the Graph Visualization Application. See Setting Up Transport Layer Security for more details.

A.8.2 Quick Start: Create, Query, and Analyze a Graph in Graph Server (PGX)

This tutorial shows how you can quickly get started using property graph data when using the graph server (PGX).

This is for use cases where the graph is available as long as the graph server (PGX) session is active. The graph is not persisted in the database.

- Create a graph in the graph server (PGX), directly from existing relational data
- Query this graph using PGQL in the graph server (PGX)
- Run graph algorithms in the graph server (PGX) on this graph and display results

Prerequisites for the following quickstart are:

- An installation of Oracle Graph server.

  See Installing Oracle Graph Server for information to download Oracle Graph Server.
- An installation of Oracle Graph client.

  See Installing the Java Client From the Graph Server and Client Downloads for information to download Oracle Graph Client.

  You will authenticate yourself as the database user to the graph server, and these database credentials are used to access the database tables and create a graph.
- Java 11
  - The graph server can work with Java 8 or Java 11.
  - The JShell client used in this example requires Java 11.

  For Java downloads, see https://www.oracle.com/technetwork/java/javase/overview/index.html.

Major tasks for this tutorial:

- Set up the example data
- Start the shell

- Write and execute the graph creation statement
- Run a few PGQL queries
- Execute algorithms and query the algorithm results
- Share the Graph with Other Sessions

Set up the example data

This example uses the HR (human resources) sample dataset.

- For instructions how to import that data into a user managed database, see: https://github.com/oracle/db-sample-schemas
- If you are using Autonomous Database, see: https://www.thatjeffsmith.com/archive/2019/07/creating-hr-in-oracle-autonomous-database-w-sql-developer-web/

Note that the database schema storing the graph must have the privileges listed in Required Privileges for Database Users.

Start the shell

On the system where Oracle Graph Client is installed, start the shell as follows. This is an example of starting a shell in remote mode and connecting to the graph server (PGX):

```
./bin/opg4j --base_url https://<graph server host>:7007 --username
<graphuser>
```

`<graphuser>` is the database user you will use to for the PGX server authentication. You will be prompted for the database password.

> **Note:**
>
> For demo purposes only, if you have set `enable_tls` to `false` in the `/etc/oracle/graph/server.conf` file you can use an `http` instead of `https` connection.

```
./bin/opg4j --base_url http://<graph server host>:7007 --username
<graphuser>
```

This starts the shell and makes a connection to the graph server.

Note that, `JAVA_HOME` should be set to Java 11 before you start the shell. For example:

```
export JAVA_HOME=/usr/lib/jvm/java-11-oracle
```

See Interactive Graph Shell CLIs for details about the shell.

Write and execute the graph creation statement

Create a graph with employees, departments, and "`employee works at department`", by executing a `CREATE PROPERTY GRAPH` statement. The following statement creates a graph in the graph server (PGX):

```
opg4j> String statement =
      "CREATE PROPERTY GRAPH hr_simplified "
    + "  VERTEX TABLES ( "
    + "    hr.employees LABEL employee "
    + "      PROPERTIES ARE ALL COLUMNS EXCEPT ( job_id, manager_id,
department_id ), "
    + "    hr.departments LABEL department "
    + "      PROPERTIES ( department_id, department_name ) "
    + "  ) "
    + "  EDGE TABLES ( "
    + "    hr.employees AS works_at "
    + "      SOURCE KEY ( employee_id ) REFERENCES employees (employee_id) "
    + "      DESTINATION departments "
    + "      PROPERTIES ( employee_id ) "
    + "  )"
opg-jshell> session.executePgql(statement)
```

To get a handle to the graph, execute:

```
opg4j> var g = session.getGraph("HR_SIMPLIFIED")
```

Run a few PGQL queries

You can use this handle to run PGQL queries on this graph. For example, to find the department that "Nandita Sarchand" works for, execute:

```
opg4j> String query =
    "SELECT dep.department_name "
  + "FROM MATCH (emp:Employee) -[:works_at]-> (dep:Department) "
  + "WHERE emp.first_name = 'Nandita' AND emp.last_name = 'Sarchand' "
  + "ORDER BY 1"
opg4j> var resultSet = g.queryPgql(query)
opg4j> resultSet.print()
+-----------------+
| department_name |
+-----------------+
| Shipping        |
+-----------------+
```

To get an overview of the types of vertices and their frequencies, execute:

```
opg4j> String query =
      "SELECT label(n), COUNT(*) "
    + "FROM MATCH (n) "
    + "GROUP BY label(n) "
    + "ORDER BY COUNT(*) DESC"
```

```
opg4j> var resultSet = g.queryPgql(query)
opg4j> resultSet.print()

+------------------------+
| label(n)    | COUNT(*) |
+------------------------+
| EMPLOYEE    | 107      |
| DEPARTMENT  | 27       |
+------------------------+
```

To get an overview of the types of edges and their frequencies, execute:

```
opg4j> String query =
    "SELECT label(n) AS srcLbl, label(e) AS edgeLbl, label(m) AS
dstLbl, COUNT(*) "
  + "FROM MATCH (n) -[e]-> (m) "
  + "GROUP BY srcLbl, edgeLbl, dstLbl "
  + "ORDER BY COUNT(*) DESC"
opg4j> var resultSet = g.queryPgql(query)
opg4j> resultSet.print()

+---------------------------------------------+
| srcLbl   | edgeLbl  | dstLbl     | COUNT(*) |
+---------------------------------------------+
| EMPLOYEE | WORKS_AT | DEPARTMENT | 106      |
+---------------------------------------------+
```

Execute algorithms and query the algorithm results

Now that you have the graph in memory, you can run each built-in algorithms using a single API invocation. For example, for `pagerank`:

```
opg4j> analyst.pagerank(g)
$31==> VertexProperty[name=pagerank,type=double,graph=hr]
```

As you can see from the preceding outputs, each algorithm created a new vertex property on the graph holding the output of the algorithm. To print the most important people in the graph (according to pagerank), you can run the following query:

```
opg4j> session.queryPgql("SELECT m.FIRST_NAME, m.LAST_NAME, m.pagerank
FROM MATCH (m:EMPLOYEE) "
...> + "ON hr_simplified WHERE m.FIRST_NAME = 'Nandita'
").print().close()
+-----------------------------------------------------+
| m.FIRST_NAME | m.LAST_NAME | m.pagerank             |
+-----------------------------------------------------+
| Nandita      | Sarchand    | 0.001119402985074627 |
+-----------------------------------------------------+
```

In the following example, we order departments by their `pagerank` value. Departments with higher `pagerank` values have more employees.

```
opg4j> session.queryPgql("SELECT m.DEPARTMENT_NAME, m.pagerank FROM MATCH
(m:DEPARTMENT) ON hr_simplified ORDER BY m.pagerank").print().close()
```

```
+---------------------------------------------+
| DEPARTMENT_NAME      | pagerank             |
+---------------------------------------------+
| Manufacturing        | 0.001119402985074627  |
| Construction         | 0.001119402985074627  |
| Contracting          | 0.001119402985074627  |
| Operations           | 0.001119402985074627  |
| IT Support           | 0.001119402985074627  |
| NOC                  | 0.001119402985074627  |
| IT Helpdesk          | 0.001119402985074627  |
| Government Sales     | 0.001119402985074627  |
| Retail Sales         | 0.001119402985074627  |
| Recruiting           | 0.001119402985074627  |
| Payroll              | 0.001119402985074627  |
| Treasury             | 0.001119402985074627  |
| Corporate Tax        | 0.001119402985074627  |
| Control And Credit   | 0.001119402985074627  |
| Shareholder Services | 0.001119402985074627  |
| Benefits             | 0.001119402985074627  |
| Human Resources      | 0.0020708955223880596 |
| Administration       | 0.0020708955223880596 |
| Public Relations     | 0.0020708955223880596 |
| Marketing            | 0.003022388059701493  |
| Accounting           | 0.003022388059701493  |
| Executive            | 0.003973880597014925  |
| IT                   | 0.005876865671641792  |
| Purchasing           | 0.006828358208955224  |
| Finance              | 0.006828358208955224  |
| Sales                | 0.03347014925373134   |
| Shipping             | 0.043936567164179076  |
+---------------------------------------------+
```

Share the Graph with Other Sessions

After you load the graph into the server, you can use the `publish()` API to make the graph visible to other sessions, such as the graph visualization session. For example:

```
opg4j> graph.publish(VertexProperty.ALL, EdgeProperty.ALL)
```

The published graph will include any new properties you add to the graph by calling functions, such as `pagerank`.

Ensure that the logged-in user has the privilege to publish graphs. You can do this by adding the privilege `PGX_SESSION_ADD_PUBLISHED_GRAPH` to the `GRAPH_DEVELOPER` role as explained in Adding Permissions to Publish the Graph. We had given the `GRAPH_DEVELOPER` role to the database user in Installing PL/SQL Packages in Oracle Database.

You can use the Graph Visualization Application by navigating to `<my-server-name>:7007/ui/` in your browser.

You can connect to a particular client session by providing the session ID when you log into the Graph Visualization Application. You will then be able to visualize all graphs in the session, even if they have not been published.

```
opg4j> session
session ==> PgxSession[ID=5adf83ab-31b1-4a0e-8c08-
d6a95ba63ee0,source=pgxShell]
```

The session id is `5adf83ab-31b1-4a0e-8c08-d6a95ba63ee0`.

> **Note:**
>
> You must create a server certificate to connect to the graph server (PGX) from the Graph Visualization Application. See Setting Up Transport Layer Security for more details.

A.9 Working with Property Graph Objects in SQL Developer

You can use Oracle SQL Developer to execute PGQL statements and queries directly on property graph schema graphs in the database.

You can view all the property graph objects existing in your database schema by expanding **PG Objects** under the **Property Graph** node in the **Connections** navigator.

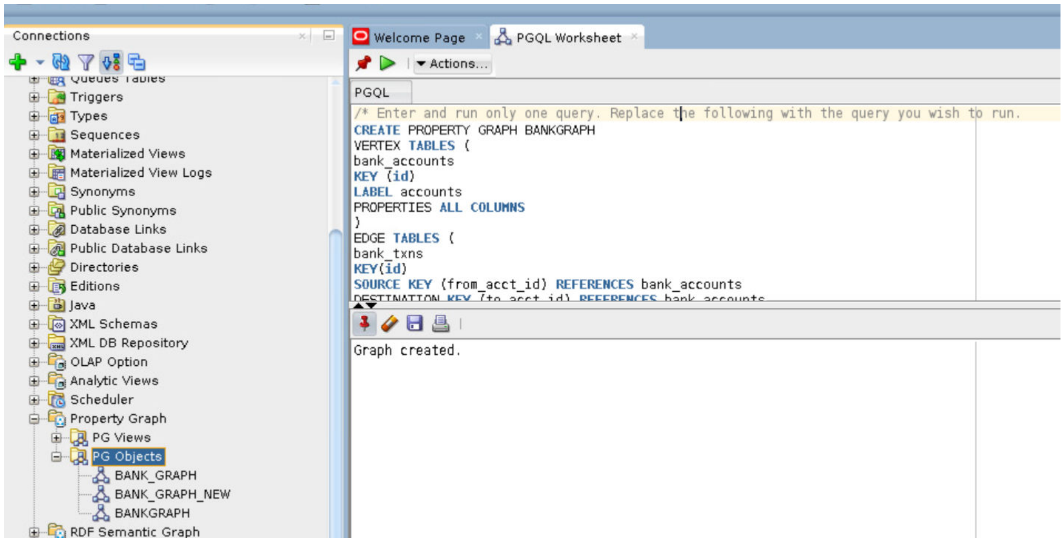
You can run PGQL queries for a property graph object in a **PGQL Worksheet**. The following steps show a few examples for creating, updating and dropping a property graph object using SQL Developer.

1. Right-click the **Property Graph** node and select **Open PGQL Worksheet**.

   PGQL Worksheet opens in a new tab and it contains the **Run Query** icon for executing PGQL queries.

2. Create a property graph object by running a `CREATE PROPERTY GRAPH` statement in the PGQL Worksheet. For example:

Figure A-2 Creating a Property Graph Object



The result of the query execution is displayed in the bottom pane of the Editor. On successful query execution, you can right-click and refresh the **PG Objects** node to view the newly created graph under **PG Objects**.

3. Click on the newly created graph.

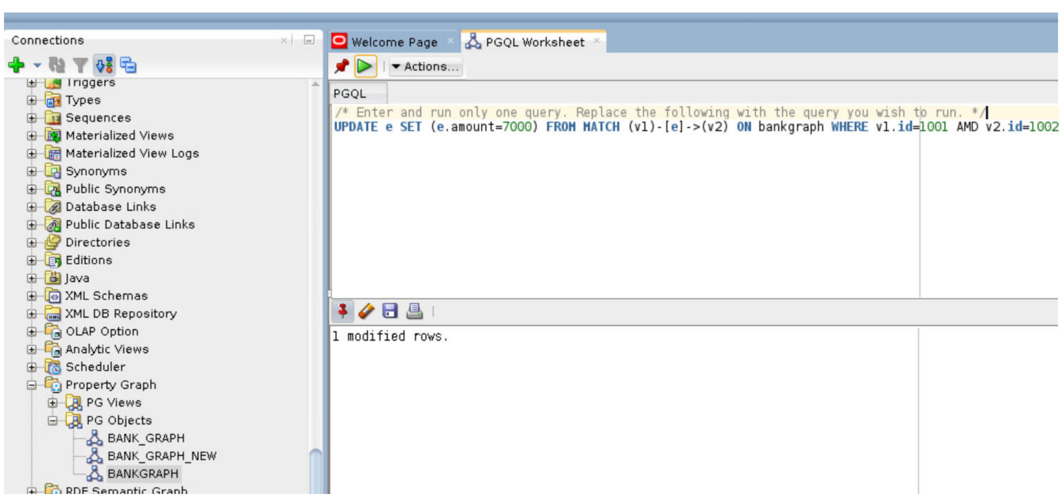
   This opens a **PGQL Worksheet** in a new tab with the following default query:

   ```
   SELECT id(e), id(v), id(n) FROM MATCH (v)-[e]-(n) ON <graph_name> LIMIT
   100
   ```

4. Run any PGQL update query like performing an `INSERT` or an `UPDATE` operation against a property graph object.

   For example, the following shows the execution of a PGQL `UPDATE` query:

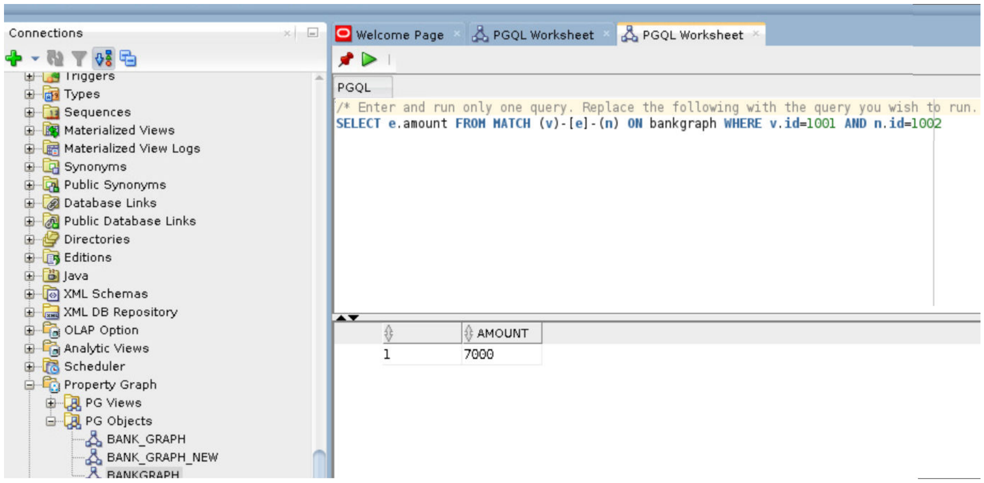
Figure A-3 Updating a Property Graph Object



The related edge is updated in the graph.

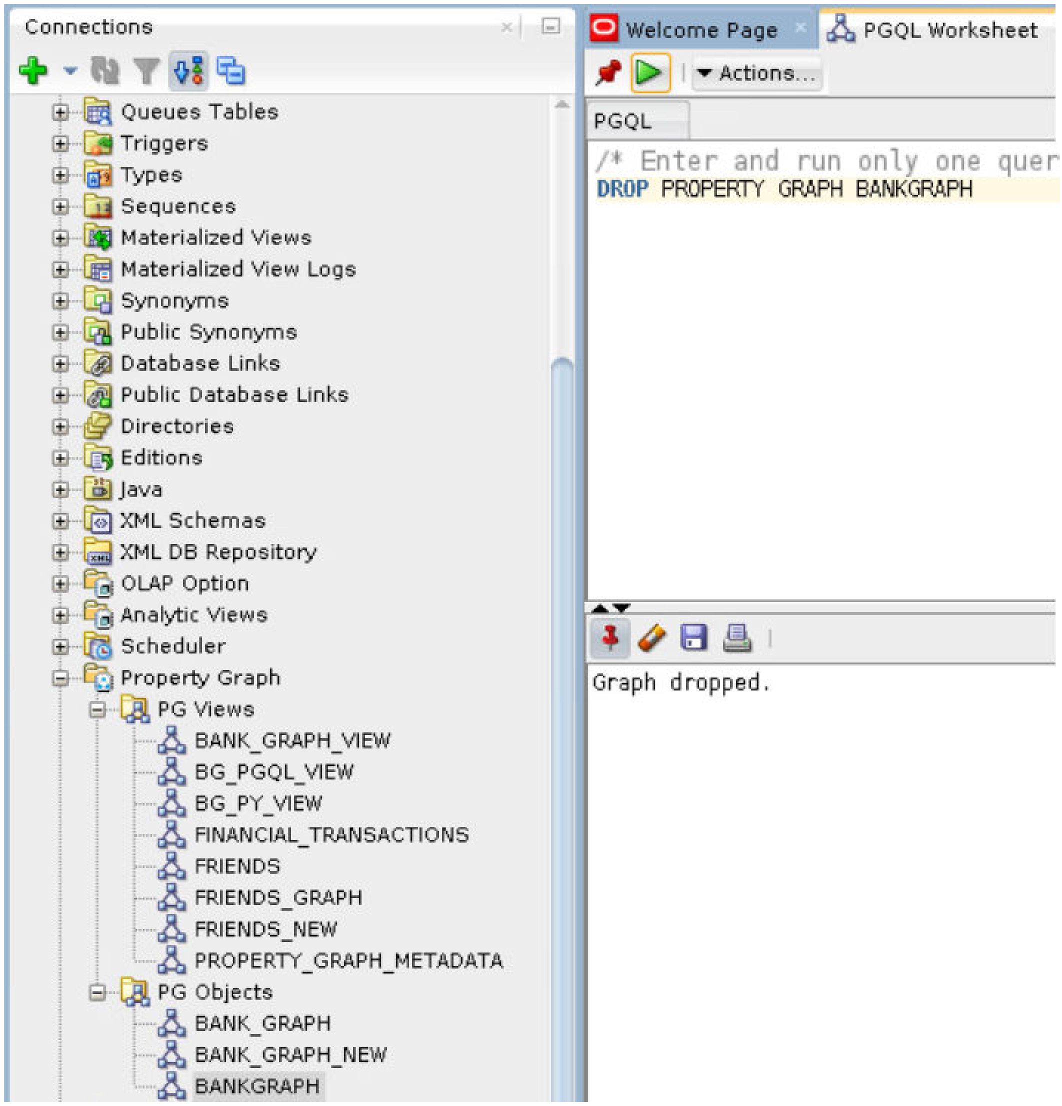
5. Run a PGQL `SELECT` query to view the newly updated edge as shown:

Figure A-4 Running a PGQL SELECT Query



6. Delete the Property Graph Object as shown:

Figure A-5 Dropping a Property Graph Object



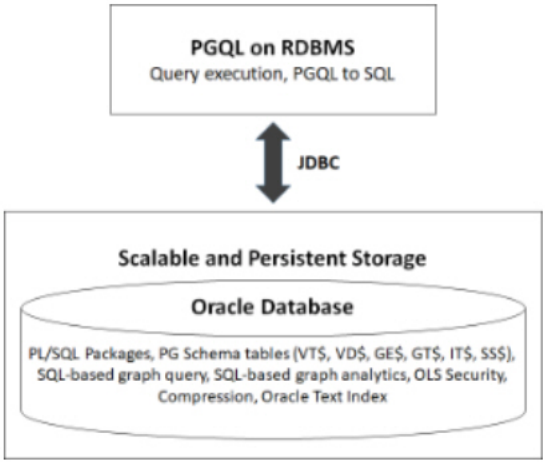
The graph is dropped.

A.10 Executing PGQL Queries Against Property Graph Schema Tables

This topic explains how you can execute PGQL queries directly against the graph stored in property graph schema tables.

The PGQL query execution flow is shown in the following figure.

Figure A-6 PGQL on Property Graph Schema Tables in Oracle Database (RDBMS)



The basic execution flow is:

1. The PGQL query is submitted to PGQL on RDBMS through a Java API.
2. The PGQL query is translated to SQL.
3. The translated SQL is submitted to Oracle Database by JDBC.
4. The SQL result set is wrapped as a PGQL result set and returned to the caller.

The ability to execute PGQL queries directly against property graph data stored in Oracle Database provides several benefits.

- PGQL provides a more natural way to express graph queries than SQL manually written to query schema tables, including VT$, VD$, GE$, and GT$.
- PGQL queries can be executed without the need to load a snapshot of your graph data into PGX, so there is no need to worry about staleness of frequently updated graph data.
- PGQL queries can be executed against graph data that is too large to fit in memory.
- The robust and scalable Oracle SQL engine can be used to execute PGQL queries.
- Mature tools for management, monitoring and tuning of Oracle Database can be used to tune and monitor PGQL queries.

- PGQL Features Supported in Property Graph Schema
- Creating Property Graphs through CREATE PROPERTY GRAPH Statements
- Dropping Property Graphs through DROP PROPERTY GRAPH Statements
- Using the oracle.pg.rdbms.pgql Java Package to Execute PGQL Queries
- Using the Python Client to Execute PGQL Queries
- Performance Considerations for PGQL Queries

A.10.1 PGQL Features Supported in Property Graph Schema

PGQL is a SQL-like query language for querying property graph data. It is based on the concept of graph pattern matching and allows you to specify, among other things, topology constraints, paths, filters, sorting and aggregation.

The Java API for PGQL defined in the `oracle.pg.rdbms.pgql` package supports the PGQL specification with a few exceptions. (Refer to the PGQL Specification).

The following table describes the list of supported and unsupported PGQL features:

Table A-1 Supported PGQL Features and Limitations for PG Schema Graphs

Feature	PG Schema
`CREATE PROPERTY GRAPH`	Supported
`DROP PROPERTY GRAPH`	Supported
Fixed-length pattern matching	Supported
Variable-length pattern matching goals	Supported: • Reachability Limitations: • `ANY` • `ANY SHORTEST` • `TOP k SHORTEST` • `ALL SHORTEST` • `ANY CHEAPEST` • `TOP k CHEAPEST` • `ALL`
Variable-length pattern matching quantifiers	Supported: • * • + • ? • { n } • { n, } • { n, m } • { , m }
Variable-length path unnesting	Not supported
`GROUP BY`	Supported
`HAVING`	Supported
Aggregations	Supported: • `COUNT` • `MIN`, `MAX`, `AVG`, `SUM` Limitations: • `LISTAGG` • `ARRAY_AGG`
`DISTINCT` • `SELECT DISTINCT` • Aggregation with `DISTINCT` (such as, `COUNT(DISTINCT e.prop)`)	Supported
`SELECT v.*`	Not Supported

Table A-1 (Cont.) Supported PGQL Features and Limitations for PG Schema Graphs

Feature	PG Schema
ORDER BY (+ASC/DESC), LIMIT, OFFSET	Supported
Data Types	Supported: • NVARCHAR2(15000) • NUMBER • BOOLEAN (stored like NVARCHAR) • TIMESTAMP(6) WITH TIME ZONE
JSON	No built-in JSON support. However, JSON strings (VARCHAR2) can be mapped into NVARCHAR2(15000) data type.
Operators	Supported: • Relational: +, -, *, /, %, - (unary minus) • Arithmetic: =, <>, <, >, <=, >= • Logical: AND, OR, NOT Limitations: • String: || (concat)
Functions and predicates	Supported: • IS NULL, IS NOT NULL • JAVA_REGEXP_LIKE (based on CONTAINS) • ABS, CEIL/CEILING, FLOOR, ROUND • EXTRACT • ID • LABEL, HAS_LABEL • ALL_DIFFERENT • IN_DEGREE, OUT_DEGREE • CAST • CASE • IN and NOT IN Limitations: • LOWER, UPPER • SUBSTRING • LABELS
User-defined functions	Not supported
Subqueries: • Scalar subqueries • EXISTS and NOT EXISTS subqueries	Supported
INSERT/UPDATE/DELETE	Supported for Oracle Database 19c and later
INTERVAL literals and operations	Not supported

The following explains a few PGQL features that require special consideration.

- Temporal Types
- Type Casting
- CONTAINS Built-in Function

A.10.1.1 Temporal Types

The temporal types DATE, TIMESTAMP and TIMESTAMP WITH TIMEZONE are supported in PGQL queries.

All of these value types are represented internally using the Oracle SQL TIMESTAMP WITH TIME ZONE type. DATE values are automatically converted to TIMESTAMP WITH TIME ZONE by assuming the earliest time in UTC+0 timezone (for example, 2000-01-01 becomes 2000-01-01 00:00:00.00+00:00). TIMESTAMP values are automatically converted to TIMESTAMP WITH TIME ZONE by assuming UTC+0 timezone (for example, 2000-01-01 12:00:00.00 becomes 2000-01-01 12:00:00.00+00:00).

Temporal constants are written in PGQL queries as follows.

- DATE 'YYYY-MM-DD'
- TIMESTAMP 'YYYY-MM-DD HH24:MI:SS.FF'
- TIMESTAMP WITH TIMEZONE 'YYYY-MM-DD HH24:MI:SS.FFTZH:TZM'

Some examples are DATE '2000-01-01', TIMESTAMP '2000-01-01 14:01:45.23', TIMESTAMP WITH TIMEZONE '2000-01-01 13:00:00.00-05:00', and TIMESTAMP WITH TIMEZONE '2000-01-01 13:00:00.00+01:00'.

In addition, temporal values can be obtained by casting string values to a temporal type. The supported string formats are:

- DATE 'YYYY-MM-DD'
- TIMESTAMP 'YYYY-MM-DD HH24:MI:SS.FF' and 'YYYY-MM-DD"T"HH24:MI:SS.FF'
- TIMESTAMP WITH TIMEZONE 'YYYY-MM-DD HH24:MI:SS.FFTZH:TZM' and 'YYYY-MM-DD"T"HH24:MI:SS.FFTZH:TZM'.

Some examples are CAST ('2005-02-04' AS DATE), CAST ('1990-01-01 12:00:00.00' AS TIMESTAMP), CAST ('1985-01-01T14:05:05.00-08:00' AS TIMESTAMP WITH TIMEZONE).

When consuming results from a `PgqlResultSet` object, `getObject` returns a `java.sql.Timestamp` object for temporal types.

Bind variables can only be used for the TIMESTAMP WITH TIMEZONE temporal type in PGQL, and a `setTimestamp` method that takes a `java.sql.Timestamp` object as input is used to set the bind value. As a simpler alternative, you can use a string bind variable in a CAST statement to bind temporal values (for example, `CAST (? AS TIMESTAMP WITH TIMEZONE)` followed by `setString(1, "1985-01-01T14:05:05.00-08:00")`). See also Using Bind Variables in PGQL Queries for more information about bind variables.

A.10.1.2 Type Casting

Type casting is supported in PGQL with a SQL-style CAST (VALUE AS DATATYPE) syntax, for example CAST('25' AS INT), CAST (10 AS STRING), CAST ('2005-02-04' AS DATE), CAST(e.weight AS STRING). Supported casting operations are summarized in the following table. Y indicates that the conversion is supported, and N indicates that it is not supported. Casting operations on invalid values (for example, CAST('xyz' AS INT)) or unsupported conversions (for example, CAST (10 AS TIMESTAMP)) return NULL instead of raising a SQL exception.

Table A-2 Type Casting Support in PGQL (From and To Types)

"to" type	from STRING	from INT	from LONG	from FLOAT	from DOUBLE	from BOOLEAN	from DATE	from TIMESTAMP	from TIMESTAMP WITH TIMEZONE
to STRING	Y	Y	Y	Y	Y	Y	Y	Y	Y
to INT	Y	Y	Y	Y	Y	Y	N	N	N
to LONG	Y	Y	Y	Y	Y	Y	N	N	N
to FLOAT	Y	Y	Y	Y	Y	Y	N	N	N
to DOUBLE	Y	Y	Y	Y	Y	Y	N	N	N
to BOOLEAN	Y	Y	Y	Y	Y	Y	N	N	N
to DATE	Y	N	N	N	N	N	Y	Y	Y
to TIMESTAMP	Y	N	N	N	N	N	Y	Y	Y
to TIMESTAMP WITH TIMEZONE	Y	N	N	N	N	N	Y	Y	Y

An example query that uses type casting is:

```
SELECT e.name, CAST (e.birthDate AS STRING) AS dob
FROM MATCH (e)
WHERE e.birthDate < CAST ('1980-01-01' AS DATE)
```

A.10.1.3 CONTAINS Built-in Function

A CONTAINS built-in function is supported. It is used in conjunction with an Oracle Text index on vertex and edge properties. CONTAINS returns `true` if a value matches an Oracle Text search string and `false` if it does not match.

An example query is:

```
SELECT v.name
FROM MATCH (v)
WHERE CONTAINS(v.abstract, 'Oracle')
```

See also Using a Text Index with PGQL Queries for more information about using full text indexes with PGQL.

A.10.2 Creating Property Graphs through CREATE PROPERTY GRAPH Statements

You can use PGQL to create property graphs from relational database tables. A CREATE PROPERTY GRAPH statement defines a set of vertex tables that are transformed into vertices and a set of edge tables that are transformed into edges. For each table a key, a label and a set of column properties can be specified. The column types CHAR, NCHAR, VARCHAR, VARCHAR2, NVARCHAR2 , NUMBER, LONG, FLOAT, DATE, TIMESTAMP and TIMESTAMP WITH TIMEZONE are supported for CREATE PROPERTY GRAPH column properties.

When a CREATE PROPERTY GRAPH statement is called, a property graph schema for the graph is created, and the data is copied from the source tables into the property graph schema tables. The graph is created as a one-time copy and is not automatically kept in sync with the source data.

