Oracle9*i*

Data Warehousing Guide

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Oracle9*i* Data Warehousing Guide, Release 1 (9.0.1)

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Oracle9*i* Data Warehousing Guide, Release 9.0.1

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Preface

This manual provides information about Oracle9*i*'s data warehousing capabilities.

This preface contains these topics:

Audience

Oracle9*i* Data Warehousing Guide is intended for database administrators, system administrators, and database application developers who perform the following tasks:

- design, maintain, and use data warehouses.

To use this document, you need to be familiar with relational database concepts, basic Oracle server concepts, and the operating system environment under which you are running Oracle.

Organization

This document contains:

Chapter 1, Data Warehousing Concepts

This chapter contains an overview of data warehousing concepts.

Chapter 2, Logical Design in Data Warehouses

This chapter discusses the logical design of a data warehouse.

Chapter 3, Physical Design in Data Warehouses

This chapter discusses the physical design of a data warehouse.

Chapter 4, Hardware and I/O Considerations in Data Warehouses

This chapter describes some hardware and input-output issues.

Chapter 5, Parallelism and Partitioning in Data Warehouses

This chapter describes the basics of parallelism and partitioning in data warehouses.

Chapter 6, Indexes

This chapter describes how to use indexes in data warehouses.

Chapter 7, Integrity Constraints

This chapter describes some issues involving constraints.

Chapter 8, Materialized Views

This chapter describes how to use materialized views in data warehouses.

Chapter 9, Dimensions

This chapter describes how to use dimensions in data warehouses.

Chapter 10, Overview of Extraction, Transformation, and Loading

This chapter is an overview of the ETL process.

Chapter 11, Extraction in Data Warehouses

This chapter describes extraction issues.

Chapter 12, Transportation in Data Warehouses

This chapter describes transporting data in data warehouses.

Chapter 13, Loading and Transformation

This chapter describes transforming data in data warehouses.

Chapter 14, Maintaining the Data Warehouse

This chapter describes how to refresh in a data warehousing environment.

Chapter 16, Summary Advisor

This chapter describes how to use the Summary Advisor utility.

Chapter 17, Schema Modeling Techniques

This chapter describes the schemas useful in data warehousing environments.

Chapter 18, SQL for Aggregation in Data Warehouses

This chapter explains how to use SQL aggregation in data warehouses.

Chapter 19, SQL for Analysis in Data Warehouses

This chapter explains how to use analytic functions in data warehouses.

Chapter 20, Advanced Analytic Services

This chapter describes using analytic services in combination with Oracle9*i*.

Chapter 21, Using Parallel Execution

This chapter describes how to tune data warehouses using parallel execution.

Chapter 22, Query Rewrite

This chapter describes how to use Query Rewrite.

Appendix A, "Glossary"

This chapter defines commonly used data warehousing terms.

Appendix B, "Sample Data Warehousing Schema"

This chapter details the schema used throughout much of the book.

Related Documentation

For more information, see these Oracle resources:

- *Oracle9i Database Performance Guide and Reference*

Many of the examples in this book use the sample schemas of the seed database, which is installed by default when you install Oracle. Refer to *Oracle9i Sample Schemas* for information on how these schemas were created and how you can use them yourself.

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`http://technet.oracle.com/membership/index.htm`

If you already have a username and password for OTN, then you can go directly to the documentation section of the OTN Web site at

`http://technet.oracle.com/docs/index.htm`

For additional information, see:

- *The Data Warehouse Toolkit* by Ralph Kimball (John Wiley and Sons, 1996)
- *Building the Data Warehouse* by William Inmon (John Wiley and Sons, 1996)

Conventions

This section describes the conventions used in the text and code examples of the this documentation set. It describes:

- Conventions in Text
- Conventions in Code Examples

Conventions in Text

We use various conventions in text to help you more quickly identify special terms. The following table describes those conventions and provides examples of their use.

Convention	Meaning	Example
Bold	Bold typeface indicates terms that are defined in the text or terms that appear in a glossary, or both.	When you specify this clause, you create an **index-organized table**.
Italics	Italic typeface indicates book titles or emphasis.	*Oracle9i Database Concepts* Ensure that the recovery catalog and target database do *not* reside on the same disk.
`UPPERCASE monospace (fixed-width font)`	Uppercase monospace typeface indicates elements supplied by the system. Such elements include parameters, privileges, datatypes, RMAN keywords, SQL keywords, SQL*Plus or utility commands, packages and methods, as well as system-supplied column names, database objects and structures, usernames, and roles.	You can specify this clause only for a `NUMBER` column. You can back up the database by using the `BACKUP` command. Query the `TABLE_NAME` column in the `USER_TABLES` data dictionary view. Use the `DBMS_STATS.GENERATE_STATS` procedure.

Convention	Meaning	Example
`lowercase monospace (fixed-width font)`	Lowercase monospace typeface indicates executables, filenames, directory names, and sample user-supplied elements. Such elements include computer and database names, net service names, and connect identifiers, as well as user-supplied database objects and structures, column names, packages and classes, usernames and roles, program units, and parameter values. **Note:** Some programmatic elements use a mixture of UPPERCASE and lowercase. Enter these elements as shown.	Enter `sqlplus` to open SQL*Plus. The password is specified in the `orapwd` file. Back up the datafiles and control files in the `/disk1/oracle/dbs` directory. The `department_id`, `department_name`, and `location_id` columns are in the `hr.departments` table. Set the `QUERY_REWRITE_ENABLED` initialization parameter to `true.` Connect as `oe` user. The `JRepUtil` class implements these methods.
`lowercase monospace (fixed-width font) italic`	Lowercase monospace italic font represents placeholders or variables.	You can specify the *`parallel_clause`*. Run `U`*`old_release`*`.SQL` where *`old_release`* refers to the release you installed prior to upgrading.

Conventions in Code Examples

Code examples illustrate SQL, PL/SQL, SQL*Plus, or other command-line statements. They are displayed in a monospace (fixed-width) font and separated from normal text as shown in this example:

```
SELECT username FROM dba_users WHERE username = 'MIGRATE';
```

The following table describes typographic conventions used in code examples and provides examples of their use.

Convention	Meaning	Example
[ ]	Brackets enclose one or more optional items. Do not enter the brackets.	`DECIMAL (`*`digits`*` [ , `*`precision`*` ])`
{ }	Braces enclose two or more items, one of which is required. Do not enter the braces.	`{ENABLE | DISABLE}`

|	A vertical bar represents a choice of two or more options within brackets or braces. Enter one of the options. Do not enter the vertical bar.	`{ENABLE | DISABLE}`
		
		`[COMPRESS | NOCOMPRESS]`

Convention	Meaning	Example
`...`	Horizontal ellipsis points indicate either:	
	■ That we have omitted parts of the code that are not directly related to the example	`CREATE TABLE ... AS` *`subquery`*`;`
	■ That you can repeat a portion of the code	`SELECT` *`col1`*`,` *`col2`*`, ... ,` *`coln`* `FROM employees;`
. . .	Vertical ellipsis points indicate that we have omitted several lines of code not directly related to the example.	

Other notation	You must enter symbols other than brackets, braces, vertical bars, and ellipsis points as shown.	`acctbal NUMBER(11,2);`
		`acct    CONSTANT NUMBER(4) := 3;`

`Italics`	Italicized text indicates placeholders or variables for which you must supply particular values.	`CONNECT SYSTEM/`*`system_password`*
		`DB_NAME =` *`database_name`*

`UPPERCASE`	Uppercase typeface indicates elements supplied by the system. We show these terms in uppercase in order to distinguish them from terms you define. Unless terms appear in brackets, enter them in the order and with the spelling shown. However, because these terms are not case sensitive, you can enter them in lowercase.	`SELECT last_name, employee_id FROM employees;`
		`SELECT * FROM USER_TABLES;`
		`DROP TABLE hr.employees;`

`lowercase`	Lowercase typeface indicates programmatic elements that you supply. For example, lowercase indicates names of tables, columns, or files.
	Note: Some programmatic elements use a mixture of UPPERCASE and lowercase. Enter these elements as shown.
		`SELECT last_name, employee_id FROM employees;`
		`sqlplus hr/hr`
		`CREATE USER mjones IDENTIFIED BY ty3MU9;`

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JAWS, a Windows screen reader, may not always correctly read the code examples in this document. The conventions for writing code require that closing braces should appear on an otherwise empty line; however, JAWS may not always read a line of text that consists solely of a bracket or brace.

Part I
Concepts

This section introduces basic data warehousing concepts.

It contains the following chapter:

1
Data Warehousing Concepts

This chapter provides an overview of the Oracle data warehousing implementation. It includes:

- What is a Data Warehouse?
- Data Warehouse Architectures

Note that this book is meant as a supplement to standard texts about data warehousing. This book focuses on Oracle-specific material and does not reproduce in detail material of a general nature. Two standard texts are:

- *The Data Warehouse Toolkit* by Ralph Kimball (John Wiley and Sons, 1996)
- *Building the Data Warehouse* by William Inmon (John Wiley and Sons, 1996)

What is a Data Warehouse?

A data warehouse is a relational database that is designed for query and analysis rather than for transaction processing. It usually contains historical data derived from transaction data, but it can include data from other sources. It separates analysis workload from transaction workload and enables an organization to consolidate data from several sources.

In addition to a relational database, a data warehouse environment includes an extraction, transportation, transformation, and loading (ETL) solution, an online analytical processing (OLAP) engine, client analysis tools, and other applications that manage the process of gathering data and delivering it to business users.

See Also: Chapter 10, "Overview of Extraction, Transformation, and Loading"

A common way of introducing data warehousing is to refer to the characteristics of a data warehouse as set forth by William Inmon:

- Subject Oriented
- Integrated
- Nonvolatile
- Time Variant

Subject Oriented

Data warehouses are designed to help you analyze data. For example, to learn more about your company's sales data, you can build a warehouse that concentrates on sales. Using this warehouse, you can answer questions like "Who was our best customer for this item last year?" This ability to define a data warehouse by subject matter, sales in this case, makes the data warehouse **subject oriented**.

Integrated

Integration is closely related to subject orientation. Data warehouses must put data from disparate sources into a consistent format. They must resolve such problems as naming conflicts and inconsistencies among units of measure. When they achieve this, they are said to be **integrated**.

Nonvolatile

Nonvolatile means that, once entered into the warehouse, data should not change. This is logical because the purpose of a warehouse is to enable you to analyze what has occurred.

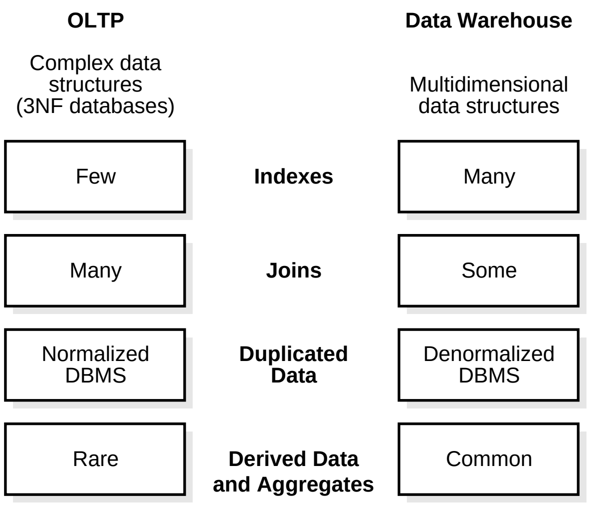
Time Variant

In order to discover trends in business, analysts need large amounts of data. This is very much in contrast to online transaction processing (OLTP) systems, where performance requirements demand that historical data be moved to an archive. A data warehouse's focus on change over time is what is meant by the term **time variant**.

Contrasting OLTP and Data Warehousing Environments

Figure 1–1 illustrates key differences between an OLTP system and a data warehouse.

Figure 1–1 Contrasting OLTP and Data Warehousing Environments



OLTP		Data Warehouse
Complex data structures (3NF databases)		Multidimensional data structures
Few	**Indexes**	Many
Many	**Joins**	Some
Normalized DBMS	**Duplicated Data**	Denormalized DBMS
Rare	**Derived Data and Aggregates**	Common

One major difference between the types of system is that data warehouses are not usually in third normal form (3NF), a type of data normalization common in OLTP environments.

Data warehouses and OLTP systems have very different requirements. Here are some examples of differences between typical data warehouses and OLTP systems:

- Workload

  Data warehouses are designed to accommodate *ad hoc* queries. You might not know the workload of your data warehouse in advance, so a data warehouse should be optimized to perform well for a wide variety of possible query operations.

  OLTP systems support only predefined operations. Your applications might be specifically tuned or designed to support only these operations.

- Data Modifications

  A data warehouse is updated on a regular basis by the ETL process (run nightly or weekly) using bulk data modification techniques. The end users of a data warehouse do not directly update the data warehouse.

  In OLTP systems, end users routinely issue individual data modification statements to the database. The OLTP database is always up to date, and reflects the current state of each business transaction.

- Schema Design

  Data warehouses often use denormalized or partially denormalized schemas (such as a star schema) to optimize query performance.

  OLTP systems often use fully normalized schemas to optimize update/insert/delete performance, and to guarantee data consistency.

- Typical Operations

  A typical data warehouse query scans thousands or millions of rows. For example, "Find the total sales for all customers last month."

  A typical OLTP operation accesses only a handful of records. For example, "Retrieve the current order for this customer."

- Historical Data

  Data warehouses usually store many months or years of data. This is to support historical analysis.

  OLTP systems usually store data from only a few weeks or months. The OLTP system stores only historical data as needed to successfully meet the requirements of the current transaction.

Data Warehouse Architectures

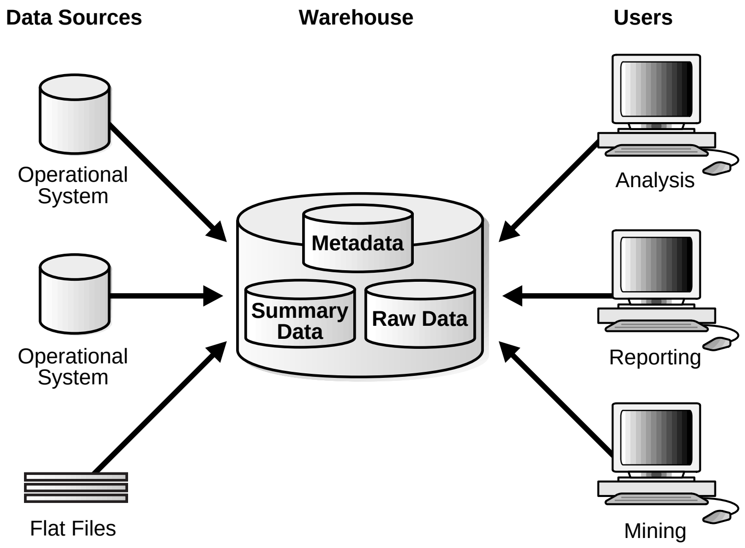
Data warehouses and their architectures vary depending upon the specifics of an organization's situation. Three common architectures are:

- Data Warehouse Architecture (Basic)
- Data Warehouse Architecture (with a Staging Area)
- Data Warehouse Architecture (with a Staging Area and Data Marts)

Data Warehouse Architecture (Basic)

Figure 1–2 shows a simple architecture for a data warehouse. End users directly access data derived from several source systems through the data warehouse.

Figure 1–2 Architecture of a Data Warehouse

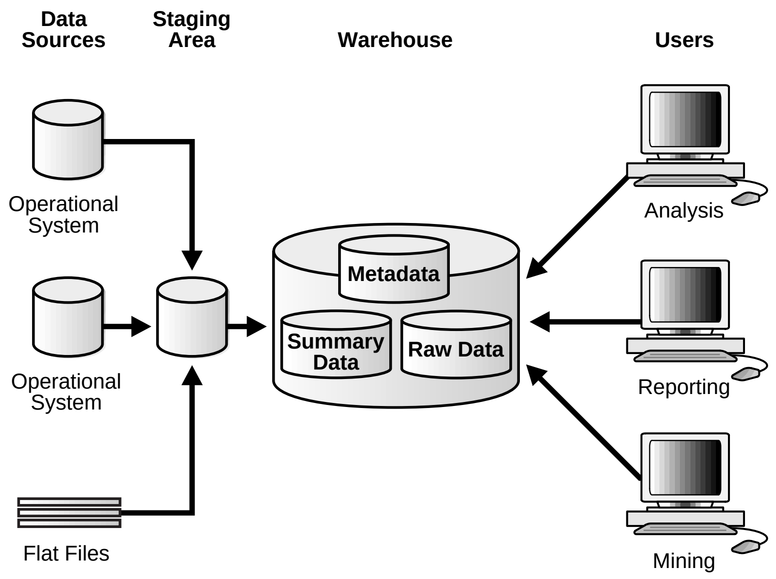


In Figure 1–2, the metadata and raw data of a traditional OLTP system is present, as is an additional type of data, summary data. Summaries are very valuable in data warehouses because they pre-compute long operations in advance. For example, a typical data warehouse query is to retrieve something like August sales. Summaries in Oracle are called **materialized views**.

Data Warehouse Architecture (with a Staging Area)

In Figure 1–2, you need to clean and process your operational data before putting it into the warehouse. You can do this programmatically, although most data warehouses use a **staging area** instead. A staging area simplifies building summaries and general warehouse management. Figure 1–3 illustrates this typical architecture.

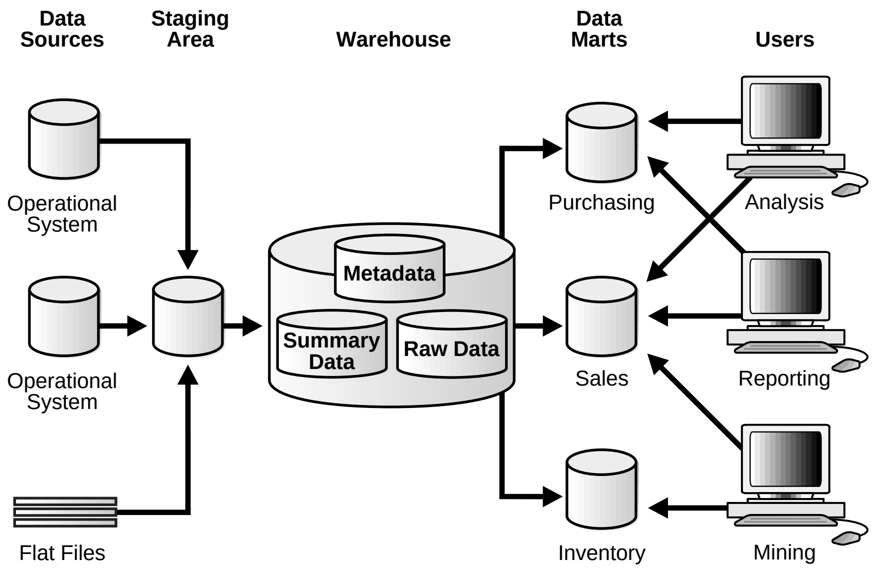
Figure 1–3 Architecture of a Data Warehouse with a Staging Area



Data Warehouse Architecture (with a Staging Area and Data Marts)

Although the architecture in Figure 1–3 is quite common, you may want to customize your warehouse's architecture for different groups within your organization. You can do this by adding **data marts**, which are systems designed for a particular line of business. Figure 1–4 illustrates an example where purchasing, sales, and inventories are separated. In this example, a financial analyst might want to analyze historical data for purchases and sales.

Figure 1–4 Architecture of a Data Warehouse with a Staging Area and Data Marts



Note: Data marts are an important part of many warehouses, but they are not the focus of this book.

See Also: *Data Mart Suites* documentation for further information regarding data marts

Part II

Logical Design

This section deals with the issues in logical design in a data warehouse.

It contains the following chapter:

2 Logical Design in Data Warehouses

This chapter tells you how to design a data warehousing environment and includes the following topics:

Logical versus Physical Design in Data Warehouses

Your organization has decided to build a data warehouse. You have defined the business requirements and agreed upon the scope of your application, and created a conceptual design. Now you need to translate your requirements into a system deliverable. To do so, you create the logical and physical design for the data warehouse. You then define:

- The specific data content
- Relationships within and between groups of data
- The system environment supporting your data warehouse
- The data transformations required
- The frequency with which data is refreshed

The logical design is more conceptual and abstract than the physical design. In the **logical design**, you look at the logical relationships among the objects. In the **physical design**, you look at the most effective way of storing and retrieving the objects as well as handling them from a transportation and backup/recovery perspective.

Orient your design toward the needs of the end users. End users typically want to perform analysis and look at aggregated data, rather than at individual transactions. However, end users might not know what they need until they see it. In addition, a well-planned design allows for growth and changes as the needs of users change and evolve.

By beginning with the logical design, you focus on the information requirements and save the implementation details for later.

Creating a Logical Design

A logical design is conceptual and abstract. You do not deal with the physical implementation details yet. You deal only with defining the types of information that you need.

One technique you can use to model your organization's logical information requirements is entity-relationship modeling. Entity-relationship modeling involves identifying the things of importance (entities), the properties of these things (attributes), and how they are related to one another (relationships).

The process of logical design involves arranging data into a series of logical relationships called entities and attributes. An **entity** represents a chunk of information. In relational databases, an entity often maps to a table. An **attribute** is a component of an entity that helps define the uniqueness of the entity. In relational databases, an attribute maps to a column.

To be sure that your data is consistent, you need to use **unique identifiers**. A unique identifier is something you add to tables so that you can differentiate between the same item when it appears in different places. In a physical design, this is usually a primary key.

While entity-relationship diagramming has traditionally been associated with highly normalized models such as OLTP applications, the technique is still useful for data warehouse design in the form of **dimensional modeling**. In dimensional modeling, instead of seeking to discover atomic units of information (such as entities and attributes) and all of the relationships between them, you identify which information belongs to a central fact table and which information belongs to its associated dimension tables. You identify business subjects or fields of data, define relationships between business subjects, and name the attributes for each subject.

See Also: Chapter 9, "Dimensions" for further information regarding dimensions

Your logical design should result in (1) a set of entities and attributes corresponding to fact tables and dimension tables and (2) a model of operational data from your source into subject-oriented information in your target data warehouse schema.

You can create the logical design using a pen and paper, or you can use a design tool such as Oracle Warehouse Builder (specifically designed to support modeling the ETL process) or Oracle Designer (a general purpose modeling tool).

See Also: *Oracle Designer* and *Oracle Warehouse Builder* documentation sets

Data Warehousing Schemas

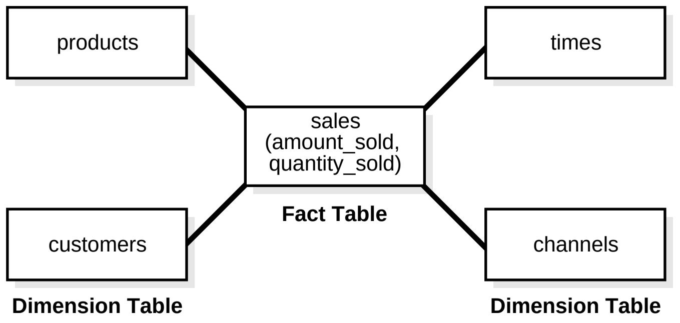
A schema is a collection of database objects, including tables, views, indexes, and synonyms. You can arrange schema objects in the schema models designed for data warehousing in a variety of ways. Most data warehouses use a dimensional model.

The model of your source data and the requirements of your users help you design the data warehouse schema. You can sometimes get the source model from your company's enterprise data model and reverse-engineer the logical data model for the data warehouse from this. The physical implementation of the logical data warehouse model may require some changes to adapt it to your system parameters—size of machine, number of users, storage capacity, type of network, and software.

Star Schemas

The **star schema** is the simplest data warehouse schema. It is called a star schema because the diagram resembles a star, with points radiating from a center. The center of the star consists of one or more fact tables and the points of the star are the dimension tables, as shown in Figure 2–1.

Figure 2–1 Star Schema



The most natural way to model a data warehouse is as a star schema, only one join establishes the relationship between the fact table and any one of the dimension tables.

A star schema optimizes performance by keeping queries simple and providing fast response time. All the information about each level is stored in one row.

Note: The Oracle Corporation recommends that you choose a star schema unless you have a clear reason not to.

Other Schemas

Some schemas in data warehousing environments use third normal form rather than star schemas. Another schema that is sometimes useful is the snowflake schema, which is a star schema with normalized dimensions in a tree structure.

See Also: Chapter 17, "Schema Modeling Techniques", for further information regarding star and snowflake schemas in data warehouses and *Oracle9i Database Concepts* for further conceptual material

Data Warehousing Objects

The following types of objects are commonly used in dimensional data warehouse schemas:

Fact tables are the large tables in your warehouse schema that store business measurements. Fact tables typically contain facts and foreign keys to the dimension tables. Fact tables represent data, usually numeric and additive, that can be analyzed and examined. Examples include `sales`, `cost`, and `profit`.

Dimension tables, also known as lookup or reference tables, contain the relatively static data in the warehouse. Dimension tables store the information you normally use to contain queries. Dimension tables are usually textual and descriptive and you can use them as the row headers of the result set. Examples are `customers` or `products`.

Fact Tables

A fact table typically has two types of columns: those that contain numeric facts (often called measurements), and those that are foreign keys to dimension tables. A fact table contains either detail-level facts or facts that have been aggregated. Fact tables that contain aggregated facts are often called **summary tables**. A fact table usually contains facts with the same level of aggregation. Though most facts are additive, they can also be semi-additive or non-additive. Additive facts can be aggregated by simple arithmetical addition. A common example of this is sales. Non-additive facts cannot be added at all. An example of this is averages. Semi-additive facts can be aggregated along some of the dimensions and not along others. An example of this is inventory levels, where you cannot tell what a level means simply by looking at it.

Creating a New Fact Table

You must define a fact table for each star schema. From a modeling standpoint, the primary key of the fact table is usually a composite key that is made up of all of its foreign keys.

Dimension Tables

A dimension is a structure, often composed of one or more hierarchies, that categorizes data. Dimensional attributes help to describe the dimensional value. They are normally descriptive, textual values. Several distinct dimensions, combined with facts, enable you to answer business questions. Commonly used dimensions are customers, products, and time.

Dimension data is typically collected at the lowest level of detail and then aggregated into higher level totals that are more useful for analysis. These natural rollups or aggregations within a dimension table are called hierarchies.

Hierarchies

Hierarchies are logical structures that use ordered levels as a means of organizing data. A hierarchy can be used to define data aggregation. For example, in a `time` dimension, a hierarchy might aggregate data from the `month` level to the `quarter` level to the `year` level. A hierarchy can also be used to define a navigational drill path and to establish a family structure.

Within a hierarchy, each level is logically connected to the levels above and below it. Data values at lower levels aggregate into the data values at higher levels. A dimension can be composed of more than one hierarchy. For example, in the `product` dimension, there might be two hierarchies—one for product categories and one for product suppliers.

Dimension hierarchies also group levels from general to granular. Query tools use hierarchies to enable you to drill down into your data to view different levels of granularity. This is one of the key benefits of a data warehouse.

When designing hierarchies, you must consider the relationships in business structures. For example, a divisional multilevel sales organization.

Hierarchies impose a family structure on dimension values. For a particular level value, a value at the next higher level is its parent, and values at the next lower level are its children. These familial relationships enable analysts to access data quickly.

Levels A level represents a position in a hierarchy. For example, a `time` dimension might have a hierarchy that represents data at the `month`, `quarter`, and `year` levels. Levels range from general to specific, with the root level as the highest or most general level. The levels in a dimension are organized into one or more hierarchies.

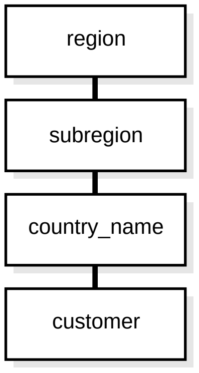
Level Relationships Level relationships specify top-to-bottom ordering of levels from most general (the root) to most specific information. They define the parent-child relationship between the levels in a hierarchy.

Hierarchies are also essential components in enabling more complex rewrites. For example, the database can aggregate an existing sales revenue on a quarterly base to a yearly aggregation when the dimensional dependencies between quarter and year are known.

Typical Dimension Hierarchy

Figure 2–2 illustrates a dimension hierarchy based on `customers`.

Figure 2–2 Typical Levels in a Dimension Hierarchy



See Also: Chapter 9, "Dimensions" and Chapter 22, "Query Rewrite" for further information regarding hierarchies

Unique Identifiers

Unique identifiers are specified for one distinct record in a dimension table. Artificial unique identifiers are often used to avoid the potential problem of unique identifiers changing. Unique identifiers are represented with the # character. For example, `#customer_id`.

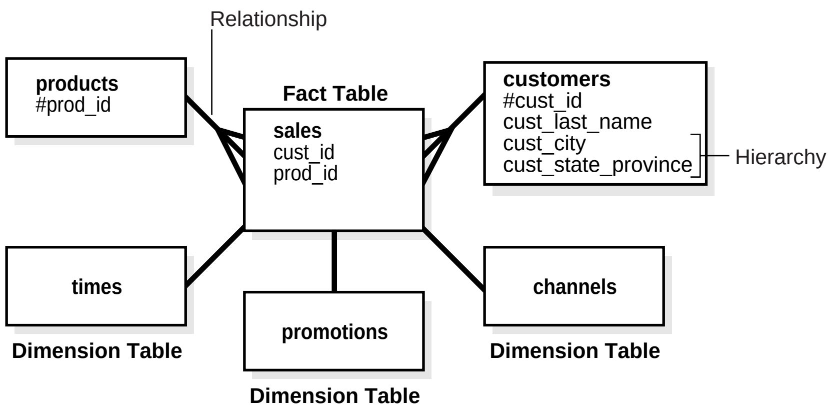
Relationships

Relationships guarantee business integrity. An example is that if a business sells something, there is obviously a customer and a product. Designing a relationship between the sales information in the fact table and the dimension tables products and customers enforces the business rules in databases.

Typical Example of Data Warehousing Objects and Their Relationships

Figure 2–3 illustrates a common example of a `sales` fact table and dimension tables `customers`, `products`, `promotions`, `times`, and `channels`.

Figure 2–3 Typical Data Warehousing Objects



Part III

Physical Design

This section deals with the physical design of a data warehouse.

It contains the following chapters:

3 Physical Design in Data Warehouses

This chapter describes the physical design of a data warehousing environment, and includes the following:

Moving from Logical to Physical Design

Logical design is what you draw with a pen and paper or design with Oracle Warehouse Builder or Designer before building your warehouse. Physical design is the creation of the database with SQL statements.

During the physical design process, you convert the data gathered during the logical design phase into a description of the physical database structure. Physical design decisions are mainly driven by query performance and database maintenance aspects. For example, choosing a partitioning strategy that meets common query requirements enables Oracle to take advantage of partition pruning, a way of narrowing a search before performing it.

See Also:

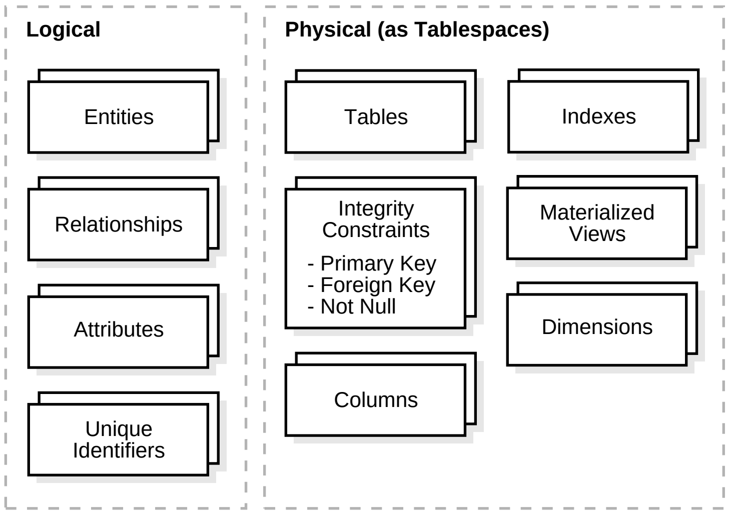
- Chapter 5, "Parallelism and Partitioning in Data Warehouses" for further information regarding partitioning
- *Oracle9i Database Concepts* for further conceptual material regarding all design matters

Physical Design

During the logical design phase, you defined a model for your data warehouse consisting of entities, attributes, and relationships. The entities are linked together using relationships. Attributes are used to describe the entities. The unique identifier (UID) distinguishes between one instance of an entity and another.

Figure 3–1 offers you a graphical way of looking at the different ways of thinking about logical and physical designs.

