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

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

Documentation Accessibility

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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 in Oracle Graph Server and Client 24.4

Features That Work With Oracle Database Release 23ai and Prior Oracle Database Releases

- Added support for loading a graph, subgraph, or frame from database tables containing columns with CLOB data type into the graph server (PGX). The CLOB data type columns are processed as String properties in the graph server (PGX).
  See Loading a SQL Property Graph with Properties Mapped to CLOB Data Type Columns for an example.
- Progress tracking support for graph algorithms is extended to include more built-in graph algorithms.
  See Getting the Progress of a Running Algorithm for the list of supported built-in graph algorithms.
- Added the new *Dijkstra Single Source Multi-Destination* built-in graph algorithm. Dijkstra is a fast algorithm designed for finding a shortest path in a graph. This variant of the algorithm tries to find the shortest path between the source and all vertices of the graph.
- Improved traceability of graphs loaded from database to do traceability at the provider level. Therefore, graphs are now considered traceable only when all providers are traceable.
  See Graph Sharing Options and Validating Graph Permissions for more information.
- The source and destination keys of the edge table can reference any unique column of the vertex table.
  See the REFERENCES Clause for more information.
- Added support for Network Evolution in the Graph Visualization Application.
  See Using Network Evolution in Graph Visualization for more information.
- Added full screen mode support in the Graph Visualization application.
- Added support for cluster-based layout and enhanced the **Attributes** configuration section in the latest version of the Graph Visualization Plug-in, which is available in the Oracle APEX 24.1 GitHub repository.
  See Configuring Attributes for the APEX Graph Visualization Plug-in for more information.
- Key Property Graph Features in Oracle Database Release 23ai
  Learn about the key property graph features in Oracle Database 23ai.
- Deprecated Features
  Review the deprecated features in Oracle Graph Server and Client.

- Desupported Features
  Review the desupported features in Oracle Graph Server and Client.

Key Property Graph Features in Oracle Database Release 23ai

Learn about the key property graph features in Oracle Database 23ai.

New Feature in Release Update 23.8

- Added support for `MATCHNUM` and `ELEMENT_NUMBER` functions in the `COLUMNS` clause of SQL graph queries.
  See the following topics for more information:
  - Using the MATCHNUM Function
  - Using the ELEMENT_NUMBER Function

New Feature in Release Update 23.7

- Added support for retrieving results using `ONE ROW PER MATCH`, `ONE ROW PER VERTEX`, or `ONE ROW PER STEP` option in SQL graph queries. These options are supported in combination with variable-length path patterns.
  See Using ONE ROW PER Clause in a SQL Graph Query for more information.

New Feature in Release Update 23.6

- Added support for using `binding_count` in SQL graph queries. `binding_count` is an aggregate to count the number of bindings to an element variable.
  See Using binding_count() in SQL Graph Queries for more information.

New Features in Release Update 23.4

- Support for selecting all the vertex or edge properties in the `COLUMNS` clause of a SQL graph query.
  See Selecting All Properties in the COLUMNS Clause for more information.
- Support for determining the direction of edges using the `SOURCE` and `DESTINATION` predicates inside the `WHERE` or `COLUMNS` clause of a SQL graph query.
  See Using the SOURCE and DESTINATION Predicates for more information.

Property Graph Features in Oracle Database Release 23ai

- Support for creating SQL property graph objects in Oracle Database.
  See Introduction to SQL Property Graphs for more information.
- Support for running graph queries on SQL property graphs.
  See SQL Graph Queries for more information.
- Support for using aggregate functions in SQL graph queries.
  See Using Aggregate Functions in SQL Graph Queries for more information.
- Support for loading SQL property graphs into the graph server (PGX).
  See Loading a SQL Property Graph Using the readGraphByName API for more information.
- Support for loading a subgraph from a SQL property graph into the graph server (PGX).
  See Loading a Subgraph Using PGQL Queries for more information.
- Support for dynamically expanding a subgraph in the graph server (PGX).
  See Expanding a Subgraph for more information.

- Support for running PGQL SELECT queries against SQL property graphs.
  See Executing PGQL Queries Against SQL Property Graphs for more information.
- Support for visualizing SQL graph queries on graphs in the database using the Graph Visualization application.
  See Visualizing Graph Queries on SQL Property Graphs for more information.
- Support for visualizing SQL graph queries using the APEX Graph Visualization plug-in in APEX applications.
  See Visualizing SQL Graph Queries Using the APEX Graph Visualization Plug-in for more information.

Deprecated Features

Review the deprecated features in Oracle Graph Server and Client.

- **Oracle Linux 7**
  Oracle Linux 7 is deprecated. Instead, use Oracle Linux 8.
- **Graph Server REST API Version 1**
  Graph Server REST API Version 1 is deprecated. It is recommended that you use Graph Server REST API Version 2.
- **`formatter` parameter in `https://localhost:7007/v2/runQuery` endpoint**
  The `formatter` parameter in `https://localhost:7007/v2/runQuery` endpoint is deprecated.
- **PG_VIEW field**
  The PG_VIEW constant is deprecated from GraphSource and SourceType. Instead, use PG_PGQL.
- **Interfaces, Classes and Methods deprecated for `oracle.pgx.api`**
  - `CompiledProgram.destroy(boolean)` is deprecated. Instead, use `CompiledProgram.destroy()`.
  - `ComponentCollection.destroy(boolean)` is deprecated. Instead, use `ComponentCollection.destroy()`.
  - `Partition.destroy(boolean)` is deprecated. Instead, use `Partition.destroy()`.
  - `PgxGraph.destroy(PgxGraph.Retention)` is deprecated. Instead, use `PgxGraph.destroy()`.
  - `PgxVertexTableFromFramesCreator` is deprecated. Instead, use `PgxVertexProviderFromFramesCreator`.
  - `PgxEdgeTableFromFramesCreator` is deprecated. Instead, use `PgxEdgeProviderFromFramesCreator`.
  - `PgxGraphFromFramesCreator.edgeTable(...)` is deprecated. Instead, use `PgxGraphFromFramesCreator.edgeProvider(String, String, String, PgxFrame)`.
  - `PgxGraphFromFramesCreator.vertexTable(...)` is deprecated. Instead, use `PgxGraphFromFramesCreator.vertexProvider(String, PgxFrame)`.
  - `GraphConfig.getLoading()` is deprecated. Instead, use `GraphConfig.getLoadingOptions()`.
  - `AbstractFileGraphConfigBuilder.setStoringConfig(...)` is deprecated. Instead, use `AbstractFileGraphConfigBuilder.setStoringOptions(FileGraphStoringConfig)`.

- `AbstractFileGraphConfig.getStoring()` is deprecated. Instead, use `AbstractFileGraphConfig.getStoringOptions()`.
- `AbstractFileEntityProviderConfig.getStoring()` is deprecated. Instead, use `AbstractFileEntityProviderConfig.getStoringOptions()`.
- `FileEntityProviderConfigBuilder.setStoring(FileGraphStoringConfig)` is deprecated. Instead, use `FileEntityProviderConfigBuilder.setStoringOptions(FileGraphStoringConfig)`.
- `PartitionedGraphConfigBuilder.setPgViewName(String)` is deprecated. Instead, use `PartitionedGraphConfigBuilder.setSourceName(String)` and `PartitionedGraphConfigBuilder.setSourceType(sourceType)`.
- `PickingStrategyBuilder.setPickByProperty(String , PickingStrategyFunction)` is deprecated. Instead, use `PickingStrategyBuilder.setPickByProperty(EdgeProperty, PickingStrategyFunction)`.
- `VertexFilter(String filterExpression)` is deprecated. Instead, use `VertexFilter.fromExpression(String)`.
- `EdgeFilter(String filterExpression)` is deprecated. Instead, use `EdgeFilter.fromExpression(String)`.
- `ServerInstance.getSessionInfo(...)` is deprecated. Instead, use `ServerInstance.getServerState(...)`.
- `ServerInstance.getGraphInfo(...)` is deprecated. Instead, use `ServerInstance.getServerState(...)`.
- `ServerInstance.getMemoryInfo(...)` is deprecated. Instead, use `ServerInstance.getServerState(...)`.
- `ServerInstance.getThreadPoolInfo(...)` is deprecated. Instead, use `ServerInstance.getServerState(...)`.
- `ControlResource.getSessionBoundGraphInfo(String, String, Request, UriInfo)` is deprecated. Instead, use `ControlResource.getServerState(String, Request, UriInfo)`.
- `oracle.pgx.api.filter.ResultSetFilter` is deprecated. Instead, use `oracle.pgx.api.filter.internal.ResultSetFilter`.
- `oracle.pgx.api.filter.ResultSetVertexFilter` is deprecated. Instead, use `oracle.pgx.api.filter.internal.ResultSetVertexFilter`.
- `oracle.pgx.api.filter.ResultSetEdgeFilter` is deprecated. Instead, use `oracle.pgx.api.filter.internal.ResultSetEdgeFilter`.

- **PgxML**
  - `UnsupervisedGraphWiseModel.getDgiLayerConfigs()` is deprecated. Instead, use `UnsupervisedGraphWiseModel.getEmbeddingConfig()`.
  - `UnsupervisedGraphWiseModelConfig.getDgiLayerConfigs()` is deprecated. Instead, use `UnsuperVisedGraphWiseModelConfig.getEmbeddingConfig()`.
  - `UnsupervisedGraphWiseModelConfig.setDgiLayerConfigs(GraphWiseDgiLayerConfig)` is deprecated. Instead, use `UnsupervisedGraphWiseModelConfig.setEmbeddingConfig(GraphWiseEmbeddingConfig)`.

- The `SupervisedGraphWiseModel.getLossFunction()` method is deprecated. Instead, use `SupervisedGraphWiseModel.getLossFunctionClass()`.

- **Configuration Fields**
  - `node_id_type` is deprecated. Instead, use `vertex_id_type`.
  - `node_props` is deprecated. Instead, use `vertex_props`.
  - `create_node_id_index` is deprecated. Instead, use `create_vertex_id_index`.
  - `create_node_id_mapping` is deprecated. Instead, use `create_vertex_id_mapping`.
  - `pg_view_name` in `PartitionedGraphConfig` is deprecated. Instead, use `source_name`, `source_type`, and `pg_view`.
  - `PropertyType.RO_STRING_SET, LONG_SET, SPARSE` is deprecated.
  - `enable_client_authentication` is deprecated. Instead, use native PGX authentication.
- **PgxSession.readSubgraph() methods**
  - `session.readSubgraph().fromPgView()` is deprecated. Instead, use `session.readSubgraph().fromPgPgql()`.
  - `graph.expandGraph().withPgql().fromPgView()` is deprecated. Instead, use `graph.expandGraph().withPgql().fromPgPgql()`.
- **PyPGX**
  - `PgxSession.read_subgraph_from_pg_view()` is deprecated. Instead, use `PgxSession.read_subgraph_from_pg_pgql()`.
  - The following function signatures are deprecated for `PgxGraph`:
    * `get_or_create_edge_property(name, data_type=None, dim=0)` Instead, use `get_or_create_edge_property(type, /, name)`.
    * `get_or_create_edge_vector_property(data_type, dim, name=None)` Instead, use `get_or_create_edge_vector_property(type, dimension, /, name)`.
    * `get_or_create_vertex_property(name, data_type=None, dim=0)` Instead, use `get_or_create_vertex_property(type, /, name)`.
    * `get_or_create_vertex_vector_property(data_type, dim, name=None)` Instead, use `get_or_create_vertex_vector_property(type, dimension, /, name)`.

    Note the following changes that apply for the new signatures:
    * `name` is no longer optional
    * `type` is the first argument followed by `dimension`, and `name` is the final argument
    * `data_type` and `dim` are deprecated
  - `DeepWalkModel.validation_fraction`, `Pg2vecModel.validation_fraction`, and the `validation_fraction` argument of `Analyst.pg2vec_builder()` are deprecated. The loss is computed on all samples.
  - 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_standarize` in `GraphWiseModelConfig` is deprecated. Instead, use `set_standardize`.
  - The return value of `PgqlResultSet.get_vertex_labels` may or may not be a list.

Desupported Features

Review the desupported features in Oracle Graph Server and Client.

- The Graph Visualization application which runs on `https://<server_host>:7007/ui/` is desupported. Instead, use the new Graph Visualization application by opening the URL `https://<server_host>:7007/dash/` in your browser (see Running the Graph Visualization Web Client).
  Note that accessing the old URL `https://<server_host>:7007/ui/` will automatically redirect you to the new URL `https://<server_host>:7007/dash/`.
- Oracle Database 12.2 is desupported.
- The graph server configuration fields, `server_cert` and `server_private_key` are desupported. Instead, use `server_keystore`.
- The following `GraphServer#getInstance` APIs are desupported:
  - `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.
- Oracle JDK 8 is desupported.
- Oracle Graph HDFS connector is desupported.
- Creating a property graph in the Oracle database using the property graph schema objects is desupported. The related `OPG_APIS` and `OPG_GRAPHOP` PL/SQL packages for working with property graph schema objects are also desupported.
  Instead, you can create SQL Property Graphs or PGQL Property Graphs.
- `SupervisedGraphWiseModel.inferAndGetExplanation(...)` is desupported. Instead, use `SupervisedGraphWiseModel.inferAndExplain(...)`.
- `UnsupervisedGraphWiseModel.inferAndGetExplanation(...)` is desupported. Instead, use `UnsupervisedGraphWiseModel.inferAndExplain(PgxGraph, PgxVertex)`.
- `Pg2vecModelBuilder.setUseGraphletSize(java.lang.Boolean useGraphletSize)` method in `oracle.pgx.api.mllib` API is desupported. Instead, use the `Pg2vecModelBuilder.setUseGraphletSize(boolean useGraphletSize)` method.
- `AbstractGraphConfigBuilder.setFilter(final GraphFilter filter)` is desupported. Instead use Loading a Subgraph from a PGQL Property Graph.

- `AbstractGraphConfigBuilder.setFilterStrategy(final FilterStrategy filterStrategy)` is desupported. Instead use Loading a Subgraph from a PGQL Property Graph.
- `GraphConfig.getLoadingFilter()` is desupported. Instead use Loading a Subgraph from a PGQL Property Graph.
- `SupervisedGraphWiseModelBuilder.setLossFunction(SupervisedGraphWiseModelConfig.LossFunction ...)` is desupported. Instead, use `SupervisedGraphWiseModelBuilder.setLossFunction(LossFunction)`.
- `PgqlViewGraphExpander.schema(String)` is desupported. Instead, use `PgqlViewGraphExpander.fromPgPgql(String, String)`.
- `PgqlViewGraphExpander.owner(String)` is desupported. Instead, use `PgqlViewGraphExpander.fromPgPgql(String, String)`.
- The `PgxSession.getGraphs()` method is desupported. Instead, use `PgxSession.getGraphs(Namespace namespace)`.
- The `PgxSession.getGraphsAsync()` method is desupported. Instead, use `PgxSession.getGraphsAsync(Namespace namespace)`.
- The methods `setValidationFraction` and `getValidationFraction` are desupported for DeepWalk and Pg2vec, The loss is now computed on all samples.
- Desupported the edge pattern syntax `--`, `-->`, and `<--` from PGQL 0.9 and PGQL 1.0. Instead, use `-`, `->` and `<-` respectively.
- The `WHERE` clause syntax `WHERE n -> m` in PGQL 0.9 is desupported. Instead, use `WHERE (n) -> (m)`.
- `pypgx.api.FlashbackSynchronizer` is desupported. Instead, use `pypgx.api.Synchronizer`.
- The `connection` parameter in `PgxGraph.create_synchronizer()` is desupported. Instead, use `jdbc_url`, `username`, and `password`.
  Also, note that the `synchronizer_class` and `invalid_change_policy` parameters are now keyword-only parameters.
- The following classes are desupported in `pypgx` package. Instead, use `pypgx.api.filters` subpackage to access these classes:
  - `EdgeFilter`
  - `GraphFilter`
  - `VertexFilter`
  - `PathFindingFilter`
- `Analyst.deepwalk_builder()`: the parameter `validation_fraction` has been removed. The loss is computed on all samples.
- `set_standarize` in `GraphWiseModelConfig` is desupported. Instead, use `set_standardize`.
- The parameters `redirect_stdout` and `redirect_stderr` in `pypgx.get_session()` are desupported.
- The Java API method `AbstractGraphConfigBuilder#setNodeIdType` in `oracle.pgx.config` is desupported. Instead, use `AbstractGraphConfigBuilder#setVertexIdType()`.

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).

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:

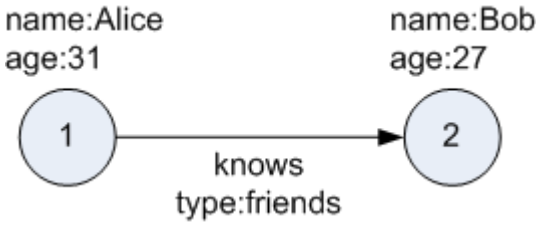
- An outgoing vertex
- An incoming vertex
- A text label that describes the relationship between the two vertices

- 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.

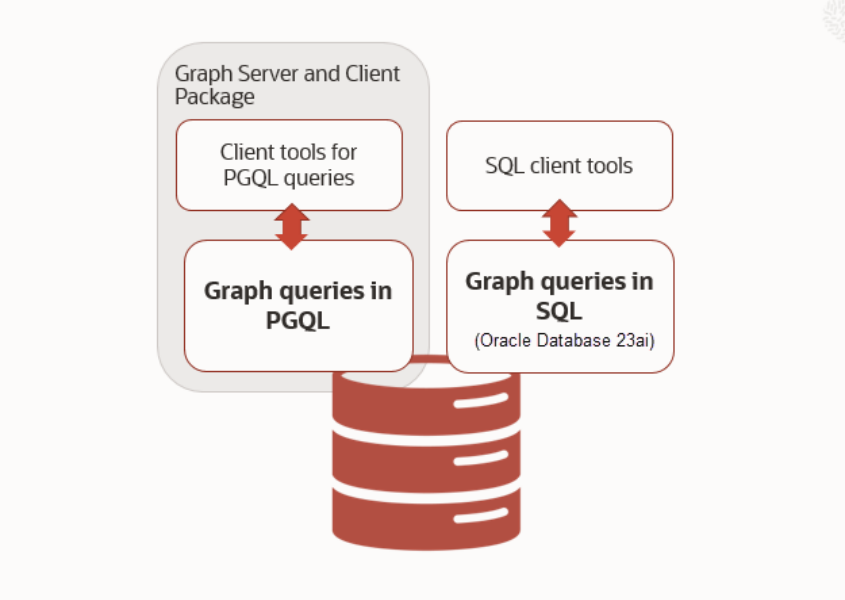
- Architecture Model for Running Graph Queries in the Database
  Using any of the supported client tools, you can directly interact with the graph data stored in the relational tables in the database.
- Architecture Model for Running Graph Analytics
  You can load your property graph into the graph server (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 PGQL property graph directly over the graph data in the tables. See PGQL Property Graphs for more information.

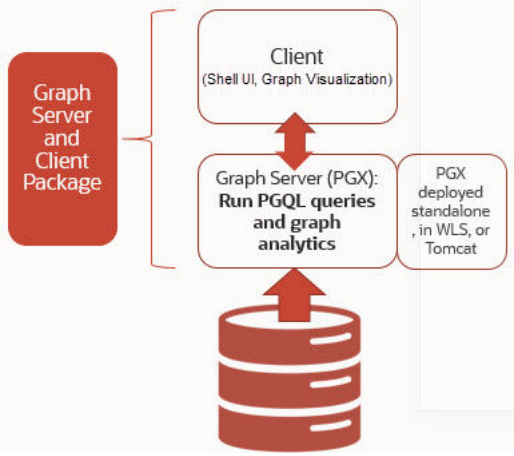
You can directly query the graphs, without loading the graphs into the graph server (PGX), using PGQL. Additionally, you can also run graph pattern matching queries on SQL property graphs using the `GRAPH_TABLE` operator. See SQL Graph Queries for more information.

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.

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.

You can create a graph directly from the relational tables in the graph server (PGX). In addition, you can load a PGQL property graph or a SQL property graph from 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 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.

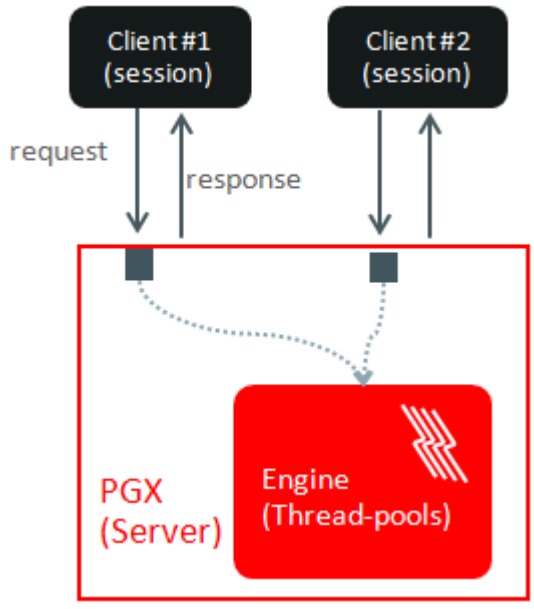
- Design of the Graph Server (PGX)
- Usage Modes of the Graph Server (PGX)

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.

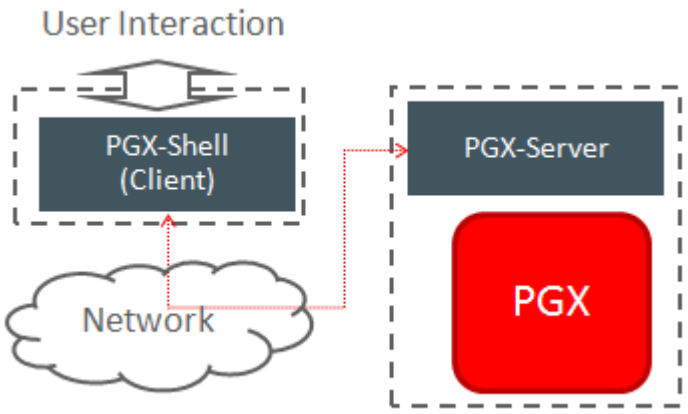
Remote Server Mode

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.

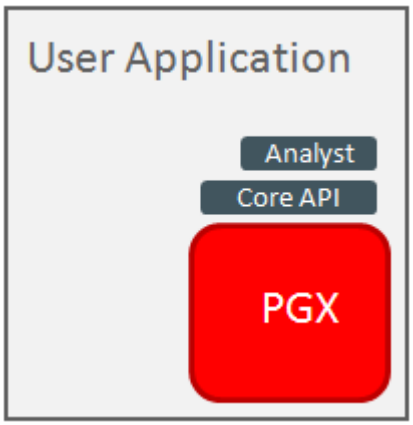
See Starting the Graph Server (PGX) for instructions on how to start the graph server (PGX) in remote server mode.

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 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 8.
- 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.

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 Serverless 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 Serverless 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 `CREATE SESSION` and `CREATE TABLE` privileges.

- 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 Running the Graph Visualization Web Client for more details.

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.oraclecloud.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 23ai, 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, rename, and drop SQL property graphs using SQL data definition language (DDL) statements.
- SQL Graph Queries
  You can query a SQL property graph using the `GRAPH_TABLE` operator to express graph pattern matching queries.
- Loading a SQL Property Graph into the Graph Server (PGX)
  You can load a full SQL property graph or a subgraph into memory in the graph server (PGX).
- Executing PGQL Queries Against SQL Property Graphs
  You can directly run PGQL queries against a SQL property graph in the database.
- Visualizing SQL Graph Queries Using the APEX Graph Visualization Plug-in
  You can use the Oracle Application Express (APEX) Graph Visualization plug-in to visualize and interact with SQL property graphs in an APEX application.

3

Introduction to SQL Property Graphs

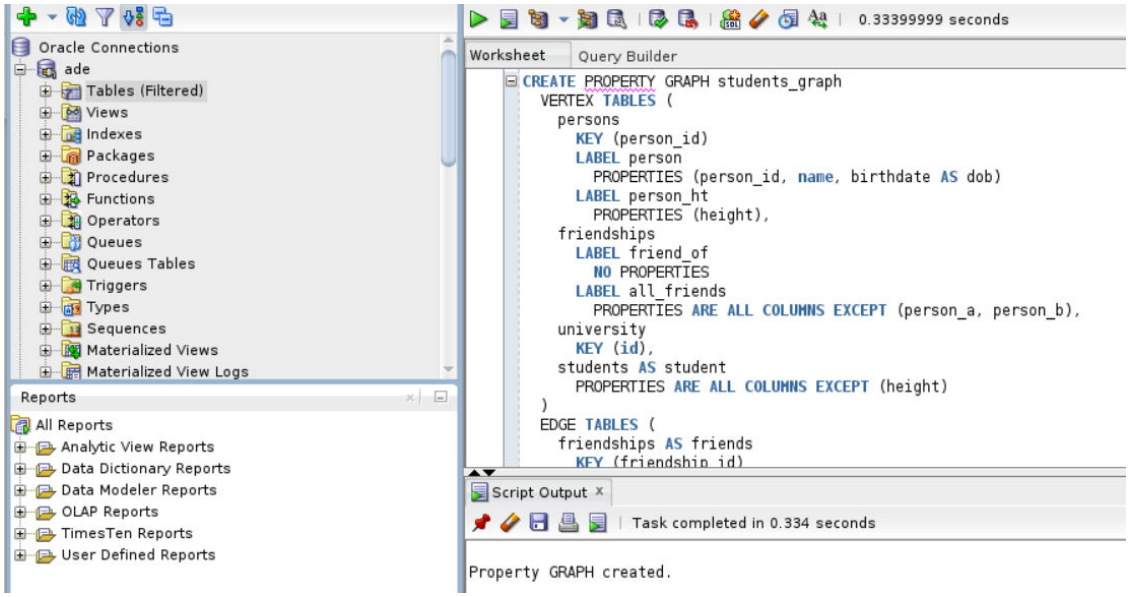
You can work with SQL property graphs in any SQL based interface (such as SQL Developer, SQLPLUS, or SQLcl) or from a Java program using JDBC.

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.
- Rename 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, querying, and running graph algorithms on a SQL property graph.

3.1 Quick Start for Working with SQL Property Graphs

This tutorial helps you get started on creating, querying, and running graph algorithms on 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 7 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
  2    VERTEX TABLES (
  3      bank_accounts
  4      KEY (id)
  5      LABEL account
  6      PROPERTIES ALL COLUMNS
  7    )
  8    EDGE TABLES (
  9      bank_txns
 10        KEY (txn_id)
 11        SOURCE KEY (from_acct_id) REFERENCES bank_accounts (id)
 12        DESTINATION KEY (to_acct_id) REFERENCES bank_accounts (id)
 13        LABEL transfer
 14        PROPERTIES ALL COLUMNS
 15*   );

Property created.
```

   On execution, the `bank_sql_pg` graph 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 SQL graph 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
  2    MATCH
  3    (a IS account WHERE a.id = 816) -[e IS transfer]-> (b IS account)
  4    COLUMNS (a.id AS acc_a, e.amount AS amount, b.id AS acc_b)
  5* );

   ACC_A    AMOUNT    ACC_B
```

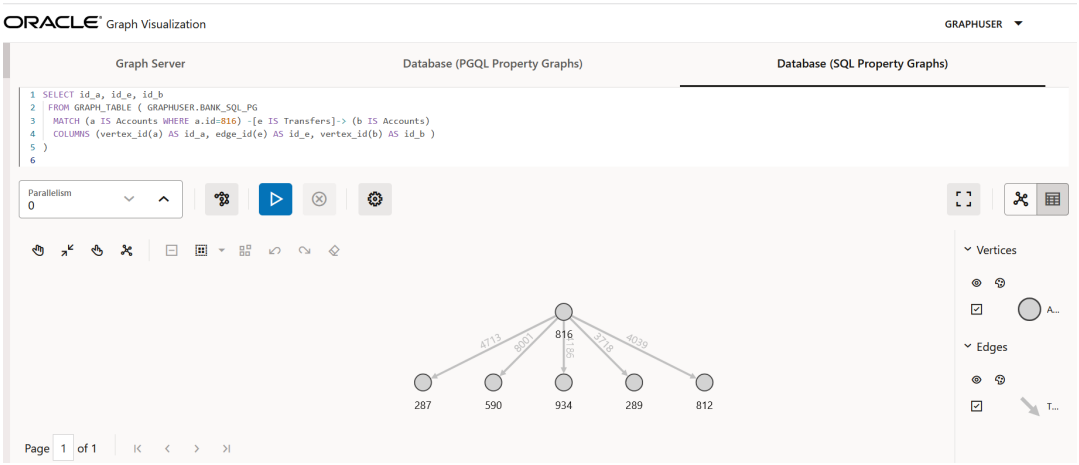
```
_________ _________ _________
      816      4713       287
      816      8001       590
      816      4186       934
      816      3718       289
      816      4039       812
```

See SQL Graph Queries for more information.

3. Optionally, if you have installed the graph server (PGX), then you can also visualize the preceding SQL graph 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 SQL graph 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` functions:

Figure 3-2 Visualizing a SQL Graph Query



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

4. Load the graph into the graph server (PGX) if you want to run graph algorithms.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("BANK_SQL_PG",
GraphSource.PG_SQL)
graph ==> PgxGraph[name=BANK_SQL_PG,N=1000,E=5001,created=1681020302077]
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_SQL_PG",
GraphSource.PG_SQL);
```

Python

```
>>> graph = session.read_graph_by_name("BANK_SQL_PG", "pg_sql")
>>> graph
PgxGraph(name: BANK_SQL_PG, v: 1000, e: 5001, directed: True, memory(Mb):
0)
```

See Loading a SQL Property Graph into the Graph Server (PGX) for more information.

5. Execute the PageRank algorithm as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var analyst = session.createAnalyst()
analyst ==> NamedArgumentAnalyst[session=0fb6bea7-
d467-458d-90c3-803d2932df12]
opg4j> analyst.pagerank(graph)
$3 ==> VertexProperty[name=pagerank,type=double,graph=BANK_SQL_PG]
```

Java

```
Analyst analyst = session.createAnalyst();
analyst.pagerank(graph);
```

Python

```
>>> analyst = session.create_analyst()
>>> analyst.pagerank(graph)
VertexProperty(name: pagerank, type: double, graph: BANK_SQL_PG)
```

6. Query the graph to list the top 10 accounts by pagerank:

- JShell

- Java
- Python

JShell

```
opg4j> session.queryPgql("SELECT a.id, a.pagerank FROM MATCH (a) ON
BANK_SQL_PG ORDER BY a.pagerank DESC LIMIT 5").print()
+-----------------------------+
| id  | pagerank              |
+-----------------------------+
| 387 | 0.007302836252205924  |
| 406 | 0.006734430614559079  |
| 135 | 0.006725965475577353  |
| 934 | 0.006641340764834484  |
| 397 | 0.005701607531213459 5|
+-----------------------------+
$5 ==> PgqlResultSetImpl[graph=BANK_SQL_PG,numResults=5]
```

Java

```
session.queryPgql("SELECT a.id, a.pagerank FROM MATCH (a) ON BANK_SQL_PG
ORDER BY a.pagerank DESC LIMIT 5").print();
```

Python

```
>>> session.query_pgql("SELECT a.id, a.pagerank FROM MATCH (a) ON
BANK_SQL_PG ORDER BY a.pagerank DESC LIMIT 5").print()
+-----------------------------+
| id  | pagerank              |
+-----------------------------+
| 387 | 0.007302836252205924  |
| 406 | 0.006734430614559079  |
| 135 | 0.006725965475577353  |
| 934 | 0.006641340764834484  |
| 397 | 0.005701607531213459 5|
+-----------------------------+
```

7. 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, rename, 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 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 object in the database.
- Renaming a SQL Property Graph
  You can rename an existing SQL property graph using the `RENAME` DDL statement.
- Dropping a SQL Property Graph
  Using the `DROP PROPERTY GRAPH` DDL statement, you can remove a property graph 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 SQL graph query.

4.1 Creating a SQL Property Graph

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

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

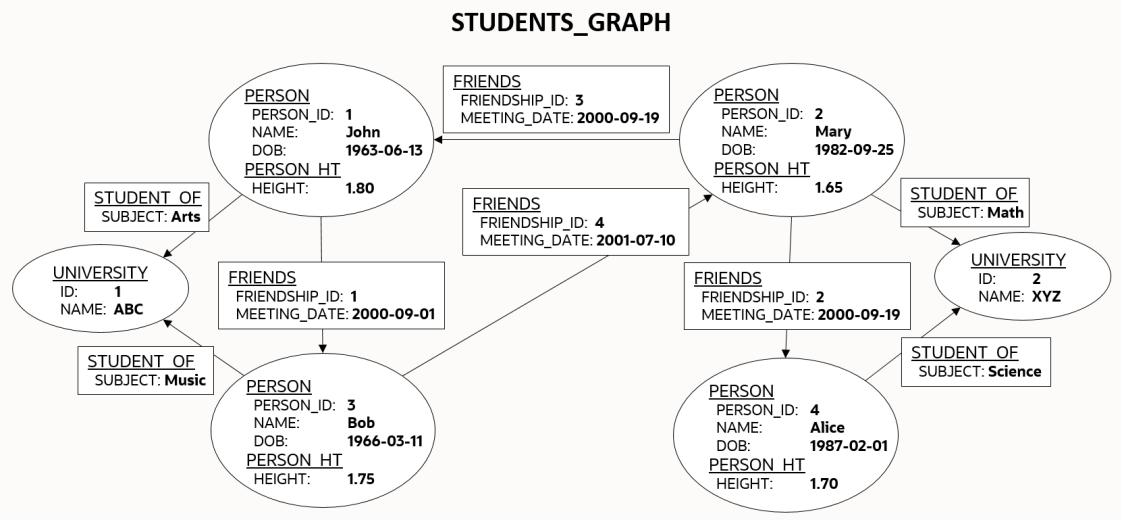
This example creates a SQL property graph, `students_graph`, using `persons`, `university`, `friends`, and `student_of` as the underlying database tables for the graph.

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.

The following diagram illustrates the `students_graph`:

Figure 4-1 STUDENTS_GRAPH



The corresponding SQL propery graph DDL statement is as shown:

```
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),
    university KEY (id)
  )
  EDGE TABLES (
    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),
    student_of
      KEY (s_id)
      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 SQL property graph 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 the graph 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:

- Two 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.
  - **university:** The label for the table is implicitly inferred and by default all visible columns of the underlying database table are exposed as properties.
- 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
  Learn about the new system and object privileges for performing operations on SQL property graphs.

- Retrieving Metadata for SQL Property Graphs
  The metadata of SQL property graphs can be accessed through a series of data dictionary views.
- 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.

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, height VARCHAR2(4),
CONSTRAINT t2_pk PRIMARY KEY (id));

INSERT INTO t2 (id, height) VALUES (1, '1.80');
INSERT INTO t2 (id, height) VALUES (2, '1.65');

CREATE TABLE t3 (id NUMBER, height BINARY_DOUBLE,
CONSTRAINT t3_pk PRIMARY KEY (id));

INSERT INTO t3 (id, height) VALUES (1, 1.80);
INSERT INTO t3 (id, height) VALUES (2, 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),
   t2
      LABEL t2 PROPERTIES (height),
   t3
      LABEL t3 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 t2` is `VARCHAR`
* `LABEL t3` is `BINARY_DOUBLE`

However, when querying this graph, the property type for `height` is dependent on the label constraint used in the SQL graph 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),
      t3
        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

Learn about the new system and object privileges for performing operations on SQL property graphs.

Table 4-1 System Privileges for SQL Property Graph 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 SQL graph query

Table 4-2 (Cont.) Object Privileges for SQL Property Graphs

Object Privileges	Description
[1]SELECT	To query a SQL property graph with a SQL graph 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 Metadata for SQL Property Graphs

The metadata of SQL property graphs can be accessed through a series of data dictionary views.

The following table provides a complete list of the data dictionary views that you can access to retrieve the metadata for SQL property graphs. Note that the metadata for each category in the table exists across ALL_ , USER_, and DBA_ view set. Depending upon your level of privilege, you can access the corresponding view.

Table 4-3 List of Data Dictionary Views to Retrieve Metadata for SQL Property Graphs

View Name[1]	Description
• ALL_PROPERTY_GRAPHS • USER_PROPERTY_GRAPHS • DBA_PROPERTY_GRAPHS	To describe all the property graphs in the database.
• ALL_PG_ELEMENTS • USER_PG_ELEMENTS • DBA_PG_ELEMENTS	To describe all the graph element tables of the property graphs in the database.
• ALL_PG_EDGE_RELATIONSHIPS • USER_PG_EDGE_RELATIONSHIPS • DBA_PG_EDGE_RELATIONSHIPS	To describe all the columns used to define the edge relationships.

Table 4-3 (Cont.) List of Data Dictionary Views to Retrieve Metadata for SQL Property Graphs

View Name[1]	Description
• ALL_PG_KEYS • USER_PG_KEYS • DBA_PG_KEYS	To describe all the columns used as the key for the graph element tables.
• ALL_PG_LABELS • USER_PG_LABELS • DBA_PG_LABELS	To describe labels of property graphs in the database.
• ALL_PG_LABEL_PROPERTIES • USER_PG_LABEL_PROPERTIES • DBA_PG_LABEL_PROPERTIES	To describe the properties of all the labels of the property graphs in the database.
• ALL_PG_PROP_DEFINITIONS • USER_PG_PROP_DEFINITIONS • DBA_PG_PROP_DEFINITIONS	To describe all the column expressions used to define the properties of labels.
• ALL_PG_ELEMENT_LABELS • USER_PG_ELEMENT_LABELS • DBA_PG_ELEMENT_LABELS	To describe all the labels of all the graph element tables of the property graphs in the database.

1 See *Oracle Database Reference* for more information on the views.

The following example retrieves the graph element tables that were defined for the SQL property graph (`students_graph`) created in Creating a SQL Property Graph.

```
SQL> SELECT * FROM USER_PG_ELEMENTS;

GRAPH_NAME           ELEMENT_NAME    ELEMENT_KIND    OBJECT_OWNER
OBJECT_NAME
-------------------- --------------- --------------- ---------------
---------------
STUDENTS_GRAPH       PERSONS         VERTEX          GRAPHUSER       PERSONS
STUDENTS_GRAPH       UNIVERSITY      VERTEX          GRAPHUSER
UNIVERSITY
STUDENTS_GRAPH       FRIENDS         EDGE            GRAPHUSER       FRIENDS
STUDENTS_GRAPH       STUDENT_OF      EDGE            GRAPHUSER
STUDENT_OF
```

4.1.7 Retrieving SQL Creation DDL Using the DBMS_METADATA Package

You can retrieve the creation DDL for a SQL property graph 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"."PERSONS" AS "PERSONS" KEY ("PERSON_ID")
      LABEL PERSON PROPERTIES ("PERSON_ID", "NAME", "BIRTHDATE" AS "DOB")
      LABEL PERSON_HT PROPERTIES ("HEIGHT"),
   "GRAPHUSER"."UNIVERSITY" AS "UNIVERSITY" KEY ("ID")
      PROPERTIES ("ID", "NAME") )
  EDGE TABLES (
   "GRAPHUSER"."FRIENDS" 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"."STUDENT_OF" 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)
```

4.1.8 Limitations of Creating a SQL Property Graph

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

- Views cannot be used as graph element tables in 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 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 Renaming a SQL Property Graph

You can rename an existing SQL property graph using the `RENAME` DDL statement.

The following example renames the property graph `students_graph` to a new name `students`.

Example 4-3 Renaming a SQL Property Graph

```
RENAME students_graph TO students;
```

4.4 Dropping a SQL Property Graph

Using the `DROP PROPERTY GRAPH` DDL statement, you can remove a property graph 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 4-4 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 object does not remove the underlying database tables.

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

4.5 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 SQL graph 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 SQL graph query.

Example 4-5 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.hr_data.department.string() AS "works_in",
               JSON_VALUE(person_data, '$.role') AS "works_as")
  )
  EDGE TABLES (
      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 4-6 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 4-7 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.hr_data AS "p_data")
  )
  EDGE TABLES (
      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 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 set of path patterns 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 SQL graph 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.
- **`ONE ROW PER` clause:** An optional clause to limit the number of output rows. See Using ONE ROW PER Clause in a SQL Graph Query for more information.
- **`COLUMNS` clause:** This contains the query output columns.

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

The following sections explain SQL graph queries in detail:

- About Graph Pattern
  The `GRAPH_TABLE` operator in a SQL graph query contains a graph pattern.
- 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` functions, respectively, in a SQL graph query.
- Using ONE ROW PER Clause in a SQL Graph Query
  You can use the `ONE ROW PER` optional clause in a SQL graph query to determine the number of rows to be returned by the query.
- Using Aggregate Functions in SQL Graph Queries
  You can use aggregate functions in a SQL graph query to obtain an aggregated output.
- Selecting All Properties in the COLUMNS Clause
  You can select all the vertex or edge properties based on the element type (vertex or edge) and any label expression specified for the element in the `COLUMNS` clause of a SQL graph query.
- Using the SOURCE and DESTINATION Predicates
  You can determine if a vertex is a source or destination using the `IS [NOT] SOURCE OF` or `IS [NOT] DESTINATION OF` predicate in a value expression inside a `WHERE` or `COLUMNS` clause.
- Running SQL Graph Queries at a Specific SCN
  You can run a SQL graph 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 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 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.
- Viewing and Querying SQL Property Graphs Using SQL Developer
  Using SQL Developer 23.1, you can view all the SQL property graphs existing in your database schema by expanding **SQL Property Graphs** under the **Property Graph** node in the **Connections** navigator.

5.1 About Graph Pattern

The `GRAPH_TABLE` operator in a SQL graph query contains a graph pattern.

A graph pattern is expressed between the input graph name and the `COLUMNS` clause inside the `GRAPH_TABLE` operator.

A graph pattern contains one or more comma-separated path patterns, which are composed of vertex and edge patterns. For example, the following path 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.

> **See Also:**
>
> Graph Pattern in *Oracle Database SQL Language Reference*

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 depending on the type of the element variable, either all vertex properties or all edge properties in the graph can be referenced. Otherwise, if a label expression is specified, then the set of properties that can be referenced is the union of the properties of labels belonging to vertex (or edge) tables that have at least one label that satisfies the label expression.

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.

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

Vertex Label Expression	Edge Label Expression	Description
`(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.
`(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.
`(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.

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

Vertex Label Expression	Edge Label Expression	Description
`(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 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.
- If an element variable is not bound to a graph element, then the result is a null value. This can happen only when an element variable is optionally bound, such as when the element variable is an iterator variable declared in `ONE ROW PER STEP`. Specifically, the edge variable and the second vertex variable declared in `ONE ROW PER STEP` will not be bound to a graph element when the path pattern matches an empty path (that is, when a quantifier iterated zero times). See Using ONE ROW PER Clause in a SQL Graph Query for more information on `ONE ROW PER STEP`.

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|t3)
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
```

In the SQL property graph `g1`, the property type for `height` associated with the labels `person` and `t3` 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 SQL graph 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
```

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)

Note that the lower bound should be 0 or greater, while the upper bound should be 1 or greater and should also be greater than or equal to the lower bound.

See Example 5-14 for example queries using recursive path patterns with bounded quantifiers.

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` functions, respectively, in a SQL graph 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 functions can be used in any expression appearing in the COLUMNS or WHERE clause in a SQL graph query.

> **Note:**
>
> In order to use the VERTEX_ID and EDGE_ID functions, you must have READ or SELECT privilege on the property graph. In addition, for each vertex or edge table from which the vertex or edge IDs are requested, ensure at least one of the following:
>
> - Each of its key columns is directly exposed as a property.
> - You have READ or SELECT privilege on its underlying database table.

The input to the VERTEX_ID function 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 function 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 functions 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.

If the referenced element variable is not bound to a graph element, then the VERTEX_ID and EDGE_ID functions return the null value.

See Example 5-25 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 SQL graph query.

If at least one of the referenced element variables is not bound to a graph element, then the predicates evaluate to the null value. Otherwise, they evaluate to TRUE or FALSE.

See Example 5-26 for more information.

5.5 Using ONE ROW PER Clause in a SQL Graph Query

You can use the `ONE ROW PER` optional clause in a SQL graph query to determine the number of rows to be returned by the query.

The `ONE ROW PER` clause can be placed after the `MATCH` clause (or if present, after a `WHERE` clause) and before the `COLUMNS` clause in a SQL graph query.

The `ONE ROW PER` clause supports the following options which determine the number of rows to be returned by the query:

- `ONE ROW PER MATCH` (default): This specifies that one row is returned per match to the graph pattern. See Example 5-16 for more information.
- `ONE ROW PER VERTEX`: This creates one row for each vertex along a path. It declares a single iterator vertex variable and iterates through the vertices in paths, binding the iterator variable to different vertices in different iterations. For each path, it creates as many rows as there are vertices in the path.
  For example, consider the following path with three vertices - `(v1) → (v2) → (v3)`. In this case `ONE ROW PER VERTEX (v)` creates three rows, one for each of `v1` ,`v2`, and `v3`.

  For zero hop paths, `ONE ROW PER VERTEX (v)` creates one row, where `v` binds to the only vertex (which is the source and destination of the path).

  See Example 5-17 for more information.
- `ONE ROW PER STEP`: This declares an iterator vertex variable, an iterator edge variable, and another iterator vertex variable. It creates one row for every hop, where the first vertex variable binds to the source of this hop, the edge variable is the edge of the hop and the second vertex variable is the destination of the hop. It iterates through the steps of the different paths. A step is a vertex-edge-vertex triple. If a path is non-empty and thus contains at least one edge and two vertices, then there are as many steps as there are edges and each iteration binds the iterator variables to the next edge and its source and destination in the path.
  For example, consider the following path - `v1 -[e1]→ v2 -[e2]→ v3`. In this case `ONE ROW PER STEP (v1,e,v2)` returns the following two rows:

  ```
  v1, e1, v2
  v2, e2, v3
  ```

  However, if a path is empty and consists of a single vertex only, then the path has a single step and the first iterator vertex variable binds to that vertex, while the iterator edge variable and the second iterator vertex variable are not bound to any graph element.

  See Example 5-18 for more information.

Note that if `ONE ROW PER VERTEX` or `ONE ROW PER STEP` is specified in a SQL graph query, then the `MATCH` clause must contain a single path pattern only.

The following describes a few restrictions for the iterator variables:

- All iterator variables have to be unique. This implies that these variables need to be different from the graph element variables used in the `MATCH` clause. In case of `ONE ROW PER STEP`, all the three iterator variables need to be different.
- Iterator variables cannot be referenced in the graph pattern or graph pattern `WHERE` clause of the SQL graph query. They can only be used in the `COLUMNS` clause of the query.

> **Note:**
>
> If you use `ONE ROW PER` clause in a SQL graph query in the Graph Visualization application or APEX plug-in for graph visualization, then ensure that the underlying SQL property graph definition does not contain any vertex or edge table alias (`AS` clause).

- Using the MATCHNUM Function
  The `MATCHNUM` function returns a number that uniquely identifies a match in a set of matches.
- Using the ELEMENT_NUMBER Function
  The `ELEMENT_NUMBER` function can only be used for iterator variables that are defined in the `ONE ROW PER VERTEX` or `ONE ROW PER STEP` clause in a SQL graph query.

5.5.1 Using the MATCHNUM Function

The `MATCHNUM` function returns a number that uniquely identifies a match in a set of matches.

The numbers are not necessarily consecutive, and gaps may appear (for instance, when matches are filtered out). Rows returned from `GRAPH_TABLE` have unique match numbers unless `ONE ROW PER VERTEX` or `ONE ROW PER STEP` is specified, in which case the same match number is returned for different iterations within a match.

`MATCHNUM` can be used only in the `COLUMNS` clause of the SQL graph query as shown.

```
SELECT *
FROM GRAPH_TABLE ( g
       MATCH (p IS person)
       COLUMNS (MATCHNUM() AS matchnum,
                p.name)
)ORDER BY matchnum;
```

The preceding graph query matches all person vertices and for each match returns a unique match number as well as the name of the `person`.

See Example 5-19 for more information.

5.5.2 Using the ELEMENT_NUMBER Function

The `ELEMENT_NUMBER` function can only be used for iterator variables that are defined in the `ONE ROW PER VERTEX` or `ONE ROW PER STEP` clause in a SQL graph query.

The function references an iterator variable and returns the sequential element number that the iterator variable currently binds to. Since paths always start with a vertex and alternate between vertices and edges, the first element is a vertex with element number 1, the second element is an edge with element number 2, the third element is a vertex with element number

3, and so on. For example, consider the following path: `v1 -[e1]-> v2 -[e2]-> v3`. Then the element numbers are generated from left to right as shown:

```
v1:1, e1:2, v2:3, e2:4, v3:5
```

Therefore, vertices always have odd element numbers while edges have even element numbers.

If `ONE ROW PER STEP` is specified and the path is empty (that is, only has a single vertex and no edges), then `ELEMENT_NUMBER` returns `NULL` when the iterator edge variable or the second iterator vertex variable is referenced. Note that empty paths result in single steps in which only the first iterator (vertex) variable is bound.

Also, note the following:

- `ELEMENT_NUMBER` can be used only in the `COLUMNS` clause.
- `ELEMENT_NUMBER` function can only be used if `ONE ROW PER VERTEX` or `ONE ROW PER STEP` is specified in the SQL graph query.
- `ELEMENT_NUMBER` cannot reference any type of variable other than an iterator variable.

For instance, consider the following sample query. The query uses `ONE ROW PER STEP` and the `ELEMENT_NUMBER` function returns the element number of the graph element that is bound by the iterator variable `v`.

```
SELECT *
FROM GRAPH_TABLE ( g
       MATCH (a) ->{0,2} ONE ROW PER STEP (v,e,v2)
       COLUMNS (ELEMENT_NUMBER(v) AS elementNumber)
)
```

See Example 5-20 for more information.

5.6 Using Aggregate Functions in SQL Graph Queries

You can use aggregate functions in a SQL graph query to obtain an aggregated output.

Both SQL built-in Aggregate Functions and user-defined aggregates are supported. These functions can be included in both fixed length and variable length path patterns in a SQL graph query.

The aggregate functions can be applied in the `COLUMNS` clause or in the graph pattern `WHERE` clause of the SQL graph query. For instance, consider the following sample query:

```
SELECT *
FROM GRAPH_TABLE ( g
       MATCH (v1) (-[e]->(v2)){1,2}
       COLUMNS (LISTAGG(v2.id, ',') AS id_list)
)
```

The preceding graph query describes a variable length path pattern having `{1,2}` as the quantifier. The `LISTAGG` aggregate function is used in the `COLUMNS` clause to list all the `id`s along a path.

Similarly, you can also apply aggregations in a fixed length path pattern as shown:

```
SELECT *
FROM GRAPH_TABLE ( g
       MATCH (v1) (-[e]->(v2)){2}
       WHERE AVG(v2.age) >= 30
       COLUMNS (LISTAGG(v2.id, ',') AS id_list)
)
```

The preceding graph query describes a fixed length path pattern. The `AVG` aggregate used in the `WHERE` clause determines only those paths where the average `age >= 30` condition is met. The resulting query output is a list of `id`s along a path.

See Example 5-15 for example queries using aggregations.

Using binding_count() in SQL Graph Queries

You can use the `binding_count()` aggregate to count the number of bindings to an element variable. This aggregate can only be used inside the `COLUMNS` clause or in the graph pattern `WHERE` clause of the SQL graph query. Also, note that you cannot specify `UNIQUE` or `DISTINCT` on the `binding_count()` element variable.

For instance, consider the following sample query:

```
SELECT *
FROM GRAPH_TABLE ( g
       MATCH (v1) (-[e]->(v2)){1,2}
       COLUMNS (binding_count(v2) AS cnt, LISTAGG(v2.id, ',') AS id_list)
)
```

The preceding graph query outputs a list of `id`s along a path together with the count of bindings to `v2`.

Also, see the Using binding_count() Aggregate example in Example 5-15.

> **See Also:**
>
> Graph Pattern in *Oracle Database SQL Language Reference* for more examples on aggregations

5.7 Selecting All Properties in the COLUMNS Clause

You can select all the vertex or edge properties based on the element type (vertex or edge) and any label expression specified for the element in the `COLUMNS` clause of a SQL graph query.

The set of properties is the union of properties of the vertex (or edge) labels belonging to tables that have at least one label that satisfies the label expression. In case some of these matching tables define a property while other tables do not, then NULL values will be returned for those tables that do not define the property.

For instance, the following example matches all the vertices in the graph `g` and retrieves all the valid properties through `n.*` in the `COLUMNS` clause.

```
SELECT *
FROM GRAPH_TABLE ( g
  MATCH (n IS person)
  COLUMNS ( n.* )
)
```

See Example 5-28 for more information.

5.8 Using the SOURCE and DESTINATION Predicates

You can determine if a vertex is a source or destination using the `IS [NOT] SOURCE OF` or `IS [NOT] DESTINATION OF` predicate in a value expression inside a `WHERE` or `COLUMNS` clause.

These predicates are mainly useful for determining the direction of edges that are matched through any-directed edge patterns (`<-[]->` or `-[]-`).

The `IS [NOT] SOURCE OF` predicate takes a vertex and an edge as input and returns `TRUE` or `FALSE` depending on whether the vertex is (or not) the source of the edge.

The `IS [NOT] DESTINATION OF` predicate also takes a vertex and an edge as input and returns `TRUE` or `FALSE` depending on whether the vertex is (or not) the destination of the edge.

If at least one of the referenced element variables is not bound to a graph element, then the source and destination predicates evaluate to the null value. Otherwise, they evaluate to TRUE or FALSE.

See Example 5-29 for more information.

5.9 Running SQL Graph Queries at a Specific SCN

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

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

- `AS OF SCN`: See Example 5-23
- `AS OF TIMESTAMP`: See Example 5-24

5.10 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 SQL graph 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 SQL graph queries with `VERTEX_ID` and `EDGE_ID` functions, the graph user must additionally have `READ` or `SELECT` privilege on the underlying database tables.

5.11 Examples for SQL 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 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 Query Using An Edge Pattern Directed Right-To-Left

The following example shows a 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 Query Using Any-Directed Edge Pattern

The following example shows a 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 Query Using an Anonymous Edge Variable

The following example shows a 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 Query Using Multiple Path Patterns

The following example shows a 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 Query Using Disjoint Path Patterns

The following example shows a 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 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 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 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 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 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 Queries Using Aggregations

The following example finds all paths that have a length between two and three edges (`{2,3}`), starting from a person named `John` and following only outgoing edges labeled `friends` and vertices labeled `person`. Vertices along paths should not have the same `person_id` as `John` (`WHERE p.person_id <> friend.person_id`). The example uses the following four aggregates in the `COLUMNS` clause:

- `LISTAGG`: The first one creates a comma-separated list of the person names along the path and the second one creates a comma-separated list of the person ages along the path.
- `AVG`: This computes the average age of the person group in a path.
- `COUNT`: This computes the length of each path.

```
SQL> SELECT * FROM GRAPH_TABLE ( students_graph
MATCH (p IS person) (-[e IS friends]-> (friend IS person)
                      WHERE p.person_id <> friend.person_id){2,3}
WHERE p.name = 'John'
COLUMNS (LISTAGG(friend.name, ',') as fnames,
         LISTAGG(EXTRACT(YEAR from SYSDATE) - EXTRACT(YEAR from friend.dob),
',') AS age_list,
         AVG(EXTRACT(YEAR from SYSDATE) - EXTRACT(YEAR from friend.dob)) AS
avg_age_group,
         COUNT(e.friendship_id) AS path));
```

The preceding code produces the following output:

```
FNAMES                         AGE_LIST        AVG_AGE_GROUP       PATH
------------------------------ --------------- ------------- ----------
Bob,Mary                       57,41                   49.00          2
Bob,Mary,Alice                 57,41,36                44.67          3
```

The following example finds all paths between university `ABC` and university `XYZ` such that paths have a length of up to three edges (`{,3}`). For each path, a JSON array is returned such that the array contains the `friendship_id` value for edges labeled `friends`, and the `subject` value for edges labeled `student_of`. Note that the `friendship_id` property is casted to `VARCHAR(100)` to make it type-compatible with the `subject` property.

```
SELECT * FROM GRAPH_TABLE ( students_graph
MATCH (u1 IS university) -[e]-{,3} (u2 IS university)
WHERE u1.name = 'ABC' AND u2.name = 'XYZ'
COLUMNS (JSON_ARRAYAGG(CASE WHEN e.subject IS NOT NULL THEN
e.subject
                       ELSE CAST(e.friendship_id AS VARCHAR(100)) END) AS
path));
```

The preceding code produces the following output:

```
PATH
----------------------------------------
["Arts","3","Math"]
["Music","4","Math"]
```

Using `binding_count()` Aggregate:

The following example finds all paths that have a length between two and three edges (`{2,3}`), starting from a person named `John` and following only outgoing edges labeled `friends` and vertices labeled `person`. The example uses the `binding_count` aggregate to count the number of bindings on the `friend` element variable in the `COLUMNS` clause:

```
SELECT * FROM GRAPH_TABLE ( students_graph
MATCH (p IS person) (-[e IS friends]-> (friend IS person)
WHERE p.person_id <> friend.person_id){2,3}
WHERE p.name = 'John'
COLUMNS (LISTAGG(friend.name, ',') AS friends,
binding_count(friend) AS cnt,
LISTAGG(EXTRACT(YEAR from SYSDATE) - EXTRACT(YEAR from friend.dob),
',') AS age_list,
COUNT(e.friendship_id) AS path));
```

The preceding code produces the following output:

```
FRIENDS        CNT AGE_LIST             PATH
-------------- --- -------------------- ----
Bob,Mary         2 58,42                   2
Bob,Mary,Alice   3 58,42,37                3
```

Example 5-16 Query Using `ONE ROW PER MATCH` Clause

The following example query uses `ONE ROW PER MATCH` and finds all friends path with length between *0* and *3* starting from a person named *John*.

```
SELECT * FROM GRAPH_TABLE ( students_graph
MATCH (n1 IS person) -[e1 IS friends]->{0,3} (n2 IS person)
WHERE n1.name = 'John'
ONE ROW PER MATCH
COLUMNS (LISTAGG(e1.friendship_id, ', ') AS friendship_ids, n2.name)
);
```

The example shows the following output from five paths that were matched, and the corresponding name of the person in that specific path. Note that the empty path (zero `friendship_ids`) is bound to a single person named *John*.

```
FRIENDSHIP_IDS       NAME
-------------------- ----------
                     John
1                    Bob
1, 4                 Mary
1, 4, 2              Alice
1, 4, 3              John
```

Example 5-17 Query Using `ONE ROW PER VERTEX` Clause

The following example query uses `ONE ROW PER VERTEX` and finds all friends path with length between *0* and *3* starting from a person named *John*. The query outputs one row per vertex.

```
SELECT * FROM GRAPH_TABLE ( students_graph
MATCH (n IS person) -[e1 IS friends]->{0,3} (IS person)
WHERE n.name = 'John'
ONE ROW PER VERTEX (v)
COLUMNS (LISTAGG(e1.friendship_id, ', ') AS friendship_ids,
        v.name)
);
```

The example produces the following output:

```
 FRIENDSHIP_IDS  NAME
--------------- ------
                John
1               John
1               Bob
1, 4            John
1, 4            Bob
1, 4            Mary
1, 4, 2         John
1, 4, 2         Bob
1, 4, 2         Mary
1, 4, 2         Alice
1, 4, 3         John
1, 4, 3         Bob
1, 4, 3         Mary
1, 4, 3         John

14 rows selected.
```

The preceding output shows data from five paths that were matched:

- The empty path (zero `friendship_ids`) contains a single person (*John*).
- The path with `friendship_ids` *1* contains two persons (*John* and *Bob*).
- The path with `friendship_ids` *1, 4* contains three persons (*John*, *Bob*, and *Mary*).
- The path with `friendship_ids` *1, 4, 2* contains four persons (*John*, *Bob*, *Mary*, and *Alice*).
- The path with `friendship_ids` *1, 4, 3* contains four persons and this forms a cycle (*John*, *Bob*, *Mary*, and *John*).

The following example query matches paths between universities `ABC` and `XYZ` such that the paths consist of an incoming `student_of` edge, followed by one or two `friends` edges, and finally followed by an outgoing `student_of` edge. The query returns one row per vertex and for each row it returns the match number, the element number, the type of the vertex (either `person` or `university`), as well as the name of the `university` or the `person`.

```
SELECT *
FROM GRAPH_TABLE ( students_graph
       MATCH (u1 IS university)
               <-[IS student_of]- (p1 IS person)
```

```
               -[IS friends]-{1,2} (p2 IS person)
               -[IS student_of]-> (u2 IS university)
        WHERE u1.name = 'ABC' AND u2.name = 'XYZ'
        ONE ROW PER VERTEX (v)
        COLUMNS (MATCHNUM() AS matchnum,
                 ELEMENT_NUMBER(v) AS element_number,
                 CASE WHEN v.person_id IS NOT NULL
                   THEN 'person'
                   ELSE 'university'
                   END AS label,
                 v.name))
ORDER BY matchnum, element_number;
```

The example produces the following output. Note that a total of 6 paths were matched with match numbers `1`, `2`, `3`, `4`, `6` and `8`. Each path has university `ABC` as the first vertex and university `XYZ` as the last vertex. Furthermore, paths with match numbers `1` and `3` contain two person vertices while the other paths (match numbers `2`, `4`, `6` and `8`) contain three person vertices.

```
MATCHNUM ELEMENT_NUMBER LABEL      NAME
---------- -------------- ---------- ----------
         1              1 university ABC
         1              3 person     John
         1              5 person     Mary
         1              7 university XYZ
         2              1 university ABC
         2              3 person     Bob
         2              5 person     John
         2              7 person     Mary
         2              9 university XYZ
         3              1 university ABC
         3              3 person     Bob
         3              5 person     Mary
         3              7 university XYZ
         4              1 university ABC
         4              3 person     John
         4              5 person     Mary
         4              7 person     Alice
         4              9 university XYZ
         6              1 university ABC
         6              3 person     John
         6              5 person     Bob
         6              7 person     Mary
         6              9 university XYZ
         8              1 university ABC
         8              3 person     Bob
         8              5 person     Mary
         8              7 person     Alice
         8              9 university XYZ

28 rows selected.
```

Example 5-18 Query Using `ONE ROW PER STEP` Clause

The following example query uses `ONE ROW PER STEP` and finds all friends path with length between *0* and *3* starting from a person named *John*. The query outputs one row per step.

```
SELECT * FROM GRAPH_TABLE ( students_graph
MATCH (n IS person) -[e1 IS friends]->{0,3} (IS person)
WHERE n.name = 'John'
ONE ROW PER STEP (src, e2, dst)
COLUMNS (LISTAGG(e1.friendship_id, ', ') AS friendship_ids,
         src.name AS src_name,
         e2.friendship_id,
         dst.name AS dst_name)
);
```

The example produced the following output:

```
 FRIENDSHIP_IDS  SRC_NAME   FRIENDSHIP_ID DST_NAME
--------------- ---------- ------------- ----------
                John
1               John       1             Bob
1, 4            John       1             Bob
1, 4            Bob        4             Mary
1, 4, 2         John       1             Bob
1, 4, 2         Bob        4             Mary
1, 4, 2         Mary       2             Alice
1, 4, 3         John       1             Bob
1, 4, 3         Bob        4             Mary
1, 4, 3         Mary       3             John

10 rows selected.
```

The preceding output shows data from five paths that were matched:

- The empty path (zero `friendship_ids`) has a single step in which iterator vertex variable `src` is bound to the vertex corresponding to the person named *John*, while iterator edge variable `e2` and iterator vertex variable `dst` are not bound, resulting in NULL values for `FRIENDSHIP_IDS` and `DST_NAME`.
- The path with `friendship_ids` *1* has a single step since it has a single edge. In this step, iterator vertex variable `src` is bound to the vertex corresponding to *John*, iterator edge variable `e2` is bound to the edge with `friendship_id` *1*, and iterator vertex variable `dst` is bound to the vertex corresponding to *Bob*.
- The path with `friendship_ids` *1, 4* has two steps since it has two edges.
- The path with `friendship_ids` *1, 4, 3* has three steps since it has three edges.
- The path with `friendship_ids` *1, 4, 2* again has three steps since it has three edges.

Example 5-19 Query Using `MATCHNUM` Function

The following query finds paths connecting John and Mary either directly or indirectly through a common friend. For each match, the query returns one row per vertex, which means one row

per person along the friendship path. Each result contains a match number, the element number of the `person` vertex, and the name of the `person`.

```
SELECT *
FROM GRAPH_TABLE ( students_graph
       MATCH (p1 IS person) -[IS friends]-{1,2} (p2 IS person)
       WHERE p1.name = 'John' AND p2.name = 'Mary'
       ONE ROW PER VERTEX (v)
       COLUMNS (MATCHNUM() AS matchnum,
                ELEMENT_NUMBER(v) AS element_number,
                v.name))
ORDER BY matchnum, element_number
```

The output for the preceding query is as shown:

```
  MATCHNUM ELEMENT_NUMBER NAME
---------- -------------- ----------
         1              1 John
         1              3 Mary
         2              1 John
         2              3 Bob
         2              5 Mary
```

Example 5-20 Query Using `ELEMENT_NUMBER` Function

The following query finds paths connecting John and Mary either directly or indirectly through a common friend. For each match, the query returns one row per step. Each result contains a match number, the element number of the `friends` edge in the step, the `friendship_id`, and the names of the two persons in the step.

```
SELECT *
FROM GRAPH_TABLE ( students_graph
       MATCH (p1 IS person) -[IS friends]-{1,2} (p2 IS person)
       WHERE p1.name = 'John' AND p2.name = 'Mary'
       ONE ROW PER STEP (v1, e, v2)
       COLUMNS (MATCHNUM() AS matchnum,
                ELEMENT_NUMBER(e) AS element_number,
                v1.name AS name1,
                e.friendship_id,
                v2.name AS name2))
ORDER BY matchnum, element_number;
```

The output for the preceding query is as shown:

```
  MATCHNUM ELEMENT_NUMBER NAME1      FRIENDSHIP_ID NAME2
---------- -------------- ---------- ------------- ----------
         1              2 John                    3 Mary
         2              2 John                    1 Bob
         2              4 Bob                     4 Mary
```

The following query finds all people connected to John through 0 or 1 `friends` edges. For each match, the query returns one row per step. Each result contains a match number, the element

number of the `friends` edge in the step, the `friendship_id`, and the names of the two persons in the step.

```
SELECT *
FROM GRAPH_TABLE ( students_graph
       MATCH (p1 IS person) -[IS friends]-{0,1} (p2 IS person)
       WHERE p1.name = 'John'
       ONE ROW PER STEP (v1, e, v2)
       COLUMNS (MATCHNUM() AS matchnum,
                ELEMENT_NUMBER(e) AS element_number,
                v1.name AS name1,
                e.friendship_id,
                v2.name AS name2))
ORDER BY matchnum, element_number;
```

The query produced the following output:

```
  MATCHNUM ELEMENT_NUMBER NAME1      FRIENDSHIP_ID NAME2
---------- -------------- ---------- ------------- ----------
         1                John
         2              2 John                    3 Mary
         4              2 John                    1 Bob
```

As seen in the preceding output, three paths were matched. The path with match number `1` has one vertex and zero edges. Thus, there is a single step in which the iterator vertex variable `v1` is bound but the iterator edge variable `e` and iterator vertex variable `v2` are not bound, leading to the `NULL` values in the `ELEMENT_NUMBER`, `FRIENDSHIP_ID`, and `NAME2` columns. The other two paths (with match numbers `2` and `4`) also have a single step, but since these paths do contain an edge as well as a second vertex, all three iterator variables are bound, and no `NULL` values are returned.

Example 5-21 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 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 5-22 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 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) > 50)
  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
---------- ---------- ---------- ---------
John               60 Bob        01-SEP-00
Bob                57 Mary       10-JUL-01
```

Example 5-23 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 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 5-24 Query Using TIMESTAMP

The following 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 5-25 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 5-26 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}}
```

Example 5-27 Query Using the `IS SOURCE OF` and `IS DESTINATION OF` Predicates

The following query matches `FRIENDS` edges that are either incoming or outgoing from ***`Mary`***. For each edge, it return the *`NAME`* property for the source of the edge as well as the *`NAME`* property for the destination of the edge.

```
SELECT *
FROM GRAPH_TABLE ( students_graph
       MATCH (p1 IS person) -[e IS friends]- (p2 IS person)
```

```
       WHERE p1.name = 'Mary'
       COLUMNS (e.friendship_id,
                e.meeting_date,
                CASE WHEN p1 IS SOURCE OF e THEN p1.name ELSE p2.name END AS
from_person,
                CASE WHEN p1 IS DESTINATION OF e THEN p1.name ELSE p2.name
END AS to_person))
ORDER BY friendship_id;


FRIENDSHIP_ID MEETING_DATE FROM_PERSON TO_PERSON
------------- ------------ ----------- ---------
            2 19-SEP-00    Mary        Alice
            3 19-SEP-00    Mary        John
            4 10-JUL-01    Bob         Mary
```

Example 5-28 Queries Fetching All the Vertex and Edge Properties

The following query matches all `FRIENDS` edges between two persons `P1` and `P2` and uses *all properties references* `P1.*` and `E.*` to retrieve all the properties of vertex `P1` as well as all properties of edge `E`.

```
SELECT *
FROM GRAPH_TABLE ( students_graph
  MATCH (p1 IS person) -[e IS friends]-> (p2 IS person)
  COLUMNS ( p1.*, p2.name AS p2_name, e.* )
)
ORDER BY 1, 2, 3, 4, 5;
```

Note that the following result for `P1.*` includes properties `PERSON_ID`, `NAME` and `DOB` of label `PERSON` as well as property `HEIGHT` of label `PERSON_HT`. Furthermore, the result for `E.*` includes properties `FRIENDSHIP_ID` and `MEETING_DATE` of label `FRIENDS`.

```
 PERSON_ID NAME       DOB           HEIGHT P2_NAME    FRIENDSHIP_ID MEETING_D
---------- ---------- --------- ---------- ---------- ------------- ---------
         1 John       13-JUN-63        1.8 Bob                    1 01-SEP-00
         2 Mary       25-SEP-82       1.65 Alice                  2 19-SEP-00
         2 Mary       25-SEP-82       1.65 John                   3 19-SEP-00
         3 Bob        11-MAR-66       1.75 Mary                   4 10-JUL-01
```

The following query matches all vertices in the graph and retrieves all their properties:

```
SELECT *
FROM GRAPH_TABLE ( students_graph
  MATCH (v)
  COLUMNS ( v.* )
)
ORDER BY 1, 2, 3, 4, 5;
```

The query produces the following result. Note that since the `PERSON` vertices do not have an `ID` property, the query returns `NULL` values (empty strings). Similarly, `UNIVERSITY` vertices do not

have `PERSON_ID`, `DOB` and `HEIGHT` properties, and so again the query returns `NULL` values (empty strings).

```
 PERSON_ID NAME       DOB           HEIGHT         ID
---------- ---------- --------- ---------- ----------
         1 John       13-JUN-63        1.8
         2 Mary       25-SEP-82       1.65
         3 Bob        11-MAR-66       1.75
         4 Alice      01-FEB-87        1.7
           ABC                                      1
           XYZ                                      2

6 rows selected.
```

Example 5-29 Query Using the `IS SOURCE OF` and `IS DESTINATION OF` Predicates

The following query matches `FRIENDS` edges that are either incoming or outgoing from ***`Mary`***. For each edge, it returns the *`NAME`* property for the source of the edge as well as the *`NAME`* property for the destination of the edge.

```
SELECT *
FROM GRAPH_TABLE ( students_graph
       MATCH (p1 IS person) -[e IS friends]- (p2 IS person)
       WHERE p1.name = 'Mary'
       COLUMNS (e.friendship_id,
                e.meeting_date,
                CASE WHEN p1 IS SOURCE OF e THEN p1.name ELSE p2.name END AS
from_person,
                CASE WHEN p1 IS DESTINATION OF e THEN p1.name ELSE p2.name
END AS to_person))
ORDER BY friendship_id;


FRIENDSHIP_ID MEETING_DATE FROM_PERSON TO_PERSON
------------- ------------ ----------- ---------
            2 19-SEP-00    Mary        Alice
            3 19-SEP-00    Mary        John
            4 10-JUL-01    Bob         Mary
```

- Setting Up Sample Data in the Database

5.11.1 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,
     hr_data JSON,
     CONSTRAINT person_pk PRIMARY KEY (person_id)
   );

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

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

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

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

CREATE TABLE student_of (
      s_id NUMBER GENERATED ALWAYS AS IDENTITY (START WITH 1 INCREMENT BY
1),
      s_univ_id NUMBER,
      s_person_id NUMBER,
      subject VARCHAR2(10),
      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 student_of(s_univ_id, s_person_id,subject) VALUES (1,1,'Arts');
INSERT INTO student_of(s_univ_id, s_person_id,subject) VALUES
(1,3,'Music');
INSERT INTO student_of(s_univ_id, s_person_id,subject) VALUES (2,2,'Math');
INSERT INTO student_of(s_univ_id, s_person_id,subject) VALUES
(2,4,'Science');

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

5.12 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 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 5-21.
- `VERTEX_ID` and `EDGE_ID` functions that uniquely identify a vertex and an edge respectively can be used within a SQL graph query.
  - See Vertex and Edge Identifiers.
  - See Example 5-25.
- `VERTEX_EQUAL` and `EDGE_EQUAL` predicates for matching vertex and edge identifiers are supported.
  - See Vertex and Edge Identifiers.
  - See Example 5-26.