Example A-24   PgqlCreateExample1.java

This example shows how to create a property graph from a set of relational tables. Notice that the example creates tables Person, Hobby, and Hobbies, so they should not exist before running the example. The example also shows how to execute a query against a property graph.

```
import java.sql.Connection;
import java.sql.Statement;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to create a Property Graph from relational
 * data stored in Oracle Database executing a PGQL create statement.
 */
public class PgqlCreateExample1
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    Statement stmt = null;
    PgqlStatement pgqlStmt = null;
    PgqlResultSet rs = null;
```

```
    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();

pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();
      conn.setAutoCommit(false);

      // Create relational data
      stmt = conn.createStatement();

      //Table Person
      stmt.executeUpdate(
        "create table Person(  " +
        "  id    NUMBER,       " +
        "  name  VARCHAR2(20), " +
        "  dob   TIMESTAMP     " +
        ")");

      // Insert some data
      stmt.executeUpdate("insert into Person values(1,'Alan', DATE
'1995-05-26')");
      stmt.executeUpdate("insert into Person values(2,'Ben', DATE
'2007-02-15')");
      stmt.executeUpdate("insert into Person values(3,'Claire', DATE
'1967-11-30')");

      // Table Hobby
      stmt.executeUpdate(
        "create table Hobby(   " +
        "  id    NUMBER,       " +
        "  name  VARCHAR2(20)  " +
        ")");

      // Insert some data
      stmt.executeUpdate("insert into Hobby values(1, 'Sports')");
      stmt.executeUpdate("insert into Hobby values(2, 'Music')");

      // Table Hobbies
      stmt.executeUpdate(
        "create table Hobbies( "+
        "  person    NUMBER, "+
        "  hobby     NUMBER, "+
        "  strength  NUMBER  "+
        ")");

      // Insert some data
      stmt.executeUpdate("insert into Hobbies values(1, 1, 20)");
      stmt.executeUpdate("insert into Hobbies values(1, 2, 30)");
      stmt.executeUpdate("insert into Hobbies values(2, 1, 10)");
```

```
  stmt.executeUpdate("insert into Hobbies values(3, 2, 20)");

  //Commit changes
  conn.commit();

  // Get a PGQL connection
  PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);

  // Create a PgqlStatement
  pgqlStmt = pgqlConn.createStatement();

  // Execute PGQL to create property graph
  String pgql =
    "Create Property Graph " + graph + " " +
    "VERTEX TABLES ( " +
    "  Person " +
    "    Key(id) " +
    "    Label \"people\"" +
    "    PROPERTIES(name AS \"first_name\", dob AS \"birthday\")," +
    "  Hobby  " +
    "    Key(id) Label \"hobby\"  PROPERTIES(name AS \"name\")" +
    ")" +
    "EDGE TABLES (" +
    "  Hobbies" +
    "    SOURCE KEY(person) REFERENCES Person (id) " +
    "    DESTINATION KEY(hobby) REFERENCES Hobby (id) " +
    "    LABEL \"likes\" PROPERTIES (strength AS \"score\")" +
    ")";
  pgqlStmt.execute(pgql);

  // Execute a PGQL query to verify Graph creation
  pgql =
    "SELECT p.\"first_name\", p.\"birthday\", h.\"name\", e.\"score\" " +
    "FROM MATCH (p:\"people\")-[e:\"likes\"]->(h:\"hobby\") ON " + graph;
  rs = pgqlStmt.executeQuery(pgql, "");

  // Print the results
  rs.print();
}
finally {
  // close the sql statment
  if (stmt != null) {
    stmt.close();
  }
  // close the result set
  if (rs != null) {
    rs.close();
  }
  // close the statement
  if (pgqlStmt != null) {
    pgqlStmt.close();
  }
  // close the connection
  if (conn != null) {
    conn.close();
```

```
        }
      }
    }
  }
```

The output for `PgqlCreateExample1.java` is:

```
+---------------------------------------------------------+
|   first_name |   birthday              |   name |   score |
+---------------------------------------------------------+
| Alan         | 1995-05-25 17:00:00.0 | Music  | 30.0    |
| Claire       | 1967-11-29 16:00:00.0 | Music  | 20.0    |
| Ben          | 2007-02-14 16:00:00.0 | Sports | 10.0    |
| Alan         | 1995-05-25 17:00:00.0 | Sports | 20.0    |
+---------------------------------------------------------+
```

Example A-25   PgqlCreateExample2.java

This example shows how a create property graph statement without specifying any keys. Notice that the example creates tables Person, Hobby, and Hobbies, so they should not exist before running the example.

```
import java.sql.Connection;
import java.sql.Statement;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to create a Property Graph from relational
 * data stored in Oracle Database executing a PGQL create statement.
 */
public class PgqlCreateExample2
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    Statement stmt = null;
    PgqlStatement pgqlStmt = null;
    PgqlResultSet rs = null;

    try {
```

```
        //Get a jdbc connection
        PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
        pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
        pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
        pds.setUser(user);
        pds.setPassword(password);
        conn = pds.getConnection();
        conn.setAutoCommit(false);

        // Create relational data
        stmt = conn.createStatement();

        //Table Person
        stmt.executeUpdate(
          "create table Person(   " +
          "  id    NUMBER,        " +
          "  name  VARCHAR2(20),  " +
          "  dob   TIMESTAMP,     " +
          "  CONSTRAINT pk_person PRIMARY KEY(id)" +
          ")");

        // Insert some data
        stmt.executeUpdate("insert into Person values(1,'Alan', DATE
  '1995-05-26')");
        stmt.executeUpdate("insert into Person values(2,'Ben', DATE
  '2007-02-15')");
        stmt.executeUpdate("insert into Person values(3,'Claire', DATE
  '1967-11-30')");

        // Table Hobby
        stmt.executeUpdate(
          "create table Hobby(    " +
          "  id    NUMBER,        " +
          "  name  VARCHAR2(20),  " +
          "  CONSTRAINT pk_hobby PRIMARY KEY(id)" +
          ")");

        // Insert some data
        stmt.executeUpdate("insert into Hobby values(1, 'Sports')");
        stmt.executeUpdate("insert into Hobby values(2, 'Music')");

        // Table Hobbies
        stmt.executeUpdate(
          "create table Hobbies( "+
          "  person    NUMBER, "+
          "  hobby     NUMBER, "+
          "  strength  NUMBER, "+
          "  CONSTRAINT fk_hobbies1 FOREIGN KEY (person) REFERENCES
  Person(id), "+
          "  CONSTRAINT fk_hobbies2 FOREIGN KEY (hobby)  REFERENCES Hobby(id)"+
          ")");

        // Insert some data
        stmt.executeUpdate("insert into Hobbies values(1, 1, 20)");
        stmt.executeUpdate("insert into Hobbies values(1, 2, 30)");
```

```
  stmt.executeUpdate("insert into Hobbies values(2, 1, 10)");
  stmt.executeUpdate("insert into Hobbies values(3, 2, 20)");

  //Commit changes
  conn.commit();

  // Get a PGQL connection
  PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);

  // Create a PgqlStatement
  pgqlStmt = pgqlConn.createStatement();

  // Execute PGQL to create property graph
  String pgql =
    "Create Property Graph " + graph + " " +
    "VERTEX TABLES ( " +
    "  Person " +
    "    Label people +
    "    PROPERTIES ALL COLUMNS," +
    "  Hobby  " +
    "    Label hobby PROPERTIES ALL COLUMNS EXCEPT(id)" +
    ")" +
    "EDGE TABLES (" +
    "  Hobbies" +
    "    SOURCE Person DESTINATION Hobby " +
    "    LABEL likes NO PROPERTIES" +
    ")";
  pgqlStmt.execute(pgql);

  // Execute a PGQL query to verify Graph creation
  pgql =
    "SELECT p.NAME AS person, p.DOB, h.NAME AS hobby " +
    "FROM MATCH (p:people)-[e:likes]->(h:hobby) ON " + graph;
  rs = pgqlStmt.executeQuery(pgql, "");

  // Print the results
  rs.print();
}
finally {
  // close the sql statment
  if (stmt != null) {
    stmt.close();
  }
  // close the result set
  if (rs != null) {
    rs.close();
  }
  // close the statement
  if (pgqlStmt != null) {
    pgqlStmt.close();
  }
  // close the connection
  if (conn != null) {
    conn.close();
  }
```

```
    }
  }
}
```

The output for `PgqlCreateExample2.java` is:

```
+---------------------------------------+
| PERSON |   DOB                 |  HOBBY |
+---------------------------------------+
| Alan   | 1995-05-25 17:00:00.0 | Music  |
| Claire | 1967-11-29 16:00:00.0 | Music  |
| Ben    | 2007-02-14 16:00:00.0 | Sports |
| Alan   | 1995-05-25 17:00:00.0 | Sports |
+---------------------------------------+
```

A.10.3 Dropping Property Graphs through DROP PROPERTY GRAPH Statements

You can use PGQL to drop property graphs. When a `DROP PROPERTY GRAPH` statement is called, all the property graph schema tables of the graph are dropped.

Example A-26 PgqlDropExample1.java

This example shows how to drop a property graph.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to drop a Property executing a PGQL drop statement.
 */
public class PgqlDropExample1
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host              = args[idx++];
    String port              = args[idx++];
    String sid               = args[idx++];
    String user              = args[idx++];
    String password          = args[idx++];
    String graph             = args[idx++];

    Connection conn = null;
    PgqlStatement pgqlStmt = null;

    try {

      //Get a jdbc connection
```

```
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();
      conn.setAutoCommit(false);

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);

      // Create a PgqlStatement
      pgqlStmt = pgqlConn.createStatement();

      // Execute PGQL to drop property graph
      String pgql = "Drop Property Graph " + graph;
      pgqlStmt.execute(pgql);

    }
    finally {
      // close the statement
      if (pgqlStmt != null) {
        pgqlStmt.close();
      }
      // close the connection
      if (conn != null) {
        conn.close();
      }
    }
  }
}
```

A.10.4 Using the oracle.pg.rdbms.pgql Java Package to Execute PGQL Queries

The Java API in the `oracle.pg.rdbms.pgql` package provides support for executing PGQL queries against Oracle Database. This topic explains how to use the Java API through a series of examples.

Note:

Effective with Release 21c, the following classes in the `oracle.pg.rdbms` package are deprecated:

```
oracle.pg.rdbms.OraclePgqlColumnDescriptorImpl
oracle.pg.rdbms.OraclePgqlColumnDescriptor
oracle.pg.rdbms.OraclePgqlExecutionFactory
oracle.pg.rdbms.OraclePgqlExecution
oracle.pg.rdbms.PgqlPreparedStatement
oracle.pg.rdbms.OraclePgqlResultElementImpl
oracle.pg.rdbms.OraclePgqlResultElement
oracle.pg.rdbms.OraclePgqlResultImpl
oracle.pg.rdbms.OraclePgqlResultIterable
oracle.pg.rdbms.OraclePgqlResultIteratorImpl
oracle.pg.rdbms.OraclePgqlResult
oracle.pg.rdbms.OraclePgqlResultSetImpl
oracle.pg.rdbms.OraclePgqlResultSet
oracle.pg.rdbms.OraclePgqlResultSetMetaDataImpl
oracle.pg.rdbms.OraclePgqlResultSetMetaData
oracle.pg.rdbms.PgqlSqlQueryTransImpl
oracle.pg.rdbms.PgqlSqlQueryTrans
oracle.pg.rdbms.PgqlStatement
```

You should instead use equivalent classes in `oracle.pg.rdbms.pgql`:

```
oracle.pg.rdbms.pgql.PgqlColumnDescriptorImpl
oracle.pg.rdbms.pgql.PgqlColumnDescriptor
oracle.pg.rdbms.pgql.PgqlConnection
oracle.pg.rdbms.pgql.PgqlExecution
oracle.pg.rdbms.pgql.PgqlPreparedStatement
oracle.pg.rdbms.pgql.PgqlResultElementImpl
oracle.pg.rdbms.pgql.PgqlResultElement
oracle.pg.rdbms.pgql.PgqlResultSetImpl
oracle.pg.rdbms.pgql.PgqlResultSet
oracle.pg.rdbms.pgql.PgqlResultSetMetaDataImpl
oracle.pg.rdbms.pgql.PgqlSqlTransImpl
oracle.pg.rdbms.pgql.PgqlSqlTrans
oracle.pg.rdbms.pgql.PgqlStatement
```

One difference between `oracle.pg.rdbms.OraclePgqlResultSet` and `oracle.pg.rdbms.`**`pgql`**`.PgqlResultSet` is that oracle.pg.rdbms.pgql.PgqlResultSet does not provide APIs to retrieve vertex and edge objects. Existing code using those interfaces should be changed to project IDs rather than `OracleVertex` and `OracleEdge` objects. You can obtain an `OracleVertex` or `OracleEdge` object from the projected ID values by calling `OracleVertex.getInstance()` or `OracleEdge.getInstance()`. (For an example, see Example A-41.)

See Oracle Graph Property Graph Java APIs for more details on setting the classpath for compiling and executing your Java applications.

The following `test_graph` data set in Oracle flat file format will be used in the examples in subtopics that follow. The data set includes a vertex file (`test_graph.opv`) and an edge file (`test_graph.ope`).

`test_graph.`**`opv`**:

```
2,fname,1,Ray,,,person
2,lname,1,Green,,,person
2,mval,5,,,1985-01-01T12:00:00.000Z,person
2,age,2,,41,,person
0,bval,6,Y,,,person
0,fname,1,Bill,,,person
0,lname,1,Brown,,,person
0,mval,1,y,,,person
0,age,2,,40,,person
1,bval,6,Y,,,person
1,fname,1,John,,,person
1,lname,1,Black,,,person
1,mval,2,,27,,person
1,age,2,,30,,person
3,bval,6,N,,,person
3,fname,1,Susan,,,person
3,lname,1,Blue,,,person
3,mval,6,N,,,person
3,age,2,,35,,person
```

`test_graph`.**ope**:

```
4,0,1,knows,mval,1,Y,,
4,0,1,knows,firstMetIn,1,MI,,
4,0,1,knows,since,5,,,1990-01-01T12:00:00.000Z
16,0,1,friendOf,strength,2,,6,
7,1,0,knows,mval,5,,,2003-01-01T12:00:00.000Z
7,1,0,knows,firstMetIn,1,GA,,
7,1,0,knows,since,5,,,2000-01-01T12:00:00.000Z
17,1,0,friendOf,strength,2,,7,
9,1,3,knows,mval,6,N,,
9,1,3,knows,firstMetIn,1,SC,,
9,1,3,knows,since,5,,,2005-01-01T12:00:00.000Z
10,2,0,knows,mval,1,N,,
10,2,0,knows,firstMetIn,1,TX,,
10,2,0,knows,since,5,,,1997-01-01T12:00:00.000Z
12,2,3,knows,mval,3,,342.5,
12,2,3,knows,firstMetIn,1,TX,,
12,2,3,knows,since,5,,,2011-01-01T12:00:00.000Z
19,2,3,friendOf,strength,2,,4,
14,3,1,knows,mval,1,a,,
14,3,1,knows,firstMetIn,1,CA,,
14,3,1,knows,since,5,,,2010-01-01T12:00:00.000Z
15,3,2,knows,mval,1,z,,
15,3,2,knows,firstMetIn,1,CA,,
15,3,2,knows,since,5,,,2004-01-01T12:00:00.000Z
5,0,2,knows,mval,2,,23,
5,0,2,knows,firstMetIn,1,OH,,
5,0,2,knows,since,5,,,2002-01-01T12:00:00.000Z
6,0,3,knows,mval,3,,159.7,
6,0,3,knows,firstMetIn,1,IN,,
6,0,3,knows,since,5,,,1994-01-01T12:00:00.000Z
8,1,2,knows,mval,6,Y,,
8,1,2,knows,firstMetIn,1,FL,,
8,1,2,knows,since,5,,,1999-01-01T12:00:00.000Z
18,1,3,friendOf,strength,2,,5,
11,2,1,knows,mval,2,,1001,
11,2,1,knows,firstMetIn,1,OK,,
11,2,1,knows,since,5,,,2003-01-01T12:00:00.000Z
13,3,0,knows,mval,5,,,2001-01-01T12:00:00.000Z
13,3,0,knows,firstMetIn,1,CA,,
```

```
13,3,0,knows,since,5,,,2006-01-01T12:00:00.000Z
20,3,1,friendOf,strength,2,,3,
```

- Basic Query Execution
- Security Techniques for PGQL Queries
- Using a Text Index with PGQL Queries
- Obtaining the SQL Translation for a PGQL Query
- Additional Options for PGQL Translation and Execution
- Querying Another User's Property Graph
- Using Query Optimizer Hints with PGQL
- Modifying Property Graphs through INSERT, UPDATE, and DELETE Statements

A.10.4.1 Basic Query Execution

Two main Java Interfaces, `PgqlStatement` and `PgqlResultSet`, are used for PGQL execution. This topic includes several examples of basic query execution.

Example A-27 GraphLoaderExample.java

`GraphLoaderExample.java` loads some Oracle property graph data that will be used in subsequent examples in this topic.

```
import oracle.pg.rdbms.Oracle;
import oracle.pg.rdbms.OraclePropertyGraph;
import oracle.pg.rdbms.OraclePropertyGraphDataLoader;

/**
 * This example shows how to create an Oracle Property Graph
 * and load data into it from vertex and edge flat files.
 */
public class GraphLoaderExample
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];
    String vertexFile         = args[idx++];
    String edgeFile           = args[idx++];

    Oracle oracle = null;
    OraclePropertyGraph opg = null;

    try {
      // Create a connection to Oracle
      oracle = new Oracle("jdbc:oracle:thin:@"+host+":"+port +":"+sid, user, 
password);
```

```
      // Create a property graph
      opg = OraclePropertyGraph.getInstance(oracle, graph);

      // Clear any existing data
      opg.clearRepository();

      // Load data from opv and ope files
      OraclePropertyGraphDataLoader opgLoader = 
OraclePropertyGraphDataLoader.getInstance();
      opgLoader.loadData(opg, vertexFile, edgeFile, 1);

      System.out.println("Vertices loaded:" + opg.countVertices());
      System.out.println("Edges loaded:" + opg.countEdges());

    }
    finally {
      // close the property graph
      if (opg != null) {
        opg.close();
      }
      // close oracle
      if (oracle != null) {
        oracle.dispose();
      }
    }
  }
}
```

`GraphLoaderExample.java` gives the following output for `test_graph`.

```
Vertices loaded:4
Edges loaded:17
```

Example A-28 PgqlExample1.java

`PgqlExample1.java` executes a PGQL query and prints the query result. `PgqlConnection` is used to obtain a `PgqlStatement`. Next, it calls the `executeQuery` method of `PgqlStatement`, which returns a `PgqlResultSet` object. `PgqlResultSet` provides a `print()` method, which shows results in a tabular mode.

The `PgqlResultSet` and `PgqlStatement` objects should be closed after consuming the query result.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to execute a basic PGQL query against disk-
```

```
resident
 * PG data stored in Oracle Database and iterate through the result.
 */
public class PgqlExample1
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Execute query to get a PgqlResultSet object
      String pgql =
        "SELECT v.\"fname\" AS fname, v.\"lname\" AS lname, v.\"mval\" AS
mval "+
        "FROM MATCH (v)";
      rs = ps.executeQuery(pgql, /* query string */
                           ""    /* options */);

      // Print the results
      rs.print();
    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
      }
      // close the statement
      if (ps != null) {
```

```
          ps.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
}
```

PgqlExample1.java gives the following output for test_graph (which can be loaded using GraphLoaderExample.java code).

```
+---------------------------------------+
| FNAME | LNAME | MVAL                  |
+---------------------------------------+
| Susan | Blue  | false                 |
| Bill  | Brown | y                     |
| Ray   | Green | 1985-01-01 04:00:00.0 |
| John  | Black | 27                    |
+---------------------------------------+
```

Example A-29 PgqlExample2.java

PgqlExample2.java shows a PGQL query with a temporal filter on an edge property.

- PgqlResultSet provides an interface for consuming the query result that is very similar to the java.sql.ResultSet interface.
- A next() method allows moving through the query result, and a close() method allows releasing resources after the application is fiished reading the query result.
- In addition, PgqlResultSet provides getters for String, Integer, Long, Float, Double, Boolean, LocalDateTime, and OffsetDateTime, and it provides a generic getObject() method for values of any type.

```
import java.sql.Connection;

import java.text.SimpleDateFormat;

import java.util.Date;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.pgql.lang.ResultSet;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to execute a PGQL query with a temporal edge
 * property filter against disk-resident PG data stored in Oracle
Database
 * and iterate through the result.
 */
public class PgqlExample2
```

```
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host              = args[idx++];
    String port              = args[idx++];
    String sid               = args[idx++];
    String user              = args[idx++];
    String password          = args[idx++];
    String graph             = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    ResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Create a Pgql connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Execute query to get a ResultSet object
      String pgql =
        "SELECT v.\"fname\" AS n1, v2.\"fname\" AS n2, e.\"firstMetIn\" AS 
loc "+
        "FROM MATCH (v)-[e:\"knows\"]->(v2) "+
        "WHERE e.\"since\" > TIMESTAMP '2000-01-01 00:00:00.00+00:00'";
      rs = ps.executeQuery(pgql, "");

      // Print results
      printResults(rs);
    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
      }
      // close the statement
      if (ps != null) {
        ps.close();
      }
      // close the connection
      if (conn != null) {
```

```
        conn.close();
      }
    }
  }

  /**
   * Prints a PGQL ResultSet
   */
  static void printResults(ResultSet rs) throws Exception
  {
    StringBuffer buff = new StringBuffer("");
    SimpleDateFormat sdf = new SimpleDateFormat("yyyy-MM-
dd'T'HH:mm:ss.SSSXXX");
    while (rs.next()) {
      buff.append("[");
      for (int i = 1; i <= rs.getMetaData().getColumnCount(); i++) {
        // use generic getObject to handle all types
        Object mval = rs.getObject(i);
        String mStr = "";
        if (mval instanceof java.lang.String) {
          mStr = "STRING: "+mval.toString();
        }
        else if (mval instanceof java.lang.Integer) {
          mStr = "INTEGER: "+mval.toString();
        }
        else if (mval instanceof java.lang.Long) {
          mStr = "LONG: "+mval.toString();
        }
        else if (mval instanceof java.lang.Float) {
          mStr = "FLOAT: "+mval.toString();
        }
        else if (mval instanceof java.lang.Double) {
          mStr = "DOUBLE: "+mval.toString();
        }
        else if (mval instanceof java.sql.Timestamp) {
          mStr = "DATE: "+sdf.format((Date)mval);
        }
        else if (mval instanceof java.lang.Boolean) {
          mStr = "BOOLEAN: "+mval.toString();
        }
        if (i > 1) {
          buff.append(",\t");
        }
        buff.append(mStr);
      }
      buff.append("]\n");
    }
    System.out.println(buff.toString());
  }
}
```

`PgqlExample2.java` gives the following output for `test_graph` (which can be loaded using `GraphLoaderExample.java` code).

```
[STRING: Susan, STRING: Bill,   STRING: CA]
[STRING: Susan, STRING: John,   STRING: CA]
[STRING: Susan, STRING: Ray,    STRING: CA]
[STRING: Bill,  STRING: Ray,    STRING: OH]
[STRING: Ray,   STRING: John,   STRING: OK]
[STRING: Ray,   STRING: Susan,  STRING: TX]
[STRING: John,  STRING: Susan,  STRING: SC]
[STRING: John,  STRING: Bill,   STRING: GA]
```

Example A-30 PgqlExample3.java

`PgqlExample3.java` shows a PGQL query with grouping and aggregation.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to execute a PGQL query with aggregation
 * against disk-resident PG data stored in Oracle Database and iterate
 * through the result.
 */
public class PgqlExample3
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host              = args[idx++];
    String port              = args[idx++];
    String sid               = args[idx++];
    String user              = args[idx++];
    String password          = args[idx++];
    String graph             = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {
      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Create a Pgql connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);
```

```
        // Create a PgqlStatement
        ps = pgqlConn.createStatement();

        // Execute query to get a ResultSet object
        String pgql =
          "SELECT v.\"fname\" AS \"fname\", COUNT(v2) AS \"friendCnt\" "+
          "FROM MATCH (v)-[e:\"friendOf\"]->(v2) "+
          "GROUP BY v "+
          "ORDER BY \"friendCnt\" DESC";
        rs = ps.executeQuery(pgql, "");

        // Print results
        rs.print();
      }
      finally {
        // close the result set
        if (rs != null) {
          rs.close();
        }
        // close the statement
        if (ps != null) {
          ps.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
  }
```

`PgqlExample3.java` gives the following output for `test_graph` (which can be loaded using `GraphLoaderExample.java` code).

```
+-------------------+
| fname | friendCnt |
+-------------------+
| John  | 2         |
| Bill  | 1         |
| Ray   | 1         |
| Susan | 1         |
+-------------------+
```

Example A-31 PgqlExample4.java

`PgqlExample4.java` shows a PGQL path query.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;
```

```
/**
 * This example shows how to execute a path query in PGQL against
 * disk-resident PG data stored in Oracle Database and iterate
 * through the result.
 */
public class PgqlExample4
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Create a Pgql connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

  // Execute query to get a ResultSet object
      String pgql =
        "PATH fof AS ()-[:\"friendOf\"|\"knows\"]->() "+
        "SELECT v2.\"fname\" AS friend "+
        "FROM MATCH (v)-/:fof*/->(v2) "+
        "WHERE v.\"fname\" = 'John' AND v != v2";
      rs = ps.executeQuery(pgql, "");

      // Print results
      rs.print();
    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
```

```
        }
        // close the statement
        if (ps != null) {
          ps.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
}
```

`PgqlExample4.java` gives the following output for `test_graph`(which can be loaded using `GraphLoaderExample.java` code).

```
+--------+
| FRIEND |
+--------+
| Susan  |
| Bill   |
| Ray    |
+--------+
```

A.10.4.2 Security Techniques for PGQL Queries

Programs executing dynamic queries might be subject to injection attacks that could compromise integrity and functioning of the applications.

This topic presents some techniques that can be used to prevent injection attacks when building PGQL queries using string concatenation.

- Using Bind Variables in PGQL Queries
- Verifying PGQL Identifiers

A.10.4.2.1 Using Bind Variables in PGQL Queries

Bind variables can be used in PGQL queries for better performance and increased security. Constant scalar values in PGQL queries can be replaced with bind variables. Bind variables are denoted by a '?' (question mark). Consider the following two queries that select people who are older than a constant age value.

```
// people older than 30
SELECT v.fname AS fname, v.lname AS lname, v.age AS age
FROM MATCH (v)
WHERE v.age > 30

// people older than 40
SELECT v.fname AS fname, v.lname AS lname, v.age AS age
FROM MATCH (v)
WHERE v.age > 40
```

The SQL translations for these queries would use the constants 30 and 40 in a similar way for the age filter. The database would perform a hard parse for each of these queries. This hard parse time can often exceed the execution time for simple queries.

You could replace the constant in each query with a bind variable as follows.

```
SELECT v.fname AS fname, v.lname AS lname, v.age AS age
FROM MATCH (v)
WHERE v.age > ?
```

This will allow the SQL engine to create a generic cursor for this query, which can be reused for different age values. As a result, a hard parse is no longer required to execute this query for different age values, and the parse time for each query will be drastically reduced.

In addition, applications that use bind variables in PGQL queries are less vulnerable to injection attacks than those that use string concatenation to embed constant values in PGQL queries.

See also *Oracle Database SQL Tuning Guide* for more information on cursor sharing and bind variables.

The `PgqlPreparedStatement` interface can be used to execute queries with bind variables as shown in `PgqlExample5.java`. `PgqlPreparedStatement` provides several set methods for different value types that can be used to set values for query execution.

There are a few limitations with bind variables in PGQL. Bind variables can only be used for constant property values. That is, vertices and edges cannot be replaced with bind variables. Also, once a particular bind variable has been set to a type, it cannot be set to a different type. For example, if `setInt(1, 30)` is executed for an `PgqlPreparedStatement`, you cannot call `setString(1, "abc")` on that same `PgqlPreparedStatement`.

Example A-32 PgqlExample5.java

`PgqlExample5.java` shows how to use bind variables with a PGQL query.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlPreparedStatement;
import oracle.pg.rdbms.pgql.PgqlResultSet;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to use bind variables with a PGQL query.
 */
public class PgqlExample5
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];
```

```
    Connection conn = null;
    PgqlPreparedStatement pps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();

pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Create a Pgql connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Query string with a bind variable (denoted by ?)
      String pgql =
        "SELECT v.\"fname\" AS fname, v.\"lname\" AS lname, v.\"age\"
AS age "+
        "FROM MATCH (v) "+
        "WHERE v.\"age\" > ?";

      // Create a PgqlPreparedStatement
      pps = pgqlConn.prepareStatement(pgql);

      // Set filter value to 30
      pps.setInt(1, 30);

      // execute query
      rs = pps.executeQuery();

      // Print query results
      System.out.println("-- Values for v.\"age\" > 30 --");
      rs.print();
      // close result set
      rs.close();

      // set filter value to 40
      pps.setInt(1, 40);

      // execute query
      rs = pps.executeQuery();

      // Print query results
      System.out.println("-- Values for v.\"age\" > 40 --");
      rs.print();
      // close result set
      rs.close();
    }
    finally {
      // close the result set
```

```
        if (rs != null) {
          rs.close();
        }
        // close the statement
        if (pps != null) {
          pps.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
}
```

`PgqlExample5.java` has the following output for `test_graph` (which can be loaded using `GraphLoaderExample.java` code).

```
-- Values for v.age > 30 --
+---------------------+
| fname | lname | age |
+---------------------+
| Susan | Blue  | 35  |
| Bill  | Brown | 40  |
| Ray   | Green | 41  |
+---------------------+
-- Values for v.age > 40 --
+---------------------+
| fname | lname | age |
+---------------------+
| Ray   | Green | 41  |
+---------------------+
```

Example A-33   PgqlExample6.java

`PgqlExample6.java` shows a query with two bind variables: one String variable and one Timestamp variable.

```
import java.sql.Connection;
import java.sql.Timestamp;

import java.time.OffsetDateTime;
import java.time.ZoneOffset;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlPreparedStatement;
import oracle.pg.rdbms.pgql.PgqlResultSet;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to use multiple bind variables with a PGQL query.
 */
public class PgqlExample6
{
```

```
  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host              = args[idx++];
    String port              = args[idx++];
    String sid               = args[idx++];
    String user              = args[idx++];
    String password          = args[idx++];
    String graph             = args[idx++];

    Connection conn = null;
    PgqlPreparedStatement pps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();

pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Create a Pgql connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Query string with multiple bind variables
      String pgql =
        "SELECT v1.\"fname\" AS fname1, v2.\"fname\" AS fname2 "+
        "FROM MATCH (v1)-[e:\"knows\"]->(v2) "+
        "WHERE e.\"since\" < ? AND e.\"firstMetIn\" = ?";

      // Create a PgqlPreparedStatement
      pps = pgqlConn.prepareStatement(pgql);

      // Set e.since < 2006-01-01T12:00:00.00Z
      Timestamp t =
Timestamp.valueOf(OffsetDateTime.parse("2006-01-01T12:00:01.00Z").atZon
eSameInstant(ZoneOffset.UTC).toLocalDateTime());
      pps.setTimestamp(1, t);
      // Set e.firstMetIn = 'CA'
      pps.setString(2, "CA");

      // execute query
      rs = pps.executeQuery();

      // Print query results
      System.out.println("-- Values for e.\"since\" <
2006-01-01T12:00:01.00Z AND e.\"firstMetIn\" = 'CA' --");
      rs.print();
      // close result set
```

```
      rs.close();

      // Set e.since < 2000-01-01T12:00:00.00Z
      t =
Timestamp.valueOf(OffsetDateTime.parse("2000-01-01T12:00:00.00Z").atZoneSameI
nstant(ZoneOffset.UTC).toLocalDateTime());
      pps.setTimestamp(1, t);
      // Set e.firstMetIn = 'TX'
      pps.setString(2, "TX");

      // execute query
      rs = pps.executeQuery();

      // Print query results
      System.out.println("-- Values for e.\"since\" <
2000-01-01T12:00:00.00Z AND e.\"firstMetIn\" = 'TX' --");
      rs.print();
      // close result set
      rs.close();
    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
      }
      // close the statement
      if (pps != null) {
        pps.close();
      }
      // close the connection
      if (conn != null) {
        conn.close();
      }
    }
  }
}
```

`PgqlExample6.java` gives the following output for `test_graph` (which can be loaded using `GraphLoaderExample.java` code).

```
-- Values for e."since" <  2006-01-01T12:00:01.00Z AND e."firstMetIn" = 'CA' --
+-----------------+
| FNAME1 | FNAME2 |
+-----------------+
| Susan  | Bill   |
| Susan  | Ray    |
+-----------------+
-- Values for e."since" <  2000-01-01T12:00:00.00Z AND e."firstMetIn" = 'TX' --
+-----------------+
| FNAME1 | FNAME2 |
+-----------------+
| Ray    | Bill   |
+-----------------+
```

A.10.4.2.2 Verifying PGQL Identifiers

For some parts of a PGQL query the parser does not allow use of bind variables. In such cases, the input can be verified using the `printIdentifier` method in package `oracle.pgql.lang.ir.PgqlUtils`.

Consider the following query execution that concatenates the graph against which the graph pattern will be matched:

```
stmt.executeQuery("SELECT n.name FROM MATCH (n) ON " + graphName, "");
```

In order to avoid injection, the identifier `graphName` should be verified as follows:

```
stmt.executeQuery("SELECT n.name FROM MATCH (n) ON " +
PgqlUtils.printIdentifier(graphName), "");
```

A.10.4.3 Using a Text Index with PGQL Queries

PGQL queries executed against Oracle Database can use Oracle Text indexes created for vertex and edge properties. After creating a text index, you can use the CONTAINS operator to perform a full text search. CONTAINS has two arguments: a vertex or edge property, and an Oracle Text search string. Any valid Oracle Text search string can be used, including advanced features such as wildcards, stemming, and soundex.

Example A-34 PgqlExample7.java

`PgqlExample7.java` shows how to execute a CONTAINS query.