Figure 3–1 Logical Design Compared with Physical Design



During the physical design process, you translate the expected schemas into actual database structures. At this time, you have to map:

- Entities to Tables
- Relationships to Foreign Key Constraints
- Attributes to Columns
- Primary Unique Identifiers to Primary Key Constraints
- Unique Identifiers to Unique Key Constraints

Physical Design Structures

Once you have converted your logical design to a physical one, you will need to create some or all of the following structures:

- Tablespaces
- Tables and Partitioned Tables
- Views
- Integrity Constraints
- Views
- Dimensions

Some of these structures require disk space. Others exist only in the data dictionary. Additionally, the following structures may be created for performance improvement:

- Indexes and Partitioned Indexes
- Materialized Views

Tablespaces

A tablespace consists of one or more datafiles, which are physical structures within the operating system you are using. A datafile is associated with only one tablespace. From a design perspective, tablespaces are containers for physical design structures.

Tablespaces need to be separated by differences. For example, tables should be separated from their indexes and small tables should be separated from large tables. Tablespaces should also represent logical business units if possible. Because a tablespace is the coarsest granularity for backup and recovery or the transportable tablespaces mechanism, the logical business design affects availability and maintenance operations.

> **See Also:** Chapter 4, "Hardware and I/O Considerations in Data Warehouses" for further information regarding tablespaces

Tables and Partitioned Tables

Tables are the basic unit of data storage. They are the container for the expected amount of raw data in your data warehouse.

Using partitioned tables instead of nonpartitioned ones addresses the key problem of supporting very large data volumes by allowing you to decompose them into smaller and more manageable pieces. The main design criterion for partitioning is manageability, though you will also see performance benefits in most cases because of partition pruning or intelligent parallel processing. For example, you might choose a partitioning strategy based on a sales transaction date and a monthly granularity. If you have four years' worth of data, you can delete a month's data as it becomes older than four years with a single, quick DDL statement and load new data while only affecting 1/48th of the complete table. Business questions regarding the last quarter will only affect three months, which is equivalent to three partitions, or 3/48ths of the total volume.

Partitioning large tables improves performance because each partitioned piece is more manageable. Typically, you partition based on transaction dates in a data warehouse. For example, each month, one month's worth of data can be assigned its own partition.

See Also: Chapter 5, "Parallelism and Partitioning in Data Warehouses" and Chapter 14, "Maintaining the Data Warehouse"

Views

A view is a tailored presentation of the data contained in one or more tables or other views. A view takes the output of a query and treats it as a table. Views do not require any space in the database.

See Also: *Oracle9i Database Concepts*

Integrity Constraints

Integrity constraints are used to enforce business rules associated with your database and to prevent having invalid information in the tables. Integrity constraints in data warehousing differ from constraints in OLTP environments. In OLTP environments, they primarily prevent the insertion of invalid data into a record, which is not a big problem in data warehousing environments because accuracy has already been guaranteed. In data warehousing environments, constraints are only used for query rewrite. `NOT NULL` constraints are particularly common in data warehouses. Under some specific circumstances, constraints need space in the database. These constraints are in the form of the underlying unique index.

See Also: Chapter 7, "Integrity Constraints" and Chapter 22, "Query Rewrite"

Indexes and Partitioned Indexes

Indexes are optional structures associated with tables or clusters. In addition to the classical B-tree indexes, bitmap indexes are very common in data warehousing environments. Bitmap indexes are optimized index structures for set-oriented operations. Additionally, they are necessary for some optimized data access methods such as star transformations.

Indexes are just like tables in that you can partition them, although the partitioning strategy is not dependent upon the table structure. Partitioning indexes makes it easier to manage the warehouse during refresh and improves query performance.

See Also: Chapter 6, "Indexes" and Chapter 14, "Maintaining the Data Warehouse"

Materialized Views

Materialized views are query results that have been stored in advance so long-running calculations are not necessary when you actually execute your SQL statements. From a physical design point of view, materialized views resemble tables or partitioned tables.

See Also: Chapter 8, "Materialized Views"

Dimensions

A dimension is a schema object that defines hierarchical relationships between columns or column sets. A hierarchical relationship is a functional dependency from one level of a hierarchy to the next one. A dimension is a container of logical relationships and does not require any space in the database. A typical dimension is city, state (or province), region, and country.

See Also: Chapter 9, "Dimensions"

4

Hardware and I/O Considerations in Data Warehouses

This chapter explains some of the hardware and I/O issues in a data warehousing environment and includes the following topics:

- Overview of Hardware and I/O Considerations in Data Warehouses
- RAID Configurations

Overview of Hardware and I/O Considerations in Data Warehouses

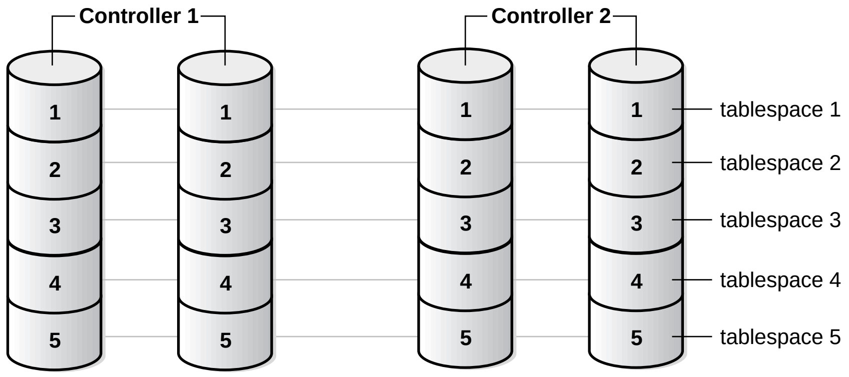
Data warehouses are normally very concerned with I/O performance. This is in contrast to OLTP systems, where the potential bottleneck depends on user workload and application access patterns. When a system is constrained by I/O capabilities, it is **I/O bound**, or has an **I/O bottleneck**. When a system is constrained by having limited CPU resources, it is **CPU bound**, or has a **CPU bottleneck**.

Database architects frequently use RAID (Redundant Arrays of Inexpensive Disks) systems to overcome I/O bottlenecks and to provide higher availability. RAID can be implemented in several levels, ranging from 0 to 7. Many hardware vendors have enhanced these basic levels to lessen the impact of some of the original restrictions at a given RAID level. The most common RAID levels are discussed later in this chapter.

Why Stripe the Data?

To avoid I/O bottlenecks during parallel processing or concurrent query access, all tablespaces accessed by parallel operations should be striped. Striping divides the data of a large table into small portions and stores them on separate datafiles on separate disks. As shown in Figure 4–1, tablespaces should always stripe *over at least as many devices as CPUs*. In this example, there are four CPUs, two controllers, and five devices containing tablespaces.

Figure 4–1 Striping Objects Over at Least as Many Devices as CPUs



See Also: *Oracle9i Database Concepts* for further details about disk striping

You should stripe tablespaces for tables, indexes, rollback segments, and temporary tablespaces. You must also spread the devices over controllers, I/O channels, and internal buses. To make striping effective, you must make sure that enough controllers and other I/O components are available to support the bandwidth of parallel data movement into and out of the striped tablespaces.

You can use RAID systems or you can perform striping manually through careful data file allocation to tablespaces.

The striping of data across physical drives has several consequences besides balancing I/O. One additional advantage is that logical files can be created that are larger than the maximum size usually supported by an operating system. There are disadvantages however. Striping means that it is no longer possible to locate a single datafile on a specific physical drive. This can cause the loss of some application tuning capabilities. Also, it can cause database recovery to be more time-consuming. If a single physical disk in a RAID array needs recovery, all the disks that are part of that logical RAID device must be involved in the recovery.

Automatic Striping

Automatic striping is usually flexible and easy to manage. It supports many scenarios such as multiple users running sequentially or as single users running in parallel. Two main advantages make automatic striping preferable to manual striping, unless the system is very small or availability is the main concern:

- For parallel scan operations (such as full table scan or fast full scan), operating system striping increases the number of disk seeks. Nevertheless, this is largely offset by the large I/O size (`DB_BLOCK_SIZE` * `MULTIBLOCK_READ_COUNT`), which should enable this operation to reach the maximum I/O throughput for your platform. This maximum is in general limited by the number of controllers or I/O buses of the platform, not by the number of disks (unless you have a small configuration and/or are using large disks).
- For index probes (for example, within a nested loop join or parallel index range scan), operating system striping enables you to avoid hot spots by evenly distributing I/O across the disks.

Oracle Corporation recommends using a large stripe size of at least 64 KB. Stripe size must be at least as large as the I/O size. If stripe size is larger than I/O size by a factor of two or four, then trade-offs may arise. The large stripe size can be advantageous because it lets the system perform more sequential operations on each disk; it decreases the number of seeks on disk. Another advantage of large stripe sizes is that more users can work on the system without affecting each other. The disadvantage is that large stripes reduce the I/O parallelism, so fewer disks are simultaneously active. If you encounter problems, increase the I/O size of scan operations (for example, from 64 KB to 128 KB), instead of changing the stripe size. The maximum I/O size is platform-specific (in a range, for example, of 64 KB to 1 MB).

With automatic striping, from a performance standpoint, the best layout is to stripe data, indexes, and temporary tablespaces across all the disks of your platform. This layout is also appropriate when you have little information about system usage. To increase availability, it may be more practical to stripe over fewer disks to prevent a single disk value from affecting the entire data warehouse. However, for better performance, it is crucial to stripe all objects over multiple disks. In this way, maximum I/O performance (both in terms of throughput and in number of I/Os per second) can be reached when one object is accessed by a parallel operation. If multiple objects are accessed at the same time (as in a multiuser configuration), striping automatically limits the contention.

Manual Striping

You can use manual striping on all platforms. To do this, add multiple files to each tablespace, with each file on a separate disk. If you use manual striping correctly, your system's performance improves significantly. However, you should be aware of several drawbacks that can adversely affect performance if you do not stripe correctly.

When using manual striping, the degree of parallelism (DOP) is more a function of the number of disks than of the number of CPUs. First, it is necessary to have one server process per datafile to drive all the disks and limit the risk of experiencing I/O bottlenecks. Second, manual striping is very sensitive to datafile size skew, which can affect the scalability of parallel scan operations. Third, manual striping requires more planning and set-up effort than automatic striping.

Note: The Oracle Corporation recommends that you choose automatic striping unless you have a clear reason not to.

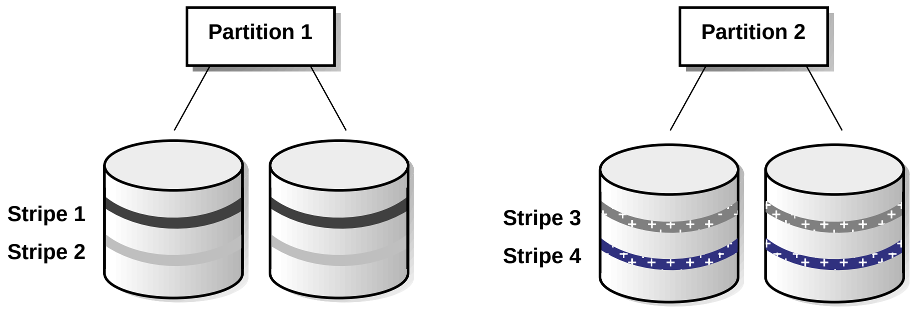
Local and Global Striping

Local striping, which applies only to partitioned tables and indexes, is a form of non-overlapping, disk-to-partition striping. Each partition has its own set of disks and files, as illustrated in Figure 4–2. Disk access does not overlap, nor do files.

An advantage of local striping is that if one disk fails, it does not affect other partitions. Moreover, you still have some striping even if you have data in only one partition.

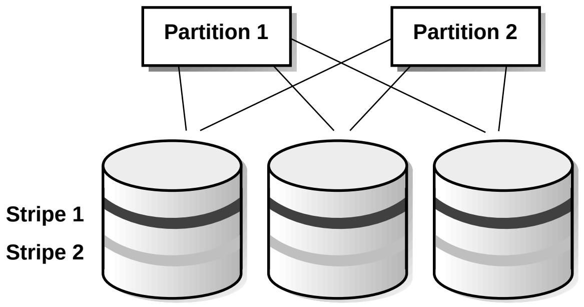
A disadvantage of local striping is that you need many disks to implement it—each partition requires multiple disks of its own. Another major disadvantage is that when partitions are reduced to a few or even a single partition, the system retains limited I/O bandwidth. As a result, local striping is not optimal for parallel operations. For this reason, consider local striping only if your main concern is availability, rather than parallel execution.

Figure 4–2 Local Striping



Global striping, illustrated in Figure 4–3, entails overlapping disks and partitions.

Figure 4–3 Global Striping



Global striping is advantageous if you have partition pruning and need to access data in only one partition. Spreading the data in that partition across many disks improves performance for parallel execution operations. A disadvantage of global striping is that if one disk fails, all partitions are affected if the disks are not mirrored.

> **See Also:** *Oracle9i Database Concepts* for information on disk striping and partitioning. For MPP systems, see your operating system specific Oracle documentation regarding the advisability of disabling disk affinity when using operating system striping

Analyzing Striping

Two considerations arise when analyzing striping issues for your applications. First, consider the **cardinality** of the relationships among the objects in a storage system. Second, consider what you can optimize in your striping effort: full table scans, general tablespace availability, partition scans, or some combinations of these goals. Cardinality and optimization are discussed in the following section.

Cardinality of Storage Object Relationships

To analyze striping, consider the following relationships:

Figure 4–4 Cardinality of Relationships

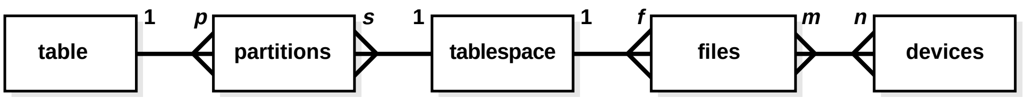


Figure 4–4 shows the cardinality of the relationships among objects in a typical Oracle storage system. For every table there may be:

- *p* partitions, shown in Figure 4–4 as a one-to-many relationship
- *s* partitions for every tablespace, shown in Figure 4–4 as a many-to-one relationship
- *f* files for every tablespace, shown in Figure 4–4 as a one-to-many relationship
- *m* files to *n* devices, shown in Figure 4–4 as a many-to-many relationship

Goals. You may wish to stripe an object across devices to achieve one of three goals:

- Goal 1: To optimize full table scans, place a table on many devices.
- Goal 2: To optimize availability, restrict the tablespace to a few devices.
- Goal 3: To optimize partition scans, achieve intra-partition parallelism by placing each partition on many devices.

To attain both Goals 1 and 2 (having the table reside on many devices, with the highest possible availability), maximize the number of partitions *p* and minimize the number of partitions per tablespace *s*.

To maximize Goal 1 but with minimal intra-partition parallelism, place each partition in its own tablespace. Do not used striped files, and use one file per tablespace.

To minimize Goal 2 and thereby minimize availability, set *f* and *n* equal to 1. When you minimize availability, you maximize intra-partition parallelism. Goal 3 conflicts with Goal 2 because you cannot simultaneously maximize the formula for Goal 3 and minimize the formula for Goal 2. You must compromise to achieve some of the benefits of both goals.

Goal 1: To optimize full table scans. Having a table reside on many devices ensures scalable full table scans.

To calculate the optimal number of devices per table, use this formula:

$$\textit{Number of devices per table} = \frac{p \times f \times n}{s \times m}$$

You can do this by having *t* partitions, with every partition in its own tablespace, if every tablespace has one file, and these files are not striped.

$t \times 1 / p \times 1 \times 1$, *up to t devices*

If the table is not partitioned, but is in one tablespace in one file, stripe it over *n* devices.

$1 \times 1 \times n$ *devices*

There are a maximum of *t* partitions, every partition in its own tablespace, *f* files in each tablespace, each tablespace on a striped device:

$t \times f \times n$ *devices*

Goal 2: To optimize availability. Restricting each tablespace to a small number of devices and having as many partitions as possible helps you achieve high availability.

$$\textit{Number of devices per tablespace} = \frac{f \times n}{m}$$

Availability is maximized when $f = n = m = 1$ and p is much greater than 1.

Goal 3: To optimize partition scans. Achieving intra-partition parallelism is advantageous because partition scans are scalable. To do this, place each partition on many devices.

$$\textit{Number of devices per partition} = \frac{f \times n}{s \times m}$$

Partitions can reside in a tablespace that can have many files. You can have either

- Many files per tablespace or
- A striped file

RAID Configurations

RAID systems, also called disk arrays, can be hardware- or software-based systems. The difference between the two is how CPU processing of I/O requests is handled. In software-based RAID systems, the operating system or an application level handles the I/O request, while in hardware-based RAID systems, disk controllers handle I/O requests. RAID usage is transparent to Oracle. All the features specific to a given RAID configuration are handled by the operating system and Oracle does not need to worry about them.

Primary logical database structures have different access patterns during read and write operations. Therefore, different RAID implementations will be better suited for these structures. The purpose of this chapter is to discuss some of the basic decisions you must make when designing the physical layout of your data warehouse implementation. It is not meant as a replacement for operating system and storage documentation or a consultant's analysis of your I/O requirements.

> **See Also:** *Oracle9i Database Performance Guide and Reference* for more information regarding RAID

There are advantages and disadvantages to using RAID, and those depend on the RAID level under consideration and the specific system in question. The most common configurations in data warehouses are:

- RAID 0 (Striping)
- RAID 1 (Mirroring)
- RAID 0+1 (Striping and Mirroring)
- RAID 5

RAID 0 (Striping)

RAID 0 is a non-redundant disk array, so there will be data loss with any disk failure. If something on the disk becomes corrupted, you cannot restore or recalculate that data. RAID 0 provides the best write throughput performance because it never updates redundant information. Read throughput is also quite good, but you can improve it by combining RAID 0 with RAID 1.

Oracle does not recommend using RAID 0 systems without RAID 1 because the loss of one disk in the array will affect the complete system and make it unavailable. RAID 0 systems are used mainly in environments where performance and capacity are the primary concerns rather than availability.

RAID 1 (Mirroring)

RAID 1 provides full data redundancy by complete mirroring of all files. If a disk failure occurs, the mirrored copy is used to transparently service the request. RAID 1 mirroring requires twice as much disk space as there is data. In general, RAID 1 is most useful for systems where complete redundancy of data is required and disk space is not an issue. For large datafiles or systems with less disk space, RAID 1 may not be feasible, because it requires twice as much disk space as there is data. Writes under RAID 1 are no faster and no slower than usual. Reading data can be faster than on a single disk because the system can choose to read the data from the disk that can respond faster.

RAID 0+1 (Striping and Mirroring)

RAID 0+1 offers the best performance of all RAID systems, but costs the most because you double the number of drives. Basically, it combines the performance of RAID 0 and the fault tolerance of RAID 1. You should consider RAID 0+1 for datafiles with high write rates, for example, table datafiles, and online and archived redo log files.

Striping, Mirroring, and Media Recovery

Striping affects media recovery. Loss of a disk usually means loss of access to all objects stored on that disk. If all datafiles in a database are striped over all disks, then loss of any disk stops the entire database. Furthermore, you may need to restore all these database files from backups, even if each file has only a small fraction of its total data stored on the failed disk.

Often, the same system that provides striping also provides mirroring. With the declining price of disks, mirroring can provide an effective supplement to, but not a substitute for, backups and log archives. Mirroring can help your system recover from disk failures more quickly than using a backup, but mirroring is not as robust. Mirroring does not protect against software faults and other problems against which an independent backup would protect your system.

You can effectively use mirroring if you are able to reload read-only data from the original source tapes. If you have a disk failure, restoring data from backups can involve lengthy downtime, whereas restoring from a mirrored disk enables your system to get back online quickly or even stay online while the crashed disk is replaced and resynchronized.

RAID 5

RAID 5 systems provide redundancy for the original data while storing parity information as well. The parity information is striped over all disks in the system to avoid a single disk as a bottleneck during write operations. The I/O throughput of RAID 5 systems depends upon the implementation and the striping size. For a typical RAID 5 system, the throughput is normally lower than RAID 0 + 1 configurations. In particular, the performance for high concurrent write operations such as parallel load can be poor.

Many vendors use memory (as battery-backed cache) in front of the disks to increase throughput and to become comparable to RAID 0+1. Contact your disk array vendor for specific details.

The Importance of Specific Analysis

A data warehouse's requirements are at many levels, and resolving a problem at one level can cause problems with another. For example, resolving a problem with query performance during the ETL process can affect load performance. You cannot simply maximize query performance at the expense of an unrealistic load time. If you do, your implementation will fail. In addition, a particular process is dependent upon the warehouse's architecture. If you decide to change something in your system, it can cause performance to become unacceptable in another part of the warehousing process. An example of this is switching from using database files to flat files during the loading process. Flat files can have different read performance.

This chapter is not meant as a replacement for operating system and storage documentation. Your system's requirements will require detailed analysis prior to implementation. Only a detailed data warehouse architecture and I/O analysis will help you when deciding hardware and I/O strategies.

See Also: *Oracle9i Database Performance Guide and Reference* for details regarding how to analyze I/O requirements

5

Parallelism and Partitioning in Data Warehouses

Data warehouses often contain large tables and require techniques both for managing these large tables and for providing good query performance across these large tables. This chapter discusses two key methodologies for addressing these needs: parallelism and partitioning.

These topics are discussed:

Note: Parallel execution is available only with the Oracle9*i* Enterprise Edition.

Overview of Parallel Execution

Parallel execution dramatically reduces response time for data-intensive operations on large databases typically associated with decision support systems (DSS) and data warehouses. You can also implement parallel execution on certain types of online transaction processing (OLTP) and hybrid systems. Parallel execution is sometimes called **parallelism**. Simply expressed, parallelism is the idea of breaking down a task so that, instead of one process doing all of the work in a query, many processes do part of the work at the same time. An example of this is when four processes handle four different quarters in a year instead of one process handling all four quarters by itself. The improvement in performance can be quite high. In this case, each quarter will be a **partition**, a smaller and more manageable unit of an index or table.

See Also: *Oracle9i Database Concepts* for further conceptual information regarding parallel execution

When to Implement Parallel Execution

The most common use of parallel execution is in DSS environments. Complex queries, such as those involving joins of several tables or searches of very large tables, are often best executed in parallel.

Parallel execution is useful for many types of operations that access significant amounts of data. Parallel execution improves processing for:

- Large table scans and joins
- Creation of large indexes
- Partitioned index scans
- Bulk inserts, updates, and deletes
- Aggregations and copying

You can also use parallel execution to access object types within an Oracle database. For example, use parallel execution to access LOBs (large objects).

Parallel execution benefits systems that have *all* of the following characteristics:

- Symmetric multi-processors (SMP), clusters, or massively parallel systems
- Sufficient I/O bandwidth
- Underutilized or intermittently used CPUs (for example, systems where CPU usage is typically less than 30%)

- Sufficient memory to support additional memory-intensive processes such as sorts, hashing, and I/O buffers

If your system lacks any of these characteristics, parallel execution might not significantly improve performance. In fact, parallel execution can reduce system performance on overutilized systems or systems with small I/O bandwidth.

> **See Also:** Chapter 21, "Using Parallel Execution" for further information regarding parallel execution requirements

Granules of Parallelism

Different parallel operations use different types of parallelism. The optimal physical database layout depends on the parallel operations that are most prevalent in your application or even of the necessity of using partitions.

The basic unit of work in parallelism is a called a **granule**. Oracle divides the operation being parallelized (for example, a table scan, table update, or index creation) into granules. Parallel execution processes execute the operation one granule at a time. The number of granules and their size correlates with the degree of parallelism (DOP). It also affects how well the work is balanced across query server processes. There is no way you can enforce a specific granule strategy as Oracle makes this decision internally.

Block Range Granules

Block range granules are the basic unit of most parallel operations, even on partitioned tables. Therefore, from an Oracle perspective, the degree of parallelism is not related to the number of partitions.

Block range granules are ranges of physical blocks from a table. The number and the size of the granules are computed during runtime by Oracle to optimize and balance the work distribution for all affected parallel execution servers. The number and size of granules are dependent upon the size of the object and the DOP. Block range granules do not depend on static preallocation of tables or indexes. During the computation of the granules, Oracle takes the DOP into account and tries to assign granules from different datafiles to each of the parallel execution servers to avoid contention whenever possible. Additionally, Oracle considers the disk affinity of the granules on MPP systems to take advantage of the physical proximity between parallel execution servers and disks.

When block range granules are used predominantly for parallel access to a table or index, administrative considerations (such as recovery or using partitions for deleting portions of data) might influence partition layout more than performance considerations.

Partition Granules

When Oracle uses partition granules, a query server process works on an entire partition or subpartition of a table or index. Because partition granules are statically determined by the structure of the table or index when a table or index is created, partition granules do not give you the flexibility in parallelizing an operation that block granules do. The maximum allowable DOP is the number of partitions. This might limit the utilization of the system and the load balancing across parallel execution servers.

When Oracle uses partition granules for parallel access to a table or index, you should use a relatively large number of partitions (ideally, three times the DOP), so that Oracle can effectively balance work across the query server processes.

Partition granules are the basic unit of parallel index range scans and of parallel operations that modify multiple partitions of a partitioned table or index. These operations include parallel update, parallel delete, parallel creation of partitioned indexes, and parallel creation of partitioned tables.

See Also: *Oracle9i Database Concepts* for information on disk striping and partitioning

Partitioning Design Considerations

In conjunction with parallel execution, partitioning can improve performance in data warehouses. The following are the main design considerations for partitioning:

- Types of Partitioning
- Partition Pruning
- Partition-wise Joins

Types of Partitioning

This section describes the partitioning features that significantly enhance data access and improve overall application performance. This is especially true for applications that access tables and indexes with millions of rows and many gigabytes of data.

Partitioned tables and indexes facilitate administrative operations by enabling these operations to work on subsets of data. For example, you can add a new partition, organize an existing partition, or drop a partition and cause less than a second of interruption to a read-only application.

Using the partitioning methods described in this section can help you tune SQL statements to avoid unnecessary index and table scans (using partition pruning). You can also improve the performance of massive join operations when large amounts of data (for example, several million rows) are joined together by using partition-wise joins. Finally, partitioning data greatly improves manageability of very large databases and dramatically reduces the time required for administrative tasks such as backup and restore.

Granularity can be easily added or removed to the partitioning scheme by splitting partitions. Thus, if a table's data is skewed to fill some partitions more than others, the ones that contain more data can be split to achieve a more even distribution. Partitioning also allows one to swap partitions with a table. By being able to easily add, remove, or swap a large amount of data quickly, swapping can be used to keep a large amount of data that is being loaded inaccessible until loading is completed, or can be used as a way to stage data between different phases of use. Some examples are current day's transactions or online archives.

> **See Also:** *Oracle9i Database Concepts* for an introduction to the ideas behind partitioning

Partitioning Methods

Oracle offers four partitioning methods:

- Range Partitioning
- Hash Partitioning
- List Partitioning
- Composite Partitioning

Each partitioning method has different advantages and design considerations. Thus, each method is more appropriate for a particular situation.

Range Partitioning Range partitioning maps data to partitions based on ranges of partition key values that you establish for each partition. It is the most common type of partitioning and is often used with dates. For example, you might want to partition sales data into monthly partitions.

Range partitioning maps rows to partitions based on ranges of column values. Range partitioning is defined by the partitioning specification for a table or index:

```
PARTITION BY RANGE (column_list)
```

and by the partitioning specifications for each individual partition:

```
VALUES LESS THAN (value_list)
```

where:

```
column_list
```

is an ordered list of columns that determines the partition to which a row or an index entry belongs. These columns are called the partitioning columns. The values in the partitioning columns of a particular row constitute that row's partitioning key.

```
value_list
```

is an ordered list of values for the columns in the column list. Each value must be either a literal or a `TO_DATE` or `RPAD` function with constant arguments. Only the `VALUES LESS THAN` clause is allowed. This clause specifies a non-inclusive upper bound for the partitions. All partitions, except the first, have an implicit low value specified by the `VALUES LESS THAN` literal on the previous partition. Any binary values of the partition key equal to or higher than this literal are added to the next higher partition. Highest partition being where `MAXVALUE` literal is defined. Keyword, `MAXVALUE`, represents a virtual *infinite* value that sorts higher than any other value for the data type, including the null value.

Example 5–1 Range Partitioning Example

The statement below creates a table `sales_range` that is range partitioned on the `sales_date` field.

```
CREATE TABLE sales_range
(salesman_id  NUMBER(5),
salesman_name VARCHAR2(30),
sales_amount  NUMBER(10),
sales_date    DATE)
PARTITION BY RANGE(sales_date)
```

```
(
PARTITION sales_jan2000 VALUES LESS THAN(TO_DATE('02/01/2000','DD/MM/YYYY')),
PARTITION sales_feb2000 VALUES LESS THAN(TO_DATE('03/01/2000','DD/MM/YYYY')),
PARTITION sales_mar2000 VALUES LESS THAN(TO_DATE('04/01/2000','DD/MM/YYYY')),
PARTITION sales_apr2000 VALUES LESS THAN(TO_DATE('05/01/2000','DD/MM/YYYY')),
);
```

See Also: *Oracle9i SQL Reference* for partitioning syntax

Hash Partitioning Hash partitioning maps data to partitions based on a hashing algorithm that Oracle applies to a partitioning key that you identify. The hashing algorithm evenly distributes rows among partitions, giving partitions approximately the same size. Hash partitioning is the ideal method for distributing data evenly across devices. Hash partitioning is a good and easy-to-use alternative to range partitioning when data is not historical and there is no obvious column or column list where logical range partition pruning can be advantageous.

Oracle uses a linear hashing algorithm and to prevent data from clustering within specific partitions, you should define the number of partitions by a power of two (for example, 2, 4, 8).

Example 5–2 Hash Partitioning Example

The statement below creates a table `sales_hash`, which is hash partitioned on the `salesman_id` field. `data1`, `data2`, `data3`, and `data4` are tablespace names.

```
CREATE TABLE sales_hash
(salesman_id  NUMBER(5),
salesman_name VARCHAR2(30),
sales_amount  NUMBER(10),
week_no       NUMBER(2))
PARTITION BY HASH(salesman_id)
PARTITIONS 4
STORE IN (data1, data2, data3, data4);
```

See Also: *Oracle9i SQL Reference* for partitioning syntax

Note: You cannot define alternate hashing algorithms for partitions.

List Partitioning List partitioning enables you to explicitly control how rows map to partitions. You do this by specifying a list of discrete values for the partitioning column in the description for each partition. This is different from range partitioning, where a range of values is associated with a partition and with hash partitioning, where you have no control of the row-to-partition mapping. The advantage of list partitioning is that you can group and organize unordered and unrelated sets of data in a natural way.

Example 5–3 List Partitioning Example

```
CREATE TABLE sales_list
(salesman_id  NUMBER(5),
salesman_name VARCHAR2(30),
sales_state   VARCHAR2(20),
sales_amount  NUMBER(10),
sales_date    DATE)
PARTITION BY LIST(sales_state)
(
PARTITION sales_west VALUES IN('California', 'Hawaii'),
PARTITION sales_east VALUES IN ('New York', 'Virginia', 'Florida'),
PARTITION sales_central VALUES IN('Texas', 'Illinois'),
);
```

See Also: *Oracle9i SQL Reference* for partitioning syntax

Composite Partitioning Composite partitioning combines range and hash partitioning. Oracle first distributes data into partitions according to boundaries established by the partition ranges. Then Oracle uses a hashing algorithm to further divide the data into subpartitions within each range partition.

Index Partitioning

You can choose whether or not to inherit the partitioning strategy of the underlying tables. You can create both local and global indexes on a table partitioned by range, hash, or composite methods. Local indexes inherit the partitioning attributes of their related tables. For example, if you create a local index on a composite table, Oracle automatically partitions the local index using the composite method.

Oracle supports only range partitioning for global partitioned indexes. You cannot partition global indexes using the hash or composite partitioning methods.

See Also: Chapter 6, "Indexes"

Performance Issues for Range, List, Hash, and Composite Partitioning

This section describes performance issues for:

- When to Use Range Partitioning
- When to Use Hash Partitioning
- When to Use List Partitioning
- When to Use Composite Partitioning

When to Use Range Partitioning Range partitioning is a convenient method for partitioning historical data. The boundaries of range partitions define the ordering of the partitions in the tables or indexes.

Range partitioning organizes data by time intervals on a column of type `DATE`. Thus, most SQL statements accessing range partitions focus on timeframes. An example of this is a SQL statement similar to "select data from a particular period in time." In such a scenario, if each partition represents data for one month, the query "find data of month 98-DEC" needs to access only the December partition of year 98. This reduces the amount of data scanned to a fraction of the total data available, an optimization method called **partition pruning**.

Range partitioning is also ideal when you periodically load new data and purge old data. It is easy to add or drop partitions.