- SQL and JSON expressions are supported inside `WHERE` and `COLUMNS` clauses.
  See Example 4-7.
- JSON simplified syntax is supported to access properties of type `JSON`.
  See Example 4-7.
- PL/SQL functions are supported inside a `WHERE` or `COLUMNS` clause.
  See Example 5-22.
- Single line and multi-line comments are supported within a graph query.
- All identifiers within the `GRAPH_TABLE` operator in a SQL graph 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 SQL graph 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.

5.13 Tuning SQL Property Graph Queries

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

The `GRAPH_TABLE` operator with the property graph 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 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
```

5.14 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:

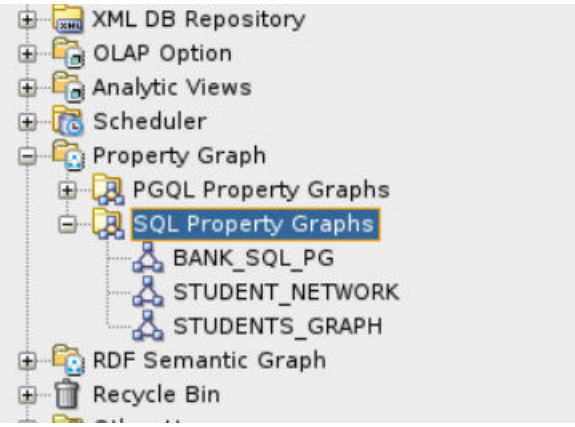
- If expressions exposed by a same property of a shared label are character data, then the data type of the property is determined as follows:
  - If all expressions are of data type `CHAR` of equal length, then the property has a data type `CHAR` of that length. If the expression are all of data type `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`.

5.15 Viewing and Querying SQL Property Graphs Using SQL Developer

Using SQL Developer 23.1, you can view all the SQL property graphs existing in your database schema by expanding **SQL Property Graphs** under the **Property Graph** node in the **Connections** navigator.

Figure 5-1 SQL Property Graphs in SQL Developer



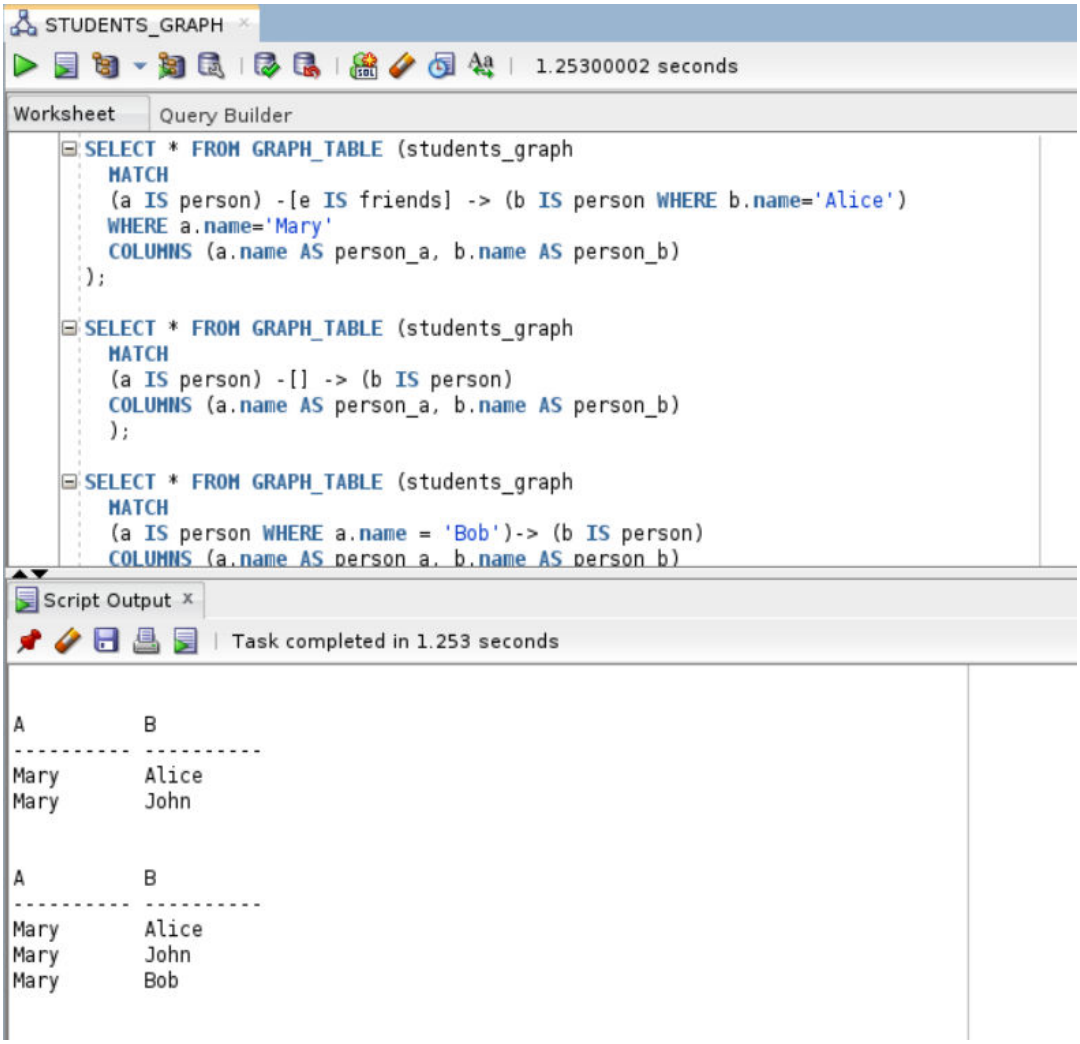
The following steps show an example for running graph queries on a SQL property graph:

1. Click on any SQL property graph.

   This opens a SQL worksheet in another tab.
2. Run one or more graph queries in the SQL worksheet.

   For example:

Figure 5-2 Running SQL Graph queries in SQL Developer



6

Loading a SQL Property Graph into the Graph Server (PGX)

You can load a full SQL property graph or a subgraph into memory in the graph server (PGX).

> **Note:**
>
> Ensure that you drop the graph when it is no longer in use to release the graph server (PGX) memory. See Deleting a Graph for more information.

The following topics describe the various ways to load a SQL property graph into the graph server (PGX).

- Loading a SQL Property Graph Using the readGraphByName API
  You can load a SQL property graph into the graph server (PGX) by calling the `readGraphByName` API on a `PgxSession` object.
- Loading a Subgraph Using PGQL Queries
  You can create an in-memory subgraph from a SQL property graph using the `PgSqlSubgraphReader` API.
- Expanding a Subgraph
  You can expand an in-memory subgraph by loading graph data from a SQL property graph into memory, and merging it with the current subgraph.
- Handling Vertex and Edge Identifiers in the Graph Server (PGX)
  The Oracle Database maintains globally unique identifiers in JSON format.
- Mapping Oracle Database Types to PGX Types
  Learn how the input Oracle database types are mapped to its corresponding PGX types, when a graph from the database is loaded into the graph server (PGX).
- Privileges to Load a SQL Property Graph
  Learn about the privileges required to load a SQL property graph into the graph server(PGX).
- Restriction on Key Types
  Learn about the vertex and edge keys restrictions when loading a full or partial SQL property graph into memory in the graph server (PGX).
- Loading SQL Property Graphs with Unsupported Key Types
  If existing keys in a SQL graph cannot be loaded into the graph server (PGX), then generated keys maintained by the database may be used instead.

6.1 Loading a SQL Property Graph Using the readGraphByName API

You can load a SQL property graph into the graph server (PGX) by calling the `readGraphByName` API on a `PgxSession` object.

When loading a SQL property graph into the graph server (PGX), the full graph schema will be determined and mapped to a graph configuration. The graphs will be loaded as partitioned graphs where each vertex or edge table will be mapped to the respective vertex or edge provider of the same name. Labels and properties will also be loaded as defined.

However, note that only one label per vertex or edge table is supported in order to load a SQL graph into the graph server (PGX).

For example, consider the following SQL property graph:

```
CREATE PROPERTY GRAPH student_network
  VERTEX TABLES (
    persons KEY (person_id)
      LABEL person
        PROPERTIES (person_id, name, birthdate AS dob)
  )
  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)
  );
```

You can load this SQL graph into memory as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName
("STUDENT_NETWORK",GraphSource.PG_SQL)
graph ==> PgxGraph[name=STUDENTS_NETWORK,N=4,E=4,created=1681007796946]
```

Java

```
PgxGraph graph = session.readGraphByName("STUDENT_NETWORK",
GraphSource.PG_SQL);
```

Python

```
>>> graph = session.read_graph_by_name("STUDENT_NETWORK", "pg_sql")
>>> graph
PgxGraph(name: STUDENTS_NETWORK, v: 4, e: 4, directed: True, memory(Mb): 0)
```

- Loading a SQL Property Graph from a Different Schema
  You can specify the schema name when using the `readGraphByName` API for loading a SQL property graph.
- Loading a SQL Property Graph Using Graph Optimization Options
  You can optimize the read or update performance, when loading a SQL property graph using the graph optimization options.
- Loading a SQL Property Graph Using OnMissingVertex Options
  If either the source or destination vertex or both are missing for an edge, then you can use the `OnMissingVertexOption` to specify the behavior for handling the edge with the missing vertex.
- Loading a SQL Property Graph with Properties Mapped to CLOB Data Type Columns
  You can load a SQL property graph from a database table having a CLOB data type column into the graph server (PGX).

6.1.1 Loading a SQL Property Graph from a Different Schema

You can specify the schema name when using the `readGraphByName` API for loading a SQL property graph.

If you only provide the graph name when calling the `readGraphByName` API, it is assumed that the graph is owned by current user. But if you want to load a graph owned by another user, then you must provide the schema name as well. Also, ensure that you have `SELECT` permission on the SQL graph and all its underlying data tables.

The following example loads a SQL property graph from the `GRAPHUSER` schema:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("GRAPHUSER", "STUDENT_NETWORK",
GraphSource.PG_SQL)
graph ==> PgxGraph[name=STUDENT_NETWORK,N=4,E=4,created=1680769031393]
```

Java

```
PgxGraph graph = session.readGraphByName("GRAPHUSER", "STUDENT_NETWORK",
GraphSource.PG_SQL);
```

Python

```
>>> graph = session.read_graph_by_name("STUDENT_NETWORK", "pg_sql",
"GRAPHUSER")
>>> graph
PgxGraph(name: STUDENT_NETWORK_2, v: 4, e: 4, directed: True, memory(Mb): 0)
```

> **See Also:**
>
> Privileges to Load a SQL Property Graph

6.1.2 Loading a SQL Property Graph Using Graph Optimization Options

You can optimize the read or update performance, when loading a SQL property graph using the graph optimization options.

The following example shows loading a SQL property graph optimized for `READ` operation:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("STUDENT_NETWORK",
GraphSource.PG_SQL,
...>     ReadGraphOption.optimizeFor(GraphOptimizedFor.READ))
graph ==> PgxGraph[name=STUDENT_NETWORK,N=4,E=4,created=1681008951415]
```

Java

```
PgxGraph graph = session.readGraphByName("STUDENT_NETWORK",
GraphSource.PG_SQL,
  ReadGraphOption.optimizeFor(GraphOptimizedFor.READ);
```

Python

```
>>> session.read_graph_by_name('STUDENT_NETWORK', 'pg_sql',
options=['optimized_for_read'])
PgxGraph(name: STUDENT_NETWORK, v: 4, e: 4, directed: True, memory(Mb): 0)
```

The following example shows loading a SQL property graph optimized for `UPDATE` operation. Also, note that the `READ` and `UPDATE` options cannot be used at the same time.

- JShell
- Java

- Python

JShell

```
opg4j> var graph = session.readGraphByName("STUDENT_NETWORK",
GraphSource.PG_SQL,
...>     ReadGraphOption.optimizeFor(GraphOptimizedFor.UPDATES))
graph ==> PgxGraph[name=STUDENT_NETWORK_2,N=4,E=4,created=1681009073501]
```

Java

```
PgxGraph graph = session.readGraphByName("STUDENT_NETWORK",
GraphSource.PG_SQL,
  ReadGraphOption.optimizeFor(GraphOptimizedFor.UPDATES));
```

Python

```
>>> session.read_graph_by_name('STUDENT_NETWORK', 'pg_sql',
options=['optimized_for_updates'])
PgxGraph(name: STUDENT_NETWORK, v: 4, e: 4, directed: True, memory(Mb): 0)
```

The following example shows loading a SQL property graph with the `SYNCHRONIZABLE` optimization option. This option can be used in combination with the `READ` and `UPDATE` options.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("STUDENT_NETWORK",
GraphSource.PG_SQL,
...>                              ReadGraphOption.SYNCHRONIZABLE)
graph ==> PgxGraph[name=STUDENT_NETWORK,N=4,E=4,created=1696341305374]
```

Java

```
PgxGraph graph = session.readGraphByName("STUDENT_NETWORK",
GraphSource.PG_SQL,
  ReadGraphOption.SYNCHRONIZABLE);
```

Python

```
>>> session.read_graph_by_name('STUDENT_NETWORK', 'pg_sql',
options=['synchronizable'])
PgxGraph(name: STUDENT_NETWORK_2, v: 4, e: 4, directed: True, memory(Mb): 0)
```

See Also:

Using the Graph Optimization Options for more information.

6.1.3 Loading a SQL Property Graph Using `OnMissingVertex` Options

If either the source or destination vertex or both are missing for an edge, then you can use the `OnMissingVertexOption` to specify the behavior for handling the edge with the missing vertex.

The supported values are:

- **`OnMissingVertex.ERROR` (default):** Specifies that an error must be thrown for edges with missing source or destination vertex.
- **`OnMissingVertex.IGNORE_EDGE`:** Specifies that the edge for a missing source or destination vertex must be ignored.
- **`OnMissingVertex.IGNORE_EDGE_LOG`:** Specifies that the edge for a missing source or destination vertex must be ignored and all ignored edges must be logged.
- **`OnMissingVertex.IGNORE_EDGE_LOG_ONCE`:** Specifies that the edge for a missing source or destination vertex must be ignored and only the first ignored edge must be logged.

The following example loads a SQL property graph by ignoring the edges with missing vertices and logging only the first ignored edge.

- JShell
- Java
- Python

JShell

```
opg4j> session.readGraphByName("STUDENT_NETWORK", GraphSource.PG_SQL,
...>
ReadGraphOption.onMissingVertex(OnMissingVertex.IGNORE_EDGE_LOG_ONCE))
$2 ==> PgxGraph[name=STUDENT_NETWORK_2,N=4,E=4,created=1697264084059]
```

Java

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

Python

```
>>> session.read_graph_by_name('STUDENT_NETWORK', 'pg_sql',
    options=['on_missing_vertex_ignore_edge_log_once'])
PgxGraph(name: STUDENT_NETWORK, v: 4, e: 4, directed: True, memory(Mb): 0)
```

6.1.4 Loading a SQL Property Graph with Properties Mapped to CLOB Data Type Columns

You can load a SQL property graph from a database table having a CLOB data type column into the graph server (PGX).

The CLOB data type columns are processed as `String` properties in the graph server (PGX).

For example, consider the following sample data in the database:

```
CREATE TABLE depts (
  dept_id       NUMBER,
  dept_name     VARCHAR2 (10),
  emp_details   CLOB,
  CONSTRAINT employees_pk PRIMARY KEY (dept_id)
);

INSERT INTO depts
VALUES (1, 'HR', '
<employees>
  <employee empNo="1234" eName="SMITH" hireDate="17-DEC-1990"></employee>
  <employee empNo="5678" ename="ALLEN" hireDate="02-JAN-1981"></employee>
  </employees>
');
INSERT INTO depts
VALUES (2, 'IT', '
<employees>
  <employee empNo="5628" ename="JONES" hireDate="13-MAR-1986"></employee>>
  <employee empNo="5628" ename="TOM"   hireDate="13-MAR-1986"></employee>>
  </employees>
');
```

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

```
CREATE PROPERTY GRAPH dept
VERTEX TABLES (
  DEPTS KEY (dept_id)
  LABEL dept
```

```
    PROPERTIES (dept_id, dept_name, emp_details)
)
```

Load the graph into the graph server (PGX) as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var g = session.readGraphByName("DEPT", GraphSource.PG_SQL)
g ==> PgxGraph[name=DEPT,N=2,E=0,created=1727242485228]
opg4j> g.queryPgql("SELECT n.* FROM MATCH (n:dept)").print()
+-------------------------------------------------------------------------------
--------------------
| DEPT_ID | DEPT_NAME | EMP_DETAILS
| 2.0     | IT        | <employees>
                          <employee empNo="5628" ename="JONES" hireDate="13-
MAR-1986"></employee>>
                          <employee empNo="5628" ename="TOM"   hireDate="13-
MAR-1986"></employee>>
                        </
employees>                                                                  |
| 1.0     | HR        | <employees>
                          <employee empNo="1234" eName="SMITH" hireDate="17-
DEC-1990"></employee>
                          <employee empNo="5678" ename="ALLEN" hireDate="02-
JAN-1981"></employee>
                        </employees>

                    |
+-------------------------------------------------------------------------------
--------------------
```

Java

```
PgxGraph g = session.readGraphByName("DEPT", GraphSource.PG_SQL);
PgqlResultSet rs = g.queryPgql("SELECT n.* FROM MATCH (n:dept)");
rs.print();
```

Python

```
>>> g = session.read_graph_by_name("DEPT", "pg_sql")
>>> g.query_pgql("SELECT n.* FROM MATCH (n:dept)").print()

+-------------------------------------------------------------------------------
--------------------
| DEPT_ID | DEPT_NAME | EMP_DETAILS
```

```
| 2.0     | IT         | <employees>
                         <employee empNo="5628" ename="JONES" hireDate="13-
MAR-1986"></employee>>
                         <employee empNo="5628" ename="TOM"   hireDate="13-
MAR-1986"></employee>>
                       </
employees>                                                              |
| 1.0     | HR         | <employees>
                         <employee empNo="1234" eName="SMITH" hireDate="17-
DEC-1990"></employee>
                         <employee empNo="5678" ename="ALLEN" hireDate="02-
JAN-1981"></employee>
                       </employees>

                    |
+-------------------------------------------------------------------------
--------------------
```

Related Topics

- Mapping Oracle Database Types to PGX Types
  Learn how the input Oracle database types are mapped to its corresponding PGX types, when a graph from the database is loaded into the graph server (PGX).

6.2 Loading a Subgraph Using PGQL Queries

You can create an in-memory subgraph from a SQL property graph using the `PgSqlSubgraphReader` API.

You can specify the subgraph to be loaded in one or more PGQL queries. Each of these PGQL queries will be executed on the database and all the matched vertices and edges will be loaded as part of the subgraph. Therefore, vertices and edges will be loaded only if they match at least one of the queries.

Also, note the following:

- You can only create subgraphs from SQL property graphs that exist in the current database user schema.
- CLOB data type columns are supported when creating a subgraph from a SQL property graph.

The following example creates a subgraph from a SQL property graph using multiple PGQL queries:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readSubgraph().
...>     fromPgSql("STUDENT_NETWORK").
...>     queryPgql("MATCH (v1 IS Person)-[e IS friends]->(v2 IS Person) WHERE
id(v1) = 'PERSONS(1)'").
...>     queryPgql("MATCH (v:Person) WHERE id(v) = 'PERSONS(2)'").
...>     load()
graph ==> PgxGraph[name=STUDENT_NETWORK_4,N=3,E=1,created=1681009569883]
```

Java

```
PgxGraph graph = session.readSubgraph()
  .fromPgSql("STUDENT_NETWORK")
  .queryPgql("MATCH (v1 IS Person)-[e IS friends]->(v2 IS Person) WHERE
id(v1) = 'PERSONS(1)'")
  .queryPgql("MATCH (v:Person) WHERE id(v) = 'PERSONS(2)'")
  .load();
```

Python

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

Loading Subgraphs with Custom Names

By default, the new subgraph gets created with the same name as the SQL property 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().
...>     fromPgSql("STUDENT_NETWORK").
...>     queryPgql("MATCH (v1 IS Person)-[e IS friends]->(v2 IS Person) WHERE
id(v1) = 'PERSONS(1)'").
...>     queryPgql("MATCH (v:Person) WHERE id(v) = 'PERSONS(2)'").
...>     load("student_subgraph")
graph ==> PgxGraph[name=student_subgraph,N=3,E=1,created=1681010160515]
```

Java

```
PgxGraph graph = session.readSubgraph()
  .fromPgSql("STUDENT_NETWORK")
  .queryPgql("MATCH (v1 IS Person)-[e IS friends]->(v2 IS Person) WHERE
id(v1) = 'PERSONS(1)'")
  .queryPgql("MATCH (v:Person) WHERE id(v) = 'PERSONS(2)'")
  .load("student_subgraph");
```

Python

```
>>> graph = session.read_subgraph_from_pg_sql("STUDENT_NETWORK",
...     ["MATCH (v1 IS Person)-[e IS friends]->(v2 IS Person) WHERE id(v1) =
'PERSONS(1)'",
...      "MATCH (v:Person) WHERE id(v) = 'PERSONS(2)'"],
...      graph_name="student_subgraph")
>>> graph
PgxGraph(name: student_subgraph, v: 3, e: 1, directed: True, memory(Mb): 0)
```

6.3 Expanding a Subgraph

You can expand an in-memory subgraph by loading graph data from a SQL property graph into memory, and merging it with the current subgraph.

The following applies when merging two subgraphs:

- Expanding a subgraph with data from another SQL graph is only possible if the graph schemas are compatible.
- The initial subgraph for expanding can also be loaded from a PGQL property graph and need not necessarily originate from a SQL property graph.
- You can only expand a subgraph by loading graph data from a property graph that exists in the current database schema.
- Also, see Dynamically Expanding a Subgraph for additional information.

The following example shows the expansion of the subgraph created in Loading a Subgraph Using PGQL Queries:

- JShell
- Java
- Python

JShell

```
opg4j> graph = graph.expandGraph().
...>     withPgql().
...>     fromPgSql("STUDENT_NETWORK").
...>     queryPgql("MATCH (v1 IS Person) WHERE id(v1) = 'PERSONS(4)'").
```

```
...>     expand()
graph ==> PgxGraph[name=anonymous_graph_31,N=4,E=1,created=1681011908378]
```

Java

```
PgxGraph graph = graph.expandGraph()
  .withPgql()
  .fromPgSql("STUDENT_NETWORK")
  .queryPgql("MATCH (v1 IS Person) WHERE id(v1) = 'PERSONS(4)'")
  .expand();
```

Python

```
>>> graph = graph.expand_with_pgql("MATCH (v1 IS Person) WHERE id(v1) =
'PERSONS(4)'", pg_sql_name="STUDENT_NETWORK")
>>> graph
PgxGraph(name: anonymous_graph_34, v: 4, e: 1, directed: True, memory(Mb): 0)
```

6.4 Handling Vertex and Edge Identifiers in the Graph Server (PGX)

The Oracle Database maintains globally unique identifiers in JSON format.

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
  }
}
```

See Vertex and Edge Identifiers for more information.

However, the graph server (PGX) will not load the full identifiers, but only the `KEY_VALUE` column. This ID will then be maintained as a partitioned ID. For instance, the partitioned ID constructed from the preceding JSON output is: `PERSONS(1)`

Note that when working with graphs loaded from SQL property graphs, always use the partitioned ID format to refer to the elements by ID.

6.5 Mapping Oracle Database Types to PGX Types

Learn how the input Oracle database types are mapped to its corresponding PGX types, when a graph from the database is loaded into the graph server (PGX).

The following table applies for both SQL property graphs and PGQL property graphs.

Table 6-1 Mapping Oracle Database Types to PGX Types

Oracle Database Type[1]	PGX Type
NUMBER	The following implicit type conversion rules apply: • NUMBER => LONG (for key columns) • NUMBER => DOUBLE (for non-key columns) • NUMBER(m) (number having precision m) with *m <= 9* => INTEGER • NUMBER(m) (number having precision m) with *9 < m <= 18* => LONG • NUMBER(m,n) (number having precision m and scale n) => DOUBLE Note that this applies if n > 0. Otherwise, it follows the same mapping as NUMBER(x), where x = m-n (that is, subtracting the scale from the precision). The PGX type can then vary, depending on the x value as shown: – *x <= 9* => INTEGER – *9 < x <= 18* => LONG – *x > 18* => DOUBLE For instance, consider a scenario where n = -100 and m = 1. In this case, x = 101 (m-n), which is greater than 18. Extremely large numbers cannot be encoded to fit in INTEGER or LONG and therefore require the DOUBLE data type.
CHAR or NCHAR	STRING
VARCHAR, VARCHAR2, or NVARCHAR2	STRING
BINARY_FLOAT	FLOAT
BINARY_DOUBLE	DOUBLE
FLOAT	The following implicit type conversion rules apply: • FLOAT(m) with *m <= 23* => FLOAT • FLOAT(m) with *23 < m* => DOUBLE In the preceding entries, *m* is the variable for precision.
CLOB	STRING
DATE or TIMESTAMP	TIMESTAMP
TIMESTAMP WITH LOCAL TIME ZONE	TIMESTAMP
TIMESTAMP WITH TIME ZONE	TIMESTAMP WITH TIME ZONE

1 Data types for **PGQL property graphs** and **SQL Property Graphs** share a one-to-one mapping with Oracle Database data types.

6.6 Privileges to Load a SQL Property Graph

Learn about the privileges required to load a SQL property graph into the graph server(PGX).

Ensure that you have the following set of permissions:

- SELECT permission is required for the SQL property graph.
  - If you are the graph owner, you will automatically get this permission.
  - Otherwise, you can grant the permission as shown:
    `GRANT SELECT ON PROPERTY GRAPH <graph_name> TO <user_name>;`

- `SELECT` permission is required for all the underlying data tables of the SQL property graph
  - This permission is required to access entity keys.
  - Note that these permissions are handled separately from the graph permissions.
  - You can grant the permission as shown:
    `GRANT SELECT ON <table_name> TO <user_name>;`

6.7 Restriction on Key Types

Learn about the vertex and edge keys restrictions when loading a full or partial SQL property graph into memory in the graph server (PGX).

The following applies when loading an entire SQL property graph into memory:

- It is mandatory that the vertex keys are both accessible and of a supported type.
  For vertices, keys need to be one these (PGX) types: `INTEGER`, `LONG`, or `STRING`.
- Composite vertex keys are not supported. This implies that each vertex table can have one and only one key column.
- Loading edge keys are optional. This means that if an edge key type is not supported, then the SQL graph can still be loaded using the `readGraphByName` API. In such as case, the graph server (PGX) will not load the edge key, but generate a new one instead.
  For edges, keys can only be numeric and the only supported type is `LONG`.
- Composite edge keys are not supported.

However, when loading a subgraph from a SQL property graph, both the vertex and edge keys must be of a supported PGX type. If the graph has at least one edge table where keys cannot be loaded (either because keys are missing, composite keys, or unsupported types), then you cannot load a subgraph into the graph server (PGX).

In most cases, this restriction can be worked around by using generated numeric keys instead of existing keys. See Loading SQL Property Graphs with Unsupported Key Types for an example.

> **See Also:**
>
> Mapping Oracle Database Types to PGX Types

6.8 Loading SQL Property Graphs with Unsupported Key Types

If existing keys in a SQL graph cannot be loaded into the graph server (PGX), then generated keys maintained by the database may be used instead.

Consider the following SQL property graph which is defined with composite edge keys (`USER1`, `USER2`) for its edge table `FRIENDS_WITH`:

```
CREATE PROPERTY GRAPH SOCIAL_NETWORK
    VERTEX TABLES (
        ACCOUNT
          KEY (ID) LABEL USER PROPERTIES (FULL_NAME, USERNAME)
    )
    EDGE TABLES (
```

```
    FRIENDS_WITH
      KEY (USER1, USER2)
      SOURCE KEY (USER1) REFERENCES ACCOUNT (USERNAME)
      DESTINATION KEY (USER2) REFERENCES ACCOUNT (USERNAME)
      NO PROPERTIES
)
OPTIONS (TRUSTED MODE);
```

Although the `SOCIAL_NETWORK` graph can be loaded into the graph server (PGX), the edge keys will not be loaded. Also, subgraph loading is not supported for composite edge keys.

In order to resolve these issues, you can perform the following workaround steps on the underlying `FRIENDS_WITH` edge table.

1. Add a numeric key column to the `FRIENDS_WITH` table.

   ```
   ALTER TABLE FRIENDS_WITH ADD ID NUMBER(5) GENERATED ALWAYS AS IDENTITY;
   ```

   The data table of the `FRIENDS_WITH` provider now has an additional `ID` column which will automatically be populated with generated numeric keys.

   Note that using `GENERATED AS IDENTITY` columns require additional permissions in the database, such as `CREATE ANY SEQUENCE`.

2. Update the graph definition to use this new column as a key for the `FRIENDS_WITH` edge table.

   a. If you want to create a graph with the same name, then you must first drop the existing graph.

      ```
      DROP PROPERTY GRAPH SOCIAL_NETWORK;
      ```

   b. Update and run the new graph definition.

      ```
      CREATE PROPERTY GRAPH SOCIAL_NETWORK
          VERTEX TABLES (
              ACCOUNT
                KEY (ID)
                LABEL USER
                PROPERTIES (FULL_NAME, USERNAME)
          )
          EDGE TABLES (
              FRIENDS_WITH
                KEY (ID)
                SOURCE KEY (USER1) REFERENCES ACCOUNT (USERNAME)
                DESTINATION KEY (USER2) REFERENCES ACCOUNT (USERNAME)
                NO PROPERTIES
          )
          OPTIONS (TRUSTED MODE);
      ```

      Alternatively, you may also use a `CREATE OR REPLACE PROPERTY GRAPH` statement, which will override a graph definition, if one with the same name exists already.

   The new graph definition supports subgraph loading using the `SOCIAL_NETWORK` SQL graph.

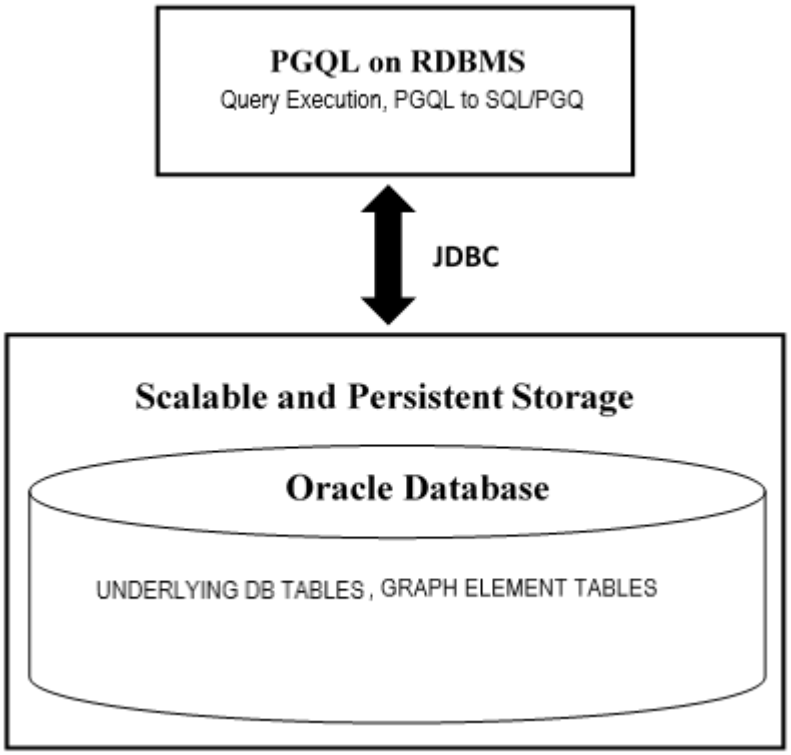
7

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 7-1 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 (SQL graph 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.

- Creating a SQL Property Graph Using PGQL
  You can create a SQL property graph from the database tables using the `CREATE PROPERTY GRAPH` PGQL DDL statement.

- 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.
- Migrating PGQL Property Graphs to SQL Property Graphs
- Supported PGQL Features and Limitations for SQL Property Graphs
  Learn about the supported PGQL features and limitations for SQL property graphs.

7.1 Creating a SQL Property Graph Using PGQL

You can create a SQL property graph from the database tables using the `CREATE PROPERTY GRAPH` PGQL DDL statement.

The following example uses the dataset tables that are created by Importing Data from CSV Files:

- JShell
- Java
- Python

JShell

```
opg4j> var jdbcUrl="jdbc:oracle:thin:@<host_name>:<port>/<service>"
opg4j> var conn =
DriverManager.getConnection(jdbcUrl,"<username>","<password>");
opg4j> var pgqlConn = PgqlConnection.getConnection(conn)
opg4j> var pgqlStmt = pgqlConn.createStatement()
opg4j> var pgql =
...> "CREATE PROPERTY GRAPH bank_sql_pg "
...> + "VERTEX TABLES ( BANK_ACCOUNTS "
...> + "KEY (ID) "
...> + "LABEL Account "
...> + "PROPERTIES (ID, NAME) "
...> + ") "
...> + "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 (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT, DESCRIPTION) "
...> + ") OPTIONS (PG_SQL) "
opg4j> pgqlStmt.execute(pgql)
```

Java

```
import java.sql.Connection;
import java.sql.Statement;
import java.sql.DriverManager;
import oracle.pg.rdbms.pgql.PgqlConnection;
import oracle.pg.rdbms.pgql.PgqlStatement;
```

```
/*
 * This example creates a SQL property graph.
 */
public class CreateSQLGraph
{

  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
      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 " +
        "KEY (id) " +
        "LABEL Account " +
        "PROPERTIES (id, name)" +
        ") " +
        "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 (from_acct_id, to_acct_id, amount, description)" +
        ") OPTIONS (PG_SQL) ";

      // 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:@<host_name>:<port>/<service>")
>>> pgql_statement = pgql_conn.create_statement()
>>> pgql = """
... CREATE PROPERTY GRAPH bank_sql_pg
... VERTEX TABLES (
...   BANK_ACCOUNTS
...     KEY (ID)
...     LABEL Account
...     PROPERTIES (ID, NAME)
... )
... 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 (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT, DESCRIPTION)
... ) OPTIONS (PG_SQL)
... """
>>> pgql_statement.execute(pgql)
False
```

See Creating a Property Graph Using PGQL to understand the PGQL concepts.

7.2 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 |
+-------+
```

7.3 Migrating PGQL Property Graphs to SQL Property Graphs

You can call the `migrate_pgql_to_sql` function to migrate a PGQL property graph to SQL property graph.

The `migrate_pgql_to_sql` function accepts the following parameters:

- ***source_schema***: Underlying schema of the original PGQL property graph.
- ***source_graph_name***: Name of the original PGQL property graph.
- ***destination_schema (optional)*** : Underlying schema of the SQL property graph. If not specified, then the graph is created in the source PGQL property graph schema.
- ***destination_graph (optional)***: Name of the new SQL property graph. If not specified, then the new graph is created with the original name of the PGQL property graph and the original graph will be renamed by appending `_PGQL` at the end of the name.

> **Note:**
>
> PGQL property graphs based on database views cannot be migrated.

Example 7-1 Migrating a PGQL Property Graph to SQL Property Graph

The following example assumes that the PGQL property graph `FRIENDS` exists in Oracle Database 23ai.

- JShell
- Java
- Python

JShell

```
opg4j> var jdbcUrl="jdbc:oracle:thin:@<host_name>:<port>/<db_service>"
opg4j> var conn =
DriverManager.getConnection(jdbcUrl,"<username>","<password>")
opg4j> PgqlConnection pgqlConn = PgqlConnection.getConnection(conn)
opg4j> PgqlStatement pgqlStmt = pgqlConn.createStatement()
opg4j> pgqlStmt.execute("CALL pg.migrate_pgql_to_sql('GRAPHUSER', 'FRIENDS',
'GRAPHUSER', 'FRIENDS_SQL_GRAPH')")
$9 ==> false
```

Java

```
DriverManager.registerDriver(new PgqlJdbcRdbmsDriver());
Connection conn = DriverManager.getConnection(<jdbcUrl>, <username>,
<password>);
PgqlConnection pgqlConn = PgqlConnection.getConnection(conn);
PgqlStatement pgqlStmt = pgqlConn.createStatement();
```

```
pgqlStmt.execute("CALL pg.migrate_pgql_to_sql('GRAPHUSER', 'FRIENDS',
'GRAPHUSER', 'FRIENDS_SQL_GRAPH')");
```

Python

```
>>> pgql_conn = opg4py.pgql.get_connection("<username>","<password>",
"jdbc:oracle:thin:@<host_name>:<port>/<db_service>")
>>> pgql_statement = pgql_conn.create_statement()
>>> pgql_statement.execute("CALL pg.migrate_pgql_to_sql('GRAPHUSER',
'FRIENDS', 'GRAPHUSER', 'FRIENDS_SQL_GRAPH')")
$4 ==> false
```

7.4 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 7-1 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` • `JSON_ARRAYAGG`
`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

Table 7-1 (Cont.) Supported PGQL Functionalities and Limitations for SQL Property Graphs

Features	PGQL on SQL Property Graphs

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

8

Visualizing SQL Graph Queries Using the APEX Graph Visualization Plug-in

You can use the Oracle Application Express (APEX) Graph Visualization plug-in to visualize and interact with SQL property graphs in an APEX application.

The following topics explain more about the plug-in:

- About the APEX Graph Visualization Plug-in
  The APEX Graph Visualization plug-in integrates a Java Script Library that supports graph visualization in APEX applications.
- Getting Started with the APEX Graph Visualization Plug-in
  This section helps you get started with the Graph Visualization plug-in in your APEX application.
- Configuring Attributes for the APEX Graph Visualization Plug-in
  Learn how to customize your graph visualization using the Graph Visualization plug-in attributes in your APEX application.

8.1 About the APEX Graph Visualization Plug-in

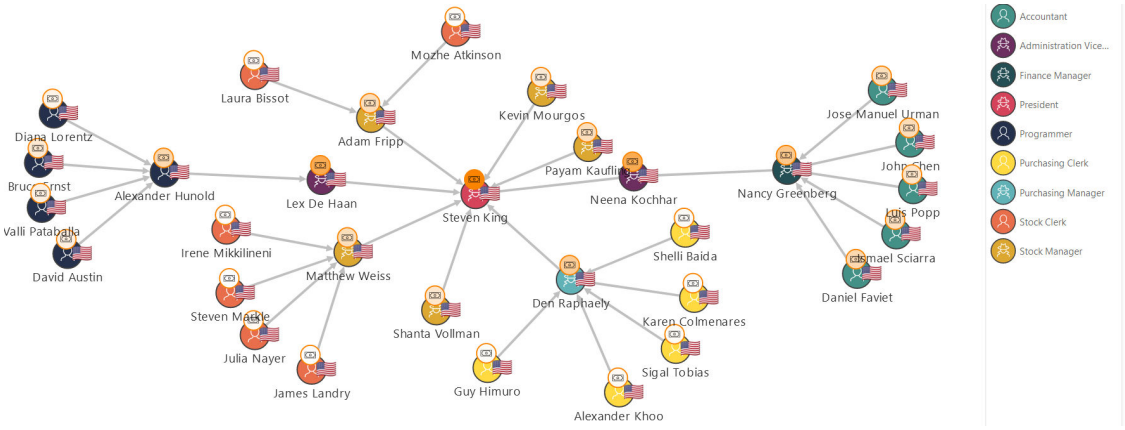
The APEX Graph Visualization plug-in integrates a Java Script Library that supports graph visualization in APEX applications.

See Graph JavaScript API Reference for Property Graph Visualization for more information.

The plug-in mainly allows you to:

- Visualize SQL property graph queries from the graph data in your database.
- Explore the graph vertices and edges. You can also select and visualize these graph elements individually or in groups.
- Interact with the graph visualization by performing various actions such as changing the graph layouts, grouping or ungrouping selected vertices, removing selected vertices or edges, and so on.
- Style the vertices and edges in the graph by configuring the style settings such as size, color, icon, label values, and so on.
- Visualize and study the evolution of the graph over time.

The following figure shows an example of graph visualization in an APEX application using the plug-in:



Note that the plug-in supports icons in the Font APEX library.

8.2 Getting Started with the APEX Graph Visualization Plug-in

This section helps you get started with the Graph Visualization plug-in in your APEX application.

Before you get started, ensure that your APEX workspace meets the following requirements:

- The target application into which you want to import the plug-in exists.
- The target application is connected to Oracle Database 23ai.
- The SQL property graph to be used for visualization exists in the default database schema. Using the command editor in the **SQL Workshop** component, you can create a SQL property graph using the `CREATE PROPERTY GRAPH` DDL statement (see Using the Command Editor).
- The Graph Visualization plug-in version in the Oracle APEX 24.1 GitHub repository is supported only on APEX 24.1 version.

1. Download the **Graph Visualization (Preview)** plug-in (`region_type_plugin_graphviz.sql`) from the Oracle APEX GitHub repository.
2. Sign in to your APEX workspace (see Signing In to Your Workspace).
3. Create the `DBMS_GVT` package in your APEX workspace.
   a. Download the `optional-23ai-only/gvt_sqlgraph_to_json.sql` file from the Oracle APEX GitHub repository.
   b. Upload and run the `gvt_sqlgraph_to_json.sql` script in your APEX workspace (see Uploading a SQL Script).
4. Import the downloaded plug-in script (`region_type_plugin_graphviz.sql`) file into your target APEX application (see Importing Plug-ins).
5. Implement the plug-in in an application page to perform various graph visualizations.

   The following basic example describes the steps to visualize a graph existing in your database using the Graph Visualization plug-in.

   a. Open the application page in **Page Designer**.
   b. Select the **Rendering** tab on the left pane of the Page Designer.
   c. Right-click an existing component and add a new region component.
   d. Select the new region and configure the following attributes in the **Region** tab of the **Property Editor** on the right pane of the Page Designer:

i. Enter the Identification **Title**.

ii. Select **Graph Visualization (Preview)** as Identification **Type**.

iii. Select the source **Location** as **Local Database**.

iv. Select the **Type** value.
You can choose either **SQL Query** or **PropertyGraph** as the Type value.

v. Embed the SQL graph query to retrieve the graph data.
Depending on the type selected in the previous step, you can provide the query as shown in the following examples:

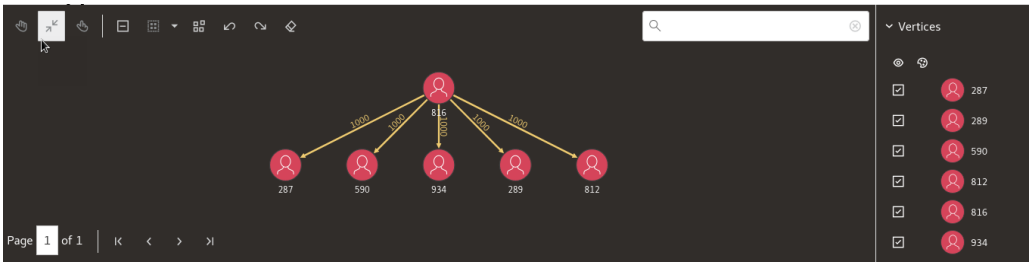
- **SQL Query:** Enter the SQL graph query input as shown:

```
SELECT *
  FROM GRAPH_TABLE (
           BANK_SQL_PG
           MATCH (a IS account) -[e IS transfer]-> (b IS account)
           WHERE a.id = 816
           COLUMNS(vertex_id(a) AS id_a, edge_id(e) AS id_e,
vertex_id(b) AS id_b)
       )
```

- **PropertyGraph :** Provide the SQL graph query as shown:
  - **Graph Name:** Select the SQL property graph name.
  - **Match Clause:** Enter the `MATCH` clause of the graph query. For example:
    `(a IS account) -[e IS transfer]-> (b IS account)`
  - **Columns Clause:** Enter the `COLUMNS` clause of the graph query. For example:
    `(vertex_id(a) AS id_a, edge_id(e) AS id_e, vertex_id(b) AS id_b)`
  - **Where Clause:** Optionally, enter the `WHERE` clause of the query. For example, `a.id = 816`.

e. Run the application page to visualize the graph rendered by the plugin.

Figure 8-1 Visualizing a SQL Graph Query in an APEX Application



6. Optionally, if you wish to implement pagination in the preceding graph visualization, then perform the following steps:

a. Switch ON the **SQL Query Supports Pagination** setting in the **Attributes** tab of the Property Editor for the graph visualization component in your APEX application.

b. Set the **Page Size** value in the **Attributes** tab of the Property Editor.

c. Save and rerun the application page.

The graph gets rendered with pagination.

7. Optionally, you can import and run the **Sample Graph Visualizations** application from Oracle APEX GitHub repository.

   See Importing the Sample Graph Visualizations Application in APEX for more information.

- Importing the Sample Graph Visualizations Application in APEX
  The **Sample Graph Visualizations** application demonstrates the use of the Graph Visualization plug-in.

8.2.1 Importing the Sample Graph Visualizations Application in APEX

The **Sample Graph Visualizations** application demonstrates the use of the Graph Visualization plug-in.

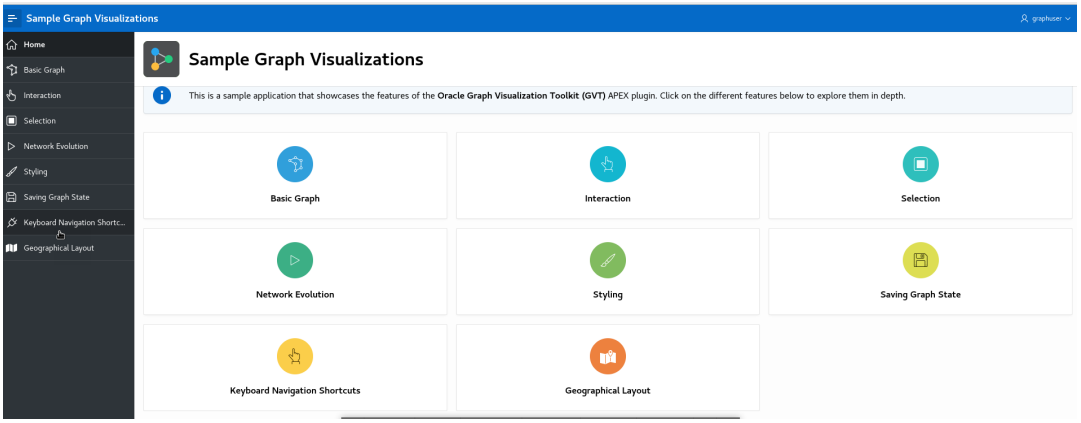
Perform the following steps to import the **Sample Graph Visualizations** application:

1. Download the **Sample Graph Visualizations** application from Oracle APEX GitHub repository.
2. Create the `DBMS_GVT` package if it is not already added in your APEX workspace.
   a. Download the `optional-23ai-only/gvt_sqlgraph_to_json.sql` file from the Oracle APEX GitHub repository.
   b. Upload and run the `gvt_sqlgraph_to_json.sql` script in your APEX workspace (see Uploading a SQL Script).
3. Import the `sample-apps/sample-graph-visualizations/sample-graph-visualizations_23ai.sql` into your APEX instance and install the application by following the steps in Importing an Application.

   When installing the sample application, ensure that you have the CREATE VIEW privilege for installing the supporting objects.

   You can directly run the sample application once it is installed.

Figure 8-2 Sample Graph Visualization Home Page



Also, note that the sample application requires a secure `HTTPS` connection. If you want to disable secure connection, then perform the following steps:

> **Caution:**
>
> It is **not** recommended to disable secure connections in production deployment.

a. Navigate to the sample application home page in **App Builder**.
b. Click **Shared Components**.
c. Click **Authentication Schemes** under **Security**.
d. Click the **Current** authentication scheme.
e. Click the **Session Sharing** tab and turn off the **Secure** switch.
f. Click **Apply Changes** and then run the application.

8.3 Configuring Attributes for the APEX Graph Visualization Plug-in

Learn how to customize your graph visualization using the Graph Visualization plug-in attributes in your APEX application.

You can configure the attributes for the plug-in component in the **Attributes tab** (Property Editor) on the right pane of the Page Designer.

The attributes are grouped as per their scope in the following panels:

- Settings
- Appearance
- Layout
- Captions
- Evolution
- Advanced and Callbacks Options

8.3.1 Settings

The **Settings** panel appears as shown:

Figure 8-3 Settings

The following table describes the attributes in the **Settings** panel:

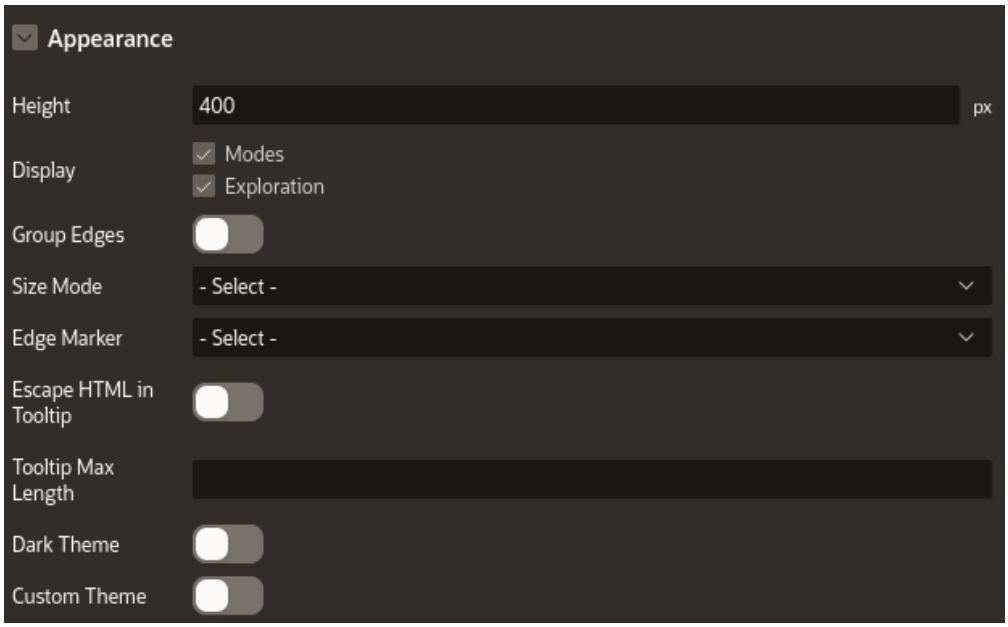
Table 8-1 Settings Attributes

Attribute	Description
SQL Query supports Pagination	Switch on this toggle if you are implementing the paginate interface.
Page Size	An integer value that determines the number of vertices and edges to be displayed per page if you enabled **SQL Query supports Pagination**.
Live Search	Switch on this toggle to enable Live Search when visualizing the graph.
Show Legend	Switch on this toggle to display the legend for the graph visualization.
Legend Width	An integer value that controls the legend width if you have enabled **Show Legend**. Default is 150.

8.3.2 Appearance

The **Appearance** panel appears as shown:

Figure 8-4 Appearance



The following table describes the attributes in the **Appearance** panel:

Table 8-2 Appearance Attributes

Attribute	Description
Height	An integer value (in `px`) to set the size of the graph visualization panel. Default value is `400 px`.

Table 8-2 (Cont.) Appearance Attributes

Attribute	Description
Display	You can enable or disable the following options : • **Modes**: Supported graph visualization modes are are: – **Move/Zoom**: – **Fit to Screen** – **Toggles Sticky Mode** • **Exploration**: Supported graph interaction options are: – **Drop**: To remove selected vertices or edges from the visualization. – **Group**: To group selected multiple vertices and collapse them into a single one. – **Ungroup**: To select a group of collapsed vertices and ungroup them. – **Undo**: To undo the last action. – **Redo**: To redo the last action. – **Reset**: To reset the visualization to the original state after the query.
Group Edges	When this option is enabled, multiple edges between the same source and target vertex will be grouped together in the graph. The grouped edges will be shown as a single edge with a number on it, indicating how many edges have been grouped.
Size Mode	Two size modes are supported: • **Normal** (default) • **Compact**
Edge Marker	Supported edge markers are: • **None** • **Arrow** (default)
Escape HTML in Tooltip	Switch on this toggle if you wish to escapes HTML content used on vertex or edge tooltip.
Tooltip Max Length	An integer value that determines the maximum length of characters for the tooltip. Default value is 100.
Dark Theme	Enable this toggle to switch to a dark theme.
Custom Theme	Enable this toggle if you wish to configure a custom theme for the following: • **Background Color**: Enter a color code or pick a color for the background. • **Text Color**: Enter a color code or pick a color for the text.

8.3.3 Layout

The **Layout** panel allows you to choose one of the following layout options:

- *Circle*
- *Concentric*
- *Force* (default)
- *Grid*
- *Hierarchical*
- *Radial*

- *Geographical*

The layout configuration parameters may vary for different layouts.

Force Layout

The *Force* layout configuration parameters are described in the following table:

Table 8-3 Force Layout Attributes

Attribute	Description
Spacing	Spacing determines how close different vertices are rendered next to each other. Default is 1.5.
Alpha Decay	Controls the rate at which the simulation's internal alpha value, which influences node movement, decreases over time, gradually stabilizing the force layout. Default is 0.01.
Velocity Decay	Determines how fast a simulation ends. Default is 0.1.
Edge Distance	The simulation tries to set each edge to the specified length. This can affect the padding between vertices. Default is 100.
Vertex Charge	Influences the underlying forces (for example, to remain within the viewport, to push vertices away from each other, and so on). If **Enable Cluster** is true, then it influences the forces among clusters. Default is -60.
Enable Cluster	Switch on this toggle if you wish to enable cluster based layout.
Cluster By	By default, the cluster layout (if enabled) uses the first element in `vertex.labels` (see Styles) to form the cluster. It can also be set to the property name of a vertex, and the clusters will be formed based on the property value.
Hide Unclustered Vertices	Determines whether to display vertices that do not belong to any cluster. Default is false.

Circle, Concentric, and Radial Layouts

The following layouts require only the **Spacing** configuration:

- *Circle*: Spacing sets the radius of the circle. Default is 2.
- *Concentric*: Spacing sets the minimum spacing in between vertices. It is used for radius adjustment. Default is 2.
- *Radial*: Spacing sets separation gap between neighboring vertices if they share the same parent vertex. If set to 0, then spacing will not be applied. Default is 2.

Grid Layout

The *Grid* layout supports the following configuration options:

- **Spacing**: Spacing sets the space between elements in the grid. Default is 2.
- **Rows**: Determines the number of rows in the grid.
- **Columns**: Determines the number of columns in the grid.

The default number of rows and columns are dynamically calculated depending on the height and the width of the graph visualization panel.

Hierarchical Layout

The `Hierarchical` layout configuration parameters are described in the following table:

Table 8-4 Hierarchical Layout Attributes

Attribute	Description
Rank Direction	Alignment of the ranked vertices. Supported options are - `Up to Left`, `Up to Right`, `Down to Left`, `Down to Right`, `Top to Bottom`, `Bottom to Top`, `Left to Right`, `Right to Left`.
Ranker	Specifies the type of algorithm used to rank the vertices. Supported algorithms are: *Network Simplex*, *Tight Tree*, and *Longest Path*.
Vertex Separation	Sets the horizontal separation between the vertices.
Edge Separation	Sets the horizontal separation between the edges.
Rank Separation	Sets the separation between two ranks(levels) in the graph.

Geographical Layout

The `Geographical` layout configuration parameters are described in the following table:

Table 8-5 Geographical Layout Attributes

Attribute	Description
Map Type	Select map type in map visualization or graph visualization settings, or provide your own sources and layers.
Longitude	Specify the vertex property to use for determining the longitude of a vertex.
Latitude	Specify the vertex property to use for determining the latitude of a vertex.
App ID	Specify the *appId* to fetch maps from `http://maps.oracle.com/elocation`. If omitted, a generic *appId* will be used.
Show Information	Enabling this toggle, displays an info box in the visualization that shows the latitude and longitude of the mouse position and the zoom level of the map.
Navigation	Displays the navigation controls towards the top right region of the map.
Markers	Displays location markers on the map

> **See Also:**
>
> Layouts page in JavaScript API Reference for Property Graph Visualization

8.3.4 Captions

The **Captions** panel appears as shown:

Figure 8-5 Captions

The following table describes the attributes in the **Caption** panel:

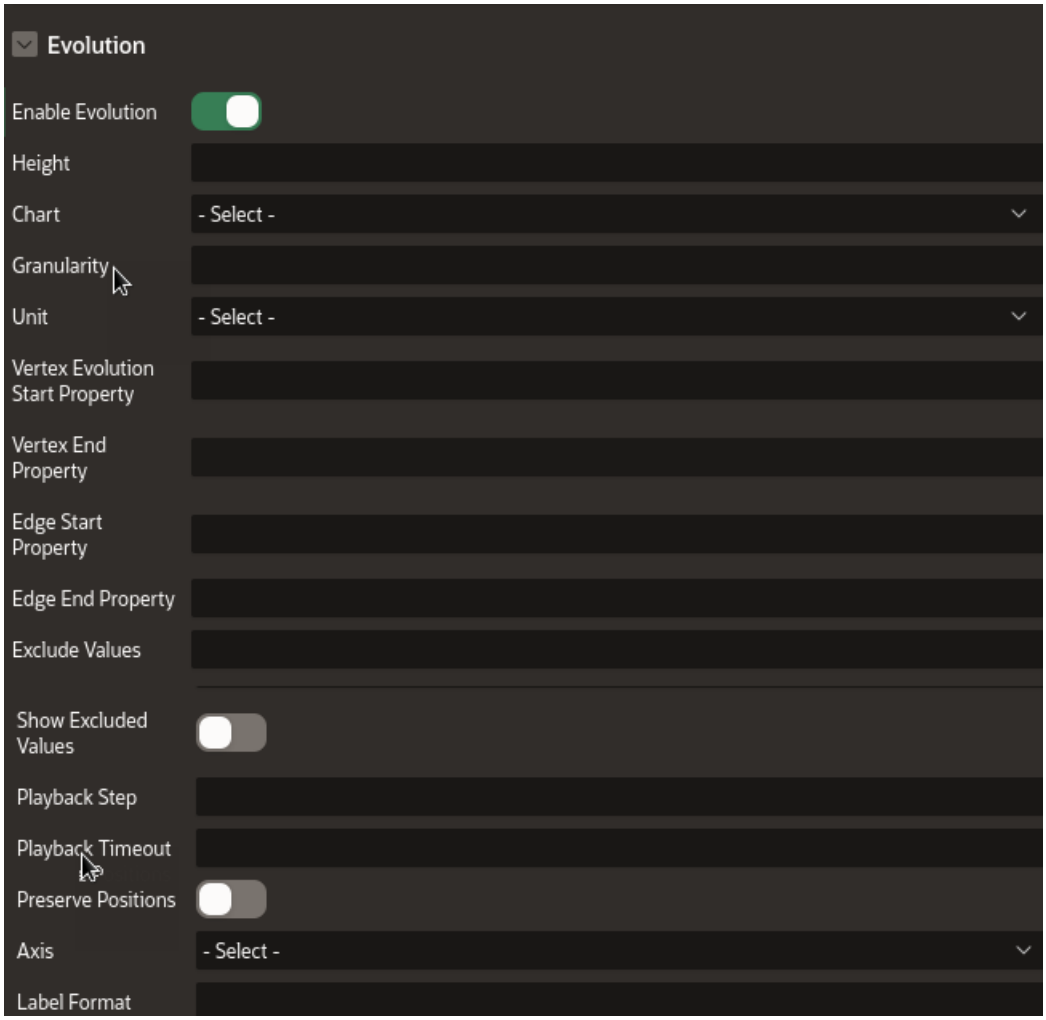
Table 8-6 Caption Attributes

Attribute	Description
Vertex Caption	Specify the property to be displayed as the vertex label.
Edge Caption	Specify the property to be displayed as the edge label.
Maximum Caption Length	Specify the maximum length of the caption.
Show full label text on hover	Enable this toggle if you wish to display the vertex and edge caption when hovering over a specific vertex or edge.

8.3.5 Evolution

The **Evolution** panel appears as shown:

Figure 8-6 Evolution



The following table describes the attributes in the **Evolution** panel:

Table 8-7 Evolution Attributes

Attribute	Description
Enable Evolution	Switch on this toggle to enable network evolution in the graph visualization.
Height	Specify the height of the chart.
Chart	Select the chart type - *Bar* or *Line*.
Granularity	Specify the aggregation granularity for the input unit.
Unit	Select the unit of time for the increment.
Vertex Evolution Start Property	Select the name of the property to use for the vertex filtering. The time frame for the graph will be after the *Vertex Evolution Start Property*.
Vertex End Property	Select the name of the property to use for the vertex filtering. The time frame for the graph will be before the *Vertex End Property*.
Edge Start Property	Select the name of the property to use for the edge filtering. The time frame for the graph will be after the *Edge Start Property*.

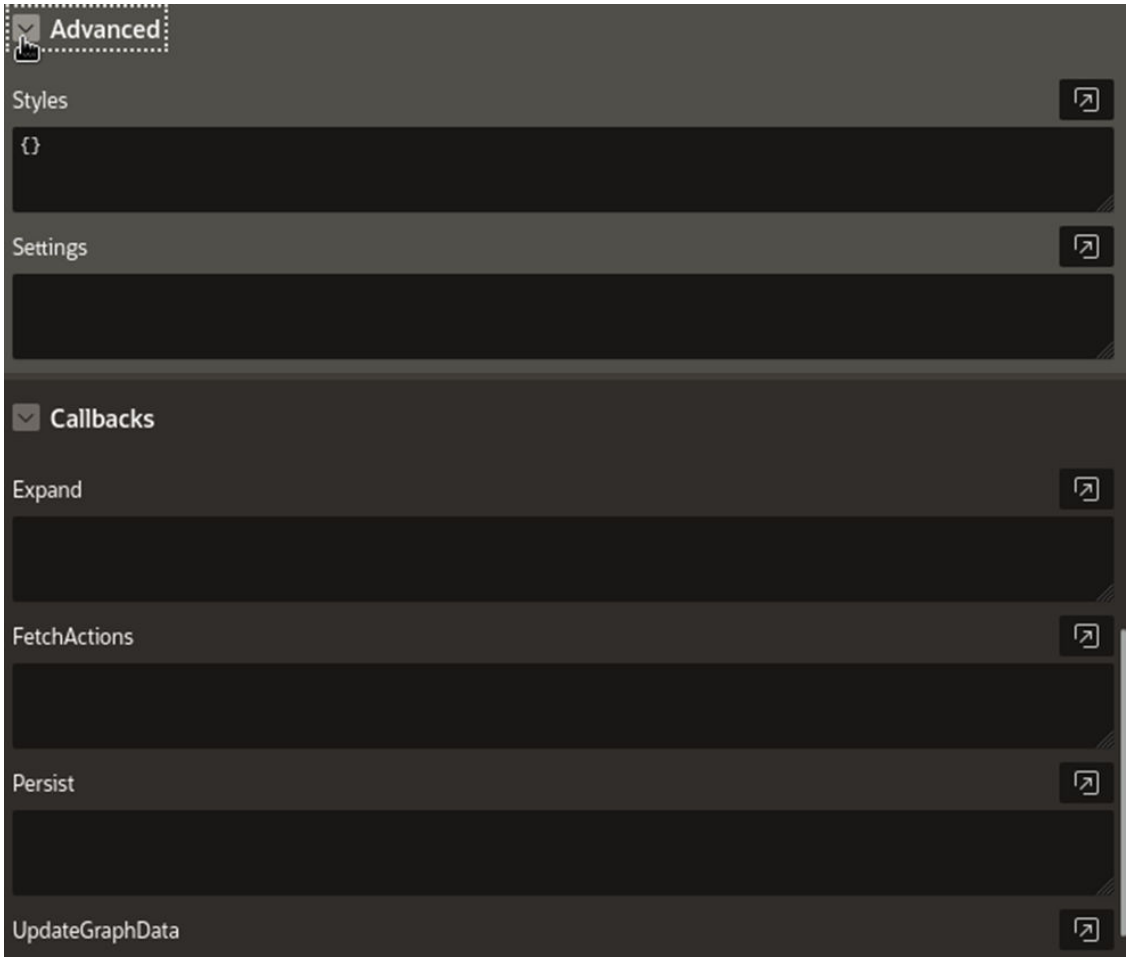
Table 8-7 (Cont.) Evolution Attributes

Attribute	Description
Edge End Property	Select the name of the property to use for the edge filtering. The time frame for the graph will be before the *Edge End Property*.
Exclude Values	Specify one or more values to be excluded.
Show Excluded Values	Enable this toggle if you wish to display the excluded values.
Playback Step	Specify a value to determine how often does the playback advance in ms.
Playback Timeout	Specify a value to determine how many steps are taken per time out during playback.
Preserve Positions	If switched on, network evolution will keep the original vertex positions of the graph during playback.
Axis	Select one of the supported values - *vertices*, *edges*, or *both*.
Label Format	Specify a string that represents the format in which the date must be displayed. Note that the format must include either YYYY, MM, or DD. Otherwise, the format will be ignored.

8.3.6 Advanced and Callbacks Options

The **Advanced** and **Callbacks** panel appear as shown:

Figure 8-7 Advanced and Callbacks Options



The **Advanced** panel allows you to configure custom settings for your graph visualization using the following options:

- **Styles**: You can specify the styles configuration in JSON format. See Styles for more information.
- **Settings**: You can specify the graph settings in JSON format. See Settings for more information.

The **Callbacks** panel comprises the following options:

Table 8-8 Callbacks Attributes

Attribute	Description
Expand	To expand a selected vertex in the graph visualization, see Expand for more information.
FetchActions	To retrieve the graph actions from a data source, refer to fetchActions for more information.
Persist	To persist the graph actions to a data source, refer to persist for more information.
UpdateGraphdata	Callback to handle events when the graph data is updated.

- Styles
  You can style a graph using the **Styles** attribute in the Property Editor of the Page Designer.
- Settings
  You can apply different graph settings such as switching layouts, grouping edges, or showing the evolution of the graph entities based on a property using the **Settings** attribute in the Property Editor of the Page Designer.
- Expand
  You can expand a selected vertex in the graph and fetch the adjacent vertices using the Expand attribute in the Property Editor of the Page Designer.

8.3.6.1 Styles

You can style a graph using the **Styles** attribute in the Property Editor of the Page Designer.

1. Select the graph visualization component in the **Rendering** tab on the left pane of the Page Designer.
2. Select **Attributes** in the Property Editor on the right pane of the Page Designer.
3. Enter the input for styling in JSON format in the **Styles** input box.

   See styles in *Oracle Graph JavaScript API Reference for Property Graph Visualization* for more information on the `Style` interface.
   The following example shows the JSON input to add a vertex style.

```
{
   "vertex":{
      "size":12,
      "label":"${properties.FirstName} ${properties.LastName}",
      "color":"#d5445a",
      "icon":"fa-user"
    }
}
```

> **Note:**
>
> If the JSON input contains styling for properties that are already set in the **Appearance** panel (such as **Vertex Label**, **Edge Label**, or **Maximum Label Length**), then the property values that are provided directly will override the JSON values.

8.3.6.2 Settings

You can apply different graph settings such as switching layouts, grouping edges, or showing the evolution of the graph entities based on a property using the **Settings** attribute in the Property Editor of the Page Designer.

1. Select the graph visualization component in the **Rendering** tab on the left pane of the Page Designer.
2. Select **Attributes** in the Property Editor on the right pane of the Page Designer.
3. Enter the input for the desired action in JSON format in the **Settings** input box in the Settings panel.

See settings in *Oracle Graph JavaScript API Reference for Property Graph Visualization* for more information on the `Settings` interface.
For instance, the following JSON example provides the `layout` and `pageSize` configurations:

```
{
"pageSize": 10,
"layout": "concentric"
}
```

> **Note:**
>
> If the JSON input contains the settings for properties that are already set in the **Appearance** panel (such as **Layout** or **Group Edges**) or **Settings** panel (**Page Size**), then the property values that are provided directly will override the JSON values.

The following JSON example shows a sample configuration for adding network evolution to the graph visualization. The evolution of the graph data is based on the `HireDate` property:

```
{
    "evolution": {
        "chart": "line",
        "unit": "year",
        "vertex": "properties.HireDate"
    }
}
```

8.3.6.3 Expand

You can expand a selected vertex in the graph and fetch the adjacent vertices using the Expand attribute in the Property Editor of the Page Designer.

1. Switch to the **Processing** tab on the left pane of the Page Designer and navigate to the **After Submit** node.
2. Right-click and select **Create Process** from the context menu.
3. Enter the process **Name**.
4. Specify **Type** as **Execute Code**.
5. Select the source **Location** as **Local Database**.
6. Select the source **Language** as **PL/SQL** and enter the following code in the PL/SQL input box.

```
DECLARE data clob;
    id VARCHAR2(100) := apex_application.g_x01;
    graph VARCHAR2(100) := '<graph_name>';
    hops NUMBER := <no_of_hops>;
    n NUMBER := hops - 1;
    match_clause VARCHAR2(100);
    query VARCHAR2(1000);
```

```
BEGIN
    IF n = 0 THEN
        match_clause := ' MATCH (x) -[e]-> (z) ';
    ELSE
        match_clause := ' MATCH (x) ->{,' || n || '} (y) -[e]-> (z) ';
    END IF;

    query := 'SELECT id_x, id_e, id_z
              FROM GRAPH_TABLE (' || graph ||  match_clause  ||
              'WHERE JSON_value(vertex_id(x), ''$.ELEM_TABLE'') ||
json_query(vertex_id(x), ''$.KEY_VALUE'' returning varchar2) = '''|| id
||''''
              COLUMNS (vertex_id(x) as id_x, edge_id(e) as id_e,
vertex_id(z) as id_z))';
    SELECT <helper_function>(query) INTO data FROM sys.dual;
    htp.p(data);
END;
```

In the preceding code:

- <*graph_name*>: Name of the graph
- <*hops*>: Number of hops to be expanded
- <*helper_function*>: Name of the function that provides the `CURSOR` for the SQL graph query as input to the `ORA_SQLGRAPH_TO_JSON` function and obtains the JSON output for visualization.

Note that the process takes the vertex `id` to be expanded as input and returns the resulting output as JSON.

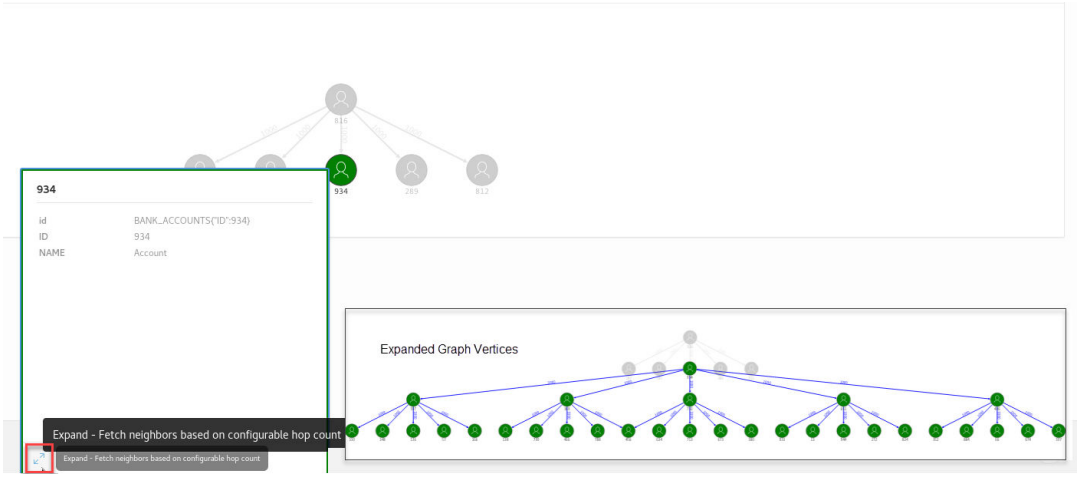
7. Select the execution **Point** as **Ajax Callback**.
8. Switch to the **Rendering** tab on the left pane of the Page Designer and select the graph visualization component.
9. Switch to the **Attributes** tab on the right pane and enter the following code in the **Expand** input box in the **Callbacks** panel.

```
const data = await apex.server.process('<process_name>', {
    x01: ids[0]
}, { dataType: 'text' });
try {
    return JSON.parse(data);
} catch (error) {
    return [];
}
```

In the preceding code, <*process_name*> refers to the name of process that was provided at step-3.