```
import java.sql.CallableStatement;
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to use an Oracle Text index with a PGQL
query.
 */
public class PgqlExample7
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
```

```
String password          = args[idx++];
String graph             = args[idx++];

Connection conn = null;
PgqlStatement ps = null;
PgqlResultSet rs = null;

try {

  //Get a jdbc connection
  PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
  pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
  pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
  pds.setUser(user);
  pds.setPassword(password);
  conn = pds.getConnection();

  // Create text index with SQL API
  CallableStatement cs = null;
  // text index on vertices
  cs = conn.prepareCall(
    "begin opg_apis.create_vertices_text_idx(:1,:2); end;"
  );
  cs.setString(1,user);
  cs.setString(2,graph);
  cs.execute();
  cs.close();
  // text index on edges
  cs = conn.prepareCall(
    "begin opg_apis.create_edges_text_idx(:1,:2); end;"
  );
  cs.setString(1,user);
  cs.setString(2,graph);
  cs.execute();
  cs.close();

  // Get a PGQL connection
  PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
  pgqlConn.setGraph(graph);

  // Create a PgqlStatement
  ps = pgqlConn.createStatement();

  // Query using CONTAINS text search operator on vertex property
  // Find all vertices with an lname property value that starts with 'B'
  String pgql =
    "SELECT v.\"fname\" AS fname, v.\"lname\" AS lname "+
    "FROM MATCH (v) "+
    "WHERE CONTAINS(v.\"lname\",'B%')";

  // execute query
  rs = ps.executeQuery(pgql, "");

  // print results
  System.out.println("-- Vertex Property Query --");
```

```
      rs.print();

      // close result set
      rs.close();

      // Query using CONTAINS text search operator on edge property
      // Find all knows edges with a firstMetIn property value that
ends with 'A'
      pgql =
        "SELECT v1.\"fname\" AS fname1, v2.\"fname\" AS fname2,
e.\"firstMetIn\" AS loc "+
        "FROM MATCH (v1)-[e:\"knows\"]->(v2) "+
        "WHERE CONTAINS(e.\"firstMetIn\",'%A')";

      // execute query
      rs = ps.executeQuery(pgql, "");

      // print results
      System.out.println("-- Edge Property Query --");
      rs.print();

    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
      }
      // close the statement
      if (ps != null) {
        ps.close();
      }
      // close the connection
      if (conn != null) {
        conn.close();
      }
    }
  }
}
```

`PgqlExample7.java` has the following output for `test_graph` (which can be loaded using `GraphLoaderExample.java` code).

```
-- Vertex Property Query --
+---------------+
| FNAME | LNAME |
+---------------+
| Susan | Blue  |
| Bill  | Brown |
| John  | Black |
+---------------+
-- Edge Property Query --
+-----------------------+
| FNAME1 | FNAME1 | LOC |
+-----------------------+
| Susan  | Bill   | CA  |
| John   | Bill   | GA  |
```

```
| Susan  | John   | CA  |
| Susan  | Ray    | CA  |
+-----------------------+
```

A.10.4.4 Obtaining the SQL Translation for a PGQL Query

You can obtain the SQL translation for a PGQL query through methods in `PgqlStatement` and `PgqlPreparedStatement`. The raw SQL for a PGQL query can be useful for several reasons:

- You can execute the SQL directly against the database with other SQL-based tools or interfaces (for example, SQL*Plus or SQL Developer).
- You can customize and tune the generated SQL to optimize performance or to satisfy a particular requirement of your application.
- You can build a larger SQL query that joins a PGQL subquery with other data stored in Oracle Database (such as relational tables, spatial data, and JSON data).

Example A-35 PgqlExample8.java

`PgqlExample8.java` shows how to obtain the raw SQL translation for a PGQL query. The `translateQuery` method of `PgqlStatement` returns an `PgqlSqlQueryTrans` object that contains information about return columns from the query and the SQL translation itself.

The translated SQL returns different columns depending on the type of "logical" object or value projected from the PGQL query. A vertex or edge projected in PGQL has two corresponding columns projected in the translated SQL:

- $IT : id type – NVARCHAR(1): 'V' for vertex or 'E' for edge
- $ID : vertex or edge identifier – NUMBER: same content as VID or EID columns in VT$ and GE$ tables

A property value or constant scalar value projected in PGQL has four corresponding columns projected in the translated SQL:

- $T : value type – NUMBER: same content as T column in VT$ and GE$ tables
- $V: value – NVARCHAR2(15000): same content as V column in VT$ and GE$ tables
- $VN: number value – NUMBER: same content as VN column in VT$ and GE$ tables
- $VT: temporal value – TIMESTAMP WITH TIME ZONE: same content as VT column in VT$ and GE$ tables

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlColumnDescriptor;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;
import oracle.pg.rdbms.pgql.PgqlSqlQueryTrans;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to obtain the SQL translation for a PGQL query.
 */
public class PgqlExample8
{
```

```
  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host              = args[idx++];
    String port              = args[idx++];
    String sid               = args[idx++];
    String user              = args[idx++];
    String password          = args[idx++];
    String graph             = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();

pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Create a Pgql connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // PGQL query to be translated
      String pgql =
        "SELECT v1, v1.\"fname\" AS fname1, e, e.\"since\" AS since "+
        "FROM MATCH (v1)-[e:\"knows\"]->(v2)";

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Get the SQL translation
      PgqlSqlQueryTrans sqlTrans = ps.translateQuery(pgql,"");

      // Get the return column descriptions
      PgqlColumnDescriptor[] cols = sqlTrans.getReturnTypes();

      // Print column descriptions
      System.out.println("-- Return Columns -----------------------");
      printReturnCols(cols);

      // Print SQL translation
      System.out.println("-- SQL Translation ----------------------");
      System.out.println(sqlTrans.getSqlTranslation());
    }
    finally {
      // close the statement
      if (ps != null) {
        ps.close();
```

```
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }

    /**
     * Prints return columns for a SQL translation
     */
    static void printReturnCols(PgqlColumnDescriptor[] cols) throws Exception
    {
      StringBuffer buff = new StringBuffer("");

      for (int i = 0; i < cols.length; i++) {

        String colName = cols[i].getColName();
        PgqlColumnDescriptor.Type colType = cols[i].getColType();
        int offset = cols[i].getSqlOffset();

        String readableType = "";
        switch(colType) {
          case VERTEX:
            readableType = "VERTEX";
            break;
          case EDGE:
            readableType = "EDGE";
            break;
          case VALUE:
            readableType = "VALUE";
            break;
        }

        buff.append("colName=["+colName+"] colType=["+readableType+"]
offset=["+offset+"]\n");
      }
      System.out.println(buff.toString());
    }
}
```

`PgqlExample8.java` has the following output for `test_graph` (which can be loaded using `GraphLoaderExample.java` code).

```
-- Return Columns -----------------------
colName=[v1] colType=[VERTEX] offset=[1]
colName=[fname1] colType=[VALUE] offset=[3]
colName=[e] colType=[EDGE] offset=[7]
colName=[since] colType=[VALUE] offset=[9]
-- SQL Translation ----------------------
SELECT n'V' AS "V1$IT",
T0$0.SVID AS "V1$ID",
T0$1.T AS "FNAME1$T",
T0$1.V AS "FNAME1$V",
T0$1.VN AS "FNAME1$VN",
T0$1.VT AS "FNAME1$VT",
```

```
n'E' AS "E$IT",
T0$0.EID AS "E$ID",
T0$0.T AS "SINCE$T",
T0$0.V AS "SINCE$V",
T0$0.VN AS "SINCE$VN",
T0$0.VT AS "SINCE$VT"
FROM ( SELECT L.EID, L.SVID, L.DVID, L.EL, R.K, R.T, R.V, R.VN, R.VT
  FROM "SCOTT".TEST_GRAPHGT$ L,
       (SELECT * FROM "SCOTT".TEST_GRAPHGE$ WHERE K=n'since' ) R
  WHERE L.EID = R.EID(+)
) T0$0,
( SELECT L.VID, L.VL, R.K, R.T, R.V, R.VN, R.VT
  FROM "SCOTT".TEST_GRAPHVD$ L,
       (SELECT * FROM "SCOTT".TEST_GRAPHVT$ WHERE K=n'fname' ) R
  WHERE L.VID = R.VID(+)
) T0$1
WHERE T0$0.SVID=T0$1.VID AND
(T0$0.EL = n'knows' AND T0$0.EL IS NOT NULL)
```

Example A-36 PgqlExample9.java

You can also obtain the SQL translation for PGQL queries with bind variables. In this case, the corresponding SQL translation will also contain bind variables. The `PgqlSqlQueryTrans` interface has a `getSqlBvList` method that returns an ordered List of Java Objects that should be bound to the SQL query (the first Object on the list should be set at position 1, and the second should be set at position 2, and so on).

`PgqlExample9.java` shows how to get and execute the SQL for a PGQL query with bind variables.

```
import java.sql.Connection;
import java.sql.PreparedStatement;
import java.sql.ResultSet;
import java.sql.Timestamp;

import java.util.List;

import oracle.pg.rdbms.pgql.PgqlColumnDescriptor;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlPreparedStatement;
import oracle.pg.rdbms.pgql.PgqlSqlQueryTrans;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to obtain and execute the SQL translation
for a
 * PGQL query that uses bind variables.
 */
public class PgqlExample9
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
```

```
    String port                = args[idx++];
    String sid                 = args[idx++];
    String user                = args[idx++];
    String password            = args[idx++];
    String graph               = args[idx++];

    Connection conn = null;
    PgqlPreparedStatement pgqlPs = null;

    PreparedStatement sqlPs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Create a Pgql connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Execute query to get a ResultSet object
      String pgql =
        "SELECT v1, v1.\"fname\" AS fname1, v1.\"age\" AS age, ? as constVal
"+
        "FROM MATCH (v1) "+
        "WHERE  v1.\"fname\" = ? OR v1.\"age\" < ?";


      // Create a PgqlStatement
      pgqlPs = pgqlConn.prepareStatement(pgql);

      // set bind values
      pgqlPs.setDouble(1, 2.05d);
      pgqlPs.setString(2, "Bill");
      pgqlPs.setInt(3, 35);

      // Get the SQL translation
      PgqlSqlQueryTrans sqlTrans = pgqlPs.translateQuery("");

      // Get the SQL String
      String sqlStr = sqlTrans.getSqlTranslation();

      // Get the return column descriptions
      PgqlColumnDescriptor[] cols = sqlTrans.getReturnTypes();

      // Get the bind values
      List<Object> bindVals = sqlTrans.getSqlBvList();

      // Print column descriptions
      System.out.println("-- Return Columns -----------------------");
```

```
        printReturnCols(cols);

        // Print SQL translation
        System.out.println("-- SQL Translation ----------------------");
        System.out.println(sqlStr);

        // Print Bind Values
        System.out.println("\n-- Bind Values
--------------------------");
        for (Object obj : bindVals) {
          System.out.println(obj.toString());
        }

        // Execute Query
        // Get PreparedStatement
        sqlPs = conn.prepareStatement("SELECT COUNT(*) FROM
("+sqlStr+")");
        // Set bind values and execute the PreparedStatement
        executePs(sqlPs, bindVals);

        // Set new bind values in the PGQL PreparedStatement
        pgqlPs.setDouble(1, 3.02d);
        pgqlPs.setString(2, "Ray");
        pgqlPs.setInt(3, 30);

        // Print Bind Values
        bindVals = sqlTrans.getSqlBvList();
        System.out.println("\n-- Bind Values
--------------------------");
        for (Object obj : bindVals) {
          System.out.println(obj.toString());
        }

        // Execute the PreparedStatement with new bind values
        executePs(sqlPs, bindVals);
      }
      finally {
        // close the SQL statement
        if (sqlPs != null) {
          sqlPs.close();
        }
        // close the statement
        if (pgqlPs != null) {
          pgqlPs.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }

    /**
     * Executes a SQL PreparedStatement with the input bind values
     */
```

```
  static void executePs(PreparedStatement ps, List<Object> bindVals) throws
Exception
  {
    ResultSet rs = null;
    try {
      // Set bind values
      for (int idx = 0; idx < bindVals.size(); idx++) {
        Object o = bindVals.get(idx);
        // String
        if (o instanceof java.lang.String) {
          ps.setNString(idx + 1, (String)o);
        }
        // Int
        else if (o instanceof java.lang.Integer) {
          ps.setInt(idx + 1, ((Integer)o).intValue());
        }
        // Long
        else if (o instanceof java.lang.Long) {
          ps.setLong(idx + 1, ((Long)o).longValue());
        }
        // Float
        else if (o instanceof java.lang.Float) {
          ps.setFloat(idx + 1, ((Float)o).floatValue());
        }
        // Double
        else if (o instanceof java.lang.Double) {
          ps.setDouble(idx + 1, ((Double)o).doubleValue());
        }
       // Timestamp
       else if (o instanceof java.sql.Timestamp) {
         ps.setTimestamp(idx + 1, (Timestamp)o);
       }
       else {
         ps.setString(idx + 1, bindVals.get(idx).toString());
       }
     }

      // Execute query
      rs = ps.executeQuery();
      if (rs.next()) {
        System.out.println("\n-- Execute Query: Result has "+rs.getInt(1)+"
rows --");
      }
    }
    finally {
      // close the SQL ResultSet
      if (rs != null) {
        rs.close();
      }
    }
  }

  /**
   * Prints return columns for a SQL translation
   */
```

```
  static void printReturnCols(PgqlColumnDescriptor[] cols) throws
Exception
  {
    StringBuffer buff = new StringBuffer("");

    for (int i = 0; i < cols.length; i++) {

      String colName = cols[i].getColName();
      PgqlColumnDescriptor.Type colType = cols[i].getColType();
      int offset = cols[i].getSqlOffset();

      String readableType = "";
      switch(colType) {
        case VERTEX:
          readableType = "VERTEX";
          break;
        case EDGE:
          readableType = "EDGE";
          break;
        case VALUE:
          readableType = "VALUE";
          break;
      }

      buff.append("colName=["+colName+"] colType=["+readableType+"]
offset=["+offset+"]\n");
    }
    System.out.println(buff.toString());
  }
}
```

`PgqlExample9.java` has the following output for `test_graph` (which can be loaded using `GraphLoaderExample.java` code).

```
--- Return Columns -----------------------
colName=[v1] colType=[VERTEX] offset=[1]
colName=[fname1] colType=[VALUE] offset=[3]
colName=[age] colType=[VALUE] offset=[7]
colName=[constVal] colType=[VALUE] offset=[11]
-- SQL Translation ----------------------
SELECT n'V' AS "V1$IT",
T0$0.VID AS "V1$ID",
T0$0.T AS "FNAME1$T",
T0$0.V AS "FNAME1$V",
T0$0.VN AS "FNAME1$VN",
T0$0.VT AS "FNAME1$VT",
T0$1.T AS "AGE$T",
T0$1.V AS "AGE$V",
T0$1.VN AS "AGE$VN",
T0$1.VT AS "AGE$VT",
4 AS "CONSTVAL$T",
to_nchar(?,'TM9','NLS_Numeric_Characters=''.,''') AS "CONSTVAL$V",
? AS "CONSTVAL$VN",
to_timestamp_tz(null) AS "CONSTVAL$VT"
FROM ( SELECT L.VID, L.VL, R.K, R.T, R.V, R.VN, R.VT
  FROM "SCOTT".TEST_GRAPHVD$ L,
       (SELECT * FROM "SCOTT".TEST_GRAPHVT$ WHERE K=n'fname' ) R
```

```
  WHERE L.VID = R.VID(+)
) T0$0,
( SELECT L.VID, L.VL, R.K, R.T, R.V, R.VN, R.VT
  FROM "SCOTT".TEST_GRAPHVD$ L,
       (SELECT * FROM "SCOTT".TEST_GRAPHVT$ WHERE K=n'age' ) R
  WHERE L.VID = R.VID(+)
) T0$1
WHERE T0$0.VID=T0$1.VID AND
((T0$0.T = 1 AND T0$0.V = ?) OR T0$1.VN < ?)

-- Bind Values --------------------------
2.05
2.05
Bill
35
-- Execute Query: Result has 2 rows --

-- Bind Values --------------------------
3.02
3.02
Ray
30
-- Execute Query: Result has 1 rows --
```

A.10.4.5 Additional Options for PGQL Translation and Execution

Several options are available to influence PGQL query translation and execution. The following are the main ways to set query options:

- Through explicit arguments to `executeQuery` and `translateQuery`
- Through flags in the `options` string argument of `executeQuery` and `translateQuery`
- Through Java JVM arguments.

The following table summarizes the available query arguments for PGQL translation and execution.

Table A-3 PGQL Translation and Execution Options

Option	Default	Explict Argument	Options Flag	JVM Argument
Degree of parallelism	0	parallel	none	none
Timeout	unlimited	timeout	none	none
Dynamic sampling	2	dynamicSampling	none	none
Maximum number of results	unlimited	maxResults	none	none
GT$ table usage	on	none	USE_GT_TAB=F	-Doracle.pg.rdbms.pgql.useGtTab=false
CONNECT BY usage	off	none	USE_RW=F	-Doracle.pg.rdbms.pgql.useRW=false

Table A-3 (Cont.) PGQL Translation and Execution Options

Option	Default	Explict Argument	Options Flag	JVM Argument
Distinct recursive WITH usage	off	none	USE_DIST_RW=T	-Doracle.pg.rdbms.pgql.useDistRW=true
Maximum path length	unlimited	none	MAX_PATH_LEN=n	-Doracle.pg.rdbms.pgql.maxPathLen=n
Project null properties	true	none	PROJ_NULL_PROPS=F	-Doracle.pg.rdbms.pgql.projNullProps=false
VT$ VL column usage	on	none	USE_VL_COL=F	-Doracle.pg.rdbms.pgql.useVLCol=false

- Query Options Controlled by Explicit Arguments
- Using the GT$ Skeleton Table
- Path Query Options
- Options for Partial Object Construction

A.10.4.5.1 Query Options Controlled by Explicit Arguments

Some query options are controlled by explicit arguments to methods in the Java API.

- The `executeQuery` method of `PgqlStatement` has explicit arguments for timeout in seconds, degree of parallelism, optimizer dynamic sampling, and maximum number of results.
- The `translateQuery` method has explicit arguments for degree of parallelism, optimizer dynamic sampling, and maximum number of results. `PgqlPreparedStatement` also provides those same additional arguments for `executeQuery` and `translateQuery`.

Example A-37 PgqlExample10.java

`PgqlExample10.java` shows PGQL query execution with additional options controlled by explicit arguments.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to execute a PGQL query with various options.
 */
```

```
public class PgqlExample10
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Execute query to get a ResultSet object
      String pgql =
        "SELECT v1.\"fname\" AS fname1, v2.\"fname\" AS fname2 "+
        "FROM MATCH (v1)-[:\"friendOf\"]->(v2)";
      rs = ps.executeQuery(pgql /* query string */,
                           100  /* timeout (sec): 0 is default and implies
no timeout */,
                           2    /* parallel: 1 is default */,
                           6    /* dynamic sampling: 2 is default */,
                           50   /* max results: -1 is default and implies no
limit */,
                           ""   /* options */);

      // Print query results
      rs.print();
    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
      }
```

```
        // close the statement
        if (ps != null) {
          ps.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
}
```

PgqlExample10.java gives the following output for test_graph (which can be loaded using GraphLoaderExample.java code).

```
+-----------------+
| FNAME1 | FNAME2 |
+-----------------+
| Ray    | Susan  |
| John   | Susan  |
| Bill   | John   |
| Susan  | John   |
| John   | Bill   |
+-----------------+
```

A.10.4.5.2 Using the GT$ Skeleton Table

The property graph relational schema defines a GT$ skeleton table that stores a single row for each edge in the graph, no matter how many properties an edge has. This skeleton table is populated by default so that PGQL query execution can take advantage of the GT$ table and avoid sorting operations on the GE$ table in many cases, which gives a significant performance improvement.

You can add "USE_GT_TAB=F" to the options argument of executeQuery and translateQuery or use -Doracle.pg.rdbms.pgql.useGtTab=false in the Java command line to turn off GT$ table usage.

Example A-38 PgqlExample11.java

PgqlExample11.java shows a query that uses the GT$ skeleton table.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlSqlQueryTrans;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to avoid using the GT$ skeleton table for
 * PGQL query execution.
 */
public class PgqlExample11
{
```

```
  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host              = args[idx++];
    String port              = args[idx++];
    String sid               = args[idx++];
    String user              = args[idx++];
    String password          = args[idx++];
    String graph             = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Execute query to get a ResultSet object
      String pgql =
        "SELECT id(v1), id(v2) "+
        "FROM MATCH (v1)-[knows]->(v2)";

      // Get the SQL translation with GT table
      PgqlSqlQueryTrans sqlTrans = ps.translateQuery(pgql,"");

      // Print SQL translation
      System.out.println("-- SQL Translation with GT Table
----------------------");
      System.out.println(sqlTrans.getSqlTranslation());

      // Get the SQL translation without GT table
      sqlTrans = ps.translateQuery(pgql,"USE_GT_TAB=F");

      // Print SQL translation
      System.out.println("-- SQL Translation without GT Table
-------------------------");
      System.out.println(sqlTrans.getSqlTranslation());

    }
    finally {
      // close the statement
```

```
        if (ps != null) {
          ps.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
  }
```

`PgqlExample11.java` gives the following output for `test_graph` (which can be loaded using `GraphLoaderExample.java` code).

```
-- SQL Translation with GT Table ----------------------
SELECT 7 AS "id(v1)$T",
to_nchar(T0$0.SVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v1)$V",
T0$0.SVID AS "id(v1)$VN",
to_timestamp_tz(null) AS "id(v1)$VT",
7 AS "id(v2)$T",
to_nchar(T0$0.DVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v2)$V",
T0$0.DVID AS "id(v2)$VN",
to_timestamp_tz(null) AS "id(v2)$VT"
FROM "SCOTT".TEST_GRAPHGT$ T0$0
-- SQL Translation without GT Table -------------------------
SELECT 7 AS "id(v1)$T",
to_nchar(T0$0.SVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v1)$V",
T0$0.SVID AS "id(v1)$VN",
to_timestamp_tz(null) AS "id(v1)$VT",
7 AS "id(v2)$T",
to_nchar(T0$0.DVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v2)$V",
T0$0.DVID AS "id(v2)$VN",
to_timestamp_tz(null) AS "id(v2)$VT"
FROM (SELECT DISTINCT EID, SVID, DVID,EL FROM "SCOTT".TEST_GRAPHGE$) T0$0
```

A.10.4.5.3 Path Query Options

A few options are available for executing path queries in PGQL. There are two basic evaluation methods available in Oracle SQL: CONNECT BY or recursive WITH clauses. Recursive WITH is the default evaluation method. In addition, you can further modify the recursive WITH evaluation method to include a DISTINCT modifier during the recursive step of query evaluation. Computing distinct vertices at each step helps prevent a combinatorial explosion in highly connected graphs. The DISTINCT modifier is not added by default because it requires a specific parameter setting in the database (`"_recursive_with_control"=8`).

You can also control the maximum length of paths searched. Path length in this case is defined as the number of repetitions allowed when evaluating the * and + operators. The default maximum length is unlimited.

Path evaluation options are summarized as follows.

- **CONNECT BY:** To use CONNECT BY, specify `'USE_RW=F'` in the `options` argument or specify `-Doracle.pg.rdbms.pgql.useRW=false` in the Java command line.
- **Distinct Modifier in Recursive WITH:** To use the DISTINCT modifier in the recursive step, first set `"_recursive_with_control"=8` in your database session,

then specify 'USE_DIST_RW=T' in the options argument or specify -Doracle.pg.rdbms.pgql.useDistRW=true in the Java command line. You will encounter ORA-32486: unsupported operation in recursive branch of recursive WITH clause if "_recursive_with_control" has not been set to 8 in your session.

- **Path Length Restriction:** To limit maximum number of repetitions when evaluating * and + to n, specify 'MAX_PATH_LEN=n' in the query options argument or specify -Doracle.pg.rdbms.pgql.maxPathLen=n in the Java command line.

Example A-39 PgqlExample12.java

PgqlExample12.java shows path query translations under various options.

```
import java.sql.Connection;
import java.sql.Statement;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlSqlQueryTrans;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to use various options with PGQL path queries.
 */
public class PgqlExample12
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);
```

```
      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Set "_recursive_with_control"=8 to enable distinct
optimization
      // optimization for recursive with
      Statement stmt = conn.createStatement();
      stmt.executeUpdate("alter session set
\"_recursive_with_control\"=8");
      stmt.close();

      // Path Query to illustrate options
      String pgql =
        "PATH fof AS ()-[:\"friendOf\"]->() "+
        "SELECT id(v1), id(v2) "+
        "FROM MATCH (v1)-/:fof*/->(v2) "+
        "WHERE id(v1) = 2";


      // get SQL translation with defaults - Non-distinct Recursive
WITH
      PgqlSqlQueryTrans sqlTrans =
        ps.translateQuery(pgql /* query string */,
                          2    /* parallel: default is 1 */,
                          2    /* dynamic sampling: default is 2 */,
                          -1   /* max results: -1 implies no limit */,
                          ""   /* options */);
      System.out.println("-- Default Path Translation
--------------------");
      System.out.println(sqlTrans.getSqlTranslation()+"\n");

      // get SQL translation with DISTINCT reachability optimization
      sqlTrans =
        ps.translateQuery(pgql /* query string */,
                          2    /* parallel: default is 1 */,
                          2    /* dynamic sampling: default is 2 */,
                          -1   /* max results: -1 implies no limit */,
                          " USE_DIST_RW=T " /* options */);
      System.out.println("-- DISTINCT RW Path Translation
--------------------");
      System.out.println(sqlTrans.getSqlTranslation()+"\n");

      // get SQL translation with CONNECT BY
      sqlTrans =
        ps.translateQuery(pgql /* query string */,
                          2    /* parallel: default is 1 */,
                          2    /* dynamic sampling: default is 2 */,
                          -1   /* max results: -1 implies no limit */,
                          " USE_RW=F " /* options */);
      System.out.println("-- CONNECT BY Path Translation
--------------------");
      System.out.println(sqlTrans.getSqlTranslation()+"\n");
    }
    finally {
      // close the statement
```

```
        if (ps != null) {
          ps.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
  }
```

`PgqlExample12.java` gives the following output for `test_graph` (which can be loaded using `GraphLoaderExample.java` code).

```
-- Default Path Translation --------------------
SELECT /*+ parallel(2) */ * FROM(SELECT 7 AS "id(v1)$T",
to_nchar(T0$0.SVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v1)$V",
T0$0.SVID AS "id(v1)$VN",
to_timestamp_tz(null) AS "id(v1)$VT",
7 AS "id(v2)$T",
to_nchar(T0$0.DVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v2)$V",
T0$0.DVID AS "id(v2)$VN",
to_timestamp_tz(null) AS "id(v2)$VT"
FROM (/*Path[*/SELECT DISTINCT SVID, DVID
FROM (
SELECT 2 AS SVID, 2 AS DVID
FROM SYS.DUAL
WHERE EXISTS(
SELECT 1
FROM "SCOTT".TEST_GRAPHVT$
WHERE VID = 2)
UNION ALL
SELECT SVID,DVID FROM
(WITH RW (ROOT, DVID) AS
( SELECT ROOT, DVID FROM
(SELECT SVID ROOT, DVID
FROM (SELECT T0$0.SVID AS SVID,
T0$0.DVID AS DVID
FROM "SCOTT".TEST_GRAPHGT$ T0$0
WHERE T0$0.SVID = 2 AND
(T0$0.EL = n'friendOf' AND T0$0.EL IS NOT NULL))
) UNION ALL
SELECT RW.ROOT, R.DVID
FROM (SELECT T0$0.SVID AS SVID,
T0$0.DVID AS DVID
FROM "SCOTT".TEST_GRAPHGT$ T0$0
WHERE (T0$0.EL = n'friendOf' AND T0$0.EL IS NOT NULL)) R, RW
WHERE RW.DVID = R.SVID )
CYCLE DVID SET cycle_col TO 1 DEFAULT 0
SELECT ROOT SVID, DVID FROM RW))/*]Path*/) T0$0
WHERE T0$0.SVID = 2)

-- DISTINCT RW Path Translation --------------------
SELECT /*+ parallel(2) */ * FROM(SELECT 7 AS "id(v1)$T",
to_nchar(T0$0.SVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v1)$V",
T0$0.SVID AS "id(v1)$VN",
to_timestamp_tz(null) AS "id(v1)$VT",
7 AS "id(v2)$T",
to_nchar(T0$0.DVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v2)$V",
```

```
T0$0.DVID AS "id(v2)$VN",
to_timestamp_tz(null) AS "id(v2)$VT"
FROM (/*Path[*/SELECT DISTINCT SVID, DVID
FROM (
SELECT 2 AS SVID, 2 AS DVID
FROM SYS.DUAL
WHERE EXISTS(
SELECT 1
FROM "SCOTT".TEST_GRAPHVT$
WHERE VID = 2)
UNION ALL
SELECT SVID,DVID FROM
(WITH RW (ROOT, DVID) AS
( SELECT ROOT, DVID FROM
(SELECT SVID ROOT, DVID
FROM (SELECT T0$0.SVID AS SVID,
T0$0.DVID AS DVID
FROM "SCOTT".TEST_GRAPHGT$ T0$0
WHERE T0$0.SVID = 2 AND
(T0$0.EL = n'friendOf' AND T0$0.EL IS NOT NULL))
) UNION ALL
SELECT DISTINCT RW.ROOT, R.DVID
FROM (SELECT T0$0.SVID AS SVID,
T0$0.DVID AS DVID
FROM "SCOTT".TEST_GRAPHGT$ T0$0
WHERE (T0$0.EL = n'friendOf' AND T0$0.EL IS NOT NULL)) R, RW
WHERE RW.DVID = R.SVID )
CYCLE DVID SET cycle_col TO 1 DEFAULT 0
SELECT ROOT SVID, DVID FROM RW))/*]Path*/) T0$0
WHERE T0$0.SVID = 2)

-- CONNECT BY Path Translation --------------------
SELECT /*+ parallel(2) */ * FROM(SELECT 7 AS "id(v1)$T",
to_nchar(T0$0.SVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v1)$V",
T0$0.SVID AS "id(v1)$VN",
to_timestamp_tz(null) AS "id(v1)$VT",
7 AS "id(v2)$T",
to_nchar(T0$0.DVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v2)$V",
T0$0.DVID AS "id(v2)$VN",
to_timestamp_tz(null) AS "id(v2)$VT"
FROM (/*Path[*/SELECT DISTINCT SVID, DVID
FROM (
SELECT 2 AS SVID, 2 AS DVID
FROM SYS.DUAL
WHERE EXISTS(
SELECT 1
FROM "SCOTT".TEST_GRAPHVT$
WHERE VID = 2)
UNION ALL
SELECT SVID, DVID
FROM
(SELECT CONNECT_BY_ROOT T0$0.SVID AS SVID, T0$0.DVID AS DVID
FROM(
SELECT T0$0.SVID AS SVID,
T0$0.DVID AS DVID
FROM "SCOTT".TEST_GRAPHGT$ T0$0
WHERE (T0$0.EL = n'friendOf' AND T0$0.EL IS NOT NULL)) T0$0
START WITH T0$0.SVID = 2
CONNECT BY NOCYCLE PRIOR DVID = SVID))/*]Path*/) T0$0
WHERE T0$0.SVID = 2)
```

The query plan for the first query with the default recursive WITH strategy should look similar to the following.

```
-- default RW
---------------------------------------------------------------------------------------
| Id  | Operation                                          | Name                       |
---------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT                                   |                            |
|   1 |  TEMP TABLE TRANSFORMATION                         |                            |
|   2 |   LOAD AS SELECT (CURSOR DURATION MEMORY)          | SYS_TEMP_0FD9D6662_37AA44 |
|   3 |    UNION ALL (RECURSIVE WITH) BREADTH FIRST        |                            |
|   4 |     PX COORDINATOR                                 |                            |
|   5 |      PX SEND QC (RANDOM)                           | :TQ20000                   |
|   6 |       LOAD AS SELECT (CURSOR DURATION MEMORY)      | SYS_TEMP_0FD9D6662_37AA44 |
|   7 |        PX PARTITION HASH ALL                       |                            |
|*  8 |     TABLE ACCESS BY LOCAL INDEX ROWID BATCHED      | TEST_GRAPHGT$              |
|*  9 |      INDEX RANGE SCAN                              | TEST_GRAPHXSG$             |
|  10 |     PX COORDINATOR                                 |                            |
|  11 |      PX SEND QC (RANDOM)                           | :TQ10000                   |
|  12 |       LOAD AS SELECT (CURSOR DURATION MEMORY)      | SYS_TEMP_0FD9D6662_37AA44 |
|  13 |        NESTED LOOPS                                |                            |
|  14 |     PX BLOCK ITERATOR                              |                            |
|* 15 |      TABLE ACCESS FULL                             | SYS_TEMP_0FD9D6662_37AA44 |
|  16 |     PARTITION HASH ALL                             |                            |
|* 17 |      TABLE ACCESS BY LOCAL INDEX ROWID BATCHED     | TEST_GRAPHGT$              |
|* 18 |       INDEX RANGE SCAN                             | TEST_GRAPHXSG$             |
|  19 |   PX COORDINATOR                                   |                            |
|  20 |    PX SEND QC (RANDOM)                             | :TQ30001                   |
|  21 |     VIEW                                           |                            |
|  22 |      HASH UNIQUE                                   |                            |
|  23 |       PX RECEIVE                                   |                            |
|  24 |        PX SEND HASH                                | :TQ30000                   |
|  25 |     HASH UNIQUE                                    |                            |
|  26 |      VIEW                                          |                            |
|  27 |       UNION-ALL                                    |                            |
|  28 |        PX SELECTOR                                 |                            |
|* 29 |         FILTER                                     |                            |
|  30 |          FAST DUAL                                 |                            |
|  31 |          PARTITION HASH SINGLE                     |                            |
|* 32 |           INDEX SKIP SCAN                          | TEST_GRAPHXQV$             |
|  33 |        VIEW                                        |                            |
|* 34 |         VIEW                                       |                            |
|  35 |          PX BLOCK ITERATOR                         |                            |
|  36 |           TABLE ACCESS FULL                        | SYS_TEMP_0FD9D6662_37AA44 |
---------------------------------------------------------------------------------------
```