It is common to keep a rolling window of data, for example keeping the past 36 months' worth of data online. Range partitioning simplifies this process. To add data from a new month, you load it into a separate table, clean it, index it, and then add it to the range-partitioned table using the `EXCHANGE PARTITION` statement, all while the original table remains online. Once you add the new partition, you can drop the trailing month with the `DROP PARTITION` statement. The alternative to using the `DROP PARTITION` statement can be to archive the partition and make it read only, but this works only when your partitions are in separate tablespaces.

In conclusion, consider using range partitioning when:

- Very large tables are frequently scanned by a range predicate on a good partitioning column, such as `ORDER_DATE` or `PURCHASE_DATE`. Partitioning the table on that column enables partition pruning.
- You want to maintain a rolling window of data
- You cannot complete administrative operations, such as backup and restore, on large tables in an allotted time frame, but you can divide them into smaller logical pieces based on the partition range column

This SQL example creates the table `sales` for a period of two years, 1999 and 2000, and partitions it by range according to the column `s_salesdate` to separate the data into eight quarters, each corresponding to a partition. In the example, the partitioning granularity is not restricted to any logical range.

```
CREATE TABLE sales
  (s_productid  NUMBER,
   s_saledate   DATE,
   s_custid     NUMBER,
   s_totalprice NUMBER)
PARTITION BY RANGE(s_saledate)
 (PARTITION sal99q1 VALUES LESS THAN (TO_DATE('01-APR-1999', 'DD-MON-YYYY')),
  PARTITION sal99q2 VALUES LESS THAN (TO_DATE('01-JUL-1999', 'DD-MON-YYYY')),
  PARTITION sal99q3 VALUES LESS THAN (TO_DATE('01-OCT-1999', 'DD-MON-YYYY')),
  PARTITION sal99q4 VALUES LESS THAN (TO_DATE('01-JAN-2000', 'DD-MON-YYYY')),
  PARTITION sal00q1 VALUES LESS THAN (TO_DATE('01-APR-2000', 'DD-MON-YYYY')),
  PARTITION sal00q2 VALUES LESS THAN (TO_DATE('01-JUL-2000', 'DD-MON-YYYY')),
  PARTITION sal00q3 VALUES LESS THAN (TO_DATE('01-OCT-2000', 'DD-MON-YYYY')),
  PARTITION sal00q4 VALUES LESS THAN (TO_DATE('01-JAN-2001', 'DD-MON-YYYY')));
```

When to Use Hash Partitioning The way Oracle distributes data in hash partitions does not correspond to a business or a logical view of the data, as it does in range partitioning. Consequently, hash partitioning is not an effective way to manage historical data. However, hash partitions share some performance characteristics with range partitions. For example, partition pruning is limited to equality predicates. You can also use partition-wise joins, parallel index access, and parallel DML.

See Also: "Partition-wise Joins" on page 5-15

As a general rule, use hash partitioning for these purposes:

- To improve the availability and manageability of large tables or to enable PDML in tables that do not store historical data.
- To avoid data skew among partitions. Hash partitioning is an effective means of distributing data because Oracle hashes the data into a number of partitions, each of which can reside on a separate device. Thus, data is evenly spread over a sufficient number of devices to maximize I/O throughput. Similarly, you can use hash partitioning to distribute evenly data among the nodes of an MPP platform that uses Oracle Real Application Clusters.
- If it is important to use partition pruning and partition-wise joins according to a partitioning key that is mostly constrained by a distinct value or value list.

Note: In hash partitioning, partition pruning uses only equality or `IN`-list predicates.

If you add or merge a hashed partition, Oracle automatically rearranges the rows to reflect the change in the number of partitions and subpartitions. The hash function that Oracle uses is especially designed to limit the cost of this reorganization. Instead of reshuffling all the rows in the table, Oracles uses an "add partition" logic that splits one and only one of the existing hashed partitions. Conversely, Oracle coalesces a partition by merging two existing hashed partitions.

Although the hash function's use of "add partition" logic dramatically improves the manageability of hash partitioned tables, it means that the hash function can cause a skew if the number of partitions of a hash partitioned table, or the number of subpartitions in each partition of a composite table, is not a power of two. In the worst case, the largest partition can be twice the size of the smallest. So for optimal performance, create a number of partitions and subpartitions per partition that is a power of two. For example, 2, 4, 8, 16, 32, 64, 128, and so on.

This example creates four hashed partitions for the table `sales` using the column `s_productid` as the partition key:

Example 5–4 Hash Partitioning Example

```
CREATE TABLE sales
  (s_productid  NUMBER,
   s_saledate   DATE,
   s_custid     NUMBER,
   s_totalprice NUMBER)
PARTITION BY HASH(s_productid)
PARTITIONS 4;
```

Specify partition names only if you want some of the partitions to have different properties from those of the table. Otherwise, Oracle automatically generates internal names for the partitions. Also, you can use the `STORE IN` clause to assign hash partitions to tablespaces in a round-robin manner.

See Also: *Oracle9i SQL Reference* for partitioning syntax

When to Use List Partitioning You should use list partitioning when you want to specifically map rows to partitions based on discrete values.

Unlike range and hash partitioning, multi-column partition keys are not supported for list partitioning. If a table is partitioned by list, the partitioning key can only consist of a single column of the table.

When to Use Composite Partitioning Composite partitioning offers the benefits of both range and hash partitioning. With composite partitioning, Oracle first partitions by range. Then within each range Oracle creates subpartitions and distributes data within them using the same hashing algorithm it uses for hash partitioned tables.

Data placed in composite partitions is logically ordered only by the boundaries that define the range level partitions. The partitioning of data within each partition has no logical organization beyond the identity of the partition to which the subpartitions belong.

Consequently, tables and local indexes partitioned using the composite method:

- Support historical data at the partition level
- Support the use of subpartitions as units of parallelism for parallel operations such as PDML or space management and backup and recovery
- Are eligible for partition pruning and partition-wise joins on the range and hash dimensions

Using Composite Partitioning Use the composite partitioning method for tables and local indexes if:

- Partitions must have a logical meaning to efficiently support historical data
- The contents of a partition can be spread across multiple tablespaces, devices, or nodes (of an MPP system)
- You require both partition pruning and partition-wise joins even when the pruning and join predicates use different columns of the partitioned table
- You require a degree of parallelism that is greater than the number of partitions for backup, recovery, and parallel operations

Most large tables in a data warehouse should use range partitioning. Composite partitioning should be used for very large tables or for data warehouses with a well-defined need for the conditions listed above. When using the composite method, Oracle stores each subpartition on a different segment. Thus, the subpartitions may have properties that differ from the properties of the table or from the partition to which the subpartitions belong.

The following example partitions the table `sales` by range on the column `s_saledate` to create four partitions that order data by time. Then, within each range partition, the data is further subdivided into 16 subpartitions by hash on the column `s_productid`.

Example 5–5 Composite Partitioning Example

```
CREATE TABLE sales(
  s_productid  NUMBER,
  s_saledate   DATE,
  s_custid     NUMBER,
  s_totalprice NUMBER)
   PARTITION BY RANGE (s_saledate)
   SUBPARTITION BY HASH (s_productid) SUBPARTITIONS 16
  (PARTITION sal99q1 VALUES LESS THAN (TO_DATE('01-APR-1999', 'DD-MON-YYYY')),
   PARTITION sal99q2 VALUES LESS THAN (TO_DATE('01-JUL-1999', 'DD-MON-YYYY')),
   PARTITION sal99q3 VALUES LESS THAN (TO_DATE('01-OCT-1999', 'DD-MON-YYYY')),
   PARTITION sal99q4 VALUES LESS THAN (TO_DATE('01-JAN-2000', 'DD-MON-YYYY')));
```

Each hashed subpartition contains sales data for a single quarter ordered by product code. The total number of subpartitions is 4x16 or 64.

Partition Pruning

Partition pruning is an essential performance feature for data warehouses. In partition pruning, the cost-based optimizer analyzes `FROM` and `WHERE` clauses in SQL statements to eliminate unneeded partitions when building the partition access list. This enables Oracle to perform operations only on those partitions that are relevant to the SQL statement. Oracle prunes partitions when you use range, equality, and `IN`-list predicates on the range partitioning columns, and when you use equality and `IN`-list predicates on the hash partitioning columns.

Partition pruning dramatically reduces the amount of data retrieved from disk and shortens the use of processing time, improving query performance and resource utilization. If you partition the index and table on different columns (with a global, partitioned index), partition pruning also eliminates index partitions even when the partitions of the underlying table cannot be eliminated.

On composite partitioned objects, Oracle can prune at both the range partition level and at the hash subpartition level using the relevant predicates. Refer to the table `sales` from the previous example, partitioned by range on the column `s_salesdate` and subpartitioned by hash on column `s_productid`, and consider the following example:

Example 5–6 Partition Pruning Example

```
SELECT * FROM sales
WHERE s_saledate BETWEEN (TO_DATE('01-JUL-1999', 'DD-MON-YYYY')) AND
 (TO_DATE('01-OCT-1999', 'DD-MON-YYYY')) AND s_productid = 1200;
```

Oracle uses the predicate on the partitioning columns to perform partition pruning as follows:

- When using range partitioning, Oracle accesses only partitions `sal99q2` and `sal99q3`.
- When using hash subpartitioning, Oracle accesses only the one subpartition in each partition that stores the rows with `s_productid=1200`. The mapping between the subpartition and the predicate is calculated based on Oracle's internal hash distribution function.

Pruning Using DATE Columns

In "Partition Pruning Example" on page 5-14, the date value was fully specified as four digits for the year using the `TO_DATE` function, just as it was in the underlying table's range partitioning description ("Composite Partitioning Example" on page 5-13). While this is the recommended format for specifying date values, the optimizer can prune partitions using the predicates on `s_salesdate` when you use other formats, as in the following example:

Example 5–7 Partition Pruning with DATE Example

```
SELECT * FROM sales
WHERE s_saledate BETWEEN TO_DATE('01-JUL-99', 'DD-MON-RR') AND
  TO_DATE('01-OCT-99', 'DD-MON-RR') AND s_productid = 1200;
```

Although "Partition Pruning with DATE Example" on page 5-14 uses the DD-MON-RR format, which is not the same as the base partition in "Hash Partitioning Example" on page 5-11, the optimizer can still prune properly.

If you execute an `EXPLAIN PLAN` statement on the query, the `PARTITION_START` and `PARTITION_STOP` columns of the output table do not specify which partitions Oracle is accessing. Instead, you see the keyword `KEY` for both columns. The keyword `KEY` for both columns means that partition pruning occurs at run-time. It can also affect the execution plan because the information about the pruned partitions is missing compared to the same statement using the same `TO_DATE` function than the partition table definition.

Avoiding I/O Bottlenecks

To avoid I/O bottlenecks, when Oracle is not scanning all partitions because some have been eliminated by pruning, spread each partition over several devices. On MPP systems, spread those devices over multiple nodes.

Partition-wise Joins

Partition-wise joins reduce query response time by minimizing the amount of data exchanged among parallel execution servers when joins execute in parallel. This significantly reduces response time and improves the use of both CPU and memory resources. In Oracle Real Application Cluster environments, partition-wise joins also avoid or at least limit the data traffic over the interconnect, which is the key to achieving good scalability for massive join operations.

Partition-wise joins can be full or partial. Oracle decides which type of join to use.

Full Partition-wise Joins

A full partition-wise join divides a large join into smaller joins between a pair of partitions from the two joined tables. To use this feature, you must equipartition both tables on their join keys. For example, consider a large join between a sales table and a customer table on the column customerid. The query "find the records of all customers who bought more than 100 articles in Quarter 3 of 1999" is a typical example of a SQL statement performing such a join. The following is an example of this:

```
SELECT c_customer_name, COUNT(*)
FROM sales, customer
WHERE s_customerid = c_customerid
   AND s_saledate BETWEEN TO_DATE('01-JUL-1999', 'DD-MON-YYYY') AND
     (TO_DATE('01-OCT-1999', 'DD-MON-YYYY')
  GROUP BY c_customer_name HAVING
  COUNT(*) > 100;
```

This large join is typical in data warehousing environments. The entire customer table is joined with one quarter of the sales data. In large data warehouse applications, this might mean joining millions of rows. The join method to use in that case is obviously a hash join. You can reduce the processing time for this hash join even more if both tables are equipartitioned on the `customerid` column. This enables a full partition-wise join.

When you execute a full partition-wise join in parallel, the granule of parallelism, as described under "Granules of Parallelism" on page 5-3, is a partition. As a result, the degree of parallelism is limited to the number of partitions. For example, you require at least 16 partitions to set the degree of parallelism of the query to 16.

You can use various partitioning methods to equipartition both tables on the column `customerid` with 16 partitions. These methods are described in these subsections.

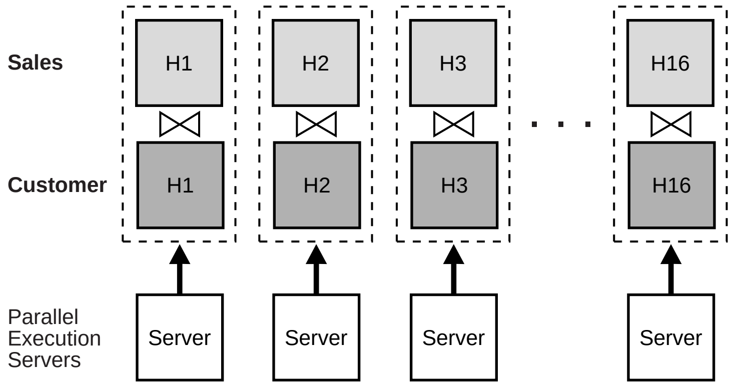
Hash - Hash This is the simplest method: the `customer` and `sales` tables are both partitioned by hash into 16 partitions, on the `s_customerid` and `c_customerid` columns. This partitioning method enables full partition-wise join when the tables are joined on `s_customerid` and `c_customerid`, both representing the same customer identification number. Because you are using the same hash function to distribute the same information (customer ID) into the same number of hash partitions, you can join the equivalent partitions. They are storing the same values.

In serial, this join is performed between pairs of matching hash partitions, one at a time. When one partition pair has been joined, the join of another partition pair begins. The join completes when the 16 partition pairs have been processed.

Note: A pair of matching hash partitions is defined as one partition with the same partition number from each table. For example, with full partition-wise joins we join partition 0 of Sales with partition 0 of customer, partition 1 of `sales` with partition 1 of `customer`, and so on.

Parallel execution of a full partition-wise join is a straightforward parallelization of the serial execution. Instead of joining one partition pair at a time, 16 partition pairs are joined in parallel by the 16 query servers. Figure 5–1 illustrates the parallel execution of a full partition-wise join.

Figure 5–1 Parallel Execution of a Full Partition-wise Join



In Figure 5–1, assume that the degree of parallelism and the number of partitions are the same, in other words, 16 for both. Defining more partitions than the degree of parallelism may improve load balancing and limit possible skew in the execution. If you have more partitions than query servers, when one query server completes the join of one pair of partitions, it requests that the query coordinator give it another pair to join. This process repeats until all pairs have been processed. This method enables the load to be balanced dynamically when the number of partition pairs is greater than the degree of parallelism, for example, 64 partitions with a degree of parallelism of 16.

Note: To guarantee an equal work distribution, the number of partitions should always be a multiple of the degree of parallelism.

In Oracle Real Application Cluster environments running on shared-nothing or MPP platforms, placing partitions on nodes is critical to achieving good scalability. To avoid remote I/O, both matching partitions should have affinity to the same node. Partition pairs should be spread over all nodes to avoid bottlenecks and to use all CPU resources available on the system.

Nodes can host multiple pairs when there are more pairs than nodes. For example, with an 8-node system and 16 partition pairs, each node receives two pairs.

See Also: *Oracle9i Real Application Clusters Concepts* for more information on data affinity

Composite - Hash This method is a variation of the hash-hash method. The `sales` table is a typical example of a table storing historical data. For all the reasons mentioned under the heading "When to Use Range Partitioning" on page 5-9, range is the logical initial partitioning method.

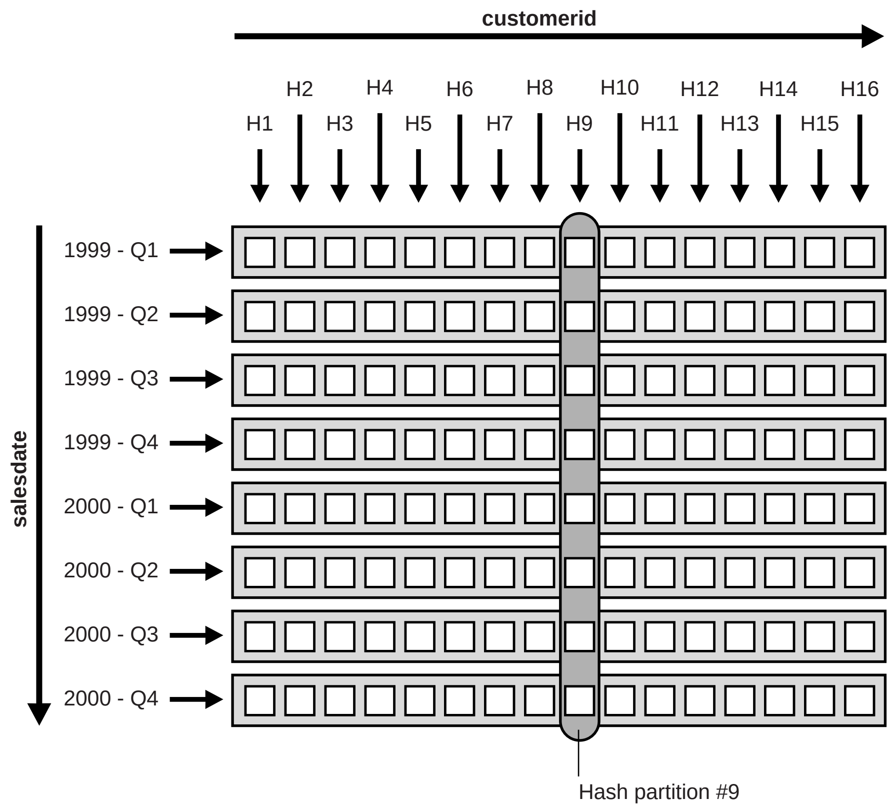
For example, assume you want to partition the `sales` table into eight partitions by range on the column `s_salesdate`. Also assume you have two years and that each partition represents a quarter. Instead of using range partitioning, you can use composite partitioning to enable a full partition-wise join while preserving the partitioning on `s_salesdate`. Partition the `sales` table by range on `s_salesdate` and then subpartition each partition by hash on `s_customerid` using 16 subpartitions per partition, for a total of 128 subpartitions. The `customer` table can still use hash partitioning with 16 partitions.

When you use the method just described, a full partition-wise join works similarly to the one created by the hash / hash method. The join is still divided into 16 smaller joins between hash partition pairs from both tables. The difference is that now each hash partition in the `sales` table is composed of a set of 8 subpartitions, one from each range partition.

Figure 5–2 illustrates how the hash partitions are formed in the `sales` table. Each cell represents a subpartition. Each row corresponds to one range partition, for a total of 8 range partitions. Each range partition has 16 subpartitions. Each column corresponds to one hash partition for a total of 16 hash partitions; each hash partition has 8 subpartitions. Note that hash partitions can be defined only if all partitions have the same number of subpartitions, in this case, 16.

Hash partitions are implicit in a composite table. However, Oracle does not record them in the data dictionary, and you cannot manipulate them with DDL commands as you can range partitions.

Figure 5–2 Range and Hash Partitions of A Composite Table



Composite-hash partitioning is effective because it lets you combine pruning (on `s_salesdate`) with a full partition-wise join (on `customerid`). In the previous example query, pruning is achieved by scanning only the subpartitions corresponding to Q3 of 1999, in other words, row number 3 in Figure 5–2. Oracle then joins these subpartitions with the customer table, using a full partition-wise join.

All characteristics of the hash-hash partition-wise join apply to the composite-hash partition-wise join. In particular, for this example, these two points are common to both methods:

- The degree of parallelism for this full partition-wise join cannot exceed 16. Even though the `sales` table has 128 subpartitions, it has only 16 hash partitions.

- The rules for data placement on MPP systems apply here. The only difference is that a hash partition is now a collection of subpartitions. You must ensure that all these subpartitions are placed on the same node as the matching hash partition from the other table. For example, in Figure 5–2, store hash partition 9 of the `sales` table shown by the eight circled subpartitions, on the same node as hash partition 9 of the `customer` table.

Composite - Composite (Hash Dimension) If needed, you can also partition the `customer` table by the composite method. For example, you partition it by range on a postal code column to enable pruning based on postal code. You then subpartition it by hash on `customerid` using the same number of partitions (16) to enable a partition-wise join on the hash dimension.

Range - Range You can also join range partitioned tables in a partition-wise manner, but this is relatively uncommon. This is more complex to implement because you must know the distribution of the data before performing the join. Furthermore, if you do not correctly identify the partition bounds so that you have partitions of equal size, data skew during the execution may result.

The basic principle for using range-range is the same as for using hash-hash: you must equipartition both tables. This means that the number of partitions must be the same and the partition bounds must be identical. For example, assume that you know in advance that you have 10 million customers, and that the values for `customerid` vary from 1 to 10,000,000. In other words, you have 10 million possible different values. To create 16 partitions, you can range partition both tables, `sales` on `c_customerid` and `customer` on `s_customerid`. You should define partition bounds for both tables in order to generate partitions of the same size. In this example, partition bounds should be defined as 625001, 1250001, 1875001, ... 10000001, so that each partition contains 625000 rows.

Range - Composite, Composite - Composite (Range Dimension) Finally, you can also subpartition one or both tables on another column. Therefore, the range/composite and composite/composite methods on the range dimension are also valid for enabling a full partition-wise join on the range dimension.

Partial Partition-wise Joins

Oracle can perform partial partition-wise joins only in parallel. Unlike full partition-wise joins, partial partition-wise joins require you to partition only one table on the join key, not both tables. The partitioned table is referred to as the reference table. The other table may or may not be partitioned. Partial partition-wise joins are more common than full partition-wise joins.

To execute a partial partition-wise join, Oracle dynamically repartitions the other table based on the partitioning of the reference table. Once the other table is repartitioned, the execution is similar to a full partition-wise join.

The performance advantage that partial partition-wise joins have over joins in non-partitioned tables is that the reference table is not moved during the join operation. Parallel joins between non-partitioned tables require both input tables to be redistributed on the join key. This redistribution operation involves exchanging rows between parallel execution servers. This is a CPU-intensive operation that can lead to excessive interconnect traffic in Oracle Real Application Cluster environments. Partitioning large tables on a join key, either a foreign or primary key, prevents this redistribution every time the table is joined on that key. Of course, if you choose a foreign key to partition the table, which is the most common scenario, select a foreign key that is involved in many queries.

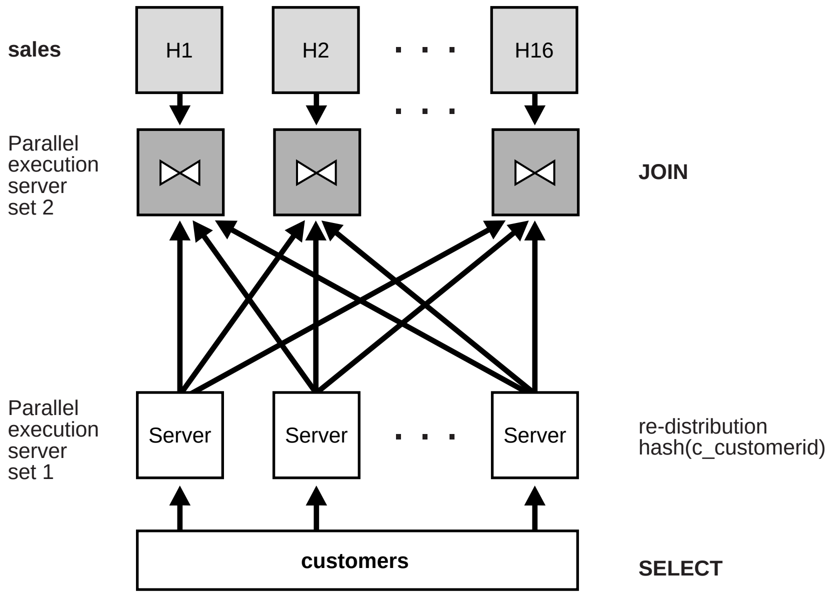
To illustrate partial partition-wise joins, consider the previous `sales/customer` example. Assume that `s_customer` is not partitioned or is partitioned on a column other than `c_customerid`. Because `sales` is often joined with `customer` on `customerid`, and because this join dominates our application workload, partition `sales` on `s_customerid` to enable partial partition-wise join every time `customer` and `sales` are joined. As in full partition-wise join, we have several alternatives:

Hash The simplest method to enable a partial partition-wise join is to partition `sales` by hash on `c_customerid`. The number of partitions determines the maximum degree of parallelism, because the partition is the smallest granule of parallelism for partial partition-wise join operations.

The parallel execution of a partial partition-wise join is illustrated in Figure 5–3, which assumes that both the degree of parallelism and the number of partitions of `sales` are 16. The execution involves two sets of query servers: one set, labeled *set 1* on the figure, scans the customer table in parallel. The granule of parallelism for the scan operation is a range of blocks.

Rows from `customer` that are selected by the first set, in this case all rows, are redistributed to the second set of query servers by hashing `customerid`. For example, all rows in `customer` that could have matching rows in partition `H1` of `sales` are sent to query server 1 in the second set. Rows received by the second set of query servers are joined with the rows from the corresponding partitions in `sales`. Query server number 1 in the second set joins all `customer` rows that it receives with partition `H1` of `sales`.

Figure 5–3   Partial Partition-wise Join


sales
H1
H2
H16
Parallel execution server set 2
JOIN
Parallel execution server set 1
Server
Server
Server
re-distribution hash(c_customerid)
customers
SELECT

Considerations for full partition-wise joins also apply to partial partition-wise joins:

- The degree of parallelism does not need to equal the number of partitions. In Figure 5–3, the query executes with two sets of 16 query servers. In this case, Oracle assigns 1 partition to each query server of the second set. Again, the number of partitions should always be a multiple of the degree of parallelism.
- In Oracle Real Application Cluster environments on shared-nothing platforms (MPPs), each hash partition of `sales` should preferably have affinity to only one node in order to avoid remote I/Os. Also, spread partitions over all nodes to avoid bottlenecks and use all CPU resources available on the system. A node can host multiple partitions when there are more partitions than nodes.

See Also: *Oracle9i Real Application Clusters Concepts* for more information on data affinity

Composite As with full partition-wise joins, the prime partitioning method for the sales table is to use the range method on column s_salesdate. This is because sales is a typical example of a table that stores historical data. To enable a partial partition-wise join while preserving this range partitioning, subpartition sales by hash on column s_customerid using 16 subpartitions per partition. Pruning and partial partition-wise joins can be used together if a query joins customer and sales and if the query has a selection predicate on s_salesdate.

When sales is composite, the granule of parallelism for a partial partition-wise join is a hash partition and not a subpartition. Refer to Figure 5–2 for an illustration of a hash partition in a composite table. Again, the number of hash partitions should be a multiple of the degree of parallelism. Also, on an MPP system, ensure that each hash partition has affinity to a single node. In the previous example, the eight subpartitions composing a hash partition should have affinity to the same node.

Range Finally, you can use range partitioning on s_customerid to enable a partial partition-wise join. This works similarly to the hash method, but a side effect of range partitioning is that the resulting data distribution could be skewed if the size of the partitions differs. Moreover, this method is more complex to implement because it requires prior knowledge of the values of the partitioning column that is also a join key.

Benefits of Partition-wise Joins

Partition-wise joins offer benefits described in this section:

- Reduction of Communications Overhead
- Reduction of Memory Requirements

Reduction of Communications Overhead When executed in parallel, partition-wise joins reduce communications overhead. This is because, in the default case, parallel execution of a join operation by a set of parallel execution servers requires the redistribution of each table on the join column into disjoint subsets of rows. These disjoint subsets of rows are then joined pair-wise by a single parallel execution server.

Oracle can avoid redistributing the partitions because the two tables are already partitioned on the join column. This enables each parallel execution server to join a pair of matching partitions.

This improved performance from using parallel execution is even more noticeable in Oracle Real Application Cluster configurations with internode parallel execution. Partition-wise joins dramatically reduce interconnect traffic. Using this feature is for large DSS configurations that use Oracle Real Application Clusters.

Currently, most Oracle Real Application Clusters platforms, such as MPP and SMP clusters, provide limited interconnect bandwidths compared with their processing powers. Ideally, interconnect bandwidth should be comparable to disk bandwidth, but this is seldom the case. As a result, most join operations in Oracle Real Application Clusters experience high interconnect latencies without parallel execution of partition-wise joins.

Reduction of Memory Requirements Partition-wise joins require less memory than the equivalent join operation of the complete data set of the tables being joined.

In the case of serial joins, the join is performed at the same time on a pair of matching partitions. If data is evenly distributed across partitions, the memory requirement is divided by the number of partitions. There is no skew.

In the parallel case, memory requirements depend on the number of partition pairs that are joined in parallel. For example, if the degree of parallelism is 20 and the number of partitions is 100, 5 times less memory is required because only 20 joins of two partitions are performed at the same time. The fact that partition-wise joins require less memory has a direct effect on performance. For example, the join probably does not need to write blocks to disk during the build phase of a hash join.

Performance Considerations for Parallel Partition-wise Joins

The cost-based optimizer weighs the advantages and disadvantages when deciding whether or not to use partition-wise joins.

- In range partitioning where partition sizes differ, data skew increases response time; some parallel execution servers take longer than others to finish their joins. Oracle recommends the use of hash (sub)partitioning to enable partition-wise joins because hash partitioning, if the number of partitions is a power of two, limits the risk of skew.

- The number of partitions used for partition-wise joins should, if possible, be a multiple of the number of query servers. With a degree of parallelism of 16, for example, you can have 16, 32, or even 64 partitions. If there is an even number of partitions, some parallel execution servers are used less than others. For example, if there are 17 evenly distributed partition pairs, only one pair will work on the last join, while the other pairs will have to wait. This is because, in the beginning of the execution, each parallel execution server works on a different partition pair. At the end of this first phase, only one pair is left. Thus, a single parallel execution server joins this remaining pair while all other parallel execution servers are idle.
- Sometimes, parallel joins can cause remote I/Os. For example, on Oracle Real Application Cluster environments running on MPP configurations, if a pair of matching partitions is not collocated on the same node, a partition-wise join requires extra internode communication due to remote I/O. This is because Oracle must transfer at least one partition to the node where the join is performed. In this case, it is better to explicitly redistribute the data than to use a partition-wise join.

6 Indexes

This chapter describes how to use indexes in a data warehousing environment and discusses the following types of index:

- Bitmap Indexes
- B-tree Indexes
- Local Indexes Versus Global Indexes

See Also: *Oracle9i Database Concepts* for general information regarding indexing

Bitmap Indexes

Bitmap indexes are widely used in data warehousing environments. The environments typically have large amounts of data and ad hoc queries, but a low level of concurrent DML transactions. For such applications, bitmap indexing provides:

- Reduced response time for large classes of ad hoc queries
- Reduced storage requirements compared to other indexing techniques
- Dramatic performance gains even on hardware with a relatively small number of CPUs or a small amount of memory
- Efficient maintenance during parallel DML and loads

Fully indexing a large table with a traditional B-tree index can be prohibitively expensive in terms of space because the indexes can be several times larger than the data in the table. Bitmap indexes are typically only a fraction of the size of the indexed data in the table.

Note: Bitmap indexes are available only if you have purchased the Oracle9*i* Enterprise Edition. See *Oracle9i Database New Features* for more information about the features available in Oracle9*i* and the Oracle9*i* Enterprise Edition.

An index provides pointers to the rows in a table that contain a given key value. A regular index stores a list of rowids for each key corresponding to the rows with that key value. In a bitmap index, a bitmap for each key value replaces a list of rowids.

Each bit in the bitmap corresponds to a possible rowid, and if the bit is set, it means that the row with the corresponding rowid contains the key value. A mapping function converts the bit position to an actual rowid, so that the bitmap index provides the same functionality as a regular index. If the number of different key values is small, bitmap indexes save space.

Bitmap indexes are most effective for queries that contain multiple conditions in the `WHERE` clause. Rows that satisfy some, but not all, conditions are filtered out before the table itself is accessed. This improves response time, often dramatically.

Benefits for Data Warehousing Applications

Bitmap indexes are primarily intended for data warehousing applications where users query the data rather than update it. They are not suitable for OLTP applications with large numbers of concurrent transactions modifying the data.