10. Click **Save**.
11. Run the application page and you can now click expand (as shown highlighted in the following figure) on any specific vertex in the graph.

Figure 8-8 Expanding on a Specific Graph Vertex



The inset image in the preceding figure shows the graph with expanded vertices as rendered by the plug-in.

Part III
PGQL Property Graphs

Learn and work with PGQL property graphs (also known as property graph views).

You can work with PGQL property graphs if you are using Oracle Database 23ai or earlier database versions.

- About PGQL Property Graphs
  You can create PGQL property graphs over data stored in Oracle Database. You can perform various graph analytics operations using PGQL on the graphs.
- Loading a PGQL property graph into the Graph Server (PGX)
  You can load a full PGQL property graph or a subgraph into the graph server (PGX).
- Quick Starts for Using PGQL Property Graphs
  This chapter contains quick start tutorials and other resources to help you get started on working with PGQL property graphs.
- 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.
- 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.

9

About PGQL Property Graphs

You can create PGQL property graphs over data stored in Oracle Database. You can perform various graph analytics operations using PGQL on the graphs.

The following sections explain PGQL property graphs in detail:

- Creating PGQL Property Graphs 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 PGQL Property Graph By Importing a GraphSON file
  Using the `GraphImporterBuilder` API, you can create a PGQL property graph 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 PGQL property graph by encoding the vertex and edge properties as a single JSON value. You can then map this to a property value in a PGQL property graph.

9.1 Creating PGQL Property Graphs 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.

PGQL property graphs are created directly over data that exists in the relational database tables. These graphs are stored in the database tables and therefore they have a schema.

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

Metadata Tables for PGQL Property Graphs

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 9-1 are part of the primary key of the table. Also all columns have a `NOT NULL` constraint.

Table 9-1 Metadata Tables for PGQL Property Graphs

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

Table 9-1 (Cont.) Metadata Tables for PGQL Property Graphs

Table Name	Description
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 9-1 To create a PGQL property graph

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_PGQL)
```

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

> **Note:**
>
> - You can create PGQL property graphs using the RDBMS Java API or through SQLcl.
> - You can query PGQL property graphs 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 `student_network` PGQL property graph.

See Executing PGQL Queries Against PGQL Property Graphs for more details to create, query and drop PGQL property graphs.

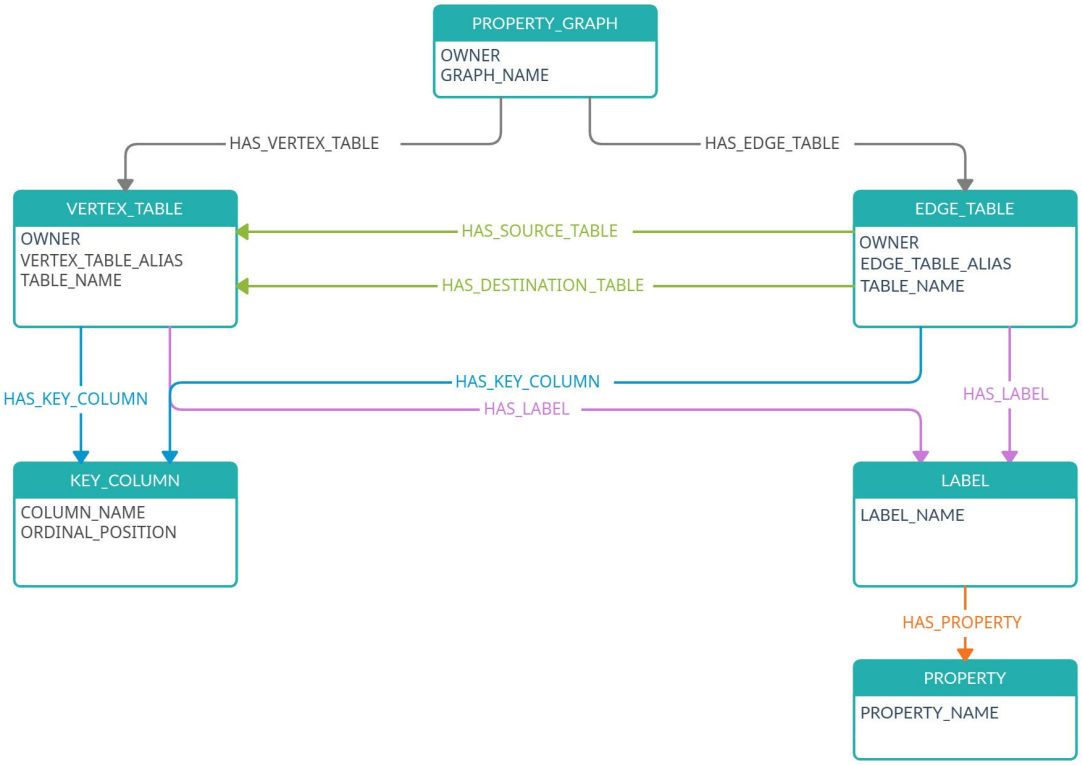
- Retrieving Metadata for PGQL Property Graphs
  You can retrieve the metadata of PGQL property graphs created in the database using the built-in `PROPERTY_GRAPH_METADATA` graph in your PGQL queries.
- Privileges for Working with PGQL Property Graphs
  Learn about the privileges that are required for working with PGQL property graphs.

9.1.1 Retrieving Metadata for PGQL Property Graphs

You can retrieve the metadata of PGQL property graphs 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 9-1 `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 important to note the following when using `PROPERTY_GRAPH_METADATA` in PGQL queries:

- The `PROPERTY_GRAPH_METADATA` graph is automatically created and updated the first time you attempt to access it in a PGQL query.
- The `PROPERTY_GRAPH_METADATA` graph is similar to a PGQL property graph and has its own set of metadata tables that describe its structure. In addition to the metadata tables for PGQL property graphs that are described in Table 9-1, the graph data for `PROPERTY_GRAPH_METADATA` is also stored in database objects that are listed in the following table:

Table 9-2 Additional Metadata Tables

Table Name	Description
PROPERTY_GRAPH_METADATA_GRAPH_LIST$	Metadata table describing the list of PGQL property graphs to which the current user has access
PROPERTY_GRAPH_METADATA_EDGE_KEY_COLUMNS$	Metadata table describing the edge key columns
PROPERTY_GRAPH_METADATA_EDGE_LABELS$	Metadata table describing the edge labels
PROPERTY_GRAPH_METADATA_EDGE_TABLES$	Metadata table describing the edge tables
PROPERTY_GRAPH_METADATA_LABEL_PROPERTIES$	Metadata table describing the vertex and edge label properties
PROPERTY_GRAPH_METADATA_LABELS$	Metadata table describing the vertex and edge labels
PROPERTY_GRAPH_METADATA_VERTEX_KEY_COLUMNS$	Metadata table describing the vertex key columns
PROPERTY_GRAPH_METADATA_VERTEX_LABELS$	Metadata table describing the vertex labels
PROPERTY_GRAPH_METADATA_VERTEX_TABLES$	Metadata table describing the vertex tables

> **Note:**
>
> It is important that you do not alter or remove any of the metadata tables for the `PROPERTY_GRAPH_METADATA` graph.

- 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          |
+---------------+
```

9.1.2 Privileges for Working with PGQL Property Graphs

Learn about the privileges that are required for working with PGQL property graphs.

In order to create PGQL property graphs, ensure that you have the following privileges:

```
CREATE SESSION
CREATE TABLE
```

Note that these privileges can be granted directly to the user:

```
GRANT CREATE SESSION, CREATE TABLE TO <graphuser>
```

Or they can be granted indirectly through an appropriate role:

```
GRANT CREATE SESSION, CREATE TABLE TO GRAPH_DEVELOPER
```

For loading a PGQL property graph created by another user into the graph server (PGX), you must have:

- `SELECT` permission on the underlying source database tables or views.
- `SELECT` permission on the metadata tables used by the PGQL property graph. See Table 9-1 and Table 9-2 for more details on the metadata tables.

9.2 Creating a PGQL Property Graph By Importing a GraphSON file

Using the `GraphImporterBuilder` API, you can create a PGQL property graph 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 PGQL property graph 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_PGQL).
...>     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_PGQL)
    .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_pgql',
...       '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_PGQL )"
```

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_PGQL).
...>     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_PGQL)
     .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 9-7 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.

9.2.1 Additional Information on the GraphImporter Parameters

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

Table 9-3 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 9-4 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

Table 9-4 (Cont.) GraphImporter Configuration Parameters

Parameter	Description	Setter in API	Default Value	Optional
`outFormat`	Output format for the importer	`setOutputFormat`	`GraphImportOutputFormat.PG_PGQL`	Yes
`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 9-5 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.	`setStringFieldSize`	`100`	Yes
`fractionalSecondsPrecision`	The fractional seconds precision parameter found in `TIMESTAMP` data type in the Oracle Database.	`setFractionalSecondsPrecision`	`6`	Yes

Table 9-6 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 9-6 (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

9.2.2 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 9-7 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`.

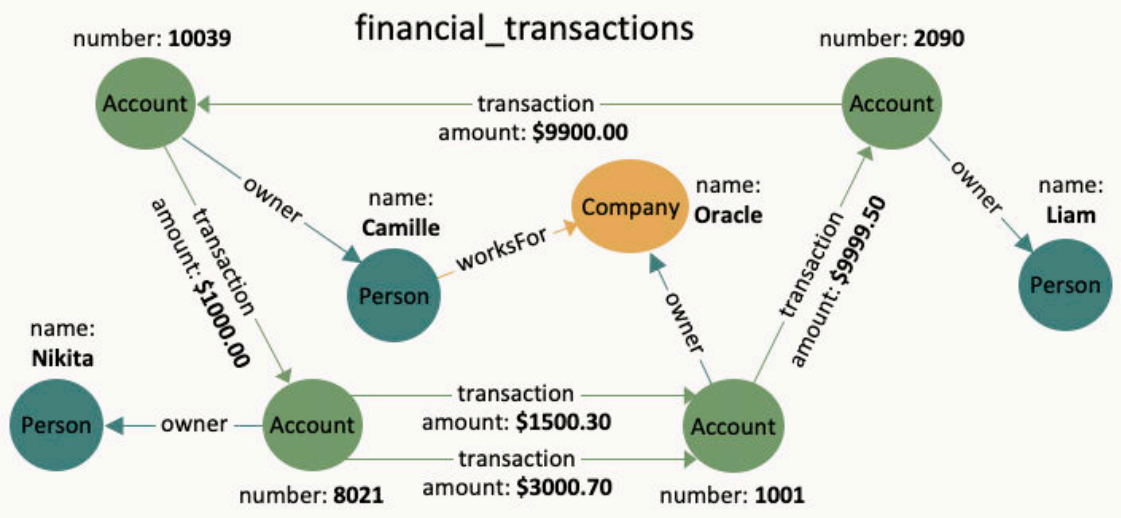
9.3 Using JSON to Store Vertex and Edge Properties

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

PGQL property graphs 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 PGQL property graphs.

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 9-2 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 9-2 Extracting JSON properties using JSON_VALUE (PGQL on RDBMS)

The following code creates a PGQL property graph 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_PGQL )");

/* 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 9-3 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_PGQL);

/* 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      |
+-----------------------------------------+
```

10

Loading a PGQL property graph into the Graph Server (PGX)

You can load a full PGQL property graph or a subgraph into the graph server (PGX).

> **Note:**
>
> Ensure that you drop the graph when it is no longer in use to release the graph server (PGX) memory. See Deleting a Graph for more information.

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

- Loading a PGQL Property Graph Using the readGraphByName API
  You can load a PGQL property graph by name into the graph server (PGX).
- Loading a Graph Using a JSON Configuration File
  To load a PGQL property graph into the graph server (PGX), you can create a graph configuration file, which contains the graph metadata 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 a PGQL Property Graph
  You can create a subgraph from a PGQL property graph and load it into memory in the graph server (PGX).

10.1 Loading a PGQL Property Graph Using the readGraphByName API

You can load a PGQL property graph by name into the graph server (PGX).

You can use the `PgxSession#readGraphByName` API to load a PGQL property graph:

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

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

Table 10-1 Parameters for the `readGraphByName` method

Parameter	Description	Optional
`schemaName`	Schema owner	Yes
`graphName`	Name of the PGQL property graph	No

Table 10-1 (Cont.) Parameters for the `readGraphByName` method

Parameter	Description	Optional
`source`	Source format for the graph: • **`GraphSource.PG_PGQL`**: This applies for PGQL property graphs. • **`GraphSource.PG_SQL`**: This applies for SQL Property Graphs (refer to Loading a SQL Property Graph Using the readGraphByName API).	No
`options`	Represents the graph optimization options	Yes

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

- JShell
- Java
- Python

JShell

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

Java

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

Python

```
>>> graph = session.read_graph_by_name('BANKDATA', 'pg_pgql')
>>> graph
PgxGraph(name: bankdata, v: 1000, e: 5001, directed: True, memory(Mb): 0)
```

The `readGraphByName()` method also allows loading of a PGQL property graph from database tables with CLOB data type columns.

- Specifying Options for the readGraphByName API
  You can specify graph optimization options, `OnMissingVertexOption` or both when using the `readGraphByName` API for loading a PGQL property graph.

- Specifying the Schema Name for the readGraphByName API
  You can specify the schema name when using the `readGraphByName` API for loading a PGQL property graph.

> **See Also:**
>
> Mapping Oracle Database Types to PGX Types for more information on the supported types in the graph server (PGX)

10.1.1 Specifying Options for the `readGraphByName` API

You can specify graph optimization options, `OnMissingVertexOption` or both when using the `readGraphByName` API for loading a PGQL property graph.

The ReadGraphOption interface supports an additional `options` parameter when loading a PGQL property graph by name.

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

Using the Graph Optimization Options

The optimization strategy determines whether the graph is optimized for read-intensive scenarios or for faster updates. It impacts the performance characteristics of graph operations such as querying and updating.

The supported graph optimization `options` are:

- **`ReadGraphOption.optimizeFor(GraphOptimizedFor.READ):`** You can choose this option when the primary operations on the graph are read-based, and updates are infrequent or non-existent.
  When this strategy is selected, the graph's data structures are replicated whenever a new graph or graph snapshot is created. This results in faster and more efficient read operations, such as traversals and queries. However, creating snapshots can be expensive and it can also lead to performance overhead and increased memory usage during updates.
- **`ReadGraphOption.optimizeFor(GraphOptimizedFor.UPDATES):`** You can choose this option when the graph is expected to undergo frequent updates, such as adding or removing nodes and edges, or modifying properties of existing elements.
  When this strategy is selected, delta logs are used to manage updates. This approach makes updates more memory-efficient and faster. However, there may be some time overhead when querying the graph due to the need to apply these delta updates.
- **`ReadGraphOption.synchronizable():`** You can choose this option when the graph is expected to 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 PGQL property graph for `SYNCHRONIZABLE` option, then ensure that the vertex and edge keys are numeric and non-composite.

The following example loads a PGQL property graph for `READ` and `SYNCHRONIZABLE` options:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("BANK_GRAPH", GraphSource.PG_PGQL,
...>
ReadGraphOption.optimizeFor(GraphOptimizedFor.READ),
...>                              ReadGraphOption.synchronizable())
graph ==> PgxGraph[name=BANK_GRAPH_2,N=1000,E=5001,created=1648457198462]
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_GRAPH", GraphSource.PG_PGQL,

ReadGraphOption.optimizeFor(GraphOptimizedFor.READ),

ReadGraphOption.synchronizable());
```

Python

```
>>> graph = session.read_graph_by_name('BANK_GRAPH',
...      'pg_pgql', options=['optimized_for_read', '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 PGQL property graph 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
- Python

JShell

```
opg4j> session.readGraphByName("REGIONS", GraphSource.PG_PGQL,
...>
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_PGQL,
ReadGraphOption.onMissingVertex(OnMissingVertex.IGNORE_EDGE_LOG_ONCE));
```

Python

```
>>> graph = session.read_graph_by_name('REGIONS',
...      'pg_pgql', options=['on_missing_vertex_ignore_edge_log_once'])
```

10.1.2 Specifying the Schema Name for the readGraphByName API

You can specify the schema name when using the `readGraphByName` API for loading a PGQL property graph.

This feature allows you to load a PGQL property graph 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 PGQL property graph from another schema.

The following example loads a PGQL property graph from the `GRAPHUSER` schema:

- JShell
- Java

JShell

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

Java

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

10.2 Loading a Graph Using a JSON Configuration File

To load a PGQL property graph into the graph server (PGX), you can create a graph configuration file, which contains the graph metadata to be loaded.

The following shows a sample JSON configuration file:

```
{
  "name": "BANK_GRAPH",
  "source_name": "BANK_GRAPH",
  "source_type": "pg_pgql",
  "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 the 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 24.4.0
```

```
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

10.2.1 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 10-2 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.

10.3 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 PGQL property graph 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_PGQL).
...>                  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_ACCO
UNTS")
                                                .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_I
D")
                                                .setSourceVertexProvider("Accoun
t")
                                                .setDestinationVertexProvider("A
ccount")
                                                .setParallelHintDegree(3)
                                                .createKeyMapping(true)
                                                .setDatabaseTableName("BANK_TXNS
")
                                                .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:1521/
orclpdb")
                            .setUsername("graphuser")
                            .setPassword("<password>")
                            .setName("bank_graph")
                            .setSourceName("bank_graph")
                            .setSourceType(SourceType.PG_PGQL)
                            .setVertexIdType(IdType.INTEGER)
                            .addVertexProvider(vertexConfig)
                            .addEdgeProvider(edgeConfig)
                            .build();
```

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

> **See Also:**
>
> Configuring PARALLEL Hint when Loading a Graph

10.4 Loading a Subgraph from a PGQL Property Graph

You can create a subgraph from a PGQL property graph 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#fromPgPgql` API to create an in-memory subgraph from a PGQL property graph using a set of PGQL queries.
- Prepared PGQL Queries
  You can also use prepared queries when loading a subgraph from a PGQL property graph.
- Providing Database Connection Credentials
  You can specify the database connection credentials with the `PgViewSubgraphReader#fromPgPgql` 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.

10.4.1 PGQL Based Subgraph Loading

You can use the `PgViewSubgraphReader#fromPgPgql` API to create an in-memory subgraph from a PGQL property graph 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 PGQL property graph.
> - Loading a subgraph with properties mapped to CLOB data type is supported.

The following example creates a subgraph from a PGQL property graph using multiple PGQL queries:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readSubgraph().
...>                     fromPgPgql("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

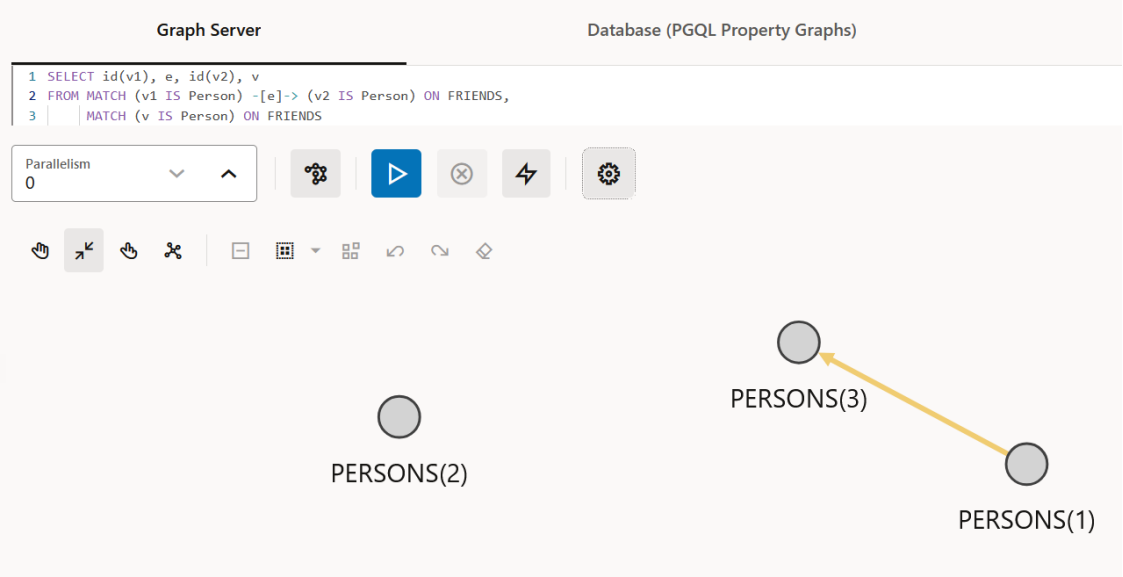
```
PgxGraph graph = session.readSubgraph()
                        .fromPgPgql("FRIENDS")
                        .queryPgql("MATCH (v1:Person)-[e:FRIENDOF]-
>(v2:Person) WHERE id(v1) = 'PERSONS(1)'")
                        .queryPgql("MATCH (v:Person) WHERE id(v) =
'PERSONS(2)'")
                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

Python

```
>>> graph = session.read_subgraph_from_pg_pgql("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 10-1 Subgraph Visualization



Loading Subgraphs with Custom Names

By default, the new subgraph gets created with the same name as the PGQL property 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().
...>                   fromPgPgql("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()
                        .fromPgPgql("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_pgql("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 PGQL property graph from another schema, you can additionally provide the schema name as an argument to the `PgViewSubgraphReader#fromPgPgql` API . You must also ensure that you have `READ` permission on all the underlying metadata and data tables for the PGQL property graph.

For example:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readSubgraph()
...> .fromPgPgql("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()
                        .fromPgPgql("GRAPHUSER", "FRIENDS")
                        .queryPgql("MATCH (v:Person) WHERE id(v) =
'PERSONS(2)'")
                        .load();
```

Python

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

10.4.2 Prepared PGQL Queries

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

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().
...>                                      fromPgPgql("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().fromPgPgql("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_pgql("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)
```

10.4.3 Providing Database Connection Credentials

You can specify the database connection credentials with the `PgViewSubgraphReader#fromPgPgql` 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().
...>                       fromPgPgql("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()
                        .fromPgPgql("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();
```

10.4.4 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().
...>           fromPgPgql("FRIENDS").
...>           queryPgql("MATCH (v1:PERSON) -[e:FRIENDOF]-> (v2:PERSON) WHERE
id(v1) = 'PERSONS(2)'").
...>           queryPgql("MATCH (v:PERSON) WHERE id(v) = 'PERSONS(4)'").
...>           expand()
graph ==> PgxGraph[name=anonymous_graph_152,N=4,E=3,created=1647347092964]
```

Java

```
graph = graph.expandGraph()
             .withPgql()
             .fromPgPgql("FRIENDS")
             .queryPgql("MATCH (v1:PERSON) -[e:FRIENDOF]-> (v2:PERSON) WHERE
id(v1) = 'PERSONS(2)'")
             .queryPgql("MATCH (v:PERSON) WHERE id(v) = 'PERSONS(4)'")
             .expand();
```

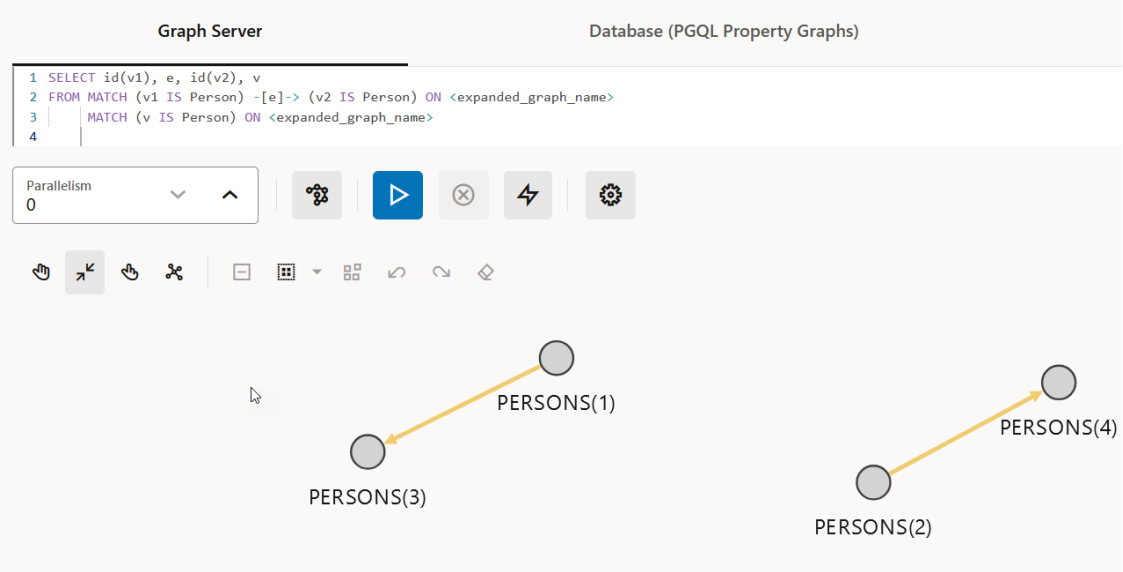
Python

```
>>> 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)'",
...                "MATCH (v:Person) WHERE id(v)= '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 10-2 Expanding a Subgraph



Expanding a Subgraph by Explicitly Specifying the Schema Name

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

For example:

- JShell
- Java
- Python

JShell

```
opg4j> graph = graph.expandGraph().
...>           withPgql().
...>           fromPgPgql("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()
             .fromPgPgql("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().
...>           fromPgPgql("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()
             .fromPgPgql("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_WIT
H_NEW_VALUES)
             .expand();
```

11
Quick Starts for Using PGQL Property Graphs

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

- Using Sample Data for Graph Analysis
- Quick Start: Working with PGQL Property Graphs
  This tutorial helps you get started on creating, querying and executing graph algorithms on PGQL property graphs.
- Quick Start: Using Graph Machine Learning on PGQL Property Graphs
  This tutorial helps you get started on applying the DeepWalk machine learning algorithm on a PGQL property graph.
- 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.

11.1 Using Sample Data for Graph Analysis

The rpm installation of the graph server provides you with sample graph data which can be used for graph analysis. You can access this sample graph data either in `/opt/oracle/graph/data` or `<client_dir>/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

11.1.1 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.

11.2 Quick Start: Working with PGQL Property Graphs

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

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 24.4.0
```

Python

```
cd /opt/oracle/graph
./bin/opg4py --no_connect
Oracle Graph Server Shell 24.4.0
```

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;

// Get a jdbc connection
String jdbcUrl="jdbc:oracle:thin:@"+<host>+":"+<port>+"/"+<service>;
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 PGQL property graph using the `CREATE PROPERTY GRAPH` statement:

- JShell
- Java
- Python

JShell

```
opg4j> String 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 (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_PGQL) "
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_PGQL)";

    pgqlStmt.execute(pgql);
```

Python

```
>>> 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 (ID)
...             DESTINATION KEY (TO_ACCT_ID) REFERENCES BANK_ACCOUNTS (ID)
...             LABEL TRANSFERS
...             PROPERTIES (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT, DESCRIPTION)
...         ) OPTIONS(PG_PGQL)
... """
>>> pgql_statement.execute(pgql)
False
```

The graph 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 "
...> + "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 " +
        "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
... 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",GraphSource.PG_PGQL)
graph ==> PgxGraph[name=BANK_GRAPH,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",GraphSource.PG_PGQL);
```

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', 'pg_pgql')
>>> graph
PgxGraph(name: BANK_GRAPH, 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]
```

Java

```
Analyst analyst = session.createAnalyst();
analyst.pagerank(graph);
```

Python

```
>>> analyst = session.create_analyst()
>>> analyst.pagerank(graph)
VertexProperty(name: pagerank, type: double, graph: BANK_GRAPH)
```

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 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,numResults=10]
```

Java

```
String pgQuery = "SELECT a.id, a.pagerank FROM MATCH (a) ON BANK_GRAPH
ORDER BY a.pagerank DESC LIMIT 10";
session.queryPgql(pgQuery).print();
```

Python

```
>>> pgql = "SELECT a.id, a.pagerank FROM MATCH (a) ON BANK_GRAPH 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  |
+-----------------------------+
```

11.3 Quick Start: Using Graph Machine Learning on PGQL Property Graphs

This tutorial helps you get started on applying the DeepWalk machine learning algorithm on a PGQL property graph.

The instructions assume that the PGQL property graph is already existing in your current database.

Run the following steps to build and work with a Deep Walk model.

1. Load the PGQL property graph into the graph server (PGX).

- 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=5af9c362-10a3-4a7c-953c-602553d4606b,source=mySession]
opg4j> var graph =
session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL)
graph ==> PgxGraph[name=BANK_GRAPH,N=1000,E=4997,created=1684315831352]
```

Java

```
ServerInstance instance = GraphServer.getInstance("https://
localhost:7007", "<username>", "<password>".toCharArray());
PgxSession session = instance.createSession("my-session");
PgxGraph graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL);
```

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", "pg_pgql")
>>> graph
PgxGraph(name: BANK_GRAPH, v: 1000, e: 4997, directed: True, memory(Mb): 0)
```

2. Build a Deep Walk model using customized hyper-parameters as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var model = session.createAnalyst().deepWalkModelBuilder().
...>                 setMinWordFrequency(1).
...>                 setBatchSize(512).
...>                 setNumEpochs(1).
...>                 setLayerSize(100).
...>                 setLearningRate(0.05).
...>                 setMinLearningRate(0.0001).
...>                 setWindowSize(3).
...>                 setWalksPerVertex(6).
...>                 setWalkLength(4).
...>                 setNegativeSample(2).
...>                 build()
model ==> oracle.pgx.api.mllib.DeepWalkModel@6e0f259e
```

Java

```
import oracle.pgx.api.mllib.DeepWalkModel;
DeepWalkModel model= session.createAnalyst().deepWalkModelBuilder()
        .setMinWordFrequency(1)
        .setBatchSize(512)
        .setNumEpochs(1)
        .setLayerSize(100)
        .setLearningRate(0.05)
        .setMinLearningRate(0.0001)
        .setWindowSize(3)
        .setWalksPerVertex(6)
        .setWalkLength(4)
        .setNegativeSample(2)
        .build();
```

Python

```
>>> model = session.create_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,
...                                   negative_sample= 2)
```

3. Train the Deep Walk model as shown:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(graph)
```

Java

```
model.fit(graph);
```

Python

```
>>> model.fit(graph)
```

4. Get the loss value as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var loss = model.getLoss()
loss ==> -2.097562355629634E-5
```

Java

```
double loss = model.getLoss();
```

Python

```
>>> loss = model.loss
>>> loss
-2.0706271243398078e-05
```

5. Compute similar vertices as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var similars = model.computeSimilars("ACCOUNTS(280)",10)
batchSimilars ==> oracle.pgx.api.frames.internal.PgxFrameImpl@308e465b
opg4j> batchSimilars.print()
```

Java

```
import oracle.pgx.api.frames.*;

PgxFrame similars = model.computeSimilars("ACCOUNTS(280)", 10);
similars.print();
```

Python

```
>>> similars = model.compute_similars("ACCOUNTS(280)",10)
>>> similars.print()
```

The example produces a similar output:

```
+-------------------------------------+
| dstVertex     | similarity          |
+-------------------------------------+
| ACCOUNTS(280) | 1.0                 |
| ACCOUNTS(486) | 0.3253505229949951  |
| ACCOUNTS(615) | 0.2806776463985443  |
| ACCOUNTS(660) | 0.27348122000694275 |
| ACCOUNTS(737) | 0.2734076678752899  |
| ACCOUNTS(368) | 0.2707795202732086  |
| ACCOUNTS(479) | 0.27019545435905457 |
| ACCOUNTS(845) | 0.2618815004825592  |
| ACCOUNTS(834) | 0.2543807625770569  |
| ACCOUNTS(249) | 0.24260951578617096 |
+-------------------------------------+
```

6. Get all trained vectors and store them in a database table as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var vertexVectors = model.getTrainedVertexVectors().flattenAll()
vertexVectors ==> oracle.pgx.api.frames.internal.PgxFrameImpl@46cb9794
opg4j>
vertexVectors.write().db().name("deepwalkframe").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("vertex_vectors"). \
...         overwrite(True). \
...         store()
```

7. Store the trained model in the database as shown:

- JShell
- Java
- Python

JShell

```
opg4j> model.export().db().
...>   modelstore("bank_model").
...>   modelname("model").
...>   description("DeepWalk Model for Bank data").
...>   store()
```

Java

```
model.export().db()
  .modelstore("bank_model")
  .modelname("model2")
  .description("DeepWalk Model for Bank data")
  .store();
```

Python

```
>>> model.export().db(model_store="bank_model",
...                   model_name="model",
...                   model_description="DeepWalk Model for Bank data")
```

8. Load a pre-trained model from the database as shown:

- JShell
- Java
- Python

JShell

```
opg4j> session.createAnalyst().loadDeepWalkModel().db().
...>   modelstore("bank_model").
...>   modelname("model").
...>   load()
```

Java

```
model = session.createAnalyst().loadDeepWalkModel().db()
  .modelstore("bank_model")
  .modelname("model")
  .load();
```

Python

```
>>> model =
session.create_analyst().get_deepwalk_model_loader().db(model_store="bank_m
odel",
...                                          model_name="model")
```

9. Destroy the model as shown:

- JShell
- Java
- Python

JShell

```
opg4j> model.destroy()
```

Java

```
model.destroy();
```

Python

```
>>> model.destroy()
```

See Using the Machine Learning Library (PgxML) for Graphs for more information on the supported machine learning algorithms.

11.4 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 (ID)
            DESTINATION KEY (to_acct_id) REFERENCES bank_accounts (ID)
            LABEL TRANSFERS
            PROPERTIES (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT, DESCRIPTION)
        ) OPTIONS(PG_PGQL)
"""
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_pgql')
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.

11.5 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.

12

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 PGQL property graphs through Python.
- Additional Client Tools for Querying PGQL Property Graphs
  When working with PGQL property graphs 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.

12.3 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 Running the Graph Visualization Web Client.

Related Topics

- Graph Visualization Application
  The Graph Visualization application enables interactive exploration and visualization of property graphs. You can visualize graphs that are loaded into the graph server(PGX) and the graphs stored in the database.

12.4 Using the Jupyter Notebook Interface

You can use the Jupyter notebook interface to create, load, and query PGQL property graphs through Python.

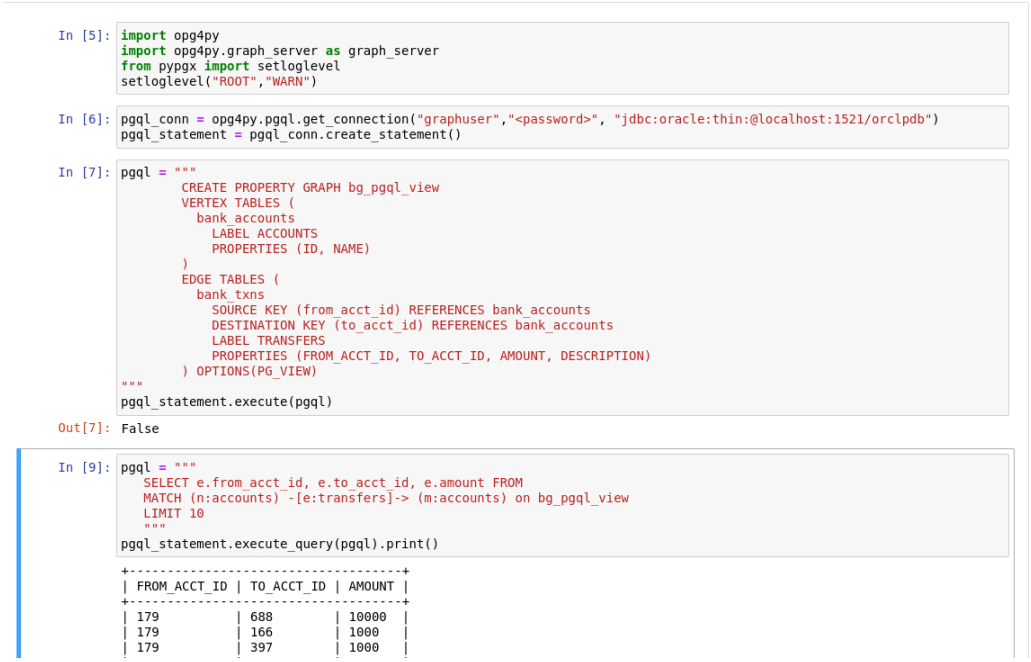
Perform the following steps to perform graph analysis using Jupyter Notebook:

1. Install the Jupyter Notebook application following the Jupyter documentation. The following example installs Jupyter with pip:

   ```
   pip3 install --user jupyter
   ```

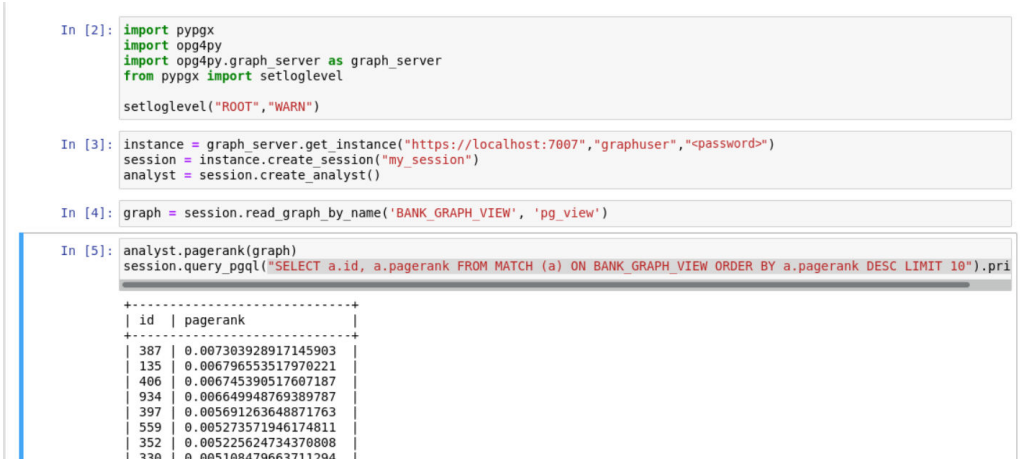
2. Ensure that your Jupyter installation is added to the `PATH` environment variable.
3. Run the notebook server using the `jupyter notebook` command.
4. Launch the web application using the generated URL and open a new notebook.
5. Create and analyse a property graph.
   - The following example shows creating a PGQL property graph and running graph queries:

Figure 12-1 Creating a PGQL property graph in Jupyter Notebook



   - The following example shows loading the PGQL property graph into the graph server (PGX) and running graph algorithms for analysis:

Figure 12-2 Running Graph Algorithms in Jupyter Notebook



12.1 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

12.1.1 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 24.4.0
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 24.4.0
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
```

12.1.2 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 these prerequisites. 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 24.4.0
>>>
```

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 24.4.0
>>>
```

12.2 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 PGQL property 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 with the `AdbGraphClient` using one of the following methods:

   Configuring the `AdbGraphClient` using Tenancy Details

   - JShell
   - Java
   - Python

JShell

```
cd /opt/oracle/graph
./bin/opg4j --no_connect
For an introduction type: /help intro
Oracle Graph Server Shell 24.4.0
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 24.4.0
>>> 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)
```

Configuring the `AdbGraphClient` using JDBC Connection

You can also configure the `AdbGraphClient` to use a JDBC connection to connect to your Autonomous Database instance (as shown in the following code). See Connect with JDBC Thin Driver in *Using Oracle Autonomous Database Serverless* on how to obtain the JDBC URL to connect to the Autonomous Database.

However, ensure that you have `READ` access to the `v$pdbs` view in your Autonomous Database instance. By default, the ADMIN user has `READ` access to the `v$pdbs` view. For all other users (non-administrator users), the `READ` access can be granted by the ADMIN (`GRANT SELECT ON v$pdbs TO <user>`).

- JShell
- Java
- Python

JShell

```
import oracle.pg.rdbms.*
opg4j> var conn = DriverManager.getConnection(<jdbcUrl>, <username>,
<password>)
opg4j> var config = AdbGraphClientConfiguration.fromConnection(conn,
<password>)
opg4j> var client = new AdbGraphClient(config)
```

Java

```
import oracle.pg.rdbms.*;
AdbGraphClientConfiguration config =
AdbGraphClientConfiguration.fromCredentials(<jdbcUrl>, <username>,
<password>);
AdbGraphClient client = new AdbGraphClient(config);
```

Python

```
>>> from opg4py.adb import AdbClient
>>> client = AdbClient.from_connection(<jdbcUrl>, <username>, <password>)
```

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 PGQL property graph from your Autonomous Database instance into memory.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("BANK_GRAPH",
GraphSource.PG_PGQL)
graph ==> PgxGraph[name=BANK_GRAPH,N=1000,E=5001,created=1647800790654]
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_GRAPH",
GraphSource.PG_PGQL);
```

Python

```
>>> graph = session.read_graph_by_name("BANK_GRAPH", "pg_pgql")
```

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
- Using the PGX JDBC Driver with the AdbGraphClient API
  Starting from Graph Server and Client Release 24.1.0, you can use the PGX JDBC driver with the `AdbGraphClient` API to query graphs stored in the memory of the graph server in Graph Studio on Autonomous Database.

12.2.1 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 information if you are configuring the `AdbGraphClient` using the tenancy details. Otherwise, skip this step.

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.
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 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 PGQL property graph.
- Download, install and start the Oracle Graph Java or Python client.

12.2.2 Using the PGX JDBC Driver with the AdbGraphClient API

Starting from Graph Server and Client Release 24.1.0, you can use the PGX JDBC driver with the `AdbGraphClient` API to query graphs stored in the memory of the graph server in Graph Studio on Autonomous Database.

To use the PGX JDBC driver to connect to your Autonomous Database instance, note the following:

- Register the PGX JDBC driver with the DriverManager:

```
import java.sql.DriverManager;
import oracle.pgx.jdbc.PgxJdbcDriver;
...
DriverManager.registerDriver(new PgxJdbcDriver());
```

- Use one of the following two ways to establish the connection using the PGX JDBC Driver:
  - **Using Properties**

```
properties = new Properties();
properties.put("tenancy_ocid", "<tenancy_OCID>");
properties.put("database_ocid", "<database_OCID>");
properties.put("database", "<database_name>");
properties.put("username", "<username>");
properties.put("password", "<password>");
Connection connection =
DriverManager.getConnection("jdbc:oracle:pgx:https://<hostname-
prefix>.adb.<region>.oraclecloudapps.com", properties);
```

  - **Using a Wallet**

```
Connection connection =
DriverManager.getConnection("jdbc:oracle:pgx:@<db_TNS_name>?
TNS_ADMIN=<path_to_wallet>", "<ADB_username>", "<ADB_password>")
```

  Note that the JDBC URL in the preceding code samples, use `jdbc:oracle:pgx:` as the prefix.

Example 12-1 Using the PGX JDBC Driver to run graph queries in Autonomous Database

The following example establishes a connection using the PGX JDBC driver to connect to an Autonomous Database instance, starts the compute environment in Graph Studio, loads a graph into the graph server (PGX), creates a statement, and runs a PGQL query on the graph.

```
import java.sql.*;
import oracle.pgx.jdbc.*;
import oracle.pg.rdbms.*;
import oracle.pgx.api.*;

public class AdbPgxJdbc {

  public static void main(String[] args) throws Exception {

    DriverManager.registerDriver(new PgxJdbcDriver());
```

```
    try (Connection conn =
DriverManager.getConnection("jdbc:oracle:pgx:@<db_TNS_name>?
TNS_ADMIN=<path_to_wallet>","ADB_username","<ADB_password>")) {
      AdbGraphClient client = conn.unwrap(AdbGraphClient.class);
      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());
        }
      PgxSession session = conn.unwrap(PgxSession.class);
      PgxGraph graph = session.readGraphByName("BANK_PGQL_GRAPH",
GraphSource.PG_PGQL);
      Statement stmt = conn.createStatement();
      ResultSet rs = stmt.executeQuery("SELECT * "+
                                       "FROM GRAPH_TABLE ( BANK_PGQL_GRAPH
"+
                                       "MATCH (a IS ACCOUNTS) -[e IS
TRANSFERS]-> (b IS ACCOUNTS) "+
                                       "WHERE a.ID = 179 AND b.ID = 688 "+
                                       "COLUMNS (e.AMOUNT AS AMOUNT ))");
      while(rs.next()){
        System.out.println("AMOUNT = " + rs.getLong("AMOUNT"));
      }

    }
  }
}
```

The resulting output of the preceding code is as shown:

```
AMOUNT = 7562
```

Related Topics

- PGX Data Type Compatibility and Casting
  You can configure a compatibility mode for the PGX JDBC driver to determine the data type returned when calling the `ResultSet#getObject()` method.
- Limitations of the PGX JDBC Driver
  Review the limiations of the PGX JDBC driver.

12.5 Additional Client Tools for Querying PGQL Property Graphs

When working with PGQL property graphs in the database, you can use other supported client tools.

- Using Oracle SQLcl
  You can access the graph in the database using SQLcl.
- Using SQL Developer with PGQL Property Graphs
  Using SQL Developer 23.1, you can view all the PGQL property graphs existing in your database schema by expanding **PGQL Property Graphs** under the **Property Graph** node in the **Connections** navigator.

12.5.1 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 PGQL property graph 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 PGQL property graph 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_PGQL);

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.

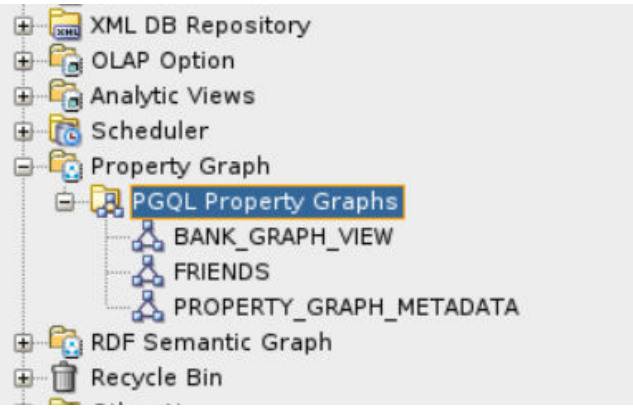
```
PGQL> DROP PROPERTY GRAPH bank_graph;

Graph dropped
```

Also, see Execute PGQL Queries in SQLcl for more information.

12.5.2 Using SQL Developer with PGQL Property Graphs

Using SQL Developer 23.1, you can view all the PGQL property graphs existing in your database schema by expanding **PGQL Property Graphs** under the **Property Graph** node in the **Connections** navigator.

Figure 12-3 PGQL Property Graphs in SQL Developer



The following steps show a few examples for working with PGQL property graphs using SQL Developer.

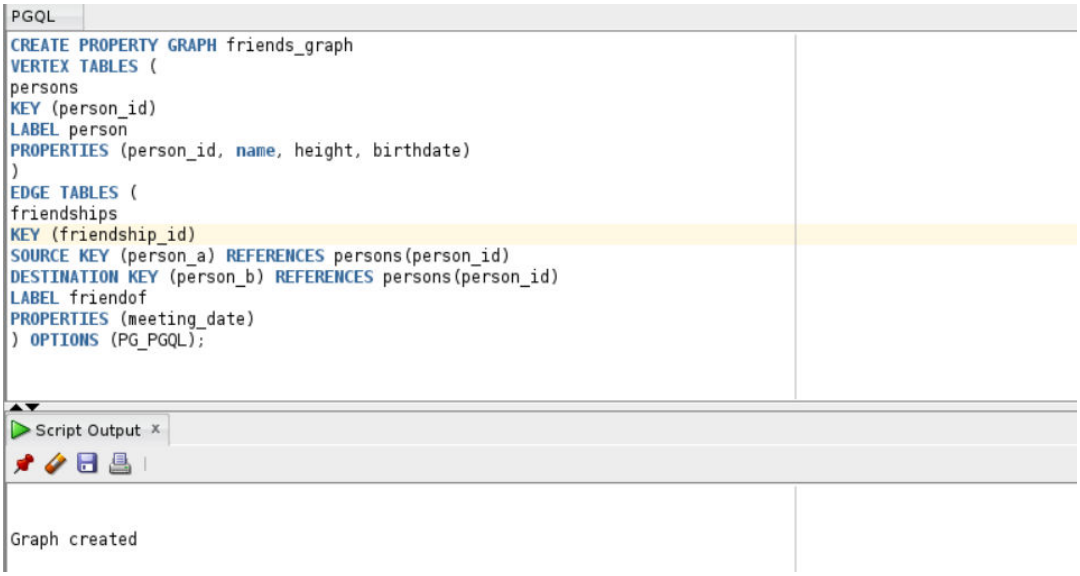
1. Right-click the **Property Graph** node and select **Open PGQL Worksheet**.

   PGQL Worksheet opens in a new tab and it supports the following actions:

   - **Run Query:** To run a single PGQL query
   - **Run Script:** To run multiple PGQL queries

2. Create a PGQL property graph by running a `CREATE PROPERTY GRAPH` statement in the PGQL Worksheet. For example:

Figure 12-4 Create a PGQL property graph



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 **PGQL Property Graphs** object to view the newly created graph under **PGQL Property Graphs**.

3. Click on the newly created graph.

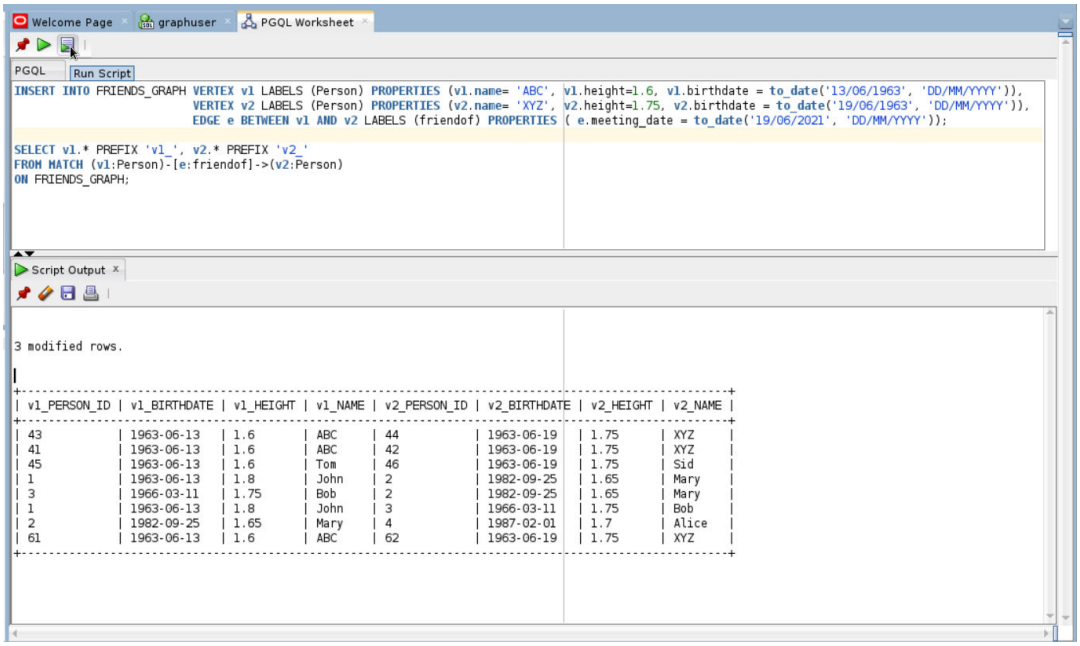
   This opens a **PGQL Worksheet** in a new tab with the following default query:

   ```
   SELECT e, v, n FROM MATCH (v)-[e]-(n) ON <graph_name> LIMIT 100
   ```

4. Run one or more PGQL queries.

   For example, the following shows the execution of PGQL `INSERT` and `SELECT` queries:

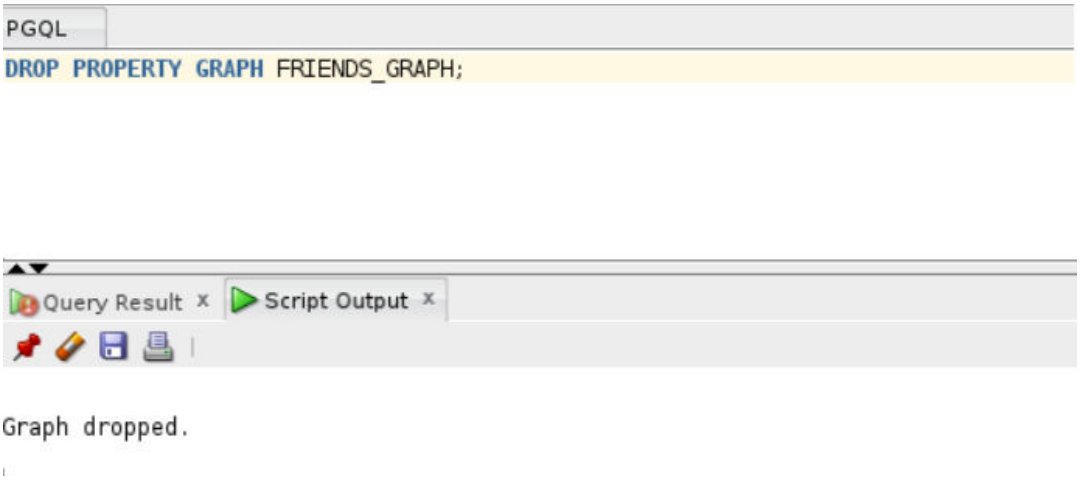
Figure 12-5 Running Multiple PGQL Queries



You can view the results in the **Script Output** tab.

5. Delete the PGQL property graph as shown:

Figure 12-6 Dropping a PGQL Property Graph



The graph is dropped.

13
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) 24.4.0 supports PGQL 2.0 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 PGQL Property Graphs and Executing PGQL Queries Against SQL Property Graphs for more information.

For more information about PGQL, see the PGQL Specification.

- Creating a Property Graph Using PGQL
- Pattern Matching with PGQL
- Edge Patterns Have a Direction with PGQL
- Vertex and Edge Labels with PGQL
- Variable-Length Paths with PGQL
- Aggregation and Sorting with PGQL
- Executing PGQL Queries Against PGQL Property Graphs
  This topic explains how you can execute PGQL queries directly against PGQL property graphs on Oracle Database tables.

13.1 Creating a Property Graph Using PGQL

`CREATE PROPERTY GRAPH` is a PGQL DDL statement to create a PGQL property graph 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.

Optionally, you can also create a PGQL property graph from existing graphs. See Creating a PGQL Property Graph with the `BASE_GRAPHS` Clause for more information.

> **Note:**
>
> The following best practices are recommended when creating a PGQL property graph:
>
> - Ensure that a primary key constraint exist for a vertex or an edge key so that the graph does not contain duplicate vertex or edge keys.
> - Ensure that a foreign key constraint exists between the edge and the referenced vertex tables so that the graph does not contain edges with missing vertices.
> - Run the `pg.validate()` function after creating the graph to verify that the vertex and edge table keys are unique and the source and destination of the edges exist.
>
> ```
> pgqlStmt.execute("CALL pg.validate('<graph_name>')")
> ```

For example, 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 PGQL property graph 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_PGQL)
```

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 specifying source and destination vertices uniquely identifies the source and destination vertex keys.
- **REFERENCES Clause**: This connects the source and destination vertices of an edge to the corresponding vertex tables. Also, note the following:
  - The source and destination keys can reference the key of the vertex table. For example:

```
VERTEX TABLES ( bank_accounts KEY(id))
EDGE TABLES (
  bank_txns KEY (txn_id)
    SOURCE KEY (from_acct_id) REFERENCES accounts (id)
    DESTINATION KEY (to_acct_id) REFERENCES accounts (id)
)
```

  - The source and destination keys can reference any set of columns of the vertex table. In case the referenced columns do not match a `PRIMARY` or `UNIQUE` key, then you must ensure to maintain data integrity in the referenced columns.

```
VERTEX TABLES ( vt KEY ( vt_c1 ) )
EDGE TABLES ( et SOURCE KEY ( et_c1 ) REFERENCES
(vt_any_unique_key_column ))
```

- **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_PGQL)
```

- **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)
)
```

For more details on the `CREATE PROPERTY GRAPH` statement, see the PGQL Specification.

Refer to the following table for creating a property graph:

Table 13-1 `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 PGQL property graph on Oracle Database tables	Creating a PGQL Property Graph

- Creating a PGQL Property Graph with the BASE_GRAPHS Clause
  You can create a PGQL property graph by providing a list of existing PGQL property graphs.
- Creating a PGQL Property Graph with Arbitrary Property Expressions
  You can create a PGQL property graph with vertex and edge properties mapped to arbitrary property expressions.

13.1.1 Creating a PGQL Property Graph with the BASE_GRAPHS Clause

You can create a PGQL property graph by providing a list of existing PGQL property graphs.

You can specify the `BASE GRAPHS` clause in the `CREATE PROPERTY GRAPH` DDL statement for specifying one or more existing PGQL property graphs from which you wish to create the new PGQL property graph. It is allowed to specify the `BASE GRAPHS` clause without specifying the `VERTEX TABLES` and `EDGE TABLES` clauses.

The syntax of the `BASE GRAPHS` clause in the `CREATE PROPERTY GRAPH` statement is as shown:

```
CreatePropertyGraph   ::= 'CREATE' 'PROPERTY' 'GRAPH' GraphName
                          BaseGraphs?
                          VertexTables?
                          EdgeTables?

BaseGraphs            ::= 'BASE' 'GRAPHS' '(' BaseGraph ( ',' BaseGraph )* ')'

BaseGraph             ::= SchemaQualifiedName

ElementTablesClause   ::=   AllElementTables
                          | ElementTablesList

AllElementTables      ::= 'ALL' 'ELEMENT' 'TABLES' ExceptElementTables?

ExceptElementTables   ::= 'EXCEPT' '(' ElementTableReference ( ','
ElementTableReference )* ')'

ElementTablesList     ::= '(' ElementTable ( ',' ElementTable )* ')'

ElementTable          ::= ElementTableReference TableAlias?

ElementTableReference ::= Identifier
```

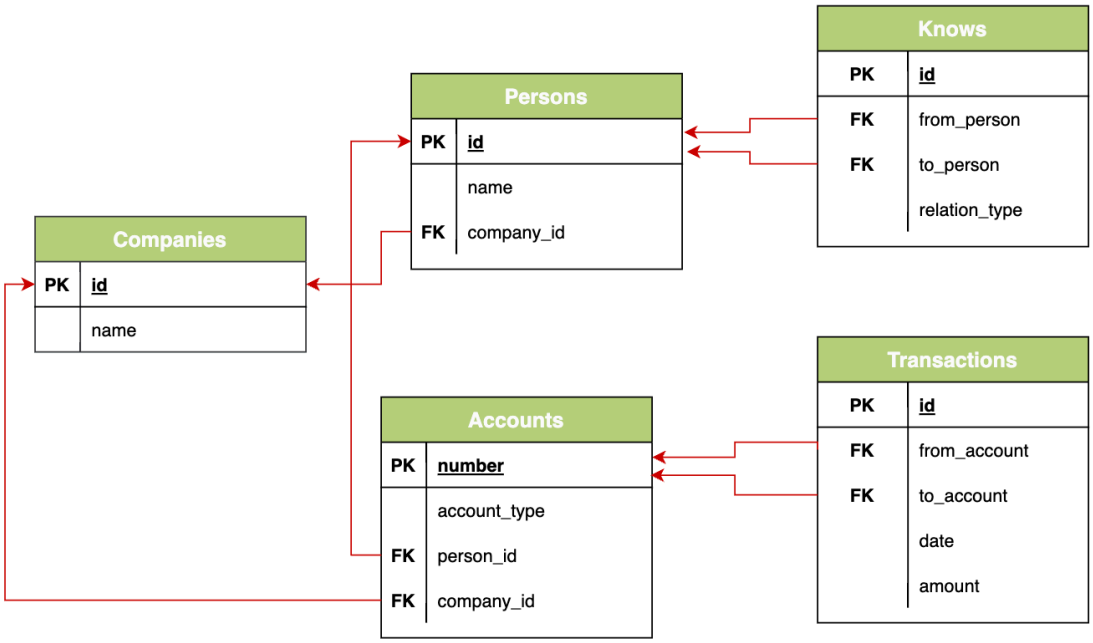
The `BASE GRAPHS` clause option allows you to duplicate a graph using a different name.

```
CREATE PROPERTY GRAPH <new_graph>
  BASE GRAPHS (<old_graph>)
  OPTIONS ( PG_PGQL )
```

Also, note that once the `new_graph` is created, it does not have any dependency on `old_graph`. This implies that updating or deleting the `old_graph` has no impact on the `new_graph`.

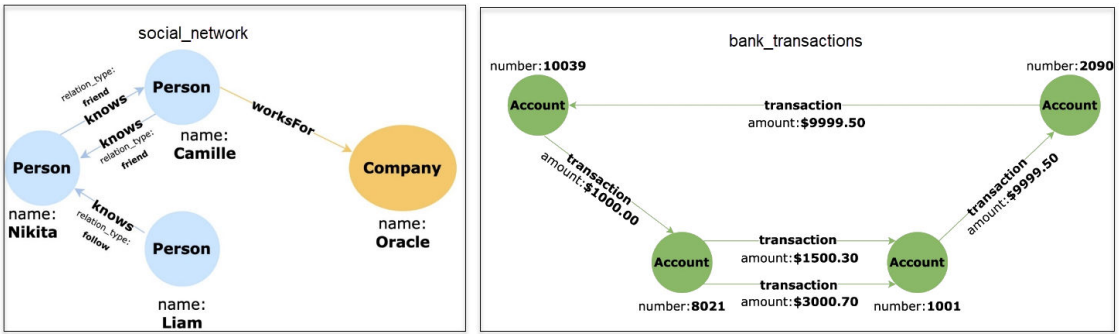
Consider the following example schema:

Figure 13-1 Example Schema



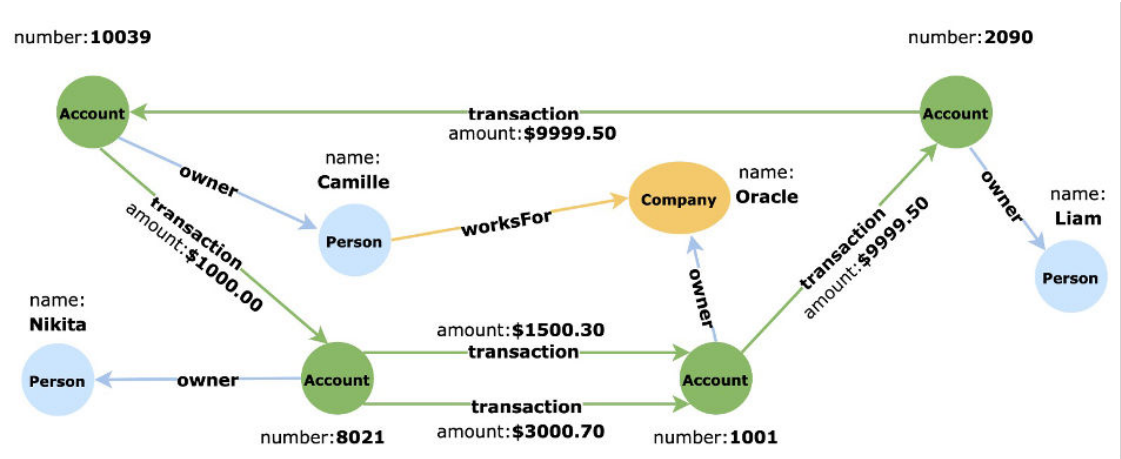
Assume that the following two graphs, `social_network` and `bank_transactions`, are created from the preceding schema:

Figure 13-2 Graphs Created from the Example Schema



Using the `BASE GRAPHS` clause, you can then create a new PGQL property graph by establishing a relationship between both the preceding graphs as shown:

Figure 13-3 Financial_Transactions Graph



To obtain this new graph based on the `social_network` and `bank_transactions` graphs:

1. Specify the names of the two graphs, `social_network` and `bank_transactions`, in the `BASE GRAPHS` clause. If a base graph does not exist in the current schema, then the user must specify the schema name.
2. Eliminate the `Knows` edge in the `social_network` graph. This can be achieved by using the `ALL ELEMENT TABLES EXCEPT` clause and specifying the `table_name` of that edge. Alternatively, you can use the `ELEMENT TABLES` clause and specify only the two tables, `Persons` and `Companies`.
3. Create a new edge between the `Accounts` vertex in the `bank_transactions` graph and the `Persons` vertex in the `social_network` graph.
4. Create a new edge between the `Accounts` vertex in the `bank_transactions` graph and the `Companies` vertex in the `social_network` graph.

The optimized `CREATE PROPERTY GRAPH` statement with the `BASE GRAPHS` clause to create the new PGQL property graph is as shown:

```
CREATE PROPERTY GRAPH financial_transactions
  BASE GRAPHS(
    bank_transactions,
    social_network ALL ELEMENT TABLES EXCEPT ( knows )
  )
  EDGE TABLES(
    Accounts AS PersonOwner
      SOURCE KEY ( "number" ) REFERENCES Accounts ( "number" )
      DESTINATION Persons
      LABEL owner NO PROPERTIES,
    Accounts AS CompanyOwner
      SOURCE KEY ( "number" ) REFERENCES Accounts ( "number" )
      DESTINATION Companies
      LABEL owner NO PROPERTIES
  ) OPTIONS ( PG_PGQL )
```

13.1.2 Creating a PGQL Property Graph with Arbitrary Property Expressions

You can create a PGQL property graph with vertex and edge properties mapped to arbitrary property expressions.

For instance, consider the following example data. The table contains `emp_dtls` as a JSON column.

```
CREATE TABLE emp_data (
  emp_id NUMBER GENERATED ALWAYS AS IDENTITY (START WITH 1 INCREMENT BY 1),
  emp_dtls JSON,
  CONSTRAINT emp_pk PRIMARY KEY (emp_id));

INSERT INTO emp_data (emp_dtls)
       VALUES ('{"name":"John","department":"IT","role":"Software
Developer"}');

INSERT INTO emp_data (emp_dtls)
       VALUES ('{"name":"Mary","department":"HR","role":"HR Manager"}');

INSERT INTO emp_data (emp_dtls)
       VALUES ('{"name":"Bob","department":"IT","role":"Technical
Consultant"}');

INSERT INTO emp_data (emp_dtls)
       VALUES ('{"name":"Alice","department":"HR","role":"HR Assistant"}');
```

You can then create a PGQL property graph with vertex and edge properties mapped to JSON data using the `JSON_VALUE` function.

```
CREATE PROPERTY GRAPH g
VERTEX TABLES (
  emp_data PROPERTIES (
           JSON_VALUE(emp_dtls, '$.name') AS name,
           JSON_VALUE(emp_dtls, '$.department') AS department,
           JSON_VALUE(emp_dtls, '$.role') AS role)
) OPTIONS(PG_PGQL)
```

Finally, you can query the vertex and edge properties of the graph as shown:

```
SELECT *
FROM GRAPH_TABLE ( g
  MATCH (n IS emp_data)
  COLUMNS (n.name, n.department, n.role) )
```

The query produces the following output:

```
+-----------------------------------------+
| NAME  | DEPARTMENT | ROLE               |
+-----------------------------------------+
| John  | IT         | Software Developer |
| Mary  | HR         | HR Manager         |
| Bob   | IT         | Technical Consultant |
```

```
| Alice | HR         | HR Assistant         |
+-----------------------------------------+
```

13.2 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.

13.3 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.

13.4 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 expression 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 expression:

```
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 Expression section in the PGQL specification

13.5 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.

13.6 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.

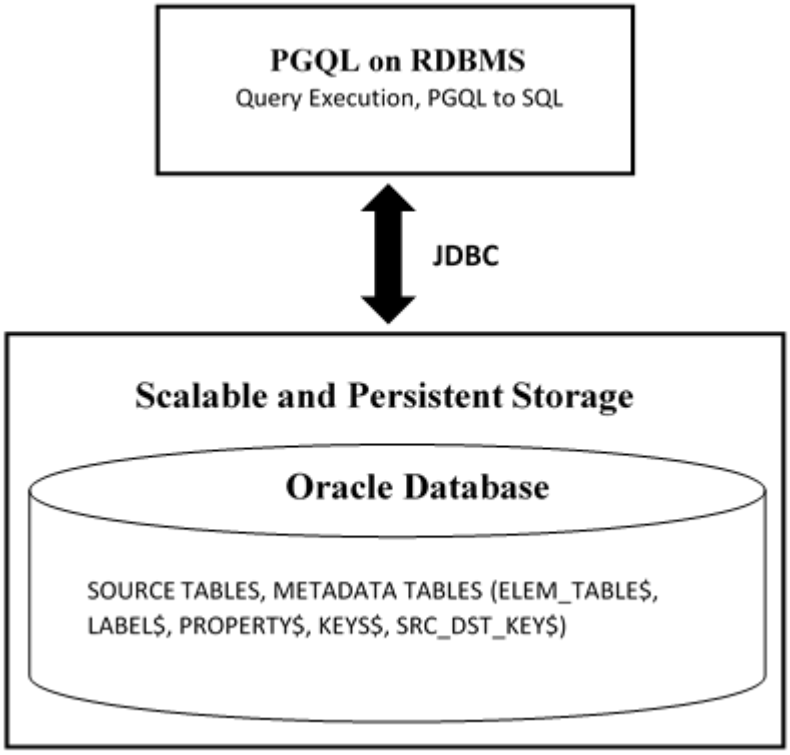
> **See Also:**
>
> - See Grouping and Aggregation for more information on `GROUP BY`
> - See Sorting and Row Limiting for more information on `ORDER BY`

13.7 Executing PGQL Queries Against PGQL Property Graphs

This topic explains how you can execute PGQL queries directly against PGQL property graphs on Oracle Database tables.