The query plan for the second query that adds a DISTINCT modifier in the recursive step should look similar to the following.

```
---------------------------------------------------------------------------------------
-----
| Id  | Operation                                                    |
Name                        |
---------------------------------------------------------------------------------------
-----
|   0 | SELECT STATEMENT
|                            |
|   1 |  TEMP TABLE TRANSFORMATION
|                            |
|   2 |   LOAD AS SELECT (CURSOR DURATION MEMORY)                    |
SYS_TEMP_0FD9D6669_37AA44 |
```

```
|   3 |    UNION ALL (RECURSIVE WITH) BREADTH FIRST
|                            |
|   4 |     PX COORDINATOR
|                            |
|   5 |      PX SEND QC (RANDOM)
| :TQ20000                   |
|   6 |       LOAD AS SELECT (CURSOR DURATION MEMORY)           |
SYS_TEMP_0FD9D6669_37AA44 |
|   7 |        PX PARTITION HASH ALL
|                            |
|*  8 |     TABLE ACCESS BY LOCAL INDEX ROWID BATCHED           |
TEST_GRAPHGT$              |
|*  9 |      INDEX RANGE SCAN                                   |
TEST_GRAPHXSG$             |
|  10 |     PX COORDINATOR
|                            |
|  11 |      PX SEND QC (RANDOM)
| :TQ10001                   |
|  12 |       LOAD AS SELECT (CURSOR DURATION MEMORY)           |
SYS_TEMP_0FD9D6669_37AA44 |
|  13 |        SORT GROUP BY
|                            |
|  14 |     PX RECEIVE
|                            |
|  15 |      PX SEND HASH
| :TQ10000                   |
|  16 |       SORT GROUP BY
|                            |
|  17 |        NESTED LOOPS
|                            |
|  18 |         PX BLOCK ITERATOR
|                            |
|* 19 |          TABLE ACCESS FULL                              |
SYS_TEMP_0FD9D6669_37AA44 |
|  20 |         PARTITION HASH ALL
|                            |
|* 21 |          TABLE ACCESS BY LOCAL INDEX ROWID BATCHED      |
TEST_GRAPHGT$              |
|* 22 |           INDEX RANGE SCAN                              |
TEST_GRAPHXSG$             |
|  23 |   PX COORDINATOR
|                            |
|  24 |    PX SEND QC (RANDOM)
| :TQ30001                   |
|  25 |     VIEW
|                            |
|  26 |      HASH UNIQUE
|                            |
|  27 |       PX RECEIVE
|                            |
|  28 |        PX SEND HASH
| :TQ30000                   |
|  29 |     HASH UNIQUE
|                            |
|  30 |      VIEW
|                            |
|  31 |       UNION-ALL
|                            |
|  32 |        PX SELECTOR
|                            |
|* 33 |         FILTER
```

```
|                           |
|  34 |          FAST DUAL
|                           |
|  35 |          PARTITION HASH SINGLE
|                           |
|* 36 |           INDEX SKIP SCAN                          |
TEST_GRAPHXQV$              |
|  37 |        VIEW
|                           |
|* 38 |         VIEW
|                           |
|  39 |          PX BLOCK ITERATOR
|                           |
|  40 |           TABLE ACCESS FULL                        |
SYS_TEMP_0FD9D6669_37AA44 |
---------------------------------------------------------------------------------------
-----
```

The query plan for the third query that uses CONNECTY BY should look similar to the following.

```
-----------------------------------------------------------------------------
| Id  | Operation                                  | Name                 |
-----------------------------------------------------------------------------
|   0 | SELECT STATEMENT                           |                      |
|   1 |  VIEW                                      |                      |
|   2 |   HASH UNIQUE                              |                      |
|   3 |    VIEW                                    |                      |
|   4 |     UNION-ALL                              |                      |
|*  5 |      FILTER                                |                      |
|   6 |       FAST DUAL                            |                      |
|   7 |       PARTITION HASH SINGLE                |                      |
|*  8 |        INDEX SKIP SCAN                     | TEST_GRAPHXQV$       |
|*  9 |      VIEW                                  |                      |
|* 10 |       CONNECT BY WITH FILTERING            |                      |
|  11 |        PX COORDINATOR                      |                      |
|  12 |     PX SEND QC (RANDOM)                    | :TQ10000             |
|  13 |      PX PARTITION HASH ALL                 |                      |
|* 14 |       TABLE ACCESS BY LOCAL INDEX ROWID BATCHED| TEST_GRAPHGT$    |
|* 15 |        INDEX RANGE SCAN                    | TEST_GRAPHXSG$       |
|  16 |        NESTED LOOPS                        |                      |
|  17 |     CONNECT BY PUMP                        |                      |
|  18 |     PARTITION HASH ALL                     |                      |
|* 19 |      TABLE ACCESS BY LOCAL INDEX ROWID BATCHED | TEST_GRAPHGT$    |
|* 20 |       INDEX RANGE SCAN                     | TEST_GRAPHXSG$       |
-----------------------------------------------------------------------------
```

Example A-40   PgqlExample13.java

`PgqlExample13.java` shows how to set length restrictions during path query evaluation.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;
```

```
/**
 * This example shows how to use the maximum path length option for
 * PGQL path queries.
 */
public class PgqlExample13
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();

pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Path Query to illustrate options
      String pgql =
        "PATH fof AS ()-[:\"friendOf\"]->() "+
        "SELECT v1.\"fname\" AS fname1, v2.\"fname\" AS fname2 "+
        "FROM MATCH (v1)-/:fof*/->(v2) "+
        "WHERE v1.\"fname\" = 'Ray'";


      // execute query for 1-hop
      rs = ps.executeQuery(pgql, " MAX_PATH_LEN=1 ");

      // print results
      System.out.println("-- Results for 1-hop ----------------");
      rs.print();

      // close result set
```

```
        rs.close();

        // execute query for 2-hop
        rs = ps.executeQuery(pgql, " MAX_PATH_LEN=2 ");

        // print results
        System.out.println("-- Results for 2-hop ----------------");
        rs.print();

        // close result set
        rs.close();

        // execute query for 3-hop
        rs = ps.executeQuery(pgql, " MAX_PATH_LEN=3 ");

        // print results
        System.out.println("-- Results for 3-hop ----------------");
        rs.print();

        // close result set
        rs.close();

      }
      finally {
        // close the result set
        if (rs != null) {
          rs.close();
        }
        // close the statement
        if (ps != null) {
          ps.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
  }
```

`PgqlExample13.java` has the following output for `test_graph` (which can be loaded using `GraphLoaderExample.java` code).

```
-- Results for 1-hop ----------------
+-----------------+
| FNAME1 | FNAME2 |
+-----------------+
| Ray    | Ray    |
| Ray    | Susan  |
+-----------------+
-- Results for 2-hop ----------------
+-----------------+
| FNAME1 | FNAME2 |
+-----------------+
| Ray    | Susan  |
| Ray    | Ray    |
```

```
| Ray    | John   |
+-----------------+
-- Results for 3-hop ----------------
+-----------------+
| FNAME1 | FNAME2 |
+-----------------+
| Ray    | Susan  |
| Ray    | Bill   |
| Ray    | Ray    |
| Ray    | John   |
+-----------------+
```

A.10.4.5.4 Options for Partial Object Construction

When reading edges from a query result, there are two possible behaviors when adding the start and end vertex to any local caches:

- Add only the vertex ID, which is available from the edge itself. This option is the default, for efficiency.
- Add the vertex ID, and retrieve all properties for the start and end vertex. For this behavior, you can call `setPartial(true)` on each `OracleVertex` object constructed from your PGQL query result set.

Example A-41 PgqlExample14.java

`PgqlExample14.java` illustrates this difference in behavior. This program first executes a query to retrieve all edges, which causes the incident vertices to be added to a local cache. The second query retrieves all vertices. The program then prints each `OracleVertex` object to show which properties have been loaded.

```
import java.sql.Connection;

import oracle.pg.rdbms.Oracle;
import oracle.pg.rdbms.OraclePropertyGraph;
import oracle.pg.rdbms.OracleVertex;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows the behavior of setPartial(true) for
OracleVertex objects
 * created from PGQL query results.
 */
public class PgqlExample14
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
```

```
String sid                = args[idx++];
String user               = args[idx++];
String password           = args[idx++];
String graph              = args[idx++];

Connection conn = null;
Oracle oracle = null;
OraclePropertyGraph opg = null;
PgqlStatement ps = null;
PgqlResultSet rs = null;

try {

  //Get a jdbc connection
  PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
  pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
  pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
  pds.setUser(user);
  pds.setPassword(password);
  conn = pds.getConnection();

  // Get a PGQL connection
  PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
  pgqlConn.setGraph(graph);

  // Create a PgqlStatement
  ps = pgqlConn.createStatement();

  // Query to illustrate set partial
  String pgql =
    "SELECT id(e), label(e) "+
    "FROM MATCH (v1)-[e:\"knows\"]->(v2)";

  // execute query
  rs = ps.executeQuery(pgql, " ");

  // print results
  System.out.println("-- Results for edge query -----------------");
  rs.print();

  // close result set
  rs.close();

  // Create an Oracle Property Graph instance
  oracle = new Oracle(conn);
  opg = OraclePropertyGraph.getInstance(oracle,graph);

  // Query to retrieve vertices
  pgql =
    "SELECT id(v) "+
    "FROM MATCH (v)";

  // Get each vertex object in result and print with toString()
  rs = ps.executeQuery(pgql, " ");
```

```
      // iterate through result
      System.out.println("-- Vertex objects retrieved from vertex
query --");
      while (rs.next()) {
        Long vid = rs.getLong(1);
        OracleVertex v = OracleVertex.getInstance(opg, vid);
        System.out.println(v.toString());
      }
      // close result set
      rs.close();

      // Execute the same query but call setPartial(true) for each
vertex
      rs = ps.executeQuery(pgql, " ");
      System.out.println("-- Vertex objects retrieved from vertex
query with setPartial(true) --");
      while (rs.next()) {
        Long vid = rs.getLong(1);
        OracleVertex v = OracleVertex.getInstance(opg, vid);
        v.setPartial(true);
        System.out.println(v.toString());
      }
      // close result set
      rs.close();
    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
      }
      // close the statement
      if (ps != null) {
        ps.close();
      }
      // close the connection
      if (conn != null) {
        conn.close();
      }
      // close the property graph
      if (opg != null) {
        opg.close();
      }
      // close oracle
      if (oracle != null) {
        oracle.dispose();
      }
    }
  }
}
```

The output for `PgqlExample14.java` (which can be loaded using `GraphLoaderExample.java` code) is:

```
-- Results for edge query -----------------
+------------------+
```

```
| id(e) | label(e) |
+-------------------+
| 6     | knows    |
| 11    | knows    |
| 10    | knows    |
| 5     | knows    |
| 4     | knows    |
| 13    | knows    |
| 9     | knows    |
| 12    | knows    |
| 8     | knows    |
| 7     | knows    |
| 14    | knows    |
| 15    | knows    |
+-------------------+
-- Vertex objects retrieved from vertex query --
Vertex ID 3 [NULL] {}
Vertex ID 0 [NULL] {}
Vertex ID 2 [NULL] {}
Vertex ID 1 [NULL] {}
-- Vertex objects retrieved from vertex query with setPartial(true) --
Vertex ID 3 [NULL] {bval:bol:false, fname:str:Susan, lname:str:Blue, mval:bol:false,
age:int:35}
Vertex ID 0 [NULL] {bval:bol:true, fname:str:Bill, lname:str:Brown, mval:str:y,
age:int:40}
Vertex ID 2 [NULL] {fname:str:Ray, lname:str:Green, mval:dat:1985-01-01 04:00:00.0,
age:int:41}
Vertex ID 1 [NULL] {bval:bol:true, fname:str:John, lname:str:Black, mval:int:27,
age:int:30}
```

A.10.4.6 Querying Another User's Property Graph

You can query another user's property graph data if you have been granted the appropriate privileges in the database. For example, to query GRAPH1 in SCOTT's schema, you must have READ privilege on SCOTT.GRAPH1GE$, SCOTT.GRAPH1VT$, SCOTT.GRAPH1GT$, and SCOTT.GRAPH1VD$.

Example A-42 PgqlExample15.java

`PgqlExample15.java` shows how another user can query a graph in SCOTT's schema.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to query a property graph located in another user's
 * schema. READ privilege on GE$, VT$, GT$ and VD$ tables for the other
user's
 * property graph are required to avoid ORA-00942: table or view does not
exist.
 */
public class PgqlExample15
```

```
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();

pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Set schema so that we can query Scott's graph
      pgqlConn.setSchema("SCOTT");

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Execute query to get a ResultSet object
      String pgql =
        "SELECT v.\"fname\" AS fname, v.\"lname\" AS lname "+
        "FROM MATCH (v)";
      rs = ps.executeQuery(pgql, "");


      // Print query results
      rs.print();
    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
      }
      // close the statement
      if (ps != null) {
        ps.close();
```

```
      }
      // close the connection
      if (conn != null) {
        conn.close();
      }
    }
  }
}
```

The following SQL statements create database user USER2 and grant the necessary privileges. You can also use the `OraclePropertyGraph.grantAccess` Java API to achieve the same effect.

```
SQL> grant connect, resource, unlimited tablespace to user2 identified by user2;

Grant succeeded.

SQL> grant read on scott.test_graphvt$ to user2;

Grant succeeded.

SQL> grant read on scott.test_graphge$ to user2;

Grant succeeded.

SQL> grant read on scott.test_graphgt$ to user2;

Grant succeeded.

SQL> grant read on scott.test_graphvd$ to user2;

Grant succeeded.
```

The output for `PgqlExample15.java` for the `test_graph` data set when connected to the database as USER2 is as follows. Note that `test_graph` should have already been loaded (using `GraphLoaderExample.java` code) as GRAPH1 by user SCOTT before running `PgqlExample15`.

```
+---------------+
| FNAME | LNAME |
+---------------+
| Susan | Blue  |
| Bill  | Brown |
| Ray   | Green |
| John  | Black |
+---------------+
```

A.10.4.7 Using Query Optimizer Hints with PGQL

The Java API allows query optimizer hints that influence the join type when executing PGQL queries. The `executeQuery` and `translateQuery` methods in `PgqlStatement` and `PgqlPreparedStatement` accept the following strings in the options argument to influence the query plan for the corresponding SQL query.

- ALL_EDGE_NL – Use Nested Loop join for all joins that involve the $GE and $GT tables.
- ALL_EDGE_HASH – Use HASH join for all joins that involve the $GE and $GT tables.
- ALL_VERTEX_NL – Use Nested Loop join for all joins that involve the $VT table.

- ALL_VERTEX_HASH – Use HASH join for all joins that involve the $VT table.

Example A-43   PgqlExample16.java

`PgqlExample16.java` shows how to use optimizer hints to influence the joins used for a graph traversal.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlSqlQueryTrans;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to use query optimizer hints with PGQL
queries.
 */
public class PgqlExample16
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host              = args[idx++];
    String port              = args[idx++];
    String sid               = args[idx++];
    String user              = args[idx++];
    String password          = args[idx++];
    String graph             = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();

pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();
      // Query to illustrate join hints
      String pgql =
        "SELECT id(v1), id(v4) "+
```

```
        "FROM MATCH (v1)-[:\"friendOf\"]->(v2)-[:\"friendOf\"]-
>(v3)-[:\"friendOf\"]->(v4)";

      // get SQL translation with hash join hint
      PgqlSqlQueryTrans sqlTrans =
        ps.translateQuery(pgql /* query string */,
                          " ALL_EDGE_HASH " /* options */);
      // print SQL translation
      System.out.println("-- Query with ALL_EDGE_HASH --------------------");
      System.out.println(sqlTrans.getSqlTranslation()+"\n");

      // get SQL translation with nested loop join hint
      sqlTrans =
        ps.translateQuery(pgql /* query string */,
                          " ALL_EDGE_NL " /* options */);
      // print SQL translation
      System.out.println("-- Query with ALL_EDGE_NL ---------------------");
      System.out.println(sqlTrans.getSqlTranslation()+"\n");
    }
    finally {
      // close the statement
      if (ps != null) {
        ps.close();
      }
      // close the connection
      if (conn != null) {
        conn.close();
      }
    }
  }
}
```

The output for `PgqlExample16.java` for `test_graph` (which can be loaded using `GraphLoaderExample.java` code) is:

```
-- Query with ALL_EDGE_HASH --------------------
SELECT /*+ USE_HASH(T0$0 T0$1 T0$2) */ 7 AS "id(v1)$T",
to_nchar(T0$0.SVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v1)$V",
T0$0.SVID AS "id(v1)$VN",
to_timestamp_tz(null) AS "id(v1)$VT",
7 AS "id(v4)$T",
to_nchar(T0$2.DVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v4)$V",
T0$2.DVID AS "id(v4)$VN",
to_timestamp_tz(null) AS "id(v4)$VT"
FROM "SCOTT".TEST_GRAPHGT$ T0$0,
"SCOTT".TEST_GRAPHGT$ T0$1,
"SCOTT".TEST_GRAPHGT$ T0$2
WHERE T0$0.DVID=T0$1.SVID AND
T0$1.DVID=T0$2.SVID AND
(T0$0.EL = n'friendOf' AND T0$0.EL IS NOT NULL) AND
(T0$1.EL = n'friendOf' AND T0$1.EL IS NOT NULL) AND
(T0$2.EL = n'friendOf' AND T0$2.EL IS NOT NULL)

-- Query with ALL_EDGE_NL ---------------------
SELECT /*+ USE_NL(T0$0 T0$1 T0$2) */ 7 AS "id(v1)$T",
to_nchar(T0$0.SVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v1)$V",
```

```
T0$0.SVID AS "id(v1)$VN",
to_timestamp_tz(null) AS "id(v1)$VT",
7 AS "id(v4)$T",
to_nchar(T0$2.DVID,'TM9','NLS_Numeric_Characters=''.,''') AS "id(v4)$V",
T0$2.DVID AS "id(v4)$VN",
to_timestamp_tz(null) AS "id(v4)$VT"
FROM "SCOTT".TEST_GRAPHGT$ T0$0,
"SCOTT".TEST_GRAPHGT$ T0$1,
"SCOTT".TEST_GRAPHGT$ T0$2
WHERE T0$0.DVID=T0$1.SVID AND
T0$1.DVID=T0$2.SVID AND
(T0$0.EL = n'friendOf' AND T0$0.EL IS NOT NULL) AND
(T0$1.EL = n'friendOf' AND T0$1.EL IS NOT NULL) AND
(T0$2.EL = n'friendOf' AND T0$2.EL IS NOT NULL)
```

The query plan for the first query that uses ALL_EDGE_HASH should look similar to the following.

```
-----------------------------------------------
| Id  | Operation               | Name          |
-----------------------------------------------
|   0 | SELECT STATEMENT        |               |
|*  1 |  HASH JOIN              |               |
|*  2 |   HASH JOIN             |               |
|   3 |    PARTITION HASH ALL |               |
|*  4 |     TABLE ACCESS FULL | TEST_GRAPHGT$ |
|   5 |    PARTITION HASH ALL |               |
|*  6 |     TABLE ACCESS FULL | TEST_GRAPHGT$ |
|   7 |   PARTITION HASH ALL  |               |
|*  8 |    TABLE ACCESS FULL  | TEST_GRAPHGT$ |
-----------------------------------------------
```

The query plan for the second query that uses ALL_EDGE_NL should look similar to the following.

```
-----------------------------------------------------------------------
| Id  | Operation                                       | Name           |
-----------------------------------------------------------------------
|   0 | SELECT STATEMENT                                |                |
|   1 |  NESTED LOOPS                                   |                |
|   2 |   NESTED LOOPS                                  |                |
|   3 |    PARTITION HASH ALL                           |                |
|*  4 |     TABLE ACCESS FULL                           | TEST_GRAPHGT$  |
|   5 |    PARTITION HASH ALL                           |                |
|*  6 |     TABLE ACCESS BY LOCAL INDEX ROWID BATCHED| TEST_GRAPHGT$  |
|*  7 |      INDEX RANGE SCAN                           | TEST_GRAPHXSG$ |
|   8 |   PARTITION HASH ALL                            |                |
|*  9 |    TABLE ACCESS BY LOCAL INDEX ROWID BATCHED | TEST_GRAPHGT$  |
|* 10 |     INDEX RANGE SCAN                            | TEST_GRAPHXSG$ |
-----------------------------------------------------------------------
```

A.10.4.8 Modifying Property Graphs through INSERT, UPDATE, and DELETE Statements

PGQL supports INSERT, UPDATE, and DELETE operations on Property Graphs. The method `execute` in `PgqlStatement` lets you execute such DML operations. This topic provides several examples of such operations.

Note:

JDBC connection auto commit must be off in order to be able to execute INSERT, UPDATE, and DELETE statements.

Example A-44 PgqlExample17.java (Insert)

`PgqlExample17.java` inserts several vertices and edges into a graph. Notice that the special property `_ora_id` is used to define ID values of vertices and edges. If the property `_ora_id` is omitted, a unique ID is generated for each new vertex or edge that is inserted into the graph.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to execute a PGQL INSERT operation.
 */
public class PgqlExample17
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();
      conn.setAutoCommit(false);

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
```

```
        pgqlConn.setGraph(graph);

        // Create a PgqlStatement
        ps = pgqlConn.createStatement();

        // Execute insert statement
        String pgql =
          "INSERT VERTEX p1 LABELS (person) PROPERTIES (p1.\"_ora_id\" =
1, p1.fname = 'Jake') "+
          "     , VERTEX p2 LABELS (person) PROPERTIES (p2.\"_ora_id\" =
2, p2.fname = 'Amy')  "+
          "     , VERTEX p3 LABELS (person) PROPERTIES (p3.\"_ora_id\" =
3, p3.fname = 'Erik') "+
          "     , VERTEX p4 LABELS (person) PROPERTIES (p4.\"_ora_id\" =
4, p4.fname = 'Jane') "+
          "     , EDGE e1 BETWEEN p1 AND p2 LABELS (knows) PROPERTIES
(e1.\"_ora_id\" = 1, e1.since = DATE '2003-04-21') "+
          "     , EDGE e2 BETWEEN p1 AND p3 LABELS (knows) PROPERTIES
(e2.\"_ora_id\" = 2, e2.since = DATE '2010-02-10') "+
          "     , EDGE e3 BETWEEN p3 AND p4 LABELS (knows) PROPERTIES
(e3.\"_ora_id\" = 3, e3.since = DATE '1999-01-03') ";
        ps.execute(pgql, /*  query string  */
                     "", /* query options  */
                     ""  /* modify options */);

        // Execute a query to verify insertion
        pgql =
            "  SELECT id(p1) AS id1, p1.fname AS person1, id(p2) as id2,
p2.fname AS person2, id(e) as e, e.since "+
            "    FROM MATCH (p1)-[e:knows]->(p2) "+
            "ORDER BY id1, id2";
        rs = ps.executeQuery(pgql, "");

        // Print the results
        rs.print();
      }
      finally {
        // close the result set
        if (rs != null) {
          rs.close();
        }
        // close the statement
        if (ps != null) {
          ps.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
  }
```

The output for `PgqlExample17.java` is:

```
+---------------------------------------------------------+
| ID1 | PERSON1 | ID2 | PERSON2 | E | SINCE                 |
+---------------------------------------------------------+
| 1   | Jake    | 2   | Amy     | 1 | 2003-04-20 17:00:00.0 |
| 1   | Jake    | 3   | Erik    | 2 | 2010-02-09 16:00:00.0 |
| 3   | Erik    | 4   | Jane    | 3 | 1999-01-02 16:00:00.0 |
+---------------------------------------------------------+
```

For more examples of INSERT statement, see the INSERT section in the PGQL specification.

Example A-45 PgqlExample18.java (Update)

`PgqlExample18.java` updates several properties of vertices and edges that are matched in the FROM clause of an UPDATE statement.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to execute a PGQL UPDATE operation.
 */
public class PgqlExample18
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();
      conn.setAutoCommit(false);

      // Get a PGQL connection
```

```
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Execute update statement
      String pgql =
        "UPDATE p1 SET (p1.age = 47, p1.lname = 'Red'), "+
        "        p2 SET (p2.age = 29, p2.lname = 'White'), "+
        "         e SET (e.strength = 100) "+
        "FROM MATCH (p1) -[e:knows]-> (p2) "+
        "WHERE p1.fname = 'Jake' AND p2.fname = 'Amy'";
      ps.execute(pgql, /*  query string  */
                 "", /* query options  */
                 ""  /* modify options */);

      // Execute a query to verify update
      pgql =
          "SELECT p1.fname AS fname1, p1.lname AS lname1, p1.age AS
age1, "+
          "        p2.fname AS fname2, p2.lname AS lname2, p2.age AS
age2, e.strength "+
          "FROM MATCH (p1) -[e:knows]-> (p2)";
      rs = ps.executeQuery(pgql, "");

      // Print the results
      rs.print();
    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
      }
      // close the statement
      if (ps != null) {
        ps.close();
      }
      // close the connection
      if (conn != null) {
        conn.close();
      }
    }
  }
}
```

The output for `PgqlExample18.java` applied on a graph where `PgqlExample17.java` has been previously executed is:

```
+-----------------------------------------------------------+
| FNAME1 | LNAME1 | AGE1   | FNAME2 | LNAME2 | AGE2   | STRENGTH |
+-----------------------------------------------------------+
| Jake   | Red    | 47     | Amy    | White  | 29     | 100      |
| Jake   | Red    | 47     | Erik   | <null> | <null> | <null>   |
```

```
| Erik   | <null> | <null> | Jane   | <null> | <null> | <null>   |
+-----------------------------------------------------------+
```

For more examples of UPDATE statement, see the UPDATE section in the PGQL specification.

Example A-46   PgqlExample19.java (Delete)

`PgqlExample19.java` deletes edges that are matched in the FROM clause of a DELETE statement.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to execute a PGQL DELETE operation.
 */
public class PgqlExample19
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();
      conn.setAutoCommit(false);

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
```

```
      ps = pgqlConn.createStatement();

      // Execute delete statement
      String pgql =
        "DELETE e "+
        "  FROM MATCH (p1) -[e:knows]-> (p2) "+
        " WHERE p1.fname = 'Jake'";
      ps.execute(pgql, /*  query string  */
                   "", /* query options  */
                   ""  /* modify options */);

      // Execute a query to verify delete
      pgql =
          "SELECT p1.fname AS fname1, p2.fname AS fname2 "+
          "  FROM MATCH (p1) -[e:knows]-> (p2)";
      rs = ps.executeQuery(pgql, "");

      // Print the results
      rs.print();
    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
      }
      // close the statement
      if (ps != null) {
        ps.close();
      }
      // close the connection
      if (conn != null) {
        conn.close();
      }
    }
  }
}
```

The output for `PgqlExample19.java` applied on a graph where `PgqlExample18.java` has been previously executed is:

```
+-----------------+
| FNAME1 | FNAME2 |
+-----------------+
| Erik   | Jane   |
+-----------------+
```

For more examples of DELETE statement, see the DELETE section in the PGQL specification.

Example A-47   PgqlExample20.java (Multiple Modifications)

`PgqlExample20.java` executes multiple modifications in the same statement: an edge is inserted, vertex properties are updated, and another edge is deleted.

```
import java.sql.Connection;
```

```
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to execute a PGQL
 * INSERT/UPDATE/DELETE operation.
 */
public class PgqlExample20
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host               = args[idx++];
    String port               = args[idx++];
    String sid                = args[idx++];
    String user               = args[idx++];
    String password           = args[idx++];
    String graph              = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();
      pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();
      conn.setAutoCommit(false);

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Execute INSERT/UPDATE/DELETE statement
      String pgql =
        "INSERT EDGE f BETWEEN p2 AND p1 LABELS (knows) PROPERTIES (f.since
= e.since) "+
        "UPDATE p1 SET (p1.age = 30) "+
        "     , p2 SET (p2.age = 25) "+
        "DELETE e "+
        "  FROM MATCH (p1) -[e:knows]-> (p2) "+
        " WHERE p1.fname = 'Erik'";
```

```
        ps.execute(pgql, /*  query string  */
                     "", /* query options  */
                     ""  /* modify options */);

        // Execute a query to verify INSERT/UPDATE/DELETE
        pgql =
            "SELECT p1.fname AS fname1, p1.age AS age1, "+
            "       p2.fname AS fname2, p2.age AS age2, e.since "+
            "  FROM MATCH (p1) -[e:knows]-> (p2)";
        rs = ps.executeQuery(pgql, "");

        // Print the results
        rs.print();
      }
      finally {
        // close the result set
        if (rs != null) {
          rs.close();
        }
        // close the statement
        if (ps != null) {
          ps.close();
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
```

The output for `PgqlExample20.java` applied on a graph where `PgqlExample19.java` has been previously executed is:

```
+-----------------------------------------------------+
| FNAME1 | AGE1 | FNAME2 | AGE2 | SINCE                 |
+-----------------------------------------------------+
| Jane   | 25   | Erik   | 30   | 1999-01-02 16:00:00.0 |
+-----------------------------------------------------+
```

For more examples of INSERT/UPDATE/DELETE statements, see the Combining INSERT, UPDATE and DELETE section in the PGQL specification.

- Additional Options for PGQL Statement Execution

A.10.4.8.1 Additional Options for PGQL Statement Execution

Several options are available to influence PGQL statement execution. The following are the main ways to set query options:

- Through flags in the `modify options` string argument of `execute`
- Through Java JVM arguments.

The following table summarizes the main options for modifying PGQL statement execution.

Table A-4 PGQL Statement Modification Options

Option	Default	Options Flag	JVM Argument
Auto commit	true if JDBC auto commit is off, false if JDBC auto commit is on	AUTO_COMMIT=F	-Doracle.pg.rdbms.pgql.autoCommit=false
Delete cascade	true	DELETE_CASCADE=F	-Doracle.pg.rdbms.pgql.deleteCascade=false

- Turning Off PGQL Auto Commit
- Turning Off Cascading Deletion

A.10.4.8.1.1 Turning Off PGQL Auto Commit

When an INSERT, UPDATE, or DELETE operation is executed, a commit is performed automatically at the end of the PGQL execution so that changes are persisted on the RDBMS side.

The flag `AUTO_COMMIT=F` can be added to the `options` argument of `execute` or the flag `Doracle.pg.rdbms.pgql.autoCommit=false` can be set in the Java command line to turn off auto commit. Notice that when auto commit is off, you must perform any necessary commits or rollbacks on the JDBC connection in order to persist or cancel graph modifications.