Parallel query and parallel DML work with bitmap indexes as they do with traditional indexes. Bitmap indexing also supports parallel create indexes and concatenated indexes.

> **See Also:** Chapter 17, "Schema Modeling Techniques" for further information about the usage of bitmap indexes in data warehousing environments

Cardinality

The advantages of using bitmap indexes are greatest for low cardinality columns in which the number of distinct values is small compared with the number of rows in the table. A gender column, which has only two distinct values (male and female), is ideal for a bitmap index. However, data warehouse administrators also build bitmap indexes on columns with higher cardinalities.

For example, on a table with one million rows, a column with 10,000 distinct values is a candidate for a bitmap index. A bitmap index on this column can out-perform a B-tree index, particularly when this column is often queried in conjunction with other indexed columns. In fact, in a typical data warehouse environments, a bitmap indexes can be considered for any non-unique column.

B-tree indexes are most effective for high-cardinality data: that is, for data with many possible values, such as `customer_name` or `phone_number`. In a data warehouse, B-tree indexes should be used only for unique columns or other columns with very high cardinalities (that is, columns that are almost unique). The majority of indexes in a data warehouse should be bitmap indexes.

In ad hoc queries and similar situations, bitmap indexes can dramatically improve query performance. `AND` and `OR` conditions in the `WHERE` clause of a query can be resolved quickly by performing the corresponding Boolean operations directly on the bitmaps before converting the resulting bitmap to rowids. If the resulting number of rows is small, the query can be answered quickly without resorting to a full table scan.

Example 6–1 Bitmap Index Example

The following shows a portion of a company's `customers` table.

```
SELECT cust_id, cust_gender, cust_marital_status, cust_income_level
FROM customers

CUST_ID    C CUST_MARITAL_STATUS  CUST_INCOME_LEVEL
---------- - -------------------- ---------------------
...
        70 F                      D: 70,000 - 89,999
        80 F married              H: 150,000 - 169,999
        90 M single               H: 150,000 - 169,999
       100 F                      I: 170,000 - 189,999
       110 F married              C: 50,000 - 69,999
       120 M single               F: 110,000 - 129,999
       130 M                      J: 190,000 - 249,999
       140 M married              G: 130,000 - 149,999
...
```

Because `cust_gender`, `cust_marital_status`, and cust_`income_level` are all low-cardinality columns (there are only three possible values for marital status and region, two possible values for gender, and 12 for income level), bitmap indexes are ideal for these columns. Do not create a bitmap index on `cust_id` because this is a unique column. Instead, a unique B-tree index on this column provides the most efficient representation and retrieval.

Table 6–1 illustrates the bitmap index for the `cust_gender` column in this example. It consists oftwo separate bitmaps, one for gender.

Table 6–1 Sample Bitmap Index

	gender='M'	gender='F'
cust_id 70	0	1
cust_id 80	0	1
cust_id 90	1	0
cust_id 100	0	1
cust_id 110	0	1
cust_id 120	1	0
cust_id 130	1	0
cust_id 140	1	0

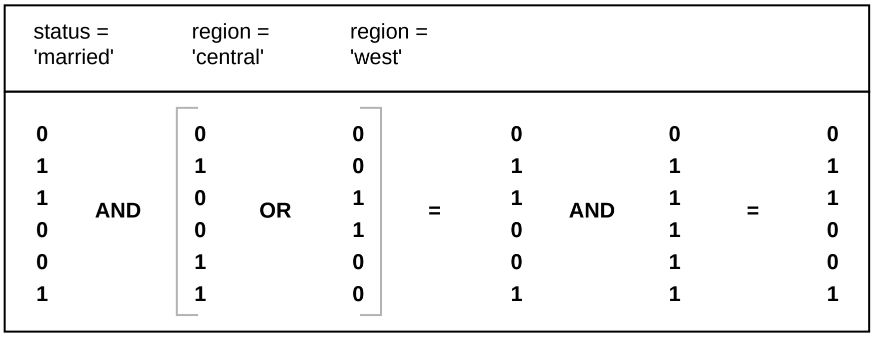
Each entry (or *bit*) in the bitmap corresponds to a single row of the customers table. The value of each bit depends upon the values of the corresponding row in the table. For instance, the bitmap cust_gender='F' contains a one as its first bit because the region is east in the first row of the customers table. The bitmap cust_gender='F' has a zero for its third bit because the gender of the third row is not F.

An analyst investigating demographic trends of the company's customers might ask, "How many of our married customers have an income level of G or H?" This corresponds to the following SQL query:

```
SELECT COUNT(*) FROM customers
WHERE cust_marital_status = 'married'
AND cust_income_level IN ('H: 150,000 - 169,999', 'G: 130,000 - 149,999');
```

Bitmap indexes can efficiently process this query by merely counting the number of ones in the bitmap illustrated in Figure 6–1. The result set will be found by using bitmap or merge operations without the necessity of a conversion to rowids. To identify additional specific customer attributes that satisfy the criteria, use the resulting bitmap to access the table after a bitmap to rowid conversion.

Figure 6–1 Executing a Query Using Bitmap Indexes



Bitmap Indexes and Nulls

Unlike most other types of indexes, bitmap indexes include rows that have NULL values. Indexing of nulls can be useful for some types of SQL statements, such as queries with the aggregate function COUNT.

Example 6–2 Bitmap Index Example

```
SELECT COUNT(*) FROM customers WHERE cust_marital_status IS NULL;
```

The above query will use a bitmap index on `cust_marital_status`. Note that this query would not be able to use a B-tree index.

```
SELECT COUNT(*) FROM emp;
```

Any bitmap index can be used for the above query because all table rows are indexed, including those that have `NULL` data. If nulls were not indexed, the optimizer would be able to use indexes only on columns with `NOT NULL` constraints.

Bitmap Indexes on Partitioned Tables

You can create bitmap indexes on partitioned tables but they must be local to the partitioned table—they cannot be global indexes. (Global bitmap indexes are supported only on nonpartitioned tables). Bitmap indexes on partitioned tables must be local indexes.

See Also: "Index Partitioning" on page 5-8 for more information

Bitmap Join Indexes

In addition to a bitmap index on a single table, you can create a bitmap join index, which is a bitmap index for the join of two or more tables. A bitmap join index is a space efficient way of reducing the volume of data that must be joined by performing restrictions in advance. For each value in a column of a table, a bitmap join index stores the rowids of corresponding rows in one or more other tables. In a data warehousing environment, the join condition is an equi-inner join between the primary key column or columns of the dimension tables and the foreign key column or columns in the fact table.

Bitmap join indexes are much more efficient in storage than materialized join views, an alternative for materializing joins in advance. This is because the materialized join views do not compress the rowids of the fact tables.

Example 6–3   Bitmap Join Index: Example 1

Using the example in "Bitmap Index Example" on page 6-4, create a bitmap join index with the following `sales` table:

```
SELECT time_id, cust_id, amount FROM sales;

TIME_ID    CUST_ID    AMOUNT
--------- ---------- ----------
01-JAN-98      29700       2291
01-JAN-98       3380        114
01-JAN-98      67830        553
01-JAN-98     179330          0
01-JAN-98     127520        195
01-JAN-98      33030        280
...

CREATE BITMAP INDEX sales_cust_gender_bjix
ON sales(customers.cust_gender)
FROM sales, customers
WHERE sales.cust_id = customers.cust_id
LOCAL;
```

The following query shows how to use the above bitmap join index and illustrates its bitmap pattern:

```
SELECT sales.time_id, customers.cust_gender, sales.amount
FROM sales, customers
WHERE sales.cust_id = customers.cust_id

TIME_ID   C AMOUNT
--------- - ----------
01-JAN-98 M       2291
01-JAN-98 F        114
01-JAN-98 M        553
01-JAN-98 M          0
01-JAN-98 M        195
01-JAN-98 M        280
01-JAN-98 M         32
...
```

Table 6–2 illustrates the bitmap join index in this example:

Table 6–2 Sample Bitmap Join Index

	cust_gender='M'	cust_gender='F'
sales record 1	1	0
sales record 2	0	1
sales record 3	1	0
sales record 4	1	0
sales record 5	1	0
sales record 6	1	0
sales record 7	1	0

You can create other bitmap join indexes using more than one column or more than one table, as shown in the below examples.

Example 6–4 Bitmap Join Index: Example 2

You can create a bitmap join index on more than one column, as in the following example, which uses `customers(gender, marital status)`:

```
CREATE BITMAP INDEX sales_cust_gender_ms_bjix
ON sales(customers.cust_gender, customers.cust_marital_status)
FROM sales, customers
WHERE sales.cust_id = customers.cust_id
LOCAL NOLOGGING;
```

Example 6–5 Bitmap Join Index: Example 3

You can create a bitmap join index on more than one table, as in the following, which uses `customers(gender)` and `products(category)`:

```
CREATE BITMAP INDEX sales_c_gender_p_cat_bjix
ON sales(customers.cust_gender, products.prod_category)
FROM sales, customers, products
WHERE sales.cust_id = customers.cust_id
AND sales.prod_id = products.prod_id
LOCAL NOLOGGING;
```

Example 6–6 Bitmap Join Index: Example 4

You can create a bitmap join index on more than one table, in which the indexed column is joined to the indexed table by using another table. For example, we can build an index on `countries.country_name`, even though the `countries` table is not joined directly to the `sales` table. Instead, the `countries` table is joined to the `customers` table, which is joined to the sales table. This type of schema is commonly called a **snowflake** schema.

```
CREATE BITMAP INDEX sales_c_gender_p_cat_bjix
ON sales(customers.cust_gender, products.prod_category)
FROM sales, customers, products
WHERE sales.cust_id = customers.cust_id
AND sales.prod_id = products.prod_id
LOCAL NOLOGGING;
```

Bitmap Join Index Restrictions

Join results must be stored, therefore, bitmap join indexes have the following restrictions:

- Parallel DML is currently only supported on the fact table. Parallel DML on one of the participating dimension tables will mark the index as unusable.
- Only one table can be updated concurrently by different transactions when using the bitmap join index.
- No table can appear twice in the join.
- You cannot create a bitmap join index on an index-organized table or a temporary table.
- The columns in the index must all be columns of the dimension tables.
- The dimension table join columns must be either primary key columns or have unique constraints.
- If a dimension table has composite primary key, each column in the primary key must be part of the join.

See Also: *Oracle9i SQL Reference* for further details

B-tree Indexes

A B-tree index is organized like an upside-down tree. The bottom level of the index holds the actual data values and pointers to the corresponding rows, much as the index in a book has a page number associated with each index entry.

See Also: *Oracle9i Database Concepts* for an explanation of B-tree structures

In general, you use B-tree indexes when you know that your typical query refers to the indexed column and retrieves a few rows. In these queries, it is faster to find the rows by looking at the index. However, using the book index analogy, if you plan to look at every single topic in a book, you might not want to look in the index for the topic and then look up the page. It might be faster to read through every chapter in the book. Similarly, if you are retrieving most of the rows in a table, it might not make sense to look up the index to find the table rows. Instead, you might want to read or scan the table.

B-tree indexes are most commonly used in a data warehouse to index unique or near-unique keys. In many cases, it may not be necessary to index these columns in a data warehouse, because unique constraints can be maintained without an index, and because typical data warehouse queries may not work better with such indexes. Bitmap indexes should be more common than B-tree indexes in most data warehouse environments.

Local Indexes Versus Global Indexes

B-tree indexes on partitioned tables can be global or local. With Oracle8*i* and earlier releases, Oracle recommended that global indexes not be used in data warehouse environments because a partition DDL statement (for example, `ALTER TABLE ... DROP PARTITION`) would invalidate the entire index, and rebuilding the index is expensive. In Oracle9*i*, global indexes can be maintained without Oracle marking them as unusable after DDL. This enhancement makes global indexes more effective for data warehouse environments.

However, local indexes will be more common than global indexes. Global indexes should be used when there is a specific requirement which cannot be met by local indexes (for example, a unique index on a non-partitioning key, or a performance requirement).

Bitmap indexes on partitioned tables are always local.

See Also: "Types of Partitioning" on page 5-4 for further details

7 Integrity Constraints

This chapter describes integrity constraints, and discusses:

- Why Integrity Constraints are Useful in a Data Warehouse
- Overview of Constraint States
- Typical Data Warehouse Integrity Constraints

Why Integrity Constraints are Useful in a Data Warehouse

Integrity constraints provide a mechanism for ensuring that data conforms to guidelines specified by the database administrator. The most common types of constraints include:

- `UNIQUE` constraints

  To ensure that a given column is unique
- `NOT NULL` constraints

  To ensure that no null values are allowed
- `FOREIGN KEY` constraints

  To ensure that two keys share a primary key to foreign key relationship

Constraints can be used for these purposes in a data warehouse:

- Data cleanliness

  Constraints verify that the data in the data warehouse conforms to a basic level of data consistency and correctness, preventing the introduction of dirty data.
- Query optimization

  The Oracle database utilizes constraints when optimizing SQL queries. Although constraints can be useful in many aspects of query optimization, constraints are particularly important for query rewrite of materialized views.

Unlike data in many relational database environments, data in a data warehouse is typically added or modified under controlled circumstances during the extraction, transformation, and loading (ETL) process. Multiple users normally do not update the data warehouse directly, as they do in an OLTP system.

> **See Also:** Chapter 10, "Overview of Extraction, Transformation, and Loading"

Many significant constraint features have been introduced for data warehousing. Readers familiar with Oracle's constraint functionality in Oracle7 and Oracle8 should take special note of the functionality described in this chapter. In fact, many Oracle7-based and Oracle8-based data warehouses lacked constraints because of concerns about constraint performance. Newer constraint functionality addresses these concerns.

Overview of Constraint States

To understand how best to use constraints in a data warehouse, you should first understand the basic purposes of constraints:

- Enforcement

  In order to use a constraint for enforcement, the constraint must be in the `ENABLE` state. An enabled constraint ensures that all data modifications upon a given table (or tables) satisfy the conditions of the constraints. Data modification operations which produce data that violates the constraint fail with a constraint violation error.

- Validation

  To use a constraint for validation, the constraint must be in the `VALIDATE` state. If the constraint is validated, then all data that currently resides in the table satisfies the constraint.

  Note that validation is independent of enforcement. Although the typical constraint in an operational system is both enabled and validated, any constraint could be validated but not enabled or vice versa (enabled but not validated). These latter two cases are useful for data warehouses.

- Belief

  In some cases, you will know that the conditions for a given constraint are true, so you do not need to validate or enforce the constraint. However, you may wish for the constraint to be present anyway to improve query optimization and performance. When you use a constraint in this way, it is called a belief or `RELY` constraint, and the constraint must be in the `RELY` state. The `RELY` state provides you with a mechanism for telling Oracle9*i* that a given constraint is believed to be true.

  Note that the `RELY` state only affects constraints that have not been validated.

Typical Data Warehouse Integrity Constraints

This section assumes that you are familiar with the typical use of constraints. That is, constraints that are both enabled and validated. For data warehousing, many users have discovered that such constraints may be prohibitively costly to build and maintain. The topics discussed are:

- UNIQUE Constraints in a Data Warehouse
- FOREIGN KEY Constraints in a Data Warehouse
- RELY Constraints
- Integrity Constraints and Parallelism
- Integrity Constraints and Partitioning
- View Constraints

UNIQUE Constraints in a Data Warehouse

A UNIQUE constraint is typically enforced using a UNIQUE index. However, in a data warehouse whose tables can be extremely large, creating a unique index can be costly both in processing time and in disk space.

Suppose that a data warehouse contains a table sales, which includes a column sales_id. sales_id uniquely identifies a single sales transaction, and the data warehouse administrator must ensure that this column is unique within the data warehouse.

One way to create the constraint is:

```
ALTER TABLE sales ADD CONSTRAINT sales_unique
  UNIQUE(prod_id, cust_id, time_id, channel_id);
```

By default, this constraint is both enabled and validated. Oracle implicitly creates a unique index on sales_id to support this constraint. However, this index can be problematic in a data warehouse for three reasons:

- The unique index can be very large, because the sales table can easily have millions or even billions of rows.
- The unique index is rarely used for query execution. Most data warehousing queries do not have predicates on unique keys, so creating this index will probably not improve performance.

- If `sales` is partitioned along a column other than `sales_id`, the unique index must be global. This can detrimentally affect all maintenance operations on the `sales` table.

A unique index is required for unique constraints to ensure that each individual row modified in the `sales` table satisfies the `UNIQUE` constraint.

For data warehousing tables, an alternative mechanism for unique constraints is:

```
ALTER TABLE sales ADD CONSTRAINT sales_unique
  UNIQUE (prod_id, cust_id, time_id, channel_id) DISABLE VALIDATE;
```

This statement creates a unique constraint, but, because the constraint is disabled, a unique index is not required. This approach can be advantageous for many data warehousing environments because the constraint now ensures uniqueness without the cost of a unique index.

However, there are trade-offs for the data warehouse administrator to consider with `DISABLE VALIDATE` constraints. Because this constraint is disabled, no DML statements that modify the unique column are permitted against the `sales` table. You can use one of two strategies for modifying this table in the presence of a constraint:

- Use DDL to add data to this table (such as exchanging partitions). See the example in Chapter 14, "Maintaining the Data Warehouse".
- Before modifying this table, drop the constraint. Then, make all necessary data modifications. Finally, re-create the disabled constraint. Re-creating the constraint is more efficient than re-creating an enabled constraint. However, this approach does not guarantee that data added to the `sales` table while the constraint has been dropped is unique.

FOREIGN KEY Constraints in a Data Warehouse

In a star schema data warehouse, `FOREIGN KEY` constraints validate the relationship between the fact table and the dimension tables. A sample constraint might be:

```
ALTER TABLE sales ADD CONSTRAINT sales_time_fk
  FOREIGN KEY (time_id) REFERENCES time (time_id)
  ENABLE VALIDATE;
```

However, in some situations, a data warehouse administrator may choose to use a different state for the FOREIGN KEY constraints, in particular, the ENABLE NOVALIDATE state. A data warehouse administrator might use an ENABLE NOVALIDATE constraint when either:

- The tables contain data that currently disobeys the constraint, but the data warehouse administrator wishes to create a constraint for future enforcement.
- An enforced constraint is required immediately.

Suppose that the data warehouse loaded new data into the fact tables every day, but refreshed the dimension tables only on the weekend. During the week, the dimension tables and fact tables may in fact disobey the FOREIGN KEY constraints. Nevertheless, the data warehouse administrator might wish to maintain the enforcement of this constraint to prevent any changes that might affect the FOREIGN KEY constraint outside of the ETL process. Thus, you can create the FOREIGN KEY constraints every night, after performing the ETL process, as shown here:

```
ALTER TABLE sales ADD CONSTRAINT sales_time_fk
  FOREIGN KEY (sales_time_id) REFERENCES time (time_id)
  ENABLE NOVALIDATE;
```

ENABLE NOVALIDATE can quickly create an enforced constraint, even when the constraint is believed to be true. Suppose that the ETL process verifies that a FOREIGN KEY constraint is true. Rather than have the database re-verify this FOREIGN KEY constraint, which would require time and database resources, the data warehouse administrator could instead create a FOREIGN KEY constraint using ENABLE NOVALIDATE.

RELY Constraints

The ETL process commonly verifies that certain constraints are true. For example, it can validate all of the foreign keys in the data coming into the fact table. This means that you can trust it to provide clean data, instead of implementing constraints in the data warehouse. You create a RELY constraint as follows:

```
ALTER TABLE sales ADD CONSTRAINT sales_time_fk
  FOREIGN KEY (sales_time_id) REFERENCES time (time_id)
  RELY DISABLE NOVALIDATE;
```

RELY constraints, even though they are not used for data validation, can:

- Enable more sophisticated query rewrites for materialized views. See Chapter 22, "Query Rewrite", for further details.
- Enable other data warehousing tools to retrieve information regarding constraints directly from the Oracle data dictionary.

Creating a RELY constraint is inexpensive and does not impose any overhead during DML or load. Because the constraint is not being validated, no data processing is necessary to create it.

Integrity Constraints and Parallelism

All constraints can be validated in parallel. When validating constraints on very large tables, parallelism is often necessary to meet performance goals. The degree of parallelism for a given constraint operation is determined by the default degree of parallelism of the underlying table.

Integrity Constraints and Partitioning

You can create and maintain constraints before you partition the data. Later chapters discuss the significance of partitioning for data warehousing. Partitioning can improve constraint management just as it does to management of many other operations. For example, Chapter 14, "Maintaining the Data Warehouse", provides a scenario creating UNIQUE and FOREIGN KEY constraints on a separate staging table, and these constraints are maintained during the EXCHANGE PARTITION statement.

View Constraints

You can create constraints on views. The only type of constraint supported on a view is a RELY constraint.

This type of constraint is useful when queries typically access views instead of base tables, and the DBA thus needs to define the data relationships between views rather than tables. View constraints are particularly useful in OLAP environments, where they may enable more sophisticated rewrites for materialized views.

> **See Also:** Chapter 8, "Materialized Views" and Chapter 22, "Query Rewrite"

8 Materialized Views

This chapter introduces you to the use of materialized views and discusses:

Overview of Data Warehousing with Materialized Views

Typically, data flows from one or more online transaction processing (OLTP) databases into a data warehouse on a monthly, weekly, or daily basis. The data is normally processed in a **staging file** before being added to the data warehouse. Data warehouses commonly range in size from tens of gigabytes to a few terabytes. Usually, the vast majority of the data is stored in a few very large fact tables.

One technique employed in data warehouses to improve performance is the creation of summaries. Summaries are special kinds of aggregate views that improve query execution times by precalculating expensive joins and aggregation operations prior to execution and storing the results in a table in the database. For example, you can create a table to contain the sums of sales by region and by product.

The summaries or aggregates that are referred to in this book and in literature on data warehousing are created in Oracle using a schema object called a **materialized view**. Materialized views can perform a number of roles, such as improving query performance or providing replicated data.

Prior to Oracle8*i*, organizations using summaries spent a significant amount of time creating summaries manually, identifying which summaries to create, indexing the summaries, updating them, and advising their users on which ones to use. The introduction of summary management in Oracle8*i* eases the workload of the database administrator and means the end user no longer has to be aware of the summaries that have been defined. The database administrator creates one or more materialized views, which are the equivalent of a summary. The end user queries the tables and views in the database. The query rewrite mechanism in the Oracle server automatically rewrites the SQL query to use the summary tables. This mechanism reduces response time for returning results from the query. Materialized views within the data warehouse are transparent to the end user or to the database application.

Although materialized views are usually accessed through the query rewrite mechanism, an end user or database application can construct queries that directly access the summaries. However, serious consideration should be given to whether users should be allowed to do this because any change to the summaries will affect the queries that reference them.

Materialized Views for Data Warehouses

In data warehouses, you can use materialized views to precompute and store aggregated data such as the sum of sales. Materialized views in these environments are often referred to as summaries, because they store summarized data. They can also be used to precompute joins with or without aggregations. A materialized view eliminates the overhead associated with expensive joins and aggregations for a large or important class of queries.

Materialized Views for Distributed Computing

In distributed environments, you can use materialized views to replicate data at distributed sites and to synchronize updates done at those sites with conflict resolution methods. The materialized views as replicas provide local access to data that otherwise would have to be accessed from remote sites. Materialized views are also useful in remote data marts.

> **See Also:** *Oracle9i Replication* and *Oracle9i Heterogeneous Connectivity Administrator's Guide* for details on distributed and mobile computing

Materialized Views for Mobile Computing

You can also use materialized views to download a subset of data from central servers to mobile clients, with periodic refreshes and updates between clients and the central servers.

This chapter focuses on the use of materialized views in data warehouses.

> **See Also:** *Oracle9i Replication* and *Oracle9i Heterogeneous Connectivity Administrator's Guide* for details on distributed and mobile computing

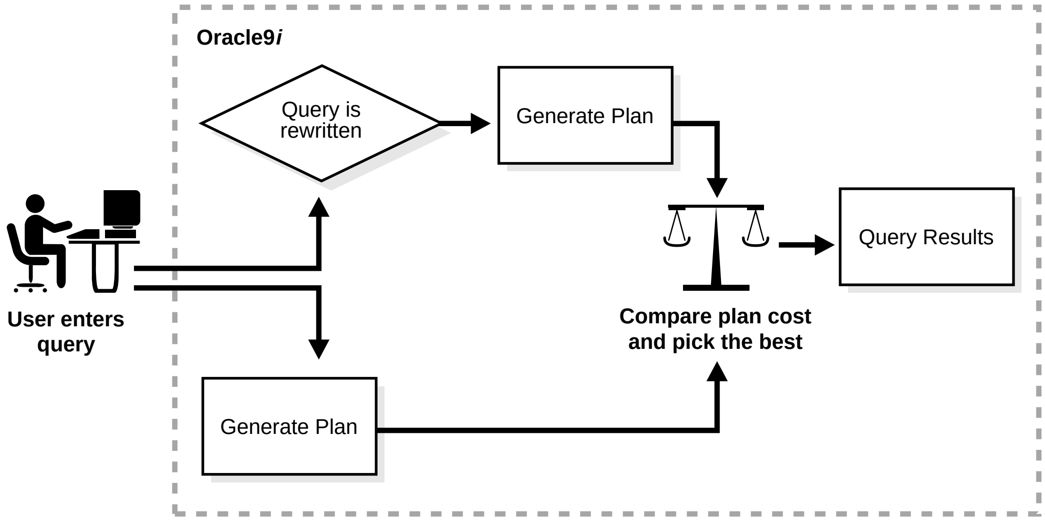
The Need for Materialized Views

Use materialized views in data warehouses to increase the speed of queries on very large databases. Queries to large databases often involve joins between tables, aggregations such as `SUM`, or both. These operations are expensive in terms of time and processing power. The type of materialized view you create determines how the materialized view is refreshed and used by query rewrite.

You can use materialized views in a number of ways, and you can use almost identical syntax to perform a number of roles. For example, a materialized view can replicate data, a process formerly achieved by using the `CREATE SNAPSHOT` statement. Now `CREATE MATERIALIZED VIEW` is a synonym for `CREATE SNAPSHOT`.

Materialized views improve query performance by precalculating expensive join and aggregation operations on the database prior to execution and storing the results in the database. The query optimizer automatically recognizes when an existing materialized view can and should be used to satisfy a request. It then transparently rewrites the request to use the materialized view. Queries go directly to the materialized view and not to the underlying detail tables. In general, rewriting queries to use materialized views rather than detail tables improves response.

Figure 8–1 Transparent Query Rewrite



When using query rewrite, create materialized views that satisfy the largest number of queries. For example, if you identify 20 queries that are commonly applied to the detail or fact tables, then you might be able to satisfy them with five or six well-written materialized views. A materialized view definition can include any number of aggregations (`SUM`, `COUNT(x)`, `COUNT(*)`, `COUNT(DISTINCT x)`, `AVG`, `VARIANCE`, `STDDEV`, `MIN`, and `MAX`). It can also include any number of joins. If you are unsure of which materialized views to create, Oracle provides a set of advisory procedures in the `DBMS_OLAP` package to help in designing and evaluating materialized views for query rewrite. These functions are also known as the Summary Advisor or the Advisor.

If a materialized view is to be used by query rewrite, it must be stored in the same database as the fact or detail tables on which it relies. A materialized view can be partitioned, and you can define a materialized view on a partitioned table. You can also define one or more indexes on the materialized view.

Unlike indexes, materialized views can be accessed directly using a `SELECT` statement.

Note: The techniques shown in this chapter illustrate how to use materialized views in data warehouses. Materialized views can also be used by Oracle Replication. See *Oracle9i Replication* for further information.

Components of Summary Management

Summary management consists of:

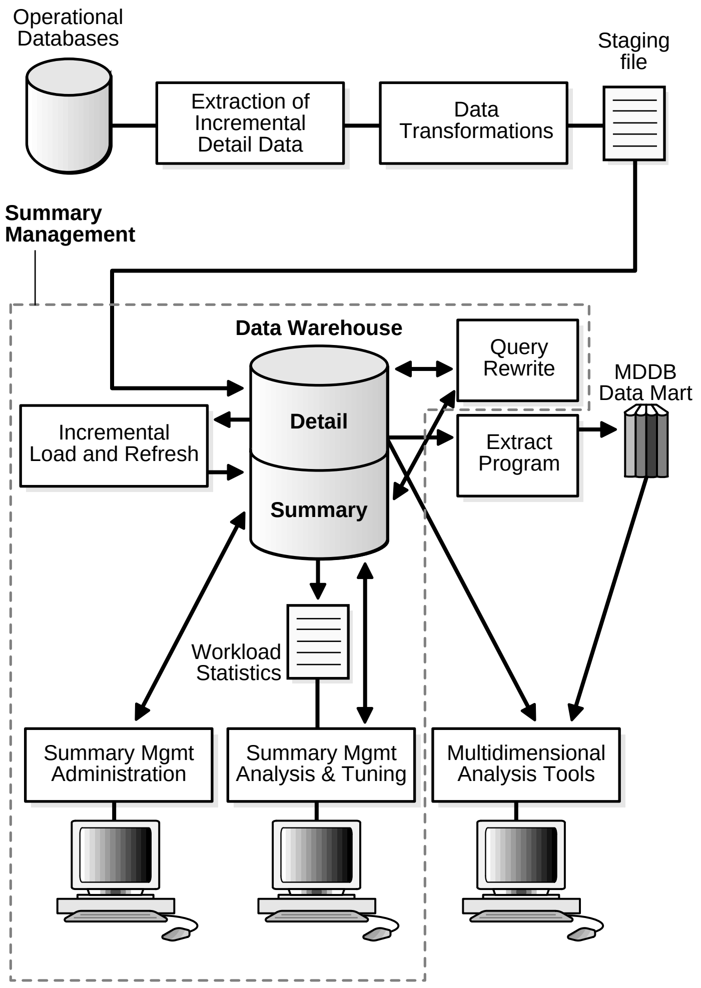
- Mechanisms to define materialized views and dimensions
- A refresh mechanism to ensure that all materialized views contain the latest data
- A query rewrite capability to transparently rewrite a query to use a materialized view
- A collection of materialized view analysis and advisory functions and procedures in the `DBMS_OLAP` package. Collectively, these functions are called the Summary Advisor, and are also available as part of Oracle Enterprise Manager.

See Also: Chapter 16, "Summary Advisor"

Many large decision support system (DSS) databases have schemas that do not closely resemble a conventional data warehouse schema, but that still require joins and aggregates. The use of summary management features imposes no schema restrictions, and can enable some existing DSS database applications to improve performance without the need to redesign the database or the application.

Figure 8–2 illustrates the use of summary management in the warehousing cycle. After the data has been transformed, staged, and loaded into the detail data in the warehouse, you can invoke the summary management process. First, use the Advisor to plan how you will use summaries. Then, create summaries and design how queries will be rewritten.

Figure 8–2 Overview of Summary Management



Understanding the summary management process during the earliest stages of data warehouse design can yield large dividends later in the form of higher performance, lower summary administration costs, and reduced storage requirements.

Hierarchies describe the business relationships and common access patterns in the database. An analysis of the dimensions, combined with an understanding of the typical work load, can be used to create materialized views.

Terminology

Some basic data warehousing terms are defined here:

- **Dimension tables** describe the business entities of an enterprise, represented as hierarchical, categorical information such as time, departments, locations, and products. Dimension tables are sometimes called **lookup** or **reference tables**.

  Dimension tables usually change slowly over time and are not modified on a periodic schedule. They are used in long-running decision support queries to aggregate the data returned from the query into appropriate levels of the dimension hierarchy.

  See Also: Chapter 9, "Dimensions"

- **Fact tables** describe the business transactions of an enterprise. Fact tables are sometimes called **detail tables**.

  The vast majority of data in a data warehouse is stored in a few very large fact tables that are updated periodically with data from one or more operational online transaction processing (OLTP) databases.

  Fact tables include **measures** such as sales, units, and inventory.

  – A simple measure is a numeric or character column of one table such as `fact.sales`.

  – A computed measure is an expression involving measures of one table, for example, `fact.revenues - fact.expenses`.

  – A multitable measure is a computed measure defined on multiple tables, for example, `fact_a.revenues - fact_b.expenses`.

  Fact tables also contain one or more foreign **keys** that organize the business transactions by the relevant business entities such as time, product, and market. In most cases, these foreign keys are non-null, form a unique compound key of the fact table, and each foreign key joins with exactly one row of a **dimension table**.

- A **materialized view** is a precomputed table comprising aggregated and joined data from fact and possibly from dimension tables. Among builders of data warehouses, a materialized view is also known as a **summary** or **aggregation**.