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

Figure 13-4 PGQL on PGQL Property Graphs 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 PGQL property graphs.
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 PGQL Property Graphs
  Learn about the supported PGQL features and limitations for PGQL property graphs.
- SQL Translation for a PGQL Query
  You can obtain the SQL translation for a PGQL query through the `translateQuery()` and `getSqlTranslation()` methods in `PgqlStatement` and `PgqlPreparedStatement`.
- Performance Considerations for PGQL Queries
- Using the Java and Python APIs to Run PGQL Queries

13.7.1 Supported PGQL Features and Limitations for PGQL Property Graphs

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

The following table describes the complete list of supported and unsupported PGQL features for PGQL property graphs:

Table 13-2 Supported PGQL Functionalities and Limitations for PGQL Property Graphs

Feature	PGQL on PGQL Property Graphs
`CREATE PROPERTY GRAPH`	Supported
`DROP PROPERTY GRAPH`	Supported
Fixed-length pattern matching	Supported
Variable-length pattern matching goals	Supported: • Reachability • Path search prefixes: – `ANY` – `ANY SHORTEST` – `SHORTEST k` – `ALL` • Path modes: – `WALK` – `TRAIL` – `SIMPLE` – `ACYCLIC` Limitations: • Path search prefixes: – `ALL SHORTEST` – `ANY CHEAPEST` – `CHEAPEST k`
Variable-length pattern matching quantifiers	Supported: • * • + • ? • { n } • { n, } • { n, m } • { , m }
Variable-length path unnesting	Supported: • ONE ROW PER STEP Limitation: Quantifier * not supported Not supported: • ONE ROW PER VERTEX
`GROUP BY`	Supported
`HAVING`	Supported
Aggregations	Supported: • `COUNT` • `MIN`, `MAX`, `AVG`, `SUM` • `LISTAGG` • `JSON_ARRAYAGG` Limitations: • `ARRAY_AGG`
`DISTINCT` • `SELECT DISTINCT` • Aggregation with `DISTINCT` (such as, `COUNT(DISTINCT e.prop)`)	Supported
`SELECT v.*`	Supported

Table 13-2 (Cont.) Supported PGQL Functionalities and Limitations for PGQL Property Graphs

Feature	PGQL on PGQL Property Graphs
`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` • `JAVA_REGEXP_LIKE` (based on `CONTAINS`) • `LOWER`, `UPPER` • `SUBSTRING` • `ABS`, `CEIL/CEILING`, `FLOOR`, `ROUND` • `EXTRACT` • `ID`, `VERTEX_ID`, `EDGE_ID` • `LABEL`, `IS [NOT] LABELED` • `ALL_DIFFERENT` • `CAST` • `CASE` • `IN` and `NOT IN` • `IS [NOT] SOURCE [OF]`, `IS [NOT] DESTINATION [OF]` (Only supported with Oracle Database 23ai) • `VERTEX_EQUAL`, `EDGE_EQUAL` Limitations: • `LABELS` • `IN_DEGREE`, `OUT_DEGREE`

Table 13-2 (Cont.) Supported PGQL Functionalities and Limitations for PGQL Property Graphs

Feature	PGQL on PGQL 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 • `LATERAL` subquery	Supported: • `EXISTS` and `NOT EXISTS` subqueries • Scalar subqueries • `LATERAL` subquery
`GRAPH_TABLE` operator	Supported Extension: • `BASE GRAPHS` clause in `CREATE PROPERTY GRAPH` for creating graphs based on metadata of other graphs
`INSERT/UPDATE/DELETE`	Supported for Oracle Database 19c and later
`INTERVAL` literals and operations	Not supported

- Additional Information on Supported PGQL Features with Examples

13.7.1.1 Additional Information on Supported PGQL Features with Examples

The following PGQL features are supported in PGQL property graphs:

- 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 13-3 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 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 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 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)
)
```

- PGQL `LATERAL` subqueries are supported. For example:

```
SELECT recipient, COUNT(*) AS num_large_transactions
FROM LATERAL ( SELECT m.id AS recipient
               FROM MATCH (n IS accounts) -[e IS transfers]-> (m IS
accounts)
               WHERE n.id = 772
               ORDER BY e.amount DESC )
GROUP BY recipient
ORDER BY num_large_transactions DESC
```

- PGQL `GRAPH_TABLE` operator is supported. For example:

```
SELECT * FROM GRAPH_TABLE ( bank_graph
  MATCH (a IS accounts) -[e IS transfers]-> (b IS accounts)
  COLUMNS ( a.id as from_ac, e.amount as amount, b.id as to_ac  )
) FETCH FIRST FIVE ROWS ONLY
```

- The source (`IS [NOT] SOURCE OF`) and destination (`IS [NOT] DESTINATION OF`) predicates to verify if a vertex is a source or destination of an edge are supported. This is useful when an edge is matched through an any directed edge pattern (`-[e]-`). Note that this PGQL feature is supported only in Oracle Database 23ai. For example:

```
SELECT e.amount, CASE WHEN n IS SOURCE OF e THEN 'Outgoing transaction'
ELSE 'Incoming transaction' END AS type
FROM MATCH (n:Accounts) -[e:transfers]- (m:Accounts)
WHERE n.id = 284
ORDER BY type, e.amount
```

  The preceding query produces the following result:

```
+------------------------------+
| AMOUNT | TYPE                |
+------------------------------+
| 1000   | Incoming transaction |
```

```
| 1200   | Outgoing transaction |
| 1300   | Outgoing transaction |
+-------------------------------+
```

- `JSON_ARRAYAGG` function (see JSON_ARRAYAGG in *Oracle Database SQL Language Reference*) to aggregate values into a JSON array is supported.

  ```
  SELECT JSON_ARRAY_AGG(n.id) AS txn_from
  FROM MATCH (n:Accounts) -[e:transfers]- (m:Accounts)
  WHERE m.id = 616
  ```

  On execution, the query produces the following result:

  ```
  +-----------------------------------------+
  | TXN_FROM                                |
  +-----------------------------------------+
  | [202,582,650,108,744,756,801,674,710,764] |
  +-----------------------------------------+
  ```

- Built-in graph validation function `pg.validate()` to check if vertex and edge keys are unique, and if the sources and destinations of edges exist.

  ```
  pgqlStmt.execute("CALL pg.validate('BANK_TXN_GRAPH')")
  $1 ==> false
  ```

  Exceptions are raised for invalid keys or edges having missing vertices as shown:

  ```
  pgqlStmt.execute("CALL pg.validate('COUNTRIES')")
  opg4j> pgqlStmt.execute("CALL pg.validate('COUNTRIES')")
  |  Exception oracle.pg.rdbms.pgql.PgqlToSqlException: Invalid vertex key
  60 for edge NO in edge table CTY_REG with destination key column(s)
  "REGION_ID" referencing REGIONS ( "REGION_ID" )
  ```

- Unnesting of paths using the `ONE ROW PER STEP` clause is supported in the PGQL `GRAPH_TABLE` operator query.

  ```
  SELECT *
  FROM GRAPH_TABLE ( financial_transactions
         MATCH
           (a IS account) -[IS transaction]->+ (a)
         KEEP SHORTEST 5 SIMPLE PATHS
         WHERE a.number = 10039
         ONE ROW PER STEP ( v1, e, v2 )
         COLUMNS( MATCHNUM() AS matchnum,
                  ELEMENT_NUMBER(e) AS elemnum,
                  v1.number AS account1,
                  v2.number AS account2, e.amount))
  ORDER BY matchnum, elemnum
  ```

As seen in the preceding example, the `ONE ROW PER STEP` clause declares an iterator vertex variable, an iterator edge variable, and another iterator vertex variable. The query produces one row per step (a step is a vertex-edge-vertex triple) as shown:

```
+-------------------------------------------------+
| matchnum | elemnum | account1 | account2 | amount |
+-------------------------------------------------+
| 0        | 2       | 10039    | 8021     | 1000.0 |
| 0        | 4       | 8021     | 1001     | 1500.3 |
| 0        | 6       | 1001     | 2090     | 9999.5 |
| 0        | 8       | 2090     | 10039    | 9900.0 |
| 1        | 2       | 10039    | 8021     | 1000.0 |
| 1        | 4       | 8021     | 1001     | 3000.7 |
| 1        | 6       | 1001     | 2090     | 9999.5 |
| 1        | 8       | 2090     | 10039    | 9900.0 |
+-------------------------------------------------+
```

The preceding output shows two paths, each having 4 edges.

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 PGQL Property Graphs for a complete list of supported and unsupported PGQL features for PGQL property graphs.
> - See Performance Considerations for PGQL Queries for details on recommended practices to enhance query performance for recursive queries.

13.7.2 SQL Translation for a PGQL Query

You can obtain the SQL translation for a PGQL query through the `translateQuery()` and `getSqlTranslation()` methods in `PgqlStatement` and `PgqlPreparedStatement`.

Using the raw SQL for a PGQL query you can:

- Run the SQL directly against the database with other SQL-based tools or interfaces (for example, SQL*Plus or SQL Developer).
- Customize and tune the generated SQL to optimize performance or to satisfy a particular requirement of your application.
- 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).

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`, `translateQuery`, and `PgqlConnection.prepareStatement` methods
- 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 13-4 PGQL Translation and Execution Options

Option	Default	Explicit 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
Reverse path optimization	True	None	`REVERSE_PATH=F`	oracle.pg.rdbms.pgql.reversePath=false
Pushing source filter optimization	True	None	`PUSH_SRC_HOPS=F`	oracle.pg.rdbms.pgql.pushSrcHops=false
Pushing destination filter optimization	False	None	`PUSH_DST_HOPS=T`	oracle.pg.rdbms.pgql.pushDstHops=true
Creation of views in shortest path translation	False	None	`SP_CREATE_VIEW=T`	oracle.pg.rdbms.pgql.spCreateView=true
Creation of tables in shortest path translation	True	None	`SP_CREATE_TABLE=F`	oracle.pg.rdbms.pgql.spCreateTable=false
Use of CLOB for path expressions	True	None	`EXP_PATH_CLOB=F`	oracle.pg.rdbms.pgql.expPathClob=false

13.7.3 Performance Considerations for PGQL Queries

The following sections explain a few recommended practices for query performance.

- Recursive Queries
- Using Query Optimizer Hints
- Speed Up Query Translation Using Graph Metadata Cache and Translation Cache

13.7.3.1 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_PGQL )
```

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_PGQL )
```

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)`

13.7.3.2 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).getSqlTranslation())
...
...
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").getSql
Translation())

...
...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"')),
...
...
```

13.7.3.3 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)`
- `setGraphMetadataRefreshInterval(long interval)`

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.

By default, both the metadata and translation caches are refreshed every `1000ms` (default value) if they are enabled. This makes it easy to sync the metadata cache in case you are modifying one graph through multiple JVMs. Also, you can increase the time (in milliseconds) taken for refreshing the cache by calling the `setGraphMetadataRefreshInterval(long interval)` function.

13.7.4 Using the Java and Python APIs to Run PGQL Queries

You can run PGQL queries on PGQL property graphs 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 PGQL Property Graph
- Executing PGQL SELECT Queries
- Executing PGQL Queries to Modify PGQL Property Graphs
- Dropping a PGQL Property Graph

13.7.4.1 Creating a PGQL Property Graph

You can create a PGQL property graph using the `CREATE PROPERTY GRAPH` statement.

Example 13-1 Creating a PGQL Property Graph

The following example describes the creation of a PGQL property graph.

- 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_PGQL) "
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 PGQL property graph.
 */
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_PGQL) ";

      // 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 as Accounts
...             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_PGQL)
... """
>>> pgql_statement.execute(pgql)
False
```

You can verify the PGQL property graph creation by checking the metadata tables that get created in the database.

13.7.4.2 Executing PGQL SELECT Queries

You can run PGQL `SELECT` queries as described in the following examples.

Example 13-2 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 PGQL property graph.
 */
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 13-3 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 13-4 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 13-5 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 |
+-----+
```

13.7.4.3 Executing PGQL Queries to Modify PGQL Property Graphs

You can execute PGQL `INSERT`, `UPDATE` and `DELETE` queries against PGQL property graphs 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
```

13.7.4.4 Dropping a PGQL Property Graph

You can use the PGQL `DROP PROPERTY GRAPH` statement to drop a PGQL property graph. Note that all the metadata tables for the PGQL property graph are dropped.

Example 13-6 Dropping a PGQL Property Graph

- 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 <graph>")
$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 PGQL property graph.
 */
public class DropPgqlGraph
{

  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 " +graph;
      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 <graph>"
>>> 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.

- Oracle Graph Server and Client Installation
  This chapter describes the steps for installing the graph server and the graph clients.
- 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.

14

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 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.

14.1 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 14-1 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 19c 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
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
6	Set up transport layer security	Configure the graph server and client to trust the self-signed keystore.	Setting Up Transport Layer Security

Table 14-1 (Cont.) Workflow for Installing Oracle Graph Server and Client

Sequence	Task	Description	More Information
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

14.1.1 Verifying Database Compatibility

Oracle Graph Server and Client works with Oracle Database 19c onwards on both on-premises and cloud environments. The cloud environment includes working with all versions of Oracle Autonomous Database Serverless and Oracle Autonomous Database Dedicated.

14.1.2 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 14-2 summarizes all the files contained in the Oracle Graph Server and Client deployment.

<ver> denoted in the file name in the Table 14-2 reflects the downloaded Oracle Graph Server and Client version.

Table 14-2 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 for Linux x86-64.
`oracle-graph-<ver>.aarch64.rpm`	Oracle Graph Server	An rpm file to deploy Oracle Graph Server for Linux ARM.
`oracle-graph-client-<ver>.zip`	Oracle Graph Client	A zip file containing Oracle Graph Client.
`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-visualization-library-<ver>.zip`	Oracle Graph Visualization Library	A zip file containing a Java Script library for the Graph Visualization application.

14.2 Oracle Graph Server Installation

You must install the Oracle Graph Server to run graph queries and analytics in the graph server (PGX).

You also require the graph server to visualize graphs loaded into the graph server (PGX) and the graphs in the database.

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.

- System Requirements for Installing Oracle Graph Server
  Verify that you meet a few system requirements when installing the Oracle Graph Server in a standalone mode or when deploying to 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.

14.2.1 System Requirements for Installing Oracle Graph Server

Verify that you meet a few system requirements when installing the Oracle Graph Server in a standalone mode or when deploying to Oracle WebLogic Server or Apache Tomcat.

Table 14-3 System Requirements

Requirement Type	Supported Version
Operating System	• Oracle Linux 7 or 8 x64 • Oracle Linux 7 or 8 for Linux 64-bit ARM • Red Hat Enterprise Linux (RHEL) 7 or 8

> **Note:**
>
> Oracle Linux 7 for the x64 and ARM architectures is deprecated. It is recommended that you use Oracle Linux 8 for the x64 and ARM architectures.

Table 14-3 (Cont.) System Requirements

Requirement Type	Supported Version
JDK version	• Oracle JDK 11, JDK 17, or JDK 21 • OpenJDK JDK 11, JDK 17 or JDK 21 **Note:** Due to a bug in Oracle JDK and OpenJDK, it is recommended to avoid the following JDK versions: • JDK 11.0.9 • JDK 11.0.10 • JDK 11.0.11 • JDK 11.0.12 See this note for more details.
Disk space	Oracle Graph Server requires at least 2 GB of disk space.

14.2.2 Using the RPM Installation

You can run the downloaded RPM file to install the Oracle Graph Server.

The Oracle Graph Server and Client deployment provides RPM files for both Linux x86-64 and ARM architectures. See Downloading Oracle Graph Server and Client for more information.

- Prerequisites for Installing Oracle Graph Server
- Installing Oracle Graph Server
- Uninstalling Oracle Graph Server
- Upgrading Oracle Graph Server

14.2.2.1 Prerequisites for Installing Oracle Graph Server

Before installing the graph server using the RPM file, ensure you perform the following prerequisite steps:

1. Ensure that you meet the system prerequisites as explained in System Requirements for Installing Oracle Graph Server.
2. 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-24.4.0-0.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.

14.2.2.2 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.
   - **For Linux x86-64**:

     ```
     sudo rpm -i oracle-graph-<version>.rpm
     ```

   - **For Linux ARM** :

     ```
     sudo rpm -i oracle-graph-<version>.aarch64.rpm
     ```

   In the preceding command, `<version>` reflects the version of the downloaded file. (For example, `oracle-graph-24.4.0.x86_64.rpm` or `oracle-graph-24.4.0.aarch64.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
```

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.

14.2.2.3 Uninstalling Oracle Graph Server

To uninstall the graph server, make sure the graph server is shut down.

- Run the following command as a `root` user or with `sudo`:

```
sudo rpm -e oracle-graph
```

  - During uninstall `/opt/oracle/graph/pgx/tmp_data/` and `/etc/oracle/graph/server_keystore.jks` are removed.

14.2.2.4 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.

1. Verify the version of your current graph server installation.

```
sudo rpm -q oracle-graph
```

2. Stop the graph server if it is already running.

```
sudo systemctl stop pgx
```

3. Upgrade the graph server by running the following command as a `root` user or with `sudo`.

   - **For Linux x86-64**:

     ```
     sudo rpm -U oracle-graph-24.4.0.x86_64.rpm
     ```

   - **For Linux ARM** :

     ```
     sudo rpm -U oracle-graph-24.4.0.aarch64.rpm
     ```

   Also, note the following:

   - The upgrade process automatically preserves the previous PGX (`pgx.conf`), server (`server.conf`), and the logging (`logback-server.xml`, `logback.xml`) configurations files. However, if the new version contains changes, then the upgrade process will create the newest versions of these files with the `.rpmnew` extension. You can them compare the two files (to verify if there are any changes in the default parameter values or if a new parameter is added) and pick up the latest changes.
   - Any manual configuration changes in the `systemd` configuration file for the PGX service (`/etc/systemd/system/pgx.service`) is lost. However, if you are using a drop-in file, then all customizations in the drop-in file are maintained.
   - Existing log files in `/var/log/oracle/graph` are preserved.
   - Existing server keystore file (`/etc/oracle/graph/server_keystore.jks`) is preserved.

   > **Caution:**
   >
   > If you are upgrading the graph server from version 22.3.0 or earlier to 24.4.0, then note that the RPM file installation in Graph Server and Client Release 24.4.0 will generate a self-signed server keystore file by default. See Setting Up Transport Layer Security for more information.

4. Verify if the `tmp_data` folder exists in the `/opt/oracle/graph/pgx/` directory path.

   If it does not exist, then create one and assign ownership and permission as shown:

```
mkdir -p /opt/oracle/graph/pgx/tmp_data
chown -R :oraclegraph /opt/oracle/graph/pgx/tmp_data
chmod 0770 /opt/oracle/graph/pgx/tmp_data
```

5. Restart the graph server.

```
sudo systemctl daemon-reload
sudo systemctl start pgx
```

14.2.3 Deploying Oracle Graph Server to a Web Server

You can deploy Oracle Graph Server to Apache Tomcat or Oracle WebLogic Server.

However, before deploying the graph server on any one of these web servers, ensure that your system meets the prerequisites explained in System Requirements for Installing Oracle Graph 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 version 14.1.1.

14.2.3.1 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-webapp-<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-webapp-<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. Export the following `JAVA_OPTS` options only if you are using Oracle JDK 17 or OpenJDK JDK 17. Otherwise, you can skip this step.

   ```
   export JAVA_OPTS="$JAVA_OPTS --add-exports jdk.compiler/
   com.sun.tools.javac.api=ALL-UNNAMED \
     --add-exports jdk.compiler/com.sun.tools.javac.processing=ALL-UNNAMED \
   ```

```
--add-exports jdk.compiler/com.sun.tools.javac.util=ALL-UNNAMED \
--add-exports jdk.compiler/com.sun.tools.javac.tree=ALL-UNNAMED \
--add-exports jdk.compiler/com.sun.tools.javac.code=ALL-UNNAMED"
```

7. Configure Tomcat specific settings, like the correct use of TLS/encryption.
8. Ensure that port 8080 is not already in use.
9. 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)

14.2.3.2 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 version 14.1.1.

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-webapp-<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. Edit the `WEB-INF/web.xml` file inside the web application archive and remove the following `<session-config>` element:

```
<session-config>
        <tracking-mode>COOKIE</tracking-mode>
        <cookie-config>
            <secure>true</secure>
            <http-only>true</http-only>
        </cookie-config>
        <session-timeout>60</session-timeout>
</session-config>
```

d. Optionally, change other servlet specific deployment descriptors by modifying the `WEB-INF/web.xml` file inside the web application archive.

e. 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. Add the following `JAVA_OPTS` argument at the beginning of the `$MW_HOME/user_projects/domains/mydomain/bin/setDomainEnv.sh` script file (Weblogic domain settings) only if you are using Oracle JDK 17 or OpenJDK JDK 17. Otherwise, you can skip this step.

```
export JAVA_OPTS="$JAVA_OPTS --add-exports jdk.compiler/
com.sun.tools.javac.api=ALL-UNNAMED \
  --add-exports jdk.compiler/com.sun.tools.javac.processing=ALL-UNNAMED \
  --add-exports jdk.compiler/com.sun.tools.javac.util=ALL-UNNAMED \
  --add-exports jdk.compiler/com.sun.tools.javac.tree=ALL-UNNAMED \
  --add-exports jdk.compiler/com.sun.tools.javac.code=ALL-UNNAMED"
```

7. 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

14.2.3.2.1 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

14.2.4 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.

- 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.

- 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.

14.2.4.1 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 19c or later, including Autonomous Database.
2. Ensure that you have SYSDBA access for your database (or ADMIN access for autonomous databases) to grant and revoke users access to the graph server (PGX).
3. Ensure that all existing users to which you plan to grant access to the graph server have at least the following privileges granted.

   ```
   CREATE SESSION, CREATE TABLE
   ```

4. Ensure that the database is accessible through JDBC from the host where the graph server runs.
5. As SYSDBA (or ADMIN on autonomous databases), run the following procedure to create the roles required by the graph server.

> **Note:**
>
> If you are using an Autonomous Database Serverless instance, or if your on-premises Oracle Database version is 23ai, then you can skip this step as these roles are pre-installed.

```
-- This procedure creates a list of roles needed for graph.
 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',
      'PGX_SESSION_SET_IDLE_TIMEOUT');
    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;
  /
```

Optionally, this procedure is also available in `/opt/oracle/graph/scripts/create_graph_roles.sql`.

See Table 14-4 for more information on the roles.

6. Assign default permissions to the roles `GRAPH_DEVELOPER`, `GRAPH_USER` and `GRAPH_ADMINISTRATOR` to group multiple permissions together.

> **Note:**
>
> If you are using an Autonomous Database serverless instance, or if your on-premises Oracle Database version is 23ai, then you can skip this step as these privileges are available by default.

```
-- This procedure add some grants to the graph roles.
  DECLARE
    PRAGMA AUTONOMOUS_TRANSACTION;
  BEGIN
    EXECUTE IMMEDIATE 'GRANT PGX_SESSION_CREATE TO GRAPH_ADMINISTRATOR';
    EXECUTE IMMEDIATE 'GRANT PGX_SERVER_GET_INFO TO GRAPH_ADMINISTRATOR';
    EXECUTE IMMEDIATE 'GRANT PGX_SERVER_MANAGE TO GRAPH_ADMINISTRATOR';
    EXECUTE IMMEDIATE 'GRANT PGX_SESSION_CREATE TO GRAPH_DEVELOPER';
    EXECUTE IMMEDIATE 'GRANT PGX_SESSION_NEW_GRAPH TO GRAPH_DEVELOPER';
    EXECUTE IMMEDIATE 'GRANT PGX_SESSION_GET_PUBLISHED_GRAPH TO
GRAPH_DEVELOPER';
```

```
    EXECUTE IMMEDIATE 'GRANT PGX_SESSION_MODIFY_MODEL TO GRAPH_DEVELOPER';
    EXECUTE IMMEDIATE 'GRANT PGX_SESSION_READ_MODEL TO GRAPH_DEVELOPER';
    EXECUTE IMMEDIATE 'GRANT PGX_SESSION_SET_IDLE_TIMEOUT TO
GRAPH_DEVELOPER';
    EXECUTE IMMEDIATE 'GRANT PGX_SESSION_CREATE TO GRAPH_USER';
    EXECUTE IMMEDIATE 'GRANT PGX_SESSION_GET_PUBLISHED_GRAPH TO
GRAPH_USER';
    BEGIN
      EXECUTE IMMEDIATE 'GRANT CREATE PROPERTY GRAPH TO GRAPH_DEVELOPER';
    EXCEPTION WHEN others then
      if sqlcode = -990 then
        mdsys.opg_log.debug('grant create property graph to
graph_developer: missing privilege, continue');
      else
        raise;
      end if;
    END;
  EXCEPTION
    when others then
      dbms_output.put_line('add_graph_roles_grants: hit error ');
      raise;
  END;
  /
```

Optionally, this procedure is also available in `/opt/oracle/graph/scripts/create_graph_roles.sql`.

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.

- Privileges and Roles in Oracle Database
  This section describes the database roles and privileges that are required only if you are using the graph server (PGX).

14.2.4.1.1 Privileges and Roles in Oracle Database

This section describes the database roles and privileges that are required only if you are using the graph server (PGX).

Table 14-4 Oracle Database Privileges and Roles Required for Using the Graph Server (PGX)

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.

14.2.4.2 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-webapp-<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.

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. Unzip the wallet to a new subdirectory in `/etc/oracle/graph/wallets/<dbname>`, and change the group permission as shown:

   ```
   sudo unzip Wallet_<dbname>.zip -d /etc/oracle/graph/wallets/<dbname>
   sudo chgrp -R oraclegraph /etc/oracle/graph/wallets/<dbname>
   ```

3. Determine the connect identifier from the `tnsnames.ora` file in `/etc/oracle/graph/wallets/<dbname>` 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.

4. 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/<dbname>",
    "token_expiration_seconds": 3600,
...
```

5. Finally, restart the graph server as shown:

```
sudo systemctl restart pgx
```

14.2.4.3 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.

14.2.4.4 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 24.4 from an earlier version.

14.2.4.5 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.readGraphByName("BANK_GRAPH_VIEW",GraphSource.PG_PGQL)  // fails
because token cannot be renewed anymore
opg4j> GraphServer.reauthenticate(instance, "<user>",
"<password>".toCharArray()) // log in again
opg4j> var graph =
session.readGraphByName("BANK_GRAPH_VIEW",GraphSource.PG_PGQL) // works now
```

14.2.4.6 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.

14.2.4.6.1 Checking Graph Permissions Using API

You can view your roles and graph permissions using the following PGX API methods:

Table 14-5 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

Table 14-5 (Cont.) API for Checking Graph Permissions

Class	Method	Description
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]
opg4j> var g = session.readGraphByName("BANK_GRAPH_VIEW", GraphSource.PG_PGQL)
g ==> PgxGraph[name=BANK_GRAPH_VIEW,N=999,E=4993,created=1688558374973]
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
```

14.2.4.6.2 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
```

14.2.4.6.3 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
```

14.2.4.6.4 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
  ```

14.2.4.7 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
```

14.2.4.8 Examples of Custom Authorization Rules

You can define custom authorization rules for developers.

- Example 14-1
- Example 14-2
- Example 14-3
- Example 14-4

Example 14-1 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 14-6 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 describes an example of granting `READ` permission on a graph to the `GRAPH_DEVELOPER` role by userA:

```
import oracle.pgx.api.*;
import oracle.pgx.common.auth.*;
...
PgxSession session = GraphServer.getInstance("<base-url>", "<userA>",
"<password-of-userA").createSession("userA");
PgxGraph g = session.readGraphByName("SAMPLE_GRAPH", GraphSource.PG_PGQL);
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 14-2 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 14-3 Allowing Developers Access to the Local File System

To allow developers access to the local file system (where the graph server runs), you must first declare a directory and then map it to a read or write permission. For example:

```
CREATE OR REPLACE DIRECTORY pgx_file_location AS '/opt/oracle/graph/data'
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.

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 14-4 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
   ```

14.2.4.9 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

14.2.4.9.1 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.

14.2.4.9.2 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.

14.2.4.9.3 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)
```

14.3 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.
- Running the Graph Visualization Web Client
  You require a running graph server (PGX) to use the Graph Visualization web application.

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.

14.3.1 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-24.4.0.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-24.4.0.zip` file that is shipped with Oracle Graph Server and Client or from PyPI.

14.3.1.1 Oracle Graph Java Client

You can install the Java client from the `oracle-graph-client-24.4.0.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 24.4.0 and install the Java client.
- Using Oracle Graph Java Client on Maven Central
  You can obtain the property graph Java client from Maven Central.

14.3.1.1.1 Installing the Java Client From the Graph Server and Client Downloads

You can download the zip file for Oracle Graph Client 24.4.0 and install the Java client.

The prerequisites for installing the Java client are:

- **Supported Operating Systems:** A Unix-based operation system (such as Linux), macOS, or Microsoft Windows
- **Supported JDK versions:**
  - Oracle JDK 11, JDK 17, or JDK21
  - OpenJDK JDK 11, JDK 17, or JDK21

> **Note:**
>
> Due to a bug in Oracle JDK and OpenJDK, which causes a deadlock when you attempt to copy and paste into a JShell session, it is recommended that you avoid the following 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-24.4.0.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 24.4.0
Variables instance, session, and analyst ready to use.
opg4j>
```

> **See Also:**
>
> Java API Reference for more information on the Java APIs

14.3.1.1.2 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:** 24.4.0

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>24.4.0</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: '24.4.0'
> ```

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>24.4.0</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 PGQL property graph using the CREATE PROPERTY GRAPH
statement
      String pgPgqlName = "BANK_GRAPH";
      String createPgPgqlQuery =
          "CREATE PROPERTY GRAPH " + pgPgqlName + " " +
          "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_PGQL)";

        pgqlStmt.execute(createPgPgqlQuery);

        // 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 " +
            pgPgqlName + " LIMIT 10";

        PgqlResultSet rs = pgqlStmt.executeQuery(pgqlQuery);
        rs.print();

        // Drop the PGQL property graph using the DROP PROPERTY GRAPH
statement
        String dropPgPgqlQuery = "DROP PROPERTY GRAPH " + pgPgqlName;
        pgqlStmt.execute(dropPgPgqlQuery);
      }
      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
```

14.3.1.2 Oracle Graph Python Client

You can install the Python client by downloading the `oracle-graph-client-24.4.0.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.

- Installing the Python Client from PyPI
  You can obtain the property graph Python client from PyPI.
- Upgrading the Python Client
  This section describes how to upgrade the Python client.
- Installing the Python Client From the Graph Server and Client Downloads
  You can download the zip file for `oracle-graph-client-24.4.0` from the Graph Server and Client downloads and install the Python client.
- 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.

14.3.1.2.1 Installing the Python Client from PyPI

You can obtain the property graph Python client from PyPI.

You can install the `oracle-graph-client-24.4.0.zip` package from the PyPI repository using `pip`.

Before installing the Python client from PyPI, ensure that your system meets the following requirements:

- **Supported operating systems:** Linux, Windows, or macOS (M1 or M2 processor)
- **Supported JDK versions:**
  - Oracle JDK 11, JDK 17, or JDK 21
  - OpenJDK JDK 11, JDK 17, or JDK21
- Python 3.8 or later
- 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

14.3.1.2.2 Upgrading the Python Client

This section describes how to upgrade the Python client.

1. Review the available Python client versions and the currently installed version.

   ```
   pip3 index versions oracle-graph-client

   WARNING: pip index is currently an experimental command. It may be removed/
   ```

```
changed in a future release without prior warning.
oracle-graph-client (23.3.0)
Available versions: 23.3.0, 23.2.0, 23.1.0
  INSTALLED: 23.1.0
  LATEST:    23.3.0
```

2. Run the following command to upgrade your Python client.

```
pip3 install oracle-graph-client --upgrade
```

14.3.1.2.3 Installing the Python Client From the Graph Server and Client Downloads

You can download the zip file for `oracle-graph-client-24.4.0` from the Graph Server and Client downloads and install the Python client.

Before you install the Python client, ensure that you meet the following prerequisites.

- **System requirements:**
  - **Supported operating system:** Linux
  - **Supported JDK versions:**
    - Oracle JDK 11, JDK 17, or JDK 21
    - OpenJDK JDK 11, JDK 17. or JDK 21
  - **Supported Python versions:** Python 3.8 or 3.9
    To verify that you are using the right version of the Python client, run the following command:

    ```
    python3 --version
    ```

    For more information on installing Python 3 on Oracle Linux, see Python for Oracle Linux.

> **Note:**
>
> If you are using any other operating system or Python version, then you can install the Python client from PyPI. See Installing the Python Client from PyPI for more information.

- Ensure that `python3-devel` is installed in your system.

```
sudo yum install python3-devel
```

> **Note:**
>
> See Python API Reference for more information on the Python APIs.

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-24.4.0.zip`.

2. Unzip the file into a directory of your choice.

   The unzipped folder contains the `oracle-graph-python-client-24.4.0.zip` file for installing the Python client.

3. Install the Python client by running the following command.

```
python3 oracle-graph-python-client-24.4.0.zip --user
```

4. Configure your client to trust the self-signed keystore. See Configuring a Client to Trust the Self-Signed Keystore for more information.
5. 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 24.4.0
>>>
```

> **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.

14.3.1.2.4 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 command:

```
 python3 /opt/oracle/graph/client/oracle-graph-python-embedded-24.4.0.zip
--user
```

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 24.4.0
>>> instance
ServerInstance(embedded: True, version: 24.4.1)
>>>
```

14.3.1.2.5 Uninstalling the Python Client

This section describes how to uninstall the Python client.

To uninstall the Python client, run the following command:

```
pip uninstall oracle-graph-client
```

14.3.2 Running the Graph Visualization Web Client

You require a running graph server (PGX) to use the Graph Visualization web application.

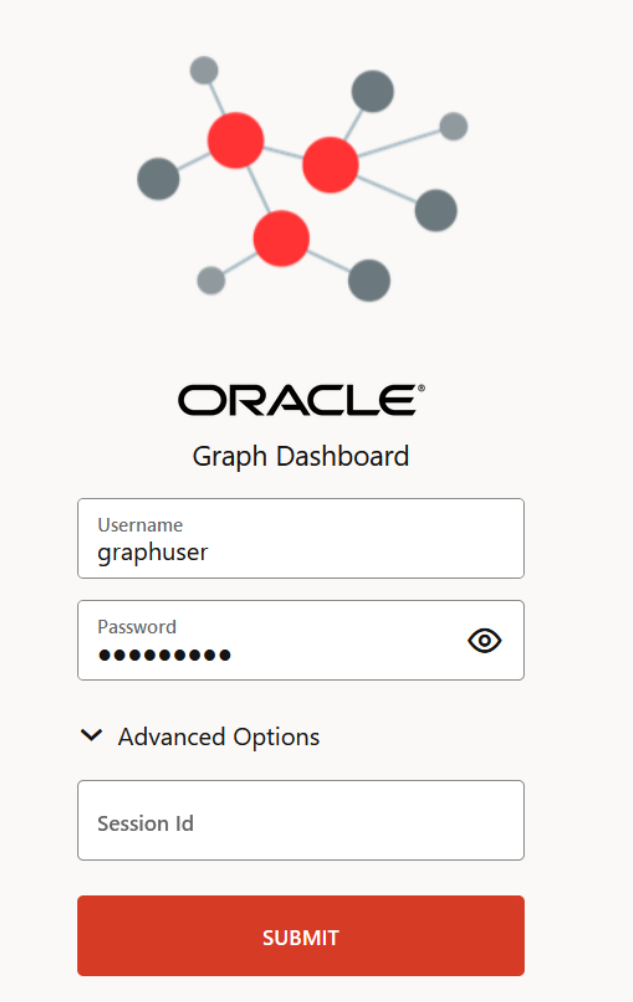
In addition, ensure that you have provided the JDBC URL for your database in the `jdbc_url` parameter in the `/etc/oracle/graph/pgx.conf` file.

To launch the graph visualization application:

1. Start the graph server on your installation.
   - See Installing Oracle Graph Server for more information on using the rpm installation.
   - See Deploying Oracle Graph Server to a Web Server for more information on graph server deployment to a web server.
2. Connect to your browser for running the Graph Visualization application.
   - For rpm installation: `https://localhost:7007/dash/`
   - For Apache Tomcat Server: `https://localhost:8080/dash`
   - For Oracle WebLogic Server: `https://<<fqdn-ip>>:<<port>>/dash`

   The Graph Visualization Login screen opens as shown:

Figure 14-1 Graph Visualization Login



3. Enter your **Username** and **Password**.
4. Optionally, provide the **PGX Session ID**.
5. Click **Submit**.
6. Click , the Graph Visualization icon.
   The **Graph Visualization** page opens and the default **Graph Server** tab is displayed. See Using the Graph Visualization Application for more information on how to visualize graphs using this web application.

14.4 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.

- 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.

14.4.1 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.

14.4.1.1 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`.

14.4.1.2 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,
     "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. Optionally, if the keystore is vaild for a different host (other than the `localhost`), then update the `base_url` parameter for the `pgx_realm` configuration in the `pgx.conf` file with the matching host details.

   ```
   ...
    "pgx_realm": {
      "implementation": "oracle.pg.identity.DatabaseRealm",
   ```

```
  "options": {
    ...
    "base_url": "<request-scheme>://localhost:<request-port>"
  }
}
...
```

In the preceding configuration:

- ***request-scheme***: Value can be either `HTTP` or `HTTPS`. If not specified, then the graph server will fetch the corresponding value automatically from the browser.
- ***request-port***: Port number to be used. If not specified, then the graph server will fetch the corresponding value automatically from the browser.

Replace the default `localhost` to the required host name.

5. Restart the graph server.

> **Caution:**
>
> - Always use a valid 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. However, it is not recommended to use self-signed certificates for production environments.
> - The steps to generate a self-signed server certificate can modify the Java installation on your client-system. Only perform these steps if you are fully aware of the implications of accepting the self-signed certificates system-wide.
> - Consider carefully when using commands with `sudo`.

14.4.1.3 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.
- 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.

You can import the root certificate as shown in the following step:

- Ensure `JAVA_HOME` is set and run the following command as a `root` user or with `sudo`.

```
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.

If you are upgrading the graph server from a previous release, then you must first delete the existing certificate before importing the new certificate. Run the following command using `sudo` or as a `root` user to delete the certificate:

```
sudo keytool -delete -alias pgx -keystore $JAVA_HOME/lib/security/cacerts -
storepass changeit
```

15

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.

15.1 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)

15.1.1 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.

15.1.2 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 15-1 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 15-1 (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_SHA384",

Table 15-1 (Cont.) Configuration Parameters for the Graph Server (PGX)

Parameter	Type	Description	Default
			"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`
`max_header_size`	`integer`	Maximum valid header size in bytes. If `null`, use the default from Tomcat.	`null`
`port`	`integer`	Port the graph server (PGX) server should listen on.	`7007`
`server_keystore`	`string`	The path to the keystore to be used for server connections. 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`

Table 15-1 (Cont.) Configuration Parameters for the Graph Server (PGX)

Parameter	Type	Description	Default
`server_keystore_type`	`string`	This is the server keystore type of `server_keystore`.	`JKS`
`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 Using a Keystore

```
{
  "port": 7007,
  "enable_tls": true,
  "server_keystore": "/pgx/cert/server_keystore.rsa",
  "server_keystore_alias": "pgx",
  "server_keystore_provider": "JsafeJCE",
  "server_keystore_type": "PKCS12"
}
```

15.2 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 Graph Server (PGX) as a Library for more information.

- Connecting with the Graph Client CLIs
- Connecting with Java
- Connecting with Python

15.2.1 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> var g = session.readGraphByName("BANK_GRAPH_VIEW", GraphSource.PG_PGQL)
09:19:51,859+0000 DEBUG o.p.c.RemoteUtils - create session cookie (session ID
= 82f5cc30-358a-4002-a0bc-80a4ad690a94)
09:19:51,862+0000 DEBUG o.p.c.RemoteUtils - no value for the sticky cookie
given
09:19:51,862+0000 DEBUG o.p.c.RemoteUtils - create csrf token cookie (token =
d43a5de8-c81c-4361-ae15-81a1867cb2d6)
09:19:51,881+0000 DEBUG o.p.c.HttpRequestExecutor - Requesting POST https://
localhost:7007/core/v2/describe
09:19:51,902+0000 DEBUG o.p.c.HttpRequestExecutor - received HTTP status 202
09:19:51,904+0000 DEBUG o.p.c.HttpRequestExecutor -
{"futureId":"457025d4-3945-400a-95ed-a1897e6df9ac"}
09:19:51,911+0000 DEBUG o.p.c.PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/status
09:19:52,322+0000 DEBUG o.p.c.PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/value
09:19:52,337+0000 DEBUG o.p.c.RemoteUtils - received HTTP status 201
09:19:52,337+0000 DEBUG o.p.c.RemoteUtils -
{"source_name":"BANK_GRAPH_VIEW","optimized_for":"UPDATES","attributes":
{},"vertex_id_type":"string","edge_id_strategy":"PARTITIONED_IDS","vertex_id_s
trategy":"PARTITIONED_IDS","error_handling":
{"on_missing_vertex":"ERROR"},"source_type":"PG_PGQL","vertex_providers":
[{"error_handling":{},"format":"rdbms","key_column":"ID","props":
[{"column":"ID","type":"long","name":"ID","dimension":0},
{"column":"NAME","type":"string","name":"NAME","dimension":0}],"name":"ACCOUNT
S","parallel_hint_degree":-1,"loading":
{"create_key_mapping":true},"database_table_name":"BANK_ACCOUNTS","schema":"GR
APHUSER","key_type":"long","label":"ACCOUNTS","attributes":
{}}],"edge_id_type":"string","loading":
{"snapshots_source":"CHANGE_SET"},"name":"BANK_GRAPH_VIEW","edge_providers":
[{"error_handling":
{},"format":"rdbms","source_column":"FROM_ACCT_ID","destination_vertex_provide
r":"ACCOUNTS","props":
[{"column":"FROM_ACCT_ID","type":"long","name":"FROM_ACCT_ID","dimension":0},
{"column":"TO_ACCT_ID","type":"long","name":"TO_ACCT_ID","dimension":0},
{"column":"AMOUNT","type":"long","name":"AMOUNT","dimension":0},
{"column":"DESCRIPTION","type":"string","name":"DESCRIPTION","dimension":0}],"
name":"TRANSFERS","parallel_hint_degree":-1,"source_vertex_provider":"ACCOUNTS
","loading":
{"create_key_mapping":false},"database_table_name":"BANK_TXNS","schema":"GRAPH
USER","destination_column":"TO_ACCT_ID","key_type":"long","label":"TRANSFERS",
"attributes":{}}]}
09:19:52,545+0000 DEBUG o.p.c.RemoteUtils - create session cookie (session ID
= 82f5cc30-358a-4002-a0bc-80a4ad690a94)
09:19:52,547+0000 DEBUG o.p.c.RemoteUtils - no value for the sticky cookie
given
```

```
09:19:52,547+0000 DEBUG o.p.c.RemoteUtils - create csrf token cookie (token =
d43a5de8-c81c-4361-ae15-81a1867cb2d6)
09:19:52,673+0000 DEBUG o.p.c.HttpRequestExecutor - Requesting POST https://
localhost:7007/core/v1/loadGraph
09:19:52,692+0000 DEBUG o.p.c.HttpRequestExecutor - received HTTP status 202
09:19:52,695+0000 DEBUG o.p.c.HttpRequestExecutor -
{"futureId":"854bd093-8b80-437b-82ff-97f691436131"}
09:19:52,695+0000 DEBUG o.p.c.PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/status
09:19:53,313+0000 DEBUG o.p.c.PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/value
09:19:53,331+0000 DEBUG o.p.c.RemoteUtils - received HTTP status 201
09:19:53,332+0000 DEBUG o.p.c.RemoteUtils - {"id":"803F9E73-87BD-461E-A11A-
A54853E8A4A0","links":[{"href":"core/v1/graphs/x-graph-
id","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"core/v1/graphs/x-graph-
id","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"graphName":"BANK_GRAPH_VIEW","vertexTables":{"ACCOUNTS":
{"name":"ACCOUNTS","metaData":{"name":"ACCOUNTS","idType":"long","labels":
["ACCOUNTS"],"properties":
[{"name":"ID","id":null,"propertyType":"long","dimension":0,"transient":true,"
links":null,"propertyId":"6997E486-C525-4C5B-8A1B-8044386CF379"},
{"name":"NAME","id":null,"propertyType":"string","dimension":0,"transient":tru
e,"links":null,"propertyId":"F5473583-61AE-4EB8-B397-
EF2E4E93DD8F"}],"edgeProviderNamesWhereSource":
["TRANSFERS"],"edgeProviderNamesWhereDestination":
["TRANSFERS"],"id":null,"links":null},"providerLabels":
["ACCOUNTS"],"keyPropertyName":"ID","entityKeyType":"long","isIdentityKeyMappi
ng":false,"vertexProperties":{"05E515A7-CCF7-4A21-BC31-D4444D3B1CF0":
{"id":"05E515A7-CCF7-4A21-BC31-D4444D3B1CF0","links":[{"href":"core/v1/
graphs/x-graph-id/properties/x-property-
name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"core/v1/graphs/x-graph-id/properties/x-property-
name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":0,"propertyId":"05E515A7-CCF7-4A21-BC31-
D4444D3B1CF0","name":"ID","entityType":"vertex","type":"long","namespace":"2C1
7C639-3771-3E30-88AE-34D6B380C5EC","transient":false},"0DCCD46B-
ED5A-4511-865E-65CDCE6C3DFC":{"id":"0DCCD46B-
ED5A-4511-865E-65CDCE6C3DFC","links":[{"href":"core/v1/graphs/x-graph-id/
properties/x-property-name","rel":"self","method":"GET","interaction":["async-
polling"]},{"href":"core/v1/graphs/x-graph-id/properties/x-property-
name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":0,"propertyId":"0DCCD46B-
ED5A-4511-865E-65CDCE6C3DFC","name":"NAME","entityType":"vertex","type":"strin
g","namespace":"2C17C639-3771-3E30-88AE-34D6B380C5EC","transient":false}},"ver
texLabels":{"id":"13FE312F-18C8-4AFF-A154-AEDC3C5E86FC","links":
[{"href":"core/v1/graphs/x-graph-id/properties/x-property-
name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"core/v1/graphs/x-graph-id/properties/x-property-
name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":-1,"propertyId":"13FE312F-18C8-4AFF-A154-
AEDC3C5E86FC","name":"__vertex_labels__","entityType":"vertex","type":"ro_stri
ng_set","namespace":"2C17C639-3771
09:19:53,457+0000 DEBUG o.p.a.PgxSession - ==> change sets as snapshot
source. Returning graph loaded by the engine
g ==> PgxGraph[name=BANK_GRAPH_VIEW,N=1000,E=4993,created=1704705593065]
```

Python

```
>>>setloglevel("oracle.pgx","DEBUG")
>>> graph = session.read_graph_by_name('BANK_GRAPH_VIEW', 'pg_pgql')
09:26:26,548+0000 DEBUG o.p.c.RemoteUtils - create session cookie (session ID
= 279f1676-9229-4c5d-bc71-473e5ce5afb9)
09:26:26,554+0000 DEBUG o.p.c.RemoteUtils - no value for the sticky cookie
given
09:26:26,555+0000 DEBUG o.p.c.RemoteUtils - create csrf token cookie (token =
354b9253-84fb-4689-8d29-79da8ec1e3cf)
09:26:26,617+0000 DEBUG o.p.c.HttpRequestExecutor - Requesting POST https://
localhost:7007/core/v2/describe
09:26:26,670+0000 DEBUG o.p.c.HttpRequestExecutor - received HTTP status 202
09:26:26,671+0000 DEBUG o.p.c.HttpRequestExecutor - {"futureId":"95a4da84-
ff08-4471-97ac-6a571c68a82f"}
09:26:26,675+0000 DEBUG o.p.c.PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/status
09:26:26,708+0000 DEBUG o.p.c.PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/value
09:26:26,716+0000 DEBUG o.p.c.RemoteUtils - received HTTP status 201
09:26:26,717+0000 DEBUG o.p.c.RemoteUtils -
{"source_name":"BANK_GRAPH_VIEW","optimized_for":"UPDATES","attributes":
{},"vertex_id_type":"string","edge_id_strategy":"PARTITIONED_IDS","vertex_id_s
trategy":"PARTITIONED_IDS","error_handling":
{"on_missing_vertex":"ERROR"},"source_type":"PG_PGQL","vertex_providers":
[{"error_handling":{},"format":"rdbms","key_column":"ID","props":
[{"column":"ID","type":"long","name":"ID","dimension":0},
{"column":"NAME","type":"string","name":"NAME","dimension":0}],"name":"ACCOUNT
S","parallel_hint_degree":-1,"loading":
{"create_key_mapping":true},"database_table_name":"BANK_ACCOUNTS","schema":"GR
APHUSER","key_type":"long","label":"ACCOUNTS","attributes":
{}}],"edge_id_type":"string","loading":
{"snapshots_source":"CHANGE_SET"},"name":"BANK_GRAPH_VIEW","edge_providers":
[{"error_handling":
{},"format":"rdbms","source_column":"FROM_ACCT_ID","destination_vertex_provide
r":"ACCOUNTS","props":
[{"column":"FROM_ACCT_ID","type":"long","name":"FROM_ACCT_ID","dimension":0},
{"column":"TO_ACCT_ID","type":"long","name":"TO_ACCT_ID","dimension":0},
{"column":"AMOUNT","type":"long","name":"AMOUNT","dimension":0},
{"column":"DESCRIPTION","type":"string","name":"DESCRIPTION","dimension":0}],"
name":"TRANSFERS","parallel_hint_degree":-1,"source_vertex_provider":"ACCOUNTS
","loading":
{"create_key_mapping":false},"database_table_name":"BANK_TXNS","schema":"GRAPH
USER","destination_column":"TO_ACCT_ID","key_type":"long","label":"TRANSFERS",
"attributes":{}}]}
09:26:26,862+0000 DEBUG o.p.c.RemoteUtils - create session cookie (session ID
= 279f1676-9229-4c5d-bc71-473e5ce5afb9)
09:26:26,862+0000 DEBUG o.p.c.RemoteUtils - no value for the sticky cookie
given
09:26:26,862+0000 DEBUG o.p.c.RemoteUtils - create csrf token cookie (token =
354b9253-84fb-4689-8d29-79da8ec1e3cf)
09:26:26,930+0000 DEBUG o.p.c.HttpRequestExecutor - Requesting POST https://
localhost:7007/core/v1/loadGraph
09:26:26,963+0000 DEBUG o.p.c.HttpRequestExecutor - received HTTP status 202
09:26:26,964+0000 DEBUG o.p.c.HttpRequestExecutor -
{"futureId":"a6ec1f14-891d-470a-a20a-3e0a4a76c11d"}
```

```
09:26:26,965+0000 DEBUG o.p.c.PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/status
09:26:27,183+0000 DEBUG o.p.c.PgxRemoteFuture - Requesting GET https://
localhost:7007/core/v1/futures/x-future-id/value
09:26:27,202+0000 DEBUG o.p.c.RemoteUtils - received HTTP status 201
09:26:27,203+0000 DEBUG o.p.c.RemoteUtils - {"id":"CCA6B5D6-46DB-4DFE-
AC60-2FDFBD8631AC","links":[{"href":"core/v1/graphs/x-graph-
id","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"core/v1/graphs/x-graph-
id","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"graphName":"BANK_GRAPH_VIEW","vertexTables":{"ACCOUNTS":
{"name":"ACCOUNTS","metaData":{"name":"ACCOUNTS","idType":"long","labels":
["ACCOUNTS"],"properties":
[{"name":"ID","id":null,"propertyType":"long","dimension":0,"transient":true,"
links":null,"propertyId":"5A6A679C-BBD8-4CA9-886C-19D7DA3041F5"},
{"name":"NAME","id":null,"propertyType":"string","dimension":0,"transient":tru
e,"links":null,"propertyId":"3B479E88-3441-49EA-95EE-
FC14EE0FD318"}],"edgeProviderNamesWhereSource":
["TRANSFERS"],"edgeProviderNamesWhereDestination":
["TRANSFERS"],"id":null,"links":null},"providerLabels":
["ACCOUNTS"],"keyPropertyName":"ID","entityKeyType":"long","isIdentityKeyMappi
ng":false,"vertexProperties":{"9B32DB07-AD6A-47AA-AD7E-56FE417D0423":
{"id":"9B32DB07-AD6A-47AA-AD7E-56FE417D0423","links":[{"href":"core/v1/
graphs/x-graph-id/properties/x-property-
name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"core/v1/graphs/x-graph-id/properties/x-property-
name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":0,"propertyId":"9B32DB07-AD6A-47AA-
AD7E-56FE417D0423","name":"ID","entityType":"vertex","type":"long","namespace"
:"2C17C639-3771-3E30-88AE-34D6B380C5EC","transient":false},"99C98B32-
FD2F-46B5-A89A-BBB043E38F7E":{"id":"99C98B32-FD2F-46B5-A89A-
BBB043E38F7E","links":[{"href":"core/v1/graphs/x-graph-id/properties/x-
property-name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"core/v1/graphs/x-graph-id/properties/x-property-
name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":0,"propertyId":"99C98B32-FD2F-46B5-A89A-
BBB043E38F7E","name":"NAME","entityType":"vertex","type":"string","namespace":
"2C17C639-3771-3E30-88AE-34D6B380C5EC","transient":false}},"vertexLabels":
{"id":"85CE5DC4-B2B3-4326-B970-F1A6EB5E0345","links":[{"href":"core/v1/
graphs/x-graph-id/properties/x-property-
name","rel":"self","method":"GET","interaction":["async-polling"]},
{"href":"core/v1/graphs/x-graph-id/properties/x-property-
name","rel":"canonical","method":"GET","interaction":["async-
polling"]}],"dimension":-1,"propertyId":"85CE5DC4-B2B3-4326-B970-
F1A6EB5E0345","name":"__vertex_labels__","entityType":"vertex","type":"ro_stri
ng_set","namespace":"2C17C639-3771
09:26:27,357+0000 DEBUG o.p.a.PgxSession - ==> change sets as snapshot
source. Returning graph loaded by the engine
```


15.2.2 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

15.2.2.1 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.

15.2.3 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 (ID)
            DESTINATION KEY (to_acct_id) REFERENCES bank_accounts (ID)
            LABEL TRANSFERS
            PROPERTIES (FROM_ACCT_ID, TO_ACCT_ID, AMOUNT, DESCRIPTION)
        ) OPTIONS(PG_PGQL)
"""
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_pgql')
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.

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
  This chapter describes the graph server REST API endpoints.

16

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 Graph Server Administrator Dashboard
  The graph server administrator can efficiently track and manage the memory usage of the graph server (PGX) using the Administrator Dashboard.
- 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.
- 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 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.

16.1 Using the Graph Server Administrator Dashboard

The graph server administrator can efficiently track and manage the memory usage of the graph server (PGX) using the Administrator Dashboard.

You can access the Administrator Dashboard only if you are granted the `GRAPH_ADMINISTRATOR` role having the `PGX_GET_SERVER_INFO` privilege.

The user-friendly interface of the Administrator Dashboard comprises the following components:

- **Memory Usage:** To view data charts on real-time memory usage, study the current memory consumption patterns and identify any potential issues.
- **Sessions:** To manage, monitor, and search active user sessions.
- **Graphs:** To track and monitor memory usage per graph for all the active users.

Perform the following steps to access the Administrator Dashboard:

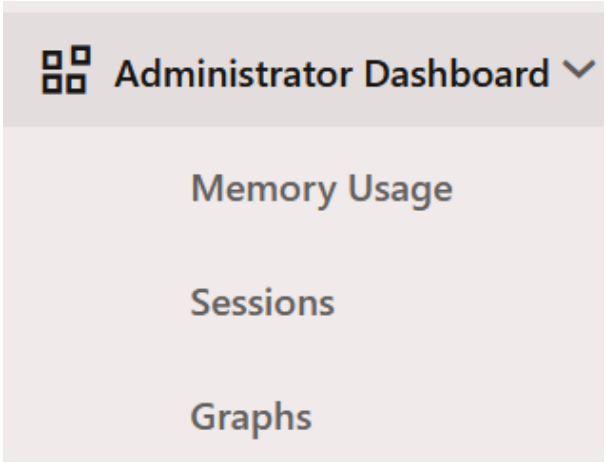
1. Open the following URL in your web browser.

   `https://<server_host>:7007/dash/`

   The Graph Dashboard login screen opens.
2. Enter your **Username** and **Password**.
3. Click **Submit**.
4. Click **Administrator Dashboard** in the left navigation menu.

   The **Memory Usage** page of the Administrator Dashboard opens.
5. Optionally, click **Sessions** or **Graphs** to navigate to the respective pages.

Figure 16-1 Administrator Dashboard Menu

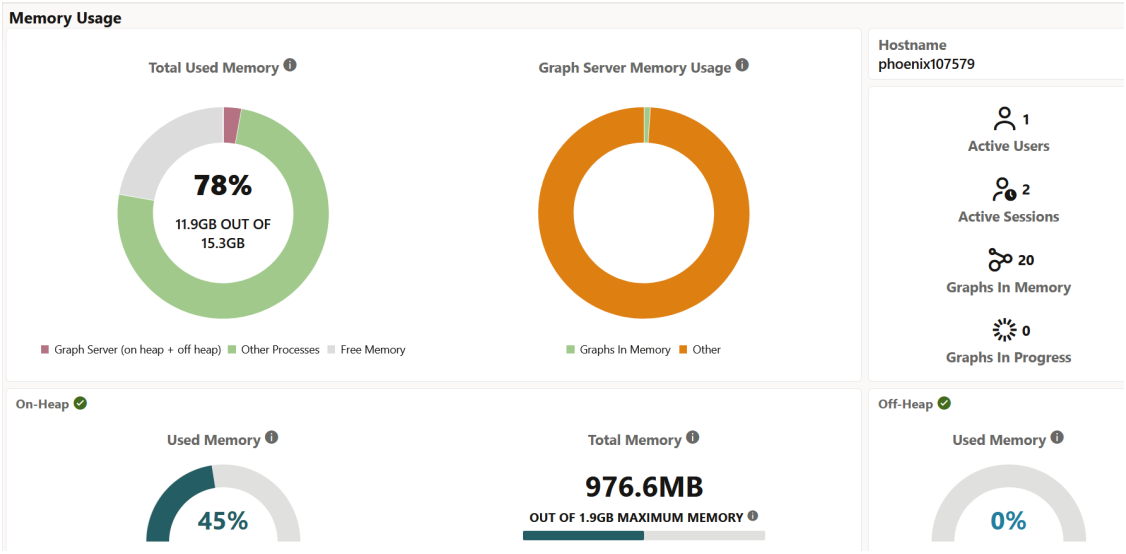


- Memory Usage
  The Memory Usage dashboard provides in-depth information on the amount of memory used by the graph server (PGX).
- Sessions
  The Sessions page displays all the active user sessions.
- Graphs
  The Graphs page lists the graphs for all the active users and provides the total memory usage for each graph.

16.1.1 Memory Usage

The Memory Usage dashboard provides in-depth information on the amount of memory used by the graph server (PGX).

Figure 16-2 Memory Usage Dashboard



The dashboard comprises the following sections:

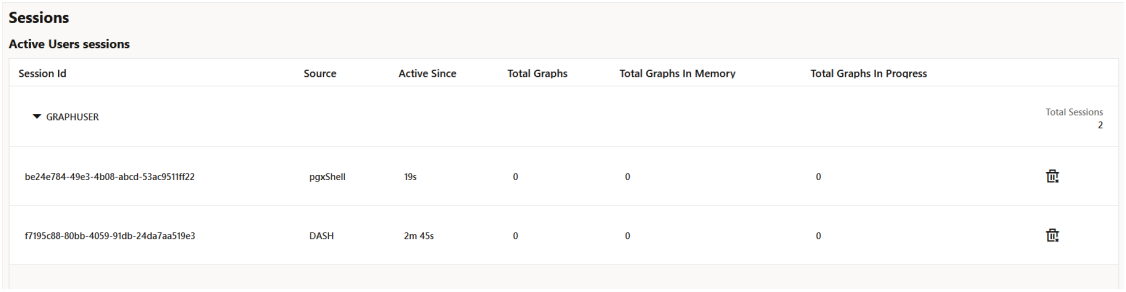
- **Total Used Memory:** This chart displays the total memory usage at the system level. It shows the memory consumption by the graph server (sum of on-heap and off-heap memory) and other processes. You can also view the available amount of free memory.
- **Graph Server Memory Usage:** This chart displays the memory consumed by graphs that are loaded into the graph server and also the memory usage for other graph operations such as loading graphs, running graph algorithms and so on.
- **On-Heap:** This section provides the following details:
  - **Used Memory:** This displays the on-heap memory used currently by the graph server out of the total heap size that is dynamically allocated by the JVM.
  - **Total Memory:** This displays the total (determined by the -Xms flag) and maximum heap size (determined by the -Xmx flag) allocated by the JVM.
- **Off-heap:** This displays the off-heap memory used currently by the graph server.
- **Hostname:** Graph server hostname
- – **Active Users:** Number of active users
  - **Active Sessions:** Number of active sessions
  - **Graphs In Memory:** Number of graphs loaded in to memory
  - **Graphs in Progress:** Number of graphs that are being loaded into memory

16.1.2 Sessions

The Sessions page displays all the active user sessions.

You can view the number of graphs associated with each session as shown in the following figure. In addition, you can terminate one or more user sessions.

Figure 16-3 Sessions



16.1.3 Graphs

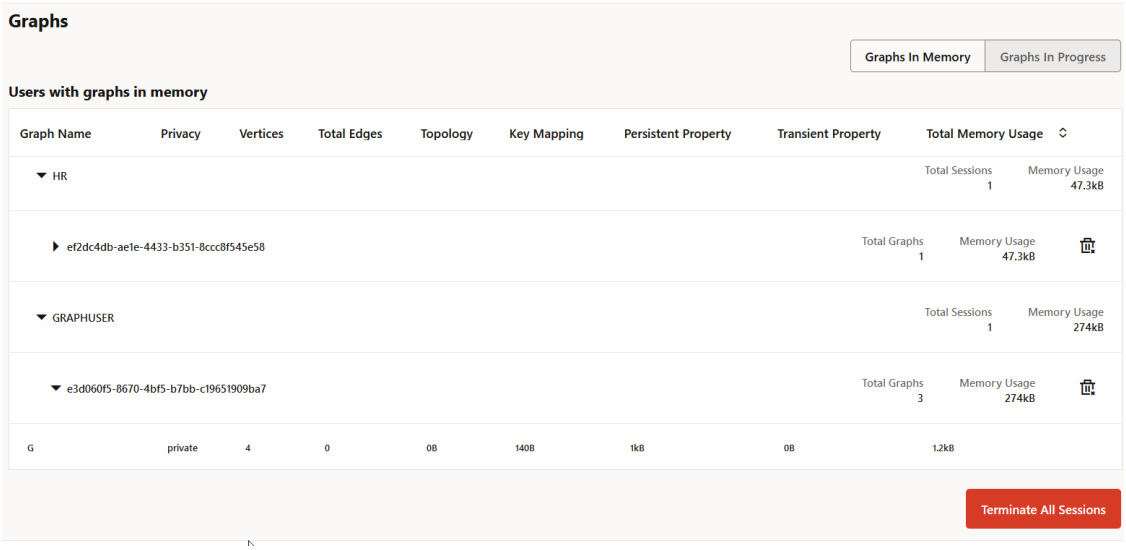
The Graphs page lists the graphs for all the active users and provides the total memory usage for each graph.

This page comprises the following two tabs:

- **Graphs In Memory (default):** Displays graphs that are loaded into memory.
- **Graphs In Progress:** Displays graphs that are being loaded into memory.

The following figure shows the Graphs page for the **Graphs In Memory** tab. You can inspect the memory usage for the graphs, or terminate one or more user sessions.

Figure 16-4 Graphs



16.2 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 `partitioned_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.

16.3 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.

> **Note:**
>
> Ensure that you drop the graph when it is no longer in use to release the graph server (PGX) memory. See Deleting a Graph for more information.

- 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 is loaded into the graph server (PGX), so that it can be referenced by other sessions. Similarly, the snapshots of a graph can also be made available to 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 `close()` method.
- Graph Sharing Options and Validating Graph Permissions
  The `graph_sharing_option` parameter in the `pgx.conf` file determines if and how a graph can be shared.

16.3.1 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.

The following options are supported for loading a graph:

SQL Property Graphs

- Using the `readGraphByName` API - see Loading a SQL Property Graph Using the readGraphByName API for more details.
- Using the `PgSqlSubgraphReader` API to create and load a subgraph - see Loading a Subgraph Using PGQL Queries for more details.
- Using the PGQL `CREATE PROPERTY GRAPH` statement - see Creating a SQL Property Graph Using PGQL for more details.

PGQL Property Graphs

- Using the `readGraphByName` API - see Loading a PGQL Property Graph 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#fromPgPgql` API to create and load a subgraph - see Loading a Subgraph from a PGQL Property Graph 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.

Also, refer to the following sections:

- Enabling Lazy Loading of Graphs
  Starting from Graph Server and Client Release 24.3, you can enable lazy loading for database graphs.
- 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.
- 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.

16.3.1.1 Enabling Lazy Loading of Graphs

Starting from Graph Server and Client Release 24.3, you can enable lazy loading for database graphs.

When lazy loading is enabled, the graphs are automatically loaded into the graph server (PGX) the first time you access them in a PGQL query. This implies that you can run a PGQL query from a `PgxSession` instance even if the graph was not loaded into the graph server (PGX) earlier. However, ensure that you specify the graph name using the `ON` clause as shown:

- JShell
- Java
- Python

JShell

```
opg4j> session.queryPgql("SELECT x.* FROM MATCH (x) ON <graph_name>")
```

Java

```
session.queryPgql("SELECT x.* FROM MATCH (x) ON <graph_name>");
```

Python

```
session.query_pgql("SELECT x.* FROM MATCH (x) ON <graph_name>")
```

Also, note the following details when lazy loading a graph into the graph server (PGX) memory:

- To use the lazy loading feature, you must add (if not previously added) and enable the `allow_lazy_loading_for_database_graphs` configuration field in the `pgx.conf` file.

  ```
  {
       "allow_lazy_loading_for_database_graphs": true
  }
  ```

- The graph will be loaded by name if it exists in the database. Loading a graph by name relies on the database credentials provided in the `pgx_realm` options in the `pgx.conf` file.
- Loading will only happen if the graph is not already loaded into the graph server (PGX) memory.
- Lazy loading is supported for both PGQL and SQL property graphs. The graph server (PGX) first attempts to load the graph as a SQL property graph. In case it does not exist, then the graph is loaded as a PGQL property graph.
- You must have `READ` permission on the graph and underlying data source tables.
- Lazily loaded graph is added as a session dependency and periodic permission checks are performed on the graph.
- The following APIs support lazy loading of graphs upon first use:
  - `PgxSession.queryPgql`
  - `PgxSession.executePgql`
  - `PgxSession.preparePgql`
  - `PgxSession.explainPgql`

The following example shows the various queries that will trigger lazing loading of a graph. The example assumes that `allow_lazy_loading_for_database_graphs` is enabled and `MY_GRAPH` exists in the database and is not already loaded into the graph server (PGX) memory.

- JShell
- Java

- Python

JShell

```
opg4j> session.queryPgql("SELECT x.name FROM MATCH (x) ON MY_GRAPH")
opg4j> session.preparePgql("SELECT x.name FROM MATCH (x) ON MY_GRAPH WHERE
x.age = ?")
opg4j> session.executePgql("SELECT x.name FROM MATCH (x) ON MY_GRAPH")
opg4j> session.explainPgql("SELECT x.name, x.* FROM MATCH (x) ON MY_GRAPH")
```

Java

```
session.queryPgql("SELECT x.name FROM MATCH (x) ON MY_GRAPH");
session.preparePgql("SELECT x.name FROM MATCH (x) ON MY_GRAPH WHERE x.age
= ?");
session.executePgql("SELECT x.name FROM MATCH (x) ON MY_GRAPH");
session.explainPgql("SELECT x.name, x.* FROM MATCH (x) ON MY_GRAPH");
```

Python

```
session.query_pgql("SELECT x.name FROM MATCH (x) ON MY_GRAPH")
session.prepare_pgql("SELECT x.name FROM MATCH (x) ON MY_GRAPH WHERE x.age
= ?")
session.execute_pgql("SELECT x.name FROM MATCH (x) ON MY_GRAPH")
session.explain_pgql("SELECT x.name, x.* FROM MATCH (x) ON MY_GRAPH")
```

16.3.1.2 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 16-1 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.
`"<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 16-1 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 16-2 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")
```

16.3.1.3 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 16-3 Asynchronous Graph Loading APIs

Data Format	API
PGQL Property Graph	session.readGraphByNameAsync()
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 PGQL property graph 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",
GraphSource.PG_PGQL)
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_3,N=999,E=4993,created=1664289985985]
```

Java

```
PgxFuture<PgxGraph> graphLoadingFuture =
session.readGraphByNameAsync("BANK_GRAPH", GraphSource.PG_PGQL);
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.

16.3.1.4 Graph Configuration Options

Learn about the graph configuration options.

The following table lists the JSON fields that are common to all graph configurations:

Table 16-4 Graph Config JSON Fields

Field	Type	Description	Default
`name`	`string`	Name of the graph.	Required

Table 16-4 (Cont.) Graph Config JSON Fields

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
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
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

Table 16-4 (Cont.) Graph Config JSON Fields

Field	Type	Description	Default
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_pgql, pg_sql]	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.	[]
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.	[]

Table 16-4 (Cont.) Graph Config JSON Fields

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 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 16-5 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

Table 16-5 (Cont.) Provider Configuration JSON file Options

Field	Type	Description	Default
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.	[]
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 16-6 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
`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`

Table 16-6 (Cont.) Property Configuration

Field	Type	Description	Default
`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 16-7 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 16-8 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`
`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`.

16.3.1.5 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.

16.3.1.6 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 16-9 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

16.3.1.7 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.

16.3.2 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 PGQL property graph 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_PGQL)
g ==> PgxGraph[name=BANK_GRAPH,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.)

16.3.3 Publishing a Graph

You can publish a graph that is loaded into the graph server (PGX), so that it can be referenced by other sessions. Similarly, the snapshots of a graph can also be made available to other sessions.

Publishing a Graph with Snapshots

After loading a graph is loaded into the graph server, if you want to make all snapshots of the graph visible to other sessions (under the same user), 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. Hence, **transient properties are not published** when calling `publishWithSnapshots()` without arguments.

Publishing a graph with `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.

- JShell
- Java
- Python

JShell

```
opg4j> graph.publishWithSnapshots()
```

Java

```
graph.publishWithSnapshots();
```

Python

```
>>> graph.publish_with_snapshots()
```

If you want to publish specific transient properties, then you can list them within the `publishWithSnapshots()` call, as shown in the following example:

- JShell

- Java

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);
Collection<VertexProperty<?, ?>> vertexProps = Arrays.asList(prop1);
Collection<EdgeProperty<?>> edgeProps = Arrays.asList(cost);
graph.publishWithSnapshots(vertexProps,edgeProps);
```

Alternatively, all properties can be published at once by passing the built-in `VertexProperty.ALL` and `EdgeProperty.ALL` to `publishWithSnapshots()`, as in the following example.

- JShell
- Java

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(VertexProperty.ALL, EdgeProperty.ALL)
```

Java

```
VertexProperty<Integer, Integer> prop1 =
graph.createVertexProperty(PropertyType.INTEGER, "prop1");
prop1.fill(0);
EdgeProperty<Double> cost = graph.createEdgeProperty(PropertyType.DOUBLE,
"cost");
cost.fill(0d);
Collection<VertexProperty<?, ?>> vertexProps = Arrays.asList(prop);
```

```
Collection<EdgeProperty<?>> edgeProps = Arrays.asList(cost);
graph.publishWithSnapshots(VertexProperty.ALL, EdgeProperty.ALL);
```

After creating a snapshot, properties in the new snapshot will inherit the publishing state of properties in the old snapshot. This implies that if a property is published in the old snapshot, it will also be published in the new snapshot. Otherwise it will remain session private in the new snapshot. This behavior is configurable with `enable_snapshot_properties_publish_state_propagation flag` (see Configuration Parameters for the Graph Server (PGX) Engine). By default, this flag is enabled. However, it can be disabled by setting its value to false, in which case, the publishing state of the properties will be ignored when creating new snapshots and the properties in new snapshots will be session-private.

> **Note:**
>
> By default, calling `publishWithSnapshots()` is allowed only on the **latest** snapshot. Calling `publishWithSnapshots()` on an old snapshot will result in an exception. To allow calling `publishWithSnapshots()` on any snapshot, set the `enable_snapshot_properties_publish_state_propagation` configuration field in the `pgx.conf` file to `false`.