Example A-48 Turn Off Auto Commit and Roll Back Changes

`PgqlExample21.java` turns off auto commit and performs a rollback of the changes.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlResultSet;
import oracle.pg.rdbms.pgql.PgqlStatement;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;

/**
 * This example shows how to modify a PGQL graph
 * with auto commit off.
 */
public class PgqlExample21
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host              = args[idx++];
    String port              = args[idx++];
    String sid               = args[idx++];
    String user              = args[idx++];
    String password          = args[idx++];
    String graph             = args[idx++];
```

```
    Connection conn = null;
    PgqlStatement ps = null;
    PgqlResultSet rs = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();

pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();
      conn.setAutoCommit(false);

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Delete all the edges in the graph
      String pgql =
        "DELETE e "+
        "  FROM MATCH () -[e]-> ()";
      ps.execute(pgql, /*  query string  */
                 "",    /* query options  */
                 "AUTO_COMMIT=F"  /* modify options */);

      // Execute a query to verify deletion
      pgql =
          "SELECT COUNT(e) "+
          "  FROM MATCH () -[e]-> ()";
      rs = ps.executeQuery(pgql, "");

      // Print the results
      System.out.println("Number of edges after deletion:");
      rs.print();
      rs.close();

      // Rollback the changes. This is possible because
      // AUTO_COMMIT=F flag was used in execute
      conn.rollback();

      // Execute a query to verify rollback
      pgql =
          "SELECT COUNT(e) "+
          "  FROM MATCH () -[e]-> ()";
      rs = ps.executeQuery(pgql, "");

      // Print the results
      System.out.println("Number of edges after rollback:");
      rs.print();
```

```
    }
    finally {
      // close the result set
      if (rs != null) {
        rs.close();
      }
      // close the statement
      if (ps != null) {
        ps.close();
      }
      // close the connection
      if (conn != null) {
        conn.close();
      }
    }
  }
}
```

`PgqlExample21.java` gives the following output for a graph with one edge:

```
Number of edges after deletion:
+----------+
| COUNT(e) |
+----------+
| 0        |
+----------+
Number of edges after rollback:
+----------+
| COUNT(e) |
+----------+
| 1        |
+----------+
```

A.10.4.8.1.2 Turning Off Cascading Deletion

When a vertex is deleted from a graph, all its input and output edges are also deleted automatically.

Using the flag `DELETE_CASCADE=F` in the `options` argument of `execute` of setting the flag or setting the flag `Doracle.pg.rdbms.pgql.autoCommit=false` in the Java command line lets you turn off cascading deletion. When a vertex with input or output edges is deleted and cascading deletion is off, an error is thrown to warn about the unsafe operation that you are trying to perform.

Example A-49 Turn Off Cascading Deletion

`PgqlExample22.java` attempts to delete a vertex with an output edge when cascading deletion is off.

```
import java.sql.Connection;

import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;
import oracle.pg.rdbms.pgql.PgqlToSqlException;

import oracle.ucp.jdbc.PoolDataSourceFactory;
import oracle.ucp.jdbc.PoolDataSource;
```

```
/**
 * This example shows the use of DELETE_CASCADE flag.
 */
public class PgqlExample22
{

  public static void main(String[] args) throws Exception
  {
    int idx=0;
    String host              = args[idx++];
    String port              = args[idx++];
    String sid               = args[idx++];
    String user              = args[idx++];
    String password          = args[idx++];
    String graph             = args[idx++];

    Connection conn = null;
    PgqlStatement ps = null;

    try {

      //Get a jdbc connection
      PoolDataSource  pds = PoolDataSourceFactory.getPoolDataSource();

pds.setConnectionFactoryClassName("oracle.jdbc.pool.OracleDataSource");
      pds.setURL("jdbc:oracle:thin:@"+host+":"+port +":"+sid);
      pds.setUser(user);
      pds.setPassword(password);
      conn = pds.getConnection();
      conn.setAutoCommit(false);

      // Get a PGQL connection
      PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
      pgqlConn.setGraph(graph);

      // Create a PgqlStatement
      ps = pgqlConn.createStatement();

      // Delete all the vertices with output edges
      // This will throw an error
      String pgql =
        "DELETE v "+
        "  FROM MATCH (v) -[e]-> ()";
      ps.execute(pgql, /*  query string  */
                 "",   /* query options  */
                 "DELETE_CASCADE=F"  /* modify options */);
    }
    catch (PgqlToSqlException ex){
      System.out.println("Error in execution: " + ex.getMessage());
    }
    finally {
      // close the statement
      if (ps != null) {
        ps.close();
```

```
        }
        // close the connection
        if (conn != null) {
          conn.close();
        }
      }
    }
  }
```

`PgqlExample22.java` gives the following output for a graph with at least one edge:

```
Error in execution: Attempting to delete vertices with incoming/outgoing edges. Drop
edges first or turn on DELETE_CASCADE option
```

A.10.5 Using the Python Client to Execute PGQL Queries

You can use the new Python package `OPG4Py` for executing PGQL queries against Oracle Database. This new package contains a sub-package `Pgql` with one or more modules that wraps around the Java API in the `oracle.pg.rdbms.pgql` package.

See Python API Reference for more information.

- Creating a Property Graph Using the Python Client
- Dropping a Property Graph Using the Python Client
- Basic Query Execution
- Iterating a Query Result Set

A.10.5.1 Creating a Property Graph Using the Python Client

You can create a property graph using the `CREATE PROPERTY GRAPH` statement in Python.

Creating a Property Graph Using the Python Client

- Launch the Python client as shown:

```
./bin/opg4py --no_connect
```

- Create a PGQL connection to connect to the database as shown:

```
>>> pgql_conn = opg4py.pgql.get_connection(<user>, <password>, <jdbc_url>)
PgqlConnection(schema: GRAPHUSER, graph: None)
```

- Create a PGQL statement as shown:

```
>>> pgql_statement = pgql_conn.create_statement()
PgqlStatement(java_pgql_statement: oracle.pg.rdbms.pgql.PgqlStatement)
```

- Define and execute the `CREATE PROPERTY GRAPH` statement as shown:

```
pgql = """
        CREATE PROPERTY GRAPH <graph_name>
        VERTEX TABLES (
          bank_accounts
```

```
            LABEL accounts
            PROPERTIES ALL COLUMNS
        )
        EDGE TABLES (
          bank_txns
            SOURCE KEY (from_acct_id) REFERENCES bank_accounts
(acct_id)
            DESTINATION KEY (to_acct_id) REFERENCES bank_accounts
(acct_id)
            LABEL transfers PROPERTIES ALL COLUMNS
        )
"""
```

where <*graph_name*> is the name of the graph.

```
pgql_statement.execute(pgql)
```

The graph gets created.

A.10.5.2 Dropping a Property Graph Using the Python Client

You can drop a property graph using the `DROP PROPERTY GRAPH` statement in Python.

Dropping a Property Graph Using the Python Client

- Define and execute the `DROP PROPERTY GRAPH` statement as shown:

```
>>> pgql = "DROP PROPERTY GRAPH <graph_name>"
```

  where <*graph_name*> is the name of the graph.

```
>>> pgql_statement.execute(pgql)
```

  The graph gets dropped.

A.10.5.3 Basic Query Execution

You can execute PGQL queries using the `opg4py.pgql` Python wrapper.

Executing PGQL Queries Using the Python Client

- Set the graph for querying as shown:

```
>>> pgql_conn.set_graph("<graph_name>")
```

  where <*graph_name*> is the name of the graph.

- Define and execute the PGQL `SELECT` query. For example,

```
>>> pgql = "SELECT e.from_acct_id, e.to_acct_id, e.amount FROM
MATCH (n:accounts) -[e:transfers]-> (m:accounts) on bank_graph
limit 10"
```

- Execute and print the result set as shown:

```
>>> pgql_result_set = pgql_statement.execute_query(pgql)
>>> pgql_result_set.print()
+-------------------------------------+
| FROM_ACCT_ID | TO_ACCT_ID | AMOUNT |
+-------------------------------------+
| 781.0        | 712.0      | 1000.0 |
| 190.0        | 555.0      | 1000.0 |
| 191.0        | 329.0      | 1000.0 |
| 198.0        | 57.0       | 1000.0 |
| 220.0        | 441.0      | 1000.0 |
| 251.0        | 387.0      | 1000.0 |
| 254.0        | 188.0      | 1000.0 |
| 259.0        | 305.0      | 1000.0 |
| 261.0        | 145.0      | 1000.0 |
| 263.0        | 40.0       | 1000.0 |
+-------------------------------------+

PgqlResultSet(java_pgql_result_set: oracle.pg.rdbms.pgql.PgqlResultSet, #
of results: 0)
```

Also, you can convert the PGQL result set obtained in the preceding code to a Pandas dataframe using the `to_pandas()` method.

> **Note:**
>
> The `pandas` package must be installed in your system to successfully execute the call to `to_pandas()`. This package is automatically installed at the time of the Python client installation for versions Python 3.8 and Python 3.9. However, if your call to `to_pandas()` fails, verify if the `pandas` module is installed in your system. In case the module is found missing or your Python version differs from the earlier mentioned versions, then install the `pandas` package manually.

A.10.5.4 Iterating a Query Result Set

You can iterate your query result set using the methods in `PgqlResultSet`.

You can position the cursor for iterating your query result set using the following methods:

- `first() : boolean`
- `next() : boolean`
- `previous() : boolean`
- `last() : boolean`
- `before_first()`
- `after_last()`
- `absolute(target_row_value) : boolean`
- `relative(offset_value) : boolean`

- `fetchone(): Tuple`
- `fetchmany(no_of_rows): List of tuples`
- `fetchall(): List of tuples`

Once the cursor is positioned at the desired row, you can use the following getters to obtain values:

- `get(column_idx) : Object`
- `get(column_name) : Object`
- `get_boolean(column_idx) : boolean`
- `get_boolean(column_name) : boolean`
- `get_date(column_idx) : datetime.date`
- `get_date(column_name) : datetime.date`
- `get_float(column_idx) : Float`
- `get_float(column_name) : Float`
- `get_integer(column_idx) : Integer`
- `get_integer(column_name) : Integer`
- `get_list(column_idx) : List`
- `get_list(column_name) : List`
- `get_string(column_idx) : String`
- `get_string(column_name) : String`
- `get_time(column_idx) : datetime.time`
- `get_time(column_name) : datetime.time`
- `get_time_with_timezone(column_idx) : datetime.time`
- `get_time_with_timezone(column_name) : datetime.time`
- `get_timestamp(column_idx) : datetime.datetime`
- `get_timestamp(column_name) : datetime.datetime`
- `get_timestamp_with_timezone(column_idx) : datetime.datetime`
- `get_timestamp_with_timezone(column_name) : datetime.datetime`
- `get_value_type(column_idx) : Integer`
- `get_value_type(column_name) : Integer`
- `get_vertex_labels(column_idx) : List`
- `get_vertex_labels(column_name) : List`

See Retrieving PGQL-on-RDBMS results documentation for more information.

The following code samples illustrate cursor operations for iterating a result set using few of the cursor position and getter methods. These examples reference the query result set obtained in the example in the previous section.

```
# Call first() and retrieve value for "FROM_ACCT_ID"
>>> pgql_result_set.first()
True
>>> pgql_result_set.get("FROM_ACCT_ID")
781.0

# Call next() and retrieve value for "FROM_ACCT_ID"
>>> pgql_result_set.next()
True
>>> pgql_result_set.get("FROM_ACCT_ID")
978.0

# Call last() and retrieve value for "FROM_ACCT_ID"
>>> pgql_result_set.last()
True
>>> pgql_result_set.get("FROM_ACCT_ID")
842.0

# Call previous() and retrieve value for "FROM_ACCT_ID"
>>> pgql_result_set.previous()
True
>>> pgql_result_set.get("FROM_ACCT_ID")
838.0

# Reset the result set and offset by 6. Then retrieve value for
"FROM_ACCT_ID"
>>> pgql_result_set.before_first()
>>> pgql_result_set.relative(6)
True
>>> pgql_result_set.get("FROM_ACCT_ID")
925.0

# Reach the end of the result set and offset by -2. Then retrieve value for
"FROM_ACCT_ID"
>>> pgql_result_set.after_last()
>>> pgql_result_set.relative(-2)
True
>>> pgql_result_set.get("FROM_ACCT_ID")
838.0

# Call absolute() and provide an absolute row value. Then retrieve value for
"FROM_ACCT_ID"
>>> pgql_result_set.absolute(3)
True
>>> pgql_result_set.get_float("FROM_ACCT_ID")
900.0

# Get a specific row or a set of rows
>>> pgql_result_set.get_slice(0,1)
[781.0, 712.0, 1000.0]
```

```
>>> pgql_result_set.get_row(0)
[781.0, 712.0, 1000.0]
```

Iterating a Result Set Using the Python Index Operator

You can also iterate through the query result set using the Python index operator as shown:

```
# Retrieving a value from a tuple
>>> pgql_result_set[4, "double", "FROM_ACCT_ID"]
907.0

# Retrieving a value using index value
>>> pgql_result_set[4].get("FROM_ACCT_ID")
907.0

# Fetch a row or a set of rows
>>> pgql_result_set[0:1]
[781.0, 712.0, 1000.0]
```

Iterating a Result Set Using a Python loop

Optionally, you can also iterate through the query result set using a Python loop. For example:

```
# Using the result set as an iterator of a for loop
>>> for result in pgql_result_set:
        print(result)
[781.0, 712.0, 1000.0]
[190.0, 555.0, 1000.0]
[191.0, 329.0, 1000.0]
[198.8. 57.0, 1000.0]
[220.0, 441.0, 1000.0]
[251.0, 387.0, 1000.0]
[254.0, 188.0, 1000.0]
[259.0, 305.0, 1000.0]
[261.0, 145.0, 1000.0]
[263.0, 40.0, 1000.0]
```

Iterating a Result Set Using Fetch Methods

You can iterate through the query result set and fetch rows using the fetch methods. For example:

```
# Using the fetch methods to fetch rows from the result set
>>> pgql_result_set.fetchone()
(781.0, 712.0, 1000.0)
>>> pgql_result_set.fetchmany(4)
[(190.0, 555.0, 1000.0), (191.0, 329.0, 1000.0), (198.8. 57.0,
1000.0), (220.0, 441.0, 1000.0)]
>>> pgql_result_set.fetchall()
[(251.0, 387.0, 1000.0), (254.0, 188.0, 1000.0), (259.0, 305.0,
1000.0), (261.0, 145.0, 1000.0), (263.0, 40.0, 1000.0)]
```

A.10.6 Performance Considerations for PGQL Queries

Many factors affect the performance of PGQL queries in Oracle Database. The following are some recommended practices for query performance.

- Query Optimizer Statistics
- Parallel Query Execution
- Optimizer Dynamic Sampling
- Bind Variables
- Path Queries

Query Optimizer Statistics

Good, up-to-date query optimizer statistics are critical for query performance. Ensure that you run OPG_APIS.ANALYZE_PG after any significant updates to your property graph data.

Parallel Query Execution

Use parallel query execution to take advantage of Oracle's parallel SQL engine. Parallel execution often gives a significant speedup versus serial execution. Parallel execution is especially critical for path queries evaluated using the recursive WITH strategy.

See also the *Oracle Database VLDB and Partitioning Guide* for more information about parallel query execution.

Optimizer Dynamic Sampling

Due to the inherent flexibility of the graph data model, static information may not always produce optimal query plans. In such cases, dynamic sampling can be used by the query optimizer to sample data at run time for better query plans. The amount of data sampled is controlled by the dynamic sampling level used. Dynamic sampling levels range from 0 to 11. The best level to use depends on a particular dataset and workload, but levels of 2 (default), 6, or 11 often give good results.

See also Supplemental Dynamic Statistics in the *Oracle Database SQL Tuning Guide*.

Bind Variables

Use bind variables for constants whenever possible. The use of bind variables gives a very large reduction in query compilation time, which dramatically increases throughput for query workloads with queries that differ only in the constant values used. In addition, queries with bind variables are less vulnerable to injection attacks.

Path Queries

Path queries in PGQL that use the `+` (plus sign) or `*` (asterisk) operator to search for arbitrary length paths require special consideration because of their high computational complexity. You should use parallel execution and use the DISTINCT option for Recursive WITH (USE_DIST_RW=T) for the best performance. Also, for large, highly connected graphs, it is a good idea to use MAX_PATH_LEN=*n* to limit the number of repetitions of the recursive step to a reasonable number. A good strategy can be to start with a small repetition limit, and iteratively increase the limit to find more and more results.

A.11 OPG_APIS Package Subprograms

The OPG_APIS package contains subprograms (functions and procedures) for working with property graphs in an Oracle database.

To use the subprograms in this chapter, you must understand the conceptual and usage information in earlier chapters of this book.

This chapter provides reference information about the subprograms, in alphabetical order.

- OPG_APIS.FIND_SP_CLEANUP
- OPG_APIS.FIND_SP_PREP
- OPG_APIS.GET_BUILD_ID
- OPG_APIS.GET_GEOMETRY_FROM_V_COL
- OPG_APIS.GET_GEOMETRY_FROM_V_T_COLS
- OPG_APIS.GET_LATLONG_FROM_V_COL
- OPG_APIS.GET_LATLONG_FROM_V_T_COLS
- OPG_APIS.GET_LONG_LAT_GEOMETRY
- OPG_APIS.GET_LATLONG_FROM_V_COL
- OPG_APIS.GET_LONGLAT_FROM_V_T_COLS
- OPG_APIS.GET_OPG_VERSION
- OPG_APIS.GET_SCN
- OPG_APIS.GET_VERSION
- OPG_APIS.GET_WKTGEOMETRY_FROM_V_COL
- OPG_APIS.GET_WKTGEOMETRY_FROM_V_T_COLS
- OPG_APIS.GRANT_ACCESS
- OPG_APIS.IMP_EDGE_TAB_STATS
- OPG_APIS.IMP_VERTEX_TAB_STATS
- OPG_APIS.PR
- OPG_APIS.PR_CLEANUP
- OPG_APIS.PR_PREP
- OPG_APIS.PREPARE_TEXT_INDEX
- OPG_APIS.RENAME_PG
- OPG_APIS.SPARSIFY_GRAPH
- OPG_APIS.SPARSIFY_GRAPH_CLEANUP
- OPG_APIS.SPARSIFY_GRAPH_PREP

A.11.1 OPG_APIS.ANALYZE_PG

Format

```
OPG_APIS.ANALYZE_PG(
     graph_name        IN VARCHAR2,
     estimate_percent  IN NUMBER,
     method_opt        IN VARCHAR2,
     degree            IN NUMBER,
     cascade           IN BOOLEAN,
     no_invalidate     IN BOOLEAN,
     force             IN BOOLEAN DEFAULT FALSE,
     options           IN VARCHAR2 DEFAULT NULL);
```

Description

Hathers, for a given property graph, statistics for the VT$, GE$, IT$, and GT$ tables.

Parameters

graph_name
Name of the property graph.

estimate_percent
Percentage of rows to estimate in the schema tables (NULL means compute). The valid range is [0.000001,100]. Use the constant `DBMS_STATS.AUTO_SAMPLE_SIZE` to have Oracle Database determine the appropriate sample size for good statistics. This is the usual default.

mrthod_opt
Accepts either of the following options, or both in combination, for the internal property graph schema tables:

- `FOR ALL [INDEXED | HIDDEN] COLUMNS [size_clause]`
- `FOR COLUMNS [size clause] column|attribute [size_clause] [,column|attribute [size_clause]...]`

`size_clause` is defined as `size_clause := SIZE {integer | REPEAT | AUTO | SKEWONLY}`

- `integer` : Number of histogram buckets. Must be in the range [1,254].
- `REPEAT` : Collects histograms only on the columns that already have histograms.
- `AUTO` : Oracle Database determines the columns to collect histograms based on data distribution and the workload of the columns.
- `SKEWONLY` : Oracle Database determines the columns to collect histograms based on the data distribution of the columns

`column` is defined as `column := column_name | (extension)`

- `column_name` : name of a column
- `extension`: Can be either a column group in the format of `(column_name, column_name [, ...])` or an expression.

The usual default is: `FOR ALL COLUMNS SIZE AUTO`

degree
Degree of parallelism for the property graph schema tables. The usual default for degree is NULL, which means use the table default value specified by the DEGREE clause in the CREATE TABLE or ALTER TABLE statement. Use the constant `DBMS_STATS.DEFAULT_DEGREE` to specify the default value based on the initialization parameters. The `AUTO_DEGREE` value determines the degree of parallelism automatically. This is either 1 (serial execution) or `DEFAULT_DEGREE` (the system default value based on number of CPUs and initialization parameters) according to size of the object.

cascade
Gathers statistics on the indexes for the property graph schema tables. Use the constant `DBMS_STATS.AUTO_CASCADE` to have Oracle Database determine whether index statistics are to be collected or not. This is the usual default.

no_invalidate
If `TRUE`, does not invalidate the dependent cursors. If `FALSE`, invalidates the dependent cursors immediately. If `DBMS_STATS.AUTO_INVALIDATE` (the usual default) is in effect, Oracle Database decides when to invalidate dependent cursors.

force
If `TRUE`, performs the operation even if one or more underlying tables are locked.

options
(Reserved for future use.)

Usage Notes

Only the owner of the property graph can call this procedure.

Examples

The following example gather statistics for property graph `mypg`.

```
EXECUTE OPG_APIS.ANALYZE_PG('mypg', estimate_percent=> 0.001, method_opt=>'FOR ALL
COLUMNS SIZE AUTO', degree=>4, cascade=>true, no_invalidate=>false, force=>true,
options=>NULL);
```

A.11.2 OPG_APIS.CF

Format

```
OPG_APIS.CF(
     edge_tab_name   IN      VARCHAR2,
     edge_label      IN      VARCHAR2,
     rating_property IN      VARCHAR2,
     iterations      IN      NUMBER DEFAULT 10,
     min_error       IN      NUMBER DEFAULT 0.001,
     k               IN      NUMBER DEFAULT 5,
     learning_rate   IN      NUMBER DEFAULT 0.0002,
     decrease_rate   IN      NUMBER DEFAULT 0.95,
     regularization  IN      NUMBER DEFAULT 0.02,
     dop             IN      NUMBER DEFAULT 8,
     wt_l            IN/OUT  VARCHAR2,
     wt_r            IN/OUT  VARCHAR2,
     wt_l1           IN/OUT  VARCHAR2,
     wt_r1           IN/OUT  VARCHAR2,
     wt_i            IN/OUT  VARCHAR2,
     wt_ld           IN/OUT  VARCHAR2,
     wt_rd           IN/OUT  VARCHAR2,
     tablespace      IN      VARCHAR2 DEFAULT NULL,
     options         IN      VARCHAR2 DEFAULT NULL);
```

Description

Runs collaborative filtering using matrix factorization on the given graph. The resulting factors of the matrix product will be stored on the left and right tables.

Parameters

edge_tab_name
Name of the property graph edge table (GE$).

edge_label
Label of the edges that hold the rating property.

rating_property
(Reserved for future use: Name of the rating property.)

iterations
Maximum number of iterations that should be performed. Default = 10.

min_error
Minimal error to reach. If at some iteration the error value is lower than this value, the procedure finishes.. Default = 0.001.

k
Number of features for the left and right side products. Default = 5.

learning_rate
Learning rate for the gradient descent. Default = 0.0002.

decrease_rate
(Reserved for future use: Decrease rate if the learning rate is too large for an effective gradient descent. Default = 0.95.)

regularization
An additional parameter to avoid overfitting. Default = 0.02

dop
Degree of parallelism. Default = 8.

wt_l
Name of the working table that holds the left side of the matrix factorization.

wt_r
Name of the working table that holds the right side of the matrix factorization.

wt_l1
Name of the working table that holds the left side intermediate step in the gradient descent.

wt_r1
Name of the working table that holds the right side intermediate step in the gradient descent.

wt_I
Name of the working table that holds intermediate matrix product.

wt_ld
Name of the working table that holds intermediate left side delta in gradient descent.

wt_rd
Name of the working table that holds intermediate right side delta in gradient descent.

tablespace
Name of the tablespace to use for storing intermediate data.

options
Additional settings for operation. An optional string with one or more (comma-separated) of the following values:

- 'INMEMORY=T' is an option for creating the schema tables with an 'inmemory' clause.
- 'IMC_MC_B=T' creates the schema tables with an INMEMORY MEMCOMPRESS BASIC clause.

Usage Notes

For information about collaborative filtering with RDF data, see SQL-Based Property Graph Analytics, especially Collaborative Filtering Overview and Examples.

If the working tables already exist, you can specify their names for the working table-related parameters. In this case, the algorithm can continue the progress of the previous iterations without recreating the tables.

If the working tables do not exist, or if you do not want to use existing working tables, you must first call the OPG_APIS.CF_PREP procedure, which creates the necessary working tables.

The final result of the collaborative filtering algorithm are the working tables `wt_l` and `wt_r`, which are the two factors of a matrix product. These matrix factors should be used when making predictions for collaborative filtering.

If (and only if) you have no interest in keeping the output matrix factors and the current progress of the algorithm for future use, you can call the OPG_APIS.CF_CLEANUP procedure to drop all the working tables that hold intermediate tables and the output matrix factors.

Examples

The following example calls the OPG_APIS.CF_PREP procedure to create the working tables, and then the OPG_APIS.CF procedures to run collaborative filtering on the `phones` graph using the edges with the `rating` label.

```
DECLARE
  wt_l varchar2(32);
  wt_r varchar2(32);
  wt_l1 varchar2(32);
  wt_r1 varchar2(32);
  wt_i varchar2(32);
  wt_ld varchar2(32);
  wt_rd varchar2(32);
  edge_tab_name    varchar2(32) := 'phonesge$';
  edge_label       varchar2(32) := 'rating';
  rating_property  varchar2(32) := '';
  iterations       integer      := 100;
  min_error        number       := 0.001;
  k                integer      := 5;
  learning_rate    number       := 0.001;
  decrease_rate    number       := 0.95;
  regularization   number       := 0.02;
  dop              number       := 2;
  tablespace       varchar2(32) := null;
  options          varchar2(32) := null;
```

```
BEGIN
 opg_apis.cf_prep(edge_tab_name,wt_l,wt_r,wt_l1,wt_r1,wt_i,wt_ld,wt_rd);
 opg_apis.cf(edge_tab_name,edge_label,rating_property,iterations,min_error,k,
             learning_rate,decrease_rate,regularization,dop,
             wt_l,wt_r,wt_l1,wt_r1,wt_i,wt_ld,wt_rd,tablespace,options);
END;
/
```

The following example assumes that OPG_APIS.CF_PREP had been run previously, and it specifies the various working tables that were created during that run. In this case, the preceding example automatically assigned suffixes like '$$CFL57' to the names of the working tables. (The output names can be printed when they are generated or be user-defined in the call to OPG_APIS.CF_PREP.) Thus, the following example can run more iterations of the algorithm using OPG_APIS.CF without needing to call OPG_APIS.CF_PREP first, thereby continuing the progress of the previous run.

```
DECLARE
  wt_l varchar2(32)  = 'phonesge$$CFL57';
  wt_r varchar2(32)  = 'phonesge$$CFR57';
  wt_l1 varchar2(32) = 'phonesge$$CFL157';
  wt_r1 varchar2(32) = 'phonesge$$CFR157';
  wt_i varchar2(32)  = 'phonesge$$CFI57';
  wt_ld varchar2(32) = 'phonesge$$CFLD57';
  wt_rd varchar2(32) = 'phonesge$$CFRD57';
  edge_tab_name    varchar2(32) := 'phonesge$';
  edge_label       varchar2(32) := 'rating';
  rating_property  varchar2(32) := '';
  iterations       integer      := 100;
  min_error        number       := 0.001;
  k                integer      := 5;
  learning_rate    number       := 0.001;
  decrease_rate    number       := 0.95;
  regularization   number       := 0.02;
  dop              number       := 2;
  tablespace       varchar2(32) := null;
  options          varchar2(32) := null;
BEGIN
 opg_apis.cf(edge_tab_name,edge_label,rating_property,iterations,min_error,k,
             learning_rate,decrease_rate,regularization,dop,
             wt_l,wt_r,wt_l1,wt_r1,wt_i,wt_ld,wt_rd,tablespace,options);
END;
/
```

A.11.3 OPG_APIS.CF_CLEANUP

Format

```
OPG_APIS.CF_CLEANUP(
     wt_l           IN/OUT  VARCHAR2,
     wt_r           IN/OUT  VARCHAR2,
     wt_l1          IN/OUT  VARCHAR2,
     wt_r1          IN/OUT  VARCHAR2,
     wt_i           IN/OUT  VARCHAR2,
     wt_ld          IN/OUT  VARCHAR2,
     wt_rd          IN/OUT  VARCHAR2,
     options        IN      VARCHAR2 DEFAULT NULL);
```

Description

Preforms cleanup work after graph collaborative filtering has been done. All the working tables that hold intermediate tables and the output matrix factors are dropped.

Parameters

edge_tab_name
Name of the property graph edge table (GE$).

wt_l
Name of the working table that holds the left side of the matrix factorization.

wt_r
Name of the working table that holds the right side of the matrix factorization.

wt_l1
Name of the working table that holds the left side intermediate step in the gradient descent.

wt_r1
Name of the working table that holds the right side intermediate step in the gradient descent.

wt_l
Name of the working table that holds intermediate matrix product.

wt_ld
Name of the working table that holds intermediate left side delta in gradient descent.

wt_rd
Name of the working table that holds intermediate right side delta in gradient descent.

options
(Reserved for future use.)

Usage Notes

Call this procedure only when you have no interest in keeping the output matrix factors and the current progress of the algorithm for future use.

Do **not** call this procedure if more predictions will be made using the resulting product factors (`wt_l` and `wt_r` tables), unless you have previous made backup copies of these two tables.

See also the information about the OPG_APIS.CF procedure.

Examples

The following example drops the working tables that were created in the example for the OPG_APIS.CF_PREP procedure.

```
DECLARE
  wt_l varchar2(32)  = 'phonesge$$CFL57';
  wt_r varchar2(32)  = 'phonesge$$CFR57';
  wt_l1 varchar2(32) = 'phonesge$$CFL157';
  wt_r1 varchar2(32) = 'phonesge$$CFR157';
  wt_i varchar2(32)  = 'phonesge$$CFI57';
  wt_ld varchar2(32) = 'phonesge$$CFLD57';
  wt_rd varchar2(32) = 'phonesge$$CFRD57';
BEGIN
  opg_apis.cf_cleanup('phonesge$',wt_l,wt_r,wt_l1,wt_r1,wt_i,wt_ld,wt_rd);
```

```
END;
/
```

A.11.4 OPG_APIS.CF_PREP

Format

```
OPG_APIS.CF_PREP(
     wt_l            IN/OUT  VARCHAR2.
     wt_r            IN/OUT  VARCHAR2.
     wt_l1           IN/OUT  VARCHAR2.
     wt_r1           IN/OUT  VARCHAR2.
     wt_i            IN/OUT  VARCHAR2.
     wt_ld           IN/OUT  VARCHAR2.
     wt_rd           IN/OUT  VARCHAR2.
     options         IN      VARCHAR2 DEFAULT NULL);
```

Description

Preforms preparation work, including creating the necessary intermediate tables, for a later call to the OPG_APIS.CF procedure that will perform collaborative filtering.

Parameters

edge_tab_name
Name of the property graph edge table (GE$).

wt_l
Name of the working table that holds the left side of the matrix factorization.

wt_r
Name of the working table that holds the right side of the matrix factorization.

wt_l1
Name of the working table that holds the left side intermediate step in the gradient descent.

wt_r1
Name of the working table that holds the right side intermediate step in the gradient descent.

wt_l
Name of the working table that holds intermediate matrix product.

wt_ld
Name of the working table that holds intermediate left side delta in gradient descent.

wt_rd
Name of the working table that holds intermediate right side delta in gradient descent.

options
Additional settings for operation. An optional string with one or more (comma-separated) of the following values:

- 'INMEMORY=T' is an option for creating the schema tables with an 'inmemory' clause.

- 'IMC_MC_B=T' creates the schema tables with an INMEMORY MEMCOMPRESS BASIC clause.

Usage Notes

The names of the working tables can be specified or left as null parameters, If the name of any working table parameter is not specified, a name is automatically genenerated and is returned as an OUT parameter. The working table names can be used when you call the OPG_APIS.CF procedure to run the collaborative filtering algorithm.

See also the Usage Notes and Examples for OPG_APIS.CF.

Examples

The following example creates the working tables for a graph named `phones`, and it prints the names that were automatically generated for the working tables.

```
DECLARE
  wt_l varchar2(32);
  wt_r varchar2(32);
  wt_l1 varchar2(32);
  wt_r1 varchar2(32);
  wt_i varchar2(32);
  wt_ld varchar2(32);
  wt_rd varchar2(32);
BEGIN
  opg_apis.cf_prep('phonesge$',wt_l,wt_r,wt_l1,wt_r1,wt_i,wt_ld,wt_rd);
  dbms_output.put_line(' wt_l ' || wt_l);
  dbms_output.put_line(' wt_r ' || wt_r);
  dbms_output.put_line(' wt_l1 ' || wt_l1);
  dbms_output.put_line(' wt_r1 ' || wt_r1);
  dbms_output.put_line(' wt_i ' || wt_i);
  dbms_output.put_line(' wt_ld ' || wt_ld);
  dbms_output.put_line(' wt_rd ' || wt_rd);
END;
/
```

A.11.5 OPG_APIS.CLEAR_PG

Format

```
OPG_APIS.CLEAR_PG(
     graph_name  IN VARCHAR2);
```

Description

Clears all data from a property graph.

Parameters

graph_name
Name of the property graph.

Usage Notes

This procedure removes all data in the property graph by deleting data in the graph tables (VT$, GE$, and so on).

Examples

The following example removes all data from the property graph named `mypg`.

```
EXECUTE OPG_APIS.CLEAR_PG('mypg');
```

A.11.6 OPG_APIS.CLEAR_PG_INDICES

Format

```
OPG_APIS.CLEAR_PG(
     graph_name   IN VARCHAR2);
```

Description

Removes all text index metadata in the IT$ table of the property graph.

Parameters

graph_name
Name of the property graph.

Usage Notes

This procedure does not actually remove text index data

Examples

The following example removes all index metadata of the property graph named `mypg`.