Schema Design Guidelines for Materialized Views

Summary management can perform many useful functions, including query rewrite and materialized view refresh, even if your data warehouse design does not follow these guidelines. However, you will realize significantly greater query execution performance and materialized view refresh performance benefits and you will require fewer materialized views if your schema design complies with these guidelines.

A materialized view definition includes any number of aggregates, as well as any number of joins. In several ways, a materialized view behaves like an index:

- The purpose of a materialized view is to increase query execution performance.
- The existence of a materialized view is transparent to SQL applications, so that a DBA can create or drop materialized views at any time without affecting the validity of SQL applications.
- A materialized view consumes storage space.
- The contents of the materialized view must be updated when the underlying detail tables are modified.

In the case of normalized or partially normalized dimensions (a dimension that is stored in more than one table), identify how these tables are joined. Note whether the joins between the dimension tables can guarantee that each child-side row joins with one and only one parent-side row. In the case of denormalized dimensions, determine whether the child-side columns uniquely determine the parent-side (or attribute) columns. These relationships can be enabled with constraints, using the `NOVALIDATE` and `RELY` options if the relationships represented by the constraints are guaranteed by other means. Note that if the joins between fact and dimension tables do not support this relationship, you still gain significant performance advantages from defining the dimension with the `CREATE DIMENSION` statement. Another alternative, subject to some restrictions, is to use outer joins in the materialized view definition (that is, in the `CREATE MATERIALIZED VIEW` statement).

You must not create dimensions in any schema that does not satisfy these relationships. Incorrect results can be returned from queries otherwise.

See Also: Chapter 9, "Dimensions"

Before starting to define and use the various components of summary management, you should review your schema design to abide by the following guidelines wherever possible:

Guideline 1: Dimensions should either be denormalized (each dimension contained in one table) or the joins between tables in a normalized or partially normalized dimension should guarantee that each child-side row joins with exactly one parent-side row. The benefits of maintaining this condition are described in "Creating Dimensions" on page 9-4.

You can enforce this condition by adding FOREIGN KEY and NOT NULL constraints on the child-side join keys and PRIMARY KEY constraints on the parent-side join keys.

Guideline 2: If dimensions are denormalized or partially denormalized, hierarchical integrity must be maintained between the key columns of the dimension table. Each child key value must uniquely identify its parent key value, even if the dimension table is denormalized. Hierarchical integrity in a denormalized dimension can be verified by calling the VALIDATE_DIMENSION procedure of the DBMS_OLAP package.

Guideline 3: Fact and dimension tables should similarly guarantee that each fact table row joins with exactly one dimension table row. This condition must be declared, and optionally enforced, by adding FOREIGN KEY and NOT NULL constraints on the fact key column(s) and PRIMARY KEY constraints on the dimension key column(s), or by using outer joins as described in Guideline 1. In a data warehouse, constraints are typically enabled with the NOVALIDATE and RELY clauses to avoid constraint enforcement performance overhead. See *Oracle9i SQL Reference* for further details.

Guideline 4: Incremental loads of your detail data should be done using the SQL*Loader direct-path option, or any bulk loader utility that uses Oracle's direct-path interface. This includes INSERT ... AS SELECT with the APPEND or PARALLEL hints, where the hints cause the direct loader log to be used during the insert. See *Oracle9i SQL Reference* and "Types of Materialized Views" on page 8-10.

Guideline 5: Range/composite partition your tables by a monotonically increasing the time column if possible (preferably of type DATE).

Guideline 6: After each load and before refreshing your materialized view, use the VALIDATE_DIMENSION procedure of the DBMS_MVIEW package to incrementally verify dimensional integrity.

Guideline 7: If a time dimension appears in the materialized view as a time column, partition and index the materialized view in the same manner as you have the fact tables. Include a local concatenated index on all the materialized view keys.

Guidelines 1 and 2 are more important than guideline 3. If your schema design does not follow guidelines 1 and 2, it does not then matter whether it follows guideline 3. Guidelines 1, 2, and 3 affect both query rewrite performance and materialized view refresh performance.

If you are concerned with the time required to enable constraints and whether any constraints might be violated, use the `ENABLE NOVALIDATE` with the `RELY` clause to turn on constraint checking without validating any of the existing constraints. The risk with this approach is that incorrect query results could occur if any constraints are broken. Therefore, as the designer, you must determine how clean the data is and whether the risk of wrong results is too great.

Types of Materialized Views

The `SELECT` clause in the materialized view creation statement defines the data that the materialized view is to contain. Only a few restrictions limit what can be specified. Any number of tables can be joined together. However, they cannot be remote tables if you wish to take advantage of query rewrite. Besides tables, other elements such as views, inline views (subqueries in the `FROM` clause of a `SELECT` statement), subqueries, and materialized views can all be joined or referenced in the `SELECT` clause.

The types of materialized views are:

- Materialized Views with Aggregates
- Materialized Views Containing Only Joins

Materialized Views with Aggregates

In data warehouses, materialized views normally contain aggregates as shown in Example 8–1 below. For fast refresh to be possible, the `SELECT` list must contain all of the `GROUP BY` columns (if present), and there must be a `COUNT(*)` and a `COUNT(column)` on any aggregated columns. Also, materialized view logs must be present on all tables referenced in the query that defines the materialized view. The valid aggregate functions are: `SUM`, `COUNT(x)`, `COUNT(*)`, `AVG`, `VARIANCE`, `STDDEV`, `MIN`, and `MAX`, and the expression to be aggregated can be any SQL value expression.

See Also: "Restrictions on Fast Refresh on Materialized Views with Aggregates" on page 8-28

Fast refresh for a materialized view containing joins and aggregates is possible after any type of DML to the base tables (direct load or conventional `INSERT`, `UPDATE`, or `DELETE`). It can be defined to be refreshed `ON COMMIT` or `ON DEMAND`. A `REFRESH ON COMMIT`, materialized view will be refreshed automatically when a transaction that does DML to one of the materialized views commits. The time taken to complete the commit may be slightly longer than usual when this method is chosen. This is because the refresh operation is performed as part of the commit process. Therefore, this method may not be suitable if many users are concurrently changing the tables upon which the materialized view is based.

Here are some examples of materialized views with aggregates. Note that materialized view logs are only created because this materialized view will be fast refreshed.

Example 8–1 Creating a Materialized View: Example 1

```
CREATE MATERIALIZED VIEW LOG ON products
WITH SEQUENCE, ROWID
(prod_id, prod_name, prod_desc, prod_subcategory, prod_subcat_desc,   prod_
category, prod_cat_desc, prod_weight_class, prod_unit_of_measure, prod_pack_
size, supplier_id, prod_status, prod_list_price, prod_min_price)
INCLUDING NEW VALUES;

CREATE MATERIALIZED VIEW LOG ON sales
WITH SEQUENCE, ROWID
(prod_id, cust_id, time_id, channel_id, promo_id, quantity_sold,
amount, cost)
INCLUDING NEW VALUES;

CREATE MATERIALIZED VIEW product_sales_mv
PCTFREE 0  TABLESPACE demo
STORAGE (initial 8k next 8k pctincrease 0)
BUILD IMMEDIATE
REFRESH FAST
ENABLE QUERY REWRITE
AS  SELECT p.prod_name, SUM(amount) AS dollar_sales,
COUNT(*) AS cnt, COUNT(amount) AS cnt_amt
FROM sales s, products p
WHERE s.prod_id = p.prod_id
              GROUP BY prod_name;
```

The statement above creates a materialized view `product_sales_mv` that computes total number and value of sales for a product. It is derived by joining the tables `sales` and `products` on the column `prod_id`. The materialized view is populated with data immediately because the build method is immediate and it is available for use by query rewrite. In this example, the default refresh method is `FAST`, which is allowed because the appropriate materialized view logs have been created on tables `product` and `sales`.

Example 8–2 Creating a Materialized View: Example 2

```
CREATE MATERIALIZED VIEW store_sales_mv
  PCTFREE 0 TABLESPACE mviews
  STORAGE (initial 16k next 16k pctincrease 0)
  BUILD DEFERRED
  REFRESH COMPLETE ON DEMAND
  ENABLE QUERY REWRITE
  AS
  SELECT
   s.store_name,
     SUM(dollar_sales) AS sum_dollar_sales
      FROM store s, fact f
      WHERE f.store_key = s.store_key
      GROUP BY s.store_name;
```

Example 8–2 creates a materialized view `store_sales_mv` that computes the sum of sales by `store`. It is derived by joining the tables `store` and `fact` on the column `store_key`. The materialized view does not initially contain any data, because the build method is `DEFERRED`. A complete refresh is required for the first refresh of a build deferred materialized view. When it is refreshed and once populated, this materialized view can be used by query rewrite.

Example 8–3 Creating a Materialized View: Example 3

```
CREATE MATERIALIZED VIEW LOG ON fact
  WITH ROWID (store_key, time_key, dollar_sales, unit_sales)
  INCLUDING NEW VALUES;

CREATE MATERIALIZED VIEW sum_sales
  PARALLEL
  BUILD IMMEDIATE
  REFRESH FAST ON COMMIT
  AS
  SELECT f.store_key, f.time_key,
         COUNT(*) AS count_grp,
  SUM(f.dollar_sales) AS sum_dollar_sales,
        COUNT(f.dollar_sales) AS count_dollar_sales,
  SUM(f.unit_sales) AS sum_unit_sales,
        COUNT(f.unit_sales) AS count_unit_sales
  FROM fact f
  GROUP BY f.store_key, f.time_key;
```

This example creates a materialized view that contains aggregates on a single table. Because the materialized view log has been created, the materialized view is fast refreshable. If DML is applied against the fact table, then the changes will be reflected in the materialized view when the commit is issued.

Table 8–1 illustrates the aggregate requirements for materialized views.

Table 8–1 Single-Table Aggregate Requirements

If aggregate X is present, aggregate Y is required and aggregate Z is optional		
X	**Y**	**Z**
`COUNT(expr)`	-	-
`SUM(expr)`	`COUNT(expr)`	-
`AVG(expr)`	`COUNT(expr)`	`SUM(expr)`

`STDDEV(expr)`	`COUNT(expr)`
	`SUM(expr)`
		`SUM(expr * expr)`

`VARIANCE(expr)`	`COUNT(expr)`
	`SUM(expr)`
		`SUM(expr * expr)`

Note that `COUNT(*)` must always be present. Oracle recommends that you include the optional aggregates in column Z in the materialized view in order to obtain the most efficient and accurate fast refresh of the aggregates.

Materialized Views with Multiple Aggregation Groups for OLAP

Oracle9*i* enables a single materialized view to contain multiple aggregate groups. A materialized view holding multiple aggregate groups supports On-Line Analytical Processing (OLAP) needs well. OLAP environments require fast response time for analytical queries under multiuser workloads. Typically, OLAP queries compare aggregates at different levels of granularity. For efficient processing of these queries, it is common to precompute all possible levels of aggregation and store them in materialized views.

When a single materialized view stores all the levels of aggregation needed in an OLAP environment, it enables efficient creation and data refresh.

Materialized views for OLAP environments have the following characteristics:

- They contain joins of all the base tables (fact table and dimension tables in a typical star schema)
- They create multiple aggregate groupings using GROUPING SETS, ROLLUP, or CUBE in the GROUP BY clause of the query definition. These grouping features are described in Chapter 18, "SQL for Aggregation in Data Warehouses".
- To enable fast refresh or general query rewrite on such a materialized view, the SELECT list includes a GROUPING_ID function using all the GROUP BY expressions as its arguments.

Example 8–4 Materialized Views with Aggregation for OLAP

Below is an example of a materialized view suited to OLAP needs, containing multiple aggregate groups. The materialized view is created using the GROUPING SETS extension to the GROUP BY clause. The example presents a retail database with a sample schema and some materialized views to illustrate how materialized views with aggregation for OLAP can be created.

```
/*the following tables and their columns*/
STORE   (store_key, store_name, store_city, store_state, store_country)
TIME    (time_key, time_day, time_week, time_month)
FACT    (store_key, prod_key, time_key, dollar_sales)

CREATE MATERIALIZED VIEW sales_mv
REFRESH FAST ON DEMAND
ENABLE QUERY REWRITE
AS
SELECT store_country, store_state, store_city,
       prod_category, prod_subcategory, prod_name,
       GROUPING_ID(store_country, store_state, store_city,
                   prod_category, prod_subcategory, prod_name) gid
       SUM(dollar_sales) s_sales,
       COUNT(dollar_sales) c_sales,
       COUNT(*) c_star
FROM sales s, product p, store st
WHERE   s.store_id = st.store_id and s.prod_id = p.prod_id
GROUP BY GROUPING SETS
  ((store_country, store_state, store_city),
   (store_country, prod_category, prod_subcategory, prod_name),
   (prod_category, prod_subcategory, prod_name),(store_country, prod_category));
```

This is a materialized view that stores aggregates at four different levels. Queries can be rewritten to use this materialized view if they require one or more these groupings.

The creation and fast refresh of such a materialized view is very efficient as all the joins are factored out (and hence, computed only once) and some groupings can be derived from other groupings, rather than going to the joined base data. For example, group (`store_country`, `prod_category`) can be computed from (`store_country`, `prod_category`, `prod_subcategory`, `prod_name`). In addition to creation and refresh efficiency, a single database object containing all the required groupings can be easier to manage than many materialized views each holding just one aggregate group.

If an OLAP environment's queries cover the full range of aggregate groupings possible in its data set, it may be best to materialize the whole hierarchical cube. This means that each dimension's aggregation hierarchy is precomputed in combination with each of the other dimensions. Naturally, precomputing a full hierarchical cube requires more disk space and higher creation and refresh times than a small set of aggregate groups. The trade-off in processing time and disk space versus query performance needs to be factored in before deciding to create it. Example 8–5 is an example of a hierarchical materialized view:

Example 8–5 Hierarchical Materialized View Example

```
CREATE MATERIALIZED VIEW sales_hierarchical_cube_mv
REFRESH FAST ON DEMAND
ENABLE QUERY REWRITE
AS
SELECT store_country, store_state, store_city, prod_category, prod_subcategory,
prod_name, time_month, time_week, time_day,
   GROUPING_ID(store_country, store_state, store_city,
      prod_category, prod_subcategory, prod_name, time_month,
      time_week, time_day) gid
                   SUM(dollar_sales) s_sales,
                   COUNT(dollar_sales) c_sales,
                   COUNT(*) c_star
FROM sales s, product p, store st, time t
WHERE   s.store_id = st.store_id and s.prod_id = p.prod_id and s.time_id
= t.time_id
GROUP BY
     ROLLUP(store_country, store_state, store_city),
     ROLLUP(prod_category, prod_subcategory, prod_name),
     ROLLUP(time_month, time_week, time_day);
```

The materialized view sales_hierarchical_cube_mv above is a superset of the materialized view sales_mv. sales_hierarchical_cube_mv in Example 8–4 contains the many groupings generated by the concatenated ROLLUPs in its GROUP BY clause.

Materialized views with multiple aggregate groups will give their best performance when partitioned appropriately. The most effective partitioning scheme for these materialized views is to use composite partitioning. For the top level partitioning, use LIST partitioning with the GROUPING_ID column. For the subpartitioning, use whichever column best fits the data distribution characteristics.

By partitioning the materialized views this way, you enable partition pruning for queries rewritten against this materialized view: only relevant aggregate groups will be accessed, greatly reducing the query processing cost.

Materialized Views Containing Only Joins

Some materialized views contain only joins and no aggregates, such as in Example 8–6, where a materialized view is created that joins the fact table to the store table. The advantage of creating this type of materialized view is that expensive joins will be precalculated.

Fast refresh for a materialized view containing only joins is possible after any type of DML to the base tables (direct-path or conventional INSERT, UPDATE, or DELETE).

A materialized view containing only joins can be defined to be refreshed ON COMMIT or ON DEMAND. If it is ON COMMIT, the refresh is performed at commit time of the transaction that does DML on the materialized view's detail table. Oracle does not allow self-joins in materialized join views.

If you specify REFRESH FAST, Oracle performs further verification of the query definition to ensure that fast refresh can be performed if *any* of the detail tables change. These additional checks are:

1. A materialized view log must be present for each detail table.
2. The rowids of all the detail tables must appear in the SELECT list of the materialized view query definition.
3. If there are no outer joins, you may have arbitrary selections and joins in the WHERE clause. However, if there are outer joins, the WHERE clause cannot have any selections. Further, if there are outer joins, all the joins must be connected by ANDs and must use the equality (=) operator.

4. If there are outer joins, unique constraints must exist on the join columns of the inner table. For example, if you are joining the fact and a dimension table and the join is an outer join with the fact table being the outer table, there must exist unique constraints on the join columns of the dimension table.

If some of the above restrictions are not met, you can create the materialized view as `REFRESH FORCE` to take advantage of fast refresh when it is possible. If the materialized view is created as `ON COMMIT`, Oracle performs all of the fast refresh checks. If one of the tables did not meet all of the criteria, but the other tables did, the materialized view would still be fast refreshable with respect to the other tables for which all the criteria are met.

A materialized view log should contain the rowid of the master table. It is not necessary to add other columns.

To speed up refresh, you should create indexes on the materialized view's columns that store the rowids of the fact table.

Example 8–6 Materialized View Containing Only Joins Example

```
CREATE MATERIALIZED VIEW LOG ON fact
  WITH ROWID;

CREATE MATERIALIZED VIEW LOG ON time
  WITH ROWID;

CREATE MATERIALIZED VIEW LOG ON store
  WITH ROWID;

CREATE MATERIALIZED VIEW detail_fact_mv
       PARALLEL BUILD IMMEDIATE
       REFRESH FAST
       AS
       SELECT
    f.rowid "fact_rid", t.rowid "time_rid", s.rowid "store_rid",
      s.store_key, s.store_name, f.dollar_sales,
      f.unit_sales, f.time_key
       FROM fact f, time t, store s
       WHERE f.store_key = s.store_key(+) AND
       f.time_key = t.time_key(+);
```

In this example, in order to perform a fast refresh, `UNIQUE` constraints should exist on `s.store_key` and `t.time_key`. You should also create indexes on the columns `fact_rid`, `time_rid`, and `store_rid`, as illustrated below. This will improve the refresh performance.

```
CREATE INDEX mv_ix_factrid
  ON detail_fact_mv(fact_rid);
```

Alternatively, if the example shown above did not include the columns `time_rid` and `store_rid`, and if the refresh method was `REFRESH FORCE`, then this materialized view would be fast refreshable only if the fact table was updated but not if the tables time or store were updated.

```
CREATE MATERIALIZED VIEW detail_fact_mv
       PARALLEL
       BUILD IMMEDIATE
       REFRESH FORCE
       AS
       SELECT
    f.rowid "fact_rid",
      s.store_key, s.store_name, f.dollar_sales,
      f.unit_sales, f.time_key
       FROM fact f, time t, store s
       WHERE f.store_key = s.store_key(+) AND
      f.time_key = t.time_key(+);
```

Nested Materialized Views

A nested materialized view is a materialized view whose definition is based on another materialized view. A nested materialized view can reference other relations in the database in addition to referencing materialized views.

Why Use Nested Materialized Views?

In a data warehouse, you typically create many aggregate views on a single join (for example, rollups along different dimensions). Incrementally maintaining these distinct materialized aggregate views can take a long time, because the underlying join has to be performed many times. By using nested materialized views, the join is performed just once (while maintaining the materialized view containing joins only). Incremental maintenance of single-table aggregate materialized views is very fast due to the self-maintenance refresh operations on this class of views.

Example 8–7 Nested Materialized View Example

You can create a materialized view containing joins only or a single-table aggregate materialized view on a single table on top of the following:

- materialized view containing joins only
- single-table aggregate materialized view

- complex materialized view (a materialized view on which Oracle cannot perform fast refresh)
- base table

All the underlying objects (materialized views or tables) on which the materialized view is defined must have a materialized view log. All the underlying objects are treated as if they were tables. All the existing options for materialized views containing joins only and single-table aggregate materialized views can be used. Thus, ON COMMIT REFRESH is supported for these types of nested materialized views.

Using the tables and their columns from Example 8–4 on page 8-14, the following materialized views illustrate how nested materialized views can be created.

```
/* create the materialized view logs */
CREATE MATERIALIZED VIEW LOG ON fact
  WITH ROWID;
CREATE MATERIALIZED VIEW LOG ON store
  WITH ROWID;
CREATE MATERIALIZED VIEW LOG ON time
  WITH ROWID;

/*create materialized join view join_fact_store_time as fast refreshable at
   COMMIT time */
CREATE MATERIALIZED VIEW join_fact_store_time
REFRESH FAST ON COMMIT AS
SELECT s.store_key, s.store_name, f.dollar_sales, t.time_key, t.time_day,
       f.prod_key, f.rowid frid, t.rowid trid, s.rowid srid
FROM fact f, store s, time t
WHERE f.time_key = t.time_key AND
      f.store_key = s.store_key;
```

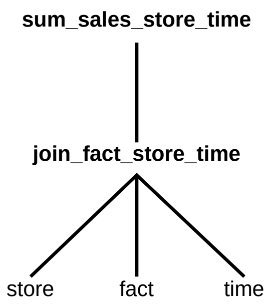
To create a nested materialized view on the table join_fact_store_time, you would have to create a materialized view log on the table. Because this will be a single-table aggregate materialized view on join_fact_store_time, you need to log all the necessary columns and use the INCLUDING NEW VALUES clause.

```
/* create materialized view log on join_fact_store_time */
CREATE MATERIALIZED VIEW LOG ON join_fact_store_time
  WITH rowid (store_name, time_day, dollar_sales)
  INCLUDING new values;
```

```
/* create the single-table aggregate materialized view sum_sales_store_time on
   join_fact_store_time as fast refreshable at COMMIT time. */
CREATE MATERIALIZED VIEW sum_sales_store_time
  REFRESH FAST ON COMMIT
  AS
  SELECT COUNT(*) cnt_all, SUM(dollar_sales) sum_sales, COUNT(dollar_sales)
         cnt_sales, store_name, time_day
  FROM join_fact_store_time
  GROUP BY store_name, time_day;
```

This schema can be diagrammatically represented as in Figure 8–3.

Figure 8–3 Nested Materialized View Schema



Nesting Materialized Views with Joins and Aggregates

Materialized views with joins and aggregates can be nested if they are refreshed as COMPLETE REFRESH. Thus, you can arbitrarily nest materialized views having joins and aggregates. No FAST REFESH is possible for these materialized views.

Note that the ON COMMIT REFRESH clause is not available for complex materialized views. Because you have to invoke the refresh functions manually, ordering has to be taken into account. This is because the refresh for a materialized view that is built on other materialized views will use the current state of the other materialized views, whether they are fresh or not. You can find the dependent materialized views for a particular object using the PL/SQL function GET_MV_DEPENDENCIES in the DBMS_MVIEW package.

Nested Materialized View Usage Guidelines

You should keep a couple of points in mind when deciding whether to use nested materialized views.

1. If you do not need the `REFRESH FAST` clause, then you can define a nested materialized view.
2. Materialized views with joins only and single-table aggregate materialized views can be `REFRESH FAST` and nested if all the materialized views that they depend on are either materialized join views or single-table aggregate materialized views.

Here are some guidelines on how to use nested materialized views:

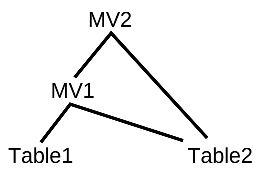
1. If you want to use fast refresh, you should fast refresh all the materialized views along any chain. It makes little sense to define a fast refreshable materialized view on top of a materialized view that must be refreshed with a complete refresh.
2. When using materialized views, you can define them to be `ON COMMIT` or `ON DEMAND`. The choice would depend on the application using the materialized views. If you expect the materialized views to always remain fresh, then all the materialized views should have the `ON COMMIT` refresh option. If the time window for refresh does not permit refreshing all the materialized views at commit time, then the appropriate materialized views could be created with (or altered to have) the `ON DEMAND` refresh option.

Restrictions when Using Nested Materialized Views

Only nested materialized join views and nested single-table aggregate materialized views can use fast refresh. If you want complete refresh for all of your materialized views, then you can still nest these materialized views.

Some restrictions exist on the way you can nest materialized views. Oracle allows nesting a materialized view only when all the immediate dependencies of the materialized view do not have any dependencies among themselves. Thus, in the dependency tree, a materialized view can never be a parent as well as a grandparent of an object. For example, Figure 8–4 shows an impermissible materialized view because `MV2` is both a parent and grandparent of `Table2`.

Figure 8–4 Nested Materialized View Restriction



Limitations of Nested Materialized Views

Nested materialized views incur the space overhead of materializing the join and having a materialized view log. In contrast, materialized aggregate views do not have demanding space requirements for the materialized join view and its log, but they have relatively long refresh times due to multiple computations of the same join.

Creating Materialized Views

A materialized view can be created with the `CREATE MATERIALIZED VIEW` statement or using Oracle Enterprise Manager. Example 8–8 creates the materialized view `store_sales_mv`.

Example 8–8 Creating a Materialized View Example

```
CREATE MATERIALIZED VIEW store_sales_mv
  PCTFREE 0 TABLESPACE mviews
  STORAGE (INITIAL 16k NEXT 16k PCTINCREASE 0)
  PARALLEL
  BUILD IMMEDIATE
  REFRESH COMPLETE
  ENABLE QUERY REWRITE
  AS
  SELECT  s.store_name,
     SUM(dollar_sales) AS sum_dollar_sales
     FROM store s, fact f
     WHERE f.store_key = s.store_key
     GROUP BY s.store_name;
```

It is not uncommon in a data warehouse to have already created summary or aggregation tables, and you might not wish to repeat this work by building a new materialized view. In this case, the table that already exists in the database can be registered as a **prebuilt** materialized view. This technique is described in "Registering Existing Materialized Views" on page 8-32.

Once you have selected the materialized views you want to create, follow the steps below for each materialized view.

1. Design the materialized view. Existing user-defined materialized views do not require this step. If the materialized view contains many rows, then, if appropriate, the materialized view should be partitioned by a time attribute (if possible) and should match the partitioning of the largest or most frequently updated detail or fact table (if possible). Refresh performance benefits from partitioning, because it can take advantage of parallel DML capabilities.
2. Use the `CREATE MATERIALIZED VIEW` statement to create and, optionally, populate the materialized view. If a user-defined materialized view already exists, then use the `ON PREBUILT TABLE` clause in the `CREATE MATERIALIZED VIEW` statement. Otherwise, use the `BUILD IMMEDIATE` clause to populate the materialized view immediately, or the `BUILD DEFERRED` clause to populate the materialized view later. A `BUILD DEFERRED` materialized view is disabled for use by query rewrite until the first `REFRESH`, after which it will be automatically enabled, provided the `ENABLE QUERY REWRITE` clause has been specified.

   See Also: *Oracle9i SQL Reference* for descriptions of the SQL statements `CREATE MATERIALIZED VIEW`, `ALTER MATERIALIZED VIEW`, and `DROP MATERIALIZED VIEW`

Naming

The name of a materialized view must conform to standard Oracle naming conventions. However, if the materialized view is based on a user-defined prebuilt table, then the name of the materialized view must exactly match that table name.

If you already have a naming convention for tables and indexes, you might consider extending this naming scheme to the materialized views so that they are easily identifiable. For example, instead of naming the materialized view `sum_of_sales`, it could be called `sum_of_sales_mv` to denote that this is a materialized view and not a table or view.

Storage Characteristics

Unless the materialized view is based on a user-defined prebuilt table, it requires and occupies storage space inside the database. Therefore, the storage needs for the materialized view should be specified in terms of the tablespace where it is to reside and the size of the extents.

If you do not know how much space the materialized view will require, then the DBMS_OLAP.ESTIMATE_SIZE package, which is described in Chapter 16, "Summary Advisor", can estimate the number of bytes required to store this materialized view. This information can then assist the design team in determining the tablespace in which the materialized view should reside.

> **See Also:** *Oracle9i SQL Reference* for a complete description of STORAGE semantics

Build Methods

Two build methods are available for creating the materialized view, as shown in the following table. If you select BUILD IMMEDIATE, the materialized view definition is added to the schema objects in the data dictionary, and then the fact or detail tables are scanned according to the SELECT expression and the results are stored in the materialized view. Depending on the size of the tables to be scanned, this build process can take a considerable amount of time.

An alternative approach is to use the BUILD DEFERRED clause, which creates the materialized view without data, thereby enabling it to be populated at a later date using the DBMS_MVIEW.REFRESH package described in Chapter 14, "Maintaining the Data Warehouse".

Build Method	Description
BUILD IMMEDIATE	Create the materialized view and then populate it with data.
BUILD DEFERRED	Create the materialized view definition but do not populate it with data.

Enabling Query Rewrite

Before creating a materialized view, you can verify what types of query rewrite are possible by calling the procedure DBMS_MVIEW.EXPLAIN_MVIEW. Once the materialized view has been created, you can use DBMS_MVIEW.EXPLAIN_REWRITE to find out if (or why not) it will rewrite a specific query.

Even though a materialized view is defined, it will not automatically be used by the query rewrite facility. You must set the QUERY_REWRITE_ENABLED initialization parameter to TRUE before using query rewrite. You also must specify the ENABLE

QUERY REWRITE clause if the materialized view is to be considered available for rewriting queries.

If this clause is omitted or specified as DISABLE QUERY REWRITE when the materialized view is created, the materialized view can subsequently be enabled for query rewrite with the ALTER MATERIALIZED VIEW statement.

If you define a materialized view as BUILD DEFERRED, it is not eligible for query rewrite until it is populated with data.

Query Rewrite Restrictions

Query rewrite is not possible with all materialized views. If query rewrite is not occurring when expected, check to see if your materialized view satisfies all of the following conditions.

Materialized View Restrictions

1. The defining query of the materialized view cannot contain any non-repeatable expressions (ROWNUM, SYSDATE, non-repeatable PL/SQL functions, and so on).
2. The query cannot contain any references to RAW or LONG RAW datatypes or object REFs.
3. The defining query of the materialized view cannot contain set operators (UNION, MINUS, and so on). However, a materialized view can have multiple query blocks (for example, inline views in the FROM clause and subselects in the WHERE or HAVING clauses).
4. If the materialized view was registered as PREBUILT, the precision of the columns must agree with the precision of the corresponding SELECT expressions unless overridden by the WITH REDUCED PRECISION clause.
5. If the materialized view contains the same table more than once, it is now possible to do a general rewrite, provided the query has the same aliases for the duplicate tables as the materialized view.

Query Rewrite Restrictions

1. If a query has both local and remote tables, only local tables will be considered for potential rewrite.
2. Neither the detail tables nor the materialized view can be owned by SYS.
3. SELECT and GROUP BY lists, if present, must be the same in the query of the materialized view.

4. Aggregate functions must occur only as the outermost part of the expression. That is, aggregates such as `AVG(AVG(x))` or `AVG(x)+ AVG(x)` are not allowed.
5. `CONNECT BY` clauses are not allowed.

Refresh Options

When you define a materialized view, you can specify two refresh options: how to refresh and what type of refresh. If unspecified, the defaults are assumed as `ON DEMAND` and `FORCE`.

The two refresh execution modes are: `ON COMMIT` and `ON DEMAND`. Depending on the materialized view you create, some of the options may not be available.

Refresh Mode	Description
`ON COMMIT`	Refresh occurs automatically when a transaction that modified one of the materialized view's detail tables commits. This can be specified as long as the materialized view is fast refreshable (in other words, not complex). The `ON COMMIT` privilege is necessary to use this mode.
`ON DEMAND`	Refresh occurs when a user manually executes one of the available refresh procedures contained in the `DBMS_MVIEW` package (`REFRESH`, `REFRESH_ALL_MVIEWS`, `REFRESH_DEPENDENT`).

When a materialized view is maintained using the `ON COMMIT` method, the time required to complete the commit may be slightly longer than usual. This is because the refresh operation is performed as part of the commit process. Therefore this method may not be suitable if many users are concurrently changing the tables upon which the materialized view is based.

If you anticipate performing insert, update or delete operations on tables referenced by a materialized view concurrently with the refresh of that materialized view, and that materialized view includes joins and aggregation, Oracle recommends you use `ON COMMIT` fast refresh rather than `ON DEMAND` fast refresh.

If you think the materialized view did not refresh, check the alert log or trace file.

If a materialized view fails during refresh at `COMMIT` time, you must explicitly invoke the refresh procedure using the `DBMS_MVIEW` package after addressing the errors specified in the trace files. Until this is done, the view will no longer be refreshed automatically at commit time.

You can specify how you want your materialized views to be refreshed from the detail tables by selecting one of four options: COMPLETE, FAST, FORCE, and NEVER.