- JShell
- Java

JShell

```
opg4j> var prop1 = graph.createVertexProperty(PropertyType.INTEGER, "prop1")
opg4j> prop1.fill(0)
opg4j> var prop2 = graph.createVertexProperty(PropertyType.INTEGER, "prop2")
opg4j> prop2.fill(0)
opg4j> var cost = graph.createEdgeProperty(PropertyType.DOUBLE, "cost")
opg4j> cost.fill(0d)

// the example intentionally avoids publishing prop2
opg4j> graph.publishWithSnapshots(List.of(prop1), List.of(cost))
opg4j> var snapshot = graph.createChangeSet().buildNewSnapshot()
opg4j> snapshot.getVertexProperty("prop1").isPublished()
=> true
opg4j> snapshot.getVertexProperty("prop2").isPublished()
=> false
opg4j> snapshot.getEdgeProperty("cost").isPublished()
=> true

// publish prop2 in snapshot, this will make it published in future snapshots
too
// but not in the previous snapshots
opg4j> snapshot.getVertexProperty("prop2").publish()
opg4j> var snapshot2 = snapshot.createChangeSet().buildNewSnapshot();
```

```
opg4j> snapshot2.getVertexProperty("prop1").isPublished()
=> true
opg4j> snapshot2.getVertexProperty("prop2").isPublished()
=> true
opg4j> snapshot2.getEdgeProperty("cost").isPublished()
=> true
```

Java

```
VertexProperty<Integer, Integer> prop1 =
graph.createVertexProperty(PropertyType.INTEGER, "prop1");
prop1.fill(0);
VertexProperty<Integer, Integer> prop2 =
graph.createVertexProperty(PropertyType.INTEGER, "prop2");
prop2.fill(0);
EdgeProperty<Double> cost = graph.createEdgeProperty(PropertyType.DOUBLE,
"cost");
cost.fill(0d);

// the example intentionally avoids publishing prop2
graph.publishWithSnapshots(List.of(prop1), List.of(cost));
PgxGraph snapshot = graph.createChangeSet().buildNewSnapshot();
System.out.println(snapshot.getVertexProperty("prop1").isPublished()); //
Returns true
System.out.println(snapshot.getVertexProperty("prop2").isPublished()); //
Returns false
System.out.println(snapshot.getEdgeProperty("cost").isPublished());    //
Returns true

// publish prop2 in snapshot, this will make it published in future snapshots
too
// but not in the previous snapshots.
snapshot.getVertexProperty("prop2").publish();
PgxGraph snapshot2 = snapshot.createChangeSet().buildNewSnapshot();
System.out.println(snapshot2.getVertexProperty("prop1").isPublished()); //
Returns true
System.out.println(snapshot2.getVertexProperty("prop2").isPublished()); //
Returns true
System.out.println(snapshot2.getEdgeProperty("cost").isPublished());    //
Returns true
```

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 14-6 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);
Collection<VertexProperty<?, ?>> vertexProps = Arrays.asList(prop);
Collection<EdgeProperty<?>> 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(float(0))
vertex_props = [prop]
edge_props = [cost]
graph.publish(vertex_props, edge_props)
```

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. By default, the publishing state of the transient properties are associated to the specific snapshot on which they are created and thus they are 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.

16.3.4 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 `close()` method.

Calling the `close()` 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 deleted automatically. If a session holds multiple `PgxGraph` objects referencing the same graph, invoking `close()` 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.close()                                  // 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.close();

// 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.close()

# 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, closing 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.close();

// 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 closed 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(<namespace>)` 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 `close()` call. See Resource Management Considerations for more information.

16.3.5 Graph Sharing Options and Validating Graph Permissions

The `graph_sharing_option` parameter in the `pgx.conf` file determines if and how a graph can be shared.

It mainly depends on whether or not the graph source is known. The graph server (PGX) supports sharing of graphs within sessions of a single user (through the publish API) or across sessions of different users (through the publish and grant permission APIs).

The graph server (PGX) defines the following three levels of graph traceability:

- *Fully Traceable Graph*: All providers of the graph are traceable. For example, loading data from a set of database tables is a traceable source. Therefore, graphs loaded using `session.readGrapbByName()` are considered traceable.
- *Partially Traceable Graph*: The graph contains mixed providers, that is, few traceable and few non-traceable providers.
- *Non-Traceable Graph*: All providers of the graph are not traceable. Graphs created as a result of mutation (through graph alteration APIs) on a loaded graph instance are considered not traceable.

In addition, the graph server (PGX) will perform periodic checks on all partially traceable and fully traceable graphs to make sure that the user holding a reference to a traceable graph has all the permissions to access the source graph data in the database. If the permission check fails (for example, the user privileges on the original data source have been revoked), then the user session will be destroyed and all sessions of the same user accessing the graph data will be released from memory. The `permission_checks_interval` field in the `pgx.conf` file can be used to control the frequency at which the graph server must check the graph permissions.

The following table shows the three `graph_sharing_option` modes that are supported by the graph server (PGX).

Table 16-10 Graph Sharing Options

Graph Sharing Option	Description	Publish API Allowed	Grant Permission API Allowed	PgetGraph rPermission oCheck dic Permission Check
ALLOW_DATA_SHARING <default>	This indicates that all graph types (traceable or not) is allowed across sessions of a single user and across users.	Yes	Yes	YYes es
ALLOW_TRACEABLE_DATA_SHARING_WITHIN_SAME_USER	This allows only sharing of fully traceable graphs among sessions of a single user. It does not allow sharing across multiple users, or sharing of non-traceable graphs or partially traceable graphs .	Yes (only for fully traceable graphs)	No	YYes es
DISALLOW_DATA_SHARING	This indicates graphs are always session private.	No	No	YYes (not ereally sneeded)

For instance, consider the following example in which the `graph_sharing_option` is set as `ALLOW_TRACEABLE_DATA_SHARING_WITHIN_SAME_USER` and the `permission_checks_interval` parameter defaults to 60 seconds in the `pgx.conf` file. Assume that a graph user's permission to an underlying source table is revoked after the user publishes the graph. If the user attempts to access the graph data, in the current or in another session, the graph gets invalidated and the respective sessions are destroyed.

The following code shows the graph invalidation scenario in the current user session:

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("HR", "EMP_GRAPH",
GraphSource.PG_PGQL)
graph ==> PgxGraph[name=EMP_GRAPH,N=134,E=11,created=1696308375704]
opg4j> session.getGraph("EMP_GRAPH")
$2 ==> graph ==> PgxGraph[name=EMP_GRAPH,N=134,E=11,created=1696402820966]
opg4j> graph.publish()
// Source table permission revoked for the user
opg4j> session.getGraph("EMP_GRAPH") //throws exception and the current
session is explicitly destroyed
```

Java

```
PgxGraph graph = session.readGraphByName("HR", "EMP_GRAPH",
GraphSource.PG_PGQL);
session.getGraph("EMP_GRAPH");
graph.publish();
// Source table permission revoked for the user
session.getGraph("EMP_GRAPH"); //throws exception and the current session is
explicitly destroyed
```

Python

```
>>> graph = session.read_graph_by_name("EMP_GRAPH", "pg_pgql", schema="HR")
>>> session.get_graph("EMP_GRAPH")
PgxGraph(name: EMP_GRAPH, v: 134, e: 11, directed: True, memory(Mb): 0)
>>> graph.publish()
>>> # Source table permission revoked for the user
>>> session.get_graph("EMP_GRAPH") #throws exception and the current session
is explicitly destroyed
```

The following code shows that the referenced graph also gets invalidated in another session of the given user after permission to the source data table is revoked for the user:

- JShell
- Java
- Python

JShell

```
opg4j> //throws exception in another session and the session gets explicitly
destroyed
opg4j> graph.queryPgql("SELECT n.* from MATCH (n:employees) LIMIT 5").print()
```

Java

```
//throws exception in another session and the session gets explicitly
destroyed
graph.queryPgql("SELECT n.* from MATCH (n:employees) LIMIT 5").print();
```

Python

```
>>> #throws exception in another session and the session gets explicitly
destroyed
>>> graph.query_pgql("SELECT n.* from MATCH (n:employees) LIMIT 5").print()
```

16.4 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 (PGQL property graphs and SQL property graphs) can be synchronized. Graphs created from other formats or graphs created via the graph builder API or PGQL property 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 SQL Property Graph
  You can synchronize a SQL property graph that is loaded into the graph server (PGX) with the changes made to the graph data in the database.
- Synchronizing a PGQL Property Graph
  You can synchronize a PGQL property graph loaded into the graph server (PGX) with the changes made to the graph data 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.

16.4.1 Synchronizing a SQL Property Graph

You can synchronize a SQL property graph that is loaded into the graph server (PGX) with the changes made to the graph data in the database.

The following example shows the steps for synchronizing a SQL property graph using the FlashbackSynchronizer API:

1. Load the SQL property graph into the graph server (PGX) using the `readGraphByName()` API as shown:

   - JShell
   - Java
   - Python

JShell

```
opg4j> var graph = session.readGraphByName("BANK_SQL_PG",
GraphSource.PG_SQL,
...>
ReadGraphOption.optimizeFor(GraphOptimizedFor.UPDATES),
...>                    ReadGraphOption.synchronizable())
graph ==> PgxGraph[name=BANK_SQL_PG_2,N=1000,E=5001,created=1697259571499
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_SQL_PG",GraphSource.PG_SQL,
                   ReadGraphOption.optimizeFor(GraphOptimizedFor.UPDATES),
                   ReadGraphOption.synchronizable());
```

Python

```
>>> graph = session.read_graph_by_name('BANK_SQL_PG', 'pg_sql',
...              options=['optimized_for_updates', 'synchronizable'])
```

2. Open a new JDBC connection to the database and change the data in the underlying database tables for the SQL property 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@738e79ec
opg4j> var stmt = conn.createStatement()
stmt ==> oracle.jdbc.driver.OracleStatementWrapper@71f056a
opg4j> stmt.executeQuery("UPDATE bank_txns SET amount=2000 WHERE txn_id=2")
$8 ==> oracle.jdbc.driver.ForwardOnlyResultSet@19b0a9f2
opg4j> conn.commit()
```

Java

```
Connection conn =
DriverManager.getConnection(<jdbcUrl>,<username>,<password>);
Statement stmt = conn.createStatement();
stmt.executeQuery("UPDATE bank_txns SET amount=2000 WHERE txn_id=2");
conn.commit();
```

Python

```
>>> conn = opg4py.pgql.get_connection(<username>,<password>,
<jdbcUrl>).get_jdbc_connection()
>>> conn.prepareStatement("UPDATE bank_txns SET amount=2000 WHERE
txn_id=2").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:

- JShell
- Java
- Python

JShell

```
opg4j>  var synchronizer =
graph.createSynchronizer(FlashbackSynchronizer.class, conn)
synchronizer ==> oracle.pgx.api.FlashbackSynchronizer@5f65e0c0
```

Java

```
Synchronizer synchronizer =
graph.createSynchronizer(FlashbackSynchronizer.class, conn);
```

Python

```
>>> synchronizer =
graph.create_synchronizer(synchronizer_class='oracle.pgx.api.FlashbackSynch
ronizer',
...              jdbc_url=<jdbcUrl>, username=<username>,
password=<password>)
```

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()
graph ==> PgxGraph[name=BANK_SQL_PG,N=1000,E=5001,created=1696332603804]
```

Java

```
graph=synchronizer.sync();
```

Python

```
graph=synchronizer.sync()
```

Note that the `Synchronizer` object needs to be created only once per session. Once created, you can perform the `synchronizer.sync()` operation multiple times to generate the latest graph snapshot that is consistent with the changes in the database.

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:Account)-
[e:Transfer]->(v2:Account) WHERE e.from_acct_id = 237 AND
e.to_acct_id=777").print()
```

Java

```
graph.queryPgql("SELECT e.amount FROM MATCH (v1:Accounts)-[e:Transfers]-
>(v2:Accounts) WHERE e.from_acct_id = 237 AND e.to_acct_id=777").print();
```

Python

```
>>> graph.query_pgql("SELECT e.amount FROM MATCH (v1:Account)-[e:Transfer]-
>(v2:Account) WHERE v1.id = 237 AND v2.id=777").print()
```

On execution, the preceding example produces the following output:

```
+--------+
| amount |
+--------+
| 2000.0 |
+--------+
```

16.4.2 Synchronizing a PGQL Property Graph

You can synchronize a PGQL property graph loaded into the graph server (PGX) with the changes made to the graph data in the database.

The following example shows the steps for synchronizing a PGQL property graph using the FlashbackSynchronizer API:

1. Load the PGQL property graph into the graph server (PGX) using the `readGraphByName()` API as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var graph =
session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL,

ReadGraphOption.optimizeFor(GraphOptimizedFor.UPDATES),ReadGraphOption.sync
hronizable())
graph ==> PgxGraph[name=BANK_GRAPH,N=999,E=4993,created=1660275936010]
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL,

ReadGraphOption.optimizeFor(GraphOptimizedFor.UPDATES),ReadGraphOption.sync
hronizable());
```

Python

```
>>> graph = session.read_graph_by_name('BANK_GRAPH','pg_pgql',
...              options=['optimized_for_updates', 'synchronizable'])
```

2. Open a new JDBC connection to the database and change the data in the underlying database tables for the PGQL property 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>,
<jdbc_url>).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)
    .setParallelHintDegree(4)
    .build();
```

Internally, the graph server keeps track of the Oracle system change number (SCN) to which the current graph snapshot belongs. 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).

You can specify the degree of parallelism in the Flashback Synchronizer builder using the `setParallelHintDegree` API. The specified parallel hint degree will be taken into account by the Flashback Synchronizer when executing the SQL queries.

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.FlashbackSynch
ronizer', jdbc_url=<jdbc_url>, username=<username>, password=<password>)
```

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,N=999,E=4993,created=1660308128037]
```

Java

```
graph=synchronizer.sync();
```

Python

```
>>> graph = synchronizer.sync()
```

Note that the `Synchronizer` object needs to be created only once per session. Once created, you can perform the `synchronizer.sync()` operation multiple times to generate the latest graph snapshot that is consistent with the changes in the database.

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 |
+--------+
```

16.4.3 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:

   - JShell
   - Java
   - Python

   ### JShell

   ```
   opg4j> var graph = session.getGraph("bank_graph")
   graph ==>
   PgxGraph[name=bank_graph_analytics_fb,N=999,E=4993,created=1664310157103]
   ```

   ### 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_config_file"
   )
   cfg ==> {"edge_providers":
   [{"destination_vertex_provider":"Accounts","database_table_name":"BANK_TXNS
   ```

```
","name":"Transfers","key_type":"long",
"props":[{"type":"float","name":"AMOUNT"},
{"type":"string","name":"DESCRIPTION"}],"format":"rdbms","source_vertex_pro
vider":"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_fi
le")
```

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.FlashbackSynch
ronizer',
                          jdbc_url=<jdbc_url>, username=<username>,
password=<password>, 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 |
+--------+
```

16.5 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.

16.6 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 16-11 Overview of Built-In Algorithms

Category	Algorithms
Classic graph algorithms	Prim's Algorithm, Prim's Algorithm (Ignoring edge directions)
Community detection	Conductance Minimization (Soman and Narang Algorithm), Infomap, Label Propagation, Louvain, LouvainDirected, Speaker Listener Label Propagation
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, Fattest Path (ignoring edge directions), Filtered Fast Path Finding, Hop Distance Algorithms
Ranking and walking	ArticleRank Algorithms, Closeness Centrality Algorithms, Degree Centrality Algorithms, Eigenvector Centrality, Harmonic 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 algorithms, Bipartite Check, Clustering Coefficient Algorithms, Conductance, Cycle Detection Algorithms, Degree Distribution Algorithms, Eccentricity Algorithms, K-Core, 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)
  The graph server (PGX) contains a set of built-in algorithms that are available as Java and Python APIs.
- Getting the Progress of a Running Algorithm
  The progress of a graph algorithm is based on the value of a monotonically increasing counter that gets incremented periodically during algorithm executions.

- Centrality Algorithms
  Centrality algorithms are used to assess the importance or influence of nodes within a graph.
- Running the Triangle Counting Algorithm

16.6.1 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 and Python APIs.

The `oracle.pgx.api.Analyst` class provides convenience methods for invoking a set of built-in algorithms.

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);
```

16.6.2 Getting the Progress of a Running Algorithm

The progress of a graph algorithm is based on the value of a monotonically increasing counter that gets incremented periodically during algorithm executions.

You can track the progress of the algorithms using the `AlgorithmProgress` Java API and review the progress by comparing the counter value at various points in time to an estimate of the final value of the counter.

The `AlgorithmProgress` object represents the progress of an algorithm execution at a certain time. It contains the following two attributes:

- **`numberOfStepsCompleted`:** This counter represents the current number of steps executed.
- **`numberOfStepsEstimatedForCompletion`:** This value is an estimation of the total number of steps needed for completion.
  A default positive value is provided for `numberOfStepsEstimatedForCompletion` for the following list of built-in algorithms:
  - *PageRank*
  - *Approximate PageRank*
  - *Personalized PageRank*

- *Personalized PageRank (for a set of vertices)*
- *Personalized Weighted PageRank*
- *Personalized Weighted PageRank (for a set of vertices)*
- *Weighted PageRank*
- *Degree Centrality*
- *In-Degree Centrality*
- *Out-Degree Centrality*
- *Filtered Speaker Listener Label Propagation*
- *Filtered Weighted Speaker Listener Label Propagation*
- *Weighted Speaker Listener Label Propagation*
- *Speaker Listener Label Propagation*
- *Label Propagation*
- *Louvain*
- *Soman and Narang*
- *Weighted Infomap*
- *Dijkstra*
- *Undirected Dijkstra*
- *Filtered Dijkstra*
- *Undirected Filtered Dijkstra*
- *Bidirectional Dijkstra*
- *Bidirectional Undirected Dijkstra*
- *Bidirectional Filtered Dijkstra*
- *Bidirectional Undirected Filtered Dijkstra*
- *Fattest Path*
- *Undirected Fattest Path*
- *Hop Distance*
- *Undirected Hop Distance*
- *Backward Hop Distance*

You cannot estimate the progress as a percentage for algorithms that do not provide a value for `numberOfStepsEstimatedForCompletion`. In such a case, you can only access the value of the counter (`numberOfStepsCompleted`).

However, you can set the `numberOfStepsEstimatedForCompletion` value for a custom PGX graph algorithm. See Tracking the Progress of a Running Custom PGX Graph Algorithm for more information.

The following example uses the in-built PageRank algorithm and describes the steps to get the progress of the running built-in algorithm using the `AlgorithmProgress` Java API:

- JShell

- Java

JShell

```
opg4j> var graph = session.readGraphByName("BANK_TXN_GRAPH",
GraphSource.PG_PGQL)
g ==> PgxGraph[name=BANK_TXN_GRAPH,N=1000,E=4993,created=1712307339271]
opg4j>  var future = analyst.pagerankAsync(graph)
future ==> oracle.pgx.api.PgxFuture@1dfe5dd1[Not completed]
opg4j> var futureProgress = future.getProgress()
futureProgress ==> oracle.pgx.api.DefaultFutureProgress@6d7bb5cc
opg4j> var algorithmProgress = futureProgress.asAlgorithmExecutionProgress()
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_TXN_GRAPH",
GraphSource.PG_PGQL);
PgxFuture<?> future = analyst.pagerank.runAsync(graph);
FutureProgress futureProgress = future.getProgress();
Optional<AlgorithmProgress> algorithmProgress =
futureProgress.asAlgorithmExecutionProgress();
```

The following code shows how you can estimate the progress as a percentage for the running algorithm:

- JShell
- Java

JShell

```
opg4j> if (algorithmProgress.isPresent()) {
...>   var progress = algorithmProgress.get();
...>   var completedSteps = progress.getNumberOfStepsCompleted();
...>   var numberOfStepsEstimatedForCompletion =
progress.getNumberOfStepsEstimatedForCompletion();
...>   var progressPercentage = completedSteps * 100 /
numberOfStepsEstimatedForCompletion;
...>   System.out.println(completedSteps);
...>   System.out.println(numberOfStepsEstimatedForCompletion);
...>   System.out.println(progressPercentage);
...> }
```

Java

```
if (algorithmProgress.isPresent()) {
  AlgorithmProgress progress = algorithmProgress.get();
  long completedSteps = progress.getNumberOfStepsCompleted();
```

```
  Long numberOfStepsEstimatedForCompletion =
progress.getNumberOfStepsEstimatedForCompletion();
  long progressPercentage = completedSteps * 100 /
numberOfStepsEstimatedForCompletion;
  System.out.println(completedSteps);
  System.out.println(numberOfStepsEstimatedForCompletion);
  System.out.println(progressPercentage);
};
```

The preceding code shows the progress at that current moment. If you try to get the progress of the running algorithm after a while (for example, `1min`), then you should get a larger value for `progressPercentage`.

16.6.3 Centrality Algorithms

Centrality algorithms are used to assess the importance or influence of nodes within a graph.

These algorithms can be broadly classified into three categories based on their locality and focus.

Table 16-12 Classification of Centrality Algorithms

Category	Description	Example Algorithms
Local Measures	These algorithms evaluate a node's importance based on its immediate connections, offering straightforward and computationally efficient insights.	Degree Centrality
Global Path-Based Measures	These algorithms evaluate nodes based on their overall connectivity and shortest paths within the entire graph.	Closeness Centrality, Harmonic Centrality, Betweenness Centrality
Global Influence-Based Measures	These algorithms evaluate a node's influence based on their direct and indirect connections, offering in-depth insights into hierarchical importance and influence within complex graphs.	Eigenvector centrality, Random Walk with Restart (RWR), PageRank, ArticleRank, Hyperlink-Induced Topic Search (HITS), Stochastic Approach for Link-Structure Analysis (SALSA)

Learn more about the Centrality algorithms in the following topics.

- Degree Centrality
  The Degree Centrality algorithm measures the number of direct connections each node has in a graph, indicating its immediate level of influence or prominence within the graph.
- Closeness Centrality
  The Closeness Centrality algorithm identifies nodes that can quickly reach all other nodes, highlighting efficient communicators or spreaders of information.
- Harmonic Centrality
  The Harmonic Centrality algorithm improves closeness centrality to better account for disconnected graphs.

- Vertex Betweenness Centrality
  The Vertex Betweenness Centrality algorithm identifies nodes that act as critical bridges, controlling the flow of information or resources through the graph.
- PageRank
  PageRank assigns a numerical weight to each vertex, measuring its relative importance within the graph.

16.6.3.1 Degree Centrality

The Degree Centrality algorithm measures the number of direct connections each node has in a graph, indicating its immediate level of influence or prominence within the graph.

This algorithm can be applied in the following scenarios:

- To quickly gain local insights into node importance based on direct connections.
- To understand immediate influence or activity levels.
- Social networking analysis, such as identifying users with most friends or followers.
- Financial transactions analysis, such as detecting accounts with the highest number of transactions.
- Studying spreading of diseases by pinpointing individuals who have direct contact with most people.

The following variants of Degree Centrality algorithms are supported:

- **Degree Centrality:** Returns the sum of the number of incoming and outgoing edges for each vertex in the graph.
- **In-Degree Centrality:** Returns the sum of the number of incoming edges for each vertex in the graph.
- **Out-Degree Centrality:** Returns the sum of the number of outgoing edges for each vertex in the graph.

See the Javadoc and Python API Reference for more information on the corresponding APIs for running these algorithms.

Example 16-2 Running the In-Degree Centrality Algorithm

The following example runs the in-degree centrality algorithm on `BANK_GRAPH` to identify the top 10 accounts having the maximum number of incoming transactions.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL)
graph ==> PgxGraph[name=BANK_GRAPH,N=1000,E=4996,created=1643308582055]
opg4j> var a = session.createAnalyst()
a ==> NamedArgumentAnalyst[session=4c054326-600d-47d3-ab40-36b41fa0e339]
opg4j> a.inDegreeCentrality(graph)
$3 ==> VertexProperty[name=in_degree,type=integer,graph=BANK_GRAPH_PGQL]
```

```
opg4j> graph.queryPgql("SELECT DISTINCT m.id, m.in_degree FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.in_degree DESC LIMIT
10").print()
+-----------------+
| id  | in_degree |
+-----------------+
| 387 | 39        |
| 934 | 39        |
| 135 | 36        |
| 534 | 32        |
| 380 | 31        |
| 330 | 30        |
| 406 | 28        |
| 746 | 28        |
| 259 | 26        |
| 352 | 26        |
+-----------------+
$5 ==> PgqlResultSetImpl[graph=BANK_GRAPH_PGQL,numResults=10]
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL);
Analyst a = session.createAnalyst();
a.inDegreeCentrality(graph);
PgqlResultSet rs = graph.queryPgql("SELECT DISTINCT m.id, m.in_degree FROM
MATCH (m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.in_degree DESC
LIMIT 10");
rs.print();
```

Python

```
>>> graph = session.read_graph_by_name('BANK_GRAPH', 'pg_pgql')
>>> a = session.create_analyst()
>>> a.in_degree_centrality(graph)
VertexProperty(name: in_degree, type: integer, graph: BANK_GRAPH_PGQL)
>>> graph.query_pgql("SELECT DISTINCT m.id, m.in_degree FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.in_degree DESC LIMIT
10").print()
+-----------------+
| id  | in_degree |
+-----------------+
| 387 | 39        |
| 934 | 39        |
| 135 | 36        |
| 534 | 32        |
| 380 | 31        |
| 330 | 30        |
| 406 | 28        |
| 746 | 28        |
| 259 | 26        |
| 352 | 26        |
+-----------------+
```

16.6.3.2 Closeness Centrality

The Closeness Centrality algorithm identifies nodes that can quickly reach all other nodes, highlighting efficient communicators or spreaders of information.

This algorithm can be applied in the following scenarios:

- To determine nodes that are central to the overall structure of the graph, facilitating efficient information flow or influence spreading.
- In social network analysis, for example, finding influencers who can disseminate information quickly to the entire network.
- In financial transactions analysis, for example, accounts with high closeness centrality might facilitate rapid money movement, making them potential candidates for closer monitoring for fraudulent activities such as money laundering.
- In studying spreading of diseases, for example, identifying individuals who can potentially spread a disease to many others quickly due to their central position in the network.

The following two variants are supported for Closeness Centrality:

- **Closeness Centrality (Unit Length):** The Closeness Centrality of a node `v` is the reciprocal of the sum of all the distances from the possible shortest paths starting from `v`. Thus the higher the centrality value of `v`, the closer it is to all the other vertices in the graph.
- **Closeness Centrality (with weights):** This takes into account the weights from the edges when computing the reciprocal of the sum of all the distances from the possible shortest paths starting from the vertex `v`, for every vertex in the graph. The weights of the edges must be positive values greater than 0.

See the Javadoc and Python API Reference for more information on the corresponding APIs for running these algorithms.

Example 16-3 Running the Closeness Centrality Algorithm

The following example runs the Closeness Centrality algorithm on `BANK_GRAPH` to identify the top five accounts that have higher levels of connections with the other accounts.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL)
graph ==> PgxGraph[name=BANK_GRAPH,N=1000,E=4996,created=1643308582055]
opg4j> var a = session.createAnalyst()
a ==> NamedArgumentAnalyst[session=4c054326-600d-47d3-ab40-36b41fa0e339]
opg4j> a.closenessCentralityUnitLength(graph)
$6 ==> VertexProperty[name=closeness,type=double,graph=BANK_GRAPH_PGQL]
opg4j> graph.queryPgql("SELECT DISTINCT m.id, m.closeness FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.closeness DESC LIMIT
5").print()
```

```
+----------------------------+
| id  | closeness            |
+----------------------------+
| 934 | 3.866976024748647E-4  |
| 135 | 3.8595137012736397E-4 |
| 387 | 3.8476337052712584E-4 |
| 406 | 3.8284839203675346E-4 |
| 330 | 3.7425149700598805E-4 |
+----------------------------+
$7 ==> PgqlResultSetImpl[graph=BANK_GRAPH_PGQL,numResults=5]
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL);
Analyst a = session.createAnalyst();
a.closenessCentralityUnitLength(graph);
PgqlResultSet rs = graph.queryPgql("SELECT DISTINCT m.id, m.closeness FROM
MATCH (m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.closeness DESC
LIMIT 5");
rs.print();
```

Python

```
>>> graph = session.read_graph_by_name('BANK_GRAPH', 'pg_pgql')
>>> a = session.create_analyst()
>>> a.closeness_centrality(graph)
VertexProperty(name: closeness, type: double, graph: BANK_GRAPH_PGQL)
>>> graph.query_pgql("SELECT DISTINCT m.id, m.closeness FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.closeness DESC LIMIT
5").print()
+----------------------------+
| id  | closeness            |
+----------------------------+
| 934 | 3.866976024748647E-4  |
| 135 | 3.8595137012736397E-4 |
| 387 | 3.8476337052712584E-4 |
| 406 | 3.8284839203675346E-4 |
| 330 | 3.7425149700598805E-4 |
+----------------------------+
```

16.6.3.3 Harmonic Centrality

The Harmonic Centrality algorithm improves closeness centrality to better account for disconnected graphs.

This algorithm can be applied in the following scenarios for a disconnected graph:

- To determine nodes that are central to the overall structure of the graph, facilitating efficient information flow or influence spreading.
- In social network analysis, for example, finding influencers who can disseminate information quickly to the entire network.

- In financial transactions analysis, for example, accounts with high closeness centrality might facilitate rapid money movement, making them potential candidates for closer monitoring for fraudulent activities such as money laundering.
- In studying spreading of diseases, for example, identifying individuals who can potentially spread a disease to many others quickly due to their central position in the network.

See the Javadoc and Python API Reference for more information on the corresponding APIs for running these algorithms.

Example 16-4 Running the Harmonic Centrality Algorithm

The following example measures the harmonic centrality value for each vertex account in `BANK_GRAPH` and prints the top five accounts that have higher levels of connections with the other accounts.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL)
graph ==> PgxGraph[name=BANK_GRAPH,N=1000,E=4996,created=1643308582055]
opg4j> var a = session.createAnalyst()
a ==> NamedArgumentAnalyst[session=4c054326-600d-47d3-ab40-36b41fa0e339]
opg4j> a.harmonicCentrality(graph)
VertexProperty[name=hc,type=double,graph=BANK_GRAPH_PGQL]
opg4j> graph.queryPgql("SELECT DISTINCT m.id, m.hc FROM MATCH (m:accounts) -
[e:transfers]-> (n:accounts) ORDER BY m.hc DESC LIMIT 5").print()
+--------------------------+
| id  | hc                 |
+--------------------------+
| 34  | 193.53134920634574 |
| 770 | 193.5238095238061  |
| 778 | 193.41904761904416 |
| 262 | 193.32936507936165 |
| 243 | 192.78293650793313 |
+--------------------------+
$9 ==> PgqlResultSetImpl[graph=BANK_GRAPH_PGQL,numResults=5]
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL);
Analyst a = session.createAnalyst();
a.harmonicCentrality(graph);
PgqlResultSet rs = g1.queryPgql("SELECT DISTINCT m.id, m.hc FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.hc DESC LIMIT 5");
rs.print();
```

Python

```
>>> graph = session.read_graph_by_name('BANK_GRAPH', 'pg_pgql')
>>> a = session.create_analyst()
>>> a.harmonic_centrality(graph)
VertexProperty(name: harmonic_centrality, type: double, graph:
BANK_GRAPH_PGQL)
>>> graph.query_pgql("SELECT DISTINCT m.id, m.harmonic_centrality FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.harmonic_centrality
DESC LIMIT 5").print()
+---------------------------+
| id  | harmonic_centrality |
+---------------------------+
| 34  | 193.3884920634886   |
| 262 | 193.32936507936165  |
| 56  | 193.10158730158386  |
| 544 | 192.87738095237754  |
| 408 | 192.73452380952043  |
+---------------------------+
```

16.6.3.4 Vertex Betweenness Centrality

The Vertex Betweenness Centrality algorithm identifies nodes that act as critical bridges, controlling the flow of information or resources through the graph.

This algorithm can be applied in the following scenarios:

- To identifying nodes that are strategically positioned for mediating interactions within the graph.
- In social network analysis, for example, highlighting users who act as connectors between different groups or communities.
- In financial transactions analysis, for example, detecting accounts that facilitate transactions between otherwise unconnected parts of the financial network.
- In studying spreading of diseases, for example, identifying individuals who serve as bridges between different social groups, potentially controlling the spread of a disease across the entire population.

The following three variants are supported for Vertex Betweenness Centrality:

- **Vertex Betweenness Centrality:** The Betweenness Centrality of a vertex `v` in a graph is the sum of the fraction of shortest paths that pass through `v` from all the possible shortest paths connecting every possible pair of vertices `s`, `t` in the graph, such that `v` is different from `s` and `t`. This algorithm applies for connected graphs.
- **Approximate Vertex Betweenness Centrality with Random Seeds:** This variant of betweenness centrality approximates the centrality of the vertices by just using k random vertices as starting points for the BFS traversals of the graph, instead of computing the exact value by using all the vertices in the graph.
- **Approximate Vertex Betweenness Centrality From seeds:** This variant of betweenness centrality approximates the centrality of the vertices by just using the vertices from the given sequence as starting points for the BFS traversals of the graph, instead of computing the exact value by using all the vertices in the graph.

See the Javadoc and Python API Reference for more information on the corresponding APIs for running these algorithms.

Example 16-5 Running the Betweenness Centrality Algorithm

The following example identifies the top five accounts that act as critical bridges in graph `g1`.

- JShell
- Java
- Python

JShell

```
opg4j> var graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL)
graph ==> PgxGraph[name=BANK_GRAPH,N=1000,E=4996,created=1643308582055]
opg4j> var a = session.createAnalyst()
a ==> NamedArgumentAnalyst[session=4c054326-600d-47d3-ab40-36b41fa0e339]
opg4j> a.vertexBetweennessCentrality(graph)
$10 ==> VertexProperty[name=betweenness,type=double,graph=BANK_GRAPH_PGQL]
opg4j> graph.queryPgql("SELECT DISTINCT m.id, m.betweenness FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.betweenness DESC LIMIT
5").print()
+--------------------------+
| id  | betweenness        |
+--------------------------+
| 387 | 18913.34886094081  |
| 352 | 16625.818593102595 |
| 135 | 15190.461087012543 |
| 934 | 14642.317059371073 |
| 222 | 13688.935057639192 |
+--------------------------+
$11 ==> PgqlResultSetImpl[graph=BANK_GRAPH_PGQL,numResults=5]
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL);
Analyst a = session.createAnalyst();
a.vertexBetweennessCentrality(graph);
PgqlResultSet rs = g1.queryPgql("SELECT DISTINCT m.id, m.betweenness FROM
MATCH (m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.betweenness DESC
LIMIT 5");
rs.print();
```

Python

```
>>> graph = session.read_graph_by_name('BANK_GRAPH', 'pg_pgql')
>>> a = session.create_analyst()
>>> a.vertex_betweenness_centrality(graph)
VertexProperty(name: betweenness, type: double, graph: BANK_GRAPH_PGQL)
>>> graph.query_pgql("SELECT DISTINCT m.id, m.betweenness FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.betweenness DESC LIMIT
```

```
5").print()
+--------------------------+
| id   | betweenness       |
+--------------------------+
| 387 | 18913.34886094081  |
| 352 | 16625.818593102595 |
| 135 | 15190.461087012543 |
| 934 | 14642.317059371073 |
| 222 | 13688.935057639192 |
+--------------------------+
```

16.6.3.5 PageRank

PageRank assigns a numerical weight to each vertex, measuring its relative importance within the graph.

This algorithm can be applied in the following scenarios:

- To identify nodes that directly and indirectly influence other nodes.
- In place of Eigenvector centrality, when the underlying process includes randomness, for example, random browsing.
- In social networks analysis, for example, finding influencers with direct and indirect influence within the graph.
- In disease spreading analysis, for example, assessing the risk of individuals in spreading a disease.

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.

The following variants of PageRank algorithms are supported:

- **Classic PageRank:** Computes ranking scores for the vertices using the network created by the incoming edges in the graph. Although it is intended for directed graphs, undirected graphs can be treated as well by converting them into directed graphs with reciprocated edges (that is, keeping the original edge and creating a second one going in the opposite direction).

- **Approximate PageRank:** Computes the ranking scores for the vertices in similar way to the classic algorithm without normalization and with a more relaxed convergence criteria since the tolerated error value is compared against each single vertex in the graph, instead of looking at the cumulative vertex error. Thus this variant will converge faster than the classic algorithm, but the ranking values might not be as accurate as in the classic implementation.
- **Weighted PageRank**: Similar to the classic PageRank algorithm, except that it allows for a weight value to be assigned to each edge. This weight determines the fraction of the PageRank score that will flow from the source vertex through the current edge to its destination vertex.

See the Javadoc and Python API Reference for more information on the corresponding APIs for running these algorithms.

Example 16-6 Running the PageRank Algorithm

The following example runs the PageRank algorithm on `BANK_GRAPH` to identify the top five accounts with the highest 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
- Python

JShell

```
opg4j> var graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL)
graph ==> PgxGraph[name=BANK_GRAPH,N=1000,E=4996,created=1643308582055]
opg4j> var a = session.createAnalyst()
a ==> NamedArgumentAnalyst[session=4c054326-600d-47d3-ab40-36b41fa0e339]
opg4j> a.pagerank(graph, 0.001, 0.85, 100)
$12 ==> VertexProperty[name=pagerank,type=double,graph=BANK_GRAPH_PGQL]
opg4j> graph.queryPgql("SELECT DISTINCT m.id, m.pagerank FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.pagerank DESC LIMIT
5").print()
+-----------------------------+
| id  | pagerank              |
+-----------------------------+
| 387 | 0.0073028362522059255 |
| 406 | 0.0067344306145590786 |
| 135 | 0.006725965475577352  |
| 934 | 0.0066413407648344865 |
| 397 | 0.0057016075312134595 |
+-----------------------------+
$13 ==> PgqlResultSetImpl[graph=BANK_GRAPH_PGQL,numResults=5]
```

Java

```
PgxGraph graph = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL);
Analyst a = session.createAnalyst();
a.pagerank(graph, 0.001, 0.85, 100);
```

```
PgqlResultSet rs = g1.queryPgql("SELECT DISTINCT m.id, m.pagerank FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.pagerank DESC LIMIT 5");
rs.print();
```

Python

```
>>> graph = session.read_graph_by_name('BANK_GRAPH', 'pg_pgql')
>>> a = session.create_analyst()
>>> a.pagerank(graph, 0.001, 0.85, 100)
VertexProperty(name: pagerank, type: double, graph: BANK_GRAPH_PGQL)
>>> graph.query_pgql("SELECT DISTINCT m.id, m.pagerank FROM MATCH
(m:accounts) -[e:transfers]-> (n:accounts) ORDER BY m.pagerank DESC LIMIT
5").print()
+-----------------------------+
| id  | pagerank              |
+-----------------------------+
| 387 | 0.0073028362522059255 |
| 406 | 0.0067344306145590786 |
| 135 | 0.006725965475577352  |
| 934 | 0.0066413407648344865 |
| 397 | 0.0057016075312134595 |
+-----------------------------+
```

16.6.4 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`.

16.7 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
- Tracking the Progress of a Running Custom PGX Graph Algorithm

16.7.1 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

16.7.1.1 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);
```

16.7.1.2 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()`.

16.7.1.3 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)
);
```

16.7.2 Compiling and Running a Custom PGX Algorithm

To be able to compile and run a custom PGX algorithm, you must perform the following actions:

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.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL)
g ==> PgxGraph[name=BANK_GRAPH_2,N=999,E=4993,created=1689325558251]
opg4j> var property = graph.createVertexProperty(PropertyType.INTEGER)
property ==>
VertexProperty[name=vertex_prop_integer_9,type=integer,graph=bank_graph_ana
lytics]
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.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL);
VertexProperty property = graph.createVertexProperty(PropertyType.INTEGER);
myAlgorithm.run(graph, property);
```

Python

```
graph = session.read_graph_by_name('BANK_GRAPH', 'pg_pgql')
property = graph.create_vertex_property("integer")
my_algorithm.run(graph, property)
{'success': True, 'canceled': False, 'exception': None, 'return_value':
42, 'execution_time(ms)': 1}
```

16.7.3 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);
  }
}
```

16.7.4 Tracking the Progress of a Running Custom PGX Graph Algorithm

You can track the progress of a running custom graph algorithm using the `AlgorithmProgress` Java API.

The `AlgorithmProgress` object, which comprises the `numberOfStepsCompleted` and `numberOfStepsEstimatedForCompletion` attributes, is used to calculate the progress of the algorithm as a percentage.

In case of custom algorithms, the value of `numberOfStepsEstimatedForCompletion` is not automatically provided. You are therefore expected to provide the value by calling `ControlFlow.setNumberOfStepsEstimatedForCompletion` while implementing your algorithms. If no value is provided, or the provided value is negative, then `number_of_steps_estimated_for_completion` uses the default `null` value.

The following example describes the steps for setting the `numberOfStepsEstimatedForCompletion` value in a custom graph algorithm followed by tracking and estimating the progress as a percentage of a running custom graph algorithm using the `AlgorithmProgress` Java API.

1. Set the value for `numberOfStepsEstimatedForCompletion` in your custom graph algorithm.

   Note that you cannot estimate the progress as a percentage for algorithms that do not provide a value for `numberOfStepsEstimatedForCompletion`. However you can still access the value of the counter (`numberOfStepsCompleted`).

   The value of `numberOfStepsEstimatedForCompletion` should ideally be equal to the total number of execution steps that an algorithm will perform. An execution step is simply a loop iteration. If the exact value cannot be specified, you should provide an upper bound estimate of that value.

   Consider the following `outDegreeCentrality` algorithm:

```
import oracle.pgx.algorithm.PgxGraph;
import oracle.pgx.algorithm.VertexProperty;
import oracle.pgx.algorithm.annotations.GraphAlgorithm;
import oracle.pgx.algorithm.annotations.Out;
import oracle.pgx.algorithm.ControlFlow;

@GraphAlgorithm
public class OutdegreeCentrality {
  public void outdegreeCentrality(PgxGraph g, @Out VertexProperty<Integer>
outdegreeCentrality) {
    g.getVertices().forEach(n ->
        outdegreeCentrality.set(n, (int) n.getOutDegree())
    );
  }
}
```

   The algorithm just iterates over all vertices of the graph and updates a property. Therefore, the total number of execution steps in this case is equal to the number of vertices of the graph:

```
@GraphAlgorithm
public class OutdegreeCentrality {
  public void outdegreeCentrality(PgxGraph g, @Out VertexProperty<Integer>
```

```
outdegreeCentrality) {

    long totNbOfSteps = g.getNumVertices();
    ControlFlow.setNumberOfStepsEstimatedForCompletion(totNbOfSteps);

    g.getVertices().forEach(n ->
        outdegreeCentrality.set(n, (int) n.getOutDegree())
    );
  }
}
```

2. Run and track the progress of the custom Out-Degree Centrality algorithm as shown:

- JShell
- Java

JShell

```
opg4j> var myAlgorithm = session.compileProgram("/path/to/
OutdegreeCentrality.java")
myAlgorithm ==> CompiledProgram[name=outdegreeCentrality]
opg4j> var graph = session.readGraphByName("BANK_TXN_GRAPH",
GraphSource.PG_PGQL)
graph ==> PgxGraph[name=BANK_TXN_GRAPH,N=1000,E=4993,created=1712307339271]
opg4j> var future = analyst.outDegreeCentralityAsync(graph)
future ==> oracle.pgx.api.PgxFuture@55fe9c2f[Not completed]
opg4j> var futureProgress = future.getProgress()
futureProgress ==> oracle.pgx.api.DefaultFutureProgress@637506d8
opg4j> var algorithmProgress =
futureProgress.asAlgorithmExecutionProgress()
```

Java

```
import oracle.pgx.algorithm.CompiledProgram;

CompiledProgram myAlgorithm = session.compileProgram("/path/to/
OutdegreeCentrality.java");
PgxGraph graph = session.readGraphByName("BANK_TXN_GRAPH",
GraphSource.PG_PGQL);
PgxFuture<?> future = analyst.pagerankAsync(graph);
FutureProgress futureProgress = future.getProgress();
Optional<AlgorithmProgress> algorithmProgress =
futureProgress.asAlgorithmExecutionProgress();
```

3. Estimate the progress of the running algorithm as a percentage.

- ```
  if (algorithmProgress.isPresent()) {
    AlgorithmProgress progress = algorithmProgress.get();
    long completedSteps = progress.getNumberOfStepsCompleted();
  ```
  ```

```
  Long numberOfStepsEstimatedForCompletion =
progress.getNumberOfStepsEstimatedForCompletion();
  long progressPercentage = completedSteps * 100 /
numberOfStepsEstimatedForCompletion;
  System.out.println(completedSteps); // 153
  System.out.println(numberOfStepsEstimatedForCompletion); // 2343
  System.out.println(progressPercentage); // 6.53
}
```

- ```
  if (algorithmProgress.isPresent()) {
    AlgorithmProgress progress = algorithmProgress.get();
    long completedSteps = progress.getNumberOfStepsCompleted();
    Long numberOfStepsEstimatedForCompletion =
  progress.getNumberOfStepsEstimatedForCompletion();
    long progressPercentage = completedSteps * 100 /
  numberOfStepsEstimatedForCompletion;
    System.out.println(completedSteps); // 153
    System.out.println(numberOfStepsEstimatedForCompletion); // 2343
    System.out.println(progressPercentage); // 6.53
  };
  ```

The preceding code shows the progress as `6.53 %` at that current moment. If you try to get the progress of the running algorithm after a while (for example, `1min`), then you should get a larger value.

> **See Also:**
>
> Getting the Progress of a Running Algorithm

16.8 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 16-13 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

Table 16-13 (Cont.) Fields for Each UDF

Field	Data Type	Description	Required?
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

16.9 Using 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.

- Using the PGX JDBC Driver when Graph Server (PGX) is Utilized as a Library
  When using the graph server (PGX) as a library, you can use the PGX JDBC driver to query graphs that are loaded from files.

16.9.1 Using the PGX JDBC Driver when Graph Server (PGX) is Utilized as a Library

When using the graph server (PGX) as a library, you can use the PGX JDBC driver to query graphs that are loaded from files.

Note the following to use the PGX JDBC driver:

- Register the PGX JDBC driver with the DriverManager:

  ```
  import java.sql.DriverManager;
  import oracle.pgx.jdbc.PgxJdbcDriver;
  DriverManager.registerDriver(new PgxJdbcDriver());
  ```

- The JDBC URL to obtain a connection object is as shown:
  `jdbc:oracle:pgx:embedded`

The following example uses the PGX JDBC driver to query a graph loaded from `.CSV` files.

```
opg4j> import oracle.pgx.jdbc.*
opg4j> DriverManager.registerDriver(new PgxJdbcDriver())
```

```
opg4j> var conn = DriverManager.getConnection("jdbc:oracle:pgx:embedded")
conn ==> oracle.pgx.jdbc.PgxConnection@1b96d447
opg4j> PgxSession session = conn.unwrap(PgxSession.class)
session ==> PgxSession[ID=738da6ff-81a5-4d6f-9bdc-a912f2193b44,source=PGX-
JDBC]
opg4j> session.readGraphFiles("/scratch/PG/Data/accounts.csv", "/scratch/PG/
Data/transfers.csv", "bank_graph")
$5 ==> PgxGraph[name=bank_graph,N=1000,E=5001,created=1705401162835]
opg4j> var stmt =  conn.createStatement()
stmt ==> oracle.pgx.jdbc.StatementWrapper@48dc9950
opg4j> var rs = stmt.executeQuery("SELECT e.AMOUNT as AMOUNT FROM MATCH (a) -
[e]-> (b) ON bank_graph LIMIT 5")
rs ==> oracle.pgx.jdbc.ResultSetWrapper@16a89351
opg4j> while(rs.next()){
...> System.out.println("AMOUNT = " + rs.getDouble("amount"));
...> }
AMOUNT = 1000.0
AMOUNT = 1000.0
AMOUNT = 1000.0
AMOUNT = 1000.0
AMOUNT = 1000.0
```

Related Topics

- Executing PGQL Queries Using the PGX JDBC Driver
  Starting from Graph Server and Client Release 24.1.0, you can use the PGX JDBC driver to access a PGX session and query graphs that are loaded in to the graph server (PGX).

17

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 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 Unsupervised GraphWise Algorithm (Vertex Embeddings)
  `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 Unsupervised EdgeWise Algorithm
  `UnsupervisedEdgeWise` 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 unsupervised learning edge embeddings for edge classification.
- Using the Unsupervised Anomaly Detection GraphWise Algorithm (Vertex Embeddings and Anomaly Scores)
  UnsupervisedAnomalyDetectionGraphWise is an inductive vertex representation learning and anomaly detection algorithm which is able to leverage vertex and edge feature information. Although it can be applied to a wide variety of tasks, it is particularly suitable for unsupervised learning of vertex embeddings for anomaly detection. After training this model, it is possible to infer anomaly scores or labels for unseen nodes.
- 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.

17.1 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 technical brief 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 a few use cases where DeepWalk algorithm can be applied:

- **Community Detection in Social Networks**: To leverage the vertex embedding to identify groups of users who interact more frequently with each other than with the rest of the network. This can help in targeted marketing, understanding social dynamics, or improving network moderation strategies.
- **New Items Recommendation**: To analyze user interactions and content consumption patterns that help recommendation systems to recommend new content (such as videos, articles, or products) based on the embeddings of similar users or items.
- **Knowledge Graph Enhancement**: To enhance knowledge graphs by generating embeddings for entities (vertices). This helps to infer missing relationships, thereby improving the completeness of the graph and its usability in search engines and question-answering systems.

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

17.1.1 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.*;
```

Python

```
# starting the Python shell will create an implicit session and 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 instance = GraphServer.getInstance("https://localhost:7007",
"<username>", "<password>".toCharArray())
opg4j> var session=instance.createSession("mySession")
opg4j> var graph =
session.readGraphByName("<graph_name>",GraphSource.PG_PGQL)
```

Java

```
ServerInstance instance = GraphServer.getInstance("https://
localhost:7007", "<username>", "<password>".toCharArray());
PgxSession session = instance.createSession("my-session");
PgxGraph graph =
session.readGraphByName("<graph_name>",GraphSource.PG_PGQL);
```

Python

```
instance = graph_server.get_instance("https://
localhost:7007","<username>","<password>")
session = instance.create_session("my_session")
graph = session.read_graph_by_name("<graph_name>", "pg_pgql")
```

17.1.2 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)
```

17.1.3 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).
                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)
    .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)
```

See DeepWalkModelBuilder in Javadoc for more explanation for each builder operation along with the default values.

17.1.4 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)
```

17.1.5 Getting the Loss Value For a DeepWalk Model

You can fetch the loss value as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var loss = model.getLoss()
```

Java

```
double loss = model.getLoss();
```

Python

```
loss = model.loss
```

17.1.6 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 |
+----------------------------------------+
```

17.1.7 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 |
+-------------------------------------------------------------------+
```

17.1.8 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").ov
erwrite(True).store()
```

17.1.9 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

17.1.9.1 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
```

17.1.10 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

17.1.10.1 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
- `loadUnsupervisedEdgeWiseModel()`: Loads an Unsupervised EdgeWise model

- `loadUnsupervisedAnomalyDetectionGraphWiseModel()`: Loads an Unsupervised Anomaly Detection GraphWise 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
- `UnsupervisedEdgeWiseModel`: represents an Unsupervised EdgeWise model
- `UnsupervisedAnomalyDetectionGraphWiseModel`: represents an Unsupervised Anomaly Detection GraphWise 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
- `loadUnsupervisedEdgeWiseModel()`: Loads an Unsupervised EdgeWise model
- `loadUnsupervisedAnomalyDetectionGraphWiseModel()`: Loads an Unsupervised Anomaly Detection GraphWise model
- `loadPg2vecModel()`: Loads a Pg2vec model

Python

```
model = analyst.<modelLoader>.db(model_store="modelstoretablename",  # name
of the model store table
                  model_name="model",                # model name (primary
key of model store table)
                  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
```

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_unsupervised_edgewise_model_loader()`: Loads an Unsupervised EdgeWise model
- `get_unsupervised_anomaly_detection_graphwise_model_loader()`: Loads an Unsupervised Anomaly Detection GraphWise model
- `get_pg2vec_model_loader()`: Loads a Pg2vec model

17.1.11 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()
```

17.2 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 a few use cases where `SupervisedGraphWise` algorithm can be applied:

- **Node Classification in Citation Networks**: To predict the category of a paper (such as biology, computer science, and so on) based on the papers it cites and its attributes. This can be useful for academic research tools and repositories that classify research papers for easier discovery.
- **Customer Segmentation**: To classify customers in a transaction network into different segments based on their purchasing behavior and relationships with other customers. This can be used for personalized marketing campaigns.
- **Disease Prediction in Healthcare Networks**: To predict the likelihood of disease spread or emergence of symptoms based on patient data and interactions within healthcare networks, such as hospitals or clinics.

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 Partitioned Graphs
- Supported Property Types for Supervised GraphWise Model
- 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
- Getting the Training Log 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

17.2.1 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
```

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;
```

Python

```
# starting the Python shell will create an implicit session and analyst
```

2. Load the **graph**.

- JShell
- Java
- Python

JShell

```
opg4j> var instance = GraphServer.getInstance("https://localhost:7007",
"<username>", "<password>".toCharArray())
opg4j> var session=instance.createSession("mySession")
opg4j> var fullGraph =
session.readGraphByName("<cora_graph>",GraphSource.PG_PGQL)
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

```
ServerInstance instance = GraphServer.getInstance("https://
localhost:7007", "<username>", "<password>".toCharArray());
PgxSession session = instance.createSession("my-session");
PgxGraph fullGraph =
session.readGraphByName("<cora_graph>",GraphSource.PG_PGQL);
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
instance = graph_server.get_instance("https://
localhost:7007","<username>","<password>")
session = instance.create_session("my_session")
full_graph = session.read_graph_by_name("<cora_graph>", "pg_pgql")
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)
```

17.2.2 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.

17.2.3 Advanced Hyperparameter Customization

You can build a GraphWise model using rich hyperparameter customization. Internally for each node, GraphWise applies an aggregation of the representation of neighbors. You can configure this operation through one of the following sub-config classes:

- `GraphWiseConvLayerConfig`: GraphWiseConvLayer is based on Inductive Representation Learning on Large Graphs (GraphSage) by Hamilton et al.
- `GraphWiseAttentionLayerConfig`: GraphWiseAttentionLayer is based on Graph Attention Neworks (GAT) by Velickovic et al. which makes the aggregation smarter but comes with larger computation cost.

The `GraphWisePredictionLayerConfig` class implements the prediction layer config.

Also, you can enable or disable a graphics processing unit (GPU) by using the `enable_ml_accelerators` graph server (PGX) configuration parameter (see Configuration Parameters for the Graph Server (PGX) Engine for more information). In addition, ensure that your system meets the following prerequisites to use the GPU support:

- You must have a GPU device with the CUDA (Compute Unified Device Architecture) toolkit installed.
- The following list of CUDA libraries are expected:
  - `libcuda.so.1`
  - `libnvrtc.so.12`
  - `libnvToolsExt.so.1`
  - `libcudart.so.12`

Note that the `enable_ml_accelerators` option is enabled by default. But if a GPU device is not detected and the CUDA toolkit is not installed, then this feature gets disabled and the CPU will be used for all the PgxML library operations.

The following code examples uses the `GraphWiseConvLayerConfig` class for the convolutional layer configuration. The examples specifies a weight decay parameter of `0.001` and dropout with dropping probability `0.5` for the GraphWise model to counteract overfitting. Also, note that the `setEnableAccelerator` method is enabled to use any available GPU.

- 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).
        setEnableAccelerator(true). // Enable or disable GPU
        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)
    .setEnableAccelerator(true) // Enable or disable GPU
    .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,
              enable_accelerator=True # Enable or disable GPU
)

model = analyst.supervised_graphwise_builder(**params)
```

In the preceding example, you can replace `GraphWiseConvLayerConfig` with the `GraphWiseAttentionLayerConfig` class to build a graph attention network model. Also, note that if the number of sampled neighbors is set to `-1` using `setNumSampledNeighbors`, then all the neighboring nodes will be sampled.

- JShell
- Java
- Python

JShell

```
opg4j> var convLayerConfig = analyst.graphWiseAttentionLayerConfigBuilder().
         setNumSampledNeighbors(25).
         setActivationFunction(ActivationFunction.LEAKY_RELU).
         setWeightInitScheme(WeightInitScheme.XAVIER_UNIFORM).
         setHeadAggregation(AggregationOperation.MEAN).
         setNumHeads(4).
         setDropoutRate(0.5).
         build()
```

Java

```
GraphWiseAttentionLayerConfig convLayerConfig =
analyst.graphWiseAttentionLayerConfigBuilder()
    .setNumSampledNeighbors(25)
    .setActivationFunction(ActivationFunction.LEAKY_RELU)
    .setWeightInitScheme(WeightInitScheme.XAVIER_UNIFORM)
    .setHeadAggregation(AggregationOperation.MEAN)
    .setNumHeads(4)
    .setDropoutRate(0.5)
    .build();
```

Python

```
conv_layer_config = dict(num_sampled_neighbors=25,
                         activation_fn='leaky_relu',
                         weight_init_scheme='xavier_uniform',
                         aggregation_operation='mean',
                         num_heads=4,
                         dropout_rate=0.5)
```

See the Javadoc for more information.

17.2.4 Building a GraphWise Model Using Partitioned 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)
```

17.2.5 Supported Property Types for Supervised GraphWise Model

The model supports two types of properties for both vertices and edges:

- `continuous properties` (boolean, double, float, integer, long)
- `categorical properties` (string)

For categorical properties, two categorical configurations are possible:

- **One-hot-encoding:** Each category is mapped to a vector, that is concatenated to other features (default)
- **Embedding table:** Each category is mapped to an embedding that is concatenated to other features and is trained along with the model

One-hot-encoding converts each category into an independent vector. This is useful if you want each category to be interpreted as an equally independent group. For instance, if there are categories ranging from A to E, where each alphabet has no specific meaning, then one-hot-encoding can be a good fit.

Embedding table is recommended if the semantics of the properties matter, and you want certain categories to be closer to each other than the others. For example, assume there is a `day` property with values ranging from *Monday* to *Sunday*. If you wish to preserve the idea that *Tuesday* is closer to *Wednesday* than *Saturday*, then by choosing the embedding table configuration, you can let the vectors that represent the categories to be learned during training, so that the vector that is mapped to *Tuesday* becomes close to that of *Wednesday*.

One advantage that the embedding table approach has over one-hot-encoding is that you can learn more suitable vectors to represent each category. However, this also means that a good amount of data is required to train the embedding table properly. The one-hot-encoding approach might be better for use-cases with limited training data.

When using the embedding table, users are allowed to set the out-of-vocabulary probability. With the given probability, the embedding will be set to the out-of-vocabulary embedding randomly during training, in order to make the model more robust to unseen categories during inference.

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.inputconfig.CategoricalPropertyConfig;
opg4j> var prop1config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_1").
    oneHotEncoding().
    setMaxVocabularySize(100).
    build()
opg4j> var prop2config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_2").
    embeddingTable().
    setShared(false). // set whether to share the vocabulary or not when
several vertex types have a property with the same name
    setEmbeddingDimension(32).
    setOutOfVocabularyProbability(0.001). // probability to set the word
embedding to the out-of-vocabulary embedding
    build()
opg4j> var model = analyst.supervisedGraphWiseModelBuilder().
    setVertexInputPropertyNames(
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3" // string feature using one-hot-encoding
(default)
    ).
    setVertexTargetPropertyName("label").
```

```
    setVertexInputPropertyConfigs(prop1config, prop2config).
    build()
```

Java

```
import oracle.pgx.config.mllib.inputconfig.CategoricalPropertyConfig;
import oracle.pgx.config.mllib.inputconfig.InputPropertyConfig;

InputPropertyConfig prop1config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_1")
    .oneHotEncoding()
    .setMaxVocabularySize(100)
    .build();
InputPropertyConfig prop2config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_2")
    .embeddingTable()
    .setShared(false) // set whether to share the vocabulary or not when
several vertex types have a property with the same name
    .setEmbeddingDimension(32)
    .setOutOfVocabularyProbability(0.001) // probability to set the word
embedding to the out-of-vocabulary embedding
    .build();
SupervisedGraphWiseModelBuilder model =
analyst.supervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames(
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3" // string feature using one-hot-encoding
(default)
    )
    .setVertexInputPropertyConfigs(prop1config, prop2config)
    .setVertexTargetPropertyName("label")
    .build();
```

Python

```
vertex_input_property_configs = [
    analyst.one_hot_encoding_categorical_property_config(
        property_name="vertex_str_feature_1",
        max_vocabulary_size=100,
    ),
    analyst.learned_embedding_categorical_property_config(
        property_name="vertex_str_feature_2",
        embedding_dim=4,
        shared=False, // set whether to share the vocabulary or not when
several  types have a property with the same name
        oov_probability=0.001 // probability to set the word embedding to the
out-of-vocabulary embedding
    )
]

model_params = dict(
    vertex_input_property_names=[
```

```
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3", // string feature using one-hot-encoding
(default)
    ],
    vertex_input_property_configs=vertex_input_property_configs,
    vertex_target_property_name="label"
)

model = analyst.supervised_graphwise_builder(**model_params)
```

17.2.6 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)
```

17.2.7 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)
```

17.2.8 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)
```

You can also add a validation step to the training. When training a model, the optimal number of training epochs is not known in advance and it is one of the key parameters that determines the model quality. Being able to monitor the training and validation losses helps you to identify a good value for the model parameters and gain visibility in the training process. The evaluation frequency can be specified in terms of epoch or step. To configure a validation step, create a `GraphWiseValidationConfig` and pass it to the model builder as shown:

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.EvaluationFrequencyScale;

opg4j> var validationConfig = analyst.graphWiseValidationConfigBuilder().
         setEvaluationFrequency(2).                                    // set
the evaluation frequency (default: 1)
         setEvaluationFrequencyScale(EvaluationFrequencyScale.EPOCH).  //
available options: EPOCH, STEP (default: EPOCH)
```

```
        build()
opg4j> var model = analyst.supervisedGraphWiseModelBuilder().
        setVertexInputPropertyNames("features").
        setVertexTargetPropertyName("labels").
        setValidationConfig(validationConfig).                    //
configuring the validation to be executed every 2 epochs
        build()
```

Java

```
import oracle.pgx.config.mllib.GraphWiseValidationConfig;
import oracle.pgx.config.mllib.EvaluationFrequencyScale;

GraphWiseValidationConfig validationConfig =
analyst.graphWiseValidationConfigBuilder()
    .setEvaluationFrequency(2)                                  // set the
evaluation frequency (default: 1)
    .setEvaluationFrequencyScale(EvaluationFrequencyScale.EPOCH)  //
available options: EPOCH, STEP (default: EPOCH)
    .build();

SupervisedGraphWiseModel model = analyst.supervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("features")
    .setVertexTargetPropertyName("labels")
    .setValidationConfig(validationConfig)  // configuring the validation to
be executed every 2 epochs
    .build();
```

Python

```
validation_config = analyst.graphwise_validation_config(
    evaluation_frequency=2,              # set the evaluation frequency
(default: 1)
    evaluation_frequency_scale="epoch",  # available options: "epoch", "step"
(default: "epoch")
)

params = dict(vertex_target_property_name="labels"
              vertex_input_property_names=["features"],
              validation_config=validation_config,  # configuring the
validation to be executed every 2 epochs
              seed=17)

model = analyst.supervised_graphwise_builder(**params)
```

After configuring a validation step, you can then pass a graph for validation to the `fit` method together with the graph for training:

- JShell

- Java
- Python

JShell

```
opg4j> model.fit(trainGraph, valGraph)
```

Java

```
model.fit(trainGraph,valGraph);
```

Python

```
model.fit(train_graph,valGraph)
```

17.2.9 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()
```

17.2.10 Getting the Training Log for a Supervised GraphWise Model

If you configured a validation step (see Training a Supervised GraphWise Model) earlier, then you can fetch the training log that contains the training and validation loss information.

- JShell
- Java
- Python

JShell

```
opg4j> var trainingLog = model.getTrainingLog()
```

Java

```
PgxFrame trainingLog = model.getTrainingLog();
```

Python

```
training_log = model.get_training_log()
```

The output frame will be similar to the following example output:

```
+-------------------------------------------------+
| epoch | training_loss      | validation_loss    |
+-------------------------------------------------+
| 2     | 1.5059218406677246 | 0.41696539521217346 |
| 4     | 0.5052874088287354 | 0.3255307078361511  |
| 6     | 0.3264007568359375 | 0.44015955924987793 |
+-------------------------------------------------+
```

Also, note the following:

- The first column will be named according to the evaluation frequency scale that was set in the validation configuration ("epoch" or "step").
- The validation loss is the average of the losses evaluated on all batches of the validation graph, while the training loss is the loss value logged at that epoch or step (that is, the loss evaluated on the last batch).
- The training log will be overwritten if the `fit` method is called multiple times.

17.2.11 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()
```

17.2.12 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   |
+-----------------------------------------+
```

17.2.13 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_vectors").ov
erwrite(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

17.2.13.1 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()
```

17.2.14 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.

17.2.15 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.

17.2.16 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()
```

17.2.17 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

17.3 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.

Supervised EdgeWise 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.

The following describes a few use cases where `SupervisedEdgeWise` algorithm can be applied:

- **Friends Recommendation**: To predict future friendships or connections between users based on current social graph data.
- **Customer Retention**: To predict which customers are likely to stop using a service by analyzing interaction patterns within the customer support network or usage logs.
- **Predictive Maintenance in IoT Networks**: To forecast potential failures in IoT (Internet of Things) networks by classifying the edges (connections) between sensors and devices based on historical data. This helps in proactive maintenance scheduling.

17.3.1 Loading a Graph

The following describes the steps for loading a graph:

1. Create a **Session** and an **Analyst**.

- 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
```

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;
```

Python

```
# starting the Python shell will create an implicit session and analyst
```

2. Load the **graph**.

- JShell
- Java
- Python

JShell

```
opg4j> var instance = GraphServer.getInstance("https://localhost:7007",
"<username>", "<password>".toCharArray())
opg4j> var session=instance.createSession("mySession")
opg4j> var fullGraph =
session.readGraphByName("<movielens_graph>",GraphSource.PG_PGQL)
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

```
ServerInstance instance = GraphServer.getInstance("https://
localhost:7007", "<username>", "<password>".toCharArray());
PgxSession session = instance.createSession("my-session");
PgxGraph fullGraph =
session.readGraphByName("<movielens_graph>",GraphSource.PG_PGQL);
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
instance = graph_server.get_instance("https://
localhost:7007","<username>","<password>")
session = instance.create_session("my_session")
full_graph = session.read_graph_by_name("<movielens_graph>", "pg_pgql")
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)
```

17.3.2 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)
```

17.3.3 Advanced Hyperparameter Customization

You can build a Supervised EdgeWise model using rich hyperparameter customization. Internally for each node, GraphWise applies an aggregation of the representation of neighbors. You can configure this operation through one of the following sub-config classes:

- `GraphWiseConvLayerConfig`: GraphWiseConvLayer is based on Inductive Representation Learning on Large Graphs (GraphSage) by Hamilton et al.
- `GraphWiseAttentionLayerConfig`: GraphWiseAttentionLayer is based on Graph Attention Networks (GAT) by Velickovic et al. which makes the aggregation smarter but comes with larger computation cost.

Also, you can enable or disable a graphics processing unit (GPU) by using the `enable_ml_accelerators` graph server (PGX) configuration parameter (see Configuration Parameters for the Graph Server (PGX) Engine for more information). In addition, ensure that your system meets the following prerequisites to use the GPU support:

- You must have a GPU device with the CUDA (Compute Unified Device Architecture) toolkit installed.
- The following list of CUDA libraries are expected:
  - `libcuda.so.1`
  - `libnvrtc.so.12`
  - `libnvToolsExt.so.1`
  - `libcudart.so.12`

Note that the `enable_ml_accelerators` option is enabled by default. But if a GPU device is not detected and the CUDA toolkit is not installed, then this feature gets disabled and the CPU will be used for all the PgxML library operations.

The following code examples uses the `GraphWiseConvLayerConfig` class for the convolutional layer configuration. The examples specifies a weight decay parameter of `0.001` and dropout with dropping probability `0.5` for the GraphWise model to counteract overfitting. Also, note that the `setEnableAccelerator` method is enabled to use any available GPU.

- 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).
         setEnableAccelerator(true). // Enable or disable GPU
         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)
    .setEnableAccelerator(true) // Enable or disable GPU
    .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,
              enable_accelerator=True # Enable or disable GPU
)

model = analyst.supervised_edgewise_builder(**params)
```

In the preceding example, you can replace `GraphWiseConvLayerConfig` with the `GraphWiseAttentionLayerConfig` class to build a graph attention network model. Also, note

that if the number of sampled neighbors is set to `-1` using `setNumSampledNeighbors`, then all the neighboring nodes will be sampled.

- JShell
- Java
- Python

JShell

```
opg4j> var convLayerConfig = analyst.graphWiseAttentionLayerConfigBuilder().
         setNumSampledNeighbors(25).
         setActivationFunction(ActivationFunction.LEAKY_RELU).
         setWeightInitScheme(WeightInitScheme.XAVIER_UNIFORM).
         setHeadAggregation(AggregationOperation.MEAN).
         setNumHeads(4).
         setDropoutRate(0.5).
         build()
```

Java

```
GraphWiseAttentionLayerConfig convLayerConfig =
analyst.graphWiseAttentionLayerConfigBuilder()
    .setNumSampledNeighbors(25)
    .setActivationFunction(ActivationFunction.LEAKY_RELU)
    .setWeightInitScheme(WeightInitScheme.XAVIER_UNIFORM)
    .setHeadAggregation(AggregationOperation.MEAN)
    .setNumHeads(4)
    .setDropoutRate(0.5)
    .build();
```

Python

```
conv_layer_config = dict(num_sampled_neighbors=25,
                         activation_fn='leaky_relu',
                         weight_init_scheme='xavier_uniform',
                         aggregation_operation='mean',
                         num_heads=4,
                         dropout_rate=0.5)
```

See the Javadoc for more information.