```
EXECUTE OPG_APIS.CLEAR_PG_INDICES('mypg');
```

A.11.7 OPG_APIS.CLONE_GRAPH

Format

```
OPG_APIS.CLONE_GRAPH(
     orgGraph      IN VARCHAR2,
     newGraph      IN VARCHAR2,
     dop           IN INTEGER DEFAULT 4,
     num_hash_ptns IN INTEGER DEFAULT 8,
     tbs           IN VARCHAR2 DEFAULT NULL);
```

Description

Makes a clone of the original graph, giving the new graph a new name.

Parameters

orgGraph
Name of the original property graph.

newGraph
Name of the new (clone) property graph.

dop
Degree of parallelism for the operation.

num_hash_ptns
Number of hash partitions used to partition the vertices and edges tables. It is recommended to use a power of 2 (2, 4, 8, 16, and so on).

tbs
Name of the tablespace to hold all the graph data and index data.

Usage Notes

The original property graph must aleady exist in the database.

Examples

The following example creates a clone graph named `mypgclone` from the property graph `mypg` in the tablespace `my_ts` using a degree of parallelism of 4 and 8 partitions.

```
EXECUTE OPG_APIS.CLONE_GRAPH('mypg', 'mypgclone', 4, 8, 'my_ts');
```

A.11.8 OPG_APIS.COUNT_TRIANGLE

Format

```
OPG_APIS.COUNT_TRIANGLE(
     edge_tab_name IN VARCHAR2,
     wt_und        IN OUT VARCHAR2,
     num_sub_ptns  IN NUMBER DEFAULT 1,
     dop           IN INTEGER DEFAULT 1,
     tbs           IN VARCHAR2 DEFAULT NULL,
     options       IN VARCHAR2 DEFAULT NULL
) RETURN NUMBER;
```

Description

Performs triangle counting in property graph.

Parameters

edge_tab_name
Name of the property graph edge table.

wt_und
A working table holding an undirected version of the graph.

num_sub_ptns
Number of logical subpartitions used in calculating triangles . Must be a positive integer, power of 2 (1, 2, 4, 8, ...). For a graph with a relatively small maximum degree, use the value 1 (the default).

dop
Degree of parallelism for the operation. The default is 1.

tbs
Name of the tablespace to hold the data stored in working tables.

options
Additional settings for the operation:

- 'PDML=T' enables parallel DML.

Usage Notes

The property graph edge table must exist in the database, and the OPG_APIS.COUNT_TRIANGLE_PREP. procedure must already have been executed.

Examples

The following example performs triangle counting in the property graph named `connections`

```
set serveroutput on
DECLARE
  wt1 varchar2(100);  -- intermediate working table
  wt2 varchar2(100);
  wt3 varchar2(100);
  n number;
BEGIN
  opg_apis.count_triangle_prep('connectionsGE$', wt1, wt2, wt3);
  n := opg_apis.count_triangle(
     'connectionsGE$',
      wt1,
      num_sub_ptns=>1,
      dop=>2,
      tbs => 'MYPG_TS',
      options=>'PDML=T'
      );
  dbms_output.put_line('total number of triangles ' || n);
END;
/
```

A.11.9 OPG_APIS.COUNT_TRIANGLE_CLEANUP

Format

```
COUNT_TRIANGLE_CLEANUP(
   edge_tab_name IN VARCHAR2,
   wt_undBM      IN VARCHAR2,
   wt_rnmap      IN VARCHAR2,
   wt_undAM      IN VARCHAR2,
   options       IN VARCHAR2 DEFAULT NULL);
```

Description

Cleans up and drops the temporary working tables used for triangle counting.

Parameters

edge_tab_name
Name of the property graph edge table.

wt_undBM
A working table holding an undirected version of the original graph (before renumbering optimization).

wt_rnmap
A working table that is a mapping table for renumbering optimization.

wt_undAM
A working table holding the undirected version of the graph data after applying the renumbering optimization.

options
Additional settings for operation. An optional string with one or more (comma-separated) of the following values:

- `PDML=T` enables parallel DML.

Usage Notes

You should use this procedure to clean up after triangle counting.

The working tables must exist in the database.

Examples

The following example performs triangle counting in the property graph named `connections`, and drops the working table after it has finished.

```
set serveroutput on

DECLARE
  wt1 varchar2(100);  -- intermediate working table
  wt2 varchar2(100);
  wt3 varchar2(100);
  n number;
BEGIN
  opg_apis.count_triangle_prep('connectionsGE$', wt1, wt2, wt3);
  n := opg_apis.count_triangle_renum(
     'connectionsGE$',
      wt1,
      wt2,
      wt3,
      num_sub_ptns=>1,
      dop=>2,
      tbs => 'MYPG_TS',
      options=>'PDML=T'
      );
  dbms_output.put_line('total number of triangles ' || n);
  opg_apis.count_triangle_cleanup('connectionsGE$', wt1, wt2, wt3);
END;
/
```

A.11.10 OPG_APIS.COUNT_TRIANGLE_PREP

Format

```
OPG_APIS.COUNT_TRIANGLE_PREP(
     edge_tab_name  IN VARCHAR2,
     wt_undBM       IN OUT VARCHAR2,
     wt_rnmap       IN OUT VARCHAR2,
     wt_undAM       IN OUT VARCHAR2,
     options        IN VARCHAR2 DEFAULT NULL);
```

Description

Prepares for running triangle counting.

Parameters

edge_tab_name
Name of the property graph edge table.

wt_undBM
A working table holding an undirected version of the original graph (before renumbering optimization).

wt_rnmap
A working table that is a mapping table for renumbering optimization.

wt_undAM
A working table holding the undirected version of the graph data after applying the renumbering optimization.

options
Additional settings for operation. An optional string with one or more (comma-separated) of the following values:

- `CREATE_UNDIRECTED=T`
- `REUSE_UNDIRECTED_TAB=T`

Usage Notes

The property graph edge table must exist in the database.

Examples

The following example prepares for triangle counting in a property graph named `connections`.

```
set serveroutput on

DECLARE
  wt1 varchar2(100);  -- intermediate working table
  wt2 varchar2(100);
  wt3 varchar2(100);
  n number;
BEGIN
  opg_apis.count_triangle_prep('connectionsGE$', wt1, wt2, wt3);

  n := opg_apis.count_triangle_renum(
     'connectionsGE$',
      wt1,
      wt2,
      wt3,
      num_sub_ptns=>1,
      dop=>2,
      tbs => 'MYPG_TS',
      options=>'CREATE_UNDIRECTED=T,REUSE_UNDIREC_TAB=T'
      );
  dbms_output.put_line('total number of triangles ' || n);
```

```
END;
/
```

A.11.11 OPG_APIS.COUNT_TRIANGLE_RENUM

Format

```
COUNT_TRIANGLE_RENUM(
   edge_tab_name IN VARCHAR2,
   wt_undBM      IN VARCHAR2,
   wt_rnmap      IN VARCHAR2,
   wt_undAM      IN VARCHAR2,
   num_sub_ptns  IN INTEGER DEFAULT 1,
   dop           IN INTEGER DEFAULT 1,
   tbs           IN VARCHAR2 DEFAULT NULL,
   options       IN VARCHAR2 DEFAULT NULL
   ) RETURN NUMBER;
```

Description

Performs triangle counting in property graph, with the optimization of renumbering the vertices of the graph by their degree.

Parameters

edge_tab_name
Name of the property graph edge table.

wt_undBM
A working table holding an undirected version of the original graph (before renumbering optimization).

wt_rnmap
A working table that is a mapping table for renumbering optimization.

wt_undAM
A working table holding the undirected version of the graph data after applying the renumbering optimization.

num_sub_ptns
Number of logical subpartitions used in calculating triangles . Must be a positive integer, power of 2 (1, 2, 4, 8, ...). For a graph with a relatively small maximum degree, use the value 1 (the default).

dop
Degree of parallelism for the operation. The default is 1 (no parallelism).

tbs
Name of the tablespace to hold the data stored in working tables.

options
Additional settings for operation. An optional string with one or more (comma-separated) of the following values:

- `PDML=T` enables parallel DML.

Usage Notes

This function makes the algorithm run faster, but requires more space.

The property graph edge table must exist in the database, and the OPG_APIS.COUNT_TRIANGLE_PREP procedure must already have been executed.

Examples

The following example performs triangle counting in the property graph named `connections`. It does not perform the cleanup after it finishes, so you can count triangles again on the same graph without calling the preparation procedure.

```
set serveroutput on

DECLARE
  wt1 varchar2(100);  -- intermediate working table
  wt2 varchar2(100);
  wt3 varchar2(100);
  n number;
BEGIN
  opg_apis.count_triangle_prep('connectionsGE$', wt1, wt2, wt3);
  n := opg_apis.count_triangle_renum(
     'connectionsGE$',
      wt1,
      wt2,
      wt3,
      num_sub_ptns=>1,
      dop=>2,
      tbs => 'MYPG_TS',
      options=>'PDML=T'
      );
  dbms_output.put_line('total number of triangles ' || n);
END;
/
```

A.11.12 OPG_APIS.CREATE_EDGES_TEXT_IDX

Format

```
OPG_APIS.CREATE_EDGES_TEXT_IDX(
     graph_owner IN VARCHAR2,
     graph_name  IN VARCHAR2,
     pref_owner  IN VARCHAR2 DEFAULT NULL,
     datastore   IN VARCHAR2 DEFAULT NULL,
     filter      IN VARCHAR2 DEFAULT NULL,
     storage     IN VARCHAR2 DEFAULT NULL,
     wordlist    IN VARCHAR2 DEFAULT NULL,
     stoplist    IN VARCHAR2 DEFAULT NULL,
     lexer       IN VARCHAR2 DEFAULT NULL,
     dop         IN INTEGER DEFAULT NULL,
     options     IN VARCHAR2 DEFAULT NULL,);
```

Description

Creates a text index on a property graph edge table.

Parameters

graph_owner
Owner of the property graph.

graph_name
Name of the property graph.

pref_owner
Owner of the preference.

datastore
The way that documents are stored.

filter
The way that documents can be converted to plain text.

storage
The way that the index data is stored.

wordlist
The way that stem and fuzzy queries should be expanded

stoplist
The words or themes that are not to be indexed.

lexer
The language used for indexing.

dop
The degree of parallelism used for index creation.

options
Additional settings for index creation.

Usage Notes

The property graph must exist in the database.

You must have the ALTER SESSION privilege to run this procedure.

Examples

The following example creates a text index on the edge table of property graph `mypg`, which is owned by user SCOTT, using the lexer `OPG_AUTO_LEXER` and a degree of parallelism of 4.

```
EXECUTE OPG_APIS.CREATE_EDGES_TEXT_IDX('SCOTT', 'mypg', 'MDSYS', null, null, null,
null, null, 'OPG_AUTO_LEXER', 4, null);
```

A.11.13 OPG_APIS.CREATE_PG

Format

```
OPG_APIS.CREATE_PG(
     graph_name    IN VARCHAR2,
     dop           IN INTEGER DEFAULT NULL,
     num_hash_ptns IN INTEGER DEFAULT 8,
```

```
     tbs           IN VARCHAR2 DEFAULT NULL,
     options       IN VARCHAR2 DEFAULT NULL);
```

Description

Creates, for a given property graph name, the necessary property graph schema tables that are necessary to store data about vertices, edges, text indexes, and snapshots.

Parameters

graph_name
Name of the property graph.

dop
Degree of parallelism for the operation.

num_hash_ptns
Number of hash partitions used to partition the vertices and edges tables. It is recommended to use a power of 2 (2, 4, 8, 16, and so on).

tbs
Name of the tablespace to hold all the graph data and index data.

options
Options that can be used to customize the creation of indexes on schema tables. (One or more, comma separated.)

- 'SKIP_INDEX=T' skips the default index creation.
- 'SKIP_ERROR=T 'ignores errors encountered during table/index creation.
- 'INMEMORY=T' creqtes the schema tables with an INMEMORYclause.
- 'IMC_MC_B=T' creates the schema tables with an INMEMORY BASIC clause.

Usage Notes

You must have the CREATE TABLE and CREATE INDEX privileges to call this procedure.

By default, all the schema tables will be created with basic compression enabled.

Examples

The following example creates a property graph named `mypg` in the tablespace `my_ts` using eight partitions.

```
EXECUTE OPG_APIS.CREATE_PG('mypg', 4, 8, 'my_ts');
```

A.11.14 OPG_APIS.CREATE_PG_SNAPSHOT_TAB

Format

```
OPG_APIS.CREATE_PG_SNAPSHOT_TAB(
     graph_owner IN VARCHAR2,
     graph_name  IN VARCHAR2,
     dop         IN INTEGER DEFAULT NULL,
     tbs         IN VARCHAR2 DEFAULT NULL,
     options     IN VARCHAR2 DEFAULT NULL);
```

or

```
OPG_APIS.CREATE_PG_SNAPSHOT_TAB(
     graph_name  IN VARCHAR2,
     dop         IN INTEGER DEFAULT NULL,
     tbs         IN VARCHAR2 DEFAULT NULL,
     options     IN VARCHAR2 DEFAULT NULL);
```

Description

Creates, for a given property graph name, the necessary property graph schema table (<graph_name>SS$) that stores data about snapshots for the graph.

Parameters

graph_owner
Name of the owner of the property graph.

graph_name
Name of the property graph.

dop
Degree of parallelism for the operation.

tbs
Name of the tablespace to hold all the graph snapshot data and associated index.

options
Additional settings for the operation:

- 'INMEMORY=T' is an option for creating the schema tables with an 'inmemory' clause.
- 'IMC_MC_B=T' creates the schema tables with an INMEMORY MEMCOMPRESS BASIC clause.

Usage Notes

You must have the CREATE TABLE privilege to call this procedure.

The created snapshot table has the following structure, which may change between releases.

```
Name                           Null?    Type
 ----------------------------------------- -------- ----------------------------
 SSID                           NOT NULL NUMBER
 CONTENTS                                BLOB
 SS_FILE                                 BINARY FILE LOB
 TS                                      TIMESTAMP(6) WITH TIME ZONE
 SS_COMMENT                              VARCHAR2(512)
```

By default, all schema tables will be created with basic compression enabled.

Examples

The following example creates a snapshot table for property graph `mypg` in the current schema, with a degree of parallelism of 4 and using the MY_TS tablespace.

```
EXECUTE OPG_APIS.CREATE_PG_SNAPSHOT_TAB('mypg', 4, 'my_ts');
```

A.11.15 OPG_APIS.CREATE_PG_TEXTIDX_TAB

Format

```
OPG_APIS.CREATE_PG_TEXTIDX_TAB(
     graph_owner IN VARCHAR2,
     graph_name  IN VARCHAR2,
     dop         IN INTEGER DEFAULT NULL,
     tbs         IN VARCHAR2 DEFAULT NULL,
     options     IN VARCHAR2 DEFAULT NULL);
```

or

```
OPG_APIS.CREATE_PG_TEXTIDX_TAB(
     graph_name  IN VARCHAR2,
     dop         IN INTEGER DEFAULT NULL,
     tbs         IN VARCHAR2 DEFAULT NULL,
     options     IN VARCHAR2 DEFAULT NULL);
```

Description

Creates, for a given property graph name, the necessary property graph text index schema table (<graph_name>IT$) that stores data for managing text index metadata for the graph.

Parameters

graph_owner
Name of the owner of the property graph.

graph_name
Name of the property graph.

dop
Degree of parallelism for the operation.

tbs
Name of the tablespace to hold all the graph index metadata and associated index.

options
Additional settings for the operation:

- 'INMEMORY=T' is an option for creating the schema tables with an 'inmemory' clause.
- 'IMC_MC_B=T' creates the schema tables with an INMEMORY MEMCOMPRESS BASIC clause.

Usage Notes

You must have the CREATE TABLE privilege to call this procedure.

The created index metadata table has the following structure, which may change between releases.

```
(
   EIN     nvarchar2(80) not null,   -- index name
   ET      number,                   -- entity type 1 - vertex, 2 -edge
   IT      number,                   -- index type 1 - auto   0 - manual
```

```
              SE      number,                  -- search engine 1 -solr, 0 - lucene
              K       nvarchar2(3100),         -- property key use an empty space when
there is no K/V
              DT      number,                  -- directory type 1 - MMAP, 2 - FS, 3 -
JDBC
              LOC     nvarchar2(3100),         -- directory location (1, 2)
              NUMDIRS number,                  -- property key used to index CAN BE NULL
              VERSION nvarchar2(100),          -- lucene version
              USEDT   number,                  -- user data type (1 or 0)
              STOREF  number,                  -- store fields into lucene
              CF      nvarchar2(3100),          -- configuration name
              SS      nvarchar2(3100),          -- solr server url
              SA      nvarchar2(3100),          -- solr server admin url
              ZT      number,                  -- zookeeper timeout
              SH      number,                  -- number of shards
              RF      number,                  -- replication factor
              MS      number,                  -- maximum shards per node
              PO      nvarchar2(3100),         -- preferred owner oracle text
              DS      nvarchar2(3100),         -- datastore
              FIL     nvarchar2(3100),         -- filter
              STR     nvarchar2(3100),         -- storage
              WL      nvarchar2(3100),         -- word list
              SL      nvarchar2(3100),         -- stop list
              LXR     nvarchar2(3100),         -- lexer
              OPTS    nvarchar2(3100),         -- options
              primary key (EIN, K, ET)
          )
```

By default, all schema tables will be created with basic compression enabled.

Examples

The following example creates a property graph text index metadata table for property graph `mypg` in the current schema, with a degree of parallelism of 4 and using the MY_TS tablespace.

```
EXECUTE OPG_APIS.CREATE_PG_TEXTIDX_TAB('mypg', 4, 'my_ts');
```

A.11.16 OPG_APIS.CREATE_STAT_TABLE

Format

```
OPG_APIS.CREATE_STAT_TABLE(
     stattab   IN VARCHAR2,
     tblspace  IN VARCHAR2 DEFAULT NULL);
```

Description

Creates a table that can hold property graph statistics.

Parameters

stattab
Name of the table to hold statistics

tblapace
Name of the tablespace to hold the statistics table. If none is specified, then the statistics table will be created in the user's default tablespace.

Usage Notes

You must have the CREATE TABLE privilege to call this procedure.

The statistics table has the following columns. Note that the columns and their types may vary between releases.

```
Name                           Null?    Type
----------------------------------------- -------- ----------------------------
STATID                             VARCHAR2(128)
TYPE                                CHAR(1)
VERSION                            NUMBER
FLAGS                                NUMBER
C1                                VARCHAR2(128)
C2                                VARCHAR2(128)
C3                                VARCHAR2(128)
C4                                VARCHAR2(128)
C5                                VARCHAR2(128)
C6                                VARCHAR2(128)
N1                                NUMBER
N2                                NUMBER
N3                                NUMBER
N4                                NUMBER
N5                                NUMBER
N6                                NUMBER
N7                                NUMBER
N8                                NUMBER
N9                                NUMBER
N10                                NUMBER
N11                                NUMBER
N12                                NUMBER
N13                                NUMBER
D1                                DATE
T1                                TIMESTAMP(6) WITH TIME ZONE
R1                                RAW(1000)
R2                                RAW(1000)
R3                                RAW(1000)
CH1                                VARCHAR2(1000)
CL1                                CLOB
```

Examples

The following example creates a statistics table named`mystat` .

```
EXECUTE OPG_APIS.CREATE_STAT_TABLE('mystat',null);
```

A.11.17 OPG_APIS.CREATE_SUB_GRAPH

Format

```
OPG_APIS.CREATE_SUB_GRAPH(
     graph_owner IN VARCHAR2,
     orgGraph    IN VARCHAR2,
     newGraph    IN VARCHAR2,
     nSrc        IN NUMBER,
     depth       IN NUMBER);
```

Description

Creates a subgraph, which is an expansion from a given vertex. The depth of expansion is customizable.

Parameters

graph_owner
Owner of the property graph.

orgGraph
Name of the original property graph.

newGraph
Name of the subgraph to be created from the original graph.

nSrc
Vertex ID: the subgraph will be created by expansion from this vertex. For example, `nSrc = 1` starts the expansion from the vertex with ID 1.

depth
Depth of expansion: the expansion, following outgoing edges, will include all vertices that are within `depth` hops away from vertex `nSrc`. For example, `depth = 2` causes the to should include all vertices that are within 2 hops away from vertex `nSrc` (vertex ID 1 in the preceding example).

Usage Notes

The original property graph must exist in the database.

Examples

The following example creates a subgraph `mypgsub` from the property graph `mypg` whose owner is SCOTT. The subgraph includes vertex 1 and all vertices that are reachable from the vertex with ID 1 in 2 hops.

```
EXECUTE OPG_APIS.CREATE_SUB_GRAPH('SCOTT', 'mypg', 'mypgsub', 1, 2);
```

A.11.18 OPG_APIS.CREATE_VERTICES_TEXT_IDX

Format

```
OPG_APIS.CREATE_VERTICES_TEXT_IDX(
     graph_owner IN VARCHAR2,
     graph_name  IN VARCHAR2,
     pref_owner  IN VARCHAR2 DEFAULT NULL,
     datastore   IN VARCHAR2 DEFAULT NULL,
     filter      IN VARCHAR2 DEFAULT NULL,
     storage     IN VARCHAR2 DEFAULT NULL,
     wordlist    IN VARCHAR2 DEFAULT NULL,
     stoplist    IN VARCHAR2 DEFAULT NULL,
     lexer       IN VARCHAR2 DEFAULT NULL,
     dop         IN INTEGER DEFAULT NULL,
     options     IN VARCHAR2 DEFAULT NULL,);
```

Description

Creates a text index on a property graph vertex table.

Parameters

graph_owner
Owner of the property graph.

graph_name
Name of the property graph.

pref_owner
Owner of the preference.

datastore
The way that documents are stored.

filter
The way that documents can be converted to plain text.

storage
The way that the index data is stored.

wordlist
The way that stem and fuzzy queries should be expanded

stoplist
The words or themes that are not to be indexed.

lexer
The language used for indexing.

dop
The degree of parallelism used for index creation.

options
Additional settings for index creation.

Usage Notes

The original property graph must exist in the database.

You must have the ALTER SESSION privilege to run this procedure.

Examples

The following example creates a text index on the vertex table of property graph `mypg`, which is owned by user SCOTT, using the lexer `OPG_AUTO_LEXER` and a degree of parallelism of 4.

```
EXECUTE OPG_APIS.CREATE_VERTICES_TEXT_IDX('SCOTT', 'mypg', null, null, null,
null, null, null, 'OPG_AUTO_LEXER', 4, null);
```

A.11.19 OPG_APIS.DROP_EDGES_TEXT_IDX

Format

```
OPG_APIS.DROP_EDGES_TEXT_IDX(
     graph_owner IN VARCHAR2,
     graph_name  IN VARCHAR2,
     options     IN VARCHAR2 DEFAULT NULL);
```

Description

Drops a text index on a property graph edge table.

Parameters

graph_owner
Owner of the property graph.

graph_name
Name of the property graph.

options
Additional settings for the operation.

Usage Notes

A text index must already exist on the property graph edge table.

Examples

The following example drops the text index on the edge table of property graph `mypg` that is owned by user SCOTT.

```
EXECUTE OPG_APIS.DROP_EDGES_TEXT_IDX('SCOTT', 'mypg', null);
```

A.11.20 OPG_APIS.DROP_PG

Format

```
OPG_APIS.DROP_PG(
     graph_name  IN VARCHAR2);
```

Description

Drops (deletes) a property graph.

Parameters

graph_name
Name of the property graph.

Usage Notes

All the graph tables (VT$, GE$, and so on) will be dropped from the database.

Examples

The following example drops the property graph named `mypg`.

```
EXECUTE OPG_APIS.DROP_PG('mypg');
```

A.11.21 OPG_APIS.DROP_PG_VIEW

Format

```
OPG_APIS.DROP_PG_VIEW(
     graph_name   IN VARCHAR2);
     options      IN VARCHAR2);
```

Description

Drops (deletes) the view definition of a property graph.

Parameters

graph_name
Name of the property graph.

options
(Reserved for future use.)

Usage Notes

Oracle supports creating physical property graphs and property graph views. For example, given an RDF model, it supports creating property graph views over the RDF model, so that you can run property graph analytics on top of the RDF graph.

This procedure cannot be undone.

Examples

The following example drops the view definition of the property graph named `mypg`.

```
EXECUTE OPG_APIS.DROP_PG_VIEW('mypg');
```

A.11.22 OPG_APIS.DROP_VERTICES_TEXT_IDX

Format

```
OPG_APIS.DROP_VERTICES_TEXT_IDX(
     graph_owner IN VARCHAR2,
     graph_name  IN VARCHAR2,
     options     IN VARCHAR2 DEFAULT NULL);
```

Description

Drops a text index on a property graph vertex table.

Parameters

graph_owner
Owner of the property graph.

graph_name
Name of the property graph.

options
Additional settings for the operation.

Usage Notes

A text index must already exist on the property graph vertex table.

Examples

The following example drops the text index on the vertex table of property graph `mypg` that is owned by user SCOTT.

```
EXECUTE OPG_APIS.DROP_VERTICES_TEXT_IDX('SCOTT', 'mypg', null);
```

A.11.23 OPG_APIS.ESTIMATE_TRIANGLE_RENUM

Format

```
COUNT_TRIANGLE_ESTIMATE(
   edge_tab_name IN VARCHAR2,
   wt_undBM      IN VARCHAR2,
   wt_rnmap      IN VARCHAR2,
   wt_undAM      IN VARCHAR2,
   num_sub_ptns  IN INTEGER DEFAULT 1,
   chunk_id      IN INTEGER DEFAULT 1,
   dop           IN INTEGER DEFAULT 1,
   tbs           IN VARCHAR2 DEFAULT NULL,
   options       IN VARCHAR2 DEFAULT NULL
   ) RETURN NUMBER;
```

Description

Estimates the number of triangles in a property graph.

Parameters

edge_tab_name
Name of the property graph edge table.

wt_undBM
A working table holding an undirected version of the original graph (before renumbering optimization).

wt_rnmap
A working table that is a mapping table for renumbering optimization.

wt_undAM
A working table holding the undirected version of the graph data after applying the renumbering optimization.

num_sub_ptns
Number of logical subpartitions used in calculating triangles . Must be a positive integer, power of 2 (1, 2, 4, 8, ...). For a graph with a relatively small maximum degree, use the value 1 (the default).

chunk_id
The logical subpartition to be used in triangle estimation (Only this partition will be counted). It must be an integer between 0 and `num_sub_ptns*num_sub_ptns-1`.

dop
Degree of parallelism for the operation. The default is 1 (no parallelism).

tbs
Name of the tablespace to hold the data stored in working tables.

options
Additional settings for operation. An optional string with one or more (comma-separated) of the following values:

- `PDML=T` enables parallel DML.

Usage Notes

This function counts the total triangles in a portion of size `1/(num_sub_ptns*num_sub_ptns)` of the graph; so to estimate the total number of triangles in the graph, you can multiply the result by `num_sub_ptns*num_sub_ptns`.

The property graph edge table must exist in the database, and the OPG_APIS.COUNT_TRIANGLE_PREP procedure must already have been executed.

Examples

The following example estimates the number of triangle in the property graph named `connections`. It does not perform the cleanup after it finishes, so you can count triangles again on the same graph without calling the preparation procedure.

```
set serveroutput on

DECLARE
  wt1 varchar2(100);  -- intermediate working table
  wt2 varchar2(100);
  wt3 varchar2(100);
  n number;
BEGIN
  opg_apis.count_triangle_prep('connectionsGE$', wt1, wt2, wt3);
  n := opg_apis.estimate_triangle_renum(
     'connectionsGE$',
      wt1,
      wt2,
      wt3,
      num_sub_ptns=>64,
      chunk_id=>2048,
      dop=>2,
      tbs => 'MYPG_TS',
      options=>'PDML=T'
```

```
      );
  dbms_output.put_line('estimated number of triangles ' || (n * 64 * 64));
END;
/
```

A.11.24 OPG_APIS.EXP_EDGE_TAB_STATS

Format

```
OPG_APIS.EXP_EDGE_TAB_STATS(
     graph_name    IN VARCHAR2,
     stattab       IN VARCHAR2,
     statid        IN VARCHAR2 DEFAULT NULL,
     cascade       IN BOOLEAN DEFAULT TRUE,
     statown       IN VARCHAR2 DEFAULT NULL,
     stat_category IN VARCHAR2 DEFAULT 'OBJECT_STATS');
```

Description

Retrieves statistics for the edge table of a given property graph and stores them in the user-created statistics table.

Parameters

graph_name
Name of the property graph.

stattab
Name of the statistics table.

statid
Optional identifier to associate with these statistics within `stattab`.

cascade
If `TRUE`, column and index statistics are exported.

statown
Schema containing `stattab`.

stat_category
Specifies what statistics to export, using a comma to separate values. The supported values are `'OBJECT_STATS'` (the default: table statistics, column statistics, and index statistics) and `'SYNOPSES'` (auxiliary statistics created when statistics are incrementally maintained).

Usage Notes

(None.)

Examples

The following example creates a statistics table, exports into this table the property graph edge table statistics, and issues a query to count the relevant rows for the newly created statistics.

```
EXECUTE OPG_APIS.CREATE_STAT_TABLE('mystat',null);

EXECUTE OPG_APIS.EXP_EDGE_TAB_STATS('mypg', 'mystat', 'edge_stats_id_1', true, null,
'OBJECT_STATS');
```

```
SELECT count(1) FROM mystat WHERE statid='EDGE_STATS_ID_1';

       153
```

A.11.25 OPG_APIS.EXP_VERTEX_TAB_STATS

Format

```
OPG_APIS.EXP_VERTEX_TAB_STATS(
     graph_name    IN VARCHAR2,
     stattab       IN VARCHAR2,
     statid        IN VARCHAR2 DEFAULT NULL,
     cascade       IN BOOLEAN DEFAULT TRUE,
     statown       IN VARCHAR2 DEFAULT NULL,
     stat_category IN VARCHAR2 DEFAULT 'OBJECT_STATS');
```

Description

Retrieves statistics for the vertex table of a given property graph and stores them in the user-created statistics table.

Parameters

graph_name
Name of the property graph.

stattab
Name of the statistics table.

statid
Optional identifier to associate with these statistics within `stattab`.

cascade
If `TRUE`, column and index statistics are exported.

statown
Schema containing `stattab`.

stat_category
Specifies what statistics to export, using a comma to separate values. The supported values are `'OBJECT_STATS'` (the default: table statistics, column statistics, and index statistics) and `'SYNOPSES'` (auxiliary statistics created when statistics are incrementally maintained).

Usage Notes

(None.)

Examples

The following example creates a statistics table, exports into this table the property graph vertex table statistics, and issues a query to count the relevant rows for the newly created statistics.

```
EXECUTE OPG_APIS.CREATE_STAT_TABLE('mystat',null);

EXECUTE OPG_APIS.EXP_VERTEX_TAB_STATS('mypg', 'mystat', 'vertex_stats_id_1',
```

```
true, null, 'OBJECT_STATS');

SELECT count(1) FROM mystat WHERE statid='VERTEX_STATS_ID_1';

       108
```

A.11.26 OPG_APIS.FIND_CC_MAPPING_BASED

Format

```
OPG_APIS.FIND_CC_MAPPING_BASED(
     edge_tab_name IN VARCHAR2,
     wt_clusters   IN OUT VARCHAR2,
     wt_undir      IN OUT VARCHAR2,
     wt_cluas      IN OUT VARCHAR2,
     wt_newas      IN OUT VARCHAR2,
     wt_delta      IN OUT VARCHAR2,
     dop           IN INTEGER DEFAULT 4,
     rounds        IN INTEGER DEFAULT 0,
     tbs           IN VARCHAR2 DEFAULT NULL,
     options       IN VARCHAR2 DEFAULT NULL);
```

Description

Finds connected components in a property graph. All connected components will be stored in the `wt_clusters` table. The original graph is treated as undirected.

Parameters

edge_tab_name
Name of the property graph edge table.

wt_clusters
A working table holding the final vertex cluster mappings. This table has two columns (VID NUMBER, CLUSTER_ID NUMBER). Column VID stores the vertex ID values, and column CLUSTER_ID stores the corresponding cluster ID values. Cluster ID values are long integers that can have gaps between them.
If an empty name is specified, a new table will be generated, and its name will be returned.

wt_undir
A working table holding an undirected version of the graph.

wt_cluas
A working table holding current cluster assignments.

wt_newas
A working table holding updated cluster assignments.

wt_delta
A working table holding changes ("delta") in cluster assignments.

dop
Degree of parallelism for the operation. The default is 4.

rounds
Maximum umber of iterations to perform in searching for connected components. The default value of 0 (zero) means that computation will continue until all connected components are found.

tbs
Name of the tablespace to hold the data stored in working tables.

options
Additional settings for the operation.

- 'PDML=T' enables parallel DML.

Usage Notes

The property graph edge table must exist in the database, and the OPG_APIS.FIND_CLUSTERS_PREP. procedure must already have been executed.

Examples

The following example finds the connected components in a property graph named `mypg`.