Refresh Option	Description
COMPLETE	Refreshes by recalculating the materialized view's defining query.
FAST	Applies incremental changes to refresh the materialized view using the information logged in the materialized view logs, or from a SQL*Loader direct-path or a partition maintenance operation.
FORCE	Applies FAST refresh if possible; otherwise, it applies COMPLETE refresh.
NEVER	Indicates that the materialized view will not be refreshed with the Oracle refresh mechanisms.

Whether the fast refresh option is available depends upon the type of materialized view. You can call the procedure DBMS_MVIEW.EXPLAIN_MVIEW to determine whether fast refresh is possible. Fast refresh is available for both general classes of materialized views:

- Materialized views with joins only
- Materialized views with aggregates

General Restrictions on Fast Refresh

The defining query of the materialized view is restricted as follows:

- The materialized view must:

  Not contain references to non-repeating expressions like SYSDATE and ROWNUM.

  Not contain references to RAW or LONG RAW data types.

Restrictions on Fast Refresh on Materialized Views without Aggregates

Defining queries for materialized views with joins only and no aggregates have these restrictions on fast refresh:

- All restrictions from "General Restrictions on Fast Refresh" on page 8-27.
- They cannot have GROUP BY clauses or aggregates.
- If the WHERE clause of the query contains outer joins, then unique constraints must exist on the join columns of the inner join table.

- If there are no outer joins, you can have arbitrary selections and joins in the WHERE clause. However, if there are outer joins, the WHERE clause cannot have any selections. Furthermore, if there are outer joins, all the joins must be connected by ANDs and must use the equality (=) operator.
- Rowids of all the tables in the FROM list must appear in the SELECT list of the query.
- Materialized view logs must exist with rowids for all the base tables in the FROM list of the query.

Restrictions on Fast Refresh on Materialized Views with Aggregates

Defining queries for materialized views with joins and aggregates have these restrictions on fast refresh:

- All restrictions from "General Restrictions on Fast Refresh" on page 8-27.

Fast refresh is supported for both ON COMMIT and ON DEMAND materialized views, however the following restrictions apply:

1. All tables in the materialized view must have materialized view logs, and the materialized view logs must:
   - contain all columns from the table referenced in the materialized view.
   - specify with ROWID and INCLUDING NEW VALUES.
   - The SEQUENCE clause is required when the materialized view log is defined in order to support fast refresh after UPDATE.
2. Only SUM, COUNT, AVG, STDDEV, VARIANCE, MIN and MAX are supported for fast refresh.
3. COUNT(*) must be specified.
4. For each aggregate AGG(expr), the corresponding COUNT(expr) must be present.
5. If VARIANCE(expr) or STDDEV(expr) is specified, COUNT(expr) and SUM(expr) must be specified. Oracle recommends that SUM(expr *expr) be specified. See Table 8–1 on page 8-13 for further details.
6. The SELECT list must contain all GROUP BY columns.
7. If the materialized view has one of the following, then fast refresh is supported on conventional DML inserts or direct loads or a combination of both but not on deletes or updates.

- Materialized views with MIN or MAX aggregates
- Materialized views which have SUM(expr) but no COUNT(expr)
- Materialized views without COUNT(*)

8. The COMPATIBILITY parameter must be set to 9.0 if the materialized aggregate view has inline views, outer joins, self joins or grouping sets and FAST REFRESH is specified during creation. Note that all other requirements for fast refresh specified above must also be satisfied.
9. Materialized views with named views or subqueries in the FROM clause can be fast refreshed provided the views can be completely merged. For information on which views will merge, refer to the *Oracle9i Database Performance Guide and Reference*.
10. Materialized aggregate views with self joins (that is, multiple instances of the same table in the defining query) are fast refreshable after conventional DML and direct loads. The two tables will be treated as if they were separate tables.
11. If there are no outer joins, you may have arbitrary selections and joins in the WHERE clause.
12. Materialized aggregate views with outer joins are fast refreshable after conventional DML and direct loads, provided only the outer table has been modified. Also, unique constraints must exist on the join columns of the inner join table. If there are outer joins, all the joins must be connected by ANDs and must use the equality (=) operator.
13. For materialized views with CUBE, ROLLUP, Grouping Sets, or concatenation of them, the following restrictions apply:
    1. The SELECT list should contain grouping distinguisher that can either be a GROUPING_ID function on all GROUP BY expressions or GROUPING functions one for each GROUP BY expression. For example, if the GROUP BY clause of the materialized view is "GROUP BY CUBE(a, b)", then the SELECT list should contain either "GROUPING_ID(a, b)" or "GROUPING(a) AND GROUPING(b)" for the materialized view to be fast refreshable.
    2. GROUP BY should not result in any duplicate groupings. For example, "GROUP BY a, ROLLUP(b, a)" is not fast refreshable because it results in duplicate groupings "(a, b), (a, b), AND (a)".

ORDER BY Clause

An ORDER BY clause is allowed in the CREATE MATERIALIZED VIEW statement. It is used only during the initial creation of the materialized view. It is not used during a full refresh or a fast refresh.

To improve the performance of queries against large materialized views, store the rows in the materialized view in the order specified in the ORDER BY clause. This initial ordering provides physical clustering of the data. If indexes are built on the columns by which the materialized view is ordered, accessing the rows of the materialized view using the index often reduces the time for disk I/O due to the physical clustering.

The ORDER BY clause is not considered part of the materialized view definition. As a result, there is no difference in the manner in which Oracle detects the various types of materialized views (for example, materialized join views with no aggregates). For the same reason, query rewrite is not affected by the ORDER BY clause. This feature is similar to the CREATE TABLE ... ORDER BY capability that exists in Oracle.

Materialized View Logs

Materialized view logs are required if you want to use fast refresh. They are defined using a CREATE MATERIALIZED VIEW LOG statement on the base table that is to be changed. They are not created on the materialized view. For fast refresh of materialized views, the definition of the materialized view logs must specify the ROWID clause. In addition, for aggregate materialized views, it must also contain every column in the table referenced in the materialized view, the INCLUDING NEW VALUES clause and the SEQUENCE clause.

An example of a materialized view log is shown below where one is created on the table sales.

```
CREATE MATERIALIZED VIEW LOG ON sales
WITH ROWID
(prod_id, cust_id, time_id, channel_id, promo_id,
 quantity_sold, amount, cost)
INCLUDING NEW VALUES;
```

The keyword SEQUENCE is new for Oracle9*i* and Oracle recommends that this clause be included in your materialized view log statement unless you are sure that you will never perform a mixed DML operation (a combination of INSERT, UPDATE, or DELETE operations on multiple tables).

The boundary of a mixed DML operation is determined by whether the materialized view is ON COMMIT or ON DEMAND.

- For ON COMMIT, the mixed DML statements occur within the same transaction because the refresh of the materialized view will occur upon commit of this transaction.
- For ON DEMAND, the mixed DML statements occur between refreshes. An example of a materialized view log is shown below where one is created on the table sales that includes the SEQUENCE keyword.

```
CREATE MATERIALIZED VIEW LOG ON sales
WITH SEQUENCE, ROWID
(prod_id, cust_id, time_id, channel_id, promo_id,
 quantity_sold, amount, cost)
INCLUDING NEW VALUES;
```

Using Oracle Enterprise Manager

A materialized view can also be created using Oracle Enterprise Manager by selecting the materialized view object type. There is no difference in the information required if this approach is used. However, you must complete three property sheets and you must ensure that the option Enable Query Rewrite on the General sheet is selected.

Using Materialized Views with NLS Parameters

When using certain materialized views, you must ensure that your NLS parameters are the same as when you created the materialized view. Materialized views with this restriction are:

- Expressions that may return different values, depending on NLS parameter settings. For example, (date > "01/02/03") or (rate <= "2.150") are NLS parameter dependent expressions.
- Equijoins where one side of the join is character data. The result of this equijoin depends on collation and this can change on a session basis, giving an incorrect result in the case of query rewrite or an inconsistent materialized view after a refresh operation.
- Expressions that generate internal conversion to character data in the SELECT list of a materialized view, or inside an aggregate of a materialized aggregate view. This restriction does not apply to expressions that involve only numeric data, for example, a+b where a and b are numeric fields.

Registering Existing Materialized Views

Some data warehouses have implemented materialized views in ordinary user tables. Although this solution provides the performance benefits of materialized views, it does not:

- Provide query rewrite to all SQL applications
- Enable materialized views defined in one application to be transparently accessed in another application
- Generally support fast parallel or fast materialized view refresh

Because of these limitations, and because existing materialized views can be extremely large and expensive to rebuild, you should register your existing materialized view tables with Oracle whenever possible. You can register a user-defined materialized view with the `CREATE MATERIALIZED VIEW` ... `ON PREBUILT TABLE` statement. Once registered, the materialized view can be used for query rewrites or maintained by one of the refresh methods, or both.

The contents of the table must reflect the materialization of the defining query at the time you register it as a materialized view, and each column in the defining query must correspond to a column in the table that has a matching datatype. However, you can specify `WITH REDUCED PRECISION` to allow the precision of columns in the defining query to be different from that of the table columns.

The table and the materialized view must have the same name, but the table retains its identity as a table and can contain columns that are not referenced in the defining query of the materialized view. These extra columns are known as **unmanaged columns**. If rows are inserted during a refresh operation, each unmanaged column of the row is set to its default value. Therefore, the unmanaged columns cannot have `NOT NULL` constraints unless they also have default values.

Unmanaged columns are not supported by single-table aggregate materialized views or materialized views containing joins only.

Materialized views based on prebuilt tables are eligible for selection by query rewrite provided the parameter `QUERY_REWRITE_INTEGRITY` is set to at least the level of `STALE_TOLERATED` or `TRUSTED`.

> **See Also:** Chapter 22, "Query Rewrite", for details about integrity levels

When you drop a materialized view that was created on a prebuilt table, the table still exists—only the materialized view is dropped.

When a prebuilt table is registered as a materialized view and query rewrite is desired, the parameter QUERY_REWRITE_INTEGRITY must be set to at least STALE_TOLERATED because, when it is created, the materialized view is marked as unknown. Therefore, only stale integrity modes can be used.

The following example illustrates the two steps required to register a user-defined table. First, the table is created, then the materialized view is defined using exactly the same name as the table. This materialized view sum_sales_tab is eligible for use in query rewrite.

```
CREATE TABLE sum_sales_tab
  PCTFREE 0  TABLESPACE mviews
   STORAGE (INITIAL 16k NEXT 16k PCTINCREASE 0)
    AS
    SELECT f.store_key
       SUM(dollar_sales) AS dollar_sales,
       SUM(unit_sales) AS unit_sales,
       SUM(dollar_cost) AS dollar_cost
         FROM fact f GROUP BY f.store_key;

CREATE MATERIALIZED VIEW sum_sales_tab
ON PREBUILT TABLE WITHOUT REDUCED PRECISION
ENABLE QUERY REWRITE
AS
SELECT f.store_key,
  SUM(dollar_sales) AS dollar_sales,
  SUM(unit_sales) AS unit_sales,
  SUM(dollar_cost) AS dollar_cost
  FROM fact f GROUP BY f.store_key;
```

In some cases, user-defined materialized views are refreshed on a schedule that is longer than the update cycle. For example, a monthly materialized view might be updated only at the end of each month, and the materialized view values always refer to complete time periods. Reports written directly against these materialized views implicitly select only data that is not in the current (incomplete) time period. If a user-defined materialized view already contains a time dimension:

- It should be registered and then fast refreshed each update cycle.
- You can create a view that selects the complete time period of interest.
- The reports should be modified to refer to the view instead of referring directly to the user-defined materialized view.

If the user-defined materialized view does not contain a time dimension, then:

- Create a new materialized view that does include the time dimension (if possible).
- The view should aggregate over the time column in the new materialized view.

Partitioning and Materialized Views

Because of the large volume of data held in a data warehouse, partitioning is an extremely useful option when designing a database.

Partitioning the fact tables improves scalability, simplifies system administration, and makes it possible to define local indexes that can be efficiently rebuilt. Partitioning the fact tables provides greater opportunities for fast refresh of the materialized view, when the partition maintenance operation occurs. Partitioning the fact tables also improves the opportunity of fast refreshing the materialized view when the partition maintenance operation occurs.

Partitioning a materialized view also has benefits for refresh, because the refresh procedure can use parallel DML to maintain the materialized view.

See Also: Chapter 5, "Parallelism and Partitioning in Data Warehouses" for further details about partitioning

Partition Change Tracking

It is possible and advantageous to track freshness to a finer grain than the entire materialized view. The ability to identify which rows in a materialized view are affected by a certain detail table partition, is known as Partition Change Tracking (PCT). When one or more of the detail tables are partitioned, it may be possible to identify the specific rows in the materialized view that correspond to a modified detail partition(s); those rows become stale when a partition is modified while all other rows remain fresh.

Partition Change Tracking can be used to identify which materialized view rows correspond to a particular detail table partition is used to support fast refresh after partition maintenance operations on detail tables. For instance, if a detail table partition is truncated or dropped, the affected rows in the materialized view are identified and deleted. Identifying which materialized view rows are fresh or stale, rather than considering the entire materialized view as stale, allows query rewrite to use those rows that are fresh while in `QUERY_REWRITE_INTEGRITY=ENFORCED` or `TRUSTED` modes.

To support PCT, a materialized view must satisfy the following requirements:

- At least one of the detail tables referenced by the materialized view must be partitioned.
- Partitioned tables must use either range or composite partitioning.
- The partition key must consist of only a single column.
- The materialized view must contain either the partition key column or a partition marker of the detail table. See *Oracle9i Supplied PL/SQL Packages and Types Reference* for details regarding the `DBMS_MVIEW.PMARKER` function.
- If a `GROUP BY` clause is used, the partition key column or the partition marker must be present in the `GROUP BY` clause.
- Data modifications can only occur on the partitioned table.
- The `COMPATIBILITY` initialization parameter must be a minimum of 9.0.0.0.0.
- Partition change tracking is not supported for a materialized view that refers to views, remote tables, or outer joins.

Partition change tracking requires sufficient information in the materialized view to be able to correlate each materialized view row back to its corresponding detail row in the source partitioned detail table. This can be accomplished by including the detail table partition key columns in the select list and, if `GROUP BY` is used, in the `GROUP BY` list. Depending on the desired level of aggregation and the distinct cardinalities of the partition key columns, this has the unfortunate effect of significantly increasing the cardinality of the materialized view. For example, say a popular metric is the revenue generated by a product during a given year. If the `sales` table were partitioned by `time_id`, it would be a required field in the `SELECT` clause and the `GROUP BY` clause of the materialized view. If there were 1000 different products sold each day, it would substantially increase the number of rows in the materialized view.

Partition Marker

In many cases, the advantages of PCT will be offset by this restriction for highly aggregated materialized views. The `DBMS_MVIEW.PMARKER` function is designed to significantly reduce the cardinality of the materialized view (see Example 8–9 on page 8-36 for an example). The function returns a partition identifier that uniquely identifies the partition for a specified row within a specified partition table. The `DBMS_MVIEW.PMARKER` function is used instead of the partition key column in the `SELECT` and `GROUP BY` clauses.

Unlike the general case of a PL/SQL function in a materialized view, use of the DBMS_MVIEW.PMARKER does not prevent rewrite with that materialized view even when the rewrite mode is QUERY_REWRITE_INTEGRITY=ENFORCED.

Example 8–9 Partition Change Tracking Example

The following example uses the Sales History Schema and the three detail tables sales, products, and times to create two materialized views. For this example, sales is a partitioned table using the time_id column and products is partitioned by the prod_category column. times is not a partitioned table.

The first materialized view is for the yearly sales revenue per product.

The second materialized view is for monthly customer sales. As customers tend to purchase in bulk, sales average just two orders per customer per month. Therefore, the impact of including the time_id in the materialized view will not unacceptably increase the number of rows stored. However, most orders are large and contain many different products. With approximately 1000 different products sold each day, including the time_id in the materialized view would substantially increase the cardinality. This materialized view uses the DBMS_MVIEW.PMARKER function.

The detail tables must have materialized view logs for FAST REFRESH.

```
CREATE MATERIALIZED VIEW LOG ON SALES WITH ROWID
   (prod_id, time_id, quantity_sold, amount)
   INCLUDING NEW VALUES;

CREATE MATERIALIZED VIEW LOG ON PRODUCTS WITH ROWID
   (prod_id, prod_name, prod_desc)
   INCLUDING NEW VALUES;
CREATE MATERIALIZED VIEW LOG ON TIMES WITH ROWID
   (time_id, calendar_month_name, calendar_year)
   INCLUDING NEW VALUES;

CREATE MATERIALIZED VIEW cust_mth_sales_mv
BUILD DEFERRED REFRESH FAST ON DEMAND
ENABLE QUERY REWRITE
AS
  SELECT s.time_id, p.prod_id, SUM(s.quantity_sold), SUM(s.amount),
         p.prod_name, t.calendar_month_name, COUNT(*),
         COUNT(s.quantity_sold),    COUNT(s.amount)
  FROM sales s, products p, times t
  WHERE  s.time_id = t.time_id AND s.prod_id = p.prod_id
  GROUP BY t.calendar_month_name, s.prod_id, p.prod_name, s.time_id;
```

cust_mth_sales_mv includes the partition key column from table sales (time_id) in both its select and group by lists. This enables PCT on table sales for materialized view cust_mth_sales_mv. However, the GROUP BY and SELECT lists include PRODUCTS.PROD_ID rather the partition key column (PROD_CATEGORY) of the products table. Therefore, PCT is not enabled on table products for this materialized view. In other words, any partition maintenance operation to the sales table will allow a PCT fast refresh of cust_mth_sales_mv. However, PCT fast refresh is not possible after any kind of modification to the products table. To correct this, the GROUP BY and SELECT lists must include column PRODUCTS.PROD_CATEGORY. Following a partition maintenance operation, such as a drop partition, it is recommended a PCT fast refresh be performed on any materialized view that is referencing the table upon which the partition operations are undertaken.

Example 8–10 Creating a Materialized View Example

```
CREATE MATERIALIZED VIEW prod_yr_sales_mv
BUILD DEFERRED
REFRESH FAST ON DEMAND
ENABLE QUERY REWRITE
AS
    SELECT DBMS_MVIEW.PMARKER(s.rowid),
           DBMS_MVIEW.PMARKER(p.rowid),
           s.prod_id, SUM(s.amount), SUM(s.quantity_sold),
           p.prod_name, t.calendar_year, COUNT(*),
           COUNT(s.amount), COUNT(s.quantity_sold)
    FROM   sales s, products p, times t
    WHERE  s.time_id = t.time_id AND
           s.prod_id = p.prod_id
    GROUP BY DBMS_MVIEW.PMARKER (s.rowid),
             DBMS_MVIEW.PMARKER (p.rowid),
              t.calendar_year, s.prod_id, p.prod_name;
```

prod_yr_sales_mv includes the DBMS_MVIEW.PMARKER function on the sales and products tables in both its SELECT and GROUP BY lists. This enables partition change tracking on both the sales table and the products table with significantly less cardinality impact than grouping by the respective partition key columns. In this example, the desired level of aggregation for the prod_yr_sales_mv is to group by times.calendar_year. Using the DBMS_MVIEW.PMARKER function, the materialized view cardinality is increased only by a factor of the number of partitions in the sales table times, the number of partitions in the products table. This would generally be significantly less than the cardinality impact of including the respective partition key columns.

A subsequent INSERT statement adds a new row to the sales_part3 partition of table SALES. At this point, because cust_mth_sales_mv and prod_yr_sales_mv have partition change tracking available on table sales, Oracle can determine that those rows in these materialized views corresponding to sales_part3 are stale, while all other rows in these materialized views are unchanged in their freshness state. An INSERT INTO products statement is not tracked for materialized view cust_mth_sales_mv. Therefore, cust_mth_sales_mv becomes completely stale when the products table is modified in this way.

Partitioning a Materialized View

Partitioning a materialized view involves defining the materialized view with the standard Oracle partitioning clauses, as illustrated in the example below. This example creates a materialized view called part_sales_mv, which uses three partitions, may be fast refreshed, and is eligible for query rewrite.

Example 8–11 Materialized View Partitioning Example

```
CREATE MATERIALIZED VIEW part_sales_mv
PARALLEL
  PARTITION by RANGE (time_key)
  (PARTITION month1
      VALUES LESS THAN (TO_DATE('31-12-1997', 'DD-MM-YYYY'))
      PCTFREE 0 PCTUSED
      STORAGE (INITIAL 64k NEXT 16k PCTINCREASE 0)
      TABLESPACE sf1,
   PARTITION month2
      VALUES LESS THAN (TO_DATE('31-01-1998', 'DD-MM-YYYY'))
      PCTFREE 0 PCTUSED
      STORAGE (INITIAL 64k NEXT 16k PCTINCREASE 0)
      TABLESPACE sf2,
   PARTITION month3
      VALUES LESS THAN (TO_DATE('28-02-1998', 'DD-MM-YYYY'))
      PCTFREE 0 PCTUSED
      STORAGE (INITIAL 64k NEXT 16k PCTINCREASE 0)
      TABLESPACE sf3)
BUILD DEFERRED
REFRESH FAST
ENABLE QUERY REWRITE
AS
SELECT f.store_key, f.time_key,
  SUM(f.dollar_sales) AS sum_dol_sales,
       SUM(f.unit_sales) AS sum_unit_sales
         FROM fact f GROUP BY f.time_key, f.store_key;
```

Partitioning a Prebuilt Table

Alternatively, a materialized view can be registered to a partitioned prebuilt table as illustrated in the following example:

```
CREATE TABLE part_fact_tab(time_key, store_key, sum_dollar_sales, sum_unit_sale)
  PARALLEL
  PARTITION by RANGE (time_key)
  (
    PARTITION month1
      VALUES LESS THAN (TO_DATE('31-12-1997', 'DD-MM-YYYY'))
      PCTFREE 0 PCTUSED 99
      STORAGE (INITITAL 64k NEXT 16k PCTINCREASE 0)
      TABLESPACE sf1,
    PARTITIION month2
      VALUES LESS THAN (TO_DATE('31-01-1998', 'DD-MM-YYYY'))
      PCTFREE 0 PCTUSED 99
      STORAGE (INITIAL 64k NEXT 16k PCTINCREASE 0)
      TABLESPACE sf2,
    PARTITION month3
      VALUES LESS THAN (TO_DATE('28-02-1998', DD-MM-YYYY'))
      PCTFREE 0 PCTUSED 99
      STORAGE (INITIAL 64k NEXT 16k PCTINCREASE 0)
      TABLESPACE sf3)
AS
SELECT f.time_key, f.store_key,
  SUM(f.dollar_sales) AS sum_dollar_sales,
  SUM(f.unit_sales)   AS sum_unit_sales
         FROM fact f GROUP BY f.time_key, f.store_key;

CREATE MATERIALIZED VIEW part_fact_tab
ON PREBUILT TABLE
ENABLE QUERY REWRITE
AS
SELECT f.time_key,  f.store_key,
  SUM(f.dollar_sales) AS sum_dollar_sales,
  SUM(f.unit_sales)   AS sum_unit_sales
        FROM fact f  GROUP BY  f.time_key , f.store_key;
```

In this example, the table `part_fact_tab` has been partitioned over three months and then the materialized view was registered to use the prebuilt table. This materialized view is eligible for query rewrite because the `ENABLE QUERY REWRITE` clause has been included.

Rolling Materialized Views

When the data warehouse or data mart contains a time dimension, it is often desirable to archive the oldest information and then reuse the storage for new information. This is called the **rolling window** scenario. If the fact tables or materialized views include a time dimension and are horizontally partitioned by the time attribute, then management of rolling materialized views can be reduced to a few fast partition maintenance operations provided the unit of data that is rolled out equals, or is at least aligned with, the range partitions.

If you plan to have rolling materialized views in your warehouse, you should determine how frequently you plan to perform partition maintenance operations, and you should plan to partition fact tables and materialized views to reduce the amount of system administration overhead required when old data is aged out.

You are not restricted to using range partitions. For example, a composite partition using both a time value and a key value could result in a good partition solution for your data.

See Also: Chapter 14, "Maintaining the Data Warehouse", for further details regarding `CONSIDER FRESH`

Choosing Indexes for Materialized Views

The two most common operations on a materialized view are query execution and fast refresh, and each operation has different performance requirements. Query execution might need to access any subset of the materialized view key columns, and might need to join and aggregate over a subset of those columns. Consequently, query execution usually performs best if a single-column bitmap index is defined on each materialized view key column.

In the case of materialized views containing only joins using fast refresh, Oracle recommends that indexes be created on the columns that contain the rowids to improve the performance of the refresh operation.

If a materialized view using joins and aggregates is fast refreshable, then an index is automatically created unless `USING NO INDEX` is specified in the `CREATE MATERIALIZED VIEW` statement.

See Also: Chapter 21, "Using Parallel Execution", for further details

Invalidating Materialized Views

Dependencies related to materialized views are automatically maintained to ensure correct operation. When a materialized view is created, the materialized view depends on the detail tables referenced in its definition. Any DML operation, such as a INSERT, or DELETE, UPDATE, or DDL operation on any dependency in the materialized view will cause it to become invalid. To revalidate a materialized view, use the ALTER MATERIALIZED VIEW COMPILE statement.

A materialized view is automatically revalidated when it is referenced. In many cases, the materialized view will be successfully and transparently revalidated. However, if a column has been dropped in a table referenced by a materialized view or the owner of the materialized view did not have one of the query rewrite privileges and that privilege has now been granted to the owner, the statement:

```
ALTER MATERIALIZED VIEW mview_name ENABLE QUERY REWRITE
```

should be used to revalidate the materialized view.

The state of a materialized view can be checked by querying the data dictionary views USER_MVIEWS or ALL_MVIEWS. The column STALENESS will show one of the values FRESH, STALE, UNUSABLE, UNKNOWN, or UNDEFINED to indicate whether the materialized view can be used. The state is maintained automatically, but it can be manually updated by issuing an ALTER MATERIALIZED VIEW <name> COMPILE statement.

Security Issues with Materialized Views

To create a materialized view in your own schema, you must have the CREATE MATERIALIZED VIEW privilege and the SELECT privilege to any tables referenced that are in another schema. To create a materialized view in another schema, you must have the CREATE ANY MATERIALIZED VIEW privilege and the owner of the materialized view needs SELECT privileges to the tables referenced if they are from another schema.

Moreover, if you enable query rewrite on a materialized view that references tables outside your schema, you must have the GLOBAL QUERY REWRITE privilege or the QUERY REWRITE object privilege on each table outside your schema.

If the materialized view is on a prebuilt container, the creator, if different from the owner, must have SELECT WITH GRANT privilege on the container table.

If you continue to get a privilege error while trying to create a materialized view and you believe that all the required privileges have been granted, then the problem is most likely due to a privilege not being granted explicitly and trying to inherit the privilege from a role instead. The owner of the materialized view must have explicitly been granted SELECT access to the referenced tables if the tables are in a different schema.

If the materialized view is being created with ON COMMIT REFRESH specified, then the owner of the materialized view requires an additional privilege if any of the tables in the defining query are outside the owner's schema. In that case, the owner requires the ON COMMIT REFRESH system privilege or the ON COMMIT REFRESH object privilege on each table outside the owner's schema.

Altering Materialized Views

Five modifications can be made to a materialized view. You can:

- Change its refresh option (FAST/FORCE/COMPLETE/NEVER)
- Change its refresh mode (ON COMMIT/ON DEMAND)
- Recompile it
- Enable or disable its use for query rewrite
- Consider it fresh

All other changes are achieved by dropping and then re-creating the materialized view.

The COMPILE clause of the ALTER MATERIALIZED VIEW statement can be used when the materialized view has been invalidated. This compile process is quick, and allows the materialized view to be used by query rewrite again.

> **See Also:** *Oracle9i SQL Reference* for further information about the ALTER MATERIALIZED VIEW statement and "Invalidating Materialized Views" on page 8-41

Dropping Materialized Views

Use the DROP MATERIALIZED VIEW statement to drop a materialized view. For example:

```
DROP MATERIALIZED VIEW sales_sum_mv;
```

This statement drops the materialized view sales_sum_mv. If the materialized view was prebuilt on a table, then the table is not dropped, but it can no longer be maintained with the refresh mechanism or used by query rewrite. Alternatively, you can drop a materialized view using Oracle Enterprise Manager.

Analyzing Materialized View Capabilities

You can use the `DBMS_MVIEW.EXPLAIN_MVIEW` procedure to learn what is possible with a materialized view or potential materialized view. In particular, this procedure enables you to determine:

- If a materialized view is fast refreshable
- What types of query rewrite you can perform with this materialized view
- Whether PCT refresh is possible

Using this procedure is straightforward. You simply call `DBMS_MVIEW.EXPLAIN_MVIEW`, passing in as a single parameter the schema and materialized view name for an existing materialized view. Alternatively, you can specify the `SELECT` string for a potential materialized view. The materialized view or potential materialized view is then analyzed and the results are written into either a table called `MV_CAPABILITIES_TABLE`, which is the default, or to an array called `MSG_ARRAY`.

Note that you must run the `utlxmv.sql` script prior to calling `EXPLAIN_MVIEW` except when you are only concerned with `VARRAY`s. The script is found in the admin directory. In addition, you must create `MV_CAPABILITIES_TABLE` in the current schema. An explanation of the various capabilities is in Table 8–2 on page 8-46, and all the possible messages are listed in Table 8–3 on page 8-48.

Using the DBMS_MVIEW.EXPLAIN_MVIEW Procedure

The `DBMS_MVIEW.EXPLAIN_MVIEW` procedure has the following parameters:

- `STMT_ID`

  An optional parameter. A client-supplied unique identifier to associate output rows with specific invocations of `EXPLAIN_MVIEW.`

- `MV`

  The name of an existing materialized view or the query definition of a potential materialized view you want to analyze.

- `MSG_ARRAY`

  The PL/SQL varray that receives the output.

DBMS_MVIEW.EXPLAIN_MVIEW analyzes the specified materialized view in terms of its refresh and rewrite capabilities and inserts its results (in the form of multiple rows) into MV_CAPABILITIES_TABLE or MSG_ARRAY.

> **See Also:** *Oracle9i Supplied PL/SQL Packages and Types Reference* for further information about the DBMS_MVIEW package

DBMS_MVIEW.EXPLAIN_MVIEW Declarations

The following PL/SQL declarations that are made for you in the DBMS_MVIEW package show the order and datatypes of these parameters for explaining an existing materialized view and a potential materialized view with output to a table and to a VARRAY.

Explain an existing or potential materialized view with output to MV_CAPABILITIES_TABLE

```
DBMS_MVIEW.EXPLAIN_MVIEW
(mv           IN VARCHAR2,
 stmt_id IN VARCHAR2:= NULL);
```

Explain an existing or potential materialized view with output to a VARRAY:

```
DBMS_MVIEW.EXPLAIN_MVIEW
(mv          IN VARCHAR2,
 msg_array   OUT SYS.ExplainMVArrayType);
```

Using MV_CAPABILITIES_TABLE

One of the simplest ways to use DBMS_MVIEW.EXPLAIN_MVIEW is with the MV_CAPABILITIES_TABLE, which has the following structure:

```
CREATE TABLE MV_CAPABILITIES_TABLE
 (
 STMT_ID      VARCHAR(30),        -- client-supplied unique statement identifier
 MV                VARCHAR(30),   -- NULL for SELECT based EXPLAIN_MVIEW
 CAPABILITY_NAME   VARCHAR(30),   -- A descriptive name of particular
                                  -- capabilities, such as REWRITE.
                                  -- See Table 8–2
 POSSIBLE          CHARACTER(1),  -- Y = capability is possible
                                  -- N = capability is not possible
 RELATED_TEXT      VARCHAR(2000), -- owner.table.column, and so on related to
                                  -- this message
 RELATED_NUM       NUMBER,        -- When there is a numeric value
                                  -- associated with a row, it goes here.
 MSGNO             INTEGER,       -- When available, message # explaining
```

```
                                      -- why disabled or more details when
                                      -- enabled.
 MSGTXT           VARCHAR(2000),  -- Text associated with MSGNO
 SEQ              NUMBER);        -- Useful in ORDER BY clause when
                                      -- selecting from this table.
```

You can use the `utlxmv.sql` script found in the admin directory to create `MV_CAPABILITIES_TABLE`.