17.3.4 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)
```

17.3.5 Supported Property Types for Supervised EdgeWise Model

The model supports two types of properties for both vertices and edges:

- `continuous properties` (boolean, double, float, integer, long)
- `categorical properties` (string)

For categorical properties, two categorical configurations are possible:

- **One-hot-encoding:** Each category is mapped to a vector, that is concatenated to other features (default).
- **Embedding table:** Each category is mapped to an embedding that is concatenated to other features and is trained along with the model.

One-hot-encoding converts each category into an independent vector. This is useful if you want each category to be interpreted as an equally independent group. For instance, if there are categories ranging from A to E, where each alphabet has no specific meaning, then one-hot-encoding can be a good fit.

Embedding table is recommended if the semantics of the properties matter, and you want certain categories to be closer to each other than the others. For example, assume there is a `day` property with values ranging from *Monday* to *Sunday*. If you wish to preserve the idea that *Tuesday* is closer to *Wednesday* than *Saturday*, then by choosing the embedding table configuration, you can let the vectors that represent the categories to be learned during training, so that the vector that is mapped to *Tuesday* becomes close to that of *Wednesday*.

One advantage that the embedding table approach has over one-hot-encoding is that you can learn more suitable vectors to represent each category. However, this also means that a good amount of data is required to train the embedding table properly. The one-hot-encoding approach might be better for use-cases with limited training data.

When using the embedding table, users are allowed to set the out-of-vocabulary probability. With the given probability, the embedding will be set to the out-of-vocabulary embedding randomly during training, in order to make the model more robust to unseen categories during inference.

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.inputconfig.CategoricalPropertyConfig;
opg4j> var prop1config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_1").
    oneHotEncoding().
    setMaxVocabularySize(100).
    build()
opg4j> var prop2config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_2").
    embeddingTable().
    setShared(false). // set whether to share the vocabulary or not when
several vertex types have a property with the same name
    setEmbeddingDimension(32).
    setOutOfVocabularyProbability(0.001). // probability to set the word
embedding to the out-of-vocabulary embedding
    build()
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
    setVertexInputPropertyNames(
        "vertex_int_feature_1", // continuous feature
```

```
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3" // string feature using one-hot-encoding
(default)
    ).
    setVertexInputPropertyConfigs(prop1config, prop2config).
    setEdgeTargetPropertyName("label").
    build()
```

Java

```
import oracle.pgx.config.mllib.inputconfig.CategoricalPropertyConfig;
import oracle.pgx.config.mllib.inputconfig.InputPropertyConfig;

InputPropertyConfig prop1config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_1")
    .oneHotEncoding()
    .setMaxVocabularySize(100)
    .build();
InputPropertyConfig prop2config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_2")
    .embeddingTable()
    .setShared(false) // set whether to share the vocabulary or not when
several vertex types have a property with the same name
    .setEmbeddingDimension(32)
    .setOutOfVocabularyProbability(0.001) // probability to set the word
embedding to the out-of-vocabulary embedding
    .build();
SupervisedGraphWiseModelBuilder model =
analyst.supervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames(
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3" // string feature using one-hot-encoding
(default)
    )
    .setVertexInputPropertyConfigs(prop1config, prop2config)
    .setEdgeTargetPropertyName("label")
    .build();
```

Python

```
vertex_input_property_configs = [
    analyst.one_hot_encoding_categorical_property_config(
        property_name="vertex_str_feature_1",
        max_vocabulary_size=100,
    ),
    analyst.learned_embedding_categorical_property_config(
        property_name="vertex_str_feature_2",
        embedding_dim=4,
        shared=False, // set whether to share the vocabulary or not when
several  types have a property with the same name
        oov_probability=0.001 // probability to set the word embedding to the
```

```
out-of-vocabulary embedding
    )
]

model_params = dict(
    vertex_input_property_names=[
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3", // string feature using one-hot-encoding
(default)
    ],
    vertex_input_property_configs=vertex_input_property_configs,
    edge_target_property_name="labels"
)

model = analyst.supervised_edgewise_builder(**model_params)
```

17.3.6 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)
```

17.3.7 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)
```

17.3.8 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)
```

17.3.9 Training a 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)
```

You can also add a validation step to the training. When training a model, the optimal number of training epochs is not known in advance and it is one of the key parameters that determines the model quality. Being able to monitor the training and validation losses helps you to identify a good value for the model parameters and gain visibility in the training process. The evaluation frequency can be specified in terms of epoch or step. To configure a validation step, create a `GraphWiseValidationConfig` and pass it to the model builder as shown:

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.EvaluationFrequencyScale;

opg4j> var validationConfig = analyst.graphWiseValidationConfigBuilder().
         setEvaluationFrequency(2).                                    // set
the evaluation frequency (default: 1)
         setEvaluationFrequencyScale(EvaluationFrequencyScale.EPOCH).  //
available options: EPOCH, STEP (default: EPOCH)
         build()

opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         setEdgeTargetPropertyName("labels").
         setValidationConfig(validationConfig).  // configuring the
validation to be executed every 2 epochs
         build()
```

Java

```
import oracle.pgx.config.mllib.GraphWiseValidationConfig;
import oracle.pgx.config.mllib.EvaluationFrequencyScale;

GraphWiseValidationConfig validationConfig =
analyst.graphWiseValidationConfigBuilder()
    .setEvaluationFrequency(2)                                    // set the
evaluation frequency (default: 1)
    .setEvaluationFrequencyScale(EvaluationFrequencyScale.EPOCH)  //
available options: EPOCH, STEP (default: EPOCH)
    .build();

SupervisedEdgeWiseModel model = analyst.supervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setEdgeTargetPropertyName("labels")
    .setValidationConfig(validationConfig)  // configuring the validation to
be executed every 2 epochs
    .build();
```

Python

```
validation_config = analyst.graphwise_validation_config(
    evaluation_frequency=2,              # set the evaluation frequency
(default: 1)
    evaluation_frequency_scale="epoch",  # available options: "epoch", "step"
(default: "epoch")
)

params = dict(edge_target_property_name="labels",
              vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              validation_config=validation_config,  # configuring the
validation to be executed every 2 epochs
```

```
                seed=17)

model = analyst.supervised_edgewise_builder(**params)
```

After configuring a validation step, you can then pass a graph for validation to the `fit` method together with the graph for training:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(trainGraph, valGraph)
```

Java

```
model.fit(trainGraph,valGraph);
```

Python

```
model.fit(train_graph,valGraph)
```

17.3.10 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()
```

17.3.11 Getting the Training Log for a Supervised EdgeWise Model

If you configured a validation step (see Training a Supervised EdgeWise Model) earlier, then you can fetch the training log that contains the training and validation loss information.

- JShell
- Java
- Python

JShell

```
opg4j> var trainingLog = model.getTrainingLog()
```

Java

```
PgxFrame trainingLog = model.getTrainingLog();
```

Python

```
training_log = model.get_training_log()
```

The output frame will be similar to the following example output:

```
+-------------------------------------------------+
| epoch | training_loss      | validation_loss    |
+-------------------------------------------------+
| 2     | 1.5059218406677246 | 0.41696539521217346 |
| 4     | 0.5052874088287354 | 0.3255307078361511  |
| 6     | 0.3264007568359375 | 0.44015955924987793 |
+-------------------------------------------------+
```

Also, note the following:

- The first column will be named according to the evaluation frequency scale that was set in the validation configuration ("epoch" or "step").

- The validation loss is the average of the losses evaluated on all batches of the validation graph, while the training loss is the loss value logged at that epoch or step (that is, the loss evaluated on the last batch).
- The training log will be overwritten if the `fit` method is called multiple times.

17.3.12 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` methoid.

17.3.13 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.

17.3.14 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").overwr
ite(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.

17.3.15 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.

17.3.16 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.

17.3.17 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()
```

17.3.18 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 |
+--------------------+
```

17.4 Using the Unsupervised GraphWise Algorithm (Vertex Embeddings)

`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 an embedding layer which defaults to 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 second embedding layer available is the Dominant Layer.

Dominant is a model that detects anomalies based on the features and the neighbors' structure. Using GCNs to reconstruct the features in an autoencoder's settings, and the mask with the dot products of the embeddings.

The loss function is computed from the feature reconstruction loss and the structure reconstruction loss. The importance given to features or to the structure can be tuned with the alpha hyperparameter.

The following describes a few use cases where `UnsupervisedGraphWise` algorithm can be applied:

- **Fraud Detection in Financial Transactions**: To identify clusters of fraudulent activities by analyzing the transaction network and generating embeddings for accounts or transactions. This helps in detecting unknown patterns of fraud.
- **Network Optimization**: To optimize network performance in telecommunications by clustering the network nodes (such as routers or cell towers) based on traffic patterns. This helps to improve data flow and reduce latency.
- **Bioinformatics**: To analyze protein-protein interaction networks and discover new clusters or communities of proteins that might share similar functions. This helps in drug discovery and understanding biological processes.

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
- Supported Property Types for Unsupervised GraphWise Model
- Building an Unsupervised GraphWise Model Using Partitioned Graphs
- Training an Unsupervised GraphWise Model
- Getting the Loss Value for an Unsupervised GraphWise Model
- Getting the Training Log for an Unsupervised GraphWise Model

17.4.1 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
```

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;
```

Python

```
# starting the Python shell will create an implicit session and analyst
```

2. Load the **graph**.

- JShell

- Java
- Python

JShell

```
opg4j> var instance = GraphServer.getInstance("https://localhost:7007",
"<username>", "<password>".toCharArray())
opg4j> var session=instance.createSession("mySession")
opg4j> var graph =
session.readGraphByName("<graph_name>",GraphSource.PG_PGQL)
```

Java

```
ServerInstance instance = GraphServer.getInstance("https://
localhost:7007", "<username>", "<password>".toCharArray());
PgxSession session = instance.createSession("my-session");
PgxGraph graph =
session.readGraphByName("<graph_name>",GraphSource.PG_PGQL);
```

Python

```
instance = graph_server.get_instance("https://
localhost:7007","<username>","<password>")
session = instance.create_session("my_session")
graph = session.read_graph_by_name("<graph_name>", "pg_pgql")
```

You do not need to use a test graph or test vertices, since the model is trained to be unsupervised.

17.4.2 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"
])
```

17.4.3 Advanced Hyperparameter Customization

You can build an Unsupervised GraphWise model using rich hyperparameter customization. Internally for each node, GraphWise applies an aggregation of the representation of neighbors. You can configure this operation through one of the following sub-config classes:

- `GraphWiseConvLayerConfig`: GraphWiseConvLayer is based on Inductive Representation Learning on Large Graphs (GraphSage) by Hamilton et al.
- `GraphWiseAttentionLayerConfig`: GraphWiseAttentionLayer is based on Graph Attention Networks (GAT) by Velickovic et al. which makes the aggregation smarter but comes with larger computation cost.

Also, you can enable or disable a graphics processing unit (GPU) by using the `enable_ml_accelerators` graph server (PGX) configuration parameter (see Configuration Parameters for the Graph Server (PGX) Engine for more information). In addition, ensure that your system meets the following prerequisites to use the GPU support:

- You must have a GPU device with the CUDA (Compute Unified Device Architecture) toolkit installed.
- The following list of CUDA libraries are expected:
  - `libcuda.so.1`
  - `libnvrtc.so.12`
  - `libnvToolsExt.so.1`
  - `libcudart.so.12`

Note that the `enable_ml_accelerators` option is enabled by default. But if a GPU device is not detected and the CUDA toolkit is not installed, then this feature gets disabled and the CPU will be used for all the PgxML library operations.

The following code examples uses the `GraphWiseConvLayerConfig` class for the convolutional layer configuration. The examples specifies a weight decay parameter of `0.001` and dropout with dropping probability `0.5` for the GraphWise model to counteract overfitting. Also, it is recommended to disable normalization of embeddings when you intend to use them in downstream classfication tasks. Note that the `setEnableAccelerator` method is enabled to use any available GPU.

- 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_CROSS_EN
TROPY).
         setEmbeddingDim(256).
         setLearningRate(0.05).
         setNumEpochs(30).
         setSeed(42).
         setShuffle(false).
         setStandardize(true).
         setNormalize(false).  // recommended
         setBatchSize(64).
         setEnableAccelerator(true). // Enable or disable GPU
         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.SIGMOID_CRO
SS_ENTROPY)
    .setConvLayerConfigs(convLayerConfig)
    .setWeightDecay(0.001)
    .setEmbeddingDim(256)
    .setLearningRate(0.05)
    .setNumEpochs(30)
    .setSeed(42)
    .setShuffle(false)
    .setStandardize(true)
    .setNormalize(false)  // recommended
    .setBatchSize(64)
    .setEnableAccelerator(true) // Enable or disable GPU
    .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,
              normalize=False,  # recommended
              batch_size=64,
              enable_accelerator=True # Enable or disable GPU
)
```

```
model = analyst.unsupervised_graphwise_builder(**params)
```

In the preceding example, you can replace `GraphWiseConvLayerConfig` with the `GraphWiseAttentionLayerConfig` class to build a graph attention network model. Also, note that if the number of sampled neighbors is set to `-1` using `setNumSampledNeighbors`, then all the neighboring nodes will be sampled.

- JShell
- Java
- Python

JShell

```
opg4j> var convLayerConfig = analyst.graphWiseAttentionLayerConfigBuilder().
         setNumSampledNeighbors(25).
         setActivationFunction(ActivationFunction.LEAKY_RELU).
         setWeightInitScheme(WeightInitScheme.XAVIER_UNIFORM).
         setHeadAggregation(AggregationOperation.MEAN).
         setNumHeads(4).
         setDropoutRate(0.5).
         build()
```

Java

```
GraphWiseAttentionLayerConfig convLayerConfig =
analyst.graphWiseAttentionLayerConfigBuilder()
    .setNumSampledNeighbors(25)
    .setActivationFunction(ActivationFunction.LEAKY_RELU)
    .setWeightInitScheme(WeightInitScheme.XAVIER_UNIFORM)
    .setHeadAggregation(AggregationOperation.MEAN)
    .setNumHeads(4)
    .setDropoutRate(0.5)
    .build();
```

Python

```
conv_layer_config = dict(num_sampled_neighbors=25,
                         activation_fn='leaky_relu',
                         weight_init_scheme='xavier_uniform',
                         aggregation_operation='mean',
                         num_heads=4,
                         dropout_rate=0.5)
```

See the Javadoc for more information.

17.4.4 Supported Property Types for Unsupervised GraphWise Model

The model supports two types of properties for both vertices and edges:

- `continuous properties` (boolean, double, float, integer, long)
- `categorical properties` (string)

For categorical properties, two categorical configurations are possible:

- **One-hot-encoding:** Each category is mapped to a vector, that is concatenated to other features (default)
- **Embedding table:** Each category is mapped to an embedding that is concatenated to other features and is trained along with the model

One-hot-encoding converts each category into an independent vector. This is useful if you want each category to be interpreted as an equally independent group. For instance, if there are categories ranging from A to E, where each alphabet has no specific meaning, then one-hot-encoding can be a good fit.

Embedding table is recommended if the semantics of the properties matter, and you want certain categories to be closer to each other than the others. For example, assume there is a `day` property with values ranging from *Monday* to *Sunday*. If you wish to preserve the idea that *Tuesday* is closer to *Wednesday* than *Saturday*, then by choosing the embedding table configuration, you can let the vectors that represent the categories to be learned during training, so that the vector that is mapped to *Tuesday* becomes close to that of *Wednesday*.

One advantage that the embedding table approach has over one-hot-encoding is that you can learn more suitable vectors to represent each category. However, this also means that a good amount of data is required to train the embedding table properly. The one-hot-encoding approach might be better for use-cases with limited training data.

When using the embedding table, users are allowed to set the out-of-vocabulary probability. With the given probability, the embedding will be set to the out-of-vocabulary embedding randomly during training, in order to make the model more robust to unseen categories during inference.

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.inputconfig.CategoricalPropertyConfig;
opg4j> var prop1config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_1").
    oneHotEncoding().
    setMaxVocabularySize(100).
    build()
opg4j> var prop2config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_2").
    embeddingTable().
```

```
    setShared(false). // set whether to share the vocabulary or not when
several vertex types have a property with the same name
    setEmbeddingDimension(32).
    setOutOfVocabularyProbability(0.001). // probability to set the word
embedding to the out-of-vocabulary embedding
    build()
opg4j> var model = analyst.unsupervisedGraphWiseModelBuilder().
    setVertexInputPropertyNames(
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3" // string feature using one-hot-encoding
(default)
    ).
    setVertexInputPropertyConfigs(prop1config, prop2config).
    build()
```

Java

```
import oracle.pgx.config.mllib.inputconfig.CategoricalPropertyConfig;
import oracle.pgx.config.mllib.inputconfig.InputPropertyConfig;

InputPropertyConfig prop1config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_1")
    .oneHotEncoding()
    .setMaxVocabularySize(100)
    .build();
InputPropertyConfig prop2config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_2")
    .embeddingTable()
    .setShared(false) // set whether to share the vocabulary or not when
several vertex types have a property with the same name
    .setEmbeddingDimension(32)
    .setOutOfVocabularyProbability(0.001) // probability to set the word
embedding to the out-of-vocabulary embedding
    .build();
SupervisedGraphWiseModelBuilder model =
analyst.unsupervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames(
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3" // string feature using one-hot-encoding
(default)
    )
    .setVertexInputPropertyConfigs(prop1config, prop2config)
    .build();
```

Python

```
vertex_input_property_configs = [
    analyst.one_hot_encoding_categorical_property_config(
        property_name="vertex_str_feature_1",
        max_vocabulary_size=100,
```

```
    ),
    analyst.learned_embedding_categorical_property_config(
        property_name="vertex_str_feature_2",
        embedding_dim=4,
        shared=False, // set whether to share the vocabulary or not when
several  types have a property with the same name
        oov_probability=0.001 // probability to set the word embedding to the
out-of-vocabulary embedding
    )
]

model_params = dict(
    vertex_input_property_names=[
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3", // string feature using one-hot-encoding
(default)
    ],
    vertex_input_property_configs=vertex_input_property_configs
)

model = analyst.supervised_graphwise_builder(**model_params)
```

17.4.5 Building an Unsupervised GraphWise Model Using Partitioned 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)
```

17.4.6 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)
```

You can also add a validation step to the training. When training a model, the optimal number of training epochs is not known in advance and it is one of the key parameters that determines the model quality. Being able to monitor the training and validation losses helps you to identify a good value for the model parameters and gain visibility in the training process. The evaluation frequency can be specified in terms of epoch or step. To configure a validation step, create a `GraphWiseValidationConfig` and pass it to the model builder as shown:

- JShell

- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.EvaluationFrequencyScale;

opg4j> var validationConfig = analyst.graphWiseValidationConfigBuilder().
         setEvaluationFrequency(100).                                    // set
the evaluation frequency (default: 1)
         setEvaluationFrequencyScale(EvaluationFrequencyScale.STEP).   //
available options: EPOCH, STEP (default: EPOCH)
         build()
opg4j> var model = analyst.unsupervisedGraphWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setValidationConfig(validationConfig).          // configuring the
validation to be executed every 100 steps
         build()
```

Java

```
import oracle.pgx.config.mllib.GraphWiseValidationConfig;
import oracle.pgx.config.mllib.EvaluationFrequencyScale;

GraphWiseValidationConfig validationConfig =
analyst.graphWiseValidationConfigBuilder()
    .setEvaluationFrequency(100)                                    // set the
evaluation frequency (default: 1)
    .setEvaluationFrequencyScale(EvaluationFrequencyScale.STEP)  // available
options: EPOCH, STEP (default: EPOCH)
    .build();

UnsupervisedGraphWiseModel model = analyst.unsupervisedGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setValidationConfig(validationConfig)  // configuring the validation to
be executed every 100 steps
    .build();
```

Python

```
validation_config = analyst.graphwise_validation_config(
    evaluation_frequency=100,           # set the evaluation frequency
(default: 1)
    evaluation_frequency_scale="step",  # available options: "epoch", "step"
(default: "epoch")
)

params = dict(vertex_input_property_names=["vertex_features"],
              validation_config=validation_config,  # configuring the
validation to be executed every 100 steps
              seed=17)

model = analyst.unsupervised_graphwise_builder(**params)
```

After configuring a validation step, you can then pass a graph for validation to the `fit` method together with the graph for training:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(trainGraph, valGraph)
```

Java

```
model.fit(trainGraph,valGraph);
```

Python

```
model.fit(train_graph,valGraph)
```

17.4.7 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()
```

17.4.8 Getting the Training Log for an Unsupervised GraphWise Model

If you configured a validation step (see Training an Unsupervised GraphWise Model) earlier, then you can fetch the training log that contains the training and validation loss information.

- JShell
- Java
- Python

JShell

```
opg4j> var trainingLog = model.getTrainingLog()
```

Java

```
PgxFrame trainingLog = model.getTrainingLog();
```

Python

```
training_log = model.get_training_log()
```

The output frame will be similar to the following example output:

```
+-------------------------------------------------+
| step  | training_loss      | validation_loss    |
+-------------------------------------------------+
| 100   | 1.5059218406677246 | 0.41696539521217346 |
| 200   | 0.5052874088287354 | 0.3255307078361511  |
| 300   | 0.3264007568359375 | 0.44015955924987793 |
+-------------------------------------------------+
```

Also, note the following:

- The first column will be named according to the evaluation frequency scale that was set in the validation configuration ("epoch" or "step").
- The validation loss is the average of the losses evaluated on all batches of the validation graph, while the training loss is the loss value logged at that epoch or step (that is, the loss evaluated on the last batch).

- The training log will be overwritten if the `fit` method is called multiple times.

17.4.9 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()).flatten_all()
vertex_vectors.write().db().table_name("table_name").name("vertex_vectors").ov
erwrite(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.

17.4.10 Classifying the Vertices Using the Obtained Embeddings

You can use the obtained embeddings in downstream vertex classification tasks.

The following code shows how you can train a multi-layer perceptron (MLP) classifier, which takes the embeddings as input. It is assumed that the vertex label information is stored under the vertex property `labels`.

- Python

Python

```
import pandas as pd
from sklearn.metrics import accuracy_score, make_scorer
from sklearn.model_selection import RepeatedStratifiedKFold, cross_val_score
from sklearn.neural_network import MLPClassifier
from sklearn.preprocessing import StandardScaler


# prepare input data
vertex_vectors_df = vertex_vectors.to_pandas().astype({"vertexId": int})
vertex_labels_df = pd.DataFrame([
    {"vertexId": v.id, "labels": properties}
    for v, properties in graph.get_vertex_property("labels").get_values()
]).astype(int)

vertex_vectors_with_labels_df = vertex_vectors_df.merge(vertex_labels_df,
on="vertexId")

feature_columns = [c for c in vertex_vectors_df.columns if
c.startswith("embedding")]
x = vertex_vectors_with_labels_df[feature_columns].to_numpy()
y = vertex_vectors_with_labels_df["labels"].to_numpy()

scaler = StandardScaler()
x = scaler.fit_transform(x)

# define an MLP classifier
model = MLPClassifier(
    hidden_layer_sizes=(6,),
    learning_rate_init=0.05,
    max_iter=2000,
    random_state=42,
)
```

```
# define a metric and evaluate with cross-validation
cv = RepeatedStratifiedKFold(n_splits=5, n_repeats=3, random_state=42)
scorer = make_scorer(accuracy_score, greater_is_better=True)
scores = cross_val_score(model, x, y, scoring=scorer, cv=cv, n_jobs=-1)
```

17.4.11 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.

17.4.12 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.

17.4.13 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()
```

17.4.14 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.readGraphByName("<graph>",GraphSource.PG_PGQL)
// 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.readGraphByName("<graph>",GraphSource.PG_PGQL); // load 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

17.5 Using the Unsupervised EdgeWise Algorithm

`UnsupervisedEdgeWise` 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 unsupervised learning edge embeddings for edge classification.

Unsupervised EdgeWise 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.

The training is based on Deep Graph Infomax (DGI) by Velickovic et al.

Model Structure

An `UnsupervisedEdgeWise` model consists of graph convolutional layers followed by an embedding layer which defaults to a DGI layer.

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 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 second embedding layer available is the Dominant Layer.

Dominant is a model that detects anomalies based on the features and the neighbors' structure. Using GCNs to reconstruct the features in an autoencoder's settings, and the mask with the dot products of the embeddings.

The loss function is computed from the feature reconstruction loss and the structure reconstruction loss. The importance given to features or to the structure can be tuned with the alpha hyperparameter.

The following describes a few use cases where `UnsupervisedEdgeWise` algorithm can be applied:

- **Supply Chain Optimization**: To analyze relationships between different entities in a supply chain network. This helps to predict potential delays or disruptions, thereby optimizing logistics and inventory management.
- **Collaboration Network Analysis**: To understand collaboration patterns between individuals or departments in research or corporate environments. This helps to improve team structures and enhance productivity.
- **Recommendation in E-commerce**: To recommend products (using edge embeddings) that are frequently bought together by analyzing the relationship between different products in a purchasing network.

The following describes the usage of the main functionalities of `UnsupervisedEdgeWise` in PGX using the Movielens graph as an example.

- Loading a Graph
- Building a Minimal Unsupervised EdgeWise Model
- Advanced Hyperparameter Customization
- Supported Property Types for Unsupervised EdgeWise Model
- Applying Unsupervised EdgeWise for Partitioned Graphs
- Setting the Edge Combination Production Method
- Training an Unsupervised EdgeWise Model
- Getting the Loss Value for an Unsupervised EdgeWise Model
- Getting the Training Log for an Unsupervised EdgeWise Model

17.5.1 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
opg4j> import oracle.pgx.config.mllib.ActivationFunction
opg4j> import oracle.pgx.config.mllib.WeightInitScheme
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.mllib.UnsupervisedEdgeWiseModel;
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.GraphWiseDgiLayerConfig;
import oracle.pgx.config.mllib.corruption.PermutationCorruption;
import oracle.pgx.config.mllib.UnsupervisedEdgeWiseModelConfig;
import oracle.pgx.config.mllib.WeightInitScheme;
```

Python

```
# starting the Python shell will create an implicit session and analyst
```

2. Load the **graph**.

- JShell
- Java
- Python

JShell

```
opg4j> var instance = GraphServer.getInstance("https://localhost:7007",
"<username>", "<password>".toCharArray())
opg4j> var session=instance.createSession("mySession")
opg4j> var fullGraph =
session.readGraphByName("<movielens_graph>",GraphSource.PG_PGQL)
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

```
ServerInstance instance = GraphServer.getInstance("https://
localhost:7007", "<username>", "<password>".toCharArray());
PgxSession session = instance.createSession("my-session");
PgxGraph fullGraph =
session.readGraphByName("<movielens_graph>",GraphSource.PG_PGQL);
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
instance = graph_server.get_instance("https://
localhost:7007","<username>","<password>")
session = instance.create_session("my_session")
full_graph = session.read_graph_by_name("<movielens_graph>", "pg_pgql")
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)
```

17.5.2 Building a Minimal Unsupervised 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.unsupervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         build()
```

Java

```
UnsupervisedEdgeWiseModel model = analyst.unsupervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .build();
```

Python

```
params = dict(vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"])

model = analyst.unsupervised_edgewise_builder(**params)
```

17.5.3 Advanced Hyperparameter Customization

You can build an Unsupervised EdgeWise model using rich hyperparameter customization. Internally for each node, GraphWise applies an aggregation of the representation of neighbors. You can configure this operation through one of the following sub-config classes:

- `GraphWiseConvLayerConfig`: GraphWiseConvLayer is based on Inductive Representation Learning on Large Graphs (GraphSage) by Hamilton et al.
- `GraphWiseAttentionLayerConfig`: GraphWiseAttentionLayer is based on Graph Attention Networks (GAT) by Velickovic et al. which makes the aggregation smarter but comes with larger computation cost.

Also, you can enable or disable a graphics processing unit (GPU) by using the `enable_ml_accelerators` graph server (PGX) configuration parameter (see Configuration Parameters for the Graph Server (PGX) Engine for more information). In addition, ensure that your system meets the following prerequisites to use the GPU support:

- You must have a GPU device with the CUDA (Compute Unified Device Architecture) toolkit installed.
- The following list of CUDA libraries are expected:
  - `libcuda.so.1`
  - `libnvrtc.so.12`
  - `libnvToolsExt.so.1`
  - `libcudart.so.12`

Note that the `enable_ml_accelerators` option is enabled by default. But if a GPU device is not detected and the CUDA toolkit is not installed, then this feature gets disabled and the CPU will be used for all the PgxML library operations.

The following code examples uses the `GraphWiseConvLayerConfig` class for the convolutional layer configuration. The examples also specifies a weight decay parameter of `0.001` and dropout with dropping probability `0.5` for the GraphWise model to counteract overfitting. Also, it is recommended to disable normalization of embeddings when you intend to use them in downstream classfication tasks. Note that the `setEnableAccelerator` method is enabled to use any available GPU.

- 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.unsupervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         setConvLayerConfigs(convLayerConfig).
         setDgiLayerConfig(dgiLayerConfig).
         setWeightDecay(0.001).
         setNormalize(false).  // recommended
```

```
        setEnableAccelerator(true). // Enable or disable GPU
        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();

UnsupervisedEdgeWiseModel model = analyst.unsupervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setConvLayerConfigs(convLayerConfig)
    .setDgiLayerConfigs(dgiLayerConfig)
    .setWeightDecay(0.001)
    .setNormalize(false)  // recommended
    .setEnableAccelerator(true) // Enable or disable GPU
    .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"],
                seed=17,
                normalize=False,  # recommended
                weight_decay=0.001,
                enable_accelerator=True) # Enable or disable GPU
)

model = analyst.unsupervised_edgewise_builder(**params)
```

In the preceding example, you can replace `GraphWiseConvLayerConfig` with the `GraphWiseAttentionLayerConfig` class to build a graph attention network model. Also, note that if the number of sampled neighbors is set to `-1` using `setNumSampledNeighbors`, then all the neighboring nodes will be sampled.

- JShell
- Java
- Python

JShell

```
opg4j> var convLayerConfig = analyst.graphWiseAttentionLayerConfigBuilder().
         setNumSampledNeighbors(25).
         setActivationFunction(ActivationFunction.LEAKY_RELU).
         setWeightInitScheme(WeightInitScheme.XAVIER_UNIFORM).
         setHeadAggregation(AggregationOperation.MEAN).
         setNumHeads(4).
         setDropoutRate(0.5).
         build()
```

Java

```
GraphWiseAttentionLayerConfig convLayerConfig =
analyst.graphWiseAttentionLayerConfigBuilder()
    .setNumSampledNeighbors(25)
    .setActivationFunction(ActivationFunction.LEAKY_RELU)
    .setWeightInitScheme(WeightInitScheme.XAVIER_UNIFORM)
    .setHeadAggregation(AggregationOperation.MEAN)
    .setNumHeads(4)
    .setDropoutRate(0.5)
    .build();
```

Python

```
conv_layer_config = dict(num_sampled_neighbors=25,
                         activation_fn='leaky_relu',
                         weight_init_scheme='xavier_uniform',
                         aggregation_operation='mean',
```

```
num_heads=4,
dropout_rate=0.5)
```

See the Javadoc for more information.

17.5.4 Supported Property Types for Unsupervised EdgeWise Model

The model supports two types of properties for both vertices and edges:

- `continuous properties` (boolean, double, float, integer, long)
- `categorical properties` (string)

For categorical properties, two categorical configurations are possible:

- **One-hot-encoding:** Each category is mapped to a vector, that is concatenated to other features (default)
- **Embedding table:** Each category is mapped to an embedding that is concatenated to other features and is trained along with the model

One-hot-encoding converts each category into an independent vector. This is useful if you want each category to be interpreted as an equally independent group. For instance, if there are categories ranging from A to E, where each alphabet has no specific meaning, then one-hot-encoding can be a good fit.

Embedding table is recommended if the semantics of the properties matter, and you want certain categories to be closer to each other than the others. For example, assume there is a `day` property with values ranging from *Monday* to *Sunday*. If you wish to preserve the idea that *Tuesday* is closer to *Wednesday* than *Saturday*, then by choosing the embedding table configuration, you can let the vectors that represent the categories to be learned during training, so that the vector that is mapped to *Tuesday* becomes close to that of *Wednesday*.

One advantage that the embedding table approach has over one-hot-encoding is that you can learn more suitable vectors to represent each category. However, this also means that a good amount of data is required to train the embedding table properly. The one-hot-encoding approach might be better for use-cases with limited training data.

When using the embedding table, users are allowed to set the out-of-vocabulary probability. With the given probability, the embedding will be set to the out-of-vocabulary embedding randomly during training, in order to make the model more robust to unseen categories during inference.

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.inputconfig.CategoricalPropertyConfig
opg4j> var prop1config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_1").
```

```
    oneHotEncoding().
    setMaxVocabularySize(100).
    build()
opg4j> var prop2config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_2").
    embeddingTable().
    setShared(false). // set whether to share the vocabulary or not when
several vertex types have a property with the same name
    setEmbeddingDimension(32).
    setOutOfVocabularyProbability(0.001). // probability to set the word
embedding to the out-of-vocabulary embedding
    build()
opg4j> var model = analyst.supervisedEdgeWiseModelBuilder().
    setVertexInputPropertyNames(
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3" // string feature using one-hot-encoding
(default)
    ).
    setVertexInputPropertyConfigs(prop1config, prop2config).
    build()
```

Java

```
import oracle.pgx.config.mllib.inputconfig.CategoricalPropertyConfig;
import oracle.pgx.config.mllib.inputconfig.InputPropertyConfig;

InputPropertyConfig prop1config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_1")
    .oneHotEncoding()
    .setMaxVocabularySize(100)
    .build();
InputPropertyConfig prop2config =
analyst.categoricalPropertyConfigBuilder("vertex_str_feature_2")
    .embeddingTable()
    .setShared(false) // set whether to share the vocabulary or not when
several vertex types have a property with the same name
    .setEmbeddingDimension(32)
    .setOutOfVocabularyProbability(0.001) // probability to set the word
embedding to the out-of-vocabulary embedding
    .build();
UnsupervisedEdgeWiseModel model = analyst.unsupervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames(
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3" // string feature using one-hot-encoding
(default)
    )
    .setVertexInputPropertyConfigs(prop1config, prop2config)
    .build();
```

Python

```
vertex_input_property_configs = [
    analyst.one_hot_encoding_categorical_property_config(
        property_name="vertex_str_feature_1",
        max_vocabulary_size=100
    ),
    analyst.learned_embedding_categorical_property_config(
        property_name="vertex_str_feature_2",
        embedding_dim=4,
        shared=False, // set whether to share the vocabulary or not when
several  types have a property with the same name
        oov_probability=0.001 // probability to set the word embedding to the
out-of-vocabulary embedding
    )
]

model_params = dict(
    vertex_input_property_names=[
        "vertex_int_feature_1", // continuous feature
        "vertex_str_feature_1", // string feature using one-hot-encoding
        "vertex_str_feature_2", // string feature using embedding table
        "vertex_str_feature_3", // string feature using one-hot-encoding
(default)
    ],
    vertex_input_property_configs=vertex_input_property_configs
)

model = analyst.unsupervised_edgewise_builder(**model_params)
```

17.5.5 Applying Unsupervised EdgeWise for Partitioned Graphs

You can apply unsupervised edgewise on partitioned graphs, where you have different providers and different features.

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.unsupervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider_features").
         setEdgeInputPropertyNames("edge_provider1_features",
"edge_provider2_features").
         build()
```

Java

```
UnsupervisedEdgeWiseModel model = analyst.unsupervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider_features")
    .setEdgeInputPropertyNames("edge_provider1_features",
"edge_provider2_features")
    .build();
```

Python

```
params = dict(vertex_input_property_names=["vertex_provider_features"],
              edge_input_property_names=["edge_provider1_features",
"edge_provider2_features"])

model = analyst.unsupervised_edgewise_builder(**params)
```

You can select which providers you want to train or infer on:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.unsupervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider_features").
         setEdgeInputPropertyNames("edge_provider1_features",
"edge_provider2_features").
         setTargetEdgeLabels("provider1").
         build()
```

Java

```
UnsupervisedEdgeWiseModel model = analyst.unsupervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider_features")
    .setEdgeInputPropertyNames("edge_provider1_features",
"edge_provider2_features")
    .setTargetEdgeLabels("provider1")
    .build();
```

Python

```
params = dict(vertex_input_property_names=["vertex_provider_features"],
              edge_input_property_names=["edge_provider1_features",
"edge_provider2_features"],
              target_edge_labels=["provider1"])
```

```
model = analyst.unsupervised_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.unsupervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
         setEdgeInputPropertyNames("edge_provider_features").
         setTargetEdgeLabels("provider1").
         build()
```

Java

```
GraphWiseConvLayerConfig convLayerConfig =
analyst.graphWiseConvLayerConfigBuilder()
    .setNumSampledNeighbors(10)
    .useVertexToVertexConnection(true)
    .useEdgeToVertexConnection(true)
    .useEdgeToEdgeConnection(false)
    .useVertexToEdgeConnection(false)
    .build();

UnsupervisedEdgeWiseModel model = analyst.unsupervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .setEdgeInputPropertyNames("edge_provider_features")
    .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(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.unsupervised_edgewise_builder(**params)
```

17.5.6 Setting the Edge Combination 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.unsupervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         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);

UnsupervisedEdgeWiseModel model = analyst.unsupervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .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(vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              edge_combination_method=method,
              seed=17)

model = analyst.unsupervised_edgewise_builder(**params)
```

17.5.7 Training an Unsupervised EdgeWise Model

You can train an `UnsupervisedEdgeWiseModel` on a graph as shown:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(trainGraph)
```

Java

```
model.fit(trainGraph);
```

Python

```
model.fit(train_graph)
```

You can also add a validation step to the training. When training a model, the optimal number of training epochs is not known in advance and it is one of the key parameters that determines the model quality. Being able to monitor the training and validation losses helps you to identify a good value for the model parameters and gain visibility in the training process. The evaluation frequency can be specified in terms of epoch or step. To configure a validation step, create a `GraphWiseValidationConfig` and pass it to the model builder as shown:

- JShell
- Java
- Python

JShell

```
opg4j> import oracle.pgx.config.mllib.EvaluationFrequencyScale;

opg4j> var validationConfig = analyst.graphWiseValidationConfigBuilder().
         setEvaluationFrequency(100).                                  // set
the evaluation frequency (default: 1)
         setEvaluationFrequencyScale(EvaluationFrequencyScale.STEP).  //
available options: EPOCH, STEP (default: EPOCH)
         build()

opg4j> var model = analyst.unsupervisedEdgeWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setEdgeInputPropertyNames("edge_features").
         setValidationConfig(validationConfig).  // configuring the
validation to be executed every 100 steps
         build()
```

Java

```
import oracle.pgx.config.mllib.GraphWiseValidationConfig;
import oracle.pgx.config.mllib.EvaluationFrequencyScale;

GraphWiseValidationConfig validationConfig =
analyst.graphWiseValidationConfigBuilder()
    .setEvaluationFrequency(100)                                  // set the
evaluation frequency (default: 1)
    .setEvaluationFrequencyScale(EvaluationFrequencyScale.STEP)  // available
```

```
options: EPOCH, STEP (default: EPOCH)
    .build();

UnsupervisedEdgeWiseModel model = analyst.unsupervisedEdgeWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEdgeInputPropertyNames("edge_features")
    .setValidationConfig(validationConfig)  // configuring the validation to
be executed every 100 steps
    .build();
```

Python

```
validation_config = analyst.graphwise_validation_config(
    evaluation_frequency=100,           # set the evaluation frequency
(default: 1)
    evaluation_frequency_scale="step",  # available options: "epoch", "step"
(default: "epoch")
)

params = dict(vertex_input_property_names=["vertex_features"],
              edge_input_property_names=["edge_features"],
              validation_config=validation_config,  # configuring the
validation to be executed every 100 steps
              seed=17)

model = analyst.unsupervised_edgewise_builder(**params)
```

After configuring a validation step, you can then pass a graph for validation to the `fit` method together with the graph for training:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(trainGraph, valGraph)
```

Java

```
model.fit(trainGraph,valGraph);
```

Python

```
model.fit(train_graph,valGraph)
```

17.5.8 Getting the Loss Value for an Unsupervised EdgeWise Model

You can fetch the training loss value for an Unsupervised 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()
```

17.5.9 Getting the Training Log for an Unsupervised EdgeWise Model

If you configured a validation step (see Training an Unsupervised EdgeWise Model) earlier, then you can fetch the training log that contains the training and validation loss information.

- JShell
- Java
- Python

JShell

```
opg4j> var trainingLog = model.getTrainingLog()
```

Java

```
PgxFrame trainingLog = model.getTrainingLog();
```

Python

```
training_log = model.get_training_log()
```

The output frame will be similar to the following example output:

```
+-------------------------------------------------+
| step  | training_loss      | validation_loss    |
+-------------------------------------------------+
| 100   | 1.5059218406677246 | 0.41696539521217346 |
| 200   | 0.5052874088287354 | 0.3255307078361511  |
| 300   | 0.3264007568359375 | 0.44015955924987793 |
+-------------------------------------------------+
```

17.5.10 Inferring Embeddings for an Unsupervised 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").overwr
ite(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 `jdbcUrl` to the `inferEmbeddings` method. Refer to Inferring Embeddings for a Model in Another Database for an example.

17.5.11 Classifying the Edges Using the Obtained Embeddings

You can use the obtained embeddings in downstream edge classification tasks.

The following code shows how you can train a multi-layer perceptron (MLP) classifier, which takes the embeddings as input. It is assumed that the edge label information is stored under the edge property `labels`.

- Python

Python

```
import pandas as pd
from sklearn.metrics import accuracy_score, make_scorer
from sklearn.model_selection import RepeatedStratifiedKFold, cross_val_score
from sklearn.neural_network import MLPClassifier
from sklearn.preprocessing import StandardScaler


# prepare input data
edge_vectors_df = edge_vectors.to_pandas().astype({"edgeId": int})
edge_labels_df = pd.DataFrame([
    {"edgeId": e.id, "labels": properties}
    for e, properties in graph.get_edge_property("labels").get_values()
]).astype(int)

edge_vectors_with_labels_df = edge_vectors_df.merge(edge_labels_df,
on="edgeId")

feature_columns = [c for c in edge_vectors_df.columns if
```

```
c.startswith("embedding")]
x = edge_vectors_with_labels_df[feature_columns].to_numpy()
y = edge_vectors_with_labels_df["labels"].to_numpy()

scaler = StandardScaler()
x = scaler.fit_transform(x)

# define an MLP classifier
model = MLPClassifier(
    hidden_layer_sizes=(6,),
    learning_rate_init=0.05,
    max_iter=2000,
    random_state=42,
)

# define a metric and evaluate with cross-validation
cv = RepeatedStratifiedKFold(n_splits=5, n_repeats=3, random_state=42)
scorer = make_scorer(accuracy_score, greater_is_better=True)
scores = cross_val_score(model, x, y, scoring=scorer, cv=cv, n_jobs=-1)
```

17.5.12 Storing an Unsupervised 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 `UnsupervisedEdgeWise` 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.

17.5.13 Loading a Pre-Trained Unsupervised EdgeWise Model

You can load a pre-trained `UnsupervisedEdgeWise` model from a model store table in the database as shown:

- JShell
- Java
- Python

JShell

```
opg4j> var model = analyst.loadUnsupervisedEdgeWiseModel().db().
                modelstore("modeltablename"). // name of the model store table
                modelname("model").           // model name (primary key of
model store table)
                load()
```

Java

```
UnsupervisedEdgeWiseModel model = analyst.loadUnsupervisedEdgeWiseModel().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_edgewise_model_loader(). \
                 db("modeltablename",       # name of the model store table
                    "model_name")           # 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.

17.5.14 Destroying an Unsupervised Anomaly Detection GraphWise Model

You can destroy an Unsupervised Anomaly Detection GraphWise model as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.destroy()
```

Java

```
model.destroy();
```

Python

```
model.destroy()
```

17.5.15 Example: Computing Edge Embeddings on the Movielens Dataset

This section describes the usage of `UnsupervisedEdgeWise` in 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 `UnsupervisedEdgeWise` model. You first build the model and fit it on the `trainGraph`.

- JShell
- Java
- Python

JShell

```
opg4j> var convLayer = analyst.graphWiseConvLayerConfigBuilder().
        setNumSampledNeighbors(10).
        build()

opg4j> var model = analyst.unsupervisedEdgeWiseModelBuilder().
        setVertexInputPropertyNames("movie_year", "avg_rating",
"movie_genres", // Movies features
            "user_occupation_label", "user_gender", "raw_user_age"). // Users
features
        setEdgeInputPropertyNames("user_rating").
        setConvLayerConfigs(convLayer).
        setNumEpochs(10).
        setEmbeddingDim(32).
        setLearningRate(0.003).
        setStandardize(true).
        setNormalize(false). //recommended
        setSeed(0).
        build()
opg4j> model.fit(trainGraph)
```

Java

```
GraphWiseConvLayerConfig convLayer = analyst.graphWiseConvLayerConfigBuilder()
        .setNumSampledNeighbors(10)
        .build();

UnsupervisedEdgeWiseModel model = analyst.unsupervisedEdgeWiseModelBuilder()
        .setVertexInputPropertyNames("movie_year", "avg_rating",
"movie_genres", // Movies features
            "user_occupation_label", "user_gender", "raw_user_age") // Users
features
        .setEdgeInputPropertyNames("user_rating")
        .setConvLayerConfigs(convLayer)
        .setNumEpochs(10)
        .setEmbeddingDim(32)
        .setLearningRate(0.003)
        .setStandardize(true)
        .setNormalize(false) //recommended
        .setSeed(0)
```

```
        .build();

model.fit(trainGraph);
```

Python

```
conv_layer_config = dict(num_sampled_neighbors=10)

conv_layer = analyst.graphwise_conv_layer_config(**conv_layer_config)

params = dict(conv_layer_config=[conv_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,
              embedding_dim=32,
              learning_rate=0.003,
              normalize=False, #recommended
              seed=0)

model = analyst.unsupervised_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 embeddings = model.inferEmbeddings(fullGraph, testEdges)
opg4j> embeddings.head().print()
```

Java

```
PgxFrame embeddings = model.inferEmbeddings(fullGraph,testEdges);
embeddings.head().print();
```

Python

```
embeddings = model.infer_embeddings(full_graph, test_edges)
embeddings.print()
```

17.6 Using the Unsupervised Anomaly Detection GraphWise Algorithm (Vertex Embeddings and Anomaly Scores)

UnsupervisedAnomalyDetectionGraphWise is an inductive vertex representation learning and anomaly detection algorithm which is able to leverage vertex and edge feature information. Although it can be applied to a wide variety of tasks, it is particularly suitable for unsupervised learning of vertex embeddings for anomaly detection. After training this model, it is possible to infer anomaly scores or labels for unseen nodes.

Model Structure

A `UnsupervisedAnomalyDetectionGraphWise` model consists of graph convolutional layers followed by an embedding layer. There are two types of embedding layers - DGI layer and Dominant layer. Both the layers are for inductive vertex representation learning with different loss functions. The embedding layer defaults to the 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, which is based on (Deep Graph Infomax (DGI) by Velickovic et al.) consists of three parts that enable 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 Dominant layer enables unsupervised learning using a deep autoencoder. It uses the graph convolutional networks (GCNs) to reconstruct the features in the autoencoder setting, together with the reconstructed structure that is estimated using the dot products of the embeddings.

The loss function is computed from the feature reconstruction loss and the structure reconstruction loss. The importance given to features or to the structure can be tuned with the alpha hyperparameter.

The following describes a few use cases where `UnsupervisedAnomalyDetectionGraphWise` algorithm can be applied:

- **Cybersecurity**: To detect abnormal behavior in network traffic by analyzing the graph of connections between devices. Anomalous patterns might indicate security breaches, malware infections, or insider threats.

- **Credit Card Fraud Detection**: To identify suspicious credit card transactions by examining the relationships between transactions, users, and vendors, and scoring those that deviate from typical patterns.
- **Smart Grid Monitoring**: To monitor power grids to detect anomalies in electricity usage patterns that can indicate faults or unauthorized usage. This helps to ensure efficient and secure energy distribution.

The following describes the usage of the main functionalities of the implementation of `Dominant` in PGX. The example demonstrates a scenario to detect fraudulent vertices based on their features.

- Loading a Graph
- Building a Minimal Unsupervised Anomaly Detection GraphWise Model
- Advanced Hyperparameter Customization
- Building an Unsupervised Anomaly Detection GraphWise Model Using Partitioned Graphs
- Training an Unsupervised Anomaly Detection GraphWise Model
- Getting the Loss Value for an Unsupervised Anomaly Detection GraphWise Model
- Inferring Embeddings for an Unsupervised Anomaly Detection GraphWise Model
- Inferring Anomalies
- Storing an Unsupervised Anomaly Detection GraphWise Model
- Loading a Pre-Trained Unsupervised Anomaly Detection GraphWise Model
- Destroying an Unsupervised Anomaly Detection GraphWise Model

17.6.1 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
```

Java

```
import oracle.pgx.api.*;
import oracle.pgx.api.mllib.UnsupervisedAnomalyDetectionGraphWiseModel;
import oracle.pgx.api.frames.*;
```

```
import oracle.pgx.config.mllib.ActivationFunction;
import oracle.pgx.config.mllib.GraphWiseConvLayerConfig;
import
oracle.pgx.config.mllib.UnsupervisedAnomalyDetectionGraphWiseModelConfig;
import oracle.pgx.config.mllib.GraphWiseEmbeddingConfig;
import oracle.pgx.config.mllib.corruption.PermutationCorruption;
import oracle.pgx.config.mllib.WeightInitScheme;
```

Python

```
# starting the Python shell will create an implicit session and analyst
```

2. Load the **graph**.

- JShell
- Java
- Python

JShell

```
opg4j> var instance = GraphServer.getInstance("https://localhost:7007",
"<username>", "<password>".toCharArray())
opg4j> var session=instance.createSession("mySession")
opg4j> var graph =
session.readGraphByName("<graph_name>",GraphSource.PG_PGQL)
```

Java

```
ServerInstance instance = GraphServer.getInstance("https://
localhost:7007", "<username>", "<password>".toCharArray());
PgxSession session = instance.createSession("my-session");
PgxGraph graph =
session.readGraphByName("<graph_name>",GraphSource.PG_PGQL);
```

Python

```
instance = graph_server.get_instance("https://
localhost:7007","<username>","<password>")
session = instance.create_session("my_session")
graph = session.read_graph_by_name("<graph_name>", "pg_pgql")
```

17.6.2 Building a Minimal Unsupervised Anomaly Detection GraphWise Model

You can build an Unsupervised Anomaly Detection GraphWise model using the minimal configuration and default hyper-parameters. Note that even though only one feature property is specified in the following example, you can specify arbitrarily many.

- JShell
- Java
- Python

JShell

```
opg4j> var model =
analyst.unsupervisedAnomalyDetectionGraphWiseModelBuilder().
          setVertexInputPropertyNames("features").
          build()
```

Java

```
UnsupervisedAnomalyDetectionGraphWiseModel model =
analyst.unsupervisedAnomalyDetectionGraphWiseModelBuilder()
    .setVertexInputPropertyNames("features")
    .build();
```

Python

```
model =
analyst.unsupervised_anomaly_detection_graphwise_builder(vertex_input_property
_names=["features"])
```

17.6.3 Advanced Hyperparameter Customization

You can build an Unsupervised Anomaly Detection GraphWise model using rich hyperparameter customization.
This is implemented using the sub-config classes, `GraphWiseConvLayerConfig` and `GraphWiseEmbeddingConfig`.

Also, you can enable or disable a graphics processing unit (GPU) by using the `enable_ml_accelerators` graph server (PGX) configuration parameter (see Configuration Parameters for the Graph Server (PGX) Engine for more information). In addition, ensure that your system meets the following prerequisites to use the GPU support:

- You must have a GPU device with the CUDA (Compute Unified Device Architecture) toolkit installed.
- The following list of CUDA libraries are expected:
  - `libcuda.so.1`
  - `libnvrtc.so.12`
  - `libnvToolsExt.so.1`
  - `libcudart.so.12`

Note that the `enable_ml_accelerators` option is enabled by default. But if a GPU device is not detected and the CUDA toolkit is not installed, then this feature gets disabled and the CPU will be used for all the PgxML library operations.

The following example specifies a weight decay parameter of `0.001` and dropout with dropping probability `0.5` for the model to counteract overfitting. The Dominant embedding layer's alpha value is specified as 0.6 to slightly increase the importance of the feature reconstruction. Also, note that the `setEnableAccelerator` method is enabled to use any available GPU.

- JShell
- Java
- Python

JShell

```
opg4j> var weightProperty = analyst.pagerank(trainGraph).getName()
opg4j> var convLayerConfig = analyst.graphWiseConvLayerConfigBuilder(). //
customize convolutional layer config
         setNumSampledNeighbors(25).
         setActivationFunction(ActivationFunction.TANH).
         setWeightInitScheme(WeightInitScheme.XAVIER).
         setWeightedAggregationProperty(weightProperty).
         setDropoutRate(0.5). // set dropout rate to prevent overfitting
         build()

opg4j> var predictionLayerConfig =
analyst.graphWisePredictionLayerConfigBuilder().
        setHiddenDimension(8).
        setActivationFunction(ActivationFunction.RELU).
        build()

opg4j> var dominantConfig = analyst.graphWiseDominantLayerConfigBuilder(). //
customize embedding layer config
        setDecoderLayerConfigs(predictionLayerConfig).
        setAlpha(0.6). // increase the importance of feature reconstruction
        build()

opg4j> var model =
analyst.unsupervisedAnomalyDetectionGraphWiseModelBuilder().
         setVertexInputPropertyNames("vertex_features").
         setConvLayerConfigs(convLayerConfig).
         setEmbeddingConfig(dominantConfig).
```

```
    setWeightDecay(0.001). // set weight decay to prevent overfitting
    setEmbeddingDim(256).
    setLearningRate(0.05).
    setNumEpochs(30).
    setSeed(42).
    setShuffle(false).
    setStandardize(true).
    setBatchSize(64).
    setEnableAccelerator(true). // Enable or disable GPU
    build()
```

Java

```
// customize convolutional layer config
String weightProperty = analyst.pagerank(trainGraph).getName()
GraphWiseConvLayerConfig convLayerConfig =
analyst.graphWiseConvLayerConfigBuilder()
    .setNumSampledNeighbors(25)
    .setActivationFunction(ActivationFunction.TANH)
    .setWeightInitScheme(WeightInitScheme.XAVIER)
    .setWeightedAggregationProperty(weightProperty)
    .setDropoutRate(0.5) // set dropout rate to prevent overfitting
    .build();

GraphWisePredictionLayerConfig predictionLayerConfig =
analyst.graphWisePredictionLayerConfigBuilder()
    .setHiddenDimension(8)
    .setActivationFunction(ActivationFunction.RELU)
    .build();

// customize embedding layer config
GraphWiseEmbeddingConfig dominantConfig =
analyst.graphWiseDominantLayerConfigBuilder()
    .setDecoderLayerConfigs(predictionLayerConfig)
    .setAlpha(0.6) // increase the importance of feature reconstruction
    .build();

// build the anomaly detection model
UnsupervisedAnomalyDetectionGraphWiseModel model =
analyst.unsupervisedAnomalyDetectionGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_features")
    .setEmbeddingConfig(dominantConfig)
    .setConvLayerConfigs(convLayerConfig)
    .setWeightDecay(0.001) // set weight decay to prevent overfitting
    .setEmbeddingDim(256)
    .setLearningRate(0.05)
    .setNumEpochs(30)
    .setSeed(42)
    .setShuffle(false)
    .setStandardize(true)
    .setBatchSize(64)
    .setEnableAccelerator(true) // Enable or disable GPU
    .build();
```

Python

```
# customize convolutional layer config
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) # set dropout rate to prevent
overfitting
conv_layer = analyst.graphwise_conv_layer_config(**conv_layer_config)

# customize embedding layer config
dominant_config = dict(alpha=0.6) # increase the importance of feature
reconstruction

dominant_layer = analyst.graphwise_dominant_layer_config(**dominant_config)

# build the anomaly detection model
params = dict(conv_layer_config=[conv_layer],
              embedding_config=dominant_layer,
              vertex_input_property_names=["vertex_features"],
              weight_decay=0.001, # set weight decay to prevent overfitting
              layer_size=256,
              learning_rate=0.05,
              num_epochs=30,
              seed=42,
              standardize=true,
              batch_size=64,
              enable_accelerator=True # Enable or disable GPU
)
model = analyst.unsupervised_anomaly_detection_graphwise_builder(**params)
```

17.6.4 Building an Unsupervised Anomaly Detection GraphWise Model Using Partitioned Graphs

You can build an Unsupervised Anomaly Detection GraphWise model using partitioned graphs which have different providers and features.

- JShell
- Java
- Python

JShell

```
opg4j> var model =
analyst.unsupervisedAnomalyDetectionGraphWiseModelBuilder().
```

```
        setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
        build()
```

Java

```
UnsupervisedAnomalyDetectionGraphWiseModel model =
analyst.unsupervisedAnomalyDetectionGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .build();
```

Python

```
params = dict(vertex_input_property_names=["vertex_provider1_features",
"vertex_provider2_features"])
model = analyst.unsupervised_anomaly_detection_graphwise_builder(**params)
```

It is possible to select which providers you want to train or infer on:

- JShell
- Java
- Python

JShell

```
opg4j> var model =
analyst.unsupervisedAnomalyDetectionGraphWiseModelBuilder().
        setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
        build()
```

Java

```
UnsupervisedAnomalyDetectionGraphWiseModel model =
analyst.unsupervisedAnomalyDetectionGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .build();
```

Python

```
params = dict(vertex_input_property_names=["vertex_provider1_features",
"vertex_provider2_features"])
model = analyst.unsupervised_anomaly_detection_graphwise_builder(**params)
```

If you wish to control the flow of the embeddings at each layer, 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.unsupervisedAnomalyDetectionGraphWiseModelBuilder().
         setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features").
         build()
```

Java

```
GraphWiseConvLayerConfig convLayerConfig =
analyst.graphWiseConvLayerConfigBuilder()
    .setNumSampledNeighbors(10)
    .useVertexToVertexConnection(true)
    .useEdgeToVertexConnection(true)
    .useEdgeToEdgeConnection(false)
    .useVertexToEdgeConnection(false)
    .build();

UnsupervisedAnomalyDetectionGraphWiseModel model =
analyst.unsupervisedAnomalyDetectionGraphWiseModelBuilder()
    .setVertexInputPropertyNames("vertex_provider1_features",
"vertex_provider2_features")
    .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"],
              conv_layer_config=[conv_layer])

model = analyst.unsupervised_anomaly_detection_graphwise_builder(**params)
```

17.6.5 Training an Unsupervised Anomaly Detection GraphWise Model

You can train an Unsupervised Anomaly Detection GraphWise model on a graph as shown:

- JShell
- Java
- Python

JShell

```
opg4j> model.fit(graph)
```

Java

```
model.fit(graph);
```

Python

```
model.fit(graph)
```

17.6.6 Getting the Loss Value for an Unsupervised Anomaly Detection GraphWise Model

You can fetch the training loss value for an Unsupervised Anomaly Detection 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()
```

17.6.7 Inferring Embeddings for an Unsupervised Anomaly Detection 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()).flatten_all()
vertex_vectors.write().db().table_name("table_name").name("vertex_vectors").ov
erwrite(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.

17.6.8 Inferring Anomalies

You can use a trained model to infer anomaly scores or labels for unseen nodes and store them in the database as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j>  var vertexScores = model.inferAnomalyScores(fullGraph,
fullGraph.getVertices()).flattenAll()
opg4j> vertexScores.write().
    db().
    name("vertex scores").
    tablename("vertexScores").
    overwrite(true).
    store()
```

Java

```
PgxFrame vertexScores =
model.inferAnomalyScores(fullGraph,fullGraph.getVertices()).flattenAll();
vertexScores.write()
    .db()
    .name("vertex scores")
    .tablename("vertexScores")
    .overwrite(true)
    .store();
```

Python

```
vertex_scores =
model.infer_anomaly_scores(full_Graph,full_Graph.get_vertices()).flatten_all()
vertex_scores.write().db().table_name("table_name").name("vertex_scores").over
write(True).store()
```

If you know the contamination factor of the data, you can use it to find a good threshold:

- JShell
- Java
- Python

JShell

```
opg4j>  var vertexLabels = model.inferAnomalyScores(fullGraph,
fullGraph.getVertices()).flattenAll()
opg4j> vertexLabels.write().
    db().
    name("vertex labels").
    tablename("vertexLabels").
    overwrite(true).
    store()
```

Java

```
PgxFrame vertexLabels =
model.inferAnomalyScores(fullGraph,fullGraph.getVertices()).flattenAll();
vertexLabels.write()
    .db()
    .name("vertex labels")
    .tablename("vertexLabels")
    .overwrite(true)
    .store();
```

Python

```
vertex_labels =
model.infer_anomaly_scores(full_Graph,full_Graph.get_vertices()).flatten_all()
vertex_labels.write().db().table_name("table_name").name("vertex_labels").over
write(True).store()
```

All the preceding examples assume that you are inferring anomalies for the model in the current logged in database. If you must infer anomalies in a different database, then you must additionally provide the database credentials such as `username`, `password`, and `jdbcUrl` to the `inferAnomalyScores` method.

- JShell
- Java
- Python

JShell

```
opg4j> vertexScores.write().
     db().
     name("vertex scores").
     tablename("vertexScores").
     username("user").
     password("password").
     jdbcUrl("jdbcUrl").
     overwrite(true).
     store()
```

Java

```
vertexScores.write()
    .db()
    .name("vertex scores")
    .tablename("vertexScores")
    .username("user")
    .password("password")
    .jdbcUrl("jdbcUrl")
    .overwrite(true)
    .store();
```

Python

```
vertex_scores.write().db().table_name("table_name") \
                          .name("vertex scores") \
                          .username("user") \
                          .password("password") \
                          .jdbc_url("jdbc_url") \
```

```
                .overwrite(True) \
                .store()
```

17.6.9 Storing an Unsupervised Anomaly Detection GraphWise Model

You can store the trained models in a 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.

17.6.10 Loading a Pre-Trained Unsupervised Anomaly Detection GraphWise Model

You can load pre-trained models from a model store table in database as follows.

- JShell
- Java
- Python

JShell

```
opg4j> var model =
analyst.loadUnsupervisedAnomalyDetectionGraphWiseModel().db().
                modelstore("modeltablename"). // name of the model store table
                modelname("model").           // model name (primary key of
model store table)
                load()
```

Java

```
UnsupervisedAnomalyDetectionGraphWiseModel model =
analyst.loadUnsupervisedAnomalyDetectionGraphWiseModel().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_anomaly_detection_graphwise_model_loader(). \
                 db("modeltablename",                  # name of the model
store table
                    "model_name")                      # 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.

17.6.11 Destroying an Unsupervised Anomaly Detection GraphWise Model

You can destroy an Unsupervised Anomaly Detection GraphWise model as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> model.destroy()
```

Java

```
model.destroy();
```

Python

```
model.destroy()
```

17.7 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 a few use cases where the `Pg2vec` algorithm can be applied:

- **Chemical Compound Analysis**: To represent chemical compounds as graphs and use `Pg2vec` to find similarities between compounds. This helps in drug discovery and chemical research.
- **Document Classification**: To represent documents as graphs of words or phrases (for example, using dependency parsing in NLP) and classify them into topics or genres based on their embeddings.
- **Network Comparison**: To compare different social or biological networks by generating embeddings for entire graphs. This can be used to study the evolution of networks over time or to compare different species' protein interaction networks in biology.

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

17.7.1 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.*;
```

Python

```
# starting the Python shell will create an implicit session and analyst
```

2. Load the **graph**.

- JShell
- Java
- Python

JShell

```
opg4j> var instance = GraphServer.getInstance("https://localhost:7007",
"<username>", "<password>".toCharArray())
opg4j> var session=instance.createSession("mySession")
opg4j> var graph =
session.readGraphByName("<graph_name>",GraphSource.PG_PGQL)
```

Java

```
ServerInstance instance = GraphServer.getInstance("https://
localhost:7007", "<username>", "<password>".toCharArray());
PgxSession session = instance.createSession("my-session");
PgxGraph graph =
session.readGraphByName("<graph_name>",GraphSource.PG_PGQL);
```

Python

```
instance = graph_server.get_instance("https://
localhost:7007","<username>","<password>")
```

```
session = instance.create_session("my_session")
graph = session.read_graph_by_name("<graph_name>", "pg_pgql")
```

17.7.2 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.

17.7.3 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).
                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)
    .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>")
```

See Pg2vecModelBuilder in Javadoc for more explanation for each builder operation along with the default values.

17.7.4 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)
```

17.7.5 Getting the Loss Value For a Pg2vec Model

You can fetch the training loss value as described in the following code:

- JShell
- Java
- Python

JShell

```
opg4j> var loss = model.getLoss()
```

Java

```
double loss = model.getLoss();
```

Python

```
loss = model.loss
```

17.7.6 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

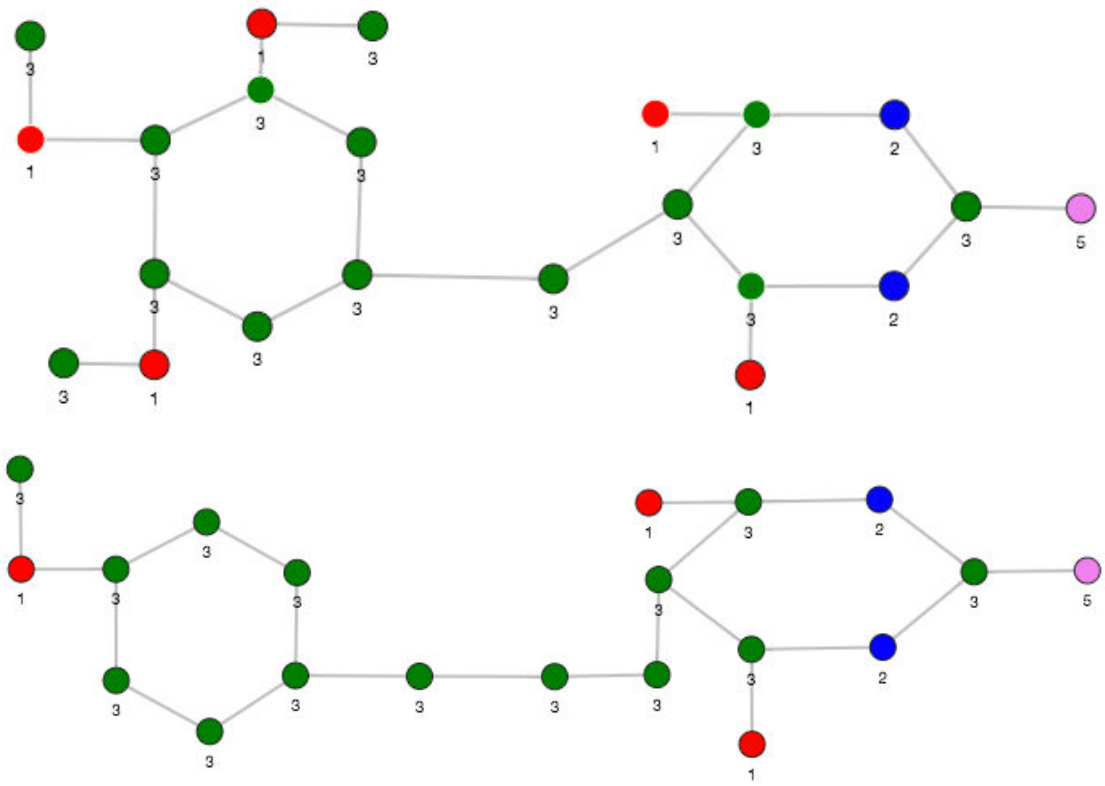
```
similars = model.compute_similars(52, 10)
```

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 17-1 Pg2vec - Visualization of Two Similar Graphlets



17.7.7 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 |
+-----------------------------------------------+
```

17.7.8 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.readGraphByName("<graph>",GraphSource.PG_PGQL)
opg4j> var inferredVector = model.inferGraphletVector(graphlet)
opg4j> inferredVector.print()
```

Java

```
PgxGraph graphlet = session.readGraphByName("<graph>",GraphSource.PG_PGQL);
PgxFrame inferredVector = model.inferGraphletVector(graphlet);
inferredVector.print();
```

Python

```
graphlet = session.read_graph_by_name("<graph>", "pg_pgql")
inferred_vector = model.infer_graphlet_vector(graphlet)
inferred_vector.print()
```

The schema for the `inferredVector` will be similar to the following output:

```
+-------------------------------------------------------------+
| graphlet                                | embedding         |
+-------------------------------------------------------------+
```

17.7.9 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.readGraphByName("<graph>", GraphSource.PG_PGQL)
opg4j> var inferredVectorBatched = model.inferGraphletVectorBatched(graphlets)
opg4j> inferredVectorBatched.print()
```

Java

```
PgxGraph graphlet = session.readGraphByName("<graph>", GraphSource.PG_PGQL);
PgxFrame inferredVectorBatched = model.inferGraphletVectorBatched(graphlets);
inferredVector.print();
```

Python

```
graphlets = session.read_graph_by_name("<graph>", "pg_pgql")
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.

17.7.10 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.

17.7.11 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.

17.7.12 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()
```

17.8 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

17.8.1 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)
                          .setBatchSize(batchSize).build()
model ==> oracle.pgx.api.mllib.DeepWalkModel@34be7efb
opg4j> var smallGraphDeepWalk =
session.readGraphByName("<graph_name>",GraphSource.PG_PGQL)
smallGraphDeepWalk ==>
PgxGraph[name=BANK_GRAPH_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)
                          .setBatchSize(batchSize).build();
PgxGraph smallGraphDeepWalk =
session.readGraphByName("<graph_name>",GraphSource.PG_PGQL);
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_pgql')
>>> 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")
```

18

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).

- Getting Started with PGQL
  Get started with PGQL in the graph server (PGX).
- Creating Property Graphs Using Options
  Learn about the different options for graph optimization and for handling edges with missing vertices.
- Supported PGQL Features and Limitations on the Graph Server (PGX)
  Learn about the supported and unsupported PGQL functionalities in the graph server (PGX).
- Java APIs for Executing CREATE PROPERTY GRAPH Statements
  You can use the `PgxSession.executePgql(String statement)` method to execute a CREATE PROPERTY GRAPH statement.
- 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.
- Executing PGQL Queries Using the PGX JDBC Driver
  Starting from Graph Server and Client Release 24.1.0, you can use the PGX JDBC driver to access a PGX session and query graphs that are loaded in to the graph server (PGX).
- Java APIs for Executing SELECT Queries
  This section describes the APIs to execute `SELECT` queries in the graph server (PGX).
- Java APIs for Executing UPDATE Queries
  The `UPDATE` queries make changes to existing graphs using the `INSERT`, `UPDATE`, and `DELETE` operations.
- Python APIs for Executing UPDATE Queries
  You can update a graph that is loaded into the graph server (PGX) using the Python APIs.
- PGQL Queries with Partitioned IDs
  You can retrieve partitioned IDs using the id() function in PGQL.
- 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.
- Best Practices for Tuning PGQL Queries
  This section describes best practices regarding memory allocation, parallelism, and query planning.

18.1 Getting Started with PGQL

Get started with PGQL in the graph server (PGX).

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 18-1 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      |
+-----------------------------------------------+
```

18.2 Creating Property Graphs Using Options

Learn about the different options for graph optimization and for handling edges with missing vertices.

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 18-1 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.

Table 18-1 (Cont.) Graph Optimization Options

OPTIONS	Description
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.

18.3 Supported PGQL Features and Limitations on the Graph Server (PGX)

Learn about the supported and unsupported PGQL functionalities in the graph server (PGX).

Table 18-2 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. • Properties need to be column references; arbitrary property expressions are not supported unless the graph is first created in the database and then loaded into the graph server (PGX).
`DROP PROPERTY GRAPH`	Not Supported
Fixed-length pattern matching	Supported

Table 18-2 (Cont.) Supported PGQL Functionalities and Limitations on the Graph Server (PGX)

Features	PGQL on the Graph Server (PGX)
Variable-length pattern matching goals	Supported: • Reachability • Path search prefixes: – `ANY` – `ANY SHORTEST` – `SHORTEST k` – `ALL SHORTEST` – `ANY CHEAPEST` – `CHEAPEST k` – `ALL` • Path modes: – `WALK` – `TRAIL` – `SIMPLE` – `ACYCLIC`
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`
`GROUP BY`	Supported
`HAVING`	Supported
Aggregations	Supported: • `COUNT` • `MIN`, `MAX`, `AVG`, `SUM` • `LISTAGG` • `ARRAY_AGG` Not Supported • `JSON_ARRAYAGG`
`DISTINCT` • `SELECT DISTINCT` • Aggregation with `DISTINCT` (such as, `COUNT(DISTINCT e.prop)`)	Supported
`SELECT v.*`	Supported
`ORDER BY (+ASC/DESC), LIMIT, OFFSET`	Supported

Table 18-2 (Cont.) Supported PGQL Functionalities and Limitations on the Graph Server (PGX)

Features	PGQL on the Graph Server (PGX)
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)
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, VERTEX_ID, EDGE_ID • LABEL, LABELS, IS [NOT] LABELED • ALL_DIFFERENT • IN_DEGREE, OUT_DEGREE • CAST • CASE • IN and NOT IN • MATCHNUM • ELEMENT_NUMBER • IS [NOT] SOURCE [OF], IS [NOT] DESTINATION [OF] • VERTEX_EQUAL, EDGE_EQUAL
User-defined functions	Supported: • Java UDFs • JavaScript UDFs

Table 18-2 (Cont.) Supported PGQL Functionalities and Limitations on the Graph Server (PGX)

Features	PGQL on the Graph Server (PGX)
Subqueries: • Scalar subqueries • `EXISTS` and `NOT EXISTS` subqueries • `LATERAL` subquery	Supported
`GRAPH_TABLE` operator	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
- Using Path Modes with PGQL
- Support for PGQL Lateral Subqueries
- Support for PGQL GRAPH_TABLE Operator
- Limitations on Quantifiers
- Limitations on WHERE and COST Clauses in Quantified Patterns

18.3.1 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     |
+--------------------------------+
```

18.3.2 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:

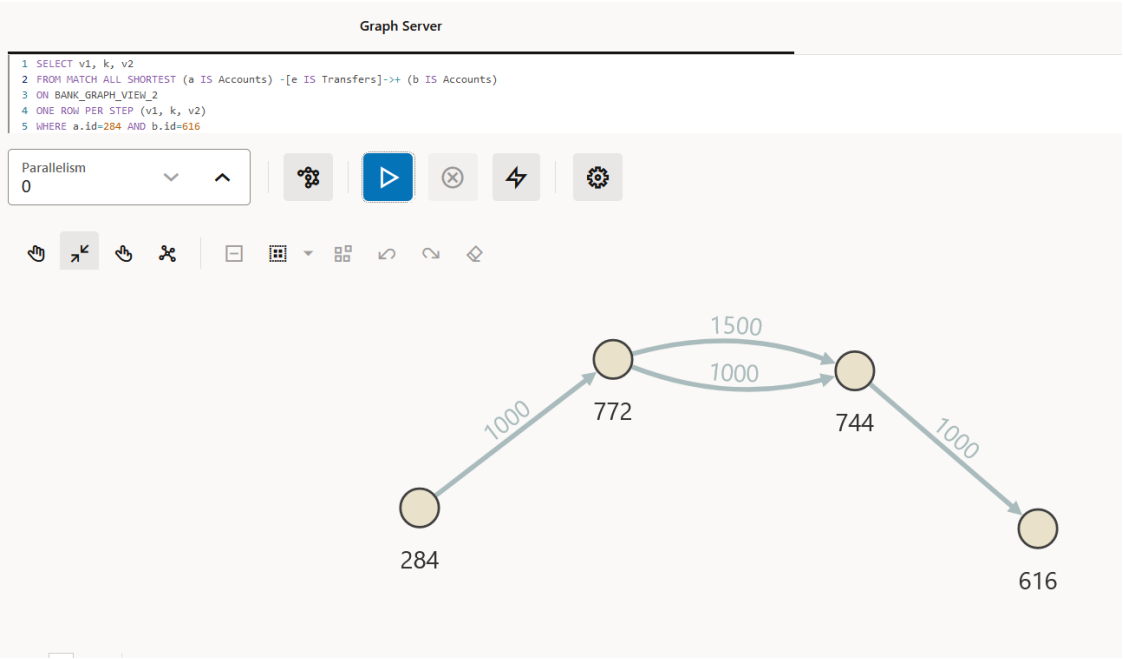
```
SELECT  v1.ACCT_ID AS src_no, k.TXN_AMOUNT, v2.ACCT_ID AS dest_no
FROM MATCH ALL SHORTEST (a:Accounts) -[e:transfers]->+ (b:Accounts)
ONE ROW PER STEP( v1,k,v2 )
WHERE a.ACCT_ID = 284 AND b.ACCT_ID = 616
```

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 18-1 Visualizing Unnesting of Variable-Length Path Queries



Also, when using the `ONE ROW PER STEP` option, if the path is empty (that is, the path length is zero), then it has a single step such that the first vertex variable (`v1`) is bound but the edge variable (`e`) and the second vertex variable (`v2`) are unbound. Note that accessing the properties of unbound variables will result in NULL values.