```
DECLARE
  wtClusters   varchar2(200) := 'mypg_clusters';
  wtUnDir      varchar2(200);
  wtCluas      varchar2(200);
  wtNewas      varchar2(200);
  wtDelta      varchar2(200);
BEGIN
  opg_apis.find_clusters_prep('mypgGE$', wtClusters, wtUnDir,
      wtCluas, wtNewas, wtDelta, '');
  dbms_output.put_line('working tables names ' || wtClusters || ' '
|| wtUnDir || ' ' || wtCluas || ' '  || wtNewas    || ' '
|| wtDelta );

opg_apis.find_cc_mapping_based(''mypgGE$', wtClusters, wtUnDir,
      wtCluas, wtNewas, wtDelta, 8, 0, 'MYTBS', 'PDML=T');

--
-- logic to consume results in wtClusters
-- e.g.:
-- select /*+ parallel(8) */ count(distinct cluster_id)
--   from mypg_clusters;

-- cleanup all the working tables
  opg_apis.find_clusters_cleanup('mypgGE$', wtClusters, wtUnDir,
      wtCluas, wtNewas, wtDelta, '');

END;
/
```

A.11.27 OPG_APIS.FIND_CLUSTERS_CLEANUP

Format

```
OPG_APIS.FIND_CLUSTERS_CLEANUP(
     edge_tab_name   IN VARCHAR2,
     wt_clusters     IN OUT VARCHAR2,
     wt_undir        IN OUT VARCHAR2,
```

```
     wt_cluas       IN OUT VARCHAR2,
     wt_newas       IN OUT VARCHAR2,
     wt_delta       IN OUT VARCHAR2,
     options        IN VARCHAR2 DEFAULT NULL);
```

Description

Cleans up after running weakly connected components (WCC) cluster detection.

Parameters

edge_tab_name
Name of the property graph edge table.

wt_clusters
A working table holding the final vertex cluster mappings. This table has two columns (VID NUMBER, CLUSTER_ID NUMBER). Column VID stores the vertex ID values, and column CLUSTER_ID stores the corresponding cluster ID values. Cluster ID values are long integers that can have gaps between them.
If an empty name is specified, a new table will be generated, and its name will be returned.

wt_undir
A working table holding an undirected version of the graph.

wt_cluas
A working table holding current cluster assignments.

wt_newas
A working table holding updated cluster assignments.

wt_delta
A working table holding changes ("delta") in cluster assignments.

options
(Reserved for future use.)

Usage Notes

The property graph edge table must exist in the database.

Examples

The following example cleans up after performing doing cluster detection in a property graph named `mypg`.

```
EXECUTE OPG_APIS.FIND_CLUSTERS_CLEANUP('mypgGE$', wtClusters, wtUnDir, wtCluas,
wtNewas, wtDelta, null);
```

A.11.28 OPG_APIS.FIND_CLUSTERS_PREP

Format

```
OPG_APIS.FIND_CLUSTERS_PREP(
     edge_tab_name   IN VARCHAR2,
     wt_clusters     IN OUT VARCHAR2,
     wt_undir        IN OUT VARCHAR2,
     wt_cluas        IN OUT VARCHAR2,
     wt_newas        IN OUT VARCHAR2,
```

```
    wt_delta        IN OUT VARCHAR2,
    options         IN VARCHAR2 DEFAULT NULL);
```

Description

Prepares for running weakly connected components (WCC) cluster detection.

Parameters

edge_tab_name
Name of the property graph edge table.

wt_clusters
A working table holding the final vertex cluster mappings. This table has two columns (VID NUMBER, CLUSTER_ID NUMBER). Column VID stores the vertex ID values, and column CLUSTER_ID stores the corresponding cluster ID values. Cluster ID values are long integers that can have gaps between them.
If an empty name is specified, a new table will be generated, and its name will be returned.

wt_undir
A working table holding an undirected version of the graph.

wt_cluas
A working table holding current cluster assignments.

wt_newas
A working table holding updated cluster assignments.

wt_delta
A working table holding changes ("delta") in cluster assignments.

options
Additional settings for index creation.

Usage Notes

The property graph edge table must exist in the database.

Examples

The following example prepares for doing cluster detection in a property graph named `mypg`.

```
DECLARE
  wtClusters   varchar2(200);
  wtUnDir      varchar2(200);
  wtCluas      varchar2(200);
  wtNewas      varchar2(200);
  wtDelta      varchar2(200);
BEGIN
  opg_apis.find_clusters_prep('mypgGE$', wtClusters, wtUnDir,
      wtCluas, wtNewas, wtDelta, '');
  dbms_output.put_line('working tables names ' || wtClusters || ' '
|| wtUnDir || ' ' || wtCluas || ' '  || wtNewas    || ' '
|| wtDelta );
END;
/
```

A.11.29 OPG_APIS.FIND_SP

Format

```
OPG_APIS.FIND_SP(
     edge_tab_name  IN VARCHAR2,
     source         IN NUMBER,
     dest           IN NUMBER,
     exp_tab        IN OUT VARCHAR2,
     dop            IN INTEGER,
     stats_freq     IN INTEGER DEFAULT 20000,
     path_output    OUT VARCHAR2,
     weights_output OUT VARCHAR2,
     edge_tab_name  IN VARCHAR2,
     options        IN VARCHAR2 DEFAULT NULL,
     scn            IN NUMBER DEFAULT NULL);
```

Description

Finds the shortest path between given source vertex and destination vertex in the property graph. It assumes each edge has a numeric weight property. (The actual edge property name is not significant.)

Parameters

edge_tab_name
Name of the property graph edge table.

source
Source (start) vertex ID.

dest
Destination (end) vertex ID.

exp_tab
Name of the expansion table to be used for shortest path calculations.

dop
Degree of parallelism for the operation.

stats_freq
Frequency for collecting statistics on the table.

path_output
The output shortest path. It consists of IDs of vertices on the shortest path, which are separated by the space character.

weights_output
The output shortest path weights. It consists of weights of edges on the shortest path, which are separated by the space character.

options
Additional settings for the operation. An optional string with one or more (comma-separated) of the following values:

- CREATE_UNDIRECTED=T
- REUSE_UNDIRECTED_TAB=T

scn
SCN for the edge table. It can be null.

Usage Notes

The property graph edge table must exist in the database, and the OPG_APIS.FIND_SP_PREP procedure must have already been called.

Examples

The following example prepares for shortest-path calculation, and then finds the shortest path from vertex 1 to vertex 35 in a property graph named mypg.

```
set serveroutput on
DECLARE
    w     varchar2(2000);
    wtExp varchar2(2000);
    vPath varchar2(2000);
BEGIN
    opg_apis.find_sp_prep('mypgGE$', wtExp, null);
    opg_apis.find_sp('mypgGE$', 1, 35,  wtExp, 1, 200000,  vPath, w, null, null);
    dbms_output.put_line('Shortest path ' || vPath);
    dbms_output.put_line('Path weights '  || w);
END;
/
```

The output will be similar to the following. It shows one shortest path starting from vertex 1, to vertex 2, and finally to the destination vertex (35).

```
Shortest path 1    2 35
Path weights 3 2   1 1
```

A.11.30 OPG_APIS.FIND_SP_CLEANUP

Format

```
OPG_APIS.FIND_SP_CLEANUP(
     edge_tab_name  IN VARCHAR2,
     exp_tab        IN OUT VARCHAR2,
     options        IN VARCHAR2 DEFAULT NULL);
```

Description

Cleans up after running one or more shortest path calculations.

Parameters

edge_tab_name
Name of the property graph edge table.

exp_tab
Name of the expansion table used for shortest path calculations.

options
(Reserved for future use.)

Usage Notes

There is no need to call this procedure after each OPG_APIS.FIND_SP call. You can run multiple shortest path calculations before calling OPG_APIS.FIND_SP_CLEANUP.

Examples

The following example does cleanup work after doing shortest path calculations in a property graph named `mypg`.

```
EXECUTE OPG_APIS.FIND_SP_CLEANUP('mypgGE$', wtExpTab, null);
```

A.11.31 OPG_APIS.FIND_SP_PREP

Format

```
OPG_APIS.FIND_SP_PREP(
     edge_tab_name  IN VARCHAR2,
     exp_tab        IN OUT VARCHAR2,
     options        IN VARCHAR2 DEFAULT NULL);
```

Description

Prepares for shortest path calculations.

Parameters

edge_tab_name
Name of the property graph edge table.

exp_tab
Name of the expansion table to be used for shortest path calculations. If it is empty, an intermediate working table will be created and the table name will be returned in `exp_tab`.

options
Additional settings for the operation. An optional string with one or more (comma-separated) of the following values:

- `CREATE_UNDIRECTED=T`
- `REUSE_UNDIRECTED_TAB=T`

Usage Notes

The property graph edge table must exist in the database.

Examples

The following example does preparation work before doing shortest path calculations in a property graph named `mypg`

```
set serveroutput on
DECLARE
    wtExp  varchar2(2000); -- name of working table for shortest path calculation
BEGIN
    opg_apis.find_sp_prep('mypgGE$', wtExp, null);
```

```
    dbms_output.put_line('Working table name ' || wtExp);
END;
/
```

The output will be similar to the following. (Your output may be different depending on the SQL session ID.)

```
Working table name "MYPGGE$$TWFS277"
```

A.11.32 OPG_APIS.GET_BUILD_ID

Format

```
OPG_APIS.GET_BUILD_ID() RETURN VARCHAR2;
```

Description

Returns the current build ID of the Oracle Spatial and Graph property graph support, in YYYYMMDD format.

Parameters

(None.)

Usage Notes

(None.)

Examples

The following example returns the current build ID of the Oracle Spatial and Graph property graph support.

```
SQL> SELECT OPG_APIS.GET_BUILD_ID() FROM DUAL;

OPG_APIS.GET_BUILD_ID()
--------------------------------------------------------------------------------
20160606
```

A.11.33 OPG_APIS.GET_GEOMETRY_FROM_V_COL

Format

```
OPG_APIS.GET_GEOMETRY_FROM_V_COL(
     v     IN NVARCHAR2,
     srid  IN NUMBER DEFAULT 8307
) RETURN SDO_GEOMETRY;
```

Description

Returns an SDO_GEOMETRY object constructed using spatial data and optionally an SRID value.

Parameters

v
A String containing spatial data in serialized form.

srid
SRID (coordinate system identifier) to be used in the resulting SDO_GEOMETRY object. The default value is 8307, the Oracle Spatial SRID for the WGS 84 longitude/latitude coordinate system.

Usage Notes

If there is incorrect syntax or a parsing error, this function returns NULL instead of generating an exception.

Examples

The following examples show point, line, and polygon geometries.

```
SQL> select opg_apis.get_geometry_from_v_col('10.0 5.0',8307) from dual;

OPG_APIS.GET_GEOMETRY_FROM_V_COL('10.05.0',8307)(SDO_GTYPE, SDO_SRID,
SDO_POINT(
-----------------------------------------------------------------------------
---
SDO_GEOMETRY(2001, 8307, SDO_POINT_TYPE(10, 5, NULL), NULL, NULL)


SQL>   select opg_apis.get_geometry_from_v_col('LINESTRING(30 10, 10 30, 40
40)',8307) from dual;

OPG_APIS.GET_GEOMETRY_FROM_V_COL('LINESTRING(3010,1030,4040)',8307)
(SDO_GTYPE, S
-----------------------------------------------------------------------------
---
SDO_GEOMETRY(2002, 8307, NULL, SDO_ELEM_INFO_ARRAY(1, 2, 1),
SDO_ORDINATE_ARRAY(
30, 10, 10, 30, 40, 40))


SQL>  select opg_apis.get_geometry_from_v_col('POLYGON((-83.6  34.1, -83.6
34.3, -83.4 34.3, -83.4 34.1, -83.6 34.1))', 8307) from dual;

OPG_APIS.GET_GEOMETRY_FROM_V_COL('POLYGON((-83.634.1,-83.634.3,-83.434.3,-83.
434
-----------------------------------------------------------------------------
---
SDO_GEOMETRY(2003, 8307, NULL, SDO_ELEM_INFO_ARRAY(1, 1003, 1),
SDO_ORDINATE_ARR
AY(-83.6, 34.1, -83.6, 34.3, -83.4, 34.3, -83.4, 34.1, -83.6, 34.1))
```

A.11.34 OPG_APIS.GET_GEOMETRY_FROM_V_T_COLS

Format

```
OPG_APIS.GET_GEOMETRY_FROM_V_T_COLS(
     v      IN NVARCHAR2,
     t      IN INTEGER,
     srid   IN NUMBER DEFAULT 8307
) RETURN SDO_GEOMETRY;
```

Description

Returns an SDO_GEOMETRY object constructed using spatial data, a type value, and optionally an SRID value.

Parameters

v
A String containing spatial data in serialized form,

t
Value indicating the type of value represented by the `v` parameter. Must be 20. (A null value or any other value besides 20 returns a null SDO_GEOMETRY object.)

srid
SRID (coordinate system identifier) to be used in the resulting SDO_GEOMETRY object. The default value is 8307, the Oracle Spatial SRID for the WGS 84 longitude/latitude coordinate system.

Usage Notes

If there is incorrect syntax or a parsing error, this function returns NULL instead of generating an exception.

Examples

The following examples show point, line, and polygon geometries.

```
SQL> select opg_apis.get_geometry_from_v_t_cols('10.0 5.0', 20, 8307)
from dual;

OPG_APIS.GET_GEOMETRY_FROM_V_T_COLS('10.05.0',20,8307)(SDO_GTYPE,
SDO_SRID, SDO_
----------------------------------------------------------------------
---------
SDO_GEOMETRY(2001, 8307, SDO_POINT_TYPE(10, 5, NULL), NULL, NULL)


SQL> select opg_apis.get_geometry_from_v_t_cols('LINESTRING(30 10, 10
30, 40 40)', 20, 8307) from dual;

OPG_APIS.GET_GEOMETRY_FROM_V_T_COLS('LINESTRING(3010,1030,4040)',20,830
7)(SDO_GT
----------------------------------------------------------------------
---------
SDO_GEOMETRY(2002, 8307, NULL, SDO_ELEM_INFO_ARRAY(1, 2, 1),
SDO_ORDINATE_ARRAY(
30, 10, 10, 30, 40, 40))


SQL>  select opg_apis.get_geometry_from_v_t_cols('POLYGON((-83.6
34.1, -83.6 34.3, -83.4 34.3, -83.4 34.1, -83.6 34.1))', 20, 8307)
from dual;

OPG_APIS.GET_GEOMETRY_FROM_V_T_COLS('POLYGON((-83.634.1,-83.634.3,-83.4
```

```
34.3,-83.
-----------------------------------------------------------------------------
---
SDO_GEOMETRY(2003, 8307, NULL, SDO_ELEM_INFO_ARRAY(1, 1003, 1),
SDO_ORDINATE_ARR
AY(-83.6, 34.1, -83.6, 34.3, -83.4, 34.3, -83.4, 34.1, -83.6, 34.1))
```

A.11.35 OPG_APIS.GET_LATLONG_FROM_V_COL

Format

```
OPG_APIS.GET_LATLONG_FROM_V_COL(
     v      IN NVARCHAR2,
     srid   IN NUMBER DEFAULT 8307
) RETURN SDO_GEOMETRY;
```

Description

Returns an SDO_GEOMETRY object constructed using spatial data and optionally an SRID value.

Parameters

v
A String containing spatial data in serialized form.

srid
SRID (coordinate system identifier) to be used in the resulting SDO_GEOMETRY object. The default value is 8307, the Oracle Spatial SRID for the WGS 84 longitude/latitude coordinate system.

Usage Notes

This function assumes that for each vertex in the geometry in the `v` parameter, the ***first*** number is the ***latitude*** value and the second number is the longitude value. (This is the reverse of the order in an SDO_GEOMETRY object definition, where longitude is first and latitude is second).

If there is incorrect syntax or a parsing error, this function returns NULL instead of generating an exception.

Examples

The following example returns a point SDO_GEOMETRY object. Notice that the coordinate values of the input point are “swapped” in the returned SDO_GEOMETRY object.

```
SQL> select opg_apis.get_latlong_from_v_col('5.1 10.0', 8307) from dual;

OPG_APIS.GET_LATLONG_FROM_V_COL('5.110.0',8307)(SDO_GTYPE, SDO_SRID,
SDO_POINT(X
-----------------------------------------------------------------------------
---
SDO_GEOMETRY(2001, 8307, SDO_POINT_TYPE(10, 5.1, NULL), NULL, NULL)
```

A.11.36 OPG_APIS.GET_LATLONG_FROM_V_T_COLS

Format

```
OPG_APIS.GET_LATLONG_FROM_V_T_COLS(
     v      IN NVARCHAR2,
     t      IN INTEGER,
     srid   IN NUMBER DEFAULT 8307
) RETURN SDO_GEOMETRY;
```

Description

Returns an SDO_GEOMETRY object constructed using spatial data, a type value, and optionally an SRID value.

Parameters

v
A String containing spatial data in serialized form.

t
Value indicating the type of value represented by the `v` parameter. Must be 20. (A null value or any other value besides 20 returns a null SDO_GEOMETRY object.)

srid
SRID (coordinate system identifier) to be used in the resulting SDO_GEOMETRY object. The default value is 8307, the Oracle Spatial SRID for the WGS 84 longitude/ latitude coordinate system.

Usage Notes

This function assumes that for each vertex in the geometry in the `v` parameter, the ***first*** number is the ***latitude*** value and the second number is the longitude value. (This is the reverse of the order in an SDO_GEOMETRY object definition, where longitude is first and latitude is second).

If there is incorrect syntax or a parsing error, this function returns NULL instead of generating an exception.

Examples

The following example returns a point SDO_GEOMETRY object. Notice that the coordinate values of the input point are “swapped” in the returned SDO_GEOMETRY object.

```
SQL> select opg_apis.get_latlong_from_v_t_cols('5.1 10.0',20,8307)
from dual;

OPG_APIS.GET_LATLONG_FROM_V_T_COLS('5.110.0',20,8307)(SDO_GTYPE,
SDO_SRID, SDO_P
-----------------------------------------------------------------------
---------
SDO_GEOMETRY(2001, 8307, SDO_POINT_TYPE(10, 5.1, NULL), NULL, NULL)
```

A.11.37 OPG_APIS.GET_LONG_LAT_GEOMETRY

Format

```
OPG_APIS.GET_LONG_LAT_GEOMETRY(
     x      IN NUMBER,
     y      IN NUMBER,
     srid   IN NUMBER DEFAULT 8307
) RETURN SDO_GEOMETRY;
```

Description

Returns an SDO_GEOMETRY object constructed using X and Y point coordinate values, and optionally an SRID value.

Parameters

x
The X (first coordinate) value in the SDO_POINT_TYPE element of the geometry definition.

y
The Y (second coordinate) value in the SDO_POINT_TYPE element of the geometry definition.

srid
SRID (coordinate system identifier) to be used in the resulting SDO_GEOMETRY object. The default value is 8307, the Oracle Spatial SRID for the WGS 84 longitude/latitude coordinate system.

Usage Notes

If there is incorrect syntax or a parsing error, this function returns NULL instead of generating an exception.

Examples

The following example returns the geometry object for a point with X, Y coordinates 10.5, 5.0, and it uses 8307 as the SRID in the resulting geometry object.

```
SQL> select opg_apis.get_long_lat_geometry(10.0, 5.0, 8307) from dual;

OPG_APIS.GET_LONG_LAT_GEOMETRY(10.0,5.0,8307)(SDO_GTYPE, SDO_SRID,
SDO_POINT(X,
-----------------------------------------------------------------------------
---
SDO_GEOMETRY(2001, 8307, SDO_POINT_TYPE(10, 5, NULL), NULL, NULL)
```

A.11.38 OPG_APIS.GET_LATLONG_FROM_V_COL

Format

```
OPG_APIS.GET_LATLONG_FROM_V_COL(
     v      IN NVARCHAR2,
     srid   IN NUMBER DEFAULT 8307
) RETURN SDO_GEOMETRY;
```

Description

Returns an SDO_GEOMETRY object constructed using spatial data and optionally an SRID value.

Parameters

v
A String containing spatial data in serialized form.

srid
SRID (coordinate system identifier) to be used in the resulting SDO_GEOMETRY object. The default value is 8307, the Oracle Spatial SRID for the WGS 84 longitude/latitude coordinate system.

Usage Notes

This function assumes that for each vertex in the geometry in the `v` parameter, the ***first*** number is the ***latitude*** value and the second number is the longitude value. (This is the reverse of the order in an SDO_GEOMETRY object definition, where longitude is first and latitude is second).

If there is incorrect syntax or a parsing error, this function returns NULL instead of generating an exception.

Examples

The following example returns a point SDO_GEOMETRY object. Notice that the coordinate values of the input point are "swapped" in the returned SDO_GEOMETRY object.

```
SQL> select opg_apis.get_latlong_from_v_col('5.1 10.0', 8307) from
dual;

OPG_APIS.GET_LATLONG_FROM_V_COL('5.110.0',8307)(SDO_GTYPE, SDO_SRID,
SDO_POINT(X
----------------------------------------------------------------------
---------
SDO_GEOMETRY(2001, 8307, SDO_POINT_TYPE(10, 5.1, NULL), NULL, NULL)
```

A.11.39 OPG_APIS.GET_LONGLAT_FROM_V_T_COLS

Format

```
OPG_APIS.GET_LONGLAT_FROM_V_T_COLS(
     v      IN NVARCHAR2,
     t      IN INTEGER,
     srid   IN NUMBER DEFAULT 8307
) RETURN SDO_GEOMETRY;
```

Description

Returns an SDO_GEOMETRY object constructed using spatial data, a type value, and optionally an SRID value.

Parameters

v
A String containing spatial data in serialized form.

t
Value indicating the type of value represented by the `v` parameter. Must be 20. (A null value or any other value besides 20 returns a null SDO_GEOMETRY object.)

srid
SRID (coordinate system identifier) to be used in the resulting SDO_GEOMETRY object. The default value is 8307, the Oracle Spatial SRID for the WGS 84 longitude/latitude coordinate system.

Usage Notes

If there is incorrect syntax or a parsing error, this function returns NULL instead of generating an exception.

Examples

This function assumes that for each vertex in the geometry in the `v` parameter, the first number is the longitude value and the second number is the latitude value (which is the order in an SDO_GEOMETRY object definition).

The following example returns a point SDO_GEOMETRY object.

```
SQL> select opg_apis.get_longlat_from_v_t_cols('5.1 10.0',20,8307) from dual;

OPG_APIS.GET_LATLONG_FROM_V_T_COLS('5.110.0',20,8307)(SDO_GTYPE, SDO_SRID,
SDO_P
-----------------------------------------------------------------------------
---
SDO_GEOMETRY(2001, 8307, SDO_POINT_TYPE(5.1, 10, NULL), NULL, NULL)
```

A.11.40 OPG_APIS.GET_OPG_VERSION

Format

```
OPG_APIS.GET_OPG_VERSION() RETURN VARCHAR2;
```

Description

Returns the Graph Server and Client version from which the PL/SQL packages were installed.

Parameters

(None.)

Usage Notes

(None.)

Examples

The following example returns the Graph Server and Client version from which the PL/SQL packages were installed.

```
SQL> SELECT OPG_APIS.GET_OPG_VERSION() FROM DUAL;

OPG_APIS.GET_OPG_VERSION()
--------------------------------------------------------------------------------
22.2
```

A.11.41 OPG_APIS.GET_SCN

Format

```
OPG_APIS.GET_SCN() RETURN NUMBER;
```

Description

Returns the SCN (system change number) of the Oracle Spatial and Graph property graph support, in YYYYMMDD format.

> **Note:**
>
> Effective with Release 20.3, the OPG_APIS.GET_SCN function is **deprecated**. Instead, to retrieve the current SCN (system change number), use the DBMS_FLASHBACK.GET_SYSTEM_CHANGE_NUMBER function:
>
> ```
> SELECT dbms_flashback.get_system_change_number FROM DUAL;
> ```

Parameters

(None.)

Usage Notes

The SCN value is incremented after each commit.

Examples

The following example returns the current build ID of the Oracle Spatial and Graph property graph support.

```
SQL> SELECT OPG_APIS.GET_SCN() FROM DUAL;

OPG_APIS.GET_SCN()
------------------
           1478701
```

A.11.42 OPG_APIS.GET_VERSION

> **Note:**
>
> The `OPG_APIS.GET_VERSION()` function is deprecated and will be desupported in a future release. Instead, use OPG_APIS.GET_OPG_VERSION.

Format

```
OPG_APIS.GET_VERSION() RETURN VARCHAR2;
```

Description

Returns the current version of the Oracle Spatial and Graph property graph support.

Parameters

(None.)

Usage Notes

(None.)

Examples

The following example returns the current version of the Oracle Spatial and Graph property graph support.

```
SQL> SELECT OPG_APIS.GET_VERSION() FROM DUAL;

OPG_APIS.GET_VERSION()
--------------------------------------------------------------------------------
12.2.0.1 P1
```

A.11.43 OPG_APIS.GET_WKTGEOMETRY_FROM_V_COL

Format

```
OPG_APIS.GET_WKTGEOMETRY_FROM_V_COL(
     v      IN NVARCHAR2,
     srid   IN NUMBER DEFAULT NULL
) RETURN SDO_GEOMETRY;
```

Description

Returns an SDO_GEOMETRY object based on a geometry in WKT (well known text) form and optionally an SRID.

Parameters

v
A String containing spatial data in serialized form.

srid
SRID (coordinate system identifier) to be used in the resulting SDO_GEOMETRY object. The default value is 8307, the Oracle Spatial SRID for the WGS 84 longitude/latitude coordinate system.

Usage Notes

If there is incorrect syntax or a parsing error, this function returns NULL instead of generating an exception.

Examples

The following statements return a point geometry and a line string geometry

```
SQL> select opg_apis.get_wktgeometry_from_v_col('POINT(10.0 5.1)',
8307) from dual;

OPG_APIS.GET_WKTGEOMETRY_FROM_V_COL('POINT(10.05.1)',8307)(SDO_GTYPE,
SDO_SRID,
-----------------------------------------------------------------------
---------
SDO_GEOMETRY(2001, 8307, SDO_POINT_TYPE(10, 5.1, NULL), NULL, NULL)


SQL> select opg_apis.get_wktgeometry_from_v_col('LINESTRING(30 10, 10
30, 40 40)',8307) from dual;

OPG_APIS.GET_WKTGEOMETRY_FROM_V_COL('LINESTRING(3010,1030,4040)',8307)
(SDO_GTYPE
-----------------------------------------------------------------------
---------
SDO_GEOMETRY(2002, 8307, NULL, SDO_ELEM_INFO_ARRAY(1, 2, 1),
SDO_ORDINATE_ARRAY(
30, 10, 10, 30, 40, 40))
```

A.11.44 OPG_APIS.GET_WKTGEOMETRY_FROM_V_T_COLS

Format

```
OPG_APIS.GET_WKTGEOMETRY_FROM_V_T_COLS(
     v     IN NVARCHAR2,
     t     IN INTEGER,
     srid  IN NUMBER DEFAULT NULL
) RETURN SDO_GEOMETRY;
```

Description

Returns an SDO_GEOMETRY object based on a geometry in WKT (well known text) form, a type value, and optionally an SRID.

Parameters

v
A String containing spatial data in serialized form.

t
Value indicating the type of value represented by the `v` parameter. Must be 20. (A null value or any other value besides 20 returns a null SDO_GEOMETRY object.)

srid
SRID (coordinate system identifier) to be used in the resulting SDO_GEOMETRY object. The default value is 8307, the Oracle Spatial SRID for the WGS 84 longitude/latitude coordinate system.

Usage Notes

If there is incorrect syntax or a parsing error, this function returns NULL instead of generating an exception.

Examples

The following statements return a point geometry and a polygon geometry

```
SQL> select opg_apis.get_wktgeometry_from_v_t_cols('POINT(10.0
5.1)',20,8307) from dual;

OPG_APIS.GET_WKTGEOMETRY_FROM_V_T_COLS('POINT(10.05.1)',20,8307)(SDO_GTYPE,
SDO_
-----------------------------------------------------------------------------
---
SDO_GEOMETRY(2001, 8307, SDO_POINT_TYPE(10, 5.1, NULL), NULL, NULL)


SQL> select opg_apis.get_wktgeometry_from_v_t_cols('POLYGON((-83.6  34.1,
-83.6 34.3, -83.4 34.3, -83.4 34.1, -83.6 34.1))',20,8307) from dual;

OPG_APIS.GET_WKTGEOMETRY_FROM_V_T_COLS('POLYGON((-83.634.1,-83.634.3,-83.434.
3,-
-----------------------------------------------------------------------------
---
SDO_GEOMETRY(2003, 8307, NULL, SDO_ELEM_INFO_ARRAY(1, 1003, 1),
SDO_ORDINATE_ARR
AY(-83.6, 34.1, -83.6, 34.3, -83.4, 34.3, -83.4, 34.1, -83.6, 34.1))
```

A.11.45 OPG_APIS.GRANT_ACCESS

Format

```
OPG_APIS.GRANT_ACCESS(
     graph_owner IN VARCHAR2,
     graph_name  IN VARCHAR2,
     other_user  IN VARCHAR2,
     privilege   IN VARCHAR2);
```

Description

Grants access privileges on a property graph to another database user.

Parameters

graph_owner
Owner of the property graph.

graph_name
Name of the property graph.

other_user
Name of the database user to which on e or more access privileges will be granted.

privilege
A string of characters indicating privileges: `R` for read, `S` for select, `U` for update, `D` for delete, `I` for insert, `A` for all. Do not use commas or any other delimiter.
If you specify `A`, do not specify any other values because `A` includes all access privileges.

Usage Notes

(None.)

Examples

The following example grants read and select (`RS`) privileges on the `mypg` property graph owned by database user SCOTT to database user PGUSR. It then connects as PGUSR and queries the `mypg` vertex table in the SCOTT schema.

```
CONNECT scott/<password>

EXECUTE OPG_APIS.GRANT_ACCESS('scott', 'mypg', 'pgusr', 'RS');

CONNECT pgusr/<password>

SELECT count(1) from scott.mypgVT$;

    17
```

A.11.46 OPG_APIS.IMP_EDGE_TAB_STATS

Format

```
OPG_APIS.IMP_EDGE_TAB_STATS(
     graph_name    IN VARCHAR2,
     stattab       IN VARCHAR2,
     statid        IN VARCHAR2 DEFAULT NULL,
     cascade       IN BOOLEAN DEFAULT TRUE,
     statown       IN VARCHAR2 DEFAULT NULL,
     no_invalidate  BOOLEAN DEFAULT FALSE,
     force              BOOLEAN DEFAULT FALSE,
     stat_category IN VARCHAR2 DEFAULT 'OBJECT_STATS');
```

Description

Retrieves statistics for the given property graph edge table (GE$) from the user statistics table identified by `stattab` and stores them in the dictionary. If `cascade` is `TRUE`, all index statistics associated with the specified table are also imported.

Parameters

graph_name
Name of the property graph.

stattab
Name of the statistics table.

statid
Optional identifier to associate with these statistics within `stattab`.

cascade
If `TRUE`, column and index statistics are exported.

statown
Schema containing `stattab`.

no_invalidate
If `TRUE`, does not invalidate the dependent cursors. If `FALSE`, invalidates the dependent cursors immediately. If `DBMS_STATS.AUTO_INVALIDATE` (the usual default) is in effect, Oracle Database decides when to invalidate dependent cursors.

force
If `TRUE`, performs the operation even if the statistics are locked.

stat_category
Specifies what statistics to export, using a comma to separate values. The supported values are `'OBJECT_STATS'` (the default: table statistics, column statistics, and index statistics) and `'SYNOPSES'` (auxiliary statistics created when statistics are incrementally maintained).

Usage Notes

(None.)

Examples

The following example creates a statistics table, exports into this table the edge table statistics, issues a query to count the relevant rows for the newly created statistics, and finally imports the statistics back.