Example 8–12 DBMS_MVIEW.EXPLAIN_MVIEW Example

First, create the materialized view. Alternatively, you can use `EXPLAIN_MVIEW` on a potential materialized view using its `SELECT` statement.

```
CREATE MATERIALIZED VIEW cal_month_sales_mv
BUILD IMMEDIATE
REFRESH FORCE
ENABLE QUERY REWRITE
AS
SELECT t.calendar_month_desc,  SUM(s.amount) AS dollars
FROM sales s,  times t
WHERE s.time_id = t.time_id
GROUP BY t.calendar_month_desc;
```

Then, you invoke `EXPLAIN_MVIEW` with the materialized view to explain.

```
EXECUTE DBMS_MVIEW.EXPLAIN_MVIEW ('SH.CAL_MONTH_SALES_MV');

SELECT capability_name, possible, SUBSTR(related_text,1,8) AS rel_text,
SUBSTR(msgtxt,1,60) AS msgtxt
FROM MV_CAPABILITIES_TABLE
ORDER BY seq;
```

You need to use the `SEQ` column in an `ORDER BY` clause so the rows will display in a logical order. If a capability is not possible, `N` will appear in the `P` column and an explanation in the `MSGTXT` column. If a capability is not possible for more than one reason, a row is displayed for each reason.

```
CAPABILITY_NAME                P    REL_TEXT     MSGTXT
---------------                -    --------     ------
PCT                            N
REFRESH_COMPLETE               Y
REFRESH_FAST                   N
REWRITE                        Y
PCT_TABLE                      N    SALES        no partition key or PMARKER in select list
PCT_TABLE                      N    TIMES        relation is not a partitioned table
```

```
REFRESH_FAST_AFTER_INSERT       N    SH.TIMES     mv log must have new values
REFRESH_FAST_AFTER_INSERT       N    SH.TIMES     mv log must have ROWID
REFRESH_FAST_AFTER_INSERT       N    SH.TIMES     mv log does not have all necessary columns
REFRESH_FAST_AFTER_INSERT       N    SH.SALES     mv log must have new values
REFRESH_FAST_AFTER_INSERT       N    SH.SALES     mv log must have ROWID
REFRESH_FAST_AFTER_INSERT       N    SH.SALES     mv log does not have all necessary columns
REFRESH_FAST_AFTER_ONETAB_DML   N    DOLLARS      SUM(expr) without COUNT(expr)
REFRESH_FAST_AFTER_ONETAB_DML   N                 see the reason why
                                                  REFRESH_FAST_AFTER_INSERT is disabled
REFRESH_FAST_AFTER_ONETAB_DML   N                 COUNT(*) is not present in the select list
REFRESH_FAST_AFTER_ONETAB_DML   N                 SUM(expr) without COUNT(expr)
REFRESH_FAST_AFTER_ANY_DML      N                 see the reason why
                                                  REFRESH_FAST_AFTER_ONETAB_DML is disabled
REFRESH_FAST_AFTER_ANY_DML      N    SH.TIMES     mv log must have sequence
REFRESH_FAST_AFTER_ANY_DML      N    SH.SALES     mv log must have sequence
REFRESH_PCT                     N                 PCT is not possible on any of the detail
                                                  tables in the materialized view
REWRITE_FULL_TEXT_MATCH         Y
REWRITE_PARTIAL_TEXT_MATCH      Y
REWRITE_GENERAL                 Y
REWRITE_PCT                     N                 PCT is not possible on any detail tables
```

See Also: Chapter 14, "Maintaining the Data Warehouse" and Chapter 22, "Query Rewrite" for further details about PCT

MV_CAPABILITIES_TABLE.CAPABILITY_NAME Details

Table 8–2 lists explanations for values in the CAPABILITY_NAME column.

Table 8–2 CAPABILITY_NAME Column Details

CAPABILITY_NAME	Description
PCT	If this capability is possible, Partition Change Tracking is possible on at least one detail relation. If this capability is not possible, PCT is not possible with any detail relation referenced by the materialized view.
REFRESH_COMPLETE	If this capability is possible, complete refresh of the materialized view is possible.
REFRESH_FAST	If this capability is possible, fast refresh is possible at least under certain circumstances.
REWRITE	If this capability is possible, at least full text match query rewrite is possible. If this capability is not possible, no form of query rewrite is possible.

Table 8–2 CAPABILITY_NAME Column Details

CAPABILITY_NAME	Description
PCT_TABLE	If this capability is possible, it is possible with respect to a particular partitioned table in the top level FROM list. When possible, PCT applies to the partitioned table named in the RELATED_TEXT column. PCT is needed to support fast fresh after partition maintenance operations on the table named in the RELATED_TEXT column. PCT may also support fast refresh with regard to updates to the table named in the RELATED_TEXT column when fast refresh from a materialized view log is not possible. (PCT-based fast refresh generally does not perform as well as fast refresh from a materialized view log.) PCT is also needed to support query rewrite in the presence of partial staleness of the materialized view with regard to the table named in the RELATED_TEXT column. When disabled, PCT does not apply to the table named in the RELATED_TEXT column. In this case, fast refresh is not possible after partition maintenance operations on the table named in the RELATED_TEXT column. In addition, PCT-based refresh of updates to the table named in the RELATED_TEXT column is not possible. Finally, query rewrite cannot be supported in the presence of partial staleness of the materialized view with regard to the table named in the RELATED_ TEXT column.
REFRESH_FAST_ AFTER_INSERT	If this capability is possible, fast refresh from a materialized view log or change capture table is possible at least in the case where the updates are restricted to INSERT operations; complete refresh is also possible. If this capability is not possible, no form of fast refresh from a materialized view log or change capture table is possible.
REFRESH_FAST_ AFTER_ONETAB_DML	If this capability is possible, fast refresh from a materialized view log is possible regardless of the type of update operation, provided all update operations are performed on a single table. If this capability is not possible, fast refresh from a materialized view log may not be possible when the update operations are performed on multiple tables.
REFRESH_FAST_ AFTER_ANY_DML	If this capability is possible, fast refresh from a materialized view log is possible regardless of the type of update operation or the number of tables updated. If this capability is not possible, fast refresh from a materialized view log may not be possible when the update operations (other than INSERT) affect multiple tables.
REFRESH_FAST_PCT	If this capability is possible, fast refresh using PCT is possible. Generally, this means that refresh is possible after partition maintenance operations on those detail tables where PCT is indicated as possible.
REWRITE_FULL_TEXT_ MATCH	If this capability is possible, full text match query rewrite is possible. If this capability is not possible, full text match query rewrite is not possible.

Table 8–2 CAPABILITY_NAME Column Details

CAPABILITY_NAME	Description
REWRITE_PARTIAL_TEXT_MATCH	If this capability is possible, at least full and partial text match query rewrite are possible. If this capability is not possible, at least partial text match query rewrite and general query rewrite are not possible.
REWRITE_GENERAL	If this capability is possible, all query rewrite capabilities are possible, including general query rewrite and full and partial text match query rewrite. If this capability is not possible, at least general query rewrite is not possible.
REWRITE_PCT	If this capability is possible, query rewrite can use a partially stale materialized view even in QUERY_REWRITE_INTEGRITY = ENFORCED or TRUSTED modes. When this capability is not possible, query rewrite can use a partially stale materialized view only in QUERY_REWRITE_INTEGRITY = STALE_TOLERATED mode.

MV_CAPABILITIES_TABLE Column Details

Table 8–3 lists the semantics for RELATED_TEXT and RELATED_NUM columns.

Table 8–3 MV_CAPABILITIES_TABLE Column Details

MSGNO	MSGTXT	RELATED_NUM	RELATED_TEXT
NULL	NULL		For PCT capability only: [<owner>.]<name> of the table upon which PCT is enabled
2066	This statement resulted in an Oracle error	Oracle error number that occurred	
2067	No partition key or PMARKER in select list		[<owner>.]<name> of relation for which PCT is not supported
2068	Relation is not partitioned		[<owner>.]<name> of relation for which PCT is not supported
2069	PCT not supported with multicolumn partition key		[<owner>.]<name> of relation for which PCT is not supported
2070	PCT not supported with this type of partitioning		[<owner>.]<name> of relation for which PCT is not supported
2071	Internal error: undefined PCT failure code	The unrecognized numeric PCT failure code	[<owner>.]<name> of relation for which PCT is not supported
2077	Mv log is newer than last full refresh		[<owner>.]<table_name> of table upon which the mv log is needed
2078	Mv log must have new values		[<owner>.]<table_name> of table upon which the mv log is needed

Table 8–3 MV_CAPABILITIES_TABLE Column Details

MSGNO	MSGTXT	RELATED_NUM	RELATED_TEXT
2079	Mv log must have ROWID		[<owner>.]<table_name> of table upon which the mv log is needed
2080	Mv log must have primary key		[<owner>.]<table_name> of table upon which the mv log is needed
2081	Mv log does not have all necessary columns		[<owner>.]<table_name> of table upon which the mv log is needed
2082	Problem with mv log		[<owner>.]<table_name> of table upon which the mv log is needed
2099	Mv references a remote table or view in the FROM list	Offset from the SELECT keyword to the table or view in question	[<owner>.]<name> of the table or view in question
2126	Multiple master sites		Name of the first different node, or NULL if the first different node is local
2129	Join or filter condition(s) are complex		[owner.]<name> of the table involved with the join or filter condition (or NULL when not available)
2130	Expression not supported for fast refresh	Offset from the SELECT keyword to the expression in question	The alias name in the select list of the expression in question
2150	Select lists must be identical across the UNION operator	Offset from the SELECT keyword to the first different select item in the select list	The alias name of the first different select item in the SELECT list

Overview of Materialized View Management Tasks

The motivation for using materialized views is to improve performance, but the overhead associated with materialized view management can become a significant system management problem. Materialized view management activities include:

- Identifying what materialized views to create initially
- Indexing the materialized views
- Ensuring that all materialized views and materialized view indexes are refreshed properly each time the database is updated
- Checking which materialized views have been used

- Determining how effective each materialized view has been on workload performance
- Measuring the space being used by materialized views
- Determining which new materialized views should be created
- Determining which existing materialized views should be dropped
- Archiving old detail and materialized view data that is no longer useful

After the initial effort of creating and populating the data warehouse or data mart, the major administration overhead is the update process, which involves:

- Periodic extraction of incremental changes from the operational systems
- Transforming the data
- Verifying that the incremental changes are correct, consistent, and complete
- Bulk-loading the data into the warehouse
- Refreshing indexes and materialized views so that they are consistent with the detail data

The update process must generally be performed within a limited period of time known as the **update window**. The update window depends on the **update frequency** (such as daily or weekly) and the nature of the business. For a daily update frequency, an update window of two to six hours might be typical.

You need to know your update window for the following activities:

1. Loading the detail data.
2. Updating or rebuilding the indexes on the detail data.
3. Performing quality assurance tests on the data.
4. Refreshing the materialized views.
5. Updating the indexes on the materialized views.

A popular and efficient way to load data into a warehouse or data mart is to use SQL*Loader with the `DIRECT` or `PARALLEL` option or to use another loader tool that uses the Oracle direct-path API.

> **See Also:** *Oracle9i Database Utilities* for the restrictions and considerations when using SQL*Loader with the DIRECT or PARALLEL keywords

Loading strategies can be classified as **one-phase** or **two-phas**e. In one-phase loading, data is loaded directly into the target table, quality assurance tests are performed, and errors are resolved by performing DML operations prior to refreshing materialized views. If a large number of deletions are possible, then storage utilization can be adversely affected, but temporary space requirements and load time are minimized. The DML that may be required after one-phase loading causes multitable aggregate materialized views to become unusable in the safest rewrite integrity level.

In a two-phase loading process:

- Data is first loaded into a temporary table in the warehouse.
- Quality assurance procedures are applied to the data.
- Referential integrity constraints on the target table are disabled, and the local index in the target partition is marked unusable.
- The data is copied from the temporary area into the appropriate partition of the target table using INSERT AS SELECT with the PARALLEL or APPEND hint.
- The temporary table is dropped.
- The constraints are enabled, usually with the NOVALIDATE option.

Immediately after loading the detail data and updating the indexes on the detail data, the database can be opened for operation, if desired. You can disable query rewrite at the system level with ALTER SYSTEM SET QUERY_REWRITE_ENABLED = FALSE until all the materialized views are refreshed.

If QUERY_REWRITE_INTEGRITY=STALE_TOLERATED, access to the materialized view can be allowed at the session level to any users who do not require the materialized views to reflect the data from the latest load by using ALTER SESSION SET QUERY_REWRITE_INTEGRITY=TRUE. This scenario does not apply when QUERY_REWRITE_INTEGRITY is either ENFORCED or TRUSTED because the system ensures in these modes that only materialized views with updated data participate in a query rewrite.

9 Dimensions

The following sections will help you create and manage a data warehouse:

What are Dimensions?

A **dimension** is a structure that categorizes data in order to enable users to answer business questions. Commonly used dimensions are `customers`, `products`, and `time`. For example, each sales channel of a clothing retailer might gather and store data regarding sales and reclamations of their Cloth assortment. The retail chain management can build a data warehouse to analyze the sales of its products across all stores over time and help answer questions such as:

- What is the effect of promoting one product on the sale of a related product that is not promoted?
- What are the sales of a product before and after a promotion?
- How does a promotion affect the various distribution channels?

The data in the retailer's data warehouse system has two important components: dimensions and facts. The dimensions are products, customers, promotions, channels, and time. One approach for identifying your dimensions is to review your reference tables, such as a product table that contains everything about a product, or a promotion table containing all information about promotions. The facts are sales (units sold) and profits. A data warehouse contains facts about the sales of each product at on a daily basis.

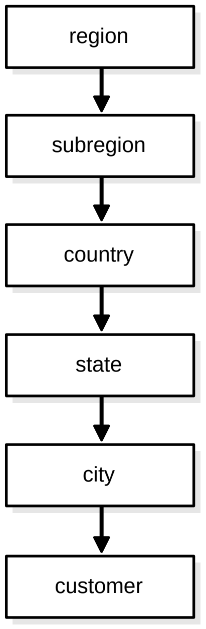
A typical relational implementation for such a data warehouse is a Star Schema. The fact information is stored in the so-called fact table, whereas the dimensional information is stored in the so-called dimension tables. In our example, each sales transaction record is uniquely defined as per customer, per product, per sales channel, per promotion, and per day (time).

> **See Also:** Chapter 17, "Schema Modeling Techniques" for further details

In Oracle9*i*, the dimensional information itself is stored in a dimension table. In addition, the **database object dimension** helps to organize and group dimensional information into hierarchies. This represents natural `1:n` relationships between columns or column groups (the levels of a hierarchy) that cannot be represented with constraint conditions. Going up a level in the hierarchy is called **rolling up** the data and going down a level in the hierarchy is called **drilling down** the data. In the retailer example:

- Within the `time` dimension, months roll up to quarters, quarters roll up to years, and years roll up to all years.
- Within the `product` dimension, products roll up to subcategories, subcategories roll up to categories, and categories roll up to all products.
- Within the `customer` dimension, customers roll up to `city`. Then cities rolls up to `state`. Then states roll up to `country`. Then countries roll up to `subregion`. Finally, subregions roll up to `region`, as shown in Figure 9–1.

Figure 9–1 Sample Rollup for a Customer Dimension



Data analysis typically starts at higher levels in the dimensional hierarchy and gradually drills down if the situation warrants such analysis.

Dimensions do not have to be defined, but spending time creating them can yield significant benefits, because they help query rewrite perform more complex types of rewrite. They are mandatory if you use the Summary Advisor (a GUI tool for materialized view management) to recommend which materialized views to create, drop, or retain.

See Also: Chapter 22, "Query Rewrite" for further details regarding query rewrite and Chapter 16, "Summary Advisor" for further details regarding the Summary Advisor

You must not create dimensions in any schema that does not satisfy these relationships. Incorrect results can be returned from queries otherwise.

Creating Dimensions

Before you can create a dimension object, the dimension tables must exist in the database, containing the dimension data. For example, if you create a customer dimension, one or more tables must exist that contain the city, state, and country information. In a star schema data warehouse, these dimension tables already exist. It is therefore a simple task to identify which ones will be used.

Now you can draw the hierarchies of a dimension as shown in Figure 9–1. For example, `city` is a child of `state` (because you can aggregate city-level data up to state), and `country`. This hierarchical information will be stored in the database object dimension.

In the case of normalized or partially normalized dimension representation (a dimension that is stored in more than one table), identify how these tables are joined. Note whether the joins between the dimension tables can guarantee that each child-side row joins with one and only one parent-side row. In the case of denormalized dimensions, determine whether the child-side columns uniquely determine the parent-side (or attribute) columns. These constraints can be enabled with the `NOVALIDATE` and `RELY` clauses if the relationships represented by the constraints are guaranteed by other means.

You create a dimension using either the `CREATE DIMENSION` statement or the Dimension Wizard in Oracle Enterprise Manager. Within the `CREATE DIMENSION` statement, use the `LEVEL` clause to identify the names of the dimension levels.

See Also: *Oracle9i SQL Reference* for a complete description of the `CREATE DIMENSION` statement

This customer dimension contains a single hierarchy with a geograph rollup, with arrows drawn from the child level to the parent level, as shown in Figure 9–1 on page 9-3.

Each arrow in this graph indicates that for any child there is one and only one parent. For example, each city must be contained in exactly one state and each state must be contained in exactly one country. States that belong to more than one country, or that belong to no country, violate hierarchical integrity. Hierarchical integrity is necessary for the correct operation of management functions for materialized views that include aggregates.

For example, you can declare a dimension `products_dim`, which contains levels `product`, `subcategory`, and `category`:

```
CREATE DIMENSION products_dim
        LEVEL product           IS (products.prod_id)
        LEVEL subcategory       IS (products.prod_subcategory)
        LEVEL category          IS (products.prod_category) ...
```

Each level in the dimension must correspond to one or more columns in a table in the database. Thus, level `product` is identified by the column `prod_id` in the products table and level `subcategory` is identified by a column called `prod_subcategory` in the same table.

In this example, the database tables are denormalized and all the columns exist in the same table. However, this is not a prerequisite for creating dimensions. "Using Normalized Dimension Tables" on page 9-9 shows how to create a dimension `customers_dim` that has a normalized schema design using the `JOIN KEY` clause.

The next step is to declare the relationship between the levels with the `HIERARCHY` statement and give that hierarchy a name. A hierarchical relationship is a **functional dependency** from one level of a hierarchy to the next level in the hierarchy. Using the level names defined previously, the `CHILD OF` relationship denotes that each child's level value is associated with one and only one parent level value. The following statements declare a hierarchy `prod_rollup` and define the relationship between `products`, `subcategory,` and `category`.

```
 HIERARCHY prod_rollup
( product         CHILD OF
  subcategory     CHILD OF
  category)
```

In addition to the `1:n` hierarchical relationships, dimensions also include `1:1` attribute relationships between the hierarchy levels and their dependent, determined dimension attributes. For example the dimension `times_dim`, as defined in Appendix B, has columns `fiscal_month_desc`, `fiscal_month_name`, and `days_in_fiscal_month`. Their relationship is defined as follows:

```
LEVEL fis_month   IS TIMES.FISCAL_MONTH_DESC
...
ATTRIBUTE fis_month DETERMINES
      (fiscal_month_desc, fiscal_month_number, fiscal_month_name,
       days_in_fis_month, end_of_fis_month)
```

The `ATTRIBUTE` ... `DETERMINES` clause relates fis_month to `fiscal_month_name and days_in_fiscal_month`. Note that this is a unidirectional determination. It is only guaranteed, that for a specific `fiscal_month`, for example, `1999-11`, you will find exactly one matching values for `fiscal_month_name`, for example, `November` and `days_in_fiscal_month`, for example, 28. You cannot determine a specific `fiscal_month_desc` based on the `fiscal_month_name`, which is `November` for every fiscal year.

In this example, suppose a query were issued that queried by `fiscal_month_name` instead of `fiscal_month_desc`. Because this `1:1` relationship exists between the attribute and the level, an already aggregated materialized view containing `fiscal_month_desc` can be joined back to the dimension information and used to identify the data.

> **See Also:** Chapter 22, "Query Rewrite" for further details of using dimensional information

An exemplary dimension definition follows:

```
CREATE DIMENSION products_dim
        LEVEL product          IS (products.prod_id)
        LEVEL subcategory      IS (products.prod_subcategory)
        LEVEL category         IS (products.prod_category)
        HIERARCHY prod_rollup (
                product        CHILD OF
                subcategory    CHILD OF
                category
        )
        ATTRIBUTE product DETERMINES
        (products.prod_name, products.prod_desc,
         prod_weight_class, prod_unit_of_measure,
         prod_pack_size,prod_status, prod_list_price, prod_min_price)
        ATTRIBUTE subcategory DETERMINES
        (prod_subcategory, prod_subcat_desc)
        ATTRIBUTE category DETERMINES
        (prod_category, prod_cat_desc);
```

The design, creation, and maintenance of dimensions is part of the design, creation, and maintenance of your data warehouse schema. Once the dimension has been created, check that it meets these requirements:

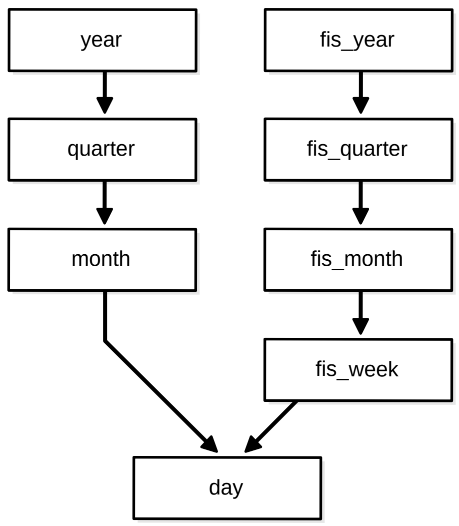
- **There must be a 1:n relationship between a parent and children.** A parent can have one or more children, but a child can have only one parent.
- **There must be a 1:1 attribute relationship between hierarchy levels and their dependent dimension attributes.** For example, if there is a column `fiscal_month_desc`, then a possible attribute relationship would be `fiscal_month_desc` to `fiscal_month_name`.
- **If the columns of a parent level and child level are in different relations, then the connection between them also requires a 1:n join relationship.** Each row of the child table must join with one and only one row of the parent table. This relationship is stronger than referential integrity alone, because it requires that the child join key must be non-null, that referential integrity must be maintained from the child join key to the parent join key, and that the parent join key must be unique.
- **Ensure (using database constraints if necessary) that the columns of each hierarchy level are non-null and that hierarchical integrity is maintained.**
- **The hierarchies of a dimension can overlap or be disconnected from each other.** However, the columns of a hierarchy level cannot be associated with more than one dimension.
- **Join relationships that form cycles in the dimension graph are not supported.** For example, a hierarchy level cannot be joined to itself either directly or indirectly.

Note: The information stored with a dimension objects is only declarative. The above discussed relationships are not enforced with the creation of a dimension object. It is highly recommended to validate any dimension definition with the `DBMS_MVIEW.VALIDATE_DIMENSION` procedure, as discussed on "Validating Dimensions" on page 9-12.

Multiple Hierarchies

A single dimension definition can contain multiple hierarchies as illustrated below. Suppose our retailer wants to track the sales of certain items over time. The first step is to define the time dimension over which sales will be tracked. Figure 9–2 illustrates a dimension `times_dim` with two time hierarchies.

Figure 9–2 times_dim Dimension with Two Time Hierarchies



From the illustration, you can construct the hierarchy of the denormalized `time_dim` dimension's `CREATE DIMENSION` statement as follows. The complete `CREATE DIMENSION` statement as well as the `CREATE TABLE` statement are shown in Appendix B, "Sample Data Warehousing Schema".

```
CREATE DIMENSION times_dim
   LEVEL day         IS TIMES.TIME_ID
   LEVEL month       IS TIMES.CALENDAR_MONTH_DESC
   LEVEL quarter     IS TIMES.CALENDAR_QUARTER_DESC
   LEVEL year        IS TIMES.CALENDAR_YEAR
   LEVEL fis_week    IS TIMES.WEEK_ENDING_DAY
   LEVEL fis_month   IS TIMES.FISCAL_MONTH_DESC
   LEVEL fis_quarter IS TIMES.FISCAL_QUARTER_DESC
   LEVEL fis_year    IS TIMES.FISCAL_YEAR
   HIERARCHY cal_rollup    (
             day     CHILD OF
             month   CHILD OF
             quarter CHILD OF
             year
   )
```

```
HIERARCHY fis_rollup    (
          day         CHILD OF
          fis_week    CHILD OF
          fis_month   CHILD OF
          fis_quarter CHILD OF
          fis_year
) <attribute determination clauses>...
```

Using Normalized Dimension Tables

The tables used to define a dimension may be normalized or denormalized and the individual hierarchies can be normalized or denormalized. If the levels of a hierarchy come from the same table, it is called a fully denormalized hierarchy. For example, `cal_rollup` in the `times_dim` dimension is a denormalized hierarchy. If levels of a hierarchy come from different tables, such a hierarchy is either a fully or partially normalized hierarchy. This section shows how to define a normalized hierarchy.

Suppose the tracking of a customer's location is done by city, state, and country. This data is stored in the tables `customers` and `countries`. The `customer` dimension `customers_dim` is partially normalized because the data entities `cust_id` and `country_id` are taken from different tables. The clause `JOIN KEY` within the dimension definition specifies how to join together the levels in the hierarchy. The dimension statement is partially shown below. The complete `CREATE DIMENSION` statement as well as the `CREATE TABLE` statement are shown in Appendix B, "Sample Data Warehousing Schema".

```
CREATE DIMENSION customers_dim
        LEVEL customer  IS (customers.cust_id)
        LEVEL city      IS (customers.cust_city)
        LEVEL state     IS (customers.cust_state_province)
        LEVEL country   IS (countries.country_id)
        LEVEL subregion IS (countries.country_subregion)
        LEVEL region IS (countries.country_region)
        HIERARCHY geog_rollup (
                customer        CHILD OF
                city            CHILD OF
                state           CHILD OF
                country         CHILD OF
                subregion       CHILD OF
                region
        JOIN KEY (customers.country_id) REFERENCES country
        ) ...<attribute determination clause>;
```

Dimension Wizard

The Dimension Wizard is automatically invoked whenever a request is made to create a dimension object in Oracle Enterprise Manager. You are then guided step by step through the information required for a dimension.

A dimension created using the Wizard can contain any of the attributes described in "Creating Dimensions" on page 9-4, such as join keys, multiple hierarchies, and attributes. You might prefer to use the Wizard because it graphically displays the hierarchical relationships as they are being constructed. When it is time to describe the hierarchy, the Wizard automatically displays a default hierarchy based on the column values, which you can subsequently amend.

See Also: *Oracle Enterprise Manager Administrator's Guide*

Viewing Dimensions

Dimensions can be viewed through one of two methods:

- Using The DEMO_DIM Package
- Using Oracle Enterprise Manager

Using The DEMO_DIM Package

Two procedures allow you to display the dimensions that have been defined. First, the file `smdim.sql`, located under `$ORACLE_HOME/rdbms/demo`, must be executed to provide the `DEMO_DIM` package, which includes:

- `DEMO_DIM.PRINT_DIM` to print a specific dimension
- `DEMO_DIM.PRINT_ALLDIMS` to print all dimensions

The `DEMO_DIM.PRINT_DIM` procedure has only one parameter: the name of the dimension to display. The example below shows how to display the dimension `TIMES_DIM`.

```
SET SERVEROUTPUT ON;
EXECUTE DEMO_DIM.PRINT_DIM ('TIMES_DIM');
```

To display all of the dimensions that have been defined, call the procedure `DEMO_DIM.PRINT_ALLDIMS` without any parameters as shown below.

```
EXECUTE DBMS_OUTPUT.ENABLE(10000);
EXECUTE DEMO_DIM.PRINT_ALLDIMS;
```

Regardless of which procedure is called, the output format is identical. A sample display is shown here.

```
DIMENSION SH.PROMO_DIM
LEVEL CATEGORY IS SH.PROMOTIONS.PROMO_CATEGORY
LEVEL PROMO IS SH.PROMOTIONS.PROMO_ID
LEVEL SUBCATEGORY IS SH.PROMOTIONS.PROMO_SUBCATEGORY
HIERARCHY PROMO_ROLLUP (
PROMO
CHILD OF SUBCATEGORY
CHILD OF CATEGORY
)
ATTRIBUTE CATEGORY DETERMINES SH.PROMOTIONS.PROMO_CATEGORY
ATTRIBUTE PROMO DETERMINES SH.PROMOTIONS.PROMO_BEGIN_DATE
ATTRIBUTE PROMO DETERMINES SH.PROMOTIONS.PROMO_COST
ATTRIBUTE PROMO DETERMINES SH.PROMOTIONS.PROMO_END_DATE
ATTRIBUTE PROMO DETERMINES SH.PROMOTIONS.PROMO_NAME
ATTRIBUTE SUBCATEGORY DETERMINES SH.PROMOTIONS.PROMO_SUBCATEGORY
```

Using Oracle Enterprise Manager

All of the dimensions that exist in the data warehouse can be viewed using Oracle Enterprise Manager. Select the `Dimension` object from within the `Schema` icon to display all of the dimensions. Select a specific dimension to graphically display its hierarchy, levels, and any attributes that have been defined.

See Also: *Oracle Enterprise Manager Administrator's Guide*

Using Dimensions with Constraints

Constraints play an important role with dimensions. Full referential integrity is sometimes enabled in data warehouses, but not always. This is because operational databases normally have full referential integrity and you can ensure that the data flowing into your warehouse never violates the already established integrity rules.

Oracle recommends that constraints be enabled and, if validation time is a concern, then the `NOVALIDATE` clause should be used as follows:

```
ENABLE NOVALIDATE CONSTRAINT pk_time;
```

Primary and foreign keys should be implemented also. Referential integrity constraints and `NOT NULL` constraints on the fact tables provide information that query rewrite can use to extend the usefulness of materialized views.

In addition, you should use the RELY clause to inform query rewrite that it can rely upon the constraints being correct as follows:

```
ALTER TABLE time MODIFY CONSTRAINT pk_time RELY;
```

This information is also used for query rewrite.

> **See Also:** Chapter 22, "Query Rewrite" for further details

Validating Dimensions

The information of a dimension object is declarative only and not enforced by the database. If the relationships described by the dimensions are incorrect, incorrect results could occur. Therefore, you should verify the relationships specified by CREATE DIMENSION using the DBMS_OLAP.VALIDATE_DIMENSION procedure periodically.

This procedure is easy to use and has only five parameters:

- Dimension name
- Owner name
- Set to TRUE to check only the new rows for tables of this dimension
- Set to TRUE to verify that all columns are not null
- Unique run ID obtained by calling the DBMS_OLAP.CREATE_ID procedure. The ID is used to identify the result of each run

The following example validates the dimension TIME_FN in the grocery schema

```
VARIABLE RID NUMBER;
EXECUTE DBMS_OLAP.CREATE_ID(:RID);
EXECUTE DBMS_OLAP.VALIDATE_DIMENSION ('TIME_FN', 'GROCERY', \
FALSE, TRUE, :RID);
```

If the VALIDATE_DIMENSION procedure encounters any errors, they are placed in a system table. The table can be accessed from the view SYSTEM.MVIEW_EXCEPTIONS. Querying this view will identify the exceptions that were found. For example:

```
SELECT * FROM SYSTEM.MVIEW_EXCEPTIONS
WHERE RUNID = :RID;
RUNID OWNER    TABLE_NAME  DIMENSION_NAME RELATIONSHIP BAD_ROWID
----- -------- ----------- -------------- ------------ ---------
678   GROCERY  MONTH       TIME_FN        FOREIGN KEY  AAAAuwAAJAAAARwAAA
```

However, rather than query this view, it may be better to query the rowid of the invalid row to retrieve the actual row that has violated the constraint. In this example, the dimension `TIME_FN` is checking a table called `month`. It has found a row that violates the constraints. Using the rowid, you can see exactly which row in the month table is causing the problem.

```
SELECT * FROM month
WHERE rowid IN (SELECT bad_rowid
                FROM SYSTEM.MVIEW_EXCEPTIONS
                WHERE RUNID = :RID);

MONTH    QUARTER FISCAL_QTR YEAR FULL_MONTH_NAME MONTH_NUMB
-------- ------- ---------- ---- --------------- ----------
  199903   19981      19981 1998 March                    3
```

Finally, to remove results from the system table for the current run:

```
EXECUTE DBMS_OLAP.PURGE_RESULTS(:RID);
```

Altering Dimensions

You can modify the dimension using the `ALTER DIMENSION` statement. You can add or drop a level, hierarchy, or attribute from the dimension using this command.

Referring to the `time` dimension in Figure 9–2, you can remove the attribute `fis_year`, drop the hierarchy `fis_rollup`, or remove the level `fiscal_year`. In addition, you can add a new level called `f_year` as shown below.

```
ALTER DIMENSION times_dim DROP ATTRIBUTE fis_year;
ALTER DIMENSION times_dim DROP HIERARCHY fis_rollup;
ALTER DIMENSION times_dim DROP LEVEL fis_year;
ALTER DIMENSION times_dim ADD LEVEL f_year IS times.fiscal_year;
```

If you try to remove anything with further dependencies inside the dimension, Oracle rejects the altering of the dimension. A dimension becomes invalid if you change any schema object that the dimension is referencing. For example, if the table on which the dimension is defined is altered, the dimension becomes invalid.