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                 |
+-------------------------------------------------------------------+
```

18.3.3 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 18-3 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 |
+--------------------------+
```

18.3.4 Using Path Modes with PGQL

The following path modes are available in combination with `ANY`, `ALL`, `ANY SHORTEST`, `SHORTEST k`, and `ALL SHORTEST`:

- **`WALK` (default path mode):** A walk is traversing a graph through a sequence of vertices and edges. The vertices and edges visited in a walk can be repeated. Hence there is no filtering of paths in this default path mode.

- **`TRAIL`:** A trail is traversing a graph without repeating the edges. Therefore, path bindings with repeated edges are not returned.

```
SELECT CAST(a.number AS STRING) || ' -> ' || LISTAGG(x.number, ' -> ') AS
accounts_along_path
FROM MATCH ALL TRAIL PATHS (a IS account) (-[IS transaction]-> (x)){2,} (b
IS Account)
WHERE a.number = 8021 AND b.number = 1001

+-----------------------------------------------+
| accounts_along_path                           |
+-----------------------------------------------+
| 8021 -> 1001 -> 2090 -> 10039 -> 8021 -> 1001 |
| 8021 -> 1001 -> 2090 -> 10039 -> 8021 -> 1001 |
+-----------------------------------------------+
```

  In the preceding output, both the paths contain the vertices 8021 and 1001 twice but they are still valid trails as long as no edges are repeated.

- **`ACYCLIC`:** If the starting and ending vertex in a graph traversal are different, then this implies that there are no cycles in the path. In this case, the path bindings with repeated vertices are not returned.

```
SELECT CAST(a.number AS STRING) || ' -> ' || LISTAGG(x.number, ' -> ') AS
accounts_along_path
FROM MATCH SHORTEST 10 ACYCLIC PATHS (a IS account) (-[IS transaction]->
(x))+ (b)
WHERE a.number = 10039 AND b.number = 1001

+-----------------------+
| accounts_along_path   |
+-----------------------+
| 10039 -> 8021 -> 1001 |
| 10039 -> 8021 -> 1001 |
+-----------------------+
```

  The preceding query requested 10 shortest paths. But only two are returned since all the other paths are cyclic.

- **`SIMPLE`:** A simple walk is traversing a graph without repeating the vertices. Therefore, path bindings with repeated vertices are not returned. The only exception is when the repeated vertex is the first and the last in a path.

```
SELECT CAST(a.number AS STRING) || ' -> ' || LISTAGG(x.number, ' -> ') AS
accounts_along_path
FROM MATCH ANY SIMPLE PATH (a IS account) (-[IS transaction]-> (x))+ (a)
WHERE a.number = 10039

+---------------------------------------+
| accounts_along_path                   |
+---------------------------------------+
| 10039 -> 8021 -> 1001 -> 2090 -> 10039 |
+---------------------------------------+
```

The preceding query returns a cyclic path. This path is a valid simple path since it starts and ends in the same vertex and there is no other cycle in the path.

Note that the path modes are syntactically placed after `ANY`, `ALL`, `ANY SHORTEST`, `SHORTEST k`, `ALL SHORTEST`, `CHEAPEST`, and `CHEAPEST k`. The path mode is optionally followed by a `PATH` or `PATHS` keyword.

Note that using `TRAIL`, `ACYCLIC`, or `SIMPLE` matching path modes for all unbounded quantifiers guarantees that the result set of a graph pattern matching will be finite.

18.3.5 Support for PGQL Lateral Subqueries

You can use a `LATERAL` subquery to pass the output rows of one query into another.

For example, you can use the `ORDER BY` or `GROUP BY` clause on top of another `ORDER BY` or `GROUP BY` clause:

```
/* Find the top-5 largest transactions and return the account number
   that received the highest number of such large transactions */
SELECT recipient, COUNT(*) AS num_large_transactions
FROM LATERAL ( SELECT m.number AS recipient
               FROM MATCH (n:account) -[e:transaction]-> (m:account)
               ORDER BY e.amount DESC
               LIMIT 5 )
GROUP BY recipient
ORDER BY num_large_transactions DESC
LIMIT 1
```

Also, the `LATERAL` subquery in the `FROM` clause can be followed by one or more `MATCH` clauses. For example:

```
SELECT path_num, elem_num, owner.name
FROM LATERAL ( SELECT v, MATCHNUM(v) AS path_num, ELEMENT_NUMBER(v) AS
elem_num
               FROM MATCH SHORTEST 2 PATHS (a1:account) -[e:transaction]->*
(a2:account)
                      ONE ROW PER VERTEX ( v )
               WHERE a1.number = 10039 AND a2.number = 2090 )
    , MATCH (v) -[:owner]-> (owner:Person|Company)
ORDER BY path_num, elem_num
```

Note that the FROM clause may contain any number of `MATCH` clauses and `LATERAL` subqueries.

Both, `MATCH` clause followed by a `LATERAL` subquery, or a `LATERAL` subquery followed by one or more `LATERAL` subqueries are supported.

Also, note the following:

- Variables exported from previous table expressions can be used in subsequent table expressions.
- Operators like `ORDER BY` and `LIMIT` can be used followed by additional pattern matching.
- Variables that are not projected from a `LATERAL` subquery cannot be accessed in the outer query.

The following example query first retrieves a list of companies, Then, it finds the respective accounts of the companies. Finally, it finds the top 2 transactions made to the account of each company in the initial list.

```
SELECT c.name, a.number, t.amount FROM
  LATERAL ( SELECT c FROM MATCH (c:Company) ORDER BY c.name LIMIT 1),
  MATCH (a:Account)->(c),
  LATERAL (SELECT t FROM MATCH ()-[t:Transaction]->(a) ORDER BY t.amount DESC
LIMIT 2)
```

In the following query, the `LATERAL` subquery is followed by two other `LATERAL` subqueries. Each subquery builds upon the output from the previous clauses:

```
SELECT f.number as fundsAccount FROM
LATERAL ( SELECT p FROM MATCH (p:Person) WHERE p.name = 'Nikita'),
LATERAL ( SELECT a FROM MATCH (a)->(p)),
LATERAL ( SELECT f FROM MATCH (f)->(a))
```

18.3.6 Support for PGQL GRAPH_TABLE Operator

The `GRAPH_TABLE` operator in PGQL increases the interoperability between graphs loaded into the graph server (PGX) and the graphs on the database.

However, in order to comply with the SQL standard, ensure that the PGQL query syntax is aligned as shown:

- The label predicate in the graph pattern `MATCH` query must use the `IS` keyword.
- To limit the number of output rows, use the `FETCH [FIRST/NEXT] x [ROW/ROWS]` clause instead of the `LIMIT x` clause.
- To verify the orientation of the edge, use `v IS [NOT] SOURCE [OF] e`/`v IS [NOT] DESTINATION [OF] e` as the standard form instead of `[NOT] is_source_of(e, v)` / `[NOT] is_destination_of(e, v)`.
- To verify if the vertex or edge has the given label, use the `x IS [NOT] LABELED <label_string>` predicate as an alternative for `has_label(x, <label_string>)`.
- To match the `k` shortest paths, use `MATCH (n) -[e]->* (m) KEEP SHORTEST k` as the standard form of `MATCH TOP k SHORTEST (n) -[e]->* (m)`.
- `ALL` keyword optional in front of fixed-length path patterns.
  `MATCH (n) -[e]->{1,4} (m)` as an alternative for `MATCH ALL (n) -[e]->{1,4} (m)`.
- `MATCH <path pattern> KEEP <path pattern prefix> <WHERE clause>` as an alternative for `MATCH <path pattern prefix> <path pattern> <WHERE clause>`

The following shows a few query examples using the **`GRAPH_TABLE`** operator:

Example 18-2 Aggregation Query Using `TRAIL` path mode with `ALL`

```
SELECT *
FROM GRAPH_TABLE ( financial_transactions
       MATCH ALL TRAIL (a IS account) -[e IS transaction]->* (b IS account)
       /* optional ONE ROW PER VERTEX/STEP clause here */
       WHERE a.number = 8021 AND b.number = 1001
```

```
      COLUMNS ( LISTAGG(e.amount, ', ') AS amounts )
    )ORDER BY amounts
```

The preceding query produces the following output:

```
+---------------------------------------+
| amounts                               |
+---------------------------------------+
| 1500.3                                |
| 1500.3, 9999.5, 9900.0, 1000.0, 3000.7 |
| 3000.7                                |
| 3000.7, 9999.5, 9900.0, 1000.0, 1500.3 |
+---------------------------------------+
```

Example 18-3 Aggregation Query Using `KEEP` Clause

```
SELECT *
FROM GRAPH_TABLE ( financial_transactions
       MATCH (a IS Account) -[e IS transaction]->+ (a)
       KEEP SIMPLE PATHS
       WHERE a.number = 10039
       COLUMNS ( LISTAGG(e.amount, ', ') AS amounts_along_path,
                 SUM(e.amount) AS total_amount )
     )
ORDER BY total_amount DESC
```

The preceding query produces the following output:

```
+-----------------------------------------------+
| amounts_along_path             | total_amount |
+-----------------------------------------------+
| 1000.0, 3000.7, 9999.5, 9900.0 | 23900.2      |
| 1000.0, 1500.3, 9999.5, 9900.0 | 22399.8      |
+-----------------------------------------------+
```

18.3.7 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).

18.3.8 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) ) ...
```

18.4 Java APIs for Executing CREATE PROPERTY GRAPH Statements

You can use the `PgxSession.executePgql(String statement)` method to execute a CREATE PROPERTY GRAPH statement.

The `PgxSession.executePgql(String statement)` Java API creates a property graph in graph server (PGX). Note that when using this API, the graph is not persisted in the database, it is only created in the graph server (PGX). To persist a graph in the database, you can create a graph in the database (see Quick Starts for Using PGQL Property Graphs), and then load the graph into the graph server (PGX).

Example 18-4 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");
```

18.5 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.

The `prepare_pgql(<pgql_query>).execute()` Python API creates a property graph in the graph server (PGX). Note that when using this API, the graph is not persisted in the database, it is only created in the graph server (PGX). If you wish to persist a graph in the database, then you can create the graph in the database (see Quick Starts for Using PGQL Property Graphs) and then load the graph into graph server (PGX).

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)
```

18.6 Executing PGQL Queries Using the PGX JDBC Driver

Starting from Graph Server and Client Release 24.1.0, you can use the PGX JDBC driver to access a PGX session and query graphs that are loaded in to the graph server (PGX).

To use the PGX JDBC driver, note the following:

- Register the PGX JDBC driver with the DriverManager:

```
import java.sql.DriverManager;
import oracle.pgx.jdbc.PgxJdbcDriver;
...
DriverManager.registerDriver(new PgxJdbcDriver());
```

- Add the `jdbc:oracle:pgx:` prefix to the JDBC URL when obtaining a connection object as shown:

```
Connection conn =
DriverManager.getConnection("jdbc:oracle:pgx:@<graph_server_host>:<server_port
>", "<username>", "<password>");
```

Example 18-5 Using the PGX JDBC Driver

The following example establishes a connection using the PGX JDBC driver, accesses the underlying PGX session to load the graph into the graph server (PGX), creates a statement, and runs a PGQL query on the graph.

```
import java.sql.*;
import oracle.pgx.jdbc.*;
import oracle.pgx.api.*;

public class PgxJdbcSample {

  public static void main(String[] args) throws Exception {


    String jdbcUrl = "jdbc:oracle:pgx:https://localhost:7007";
    String username = "graphuser";
    String password = "graph";

    DriverManager.registerDriver(new PgxJdbcDriver());
    try(Connection conn = DriverManager.getConnection(jdbcUrl, username,
password)) {
             if (conn.isWrapperFor(PgxSession.class)) {
                    PgxSession session = conn.unwrap(PgxSession.class);
                    session.readGraphByName("BANK_GRAPH_VIEW",
GraphSource.PG_PGQL);
             }
            Statement stmt = conn.createStatement();
            ResultSet rs = stmt.executeQuery("SELECT e.AMOUNT AS AMOUNT FROM
MATCH (a IS ACCOUNTS) -[e IS TRANSFERS]-> (b IS ACCOUNTS) ON BANK_GRAPH_VIEW
"+
                                             " WHERE a.ID = 179 AND b.ID =
688");
            while(rs.next()){
                 System.out.println("AMOUNT = " + rs.getLong("AMOUNT"));
            }
    }

  }
}
```

The resulting output of the preceding code is as shown:

```
AMOUNT = 1000
```

Note that when running the preceding code, you must provide the PGX client JARs on the runtime classpath.

- Limitations of the PGX JDBC Driver
  Review the limiations of the PGX JDBC driver.
- PGX Data Type Compatibility and Casting
  You can configure a compatibility mode for the PGX JDBC driver to determine the data type returned when calling the `ResultSet#getObject()` method.

Related Topics

- Using the PGX JDBC Driver when Graph Server (PGX) is Utilized as a Library
  When using the graph server (PGX) as a library, you can use the PGX JDBC driver to query graphs that are loaded from files.

18.6.1 Limitations of the PGX JDBC Driver

Review the limiations of the PGX JDBC driver.

- The following PGX data types are not supported to be returned by the PGX JDBC driver:
  - `VERTEX`
  - `EDGE`
  - `POINT2D`
- Accessing the labels of a vertex or an edge is not supported.
- Multi-dimensional properties such as vectors, and lists are not supported.

18.6.2 PGX Data Type Compatibility and Casting

You can configure a compatibility mode for the PGX JDBC driver to determine the data type returned when calling the `ResultSet#getObject()` method.

The PGX JDBC driver supports the following compatibility modes:

- **PGX (default):** By default, the PGX JDBC driver will use the PGX compatibility mode to return the PGX native types.
- **ORACLE_JDBC19:** This mode enables the driver to return data types that are compatible with Oracle Database 19c.
- **ORACLE_JDBC23:** This mode enables the driver to return data types that are compatible with Oracle Database 23ai.

The following table describes the data types returned by the driver for the different compatibility modes.

Table 18-4 Data Type Compatibility

PGX Type	PGX (Default)	ORACLE_JDBC19	ORACLE_JDBC23
BOOLEAN	BOOLEAN	java.math.BigDecimal	Boolean

Table 18-4 (Cont.) Data Type Compatibility

PGX Type	PGX (Default)	ORACLE_JDBC19	ORACLE_JDBC23
INTEGER/LONG/FLOAT/DOUBLE	INTEGER/LONG/FLOAT/DOUBLE	java.math.BigDecimal	java.math.BigDecimal
LOCAL_DATE	java.sql.Date	java.sql.Timestamp	java.sql.Timestamp
TIME	java.sql.Time	Not supported	Not supported
TIME_WITH_TIMEZONE	java.time.OffsetTime	Not supported	Not supported
TIMESTAMP	java.sql.Timestamp	oracle.sql.TIMESTAMP	oracle.sql.TIMESTAMP
TIMESTAMP_WITH_TIMEZONE	java.time.OffsetDateTime	oracle.sql.TIMESTAMPZ	oracle.sql.TIMESTAMPZ

Setting the Compatibility Mode in the PGX JDBC Driver

If you wish to use a different compatibility mode (other than the default PGX mode), then this can be set as part of the properties as shown:

```
import static oracle.pgx.jdbc.CONNECTION_PROPERTY_COMPATIBILITY_MODE;
import static oracle.pgx.jdbc.ORACLE_JDBC19;
...
Properties properties = new Properties();
properties.put(...);
properties.put(CONNECTION_PROPERTY_COMPATIBILITY_MODE, ORACLE_JDBC19); // set
compatibility mode
Connection connection = DriverManager.getConnection("<jdbc_url>", properties);
```

Data Type Conversions through Casting

The PGX JDBC driver allows casting of one type into another (regardless of the compatibility mode) as shown in the following table.

Table 18-5 Additional Supported Types through Casting

PGX Type	Default Mapping (PGX Compatibility)	Additional Supported Types (through Casting)
BOOLEAN	BOOLEAN	String, BigDecimal
INTEGER	INTEGER	String, BigDecimal, Long, Float, Double
FLOAT	FLOAT	String, BigDecimal, Double
LONG	LONG	String, BigDecimal, Double
DOUBLE	DOUBLE	String, BigDecimal
LOCAL_DATE	java.sql.Date	String, java.time.LocalDate, java.sql.Timestamp
TIME	java.sql.Time	String, java.time.LocalTime
TIME_WITH_TIMEZONE	java.time.OffsetTime	String
TIMESTAMP	java.sql.Timestamp	String, java.time.LocalDateTime, oracle.sql.TIMESTAMP

Table 18-5 (Cont.) Additional Supported Types through Casting

PGX Type	Default Mapping (PGX Compatibility)	Additional Supported Types (through Casting)
TIMESTAMP_WITH_TIMEZONE	java.time.OffsetDateTime	String, oracle.sql.TIMESTAMPZ

Data Type Conversions for `PreparedObject#setObject(int index, Object o)`

The following table describes the data type conversions when calling the `PreparedObject#setObject(int index, Object o)` method.

Table 18-6 Data Type Conversions for `setObject` Method

Given Object Type	PGX Type
BOOLEAN	BOOLEAN
INTEGER/FLOAT/LONG/DOUBLE	INTEGER/FLOAT/LONG/DOUBLE
BIGDECIMAL	DOUBLE
java.sql.Date, java.time.LocalDate	LOCAL_DATE
java.sql.Time, java.time.LocalTime	TIME
java.time.OffsetTime	TIME_WITH_TIMEZONE
java.sql.Timestamp, java.time.LocalDateTime, oracle.sql.TIMESTAMP	TIMESTAMP
java.time.OffsetDateTime, oracle.sql.TIMESTAMPZ	TIMESTAMP_WITH_TIMEZONE

18.7 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:

18.7.1 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()`).

18.7.2 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.

18.7.3 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`.

18.7.4 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                       |
+-----------------------------------------------+
```

18.8 Java APIs for Executing UPDATE Queries

The `UPDATE` queries make changes to existing graphs using the `INSERT`, `UPDATE`, and `DELETE` operations.

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
  You can also execute `UPDATE` queries against a `PgxSession`.
- 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.

18.8.1 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.readGraphByName("<graph>",GraphSource.PG_PGQL);

// 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.

18.8.2 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' ");
```

18.8.3 Executing UPDATE Queries Against a PGX Session

You can also execute `UPDATE` queries against a `PgxSession`.

The following example clones a graph and runs `UPDATE` queries against the `PgxSession`.

```
//Loads the graph into the graph server (PGX)
PgxGraph g1 = session.readGraphByName("BANK_GRAPH_VIEW",GraphSource.PG_PGQL);
//Clones the graph
PgxGraph g2 = g1.clone("BANK_GRAPH_NEW");
//Get the graph
session.getGraph("BANK_GRAPH_NEW");
//Insert vertices and an edge connecting the vertices into the graph
session.executePgql(
     "INSERT INTO BANK_GRAPH_NEW "+
     "   VERTEX v1 LABELS (Accounts) PROPERTIES (v1.id=1001, v1.name='New
account-1') "+
     ",  VERTEX v2 LABELS (Accounts) PROPERTIES (v2.id=1002, v2.name='New
account-2') "+
     ",  EDGE e1 BETWEEN v1 AND v2 LABELS (Transfers) PROPERTIES
(e1.amount=3000) "
);
//Query the graph to verify the newly added edge
session.executePgql(
     "SELECT e.amount FROM MATCH (v1:Accounts) -[e:Transfers]-> (v2:Accounts)
"+
     "ON BANK_GRAPH_NEW "+
     "WHERE v1.id=1001 AND v2.id=1002"
);
```

18.8.4 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.readGraphByName("<graph>",GraphSource.PG_PGQL);

// 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' ");
```

18.9 Python APIs for Executing UPDATE Queries

You can update a graph that is loaded into the graph server (PGX) using the Python APIs.

However, prior to updating the graph, you must first clone the graph. You can perform update operations only on the cloned graph and not on the original graph.

The following example shows the steps for running UPDATE queries against a graph in the graph server (PGX) using the Python APIs.

1. Load the PGQL property graph into the graph server (PGX).

   ```
   >>> g1 = session.read_graph_by_name('BANK_GRAPH', 'pg_pgql')
   ```

2. Clone the graph for the update operation.

   ```
   >>> g2 = g1.clone(name="BANK_GRAPH_NEW")
   ```

3. Update the cloned graph as required.

   For example:

   - **Adding one or more vertices with properties**

     ```
     >>> g2.execute_pgql(
     ...   "INSERT VERTEX v1 LABELS (Accounts) PROPERTIES (v1.id=1001,
     v1.name='New account-1') "
     ...   "     , VERTEX v2 LABELS (Accounts) PROPERTIES (v2.id=1002,
     v2.name='New account-2') "
     ... )
     ```

   - **Inserting a new edge with properties**
     The new edge gets added between all vertices that match the `WHERE` clause.

     ```
     >>> g2.execute_pgql(
     ...   "INSERT EDGE e1 BETWEEN v1 AND v2 "
     ...   "LABELS (Transfers) "
     ...   "PROPERTIES (e1.from_acct_id=1001, e1.amount=3000,
     e1.description='Transaction-A', e1.to_acct_id=1002) "
     ...   "FROM MATCH (v1:Accounts), MATCH (v2:Accounts) "
     ...   "WHERE v1.id=1001 AND v2.id=1002"
     ...   )
     ```

Optionally, query the graph to verify that the new edge is added.

```
>>> g2.execute_pgql(
...   "SELECT e.* FROM MATCH (v1:Accounts) -[e:Transfers]->
(v2:Accounts) "
...   "WHERE v1.id=1001 AND v2.id=1002"
... ).print()
+-----------------------------------------------------+
| FROM_ACCT_ID | TO_ACCT_ID | DESCRIPTION   | AMOUNT |
+-----------------------------------------------------+
| 1001         | 1002       | Transaction-A | 3000.0 |
+-----------------------------------------------------+
```

- **Updating one or more vertex property**
  The vertex properties get updated for all vertices that match the `WHERE` clause.

```
>>> g2.execute_pgql(
...   "UPDATE v SET (v.name='Account-1001') "
...   "FROM MATCH (v:Accounts) "
...   "WHERE v.id=1001"
... )
```

- **Updating one or more edge property**
  The edge properties get updated for the edge that connects the vertices in the `WHERE` clause.

```
>>> g2.execute_pgql(
...   "UPDATE e SET (e.amount=5000) "
...   "FROM MATCH (v1:Accounts) -[e:Transfers]-> (v2:Accounts) "
...   "WHERE v1.id=1001 AND v2.id=1002"
... )
```

Optionally, query the graph to verify the updated edge property.

```
>>> g2.execute_pgql(
...   "SELECT e.amount FROM MATCH (v1:Accounts) -[e:Transfers]->
(v2:Accounts) "
...   "WHERE v1.id=1001 AND v2.id=1002"
... ).print()
+--------+
| amount |
+--------+
| 5000.0 |
+--------+
```

- **Deleting a vertex**
  Note that when you delete a vertex, all edges that connect the vertex are also removed.

```
>>> g2.execute_pgql("DELETE v FROM MATCH (v:Accounts) WHERE v.id=1001")
```

Alternatively, you can combine step-2 and step-3 by using the `clone_and_execute_pgql()` method as shown:

```
>>> g2 = g1.clone_and_execute_pgql(
...   "INSERT VERTEX v1 LABELS (Accounts) PROPERTIES (v1.id=1001,
v1.name='New account-1') "
...   ",  VERTEX v2 LABELS (Accounts) PROPERTIES (v2.id=1002, v2.name='New
account-2') "
...   ",  EDGE e1 BETWEEN v1 AND v2 LABELS (Transfers) PROPERTIES
(e1.amount=3000) "
... )
```

Optionally, query the graph to verify the newly added edge.

```
>>> g2.execute_pgql(
...   "SELECT e.amount FROM MATCH (v1:Accounts) -[e:Transfers]->
(v2:Accounts) "
...   "WHERE v1.id=1001 AND v2.id=1002"
... ).print()
+--------+
| amount |
+--------+
| 3000.0 |
+--------+
```

Executing UPDATE Queries Against a `PgxSession`

You can also run UPDATE queries against a `PgxSession` as shown:

```
>>> g1 = session.read_graph_by_name('BANK_GRAPH', 'pg_pgql')
>>> g2 = g1.clone(name="BANK_GRAPH_NEW")
>>> session.execute_pgql(
...   "INSERT INTO BANK_GRAPH_NEW VERTEX v1 LABELS (Accounts) PROPERTIES
(v1.id=1001, v1.name='New account-1') "
...   ",  VERTEX v2 LABELS (Accounts) PROPERTIES (v2.id=1002, v2.name='New
account-2') "
...   ",  EDGE e1 BETWEEN v1 AND v2 LABELS (Transfers) PROPERTIES
(e1.amount=3000) "
... )
>>> session.execute_pgql(
...   "SELECT e.amount FROM MATCH (v1:Accounts) -[e:Transfers]->
(v2:Accounts) ON BANK_GRAPH_NEW "
...   "WHERE v1.id=1001 AND v2.id=1002"
... ).print()
+--------+
| amount |
+--------+
| 3000.0 |
+--------+
```

18.10 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 |
+--------------------------+
```

18.11 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.

18.11.1 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.

18.11.2 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);
```

18.12 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:

18.12.1 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.

18.12.2 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.

18.12.3 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)
```

19

REST Endpoints for the Graph Server

This chapter describes the graph server REST API endpoints.

The graph server REST API supports two different versions.

> **Note:**
>
> The version 1 (v1) endpoints of the API is deprecated. It is recommended that you use version 2 (v2) of the API (Graph Server REST API Version 2).

- Graph Server REST API Version 2
  Learn about the graph server REST API version 2 (v2).
- Graph Server REST API Version 1
  Learn about the graph server REST API version 1 (v1).

19.1 Graph Server REST API Version 2

Learn about the graph server REST API version 2 (v2).

This API version supports a token-based authentication for the REST endpoints. Therefore, you must first obtain an access token which can be used in the subsequent REST API requests.

- Get an Authentication Token
- Refresh an Authentication Token
- Get Graphs
- Run a PGQL Query
- Get the Database Version
- Get User
- Asynchronous REST Endpoints

19.1.1 Get an Authentication Token

POST `https://localhost:7007/auth/token`
Get an authentication token which can be used to authenticate the REST API requests.

Request

Request Header

- **Accept:** `application/json; charset=UTF-8`
- **Content-Type:** `application/json`

Table 19-1 Request Body Parameters

Parameter	Type	Description	Required
`username`	string	Name of the user	Yes
`password`	string	Password for the user	Yes
`createSession`	boolean	To determine if a session needs to be created	Optional. Set it to `true` if you want to run queries against the graph server (PGX).
`source`	string	A descriptive string identifying the client	Optional. Ensure to enter the source value without spaces (for example, "commandLine", "shellWithJava", and so on).
`sessionId`	string	To reuse an existing session when connecting to the graph server	Optional. Set it to an existing session `ID` if you want to reuse that session.

Sample Request Body

```
{
    "username": "graphuser",
    "password": "<password_for_graphuser>",
    "createSession": true,
    "source": "<source-value-for-pgx-session>",
    "sessionId": "<session-id>"
}
```

Response

- **201 Created**
- **Content-Type:** `application/json`

Sample Response Body

```
{
    "access_token": "<token>"
    "token_type": "bearer",
    "expires_in": 3600
}
```

cURL Example

```
curl --location 'https://localhost:7007/auth/token' \
--header 'Content-Type: application/json' \
--data '{
    "username": "graphuser",
    "password": "<password_for_graphuser>",
    "createSession": true,
    "source": "commandLine",
    "sessionId": "<session-id>"
}'
```

19.1.2 Refresh an Authentication Token

PUT `https://localhost:7007/auth/token`
Refresh a valid access token.

Request

Request Header

- **Accept:** `application/json; charset=UTF-8`
- **Content-Type:** `application/json`

Table 19-2 Request Body Parameters

Parameter	Type	Description	Required
`token`	string	Access token value	Yes
`createSession`	boolean	Flag to determine if a session needs to be created	Optional. Set it to `true` if you want to run queries against the graph server (PGX).
`sessionId`	string	To reuse an existing session when connecting to the graph server	Optional. Set it to an existing session `ID` if you want to reuse that session.

Sample Request Body

```
{
    "token": "<token>",
    "createSession": true,
    "sessionId": "<session-id>"
}
```

Response

- **201 Created**
- **Content-Type:** `application/json`

Sample Response Body

```
{
    "access_token": "<token>"
    "token_type": "bearer",
    "expires_in": 3600
}
```

cURL Example

```
curl --location --request PUT 'https://localhost:7007/auth/token' \
--header 'Content-Type: application/json' \
--data '{
    "token": "<token_value>",
    "createSession": true,
```

```
    "sessionId": "<session-id>"
}'
```

19.1.3 Get Graphs

GET `https://localhost:7007/v2/graphs`

Get the list of graphs for the specified driver.

Version: v2

Request

Request Header

- **Accept:** `application/json; charset=UTF-8`
- **Header:** `Authorization: Bearer <token>`
- **Content-Type:** `application/json`

Request Query Parameter

- **driver (required):** Specifies the PGQL driver value. This is a mandatory parameter. Supported values are as follows:
  - **`GRAPH_SERVER_PGX`:** Graphs loaded into the graph server (PGX)
  - **`PGQL_IN_DATABASE`:** PGQL property graphs in the database
  - **`SQL_IN_DATABASE`:** SQL property graphs in the database

Response

- **200 OK**
- **Content-Type:** `application/json`

Sample Response Body

```
[
    {
        "schema": <value>,
        "graphName": <value>
    }
]
```

Note that the `schema` parameter will be `NULL` for graphs created in the graph server (PGX).

cURL Example

```
curl --location --request GET 'https://localhost:7007/v2/graphs?
driver=<driver-value>' \
--header 'Authorization: Bearer <token>'
```

19.1.4 Run a PGQL Query

POST `https://localhost:7007/v2/runQuery`

Run one or multiple statements for the specified driver.

Version: v2

Request

Request Header

- **Accept:** `application/json; charset=UTF-8`
- **Header:** `Authorization: Bearer <token>`
- **Content-Type:** `application/json`

Table 19-3 Request Body Parameters

Parameter	Type	Description	Required
`statements`	string [ ]	One or multiple statements	Yes
`driver`	string	Specifies the PGQL driver. The supported values are: • **`GRAPH_SERVER_PGX`:** To run PGQL queries against the graph server (PGX) • **`PGQL_IN_DATABASE`:** To run PGQL statements or queries against the database • **`SQL_IN_DATABASE`:** To run graph queries against the database	Yes
`formatter`	string	The supported values are: • DATASTUDIO • GVT **Note**: Starting from Graph Server and Client Release 24.4, the `formatter` parameter is deprecated.	Yes

Table 19-3 (Cont.) Request Body Parameters

Parameter	Type	Description	Required
`parameters`	object • `dynamicSampling` : integer • `parallel`: integer • `start`: integer • `size`: integer	Parameters include: • Dynamic Sampling Value • Degree of Parallelism • Fetch size (= the number of rows) of the query result	Parameters are all optional. • Default value for dynamic sampling is 2. • Default value for parallelism depends on the `driver`. • Default value for start is `0`. • Default value for size is `100`.
`visualize`	boolean	Flag to set visualization	Optional. Default value is `true`.

Sample Request Body

```
{
  "statements": [
    "DROP PROPERTY GRAPH TEST_GRAPH",
    "CREATE PROPERTY GRAPH TEST_GRAPH VERTEX TABLES( Male KEY (id) LABEL Male
PROPERTIES ARE ALL COLUMNS EXCEPT (gender), Female KEY (id) LABEL Female
PROPERTIES ARE ALL COLUMNS EXCEPT (gender) ) EDGE TABLES( knowsmm KEY (id)
SOURCE KEY (sid) REFERENCES Male DESTINATION KEY (did) REFERENCES Male LABEL
knows PROPERTIES (mval, firstMetAt, since), knowsmf KEY (id) SOURCE KEY (sid)
REFERENCES Male DESTINATION KEY (did) REFERENCES Female LABEL knows
PROPERTIES (mval, firstMetAt, since), knowsfm KEY (id) SOURCE KEY (sid)
REFERENCES Female DESTINATION KEY (did) REFERENCES Male LABEL knows
PROPERTIES (mval, firstMetAt, since), knowsff KEY (id) SOURCE KEY (sid)
REFERENCES Female DESTINATION KEY (did) REFERENCES Female LABEL knows
PROPERTIES (mval, firstMetAt, since), friendOfmm KEY (id) SOURCE KEY (sid)
REFERENCES Male DESTINATION KEY (did) REFERENCES Male LABEL friendOf
PROPERTIES (strength), friendOfmf KEY (id) SOURCE KEY (sid) REFERENCES Male
DESTINATION KEY (did) REFERENCES Female LABEL friendOf PROPERTIES (strength),
friendOffm KEY (id) SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did)
REFERENCES Male LABEL friendOf PROPERTIES (strength), friendOfff KEY (id)
SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did) REFERENCES Female
LABEL friendOf PROPERTIES (strength) ) OPTIONS ( pg_pgql )",
    "SELECT v FROM MATCH (v) ON TEST_GRAPH LIMIT 1"
  ],
  "driver": "PGQL_IN_DATABASE",
  "formatter": "GVT",
  "parameters": {
    "dynamicSampling": 2,
    "parallel": 8,
    "start": 0,
    "size": 100
  },
  "visualize": true
```

Response

- **200 OK**

- **Content-Type:** `application/json`

Sample Response Body


```
{
    "results": [
        {
            "pgqlStatement": "DROP PROPERTY GRAPH TEST_GRAPH",
            "result": "Graph successfully dropped",
            "success": true,
            "error": null,
            "started": 1689656429130,
            "ended": 1689656429198
        },
        {
            "pgqlStatement": "CREATE PROPERTY GRAPH TEST_GRAPH VERTEX
TABLES( Male KEY (id) LABEL Male PROPERTIES ARE ALL COLUMNS EXCEPT (gender),
Female KEY (id) LABEL Female PROPERTIES ARE ALL COLUMNS EXCEPT (gender) )
EDGE TABLES( knowsmm KEY (id) SOURCE KEY (sid) REFERENCES Male DESTINATION
KEY (did) REFERENCES Male LABEL knows PROPERTIES (mval, firstMetAt, since),
knowsmf KEY (id) SOURCE KEY (sid) REFERENCES Male DESTINATION KEY (did)
REFERENCES Female LABEL knows PROPERTIES (mval, firstMetAt, since), knowsfm
KEY (id) SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did) REFERENCES
Male LABEL knows PROPERTIES (mval, firstMetAt, since), knowsff KEY (id)
SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did) REFERENCES Female
LABEL knows PROPERTIES (mval, firstMetAt, since), friendOfmm KEY (id) SOURCE
KEY (sid) REFERENCES Male DESTINATION KEY (did) REFERENCES Male LABEL
friendOf PROPERTIES (strength), friendOfmf KEY (id) SOURCE KEY (sid)
REFERENCES Male DESTINATION KEY (did) REFERENCES Female LABEL friendOf
PROPERTIES (strength), friendOffm KEY (id) SOURCE KEY (sid) REFERENCES Female
DESTINATION KEY (did) REFERENCES Male LABEL friendOf PROPERTIES (strength),
friendOfff KEY (id) SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did)
REFERENCES Female LABEL friendOf PROPERTIES (strength) ) OPTIONS ( pg_pgql )",
            "result": "Graph successfully created",
            "success": true,
            "error": null,
            "started": 1689656429198,
            "ended": 1689656429458
        },
        {
            "pgqlStatement": "SELECT v FROM MATCH (v) ON TEST_GRAPH LIMIT 1",
            "result":
"{\"schema\":\"GRAPHUSER\",\"name\":\"TEST_GRAPH\",\"resultSetId\":\"\",\"grap
h\":{\"vertices\":[{\"id\":\"MALE(0)\",\"properties\":
{\"AGE\":\"40\",\"BVAL\":\"Y\",\"LNAME\":\"Brown\",\"FNAME\":\"Bill\",\"PREFER
ENCES\":\"{ \\\"color\\\": \\\"blue\\\", \\\"number\\\": \\\"5\\\" }
\",\"ID\":\"0\",\"TEXT\":\"the cat sat on the
mat\",\"MVAL\":\"y\"}}],\"edges\":[],\"numResults\":1},\"table\":\"V\
\nMALE(0)\"}",
            "success": true,
            "error": null,
            "started": 1689656429458,
            "ended": 1689656430029
        }
    ]
}
```

cURL Example

```
curl --location --request POST 'https://localhost:7007/v2/runQuery' \
--header 'Content-Type: application/json' \
--header 'Authorization: Bearer <token>' \
--data '{
  "statements": [
    "DROP PROPERTY GRAPH TEST_GRAPH",
    "CREATE PROPERTY GRAPH TEST_GRAPH VERTEX TABLES( Male KEY (id) LABEL Male
PROPERTIES ARE ALL COLUMNS EXCEPT (gender), Female KEY (id) LABEL Female
PROPERTIES ARE ALL COLUMNS EXCEPT (gender) ) EDGE TABLES( knowsmm KEY (id)
SOURCE KEY (sid) REFERENCES Male DESTINATION KEY (did) REFERENCES Male LABEL
knows PROPERTIES (mval, firstMetAt, since), knowsmf KEY (id) SOURCE KEY (sid)
REFERENCES Male DESTINATION KEY (did) REFERENCES Female LABEL knows
PROPERTIES (mval, firstMetAt, since), knowsfm KEY (id) SOURCE KEY (sid)
REFERENCES Female DESTINATION KEY (did) REFERENCES Male LABEL knows
PROPERTIES (mval, firstMetAt, since), knowsff KEY (id) SOURCE KEY (sid)
REFERENCES Female DESTINATION KEY (did) REFERENCES Female LABEL knows
PROPERTIES (mval, firstMetAt, since), friendOfmm KEY (id) SOURCE KEY (sid)
REFERENCES Male DESTINATION KEY (did) REFERENCES Male LABEL friendOf
PROPERTIES (strength), friendOfmf KEY (id) SOURCE KEY (sid) REFERENCES Male
DESTINATION KEY (did) REFERENCES Female LABEL friendOf PROPERTIES (strength),
friendOffm KEY (id) SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did)
REFERENCES Male LABEL friendOf PROPERTIES (strength), friendOfff KEY (id)
SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did) REFERENCES Female
LABEL friendOf PROPERTIES (strength) ) OPTIONS ( pg_pgql )",
    "SELECT v FROM MATCH (v) ON TEST_GRAPH LIMIT 1"
  ],
  "driver": "PGQL_IN_DATABASE",
  "formatter": "GVT",
  "parameters": {
    "dynamicSampling": 2,
    "parallel": 8,
    "start": 0,
    "size": 100
  },
  "visualize": true
}'
```

19.1.5 Get the Database Version

GET `https://localhost:7007/v2/dbVersion`

Get the database version to which the graph server is connected.

Version: v2

Request

Request Header

- **Accept:** `application/json; charset=UTF-8`
- **Header:** `Authorization: Bearer <token>`
- **Content-Type:** `application/json`

Response

- **200 OK**
- **Content-Type:** `application/json`

Sample Response Body

```
{
    "dbVersion": "23.0"
}
```

cURL Example

```
curl --location --request GET 'https://localhost:7007/v2/dbVersion' \
--header 'Authorization: Bearer <token>'
```

19.1.6 Get User

GET `https://localhost:7007/v2/user`

Get the username that is currently connected to the graph server (username is attached to the token).

Version: v2

Request

Request Header

- **Accept:** `application/json; charset=UTF-8`
- **Header:** `Authorization: Bearer <token>`
- **Content-Type:** `application/json`

Response

- **200 OK**
- **Content-Type:** `application/json`

Sample Response Body

```
{
    "username": "graphuser"
}
```

cURL Example

```
curl --location --request GET 'https://localhost:7007/v2/user' \
--header 'Authorization: Bearer <token>'
```

19.1.7 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 an Asynchronous PGQL Query
- Check Asynchronous Query Completion
- Retrieve Asynchronous Query Result
- Cancel an Asynchronous Query Execution

19.1.7.1 Run an Asynchronous PGQL Query

POST `https://localhost:7007/v2/runQueryAsync`

Run a PGQL query asynchronously on a property graph.

Version: v2

Request

Request Header

- **Accept:** `application/json; charset=UTF-8`
- **Header:** `Authorization: Bearer <token>`
- **Content-Type:** `application/json`

Request Query Parameters: See Table 19-3 for details.

Sample Request Body

```
{
  "statements": [
    "DROP PROPERTY GRAPH TEST_GRAPH",
    "CREATE PROPERTY GRAPH TEST_GRAPH VERTEX TABLES( Male KEY (id) LABEL Male
PROPERTIES ARE ALL COLUMNS EXCEPT (gender), Female KEY (id) LABEL Female
PROPERTIES ARE ALL COLUMNS EXCEPT (gender) ) EDGE TABLES( knowsmm KEY (id)
SOURCE KEY (sid) REFERENCES Male DESTINATION KEY (did) REFERENCES Male LABEL
knows PROPERTIES (mval, firstMetAt, since), knowsmf KEY (id) SOURCE KEY (sid)
REFERENCES Male DESTINATION KEY (did) REFERENCES Female LABEL knows
PROPERTIES (mval, firstMetAt, since), knowsfm KEY (id) SOURCE KEY (sid)
REFERENCES Female DESTINATION KEY (did) REFERENCES Male LABEL knows
PROPERTIES (mval, firstMetAt, since), knowsff KEY (id) SOURCE KEY (sid)
REFERENCES Female DESTINATION KEY (did) REFERENCES Female LABEL knows
PROPERTIES (mval, firstMetAt, since), friendOfmm KEY (id) SOURCE KEY (sid)
REFERENCES Male DESTINATION KEY (did) REFERENCES Male LABEL friendOf
PROPERTIES (strength), friendOfmf KEY (id) SOURCE KEY (sid) REFERENCES Male
DESTINATION KEY (did) REFERENCES Female LABEL friendOf PROPERTIES (strength),
friendOffm KEY (id) SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did)
REFERENCES Male LABEL friendOf PROPERTIES (strength), friendOfff KEY (id)
SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did) REFERENCES Female
LABEL friendOf PROPERTIES (strength) ) OPTIONS ( pg_pgql )",
    "SELECT v FROM MATCH (v) ON TEST_GRAPH LIMIT 1"
```

```
  ],
  "driver": "PGQL_IN_DATABASE",
  "formatter": "GVT",
  "parameters": {
    "dynamicSampling": 2,
    "parallel": 8,
    "start": 0,
    "size": 100
  },
  "visualize": true
```

Response

- **202 OK**
- **Content-Type:** `application/json`

Sample Response Body

```
{
    "message": "Query execution started.",
    "result_id": 0
}
```

cURL Example

```
curl --location --request POST 'https://localhost:7007/v2/runQueryAsync' \
--header 'Content-Type: application/json' \
--header 'Authorization: Bearer <token>' \
--data '{
  "statements": [
    "DROP PROPERTY GRAPH TEST_GRAPH",
    "CREATE PROPERTY GRAPH TEST_GRAPH VERTEX TABLES( Male KEY (id) LABEL Male
PROPERTIES ARE ALL COLUMNS EXCEPT (gender), Female KEY (id) LABEL Female
PROPERTIES ARE ALL COLUMNS EXCEPT (gender) ) EDGE TABLES( knowsmm KEY (id)
SOURCE KEY (sid) REFERENCES Male DESTINATION KEY (did) REFERENCES Male LABEL
knows PROPERTIES (mval, firstMetAt, since), knowsmf KEY (id) SOURCE KEY (sid)
REFERENCES Male DESTINATION KEY (did) REFERENCES Female LABEL knows
PROPERTIES (mval, firstMetAt, since), knowsfm KEY (id) SOURCE KEY (sid)
REFERENCES Female DESTINATION KEY (did) REFERENCES Male LABEL knows
PROPERTIES (mval, firstMetAt, since), knowsff KEY (id) SOURCE KEY (sid)
REFERENCES Female DESTINATION KEY (did) REFERENCES Female LABEL knows
PROPERTIES (mval, firstMetAt, since), friendOfmm KEY (id) SOURCE KEY (sid)
REFERENCES Male DESTINATION KEY (did) REFERENCES Male LABEL friendOf
PROPERTIES (strength), friendOfmf KEY (id) SOURCE KEY (sid) REFERENCES Male
DESTINATION KEY (did) REFERENCES Female LABEL friendOf PROPERTIES (strength),
friendOffm KEY (id) SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did)
REFERENCES Male LABEL friendOf PROPERTIES (strength), friendOfff KEY (id)
SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did) REFERENCES Female
LABEL friendOf PROPERTIES (strength) ) OPTIONS ( pg_pgql )",
    "SELECT v FROM MATCH (v) ON TEST_GRAPH LIMIT 1"
  ],
  "driver": "PGQL_IN_DATABASE",
  "formatter": "GVT",
  "parameters": {
    "dynamicSampling": 2,
```

```
    "parallel": 8,
    "start": 0,
    "size": 100
  },
  "visualize": true
}'
```

19.1.7.2 Check Asynchronous Query Completion

GET `https://localhost:7007/v2/isAsyncQueryExecutionComplete/<result_id>`

Check if an asynchronous query execution is completed.

Version: v2

Request Header

- **Accept:** `application/json; charset=UTF-8`
- **Header:** `Authorization: Bearer <token>`
- **Content-Type:** `application/json`

Request Path Parameter:

- `result_id`: PGQL query execution result id.

Response

- **200 OK**
- **Content-Type:** `application/json`

Sample Response Body

```
true
```

cURL Example

```
curl --location --request GET 'https://localhost:7007/v2/
isAsyncQueryExecutionComplete/<result-id>' \
--header 'Authorization: Bearer <token>'
```

19.1.7.3 Retrieve Asynchronous Query Result

GET `https://localhost:7007/v2/runQueryAsync/<result_id>`

Retreive the result of an asynchronous query.

Version: v2

Request

Request Header

- **Accept:** `application/json; charset=UTF-8`
- **Header:** `Authorization: Bearer <token>`

- **Content-Type:** `application/json`

Request Path Parameter:

- `result_id`: PGQL query execution result id.

Response

- **200 OK**
- **Content-Type:** `application/json`

Sample Response Body


```
{
    "results": [
        {
            "pgqlStatement": "DROP PROPERTY GRAPH TEST_GRAPH",
            "result": "Graph successfully dropped",
            "success": true,
            "error": null,
            "started": 1689656429130,
            "ended": 1689656429198
        },
        {
            "pgqlStatement": "CREATE PROPERTY GRAPH TEST_GRAPH VERTEX
TABLES( Male KEY (id) LABEL Male PROPERTIES ARE ALL COLUMNS EXCEPT (gender),
Female KEY (id) LABEL Female PROPERTIES ARE ALL COLUMNS EXCEPT (gender) )
EDGE TABLES( knowsmm KEY (id) SOURCE KEY (sid) REFERENCES Male DESTINATION
KEY (did) REFERENCES Male LABEL knows PROPERTIES (mval, firstMetAt, since),
knowsmf KEY (id) SOURCE KEY (sid) REFERENCES Male DESTINATION KEY (did)
REFERENCES Female LABEL knows PROPERTIES (mval, firstMetAt, since), knowsfm
KEY (id) SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did) REFERENCES
Male LABEL knows PROPERTIES (mval, firstMetAt, since), knowsff KEY (id)
SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did) REFERENCES Female
LABEL knows PROPERTIES (mval, firstMetAt, since), friendOfmm KEY (id) SOURCE
KEY (sid) REFERENCES Male DESTINATION KEY (did) REFERENCES Male LABEL
friendOf PROPERTIES (strength), friendOfmf KEY (id) SOURCE KEY (sid)
REFERENCES Male DESTINATION KEY (did) REFERENCES Female LABEL friendOf
PROPERTIES (strength), friendOffm KEY (id) SOURCE KEY (sid) REFERENCES Female
DESTINATION KEY (did) REFERENCES Male LABEL friendOf PROPERTIES (strength),
friendOfff KEY (id) SOURCE KEY (sid) REFERENCES Female DESTINATION KEY (did)
REFERENCES Female LABEL friendOf PROPERTIES (strength) ) OPTIONS ( pg_pgql )",
            "result": "Graph successfully created",
            "success": true,
            "error": null,
            "started": 1689656429198,
            "ended": 1689656429458
        },
        {
            "pgqlStatement": "SELECT v FROM MATCH (v) ON TEST_GRAPH LIMIT 1",
            "result":
"{\"schema\":\"GRAPHUSER\",\"name\":\"TEST_GRAPH\",\"resultSetId\":\"\",\"grap
h\":{\"vertices\":[{\"id\":\"MALE(0)\",\"properties\":
{\"AGE\":\"40\",\"BVAL\":\"Y\",\"LNAME\":\"Brown\",\"FNAME\":\"Bill\",\"PREFER
ENCES\":\"{ \\\"color\\\": \\\"blue\\\", \\\"number\\\": \\\"5\\\" }
\",\"ID\":\"0\",\"TEXT\":\"the cat sat on the
mat\",\"MVAL\":\"y\"}}],\"edges\":[],\"numResults\":1},\"table\":\"V\
```

```
\nMALE(0)\"}",
            "success": true,
            "error": null,
            "started": 1689656429458,
            "ended": 1689656430029
        }
    ]
}
```

cURL Example

```
curl --location --request GET 'https://localhost:7007/v2/runQueryAsync/
<result-id>' \
--header 'Authorization: Bearer <token>'
```

19.1.7.4 Cancel an Asynchronous Query Execution

DELETE `https://localhost:7007/v2/runQueryAsync/<result_id>`

Cancel the execution of an asynchronous query.

Version: v2

Request

Request Header

- **Accept:** `application/json; charset=UTF-8`
- **Header:** `Authorization: Bearer <token>`
- **Content-Type:** `application/json`

Request Path Parameter:

- `result_id`: PGQL query execution result `id`.

Response

- **200 Accepted**
- **Content-Type:** `application/json`

cURL Example

```
curl --location --request DELETE 'https://localhost:7007/v2/runQueryAsync/
<result-id>' /
--header 'Authorization: Bearer <token>'
```

19.2 Graph Server REST API Version 1

Learn about the graph server REST API version 1 (v1).

> **Note:**
>
> The version 1 (v1) endpoints of the API is deprecated. It is recommended that you use Graph Server REST API Version 2.

- Login
- Get Graphs
- Run a PGQL Query
- Get User
- Logout
- Asynchronous REST Endpoints

19.2.1 Login

POST `https://localhost:7007/ui/v1/login/`

Login to the graph server.

Version: v1

Authentication: Uses cookie-based authentication.

Table 19-4 Parameters

Parameter	Parameter Type	Value	Required
`Content-type`	Header	`application/json`	Yes
`username`	Body	`<username>`	Yes
`password`	Body	`<password>`	Yes
`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 in `/opt/oracle/graph/pgx/server/graph-server-webapp-24.4.0.war` will be used.
`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.

19.2.2 Get Graphs

GET `https://localhost:7007/ui/v1/graphs`

Get the list of all graphs that belong to a user.

Version: v1

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:

```
[
  {
    "schema": "HR",
    "graphName": "MY_GRAPH"
  }
]
```

Also, note that the `schema` parameter will be `NULL` for graphs created in the graph server (PGX).

19.2.3 Run a PGQL Query

POST `https://localhost:7007/ui/v1/query`

Run a PGQL Query on a property graph.

Version: v1

Table 19-5 Request 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.
`parallelism`	Degree of Parallelism	`<parallelism_value>`	Optional. Default value depends on the PGQL driver configuration: • `pgxDriver`: `<number-of-cpus>` See `parallelism` in Table 23-1. • `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]"
}
```

19.2.4 Get User

GET `https://localhost:7007/ui/v1/user`

Get the name of the current user.

Version: v1

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"
```

19.2.5 Logout

POST `https://localhost:7007/ui/v1/logout/`

Log out from the graph server.

Version: v1

Request

The following `curl` command is to successfully log out from the graph server.

```
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.

19.2.6 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 an Asynchronous PGQL Query
- Check Asynchronous Query Completion
- Retrieve Asynchronous Query Result
- Cancel an Asynchronous Query Execution

19.2.6.1 Run an Asynchronous PGQL Query

GET `https://localhost:7007/ui/v1/async-query`

Run a PGQL query asynchronously on a property graph.

Version: 1

See Table 19-5 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.

19.2.6.2 Check Asynchronous Query Completion

GET `https://localhost:7007/ui/v1/async-query-complete`

Checks if an asynchronous query execution is completed.

Version: v1

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.

19.2.6.3 Retrieve Asynchronous Query Result

GET `https://localhost:7007/ui/v1/async-result`

Retreive the result of an asynchronous query.