```
EXECUTE OPG_APIS.CREATE_STAT_TABLE('mystat',null);

EXECUTE OPG_APIS.EXP_EDGE_TAB_STATS('mypg', 'mystat', 'edge_stats_id_1', true, null,
'OBJECT_STATS');

SELECT count(1) FROM mystat WHERE statid='EDGE_STATS_ID_1';

       153

EXECUTE OPG_APIS.IMP_EDGE_TAB_STATS('mypg', 'mystat', 'edge_stats_id_1', true, null,
false, true, 'OBJECT_STATS');
```

A.11.47 OPG_APIS.IMP_VERTEX_TAB_STATS

Format

```
OPG_APIS.IMP_VERTEX_TAB_STATS(
     graph_name    IN VARCHAR2,
     stattab       IN VARCHAR2,
     statid        IN VARCHAR2 DEFAULT NULL,
     cascade       IN BOOLEAN DEFAULT TRUE,
     statown       IN VARCHAR2 DEFAULT NULL,
     no_invalidate  BOOLEAN DEFAULT FALSE,
     force              BOOLEAN DEFAULT FALSE,
     stat_category IN VARCHAR2 DEFAULT 'OBJECT_STATS');
```

Description

Retrieves statistics for the given property graph vertex table (VT$) from the user statistics table identified by `stattab` and stores them in the dictionary. If `cascade` is `TRUE`, all index statistics associated with the specified table are also imported.

Parameters

graph_name
Name of the property graph.

stattab
Name of the statistics table.

statid
Optional identifier to associate with these statistics within `stattab`.

cascade
If `TRUE`, column and index statistics are exported.

statown
Schema containing `stattab`.

no_invalidate
If `TRUE`, does not invalidate the dependent cursors. If `FALSE`, invalidates the dependent cursors immediately. If `DBMS_STATS.AUTO_INVALIDATE` (the usual default) is in effect, Oracle Database decides when to invalidate dependent cursors.

force
If `TRUE`, performs the operation even if the statistics are locked.

stat_category
Specifies what statistics to export, using a comma to separate values. The supported values are `'OBJECT_STATS'` (the default: table statistics, column statistics, and index statistics) and `'SYNOPSES'` (auxiliary statistics created when statistics are incrementally maintained).

Usage Notes

(None.)

Examples

The following example creates a statistics table, exports into this table the vertex table statistics, issues a query to count the relevant rows for the newly created statistics, and finally imports the statistics back.

```
EXECUTE OPG_APIS.CREATE_STAT_TABLE('mystat',null);

EXECUTE OPG_APIS.EXP_VERTEX_TAB_STATS('mypg', 'mystat', 'vertex_stats_id_1', true,
null, 'OBJECT_STATS');

SELECT count(1) FROM mystat WHERE statid='VERTEX_STATS_ID_1';

       108

EXECUTE OPG_APIS.IMP_VERTEX_TAB_STATS('mypg', 'mystat', 'vertex_stats_id_1', true,
null, false, true, 'OBJECT_STATS');
```

A.11.48 OPG_APIS.PR

Format

```
OPG_APIS.PR(
     edge_tab_name   IN VARCHAR2,
     d               IN NUMBER DEFAULT 0.85,
     num_iterations  IN NUMBER DEFAULT 10,
     convergence     IN NUMBER DEFAULT 0.1,
     dop             IN INTEGER DEFAULT 4,
     wt_node_pr      IN OUT VARCHAR2,
     wt_node_nextpr  IN OUT VARCHAR2,
     wt_edge_tab_deg IN OUT VARCHAR2,
     wt_delta        IN OUT VARCHAR2,
     tablespace      IN VARCHAR2 DEFAULT NULL,
     options         IN VARCHAR2 DEFAULT NULL,
     num_vertices    OUT NUMBER);
```

Description

Prepares for page rank calculations.

Parameters

edge_tab_name
Name of the property graph edge table.

d
Damping factor.

num_iterations
Number of iterations for calculating the page rank values.

convergence
A threshold. If the difference between the page rank value of the current iteration and next iteration is lower than this threshold, then computation stops.

dop
Degree od parallelism for the operation.

wt_node_pr
Name of the working table to hold the page rank values of the vertices.

wt_node_pr
Name of the working table to hold the page rank values of the vertices.

wt_node_next_pr
Name of the working table to hold the page rank values of the vertices in the next iteration.

wt_edge_tab_deg
Name of the working table to hold edges and node degree information.

wt_delta
Name of the working table to hold information about some special vertices.

tablespace
Name of the tablespace to hold all the graph data and index data.

options
Additional settings for the operation. An optional string with one or more (comma-separated) of the following values:

- `CREATE_UNDIRECTED=T`
- `REUSE_UNDIRECTED_TAB=T`

num_vertices
Number of vertices processed by the page rank calculation.

Usage Notes

The property graph edge table must exist in the database, and the OPG_APIS.PR_PREP procedure must have been called.

Examples

The following example performs preparation, and then calculates the page rank value of vertices in a property graph named `mypg`.

```
set serveroutput on
DECLARE
    wt_pr  varchar2(2000); -- name of the table to hold PR value of the current
iteration
    wt_npr varchar2(2000); -- name of the table to hold PR value for the next
iteration
    wt3    varchar2(2000);
    wt4    varchar2(2000);
    wt5    varchar2(2000);
    n_vertices number;
BEGIN
    wt_pr := 'mypgPR';
    opg_apis.pr_prep('mypgGE$', wt_pr, wt_npr, wt3, wt4, null);
    dbms_output.put_line('Working table names  ' || wt_pr
       || ', wt_npr ' || wt_npr || ', wt3 ' || wt3 || ', wt4 '|| wt4);
    opg_apis.pr('mypgGE$', 0.85, 10, 0.01, 4, wt_pr, wt_npr, wt3, wt4, 'SYSAUX',
null, n_vertices)
;
END;
/
```

The output will be similar to the following.

```
Working table names  "MYPGPR", wt_npr "MYPGGE$$TWPRX277", wt3
"MYPGGE$$TWPRE277", wt4 "MYPGGE$$TWPRD277"
```

The calculated page rank value is stored in the mypgpr table which has the following definition and data.

```
SQL> desc mypgpr;
 Name                          Null?    Type
 ----------------------------------------- -------- ----------------------------
 NODE                          NOT NULL NUMBER
 PR                                       NUMBER
 C                                         NUMBER

SQL> select node, pr from mypgpr;

      NODE        PR
---------- ----------
       101     .1925
       201     .2775
       102     .1925
       104   .74383125
       105   .313625
       103     .1925
       100     .15
       200     .15
```

A.11.49 OPG_APIS.PR_CLEANUP

Format

```
OPG_APIS.PR_CLEANUP(
     edge_tab_name   IN VARCHAR2,
     wt_node_pr      IN OUT VARCHAR2,
     wt_node_nextpr  IN OUT VARCHAR2,
     wt_edge_tab_deg IN OUT VARCHAR2,
     wt_delta        IN OUT VARCHAR2,
     options         IN VARCHAR2 DEFAULT NULL);
```

Description

Performs cleanup after performing page rank calculations.

Parameters

edge_tab_name
Name of the property graph edge table.

wt_node_pr
Name of the working table to hold the page rank values of the vertices.

wt_node_next_pr
Name of the working table to hold the page rank values of the vertices in the next iteration.

wt_edge_tab_deg
Name of the working table to hold edges and node degree information.

wt_delta
Name of the working table to hold information about some special vertices.

options
Additional settings for the operation. An optional string with one or more (comma-separated) of the following values:

- `CREATE_UNDIRECTED=T`
- `REUSE_UNDIRECTED_TAB=T`

Usage Notes

You do not need to do cleanup after each call to the OPG_APIS.PR procedure. You can run several page rank calculations before calling the OPG_APIS.PR_CLEANUP procedure.

Examples

The following example does the cleanup work after running page rank calculations in a property graph named `mypg`.

```
EXECUTE OPG_APIS.PR_CLEANUP('mypgGE$', wt_pr, wt_npr, wt3, wt4, null);
```

A.11.50 OPG_APIS.PR_PREP

Format

```
OPG_APIS.PR_PREP(
     edge_tab_name   IN VARCHAR2,
     wt_node_pr      IN OUT VARCHAR2,
     wt_node_nextpr  IN OUT VARCHAR2,
     wt_edge_tab_deg IN OUT VARCHAR2,
     wt_delta        IN OUT VARCHAR2,
     options         IN VARCHAR2 DEFAULT NULL);
```

Description

Prepares for page rank calculations.

Parameters

edge_tab_name
Name of the property graph edge table.

wt_node_pr
Name of the working table to hold the page rank values of the vertices.

wt_node_next_pr
Name of the working table to hold the page rank values of the vertices in the next iteration.

wt_edge_tab_deg
Name of the working table to hold edges and node degree information.

wt_delta
Name of the working table to hold information about some special vertices.

options
Additional settings for the operation. An optional string with one or more (comma-separated) of the following values:

- `CREATE_UNDIRECTED=T`
- `REUSE_UNDIRECTED_TAB=T`

Usage Notes

The property graph edge table must exist in the database.

Examples

The following example does the preparation work before running page rank calculations in a property graph named `mypg`.

```
set serveroutput on
DECLARE
    wt_pr  varchar2(2000); -- name of the table to hold PR value of the current
iteration
    wt_npr varchar2(2000); -- name of the table to hold PR value for the next iteration
    wt3    varchar2(2000);
    wt4    varchar2(2000);
    wt5    varchar2(2000);
BEGIN
    wt_pr := 'mypgPR';
    opg_apis.pr_prep('mypgGE$', wt_pr, wt_npr, wt3, wt4, null);
    dbms_output.put_line('Working table names  ' || wt_pr
       || ', wt_npr ' || wt_npr || ', wt3 ' || wt3 || ', wt4 '|| wt4);
END;
/
```

The output will be similar to the following.

```
Working table names  "MYPGPR", wt_npr "MYPGGE$$TWPRX277", wt3
"MYPGGE$$TWPRE277", wt4 "MYPGGE$$TWPRD277"
```

A.11.51 OPG_APIS.PREPARE_TEXT_INDEX

Format

```
OPG_APIS.PREPARE_TEXT_INDEX();
```

Description

Performs preparatory work needed before a text index can be created on any NVARCHAR2 columns.

Parameters

None.

Usage Notes

You must have the ALTER SESSION to run this procedure.

Examples

The following example performs preparatory work needed before a text index can be created on any NVARCHAR2 columns.

```
EXECUTE OPG_APIS.PREPARE_TEXT_INDEX();
```

A.11.52 OPG_APIS.RENAME_PG

Format

```
OPG_APIS.RENAME_PG(
     graph_name     IN VARCHAR2,
     new_graph_name     IN VARCHAR2);
```

Description

Renames a property graph.

Parameters

graph_name
Name of the property graph.

new_graph_name
New name for the property graph.

Usage Notes

The `graph_name` property graph must exist in the database.

Examples

The following example changes the name of a property graph named `mypg` to `mynewpg`.

```
EXECUTE OPG_APIS.RENAME_PG('mypg', 'mynewpg');
```

A.11.53 OPG_APIS.SPARSIFY_GRAPH

Format

```
OPG_APIS.SPARSIFY_GRAPH(
     edge_tab_name IN VARCHAR2,
     threshold     IN NUMBER DEFAULT 0.5,
     min_keep      IN INTEGER DEFAULT 1,
     dop           IN INTEGER DEFAULT 4,
     wt_out_tab    IN OUT VARCHAR2,
     wt_und_tab    IN OUT VARCHAR2,
     wt_hsh_tab    IN OUT VARCHAR2,
     wt_mch_tab    IN OUT VARCHAR2,
     tbs           IN VARCHAR2 DEFAULT NULL,
     options       IN VARCHAR2 DEFAULT NULL);
```

Description

Performs sparsification (edge trimming) for a property graph edge table.

Parameters

edge_tab_name
Name of the property graph edge table (GE$).

threshold
A numeric value controlling how much sparsification needs to be performed. The lower the value, the more edges will be removed. Some typical values are: 0.1, 0.2, ..., 0.5

min_keep
A positive integer indicating at least how many adjacent edges should be kept for each vertex. A recommended value is 1.

dop
Degree of parallelism for the operation.

wt_out_tab
A working table to hold the output, a sparsified graph.

wt_und_tab
A working table to hold the undirected version of the original graph.

wt_hsh_tab
A working table to hold the min hash values of the graph.

wt_mch_tab
A working table to hold matching count of min hash values.

tbs
A working table to hold the working table data.

options
Additional settings for operation. An optional string with one or more (comma-separated) of the following values:

- 'INMEMORY=T' is an option for creating the schema tables with an 'inmemory' clause.
- 'IMC_MC_B=T' creates the schema tables with an INMEMORY MEMCOMPRESS BASIC clause.

Usage Notes

The CREATE TABLE privilege is required to call this procedure.

The sparsification algorithm used is a min hash based local sparsification. See "Local graph sparsification for scalable clustering", Proceedings of the 2011 ACM SIGMOD International Conference on Management of Data: https://cs.uwaterloo.ca/~tozsu/courses/CS848/W15/presentations/ElbagouryPresentation-2.pdf

Sparsification only involves the topology of a graph. None of the properties (K/V) are relevant.

Examples

The following example does the preparation work for the edges table of `mypg`, prints out the working table names, and runs sparsification. The output, a sparsified graph, is stored in a table named LEAN_PG, which has two columns, SVID and DVID.

```
SQL> set serveroutput on
DECLARE
```

```
  my_lean_pg  varchar2(100) := 'lean_pg'; -- output table
  wt2 varchar2(100);
  wt3 varchar2(100);
  wt4 varchar2(100);
BEGIN
  opg_apis.sparsify_graph_prep('mypgGE$', my_lean_pg, wt2, wt3, wt4, null);
  dbms_output.put_line('wt2 ' || wt2 || ', wt3 ' || wt3 || ', wt4 '|| wt4);

  opg_apis.sparsify_graph('mypgGE$', 0.5, 1, 4, my_lean_pg, wt2, wt3, wt4,
'SEMTS', null);
END;
/

wt2 "MYPGGE$$TWSPAU275", wt3 "MYPGGE$$TWSPAH275", wt4 "MYPGGE$$TWSPAM275"


SQL> describe lean_pg;
 Name                                      Null?    Type
 ----------------------------------------- -------- ----------------------------
 SVID                                               NUMBER
 DVID                                               NUMBER
```

A.11.54 OPG_APIS.SPARSIFY_GRAPH_CLEANUP

Format

```
OPG_APIS.SPARSIFY_GRAPH_CLEANUP(
     edge_tab_name IN VARCHAR2,
     wt_out_tab    IN OUT VARCHAR2,
     wt_und_tab    IN OUT VARCHAR2,
     wt_hsh_tab    IN OUT VARCHAR2,
     wt_mch_tab    IN OUT VARCHAR2,
     options       IN VARCHAR2 DEFAULT NULL);
```

Description

Cleans up after sparsification (edge trimming) for a property graph edge table.

Parameters

edge_tab_name
Name of the property graph edge table (GE$).

wt_out_tab
A working table to hold the output, a sparsified graph.

wt_und_tab
A working table to hold the undirected version of the original graph.

wt_hsh_tab
A working table to hold the min hash values of the graph.

wt_mch_tab
A working table to hold matching count of min hash values.

tbs
A working table to hold the working table data

options
(Reserved for future use.)

Usage Notes

The working tables will be dropped after the operation completes.

Examples

The following example does the preparation work for the edges table of `mypg`, prints out the working table names, runs sparsification, and then performs cleanup.

```
SQL> set serveroutput on
DECLARE
  my_lean_pg  varchar2(100) := 'lean_pg';
  wt2 varchar2(100);
  wt3 varchar2(100);
  wt4 varchar2(100);
BEGIN
  opg_apis.sparsify_graph_prep('mypgGE$', my_lean_pg, wt2, wt3, wt4, null);
  dbms_output.put_line('wt2 ' || wt2 || ', wt3 ' || wt3 || ', wt4 '|| wt4);

  opg_apis.sparsify_graph('mypgGE$', 0.5, 1, 4, my_lean_pg, wt2, wt3, wt4, 'SEMTS',
null);

  -- Add logic here to consume SVID, DVID in LEAN_PG table
  --

  -- cleanup
  opg_apis.sparsify_graph_cleanup('mypgGE$', my_lean_pg, wt2, wt3, wt4, null);
END;
/
```

A.11.55 OPG_APIS.SPARSIFY_GRAPH_PREP

Format

```
OPG_APIS.SPARSIFY_GRAPH_PREP(
     edge_tab_name IN VARCHAR2,
     wt_out_tab    IN OUT VARCHAR2,
     wt_und_tab    IN OUT VARCHAR2,
     wt_hsh_tab    IN OUT VARCHAR2,
     wt_mch_tab    IN OUT VARCHAR2,
     options       IN VARCHAR2 DEFAULT NULL);
```

Description

Prepares working table names that are necessary to run sparsification for a property graph edge table.

Parameters

edge_tab_name
Name of the property graph edge table (GE$).

wt_out_tab
A working table to hold the output, a sparsified graph.

wt_und_tab
A working table to hold the undirected version of the original graph.

wt_hsh_tab
A working table to hold the min hash values of the graph.

wt_mch_tab
A working table to hold the matching count of min hash values.

options
Additional settings for operation. An optional string with one or more (comma-separated) of the following values:

- 'INMEMORY=T' is an option for creating the schema tables with an 'inmemory' clause.
- 'IMC_MC_B=T' creates the schema tables with an INMEMORY MEMCOMPRESS BASIC clause.

Usage Notes

The sparsification algorithm used is a min hash based local sparsification. See "Local graph sparsification for scalable clustering", Proceedings of the 2011 ACM SIGMOD International Conference on Management of Data: https://cs.uwaterloo.ca/~tozsu/courses/CS848/W15/presentations/ElbagouryPresentation-2.pdf

Examples

The following example does the preparation work for the edges table of `mypg` and prints out the working table names.

```
set serveroutput on

DECLARE
  my_lean_pg  varchar2(100) := 'lean_pg';
  wt2 varchar2(100);
  wt3 varchar2(100);
  wt4 varchar2(100);
BEGIN
  opg_apis.sparsify_graph_prep('mypgGE$', my_lean_pg, wt2, wt3, wt4, null);
  dbms_output.put_line('wt2 ' || wt2 || ', wt3 ' || wt3 || ', wt4 '|| wt4);
END;
/
```

The output may be similar to the following.

```
wt2 "MYPGGE$$TWSPAU275", wt3 "MYPGGE$$TWSPAH275", wt4 "MYPGGE$$TWSPAM275"
```

A.12 OPG_GRAPHOP Package Subprograms

The OPG_GRAPHOP package contains subprograms for various operations on property graphs in an Oracle database.

To use the subprograms in this chapter, you must understand the conceptual and usage information in earlier chapters of this book.

This chapter provides reference information about the subprograms, in alphabetical order.

- OPG_GRAPHOP.POPULATE_SKELETON_TAB

A.12.1 OPG_GRAPHOP.POPULATE_SKELETON_TAB

Format

```
OPG_GRAPHOP.POPULATE_SKELETON_TAB(
     graph    IN VARCHAR2,
     dop      IN INTEGER DEFAULT 4,
     tbs      IN VARCHAR2 DEFAULT NULL,
     options  IN VARCHAR2 DEFAULT NULL);
```

Description

Populates the skeleton table (<graph-name>GT$). By default, any existing content in the skeleton table is truncated (removed) before the table is populated.

Parameters

graph
Name of the property graph.

dop
Degree of parallelism for the operation.

tbs
Name of the tablespace to hold the index data for the skeleton table.

options
Options that can be used to customize the populating of the skeleton table. (One or more, comma separated.)

- 'KEEP_DATA=T' causes any existing table not to be removed before the table is populated. New rows are added after the existing ones.
- 'PDML=T' skips the default index creation.

Usage Notes

You must have the CREATE TABLE and CREATE INDEX privileges to call this procedure.

There is a unique index constraint on EID column of the skeleton table (GE$). So if you specify the `KEEP_DATA=T` option and if the new data overlaps with existing one, then the unique key constraint will be violated, resulting in an error.

Examples

The following example populates the skeleton table of the property graph named `mypg`.

```
EXECUTE OPG_GRAPHOP.POPULATE_SKELETON_TAB('mypg',4, 'pgts', 'PDML=T');
```

B

Mapping Graph Server Roles to Default Privileges

Installing the PL/SQL packages of the Oracle Graph Server and Client distribution on the target Oracle Database, automatically creates the following roles and assigns the default permissions as shown in the following table:

Table B-1 Mapping Graph Server Roles to Default Privileges

Roles	Description	Permission
GRAPH_ADMINISTRATOR	User who performs operations on the graph server (PGX) using the Java API. (As compared to running start and stop operations as an OS user.)	PGX_SESSION_CREATE PGX_SERVER_GET_INFO PGX_SERVER_MANAGE
GRAPH_DEVELOPER	User who creates graphs, publishes graphs, modifies graphs, queries graphs, and views graphs using the Java API or SQLcl or the graph visualization application.	PGX_SESSION_CREATE PGX_SESSION_NEW_GRAPH PGX_SESSION_GET_PUBLISHED_GRAPH PGX_SESSION_MODIFY_MODEL PGX_SESSION_READ_MODEL
GRAPH_USER	User who queries graphs and views graphs Java API or SQLcl or the graph visualization application.	PGX_SESSION_CREATE PGX_SESSION_GET_PUBLISHED_GRAPH

C

Disabling Transport Layer Security (TLS) in Graph Server

For demonstration or evaluation purposes, it is possible to turn off transport layer security (TLS) of the graph server.

> **Caution:**
>
> This is **not** recommended for production. In a secure configuration, the server must always have TLS enabled.

The following instructions only apply if you installed the graph server via the RPM package.

> **Note:**
>
> If you deployed the graph server into your own web server (e.g Weblogic or Apache Tomcat), please refer to the manual of your web server for TLS configuration.

1. Edit `/etc/oracle/graph/server.conf` to change `enable_tls` to `false`.
2. Edit the `WEB-INF/web.xml` file inside the `WAR` file in `/opt/oracle/graph/graphviz` and configure cookies to be sent over non-secure connections by setting `<secure>false</secure>` as follows:

   ```
   <session-config>
           <tracking-mode>COOKIE</tracking-mode>
           <cookie-config>
               <secure>false</secure>
           </cookie-config>
           ...
   </session-config>
   ```

3. Additionally, replace `` `https` `` with `` `http` `` in the `` `pgx.base_url` `` property in the same `WEB-INF/web.xml` file. For example:

   ```
   <context-param>
       <param-name>pgx.base_url</param-name>
       <param-value>http://localhost:7007</param-value>
   </context-param>
   ```

4. Restart the server.

   ```
   sudo systemctl restart pgx
   ```

The graph server now accepts connections over HTTP instead of HTTPS.

On Oracle Linux 7, you can execute the following script to perform the preceding four steps all at once:

```
echo "$(jq '.enable_tls = false' /etc/oracle/graph/server.conf)"
> /etc/oracle/graph/server.conf
WAR=$(find /opt/oracle/graph/graphviz -name '*.war')
TMP=$(mktemp -d)
cd $TMP
unzip $WAR WEB-INF/web.xml
sed -i 's|<secure>true</secure>|<secure>false</secure>|' WEB-INF/
web.xml
sed -i 's|https://|http://|' WEB-INF/web.xml
sudo zip $WAR WEB-INF/web.xml
rm -r $TMP
sudo systemctl restart pgx
```

D

Migrating Property Graph Applications from Before Release 21c

If you are migrating from a previous version of Oracle Spatial and Graph to Release 21c, you may need to make some changes to existing property graph-related applications.

Also note that Oracle Graph Server and Client is required for property graph applications. This can be downloaded from Oracle Software Delivery Cloud or from Oracle Downloads page.

Security-Related Changes

The Property Graph feature contains a series of enhancements to further strengthen the security of the property graph component of product. The following enhancements may require manual changes to existing graph applications so that they continue to work properly.

- **Graph configuration files now require sensitive information such as passwords to be stored in Java Keystore files**
  If you use graph configuration files you are required to use Java Keystore files to store sensitive information such as passwords. (See Store the Database Password in a Keystore for how to create and reference such a keystore.)

  All existing graph configuration files with secrets in them must be migrated to the keystore-based approach.
- **In a three-tier deployment, access to the PGX server file system requires a directories allowlist**
  By default, the PGX server does not allow remote access to the local file system. This can be explicitly allowed, though, in `/etc/oracle/graph/pgx.conf` by setting `allow_local_filesystem` to `true`. If you set `allow_local_filesystem` to `true`, you must also specify a list of directories that are allowed to be accessed, by setting `datasource_dir_whitelist`. For example:

  ```
  "allow_local_filesystem": true,
  "datasource_dir_whitelist": ["/scratch/data1", "/scratch/data2"]
  ```

  This will allow remote users to read and write data on the server's file-system from and into `/scratch/data1` and `/scratch/data2`.
- **In a three-tier deployment, reading from remote locations into PGX is no longer allowed by default**
  Previously, PGX allowed graph data to be read from remote locations over FTP or HTTP. This is no longer allowed by default and requires explicit opt-in by the server administrator. To opt-in, specify the `allowed_remote_loading_locations` configuration option in `/etc/oracle/graph/pgx.conf`. For example:

  ```
  allowed_remote_loading_locations: ["*"]
  ```

  In addition:

  - The ftp and http protocols are no longer supported for loading or storing data because they are unencrypted and thus insecure.
  - Configuration files can no longer be loaded from remote locations, but must be loaded from the local file system.
- **Removed shell command line options**
  The following command line options of the Groovy-based `opg` shell have been removed and will no longer work:
  - `--attach` - the shell no longer supports attaching to existing sessions via command line
  - `--password` - the shell will prompt now for the password

  Also note that the Groovy-based shell has been deprecated, and you are encourage to use the new JShell-based shell instead (see Interactive Graph Shell CLIs).
- **Changes to PGX APIs**
  The following APIs no longer return graph configuration information:
  - `ServerInstance#getGraphInfo()`
  - `ServerInstance#getGraphInfos()`
  - `ServerInstance#getServerState()`

  The REST API now identifies collections, graphs, and properties by UUID instead of a name.

  The namespaces for graphs and properties are session private by default now. This implies that some operations that would previously throw an exception due to a naming conflict could succeed now.

  `PgxGraph#publish()` throws an exception now if a graph with the given name has been published before.

Migrating Data to a New Database Version

Oracle Graph Server and Client works with older database versions. (See Verifying Database Compatibility for information.) If as part of your upgrade you also upgraded your Oracle Database, you can migrate your existing graph data that was stored using the Oracle Property Graph format by invoking the following helper script in your database after the upgrade:

```
sqlplus> EXECUTE
mdsys.opg.migrate_pg_to_current(graph_name=>'mygraph');
```

The preceding example migrates the property graph *mygraph* to the current database version.

Uninstalling Previous Versions of Property Graph Libraries

This is only necessary if you are using Oracle Database versions 12.2, 18c, or 19c.

Use of the Property Graph feature of Oracle Database now requires Oracle Graph Server and Client that is installed separately. After you have completed the Graph Server and Client installation, complete the preceding migration steps (if needed), and confirmed that everything is working well, it is recommended that you remove the binaries of ***older*** graph installations from your Oracle Database installation by performing the following un-install steps:

1. Make sure the Property Graph mid-tier components are not in use on the target database host. For example, ensure that there is no application running which uses any files under `$ORACLE_HOME/md/property_graph`. Examples of such an application are a running PGX server on the same host as the database or a client application that references the JAR files under `$ORACLE_HOME/md/property_graph/lib`.

   It is **not** necessary to shut down the database to perform the uninstall. The Oracle database itself does not reference or use any files under `$ORACLE_HOME/md/property_graph`.

2. Remove the files under `$ORACLE_HOME/md/property_graph` on your database host. On Linux, you can copy the following helper script to your database host and run it with as the DBA operating system user: `/opt/oracle/graph/scripts/patch-opg-oracle-home.sh`

E
Upgrading From Graph Server and Client 20.4.x to 21.x

If you are upgrading from Graph Server and Client 20.4.x to 21.x version, you may need to create new roles in database and migrate authorization rules from `pgx.conf` file to the database. Also, starting from Graph Server and Client Release 21.1, TLS is enforced at the time of the RPM file installation.

One of the main enhancements of Graph Server and Client Release 21.1 is moving the graph access permissions from the `pgx.conf` file to the database. A new set of graph roles with default permissions are created automatically in the database, at the time of the PL/SQL packages installation. See Table B-1 in the appendix for more details on the default mappings.

In order to comply with this feature you must perform the database actions explained in the following sections:

Creating additional roles in the database

The roles in the database with additional privileges are created when you install the 21.x PL/SQL packages in your database as part of the upgrade. If you are not able to install the PL/SQL packages, for example if you are using an Autonomous Database, see User Authentication and Authorization for more information on manually creating these roles in the database with the default set of privileges.

Migrating authorization rules

You must execute database `GRANTS` for user-added mappings contained in the `pgx.conf` file when upgrading to 21.x.

The following examples explain the various scenarios where migration of authorization rules may or may not apply.

Example E-1 Migrating user-added mappings to database

To migrate the following user-added mappings in `pgx.conf` file:

```
...
"authorization": [{
  "pgx_role": "GRAPH_DEVELOPER",
  "pgx_permissions": [{
    "grant": "PGX_SESSION_ADD_PUBLISHED_GRAPH"
  },
...
```

You must execute the following `GRANT` statement in the database used by 21.x:

```
GRANT PGX_SESSION_ADD_PUBLISHED_GRAPH TO GRAPH_DEVELOPER
```

Example E-2 Migrating user-added file system authorization rules to database

To migrate the following user-added file system authorization rules in `pgx.conf` file:

```
...
"file_locations": [{
  "name": "my_hdfs_graph_data",
  "location": "hdfs:/data/graphs"
}],
"authorization": [{
  "pgx_role": "GRAPH_DEVELOPER",
  "pgx_permissions": [{
    "file_location": "my_hdfs_graph_data",
    "grant": "read"
  },
...
```

You must execute the following `GRANT` statement in the database used by 21.x:

```
CREATE OR REPLACE DIRECTORY my_hdfs_graph_data AS 'hdfs:/data/graphs'
GRANT READ ON DIRECTORY my_hdfs_graph_data TO GRAPH_DEVELOPER
```

Example E-3 User-added graph authorization rules for preloaded graphs

> **Note:**
>
> **No migration** required for user-added graph authorization rules for preloaded graphs.

You must not migrate user-added graph authorization rules for preloaded graphs (as shown in the following code) as these rules continue to be configured in `pgx.conf` file.

```
"preload_graphs": [{
  "path": "/data/my-graph.json",
  "name": "global_graph"
}],
"authorization": [{
  "pgx_role": "GRAPH_DEVELOPER",
  "pgx_permissions": [{
    "preloaded_graph": "global_graph",
    "grant": "read"
  },
...
```

Self-signed TLS certificate now generated upon RPM installation

In Graph Server and Client 21.x the RPM installation generates a self-signed certificate into `/etc/oracle/graph`, which the server uses to enable TLS by default.

According to security best practices, access to the certificate is restricted to the `oraclegraph` operating system user. The implication of this is that you no longer can start the graph server via the `/opt/oracle/graph/pgx/bin/start-server` script, even if your user is part of the `oraclegraph` group. Instead, manage the lifecycle of the graph server via `systemctl` commands. For example:

```
sudo systemctl start pgx
```

Another possible option is to change the ownership of the certificate as shown:

```
sudo chown <youruser> /etc/oracle/graph/server_key.pem
```

Turning off TLS is not recommended as it reduces the security of your connection. However, if you must do so, see Disabling Transport Layer Security (TLS) in Graph Server for more details.

F

Third-Party License Information for Oracle Graph Server and Client

This appendix contains licensing information about third-party products included with Oracle Graph Server and Client.

cytoscape.js

Vendor: Cytoscape Consortium

Version: 3.23.0

```
Cytoscape.js v. 3.23.0
Source URL: https://github.com/cytoscape/cytoscape.js/tree/v3.23.0
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Fourth party dependencies***
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lodash v. 4.17.21
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lodash

Vendor: OpenJS Foundation

Version: 4.17.21

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====

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Moment.js

Vendor: JS Foundation and other contributors

Version: 2.29.4

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three.js

Vendor: three.js authors

Version: 0.126.0

The MIT License

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```

Nimbus JOSE+JWT

Vendor: Connect2id Ltd.

Version: 9.14

```
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 *
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 */
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4th Party Dependencies:
1. com.github.stephenc.jcip » jcip-annotations  (Apache 2.0)
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 */
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2. net.minidev:json-smart  (Apache 2.0)
===copyright info for json-smart ========
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3.net.minidev:accessories-smart  (Apache 2.0)
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jackson-core

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It was originally written by Tatu Saloranta (tatu.saloranta@iki.fi), and has
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Monaco Editor

Vendor: Microsoft Corporation

Version: 0.34.0

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OWASP Java Encoder Project

Vendor: Open Web Application Security Project (OWASP)

Version: 1.2.3

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logback-core

Vendor: QOS.ch

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