Version: v1

> **Note:**
>
> The endpoint, `GET https://localhost:7007/ui/v1/async-result` 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]"
}
```


19.2.6.4 Cancel an Asynchronous Query Execution

DELETE `https://localhost:7007/ui/v1/async-query`

Cancels the execution of an asynchronous query.

Version: 1

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.

Part VI
Graph Visualization Application

The Graph Visualization application enables interactive exploration and visualization of property graphs. You can visualize graphs that are loaded into the graph server(PGX) and the 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
  The Graph Visualization application is based on the graph visualization library. Using this interface, you can run PGQL queries on graphs in the graph server (PGX) and database.
- Embedding the Graph Visualization Library in a Web Application
  You can integrate the graph visualization component in a web application to visualize graph data.

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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 or SQL graph queries (in case of SQL property graphs which are supported only in Oracle Database Release 23ai) as 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) at run-time by a client application and made available through the `graph.publish()` API.

See Also:

- Running the Graph Visualization Web Client
- REST Endpoints for the Graph Server

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Using the Graph Visualization Application

The Graph Visualization application is based on the graph visualization library. Using this interface, you can run PGQL queries on graphs in the graph server (PGX) and database.

> **See Also:**
>
> Graph JavaScript API Reference for Property Graph Visualization

The Graph Visualization application is made up of the following three tabs:

- **Graph Server:** To visualize graphs loaded into the graph server (PGX).
- **Database (PGQL Property Graphs):** To visualize PGQL property graphs in the database.
- **Database (SQL Property Graphs):** To visualize SQL property graphs. This tab option is supported only with Oracle Database 23ai.

Each tab comprises a query editor at the top and a graph visualization panel at the bottom of the interface.

All query level actions (such as running or canceling a query), viewing the list of graphs to which you have access in a specific tab, or configuring the settings for visualizing the output can be performed using the following toolbar:

Figure 21-1 Supported Actions

Note that the action to **Load graph into memory** is supported only in the **Graph Server** tab.

You can choose to view the results of the graph visualization query in graph (default) or tabular format using the following toolbar which is displayed on the right of the graph visualization panel:

Figure 21-2 Display Views

- Visualizing PGQL Queries on Graphs Loaded Into the Graph Server (PGX)
  You can create or load a graph into the graph server (PGX), and then run PGQL graph queries in the **Graph Server** tab of the Graph Visualization application.

- Visualizing PGQL Queries on PGQL Property Graphs
  You can visualize PGQL queries on PGQL property graphs in the database in the **Database (PGQL Property Graphs)** tab of the Graph Visualization application.
- Visualizing Graph Queries on SQL Property Graphs
  You can query and visualize a SQL property graph in the database in the **Database (SQL Property Graphs)** tab of the Graph Visualization application.
- Graph Visualization Modes and Graph Legend
  Learn about the graph visualization toolbar, supported graph visualization modes and graph legend if you are viewing the results of the query in graph format.
- Graph Visualization Settings
  You can click the **Settings** gear icon to open the Graph Visualization settings window.
- Using Network Evolution in Graph Visualization
  You can visualize the evolution of a graph over time using the **Network Evolution** feature in the Graph Visualization application.

21.1 Visualizing PGQL Queries on Graphs Loaded Into the Graph Server (PGX)

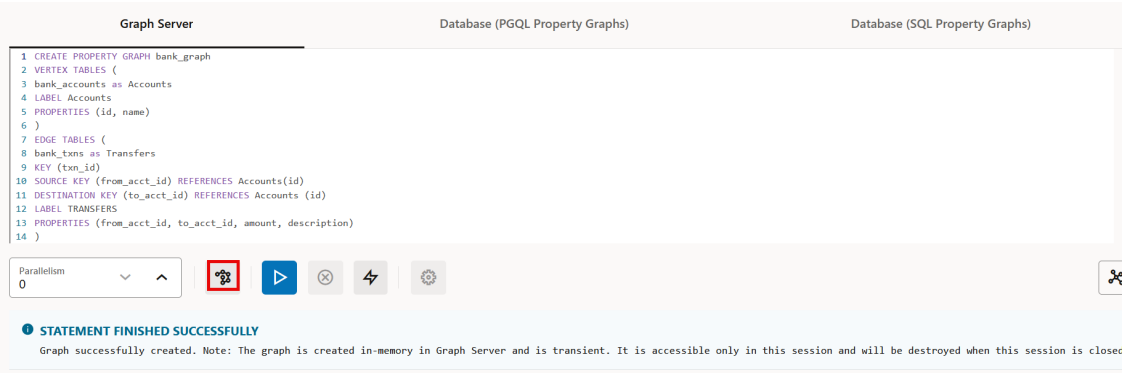
You can create or load a graph into the graph server (PGX), and then run PGQL graph queries in the **Graph Server** tab of the Graph Visualization application.

The following sections describe in detail the various actions that you can perform in the **Graph Server** tab.

Creating a Property Graph in the Graph Server (PGX)

You can run the `CREATE PROPERTY GRAPH` PGQL statement to create a graph in the graph server (PGX). For example:

Figure 21-3 Creating a Property Graph in the Graph Server Memory



The graph gets created and loaded into the graph server memory (PGX). Note that this is a transient graph which will be destroyed at the end of the session.

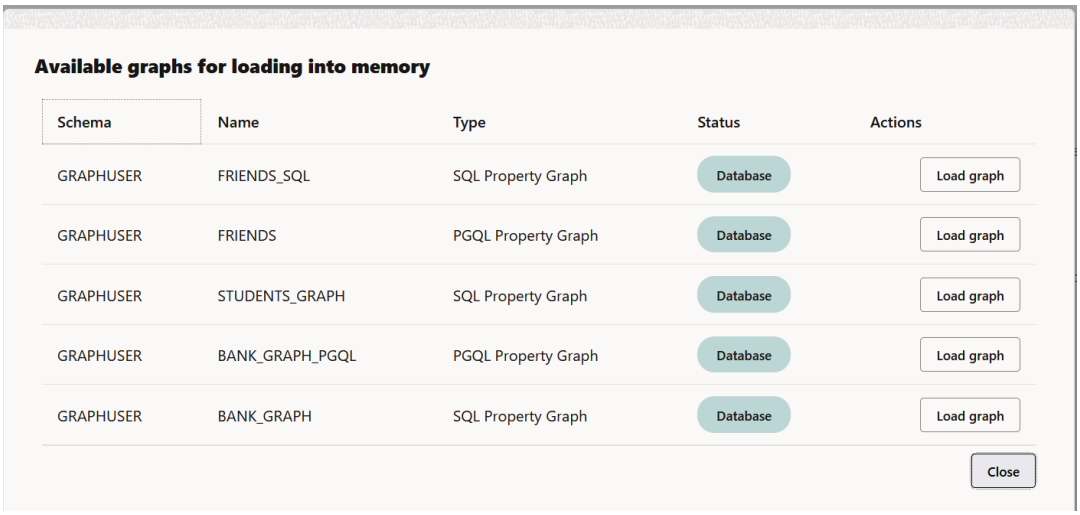
You can click the **Get Graphs List** icon (shown highlighted in the preceding figure) to view all the graphs that are loaded into the graph server memory.

Loading a Database Property Graph into the Graph Server (PGX) Memory

You can also load any existing PGQL or SQL property graph from the database into the graph server (PGX) memory by performing the following steps:

1. Click the  **Load graph into memory** icon in the **GraphServer** tab.
   The list of database graphs to which you have access are displayed as shown:

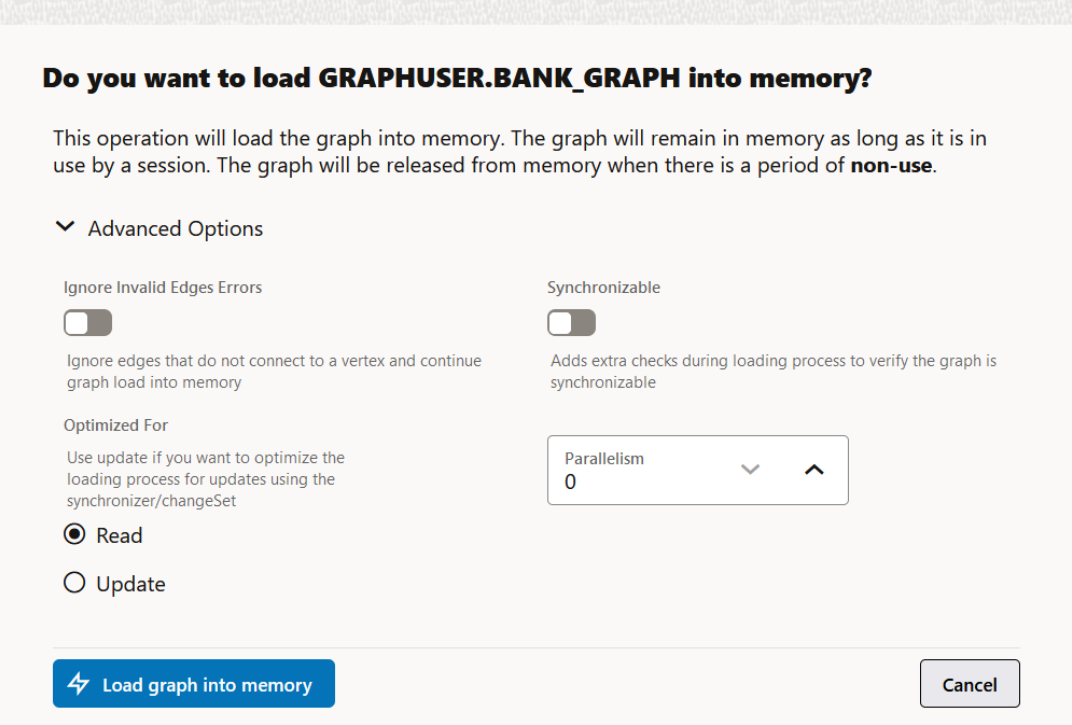
Figure 21-4 List of Database Graphs



   Note that the SQL property graphs get listed only if you are connected to Oracle Database 23ai.

2. Click **Load graph** against the desired graph.
   The confirmation dialog for loading the graph into memory opens.

Figure 21-5 Loading Graph Into Memory Confirmation



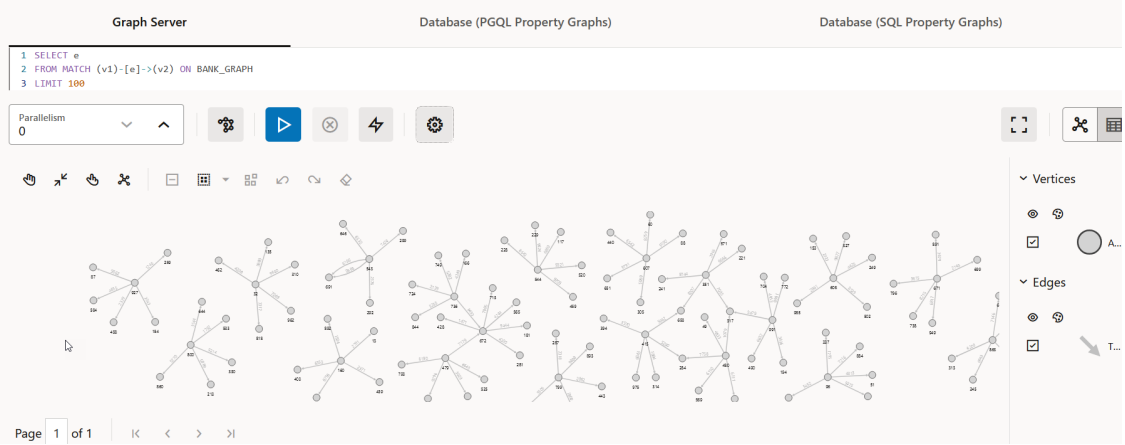
3. Optionally, click to expand the **Advanced Options** configuration.
   The following advanced options can be configured:
   - **Ignore Invalid Edges Errors:** Switch ON this toggle to ignore all edges that do not connect to a vertex.
   - **Synchronizable:** Switch ON this toggle to verify that the graph can be synchronized.
   - **Optimized For:** Select one of the following graph optimization strategies:
     - **`READ`:** To optimize for read-intensive scenarios.
     - **`UPDATE`:** To optimize for update-intensive scenarios.
   - **Parallelism:** To specify the degree of parallelism.
4. Click **Load graph into memory**.
   The **In Progress** status against the graph indicates that the graph loading process is initiated and once the graph is successfully loaded into memory, the status gets updated to **Memory**.
5. Click **Close** and click the **Get Graphs List** icon to verify that the graph is loaded into memory.

Running PGQL queries on the graph

You can enter a PGQL query on the desired graph and click **Run Query** to execute the query. On successful execution, the graph visualization result (including nodes and their connections) is displayed in the bottom panel. You can right-click a node or connection to display tooltip information, and you can drag the nodes around.

The following figure shows a sample query visualization identifying all edges that are directed edges from any vertex in the graph to any other vertex.

Figure 21-6 Visualizing a PGQL Query



21.2 Visualizing PGQL Queries on PGQL Property Graphs

You can visualize PGQL queries on PGQL property graphs in the database in the **Database (PGQL Property Graphs)** tab of the Graph Visualization application.

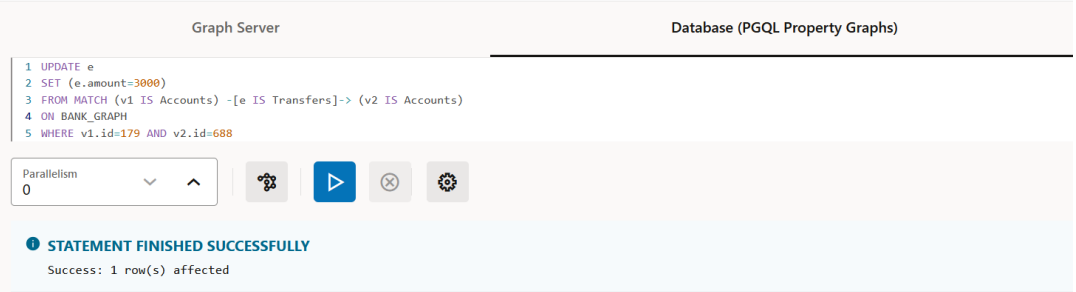
You can create, query, modify and visualize PGQL property graphs in the database using the Graph Visualization application. The following PGQL operations are supported:

- `CREATE PROPERTY GRAPH`: To create a new PGQL property graph as shown:

Figure 21-7 Creating a PGQL property graph

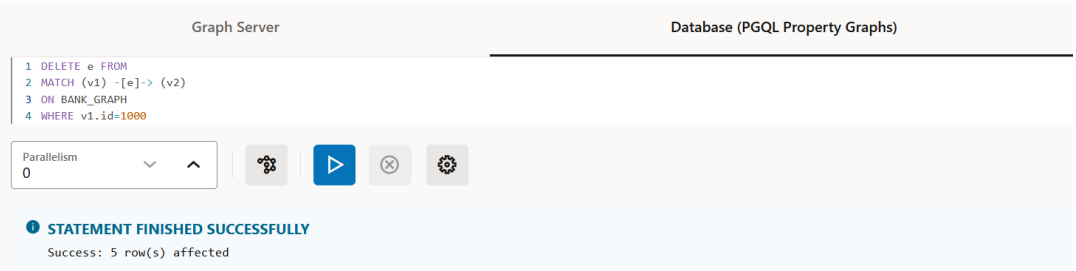
- `INSERT`, `UPDATE` and `DELETE`: To modify an existing PGQL property graph. For example:

Figure 21-8 Updating an Edge in a PGQL property graph



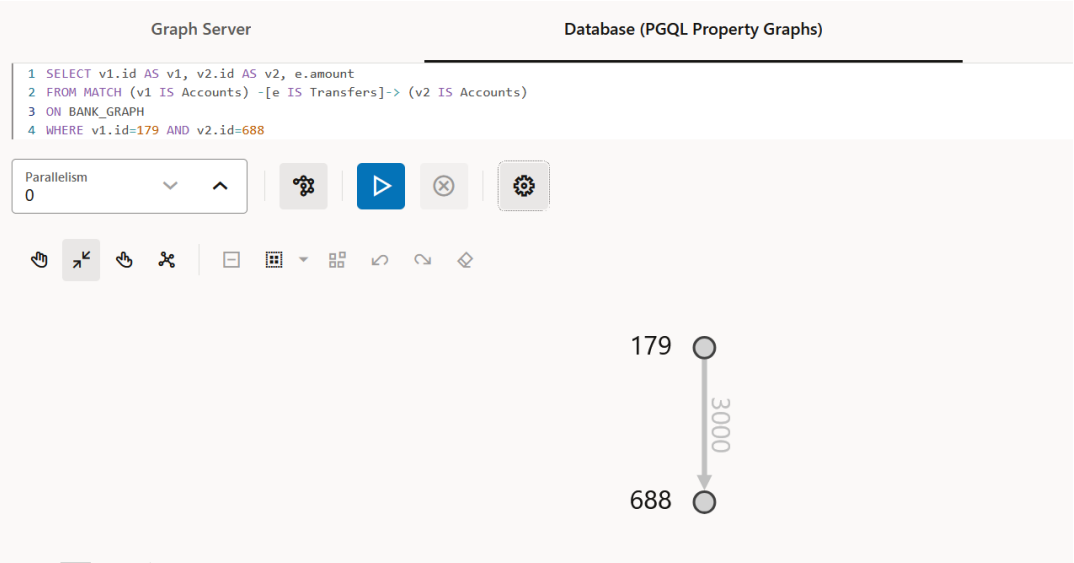
Note that you must provide the graph name in the PGQL query. You can click the **List of available graphs** icon to view the list of PGQL property graphs to which you have access.

Figure 21-9 Deleting an Edge in a PGQL property graph



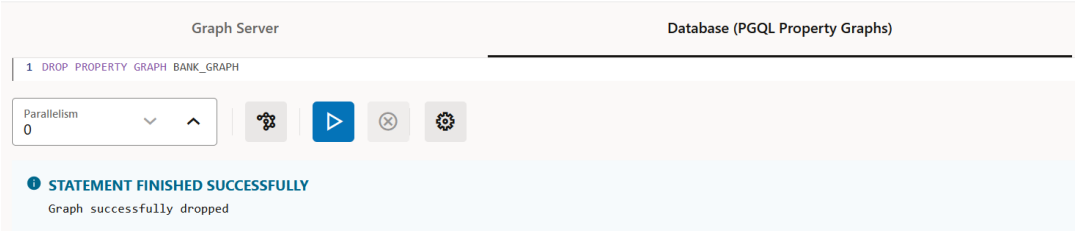
- `SELECT`: To query a PGQL property graph as shown:

Figure 21-10 Querying a PGQL property graph



- `DROP PROPERTY GRAPH`: To delete a PGQL property graph as shown:

Figure 21-11 Dropping a PGQL property graph



21.3 Visualizing Graph Queries on SQL Property Graphs

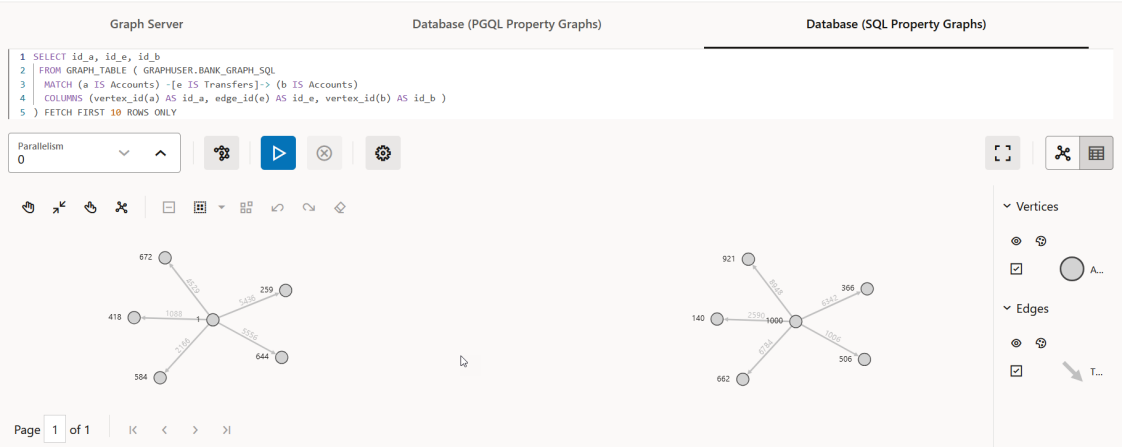
You can query and visualize a SQL property graph in the database in the **Database (SQL Property Graphs)** tab of the Graph Visualization application.

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` functions.

> **Note:**
>
> The Graph Visualization application supports only `SELECT` graph queries.

Figure 21-12 Graph Query on a SQL Property Graph



The name of the graph must be provided in the SQL graph query. You can click the **List of available graphs** icon (shown highlighted in the preceding figure) to view the list of SQL property graphs to which you have access.

> **See Also:**
>
> SQL Graph Queries for more information

21.4 Graph Visualization Modes and Graph Legend

Learn about the graph visualization toolbar, supported graph visualization modes and graph legend if you are viewing the results of the query in graph format.

Graph Visualization Toolbar

The graph visualization toolbar is displayed on the left of the graph visualization panel as shown:

Figure 21-13 Graph Visualization Toolbar

The toolbar supports the following graph visualization modes:

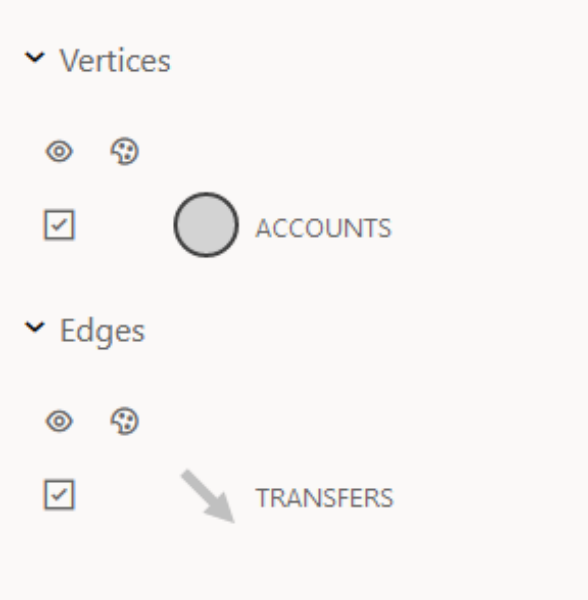
- **Move/Zoom**: This mode allows you to zoom in and out, as well as to move to another part of the visualization.
- **Fit to Screen**: This mode fits the resulting graph in the graph visualization view.
- **Toggles Sticky Mode**: This mode allows you to cancel the action of dragging the nodes around.
- **Activate Network Evolution**: This allows you to activate or deactivate network evolution.
- **Graph Manipulation**: This mode allows you to interact with your graph visualization. Supported actions are:
  - **Drop**: To remove selected vertices from the visualization. Can also be executed from the tooltip.
  - **Group**: To group selected multiple vertices and collapse them into a single one.
  - **Ungroup**: To select a group of collapsed vertices and ungroup them.
  - **Undo**: To undo the last action.
  - **Redo**: To redo the last action.
  - **Reset**: To reset the visualization to the original state after the query.

In addition,  **Toggle fullscreen mode** is available on the right of the graph visualization panel.

Graph Visualization Legend

The graph visualization legend appears on the right of the graph visualization panel and displays the legend items that represent the vertices and edges of the graph. For example:

Figure 21-14 Graph Legend



21.5 Graph Visualization Settings

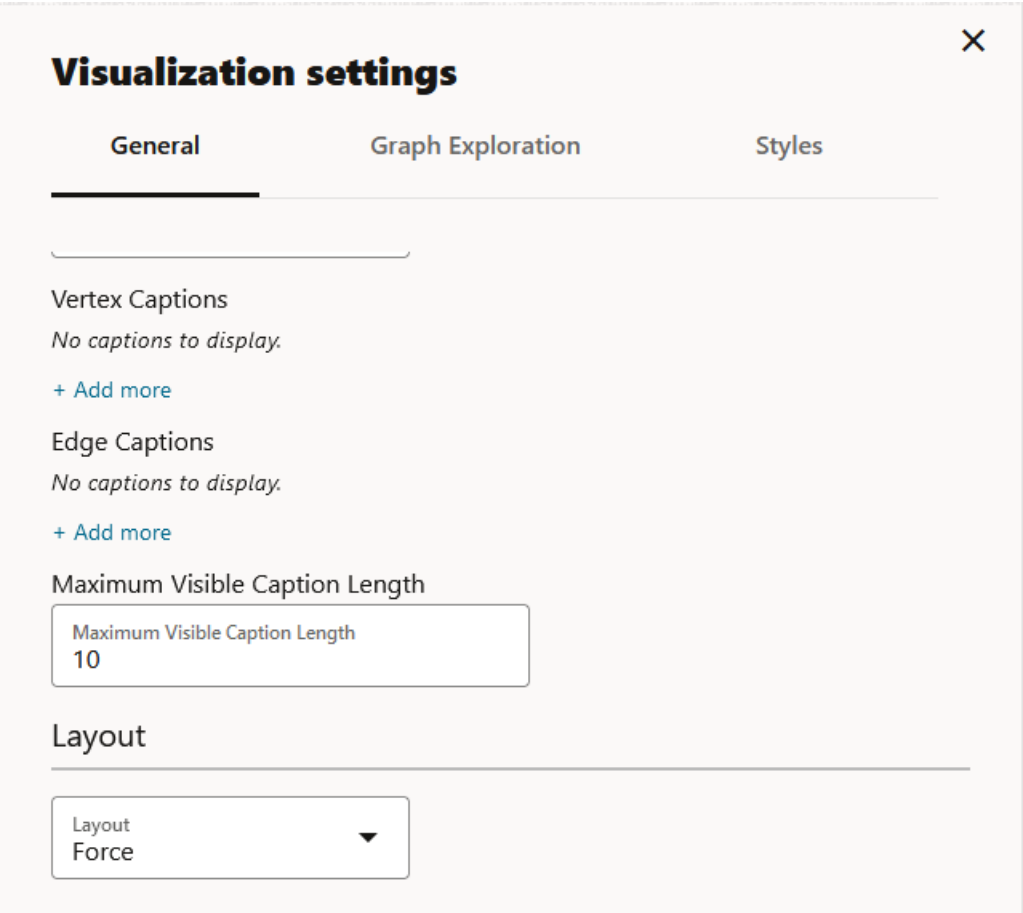
You can click the **Settings** gear icon to open the Graph Visualization settings window.

The **Visualization settings** window comprises the **General**, **Graph Exploration**, and **Styles** tab.

Configuring General Settings

You can add vertex and edge captions, set the graph layout and page size in the **General** of the **Graph Visualization** settings:

Figure 21-15 General Tab Configuration

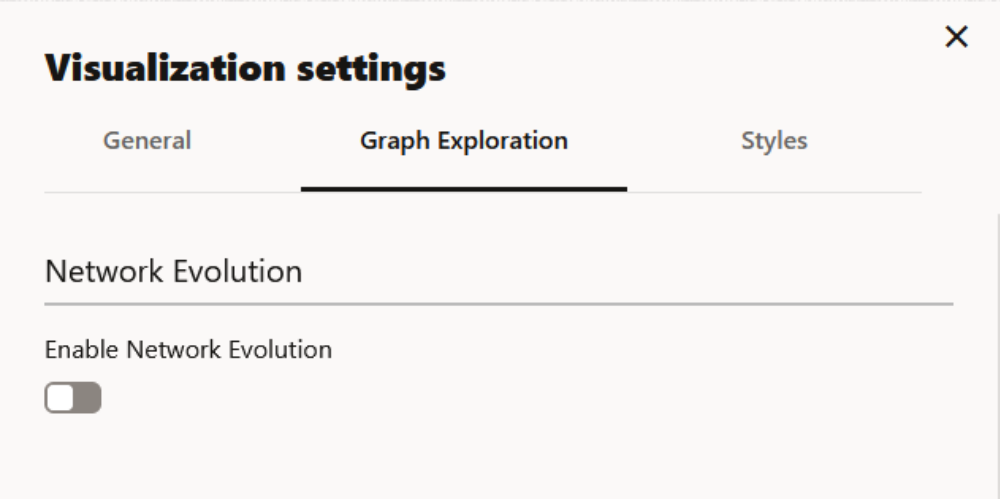


- **Vertex Caption Orientation**: Determines where the selected vertex property will be displayed.
- **Vertex Caption**: Determines the property to be displayed for a vertex.
  Click **+ Add more** to add a vertex caption and select the required vertex **Label** and vertex **Property**.
- **Edge Caption**: Determines the property to be displayed for an edge.
  Click **+ Add more** to add an edge caption and select the required edge **Label** and edge **Property**.
- **Maximum Visible Caption Length**: Maximum caption length before truncating.
- **Layout**: Computes the position of the nodes and determines the visual structure of the graph.
  Supported layouts are: *Circle*, *Concentric*, *Force (default)*, *Grid*, *Hierarchical*, *Preset*, *Radial*, and *Random*.
- **Page Size**: Determines the number of entries to be visualized from the result set.

Configuring Graph Exploration Settings

You can enable and configure **Network Evolution** in the **Graph Exploration** tab of the **Graph Visualization** settings. See Using Network Evolution in Graph Visualization for more information.

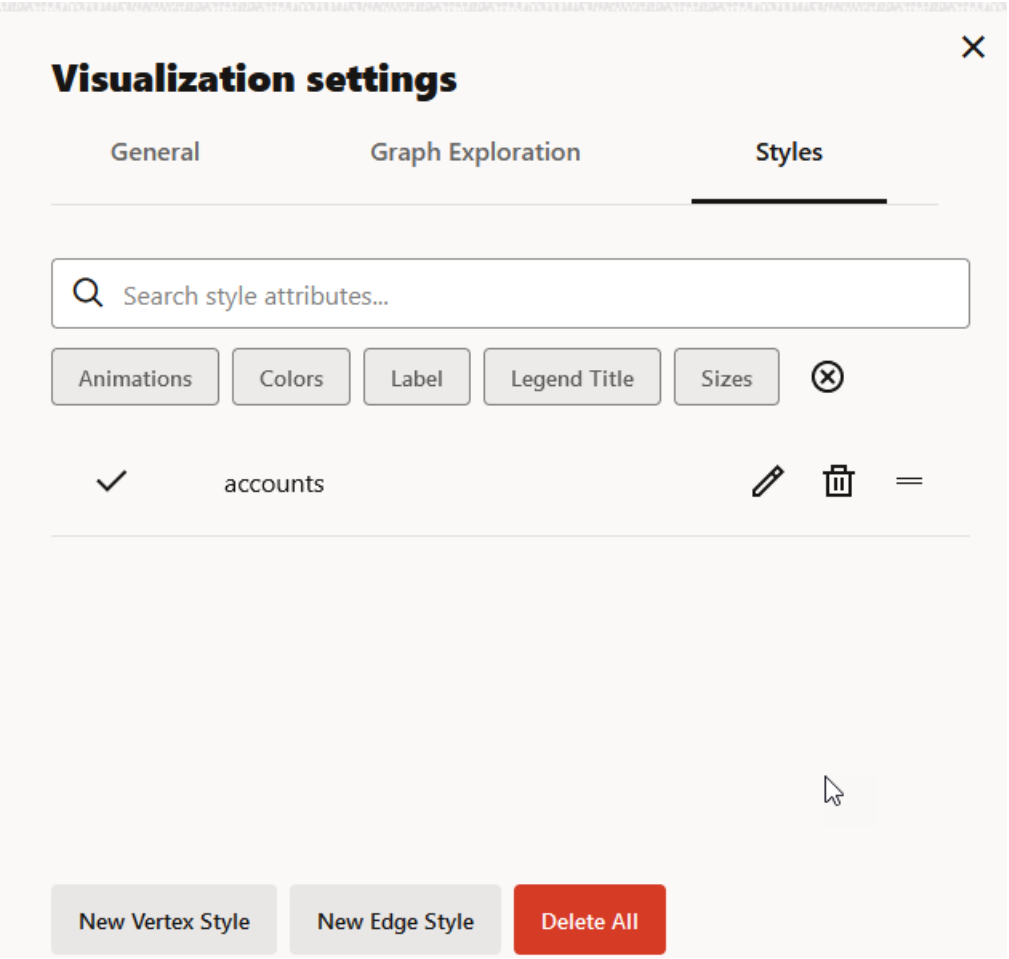
Figure 21-16 Graph Exploration Tab Configuration



Configuring Vertex and Edge Styles

You can configure and manage vertex and edge styles to customize the appearance of the vertices and edges in the graph. All the configured styles are listed in the **Styles** tab of the **Graph Visualization** settings.

Figure 21-17 Vertex and Edge Styles Configuration



To add a new vertex or edge style, click **New vertex style** or **New edge style** as appropriate and configure the following values:

- **Name**: Name of the style
- **Conditions**: Click **+** to add a condition for an element (vertex or edge) and provide the following values:
  - **Property** of the vertex or edge element.
  - **Operator** to be applied. The following operators 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)

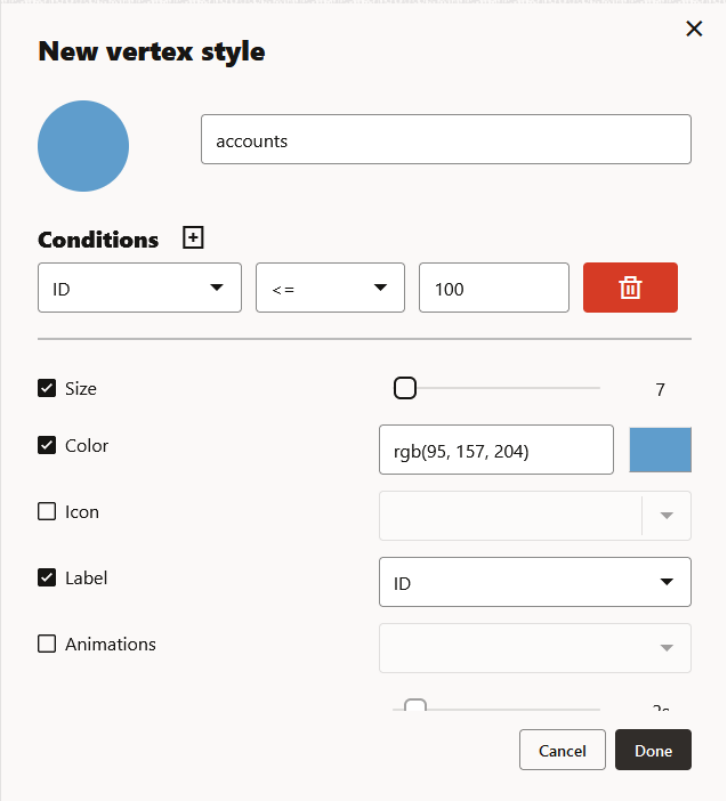
- **Value** that needs to be fulfilled for the property and the operator

You can add as many conditions as required. For all elements that meet the conditions, you can configure any of the following styling highlights:

- **Size**: Size of the vertex or edge
- **Color**: Color of the vertex or edge
- **Icon**: Image for the vertex (does not apply for edges)
- **Label**: Label for the vertex or edge
- **Animations**: Animation (*Pulsating* or *Flashing*) and duration of the animation cycle

The following example shows a sample vertex style configuration.

Figure 21-18 Adding a Vertex Style



21.6 Using Network Evolution in Graph Visualization

You can visualize the evolution of a graph over time using the **Network Evolution** feature in the Graph Visualization application.

In order to visualize a dynamic graph, it is important that the graph contains date or time properties. It can either be a vertex or an edge property.

Perform the following steps for configuring network evolution:

1. Click **Settings** in the graph visualization panel to open the graph **Visualization settings**.
2. Click the **Graph Exploration** tab.

3. Switch on the **Enable Network Evolution** toggle.
4. Select a graph element from the **Based On** drop-down list.

   You can configure the network evolution to be based on vertices, or edges, or both.

   Depending on your selection, you must select one or more of the following properties:

   - **Vertex Start Property**: Select the name of the property to use for the vertex filtering. The time frame for the graph will be after the *Vertex Start Property*.
   - **Vertex End Property**: Optionally, select the name of the property to use for the vertex filtering.
     The time frame for the graph will be before the *Vertex End Property*.
   - **Edge Start Property**: Select the name of the property to use for the edge filtering. The time frame for the graph will be after the *Edge Start Property*.
   - **Edge End Property**: Optionally, select the name of the property to use for the edge filtering.
     The time frame for the graph will be before the *Edge End Property*.
5. Select the data type from the **Property Type** drop-down list.

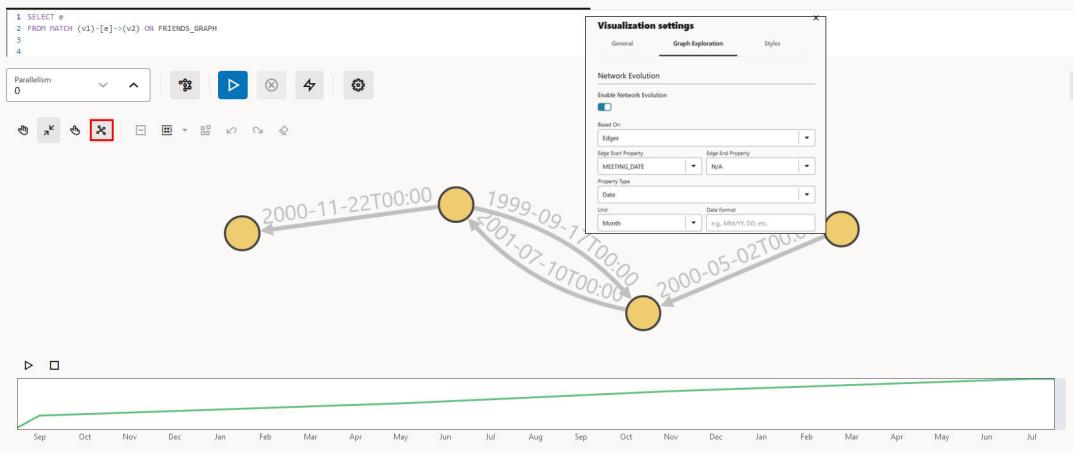
   Supported property type values are `Integer` and `Date`.
6. Optionally, select the **Unit** of time for the increment and the **Date Format** if the **Property Type** is `Date`.
7. Optionally, enable **Advanced Settings** if you want to explore advanced network evolution features and select one or more of the following options:

   - **Height**: Select a value to specify the height of the network evolution chart.
   - **Chart Type**: Select the type of the chart to be used to show the network evolution.
   - **Granularity**: Specify the aggregation granularity for the input unit.
   - **Exclude Values**: Specify one or more values to be excluded.
   - **Playback Step**: Specify a value to determine how often does the playback advance in ms.
   - **Playback Timeout**: Specify a value to determine how many steps are taken per time out during playback.
8. Close the **Settings** dialog.

   The chart displaying the evolution of the graph data gets displayed at the bottom of the graph visualization. You can view the graph animation by clicking the **Play Network Evolution** button. The animation shows the changes in the graph network over time.

   The following figure shows an example for network evolution of graph data using line chart in the graph visualization panel:

Figure 21-19 Dynamic Graph Visualization



Also, you can activate and deactivate network evolution by clicking the **Activate Network Evolution** icon which is show highlighted in the preceding figure.

22

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-24.4.0.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-24.4.0.zip` file from Oracle Software Delivery Cloud and integrate the library in you web application.

See the demo application on GitHub for an example.

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:

- Graph Server (PGX) Configuration Options
  Learn about the various configuration options for 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.
- 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.

23
Graph Server (PGX) Configuration Options

Learn about the various configuration options for the graph server (PGX).

- Configuration Parameters for the Graph Server (PGX) Engine
  You can configure the graph server (PGX) engine parameters in the `/etc/oracle/graph/pgx.conf` JSON file.
- Configuration Parameters for Connecting to the Graph Server (PGX)
  You can configure the graph server (PGX) parameters in the `/etc/oracle/graph/server.conf` JSON file.

23.1 Configuration Parameters for the Graph Server (PGX) Engine

You can configure the graph server (PGX) engine parameters in the `/etc/oracle/graph/pgx.conf` JSON file.

During startup, the graph server (PGX) picks up the settings in the `/etc/oracle/graph/pgx.conf` file, by default.

The following tables describe the different graph server (PGX) runtime configuration options.

Graph Server (PGX) Engine Parameters

The graph server (PGX) engine parameters are described in the following table:

Table 23-1 Runtime 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_lazy_loading_for_database_graphs`	`boolean`	If true, the graph server (PGX) will automatically load the graphs from the database when they are first referenced in the graph queries.	`false`
`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 23-1 (Cont.) Runtime 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). 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.	[]
authorization	array of object	Mapping of users and roles to resources and permissions for authorization.	[]
authorization_session_create_allow_all	boolean	If true allow all users to create a PGX session regardless of permissions granted to them.	false
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

Table 23-1 (Cont.) Runtime Parameters for the Graph Server (PGX) Engine

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`
`data_memory_limits`	`object`	Memory limits configuration parameters.	`null`
`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_graph_loading_cache`	`boolean`	If `true`, activate the graph loading cache that will accelerate loading of graphs that were previously loaded (can only be disabled in embedded mode).	`true`
`enable_graph_sharing`	`boolean`	Indicates if a user is allowed to grant `read` permission on its published graphs to other users. This flag is only relevant for a remote server.	`true`
`enable_memory_limits_checks`	`boolean`	If `true` the graph server will enforce the configured memory limits.	`true`
`enable_ml_accelerators`	`boolean`	If `true`, the graph server will utilize the available ML accelerators to run faster machine learning trainings.	`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`
`enable_snapshot_properties_publish_state_propagation`	`boolean`	If `true`, properties in a new snapshot will inherit the publishing state of properties in the parent snapshot.	`true`

Table 23-1 (Cont.) Runtime Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
enterprise_scheduler_config	object	Configuration parameters for the enterprise scheduler. See Table 23-3 and Table 23-4 for more information.	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, JAVA]	Front-end compiler to use.	JAVA
graph_sharing_option	enum[allow_data_sharing, disallow_data_sharing, allow_traceable_data_sharing_for_same_user]	This is to manage if a graph can be published and shared with other users.	allow_data_sharing
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
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), which once reached, the job status polling interval is fixed	1000

Table 23-1 (Cont.) Runtime Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
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
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_on_heap_memory_usage_ratio	number	Maximum ratio of on-heap memory that PGX is allowed to use, between 0 and 1.	0.9
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

Table 23-1 (Cont.) Runtime Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
`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 attempts to use a value lower than the one specified by `min_array_compaction_threshold`, it will use `min_array_compaction_threshold` instead.	`0.2`
`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`

Table 23-1 (Cont.) Runtime Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
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
permission_checks_interval	integer	Interval in seconds to perform permission checks on source graphs.	60
pgx_realm	object	Configuration parameters for the realm. See Table 23-2.	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
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.	-2446669109305703 1
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

Table 23-1 (Cont.) Runtime Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
`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`
`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`

Table 23-1 (Cont.) Runtime Parameters for the Graph Server (PGX) Engine

Parameter	Type	Description	Default
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
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.

Advanced Access Configuration

The following table lists the fields in the `pgx_realm` object that can be used to customize login behavior.

Table 23-2 Advanced Access Configuration Options

Parameters	Type	Description	Default
`token_expiration_seconds`	`integer`	After how many seconds the generated bearer token will expire.	3600 (1 hour)
`refresh_time_before_token_expiry_seconds`	`integer`	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`	`integer`	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`	`integer`	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. Starting from 23.4 onwards, a new dedicated pool with one connection is provided for token refresh. This new dedicated pool does not affect the `max_pool_size` value.	64
`max_num_users`	`integer`	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`	`integer`	Maximum amount of times a token can be automatically refreshed before requiring a login again.	24

Enterprise Scheduler Parameters

The following parameters are relevant only if the advanced scheduler is used. (They are ignored if the basic scheduler is used.)

Table 23-3 Enterprise Scheduler Parameters

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.)

Table 23-4 Basic Scheduler Parameters

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

Table 23-4 (Cont.) Basic Scheduler Parameters

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 23-1 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 23-2 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`.

23.2 Configuration Parameters for Connecting to the Graph Server (PGX)

You can configure the graph server (PGX) parameters in the `/etc/oracle/graph/server.conf` JSON file.

See Configuring the Graph Server (PGX)

24

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.

24.1 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.

You can set the `max_on_heap_memory_usage_ratio` configuration field to decide on the ratio of the total JAVA heap memory that the graph server (PGX) is allowed to use (for example a value of `0.8` would mean that the graph server(PGX) is allowed to use 80% of JAVA heap memory). The default value of this parameter is `1.0` which lets the JVM handle any out of memory errors. It is recommended to set this parameter to `0.9` to avoid the graph server (PGX) from using the full on heap memory as this may cause the server to slowdown or crash.

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.

24.1.1 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.

> **Note:**
>
> The graph server (PGX) periodically checks the on-heap memory size. If the memory usage grows above the threshold defined in the `max_on_heap_memory_usage_ratio` field (default value is `0.9`) in the `/etc/oracle/graph/pgx.conf` file, then the graph server will throw an exception and cancel the current running task (which is unable to allocate memory). This eliminates the possibility of unexpected server crashes when the heap memory is full. It is recommended that you configure the `max_on_heap_memory_usage_ratio` option to be less than one, so that the used on-heap memory value remains lesser than the JVM `-Xmx` value to ensure a safe buffer for heap memory allocation.

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 service restarted with the new memory settings:

```
systemctl status pgx
```

   You may see a similar output:

```
● pgx.service - Oracle Graph In-Memory Server
   Loaded: loaded (/etc/systemd/system/pgx.service; enabled; vendor
preset: disabled)
  Drop-In: /etc/systemd/system/pgx.service.d
           └─setup.conf
   Active: active (running) since Wed 2023-04-12 14:50:49 CEST; 5 days ago
 Main PID: 1209 (bash)
   CGroup: /system.slice/pgx.service
           ├─1209 /bin/bash start-server
           └─1469 /usr/java/jdk-11.0.6/bin/java -
Dlogback.configurationFile=/etc/oracle/graph/logback-server.xml
                    -Doracle.jdbc.fanEnabled=false -cp /opt/oracle/
graph/pgx/bin/../../pgx/server/lib/activatio...
```

   Review the **Drop-In** unit file as shown highlighted in the preceding output. This confirms that `systemd` found the drop-in file and applied the required customizations.

8. 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 $PGX_RESPONSE | jq -r '.access_token'`
curl -s -k -H 'Authorization: Bearer '"${PGX_ACCESS_TOKEN}" $BASE_URL/
control/v1/serverState|jq '.entity.memory'
```

   Note that the preceding example uses the **jq** tool to fetch and format the output.

24.1.2 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.

25

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

25.1 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.

25.2 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.

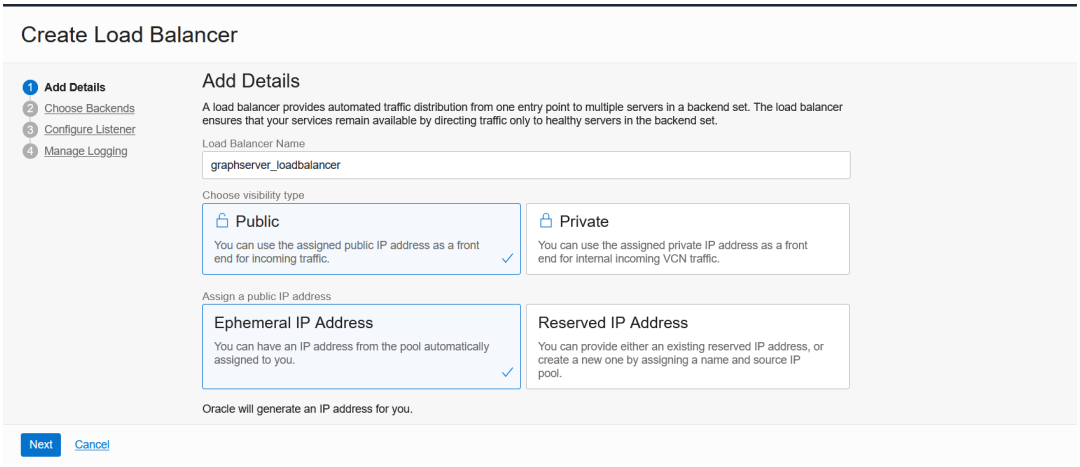
As a prerequisite requirement, you must ensure that two or more graph servers are running on different machines on the same port (7007 by default).

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 25-1 Configuring Load Balancer Details

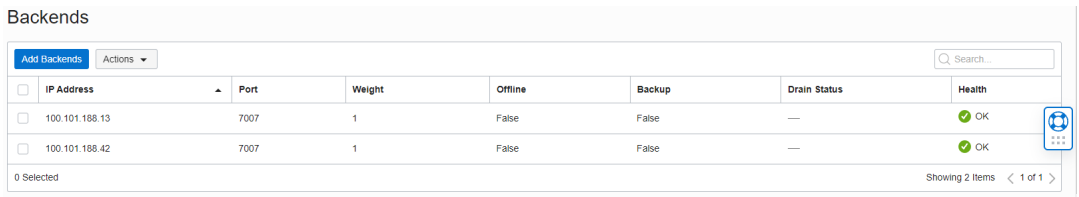


5. Optionally, edit the following details:
   - **Load Balancer Name**
   - **Choose visibility type**
   - **Choose IP address type**
6. Under **Choose Networking** section, select the **Virtual Cloud Network** where the graph server instances are running.
7. Accept the default values for all other 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 25-2 Adding Backends to Load Balancer



10. Select as many backend graph server instances as available and click **Add Selected Backends**.

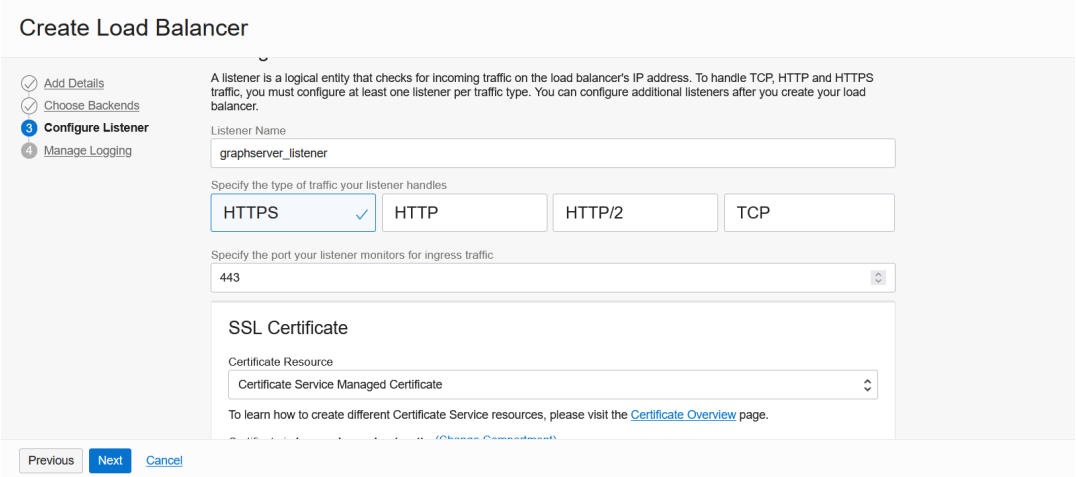
    The selected backend set appear in the **Select Backend Servers** table.
11. Specify the following values for the parameters under **Specify Health Check Policy**:
    - **Protocol:** HTTP
    - **Port:** backend port used by all the graph servers
    - **Interval in milliseconds:** default value
    - **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 25-3 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**.

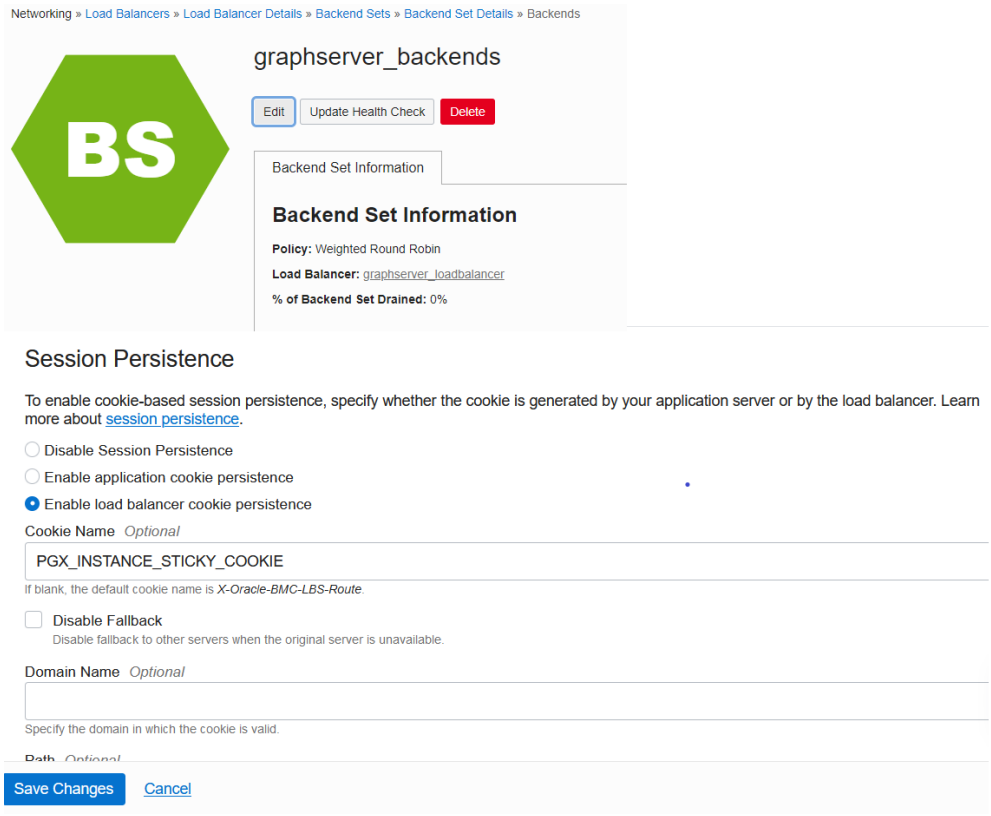
    The **Manage Logging** page opens as shown.
18. Accept all the default values on this page and click **Submit**.

    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 25-4 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.

25.3 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 `503`.

26
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.

26.1 Defining Graph Names

Graphs that are created in a session either through loading 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 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.

26.2 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.

26.3 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`.

26.4 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.

27
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 27-1 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 27-1 (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

27.1 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.

27.2 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 27-2 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 27-2 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
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	-	-	-

Table 27-2 (Cont.) Overview of Data types

Data Type	Loading & Storing	PGX Java API	PGQL and Filter Expression	Minimum Value Limitation	Maximum Value Limitation
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

27.2.1 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/opg4j> // 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

27.2.1.1 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

27.2.1.1.1 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])
```

27.2.1.1.2 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);
```

27.2.1.2 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

27.2.1.2.1 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.

27.2.1.2.2 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);
```

27.2.2 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 27-3 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 27-3 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

Table 27-3 (Cont.) 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
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

27.2.2.1 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 27-1 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")
```

27.2.2.2 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 27-1 to the format `yyyy-MM-dd H[H]:m[m][:s[s]][XXX]` as shown:

Example 27-2 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 27-3 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.

27.2.2.3 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)
```

27.2.2.4 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    |
+-------------------------------------------------------------------------------
--+
```

27.2.2.5 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.

27.3 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

27.3.1 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
}
```

27.3.2 Chaining Operation

The graph server (PGX) ships a version of Java 8's `CompletableFuture` named `PgxFuture`, an 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.

27.3.3 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.

27.3.4 Handling Concurrent Asynchronus 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);
```

27.4 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.

The following topics describe the different session actions:

- Creating a Session
  You can create a session using the `ServerInstance#createSession` methods.
- Updating Session Idle Timeout
  You can configure the idle timeout value for a session.
- Destroying a Session

27.4.1 Creating a Session

You can create a session using the `ServerInstance#createSession` methods.

- Java
- Python

Java

```
PgxSession createSession(String source)
PgxSession createSession(String source, long idleTimeout, long taskTimeout,
TimeUnit unit)
```

Python

```
session = create_session(source, idle_timeout=None, task_timeout=None,
time_unit='milliseconds')
```

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.

27.4.2 Updating Session Idle Timeout

You can configure the idle timeout value for a session.

The session idle timeout determines how long a session remains active without submitting any tasks to the graph server (PGX). The `idleTimeout` value is set during session creation. If no value is provided, then the server uses the `session_idle_timeout_secs` value specified in the `pgx.conf` configuration file. The default value for the `session_idle_timeout_secs` configuration is zero. This implies that timeout is deactivated and the session can remain active indefinitely as long as the server is running.

You can use the `setSessionIdleTimeout` API to override the session `idleTimeout` value that was set at the time of session creation. When you change the session `idleTimeout` to any positive non-zero value, then the timeout job gets reactivated.

All regular graph users having the `PGX_SESSION_SET_IDLE_TIMEOUT` permission can update the timeout value of the current session using the `PgxSession#setSessionIdleTimeout` API as shown in the following example.

> **Note:**
>
> The `PGX_SESSION_SET_IDLE_TIMEOUT` permission is granted by default to the `GRAPH_DEVELOPER` role. See Basic Steps for Using an Oracle Database for Authentication for more information.

- JShell
- Java
- Python

JShell

```
opg4j> session.setSessionIdleTimeout(10L, TimeUnit.SECONDS)
```

Java

```
session.setSessionIdleTimeout(10L, TimeUnit.SECONDS);
```

Python

```
session.set_session_idle_timeout(10, "seconds")
```

If you are a graph server administrator having the `PGX_SERVER_MANAGE` permission, then you can update the timeout value of other sessions using the `PgxInstance#setSessionIdleTimeout` API as shown.

> **Note:**
>
> The `PGX_SERVER_MANAGE` permission is granted by default to the `GRAPH_ADMINISTRATOR` role. See Basic Steps for Using an Oracle Database for Authentication for more information.

- JShell
- Java
- Python

JShell

```
opg4j> instance.setSessionIdleTimeout("<session_id>", 10L, TimeUnit.SECONDS)
```

Java

```
instance.setSessionIdleTimeout(session_id, 10L, TimeUnit.SECONDS);
```

Python

```
instance.set_session_idle_timeout('session_id', 10, 'seconds')
```

27.4.3 Destroying a Session

To destroy a session, simply call:

- JShell
- Java
- Python

JShell

```
opg4j> session.destroy()
```

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.

27.5 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 Bipartite Subgraph
- Creating a Sparsified Subgraph

27.5.1 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

27.5.1.1 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

27.5.1.1.1 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_ACCOUNTS","loa
ding":{"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@77e2a5d3
```

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","l
oading":{"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);
```

27.5.1.1.2 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@48d464cf

// 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","data
base_table_name":"BANK_EDGES_AMT","loading":
{"create_key_mapping":false},"source_column":"SRC_ID","destination_column":
"DEST_ID","key_type":"long","destination_vertex_provider":"Accounts","props":
[{"type":"float","name":"AMOUNT"}],"key_column":"ID"}

opg4j> alterationBuilder.addEdgeProvider(edgeProviderConfig)
$26 ==>
oracle.pgx.api.graphalteration.internal.GraphAlterationBuilderImpl@7b303608
```

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","destination
_vertex_provider":"Accounts","key_column":"id","format":"rdbms","source_vertex
_provider":
"Accounts","name":"Transfers","database_table_name":"bank_txns","loading":
{"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@441ccfd7
```

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);
```

27.5.1.1.3 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.GraphAlterationEmptyVertexProviderBuil
derImpl@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.GraphAlterationEmptyEdgeProviderBuilde
rImpl@54720caf
```

Java

```
alterationBuilder.addEmptyEdgeProvider("TransactionProvider", "Accounts",
"Accounts")
.setLabel("Transfers")
.createKeyMapping(false)
.addProperty("Description", PropertyType.STRING);
```

27.5.1.1.4 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`.

27.5.1.1.5 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.

27.5.2 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`.

27.5.3 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)`

27.5.4 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.

27.5.5 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

27.5.5.1 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.

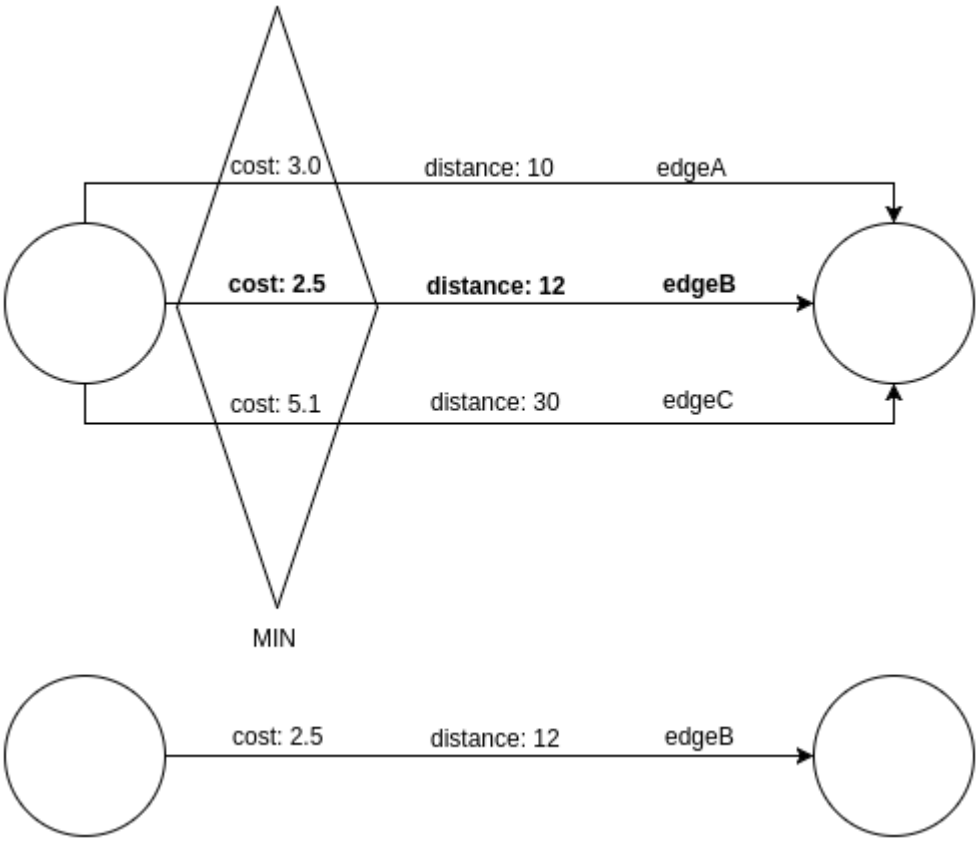
A PickingStrategy can be created using a `PickingStrategyBuilder`, which can be retrieved by calling `createPickingStrategyBuilder()` on the target graph.

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 27-1 Picking Strategy



27.5.5.2 Merging

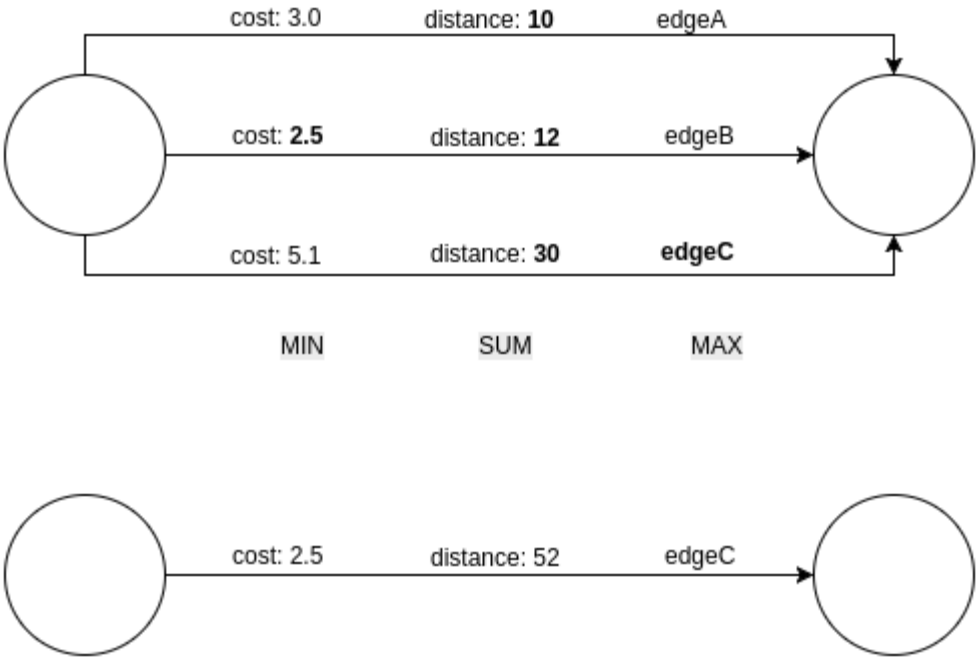
This strategy can be used to merge the properties of multi-edges. The graph server (PGX) allows the user to define a `MergingFunction` for every property. Currently, PGX supports the following functions:

- `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 27-2 Merging Strategy



27.5.5.3 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)
```

27.5.6 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`).

27.5.7 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.

27.6 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

27.6.1 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

27.6.1.1 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

27.6.1.2 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 27-4 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.

27.6.1.3 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()
```

27.6.1.4 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()
```

27.6.1.5 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()
```

27.6.1.6 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_generated',
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()
```

27.6.2 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

27.6.2.1 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()
```

27.6.2.2 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.

27.6.2.3 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.

27.6.2.4 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`.

27.7 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

27.7.1 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.

27.7.2 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.

27.8 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

27.8.1 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.

27.8.2 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
```

27.8.3 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.

27.8.4 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.

27.8.5 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.

27.8.6 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)
```

27.9 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

27.9.1 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 )");
```

27.9.2 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     |
+-----------------------+
```

27.10 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"
```


27.10.1 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 27-5 Default Temporal Formats

Property Type	Constructor
DATE	date ('yyyy-MM-dd HH:mm:ss')
LOCAL_DATE	date 'yyyy-MM-dd'
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
```

27.10.2 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.

27.10.3 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.

27.10.4 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.

27.10.5 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

27.10.5.1 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

```
from pypgx.api.filters import VertexFilter
vertex_filter = VertexFilter.from_expression("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

```
from pypgx.api.filters import EdgeFilter
edge_filter = EdgeFilter.from_expression("edge.cost > 5")
```

27.10.5.2 Defining Result Set Filters

You can define a result set vertex filter, as shown in the following code:

- JShell
- Java
- Python

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);
```

Python

```
>>> from pypgx.api.filters import VertexFilter
# Evaluates query on graph g to obtain a result set
 >>> result_set = g.query_pgql("SELECT x FROM MATCH (x) WHERE x.age > 24")
# Define a filter on the result set for the column "x"
>>> vertex_filter = VertexFilter.from_pgql_result_set(result_set, "x")
# Obtain a vertex set
>>> vertex_set = g.get_vertices(vertex_filter)
```

You can define a result set edge filter, as shown in the following code:

- JShell
- Java
- Python

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);
```

Python

```
>>> from pypgx.api.filters import EdgeFilter
# Evaluates query on graph g to obtain a result set
 >>> result_set = g.query_pgql("SELECT e FROM MATCH ()-[e]->() WHERE e.weight
>= 8")
# Define a filter on the result set for the column "e"
>>> edge_filter = EdgeFilter.from_pgql_result_set(result_set, "e")
# Obtain an edge set
>>> edge_set = g.get_edges(edge_filter)
```

27.10.5.3 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
- Python

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);
```

Python

```
from pypgx.api.filters import VertexFilter
# Evaluates query on graph g to obtain a result set
>>> result_set = g.query_pgql("SELECT x MATCH (x) WHERE x.age > 24")
# Define a filter on the result set for the column "x"
>>> result_set_vertex_filter = VertexFilter.from_pgql_result_set(result_set,
"x")
# Create a subgraph of g containing the matched vertices in the resultSet and
the edges that connect them if any
>>> new_graph = g.filter( result_set_vertex_filter)
```

You can create a subgraph from a result set edge filter, as shown in the following code:

- JShell
- Java
- Python

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);
```

Python

```
from pypgx.api.filters import EdgeFilter
# Evaluates query on graph g to obtain a result set
>>> result_set = g.query_pgql("SELECT e FROM MATCH ()-[e]->() WHERE e.cost <
100")
# Define a filter on the result set for the column "e"
>>> result_set_edge_filter = EdgeFilter.from_pgql_result_set(result_set, "e")
# Create a subgraph of g containing the matched edges in the resultSet and
their corresponding source and destination vertices
>>> new_graph = g.filter( result_set_edge_filter)
```

27.10.5.4 Defining Collection Filters

You can define a vetex collection filter, as shown in the following code:

- JShell
- Java

- Python

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);
```

Python

```
from pypgx.api.filters import VertexFilter
# Obtain a vertex collection from an algorithm, query execution or any other
way
vertex_collection = ...
# Define a filter from the collection
vertex_filter = VertexFilter.from_collection(vertex_collection)
```

You can define a edge collection filter, as shown in the following code:

- JShell
- Java
- Python

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);
```

Python

```
from pypgx.api.filters import EdgeFilter
# Obtain an edge collection from an algorithm, query execution or any other
way
edge_collection = ...
# Define a filter from the collection
edge_filter = EdgeFilter.from_collection(edge_collection)
```

27.10.5.5 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
- Python

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);
```

Python

```
from pypgx.api.filters import VertexFilter
# Obtain a vertex collection from an algorithm, query execution or any other
way
vertex_collection = ...
# Define a filter from the collection
vertex_filter = VertexFilter.from_collection(vertex_collection)
# Create a subgraph of g containing the matched vertices in the vertex
collection and the edges that connect them if any.
new_graph = g.filter(vertex_filter)
```

You can create a subgraph from edge collection filter, as shown in the following code:

- JShell
- Java
- Python

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);
```

Python

```
from pypgx.api.filters import EdgeFilter
# Obtain an edge collection from an algorithm, query execution or any other
way
edge_collection = ...
# Define a filter from the collection
```

```
edge_filter = EdgeFilter.from_collection(edge_collection)
# Create a subgraph of g containing the matched edges in the collection and
their corresponding source and destination vertices.
new_graph = g.filter(edge_filter)
```

27.10.5.6 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 that 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 that 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

```
from pypgx.api.filters import VertexFilter
from pypgx.api.filters import EdgeFilter
edge_filter = EdgeFilter.from_expression("edge.cost > 5")
```

```
vertex_filter = VertexFilter.from_expression("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`'.

27.10.5.7 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)'"))
```

27.11 Advanced Task Scheduling Using Execution Environments

This guide shows how you can use the advanced scheduling features of the enterprise scheduler.

The following topics provide more detailed information on enabling and scheduling tasks using the execution environment:

- Prerequisites for Using the Enterprise Scheduler
- Enabling Enterprise Scheduler Features
- Retrieving and Inspecting the Execution Environment
- Modifying and Submitting Tasks Under an Updated Environment
- Using Lambda Syntax
- Enterprise Scheduler Configuration Guide

27.11.1 Prerequisites for Using the Enterprise Scheduler

- Ensure that you meet the following system prerequisites to use the enterprise scheduler feature of the graph server (PGX):
  - **Operating System:** Linux (x86_64)
  - The following shared libraries are required:
    - The GNU C Library - `libc.so.6 (GLIBC_2.6)`
    - The GNU dynamic linker/loader - `ld-linux-x86-64.so.2 (GLIBC_2.3)`
    - The POSIX Threading Library - `libpthread.so.0 (GLIBC_2.3.2)`
    - The Standard Math Library - `libm.so.6 (GLIBC_2.2.5)`
    - The Realtime Extensions library - `librt.so.1 (GLIBC_2.2.5)`
    - The NUMA policy support library - `libnuma.so.1 (libnuma_1.2)`

    - The GCC low-level runtime library - `libgcc_s.so.1 (GCC_3.4)`
    - The GNU C++ Library - `libstdc++.so.6 (GLIBCXX_3.4.19 and CXXABI_1.3.5)`
- Ensure that you set the `scheduler` parameter in the `pgx.conf` file as shown:
  `"scheduler": "enterprise_scheduler"`

> **Note:**
>
> When using the enterprise scheduler, if the graph server (PGX) fails to start with the following error message in the log file - `The enterprise scheduler backend is not supported on this system`, then note that the server no longer falls back to the basic scheduler.
> If you wish to use the basic scheduler then you must set the scheduler parameter in the `pgx.conf` file as shown:
>
> `"scheduler": "basic_scheduler"`

27.11.2 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).

27.11.3 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());
}
```

27.11.4 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);
```

27.11.5 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)
```

27.11.6 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>`

Field	Type	Description	Default
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 27-4 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 27-5 Using the Enterprise Scheduler Flags

This configuration enables extra logging output from the enterprise scheduler.

```
{
  "enterprise_scheduler_flags": {
    "show_logging": true
  }
}
```

27.12 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

27.12.1 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")
```

27.12.2 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
   ...
}
```

27.12.3 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 27-6 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

Table 27-6 (Cont.) Session Information Options

Field	Description
`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.

27.12.4 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 27-7 Graph Information

Field	Description
`name`	Name of the graph.
`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.

27.12.5 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.

27.12.6 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.

27.12.7 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.

27.12.8 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.

27.13 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 27-8 Mapping between In-Place and Out-Place Operations

In-place operations	Out-place operations
`headInPlace`	`head`
`tailInPlace`	`tail`

Table 27-8 (Cont.) Mapping between In-Place and Out-Place Operations

In-place operations	Out-place operations
`flattenAllInPlace`	`flattenAll`
`renameColumnInPlace`	`renameColumn`
`renameColumnsInPlace`	`renameColumns`
`selectInPlace`	`select`

27.13.1 Converting PgqlResultSet to a PgxFrame

The following example describes how to save the `PgqlResultSet` to a `PgxFrame`.

JShell

```
opg4j> var pg = session.readGraphByName("BANK_GRAPH",GraphSource.PG_PGQL)
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",GraphSource.PG_PGQL);
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','pg_pgql')
>>> 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
```

27.13.2 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. Also, you can store a `PgxFrame` containing CLOB data type columns to 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()            // 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();
```

Python

```
>>> (
...     rs_frame.write().
...     name('F1').       # name of the frame
...     db().             # select the "format" to be relational db
```

```
...     table_name('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()
... )
```

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().
...     name('frame_name').        # name of the frame
...     db().                      # select the "format" to be relational db
...     table_name('table_name').  # 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
...     jdbc_url("<jdbc_url>").
...     username("<db_username>").
...     password("<password>").
...     store()
... )
```

27.13.3 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")
```

27.13.4 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> <firstFrame>.union(<secondFrame>).print()
```

Java

```
<firstFrame>.union(<secondFrame>).print();
```

Python

```
<first_frame>.union(<second_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.

27.13.5 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.

Assume there are two `PgxFrames` as shown:

```
//exampleFrame
+-------------------------------------------------------------------------
--+
| name     | age | salary      | married | tax_rate | random    |
date_of_birth |
+-------------------------------------------------------------------------
--+
| John     | 27  | 4133300.0   | true    | 11.0     | 123456782 |
1985-10-18    |
| Albert   | 23  | 5813000.5   | false   | 12.0     | 124343142 |
2000-01-14    |
| Heather  | 28  | 1.0130302E7 | true    | 10.5     | 827520917 |
1985-10-18    |
| Emily    | 24  | 9380080.5   | false   | 13.0     | 128973221 |
1910-07-30    |
| "D'Juan" | 27  | 1582093.0   | true    | 11.0     | 92384     |
1955-12-01    |
+-------------------------------------------------------------------------
--+

//moreInfoFrame
+--------------------------------------+
| name   | title                       |
+--------------------------------------+
| John   | Software Engineering Manager |
| Albert | Sales Manager               |
| Emily  | Operations Manager          |
+--------------------------------------+
```

The following example calls the `join` method to join `exampleFrame` and `moreInfoFrame`. The API uses the `name` column as `joinKeyColumn` to join the two frames. The column prefixes specified in the API are `leftFrame` and `rightFrame`.

- JShell
- Java
- Python

JShell

```
opg4j> exampleFrame.join(moreInfoFrame, "name", "leftFrame",
"rightFrame").print()
```

Java

```
exampleFrame.join(moreInfoFrame, "name", "leftFrame", "rightFrame").print();
```

Python

```
>>> example_frame.join(
...     more_info_frame,
...     join_key_column="name",
...     left_prefix="leftFrame",
...     right_prefix="rightFrame").print()
```

Alternatively, you can also join the frames by providing `leftjoinKeyColumn` and `rightjoinKeyColumn`. In this case `joinKeyColumn` is omitted.

- JShell
- Java
- Python

JShell

```
opg4j> exampleFrame.join(moreInfoFrame, "name", "name", "leftFrame",
"rightFrame").print()
```

Java

```
exampleFrame.join(moreInfoFrame, "name", "name", "leftFrame",
"rightFrame").print();
```

Python

```
>>> example_frame.join(
...     more_info_frame,
...     left_join_key_column="name",
...     right_join_key_column="name",
...     left_prefix="leftFrame",
...     right_prefix="rightFrame").print()
```

The resulting joined frame contains the columns of the two frames for the rows with the same `name` column as shown:

```
+-------------------------------------------------------------------------
-------------------------------------------------------------------------
----------------------+
| leftFramename | leftFrameage | leftFramesalary | leftFramemarried |
leftFrametax_rate | leftFramerandom | leftFramedate_of_birth | rightFramename
| rightFrametitle              |
+-------------------------------------------------------------------------
```

```
-------------------------------------------------------------------------------
----------------------+
| John          | 27           | 4133300.0       | true             |
11.0              | 123456782       | 1985-10-18             | John
| Software Engineering Manager |
| Albert        | 23           | 5813000.5       | false            |
12.0              | 124343142       | 2000-01-14             | Albert
| Sales Manager                |
| Emily         | 24           | 9380080.5       | false            |
13.0              | 128973221       | 1910-07-30             | Emily
| Operations Manager           |
+-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
----------------------+
```

27.13.6 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    |
+-------------------------------------------------+
```

27.13.7 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()
```

27.13.8 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   |
+-------------------------------------------------------------+
```

27.13.9 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
- Python

JShell

```
opg4j> vecFrame.flattenAll()
```

Java

```
vecFrame.flattenAll();
```

Python

```
vec_frame.flatten_all()
```

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         |
+-------------------------------------------------------------------------------
----------------------+
```

27.13.10 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
- Python

JShell

```
opg4j> vecFrame.head(2).print()
```

Java

```
vecFrame.head(2).print();
```

Python

```
vec_frame.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
- Python

JShell

```
opg4j> vecFrame.tail(2).print()
```

Java

```
vecFrame.tail(2).print();
```

Python

```
vec_frame.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
- Python

JShell

```
opg4j> var vecFrameRenamed = vecFrame.renameColumns(
  renaming("vectProp2", "vectProp2_renamed"),
  renaming("vectProp", "vectProp_renamed"),
  renaming("stringProp", "stringProp_renamed")
)
```

Java

```
PgxFrame vecFrameRenamed = vecFrame.renameColumns(renaming("vectProp2",
"vectProp2_renamed"),
                                                  renaming("vectProp",
"vectProp_renamed"),
                                                  renaming("stringProp",
"stringProp_renamed"));
```

Python

```
vec_frame_renamed = vec_frame.rename_columns({"vectProp2":
"vectProp2_renamed", "vectProp": "vectProp_renamed", "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           |
+-------------------------------------------------------------------------
---+
```

27.13.11 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    |
+-------------------------------------------------+
```

27.13.12 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")
```

27.13.13 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. Also, you can load a `PgxFrame` from a database table containing CLOB data type columns.
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

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.*

opg4j> var session = Pgx.createSession("my-session")
opg4j> var analyst = session.createAnalyst()
```

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")      // 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();
```

Python

```
>>> example_frame = (
...     session.read_frame().
...     name('Transfers').    # name of the frame
...     db().
...     table_name('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()
...     )
```

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>".toCharArray())
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
...>       jdbcUrl("<jdbcUrl>").
...>       username("<username>").
...>       keystoreAlias("<keystoreAlias>").
...>       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>".toCharArray())
PgxFrame exampleFrame = session.readFrame()
    .db()
    .name("Transfers") // name of the frame
    .tablename("T1")   // name of the table from where the data must be
loaded
    .jdbcUrl("<jdbcUrl>")
    .username("<username>")
    .keystoreAlias("<keystoreAlias>")
    .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

```
>>> session.register_keystore("<pathToKeystore>", "<keystorePassword>")
>>> example_frame = (
...     session.read_frame().
...     name('Transfers').   # name of the frame
...     db().
...     table_name('T1').    # name of the table from where the data must
be loaded
...     jdbc_url('<jdbc_url>').
...     username('<username>').
...     keystore_alias('<keystore_alias>').
```

```
...     connections(16).     # indicates that 16 connections can be used
to load in parallel
...     columns(
...       [
...         ('FROM_ACCT_ID', 'INTEGER_TYPE'),
...         ('TO_ACCT_ID', 'INTEGER_TYPE')
...       ]
...     ).  # columns to load
...     load()
...     )
```

You can also create a graph from the `PgxFrame`(s). See Creating a Graph from Multiple PgxFrame Objects for more information.

27.13.14 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')
```

27.13.15 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.

27.13.16 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).label("people")
opg4j> graphFromFramesCreator.vertexProvider("houses",
houses).vertexKeyColumn("identification")
opg4j> graphFromFramesCreator.edgeProvider("knows", "people", "people",
knows).edgeKeyColumn("identifier")
opg4j> var edge_provider = graphFromFramesCreator.edgeProvider("lives",
"people", "houses", lives)
```

```
opg4j> edge_provider.edgeKeyColumn("id")
opg4j> edge_provider.sourceVertexKeyColumn("source")
opg4j> edge_provider.destinationVertexKeyColumn("destination")
opg4j> edge_provider.label("lives")
opg4j> graphFromFramesCreator.partitioned(true)
opg4j> graphFromFramesCreator.vertexIdStrategy(IdStrategy.PARTITIONED_IDS)
opg4j> graphFromFramesCreator.vertexIdStrategy(IdStrategy.KEYS_AS_IDS)
opg4j> var graph = graphFromFramesCreator.create()
```

Java

```
PgxGraphFromFramesCreator graphFromFramesCreator =
session.createGraphFromFrames("example graph");
graphFromFramesCreator.vertexProvider("people", people).label("people");
graphFromFramesCreator.vertexProvider("houses",
houses).vertexKeyColumn("identification");
graphFromFramesCreator.edgeProvider("knows", "people", "people",
knows).edgeKeyColumn("identifier");
PgxEdgeProviderFromFramesCreator edgeProvider =
graphFromFramesCreator.edgeProvider("lives", "people", "houses", lives);
edgeProvider.edgeKeyColumn("id");
edgeProvider.sourceVertexKeyColumn("source");
edgeProvider.destinationVertexKeyColumn("destination");
edgeProvider.label("lives");
graphFromFramesCreator.partitioned(true);
graphFromFramesCreator.vertexIdStrategy(IdStrategy.PARTITIONED_IDS);
graphFromFramesCreator.edgeIdStrategy(IdStrategy.KEYS_AS_IDS);
PgxGraph graph = graphFromFramesCreator.create();
```

Python

```
vertex_providers_from_frames = [
    session.vertex_provider_from_frame("person",
                                       people,
                                       vertex_key_column="id",
                                       label="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,
                                     source_vertex_column="src",
                                     destination_vertex_column="dst",
                                     edge_key_column="identifier"),
    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",
```

```
                                    edge_key_column="id",
                                    label="lives")
]
graph = session.graph_from_frames("example graph",
          vertex_providers_from_frames,
          edge_providers_from_frames,
          partitioned=True,
          vertex_id_strategy="partitioned_ids",
          edge_id_strategy="keys_as_ids"
)
```

28

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>;
```


28.1 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

28.1.1 Graph Configuration for Loading from File

For graphs in the CSV format, the columns used to specify the key column, source column, destination column (for partitioned graphs) need to be either all specified, or none. If none are specified, the graph server (PGX) assumes the key column is the first (for vertex files) or missing (for edge files), followed by source and destination column (for edge files), and then by the property columns according to their order in the graph configuration.

Partitioned Graphs

In order to load a partitioned graph from supported files, you must set the following additional graph configuration fields.

Table 28-1 Loading a Partitioned Graph From File - Additional Graph Configuration Options

Field	Type	Description	Default
`format`	`enum[pgb, csv, rdbms, es]`	Provider format.	*required*
`name`	`string`	Entity provider name.	*required*
`attributes`	`object`	Additional attributes needed to read/write the graph data.	`null`
`destination_vertex_provider`	`string`	Name of the destination vertex provider to be used for this edge provider.	`null`
`detect_gzip`	`boolean`	Enable or disable automatic gzip compression detection when loading graphs.	`true`
`error_handling`	`object`	Error handling configuration.	`null`
`has_keys`	`boolean`	Indicates if the provided entities data have keys.	`true`
`header`	`boolean`	First line of file is meant for headers, such as `EdgeId`, `SourceId`, `DestId`, `EdgeProp1`, and `EdgeProp2`	`false`
`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`	Specifies the properties associated with this entity provider.	`[]`

Table 28-1 (Cont.) Loading a Partitioned Graph From File - Additional Graph Configuration Options

Field	Type	Description	Default
`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`
`source_vertex_provider`	`string`	Name of the source vertex provider to be used for this edge provider.	`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 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.	`[]`
`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.	`[]`
`uris`	`array of string`	List of unified resource identifiers.	`[]`
`vector_component_delimiter`	`character`	Delimiter for the different components of vector properties.	`;`

The key column, source column, destination column can be configured with the following CSV specific fields:

Table 28-2 CSV Specific Options for Partitioned Graphs

Field	Type	Description	Default
`format`	`enum[pgb, csv, rdbms, es]`	Provider format.	*required*
`name`	`string`	Entity provider name.	*required*
`attributes`	`object`	Additional attributes needed to read/write the graph data.	`null`
`destination_column`	`value`	Name or index (starting from 1) of column corresponding to edge destination (for CSV format only).	`null`

Table 28-2 (Cont.) CSV Specific Options for Partitioned Graphs

Field	Type	Description	Default
destination_vertex_provider	string	Name of the destination vertex provider to be used for this edge provider.	null
detect_gzip	boolean	Enable or disable automatic gzip compression detection when loading graphs.	true
error_handling	object	Error handling configuration.	null
has_keys	boolean	Indicates if the provided entities data have keys.	true
header	boolean	First line of file is meant for headers, such as EdgeId, SourceId, DestId, EdgeProp1, EdgeProp2.	false
key_column	value	Name or index (starting from 1) of column corresponding to keys (for CSV format only)	null
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	Specifies the properties associated with this entity provider.	[]

Table 28-2 (Cont.) CSV Specific Options for Partitioned Graphs

Field	Type	Description	Default
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
source_column	value	Name or index (starting from 1) of column corresponding to edge source (for CSV format only).	null
source_vertex_provider	string	Name of the source vertex provider to be used for this edge provider.	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 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.	[]
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.	;

28.1.2 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"]}
```

28.1.3 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:`)
- 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.

28.1.4 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)

Note that loading graphs from files encoded in UTF-8, without *Byte Order Mark* (BOM), is only supported. Therefore, to successfully load graph from files, ensure text-based provider files are UTF-8 encoded without a BOM.

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)

28.1.4.1 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 28-1 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 28-2 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"
        }
    ]
}
```

28.1.4.2 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 28-3 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.

28.1.4.3 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 28-4 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":" "
}
```

28.1.4.4 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 28-5 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.

28.1.5 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 28-6

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.

28.1.6 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 28-3 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 28-4 File Layout

Size in bytes	Description	Required	Comment
4	magic word	Yes	0x99191191
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 28-3 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 28-3 for type encoding

Table 28-4 (Cont.) File Layout

Size in bytes	Description	Required	Comment
`<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 28-10.
`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 28-19.

Vertex Key Layout

The layout of vertex keys depends on the vertexKey type. PGB supports `integer`, `long` and `string` vertex keys.

Table 28-5 Integer Vertex Keys

Size in bytes	Description	Required	Comment
`<numVertices> * 4`	key data	Yes	For each vertex, the corresponding integer key value.

Table 28-6 Long Vertex Keys

Size in bytes	Description	Required	Comment
`<numVertices> * 8`	key data	Yes	For each vertex, the corresponding long key value.

Table 28-7 String Vertex Keys

Size in bytes	Description	Required	Comment
`4`	compression scheme	Yes	reserved (must be `0`)

Table 28-7 (Cont.) String Vertex Keys

Size in bytes	Description	Required	Comment
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 28-5)

Table 28-8 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 28-9 Primitive Type Layout

Size in bytes	Description	Required	Comment
4	property type	Yes	See Table 28-3 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 28-10 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 28-3.
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 28-11 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 28-12 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 28-13.

Table 28-13 String Dictionary Element Layout

Size in bytes	Description	Required	Comment
8	string id	Yes	Unique ID of the string.
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 28-14 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 28-15 Shared Pools Layout

Size in bytes	Description	Required	Comment
1	type	Yes	1: enum, 2: prefixed

Table 28-16 Type == Enum

Size in bytes	Description	Required	Comment
8	num strings	Yes	
<number of strings> * <string table layout>	dictionary data	Yes	See Table 28-18.

Table 28-17 Type == Prefix

Size in bytes	Description	Required	Comment
8	num prefixes	Yes	
<number of prefixes> * <string table layout>	dictionary data	Yes	See Table 28-18.
8	num suffixes	Yes	
<number of suffixes> * <string table layout>	dictionary data	Yes	See Table 28-18.

Table 28-18 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 28-19 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 28-8.
<sum of size of edge property names>	edge property names	No	Follows the String Key Element Layout. See Table 28-8.

28.2 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.

28.3 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 28-20 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 28-21 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`
`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

28.3.1 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))
```

28.4 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 28-21 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 28-21) 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 28-21 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.

29

Log Management in the Graph Server (PGX)

The graph server (PGX) internally uses the SLF4J interface with Logback as the default logger implementation.

29.1 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-webapp-<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-webapp-<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.

- 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

Mapping Graph Server Roles to Default Privileges

The following table describes the graph server (PGX) roles and the default privileges that are created in Basic Steps for Using an Oracle Database for Authentication:

Table A-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

B

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 (such as 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. Optionally, if you are using Graph Server REST API Version 1 (cookie-based authentication), then perform the following by editing the `WEB-INF/web.xml` file inside the `/opt/oracle/graph/pgx/server/graph-server-webapp-24.4.0.war` file:
   a. Replace `` `https` `` with `` `http` `` for the `` `pgx.base_url` `` property. For example:

   ```
   <context-param>
       <param-name>pgx.base_url</param-name>
       <param-value>http://localhost:7007</param-value>
   </context-param>
   ```

   b. Configure the 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. 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/pgx/server -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
```

C

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 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`

D

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.

In order to comply with this feature you must perform the database actions explained in the following sections:

Creating additional roles in the database

- See Basic Steps for Using an Oracle Database for Authentication for more information on manually creating the roles in the database with the default set of privileges.
- Mapping Graph Server Roles to Default Privileges in the appendix for more details on the default mappings.

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 D-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 D-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_graph_data",
  "location": "/opt/oracle/graph/data"
}],
"authorization": [{
  "pgx_role": "GRAPH_DEVELOPER",
  "pgx_permissions": [{
    "file_location": "my_graph_data",
    "grant": "read"
  },
...
```

You must execute the following `GRANT` statement in the database used by 21.x:

```
CREATE OR REPLACE DIRECTORY my_graph_data AS '/opt/oracle/graph/data'
GRANT READ ON DIRECTORY my_graph_data TO GRAPH_DEVELOPER
```

Example D-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.

E

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.

Eclipse Parsson

Vendor: Eclipse Foundation

Version: 1.1.5

```
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```

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* https://github.com/eclipse-ee4j/parsson

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--------------------------------------------
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Titanium JSON-LD

Vendor: The original authors or authors

Version: 1.3.2

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jackson-core

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jackson-databind

Vendor: FasterXML, LLC

Version: 2.14.2

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# Jackson JSON processor

Jackson is a high-performance, Free/Open Source JSON processing library.
It was originally written by Tatu Saloranta (tatu.saloranta@iki.fi), and has
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It is currently developed by a community of developers.

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Vendor: The Apache Software Foundation

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JavaScript Extension Toolkit (JET)

Vendor: Oracle

Version: 16.1.6

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