To check the status of a dimension, view the contents of the column `invalid` in the `ALL_DIMENSIONS` data dictionary view.

To revalidate the dimension, use the `COMPILE` option as follows:

```
ALTER DIMENSION times_dim COMPILE;
```

Dimensions can also be modified using Oracle Enterprise Manager.

See Also: *Oracle Enterprise Manager Administrator's Guide*

Deleting Dimensions

A dimension is removed using the `DROP DIMENSION` statement. For example:

```
DROP DIMENSION times_dim;
```

Dimensions can also be deleted using Oracle Enterprise Manager.

See Also: *Oracle Enterprise Manager Administrator's Guide*

Part IV

Managing the Warehouse Environment

This section deals with the tasks for managing a data warehouse.

It contains the following chapters:

10

Overview of Extraction, Transformation, and Loading

This chapter discusses the process of extracting, transporting, transforming, and loading data in a data warehousing environment:

Overview of ETL

You need to load your data warehouse regularly so that it can serve its purpose of facilitating business analysis. To do this, data from one or more operational systems needs to be extracted and copied into the warehouse. The process of extracting data from source systems and bringing it into the data warehouse is commonly called **ETL**, which stands for extraction, transformation, and loading. The acronym ETL is perhaps too simplistic, because it omits the trasportation phase and implies that each of the other phases of the process is distinct. We refer to the entire process, including data loading, as ETL. You should understand that ETL refers to a broad process, and not three well-defined steps.

The methodology and tasks of ETL have been well known for many years, and are not necessarily unique to data warehouse environments: a wide variety of proprietary applications and database systems are the IT backbone of any enterprise. Data has to be shared between applications or systems, trying to integrate them, giving at least two applications the same picture of the world. This data sharing was mostly addressed by mechanisms similar to what we now call ETL.

Data warehouse environments face the same challenge with the additional burden that they not only have to exchange but to integrate, rearrange and consolidate data over many systems, thereby providing a new unified information base for business intelligence. Additionally, the data volume in data warehouse environments tends to be very large.

What happens during the ETL process? During extraction, the desired data is identified and extracted from many different sources, including database systems and applications. Very often, it is not possible to identify the specific subset of interest, therefore more data than necessary has to be extracted, so the identification of the relevant data will be done at a later point in time. Depending on the source system's capabilities (for example, operating system resources), some transformations may take place during this extraction process. The size of the extracted data varies from hundreds of kilobytes up to gigabytes, depending on the source system and the business situation. The same is true for the time delta between two (logically) identical extractions: the time span may vary between days/hours and minutes to near real-time. Web server log files for example can easily become hundreds of megabytes in a very short period of time.

After extracting data, it has to be physically transported to the target system or an intermediate system for further processing. Depending on the chosen way of transportation, some transformations can be done during this process, too. For example, a SQL statement which directly accesses a remote target through a gateway can concatenate two columns as part of the SELECT statement.

The emphasis in many of the examples in this section is scalability. Many long-time users of Oracle are experts in programming complex data transformation logic using PL/SQL. These chapters suggest alternatives for many such data manipulation operations, with a particular emphasis on implementations that take advantage of Oracle's new SQL functionality, especially for ETL and the parallel query infrastructure.

ETL Tools

Designing and maintaining the ETL process is often considered one of the most difficult and resource-intensive portions of a data warehouse project. Many data warehousing projects use ETL tools to manage this process. Oracle Warehouse Builder (OWB), for example, provides ETL capabilities and takes advantage of inherent database abilities. Other data warehouse builders create their own ETL tools and processes, either inside or outside the database.

Besides the support of extraction, transformation, and loading, there are some other tasks that are important for a successful ETL implementation as part of the daily operations of the data warehouse and its support for further enhancements. Besides the support for designing a data warehouse and the data flow, these tasks are typically addressed by ETL tools such as OWB.

Oracle9*i* is not an ETL tool and does not provide a complete solution for ETL. However, Oracle9*i* does provide a rich set of capabilities that can be used by both ETL tools and customized ETL solutions. Oracle9*i* offers techniques for transporting data between Oracle databases, for transforming large volumes of data, and for quickly loading new data into a data warehouse.

Daily Operations

The successive loads and transformations must be scheduled and processed in a specific order. Depending on the success or failure of the operation or parts of it, the result must be tracked and subsequent, alternative processes might be started. The control of the progress as well as the definition of a business worklow of the operations are typically addressed by ETL tools such as OWB.

Evolution of the Data Warehouse

As the data warehouse is a living IT system, sources and targets might change. Those changes must be maintained and tracked through the lifespan of the system without overwriting or deleting the old ETL process flow information. To build and keep a level of trust about the information in the warehouse, the process flow of each individual record in the warehouse can be reconstructed at any point in time in the future in an ideal case.

11

Extraction in Data Warehouses

This chapter discusses extraction, which is the process of taking data from an operational system and moving it to your warehouse or staging system. The chapter discusses:

Overview of Extraction in Data Warehouses

Extraction is the operation of extracting data from a source system for further use in a data warehouse environment. This is the first step of the ETL process. After the extraction, this data can be transformed and loaded into the data warehouse.

The **source systems** for a data warehouse are typically transaction processing applications. For example, one of the source systems for a sales analysis data warehouse might be an order entry system that records all of the current order activities.

Designing and creating the extraction process is often one of the most time-consuming tasks in the ETL process and, indeed, in the entire data warehousing process. The source systems might be very complex and poorly documented, and thus determining which data needs to be extracted can be difficult. The data has to be extracted normally not only once, but several times in a periodic manner to supply all changed data to the warehouse and keep it up-to-date. Moreover, the source system typically cannot be modified, nor can its performance or availability be adjusted, to accommodate the needs of the data warehouse extraction process.

These are important considerations for extraction and ETL in general. This chapter, however, focuses on the technical considerations of having different kinds of sources and extraction methods. It assumes that the data warehouse team has already identified the data that will be extracted, and discusses common techniques used for extracting data from source databases.

Designing this process means making decisions about the following two main aspects:

- Which extraction method do I choose?

  This influences the source system, the transportation process, and the time needed for refreshing the warehouse.

- How do I provide the extracted data for further processing?

  This influences the transportation method, and the need for cleaning and transforming the data.

Understanding Extraction Methods in Data Warehouses

The extraction method you should choose is highly dependent on the source system and also from the business needs in the target data warehouse environment. Very often, there’s no possibility to add additional logic to the source systems to enhance an incremental extraction of data due to the performance or the increased workload of these systems. Sometimes even the customer is not allowed to add anything to an out-of-the-box application system.

The estimated amount of the data to be extracted and the stage in the ETL process (initial load or maintenance of data) may also impact the decision of how to extract, from a logical and a physical perspective. Basically, you have to decide how to extract data logically and physically.

Logical Extraction Methods

There are two kinds of logical extraction:

- Full Extraction
- Incremental Extraction

Full Extraction

The data is extracted completely from the source system. Since this extraction reflects all the data currently available on the source system, there's no need to keep track of changes to the data source since the last successful extraction. The source data will be provided as-is and no additional logical information (for example, timestamps) is necessary on the source site. An example for a full extraction may be an export file of a distinct table or a remote SQL statement scanning the complete source table.

Incremental Extraction

At a specific point in time, only the data that has changed since a well-defined event back in history will be extracted. This event may be the last time of extraction or a more complex business event like the last booking day of a fiscal period. To identify this delta change there must be a possibility to identify all the changed information since this specific time event. This information can be either provided by the source data itself like an application column, reflecting the last-changed timestamp or a change table where an appropriate additional mechanism keeps track of the changes besides the originating transactions. In most cases, using the latter method means adding extraction logic to the source system.

Many data warehouses do not use any change-capture techniques as part of the extraction process. Instead, entire tables from the source systems are extracted to the data warehouse or staging area, and these tables are compared with a previous extract from the source system to identify the changed data. This approach may not have significant impact on the source systems, but it clearly can place a considerable burden on the data warehouse processes, particularly if the data volumes are large.

Oracle's Change Data Capture mechanism can extract and maintain such delta information.

See Also: Chapter 15, "Change Data Capture" for further details about the Change Data Capture framework

Physical Extraction Methods

Depending on the chosen logical extraction method and the capabilities and restrictions on the source side, the extracted data can be physically extracted by two mechanisms. The data can either be extracted online from the source system or from an offline structure. Such an offline structure might already exist or it might be generated by an extraction routine.

There are the following methods of physical extraction:

- Online Extraction
- Offline Extraction

Online Extraction

The data is extracted directly from the source system itself. The extraction process can connect directly to the source system to access the source tables themselves or to an intermediate system that stores the data in a preconfigured manner (for example, snapshot logs or change tables). Note that the intermediate system is not necessarily physically different from the source system.

With online extractions, you need to consider whether the distributed transactions are using original source objects or prepared source objects.

Offline Extraction

The data is not extracted directly from the source system but is staged explicitly outside the original source system. The data already has an existing structure (for example, redo logs, archive logs or transportable tablespaces) or was created by an extraction routine.

You should consider the following structures:

- Flat Files

  Data in a defined, generic format. Additional information about the source object is necessary for further processing.

- Dump Files

  Oracle-specific format. Information about the containing objects is included.

- Redo and Archive Logs

  Information is in a special, additional dump file.

- Transportable Tablespaces

  A powerful way to extract and move large volumes of data between Oracle databases. A more detailed example of using this feature to extract and transport data is provided in Chapter 12, "Transportation in Data Warehouses". Oracle Corporation recommends that you use transportable tablespaces whenever possible, because they can provide considerable advantages in performance and manageability over other extraction techniques.

> **See Also:** *Oracle9i Database Utilities* for more information on using dump and flat files and *Oracle9i Supplied PL/SQL Packages and Types Reference* for details regarding LogMiner

Change Data Capture

An important consideration for extraction is incremental extraction, also called **change data capture**. If a data warehouse extracts data from an operational system on a nightly basis, then the data warehouse requires only the data that has changed since the last extraction (that is, the data that has been modified in the past 24 hours).

When it is possible to efficiently identify and extract only the most recently changed data, the extraction process (as well as all downstream operations in the ETL process) can be much more efficient, because it must extract a much smaller volume of data. Unfortunately, for many source systems, identifying the recently modified data may be difficult or intrusive to the operation of the system. Change data capture is typically the most challenging technical issue in data extraction.

Because change data capture is often desirable as part of the extraction process and it might not be possible to use Oracle's change data capture mechanism, this section describes several techniques for implementing a self-developed change capture on Oracle source systems:

- Timestamps
- Partitioning
- Triggers

These techniques are based upon the characteristics of the source systems, or may require modifications to the source systems. Thus, each of these techniques must be carefully evaluated by the owners of the source system prior to implementation.

Each of these techniques can work in conjunction with the data extraction technique discussed above. For example, timestamps can be used whether the data is being unloaded to a file or accessed through a distributed query.

> **See Also:** Chapter 15, "Change Data Capture" for further details about the Change Data Capture framework

Timestamps

The tables in some operational systems have **timestamp** columns. The timestamp specifies the time and date that a given row was last modified. If the tables in an operational system have columns containing timestamps, then the latest data can easily be identified using the timestamp columns. For example, the following query might be useful for extracting today's data from an `orders` table:

```
SELECT * FROM orders WHERE TRUNC(CAST(order_date AS date),'dd') = TO_
DATE(SYSDATE,'dd-mon-yyyy');
```

If the timestamp information is not available in an operational source system, you will not always be able to modify the system to include timestamps. Such modification would require, first, modifying the operational system's tables to include a new timestamp column and then creating a trigger to update the timestamp column following every operation that modifies a given row.

> **See Also:** "Triggers" on page 11-7

Partitioning

Some source systems might use Oracle range partitioning, such that the source tables are partitioned along a date key, which allows for easy identification of new data. For example, if you are extracting from an `orders` table, and the `orders` table is partitioned by week, then it is easy to identify the current week's data.

Triggers

Triggers can be created in operational systems to keep track of recently updated records. They can then be used in conjunction with timestamp columns to identify the exact time and date when a given row was last modified. You do this by creating a trigger on each source table that requires change data capture. Following each DML statement that is executed on the source table, this trigger updates the timestamp column with the current time. Thus, the timestamp column provides the exact time and date when a given row was last modified.

A similar internalized trigger-based technique is used for Oracle materialized view logs. These logs are used by materialized views to identify changed data, and these logs are accessible to end users. A materialized view log can be created on each source table requiring change data capture. Then, whenever any modifications are made to the source table, a record is inserted into the materialized view log indicating which rows were modified. If you want to use a trigger-based mechanism, use change data capture.

Materialized view logs rely on triggers, but they provide an advantage in that the creation and maintenance of this change-data system is largely managed by Oracle.

However, Oracle recommends the usage of synchronous Oracle Change Data Capture for trigger based change capture, since CDC provides an externalized interface for accessing the change information and provides a framework for maintaining the distribution of this information to various clients

Trigger-based techniques affect performance on the source systems, and this impact should be carefully considered prior to implementation on a production source system.

Data Warehousing Extraction Examples

You can extract data in two ways:

- Extraction Using Data Files
- Extraction Via Distributed Operations

Extraction Using Data Files

Most database systems provide mechanisms for exporting or unloading data from the internal database format into flat files. Extracts from mainframe systems often use COBOL programs, but many databases, as well as third-party software vendors, provide export or unload utilities.

Data extraction does not necessarily mean that entire database structures are unloaded in flat files. In many cases, it may be appropriate to unload entire database tables or objects. In other cases, it may be more appropriate to unload only a subset of a given table such as the changes on the source system since the last extraction or the results of joining multiple tables together. Different extraction techniques vary in their capabilities to support these two scenarios.

When the source system is an Oracle database, several alternatives are available for extracting data into files:

- Extracting into Flat Files Using SQL*Plus
- Extracting into Flat Files Using OCI or Pro*C Programs
- Exporting into Oracle Export Files Using Oracle's Export Utility

Extracting into Flat Files Using SQL*Plus

The most basic technique for extracting data is to execute a SQL query in SQL*Plus and direct the output of the query to a file. For example, to extract a flat file, `country_city.log`, with the pipe sign as delimiter between column values, containing a list of the cities in the US in the tables countries and customers, the following SQL script could be run:

```
SET echo off
SET pagesize 0
SPOOL country_city.log
SELECT distinct t1.country_name ||'|'|| t2.cust_city
FROM countries t1, customers t2
WHERE t1.country_id = t2.country_id
AND t1.country_name= 'United States of America';
SPOOL off
```

The exact format of the output file can be specified using SQL*Plus system variables.

This extraction technique offers the advantage of being able to extract the output of any SQL statement. The example above extracts the results of a join.

This extraction technique can be parallelized by initiating multiple, concurrent SQL*Plus sessions, each session running a separate query representing a different portion of the data to be extracted. For example, suppose that you wish to extract data from an `orders` table, and that the `orders` table has been range partitioned by month, with partitions `orders_jan1998`, `orders_feb1998`, and so on. To extract a single year of data from the `orders` table, you could initiate 12 concurrent SQL*Plus sessions, each extracting a single partition. The SQL script for one such session could be:

```
SPOOL order_jan.dat
SELECT * FROM orders PARTITION (orders_jan1998);
SPOOL OFF
```

These 12 SQL*Plus processes would concurrently spool data to 12 separate files. You can then concatenate them if necessary (using operating system utilities) following the extraction. If you are planning to use SQL*Loader for loading into the target, these 12 files can be used as is for a parallel load with 12 SQL*Loader sessions. See Chapter 12, "Transportation in Data Warehouses" for an example.

Even if the `orders` table is not partitioned, it is still possible to parallelize the extraction either based on logical or physical criteria. The logical method is based on logical ranges of column values, for example:

```
SELECT ... WHERE order_date
BETWEEN TO_DATE('01-JAN-99') AND TO_DATE('31-JAN-99');
```

The physical method is based on a range of values. By viewing the data dictionary, it is possible to identify the Oracle data blocks that make up the `orders` table. Using this information, you could then derive a set of rowid-range queries for extracting data from the `orders` table:

```
SELECT * FROM orders WHERE rowid BETWEEN <value1> and <value2>;
```

Parallelizing the extraction of complex SQL queries is sometimes possible, although the process of breaking a single complex query into multiple components can be challenging. In particular, the coordination of independent processes to guarantee a globally consistent view can be difficult.

Note: All parallel techniques can use considerably more CPU and I/O resources on the source system, and the impact on the source system should be evaluated before parallelizing any extraction technique.

Extracting into Flat Files Using OCI or Pro*C Programs

OCI programs (or other programs using Oracle call interfaces, such as Pro*C programs), can also be used to extract data. These techniques typically provide improved performance over the SQL*Plus approach, although they also require additional programming. Like the SQL*Plus approach, an OCI program can extract the results of any SQL query. Furthermore, the parallelization techniques described for the SQL*Plus approach can be readily applied to OCI programs as well.

When using OCI or SQL*Plus for extraction, you need additional information besides the data itself. At minimum, you need information about the extracted columns. It is also helpful to know the extraction format, which might be the separator between distinct columns.

Exporting into Oracle Export Files Using Oracle's Export Utility

Oracle's Export utility allows tables (including data) to be exported into Oracle export files. Unlike the SQL*Plus and OCI approaches, which describe the extraction of the results of a SQL statement, Export provides a mechanism for extracting database objects. Thus, Export differs from the previous approaches in several important ways:

- The export files contain metadata as well as data. An export file contains not only the raw data of a table, but also information on how to re-create the table, potentially including any indexes, constraints, grants, and other attributes associated with that table.
- A single export file may contain a subset of a single object, many database objects, or even an entire schema.
- Export cannot be directly used to export the results of a complex SQL query. Export can be used only to extract subsets of distinct database objects.
- The output of the Export utility must be processed using the Oracle Import utility.

Oracle provides a direct-path export, which is quite efficient for extracting data. However, in Oracle8*i*, there is no direct-path import, which should be considered when evaluating the overall performance of an export-based extraction strategy.

See Also: *Oracle9i Database Utilities* for more information on using export

Extraction Via Distributed Operations

Using distributed-query technology, one Oracle database can directly query tables located in various different source systems, such as another Oracle database or a legacy system connected with the Oracle gateway technology. Specifically, a data warehouse or staging database can directly access tables and data located in a connected source system. Gateways are another form of distributed-query technology. Gateways allow an Oracle database (such as a data warehouse) to access database tables stored in remote, non-Oracle databases. This is the simplest method for moving data between two Oracle databases because it combines the extraction and transformation into a single step, and requires minimal programming. However, this is not always feasible.

Continuing our example from above, suppose that you wanted to extract a list of employee names with department names from a source database and store this data into the data warehouse. Using an Oracle Net connection and distributed-query technology, this can be achieved using a single SQL statement:

```
CREATE TABLE country_city
AS
SELECT distinct t1.country_name, t2.cust_city
FROM countries@source_db t1, customers@source_db t2
WHERE t1.country_id = t2.country_id
AND t1.country_name='United States of America';
```

This statement creates a local table in a data mart, `country_city`, and populates it with data from the `countries` and `customers` tables on the source system.

This technique is ideal for moving small volumes of data. However, the data is transported from the source system to the data warehouse through a single Oracle Net connection. Thus, the scalability of this technique is limited. For larger data volumes, file-based data extraction and transportation techniques are often more scalable and thus more appropriate.

See Also: *Oracle9i Heterogeneous Connectivity Administrator's Guide* and *Oracle9i Database Concepts* for more information on distributed queries

12 Transportation in Data Warehouses

The following topics provide information about transporting data into a data warehouse:

- Overview of Transportation in Data Warehouses
- Understanding Transportation Mechanisms in Data Warehouses

Overview of Transportation in Data Warehouses

Transportation is the operation of moving data from one system to another system. In a data warehouse environment, the most common requirements for transportation are in moving data from:

- A source system to a staging database or a data warehouse database
- A staging database to a data warehouse
- A data warehouse to a data mart

Transportation is often one of the simpler portions of the ETL process, and can be integrated with other portions of the process. For example, as shown in Chapter 11, "Extraction in Data Warehouses", distributed query technology provides a mechanism for both extracting and transporting data.

Understanding Transportation Mechanisms in Data Warehouses

You have three basic choices for transporting data in warehouses:

- Transportation Using Flat Files
- Transportation Through Distributed Operations
- Transportation Using Transportable Tablespaces

Transportation Using Flat Files

The most common method for transporting data is by the transfer of flat files, using mechanisms such as FTP or other remote file system access protocols. Data is unloaded or exported from the source system into flat files using techniques discussed in Chapter 11, "Extraction in Data Warehouses", and is then transported to the target platform using FTP or similar mechanisms.

Because source systems and data warehouses often use different operating systems and database systems, using flat files is often the simplest way to exchange data between heterogeneous systems with minimal transformations. However, even when transporting data between homogeneous systems, flat files are often the most efficient and most easy-to-manage mechanism for data transfer.

Transportation Through Distributed Operations

Distributed queries, either with or without gateways, can be an effective mechanism for extracting data. These mechanisms also transport the data directly to the target systems, thus providing both extraction and transformation in a single step. Depending on the tolerable impact on time and system resources, these mechanisms can be well suited for both extraction and transformation.

As opposed to flat file transportation, the success or failure of the transportation is recognized immediately with the result of the distributed query or transaction.

> **See Also:** Chapter 11, "Extraction in Data Warehouses", for further details

Transportation Using Transportable Tablespaces

Oracle8*i* introduced an important mechanism for transporting data: transportable tablespaces. This feature is the fastest way for moving large volumes of data between two Oracle databases.

Previous to Oracle8*i*, the most scalable data transportation mechanisms relied on moving flat files containing raw data. These mechanisms required that data be unloaded or exported into files from the source database, Then, after transportation, these files were loaded or imported into the target database. Transportable tablespaces entirely bypass the unload and reload steps.

Using transportable tablespaces, Oracle data files (containing table data, indexes, and almost every other Oracle database object) can be directly transported from one database to another. Furthermore, like import and export, transportable tablespaces provide a mechanism for transporting metadata in addition to transporting data.

Transportable tablespaces have some notable limitations: source and target systems must be running Oracle8*i* (or higher), must be running the same operating system, must use the same character set, and, prior to Oracle9*i*, must use the same block size. Despite these limitations, transportable tablespaces can be an invaluable data transportation technique in many warehouse environments.

The most common applications of transportable tablespaces in data warehouses are in moving data from a staging database to a data warehouse, or in moving data from a data warehouse to a data mart.

> **See Also:** *Oracle9i Database Concepts* for more information on transportable tablespaces

Transportable Tablespaces Example

Suppose that you have a data warehouse containing sales data, and several data marts that are refreshed monthly. Also suppose that you are going to move one month of sales data from the data warehouse to the data mart.

Step 1: Place the Data to be Transported into its own Tablespace The current month's data must be placed into a separate tablespace in order to be transported. In this example, you have a tablespace `ts_temp_sales`, which will hold a copy of the current month's data. Using the CREATE TABLE ... AS SELECT statement, the current month's data can be efficiently copied to this tablespace:

```
CREATE TABLE temp_jan_sales
NOLOGGING
TABLESPACE ts_temp_sales
AS
SELECT * FROM sales
WHERE time_id BETWEEN '31-DEC-1999' AND '01-FEB-2000';
```

Following this operation, the tablespace `ts_temp_sales` is set to read-only:

```
ALTER TABLESPACE ts_temp_sales READ ONLY;
```

A tablespace cannot be transported unless there are no active transactions modifying the tablespace. Setting the tablespace to read-only enforces this.

The tablespace `ts_temp_sales` may be a tablespace that has been especially created to temporarily store data for use by the transportable tablespace features. Following "Step 3: Copy the Datafiles and Export File to the Target System", this tablespace can be set to read / write, and, if desired, the table `temp_jan_sales` can be dropped, or the tablespace can be re-used for other transportations or for other purposes.

In a given transportable tablespace operation, all of the objects in a given tablespace are transported. Although only one table is being transported in this example, the tablespace `ts_temp_sales` could contain multiple tables. For example, perhaps the data mart is refreshed not only with the new month's worth of sales transactions, but also with a new copy of the customer table. Both of these tables could be transported in the same tablespace. Moreover, this tablespace could also contain other database objects such as indexes, which would also be transported.

Additionally, in a given transportable-tablespace operation, multiple tablespaces can be transported at the same time. This makes it easier to move very large volumes of data between databases. Note, however, that the transportable tablespace feature can only transport a set of tablespaces which contain a complete set of database objects without dependencies on other tablespaces. For example, an index cannot be transported without its table, nor can a partition be transported without the rest of the table. You can use the `DBMS_TTS` package to check that a tablespace is transportable.

See Also: *Oracle9i Supplied PL/SQL Packages and Types Reference* for detailed information about the DBMS_TTS package

In this step, we have copied the January sales data into a separate tablespace; however, in some cases, it may be possible to leverage the transportable tablespace feature without even moving data to a separate tablespace. If the sales table has been partitioned by month in the data warehouse and if each partition is in its own tablespace, then it may be possible to directly transport the tablespace containing the January data. Suppose the January partition, sales_jan2000, is located in the tablespace ts_sales_jan2000. Then the tablespace ts_sales_jan2000 could potentially be transported, rather than creating a temporary copy of the January sales data in the ts_temp_sales.

However, the same conditions must be satisfied in order to transport the tablespace ts_sales_jan2000 as are required for the specially created tablespace. First, this tablespace must be set to READ ONLY. Second, because a single partition of a partitioned table cannot be transported without the remainder of the partitioned table also being transported, it is necessary to exchange the January partition into a separate table (using the ALTER TABLE statement) to transport the January data. The EXCHANGE operation is very quick, but the January data will no longer be a part of the underlying sales table, and thus may be unavailable to users until this data is exchanged back into the sales table after the export of the metadata. The January data can be exchanged back into the sales table after you complete step 3.

Step 2: Export the Metadata The Export utility is used to export the metadata describing the objects contained in the transported tablespace. For our example scenario, the Export command could be:

```
EXP TRANSPORT_TABLESPACE=y
    TABLESPACES=ts_temp_sales
    FILE=jan_sales.dmp
```

This operation will generate an export file, jan_sales.dmp. The export file will be small, because it contains only metadata. In this case, the export file will contain information describing the table temp_jan_sales, such as the column names, column datatype, and all other information that the target Oracle database will need in order to access the objects in ts_temp_sales.

Step 3: Copy the Datafiles and Export File to the Target System Copy the data files that make up ts_temp_sales, as well as the export file jan_sales.dmp to the data mart platform, using any transportation mechanism for flat files.

Once the datafiles have been copied, the tablespace `ts_temp_sales` can be set to `READ WRITE` mode if desired.

Step 4: Import the Metadata Once the files have been copied to the data mart, the metadata should be imported into the data mart:

```
IMP TRANSPORT_TABLESPACE=y DATAFILES='/db/tempjan.f'
    TABLESPACES=ts_temp_sales
    FILE=jan_sales.dmp
```

At this point, the tablespace `ts_temp_sales` and the table `temp_sales_jan` are accessible in the data mart. You can incorporate this new data into the data mart's tables.

You can insert the data from the `temp_sales_jan` table into the data mart's sales table in one of two ways:

```
INSERT /*+ APPEND */ INTO sales SELECT * FROM temp_sales_jan;
```

Following this operation, you can delete the `temp_sales_jan` table (and even the entire `ts_temp_sales` tablespace).

Alternatively, if the data mart's sales table is partitioned by month, then the new transported tablespace and the `temp_sales_jan` table can become a permanent part of the data mart. The `temp_sales_jan` table can become a partition of the data mart's sales table:

```
ALTER TABLE sales ADD PARTITION sales_00jan VALUES
  LESS THAN (TO_DATE('01-feb-2000','dd-mon-yyyy'));
ALTER TABLE sales EXCHANGE PARTITION sales_00jan
  WITH TABLE temp_sales_jan
INCLUDING INDEXES WITH VALIDATION;
```

Other Uses of Transportable Tablespaces

The above example illustrates a typical scenario for transporting data in a data warehouse. However, transportable tablespaces can be used for many other purposes. In a data warehousing environment, transportable tablespaces should be viewed as a utility (much like Import/Export or SQL*Loader), whose purpose is to move large volumes of data between Oracle databases. When used in conjunction with parallel data movement operations such as the `CREATE TABLE ... AS SELECT` and `INSERT ... AS SELECT` statements, transportable tablespaces provide an important mechanism for quickly transporting data for many purposes.

13

Loading and Transformation

This chapter helps you create and manage a data warehouse, and discusses:

Overview of Loading and Transformation in Data Warehouses

Data transformations are often the most complex and, in terms of processing time, the most costly part of the ETL process. They can ranget from simple data conversions to extremely complex data scrubbing techniques. Many, if not all, data transformations can occur within an Oracle9*i* database, although transformations are often implemented outside of the database (for example, on flat files) as well.

This chapter introduces techniques for implementing scalable and efficient data transformations within Oracle9*i*. The examples in this chapter are relatively simple. Real-world data transformations are often considerably more complex. However, the transformation techniques introduced in this chapter meet the majority of real-world data transformation requirements, often with more scalability and less programming than alternative approaches.

This chapter does not seek to illustrate all of the typical transformations that would be encountered in a data warehouse, but to demonstrate the types of fundamental technology that can be applied to implement these transformations and to provide guidance in how to choose the best techniques.

Transformation Flow

From an architectural perspective, you can transform your data in two ways:

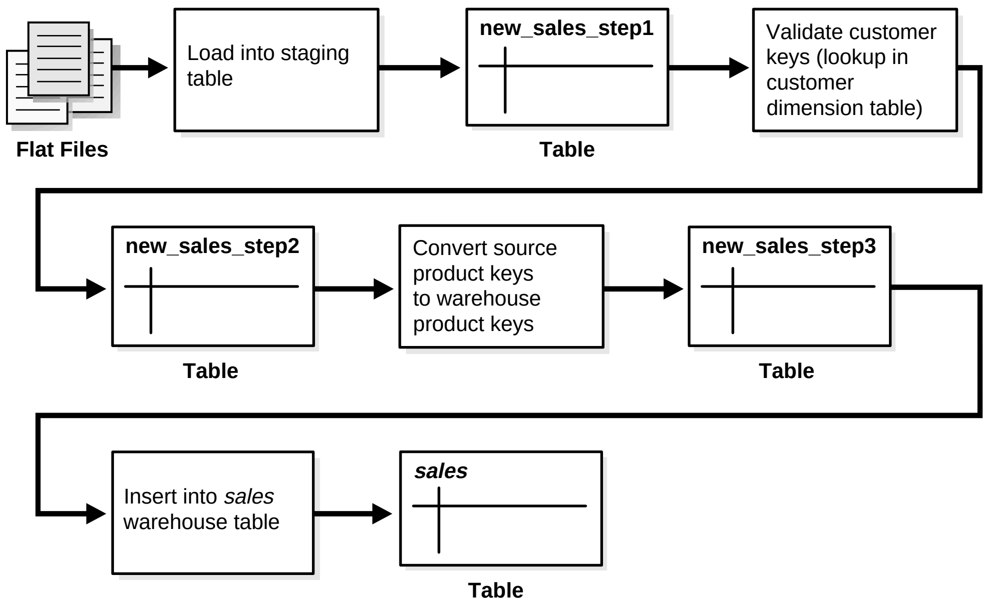
- Multistage Data Transformation
- Pipelined Data Transformation

Multistage Data Transformation

The data transformation logic for most data warehouses consists of multiple steps. For example, in transforming new records to be inserted into a sales table, there may be separate logical transformation steps to validate each dimension key.

A graphical way of looking at the transformation logic is presented in Figure 13–1:

Figure 13–1 Multi-Stage Data Transformation


Flat Files
Load into staging table
new_sales_step1
Table
Validate customer keys (lookup in customer dimension table)
new_sales_step2
Table
Convert source product keys to warehouse product keys
new_sales_step3
Table
Insert into *sales* warehouse table
sales
Table

When using Oracle9*i* as a transformation engine, a common strategy is to implement each different transformation as a separate SQL operation and to create a separate, temporary staging table (such as the tables `new_sales_step1` and `new_sales_step2` in Figure 13–1) to store the incremental results for each step. This load-then-transform strategy also provides a natural **checkpointing** scheme to the entire transformation process, which enables to the process to be more easily monitored and restarted. However, a disadvantage to multistaging is that the space and time requirements increase.

It may also be possible to combine many simple logical transformations into a single SQL statement or single PL/SQL procedure. Doing so may provide better performance than performing each step independently, but it may also introduce difficulties in modifying, adding, or dropping individual transformations, as well as recovering from failed transformations.

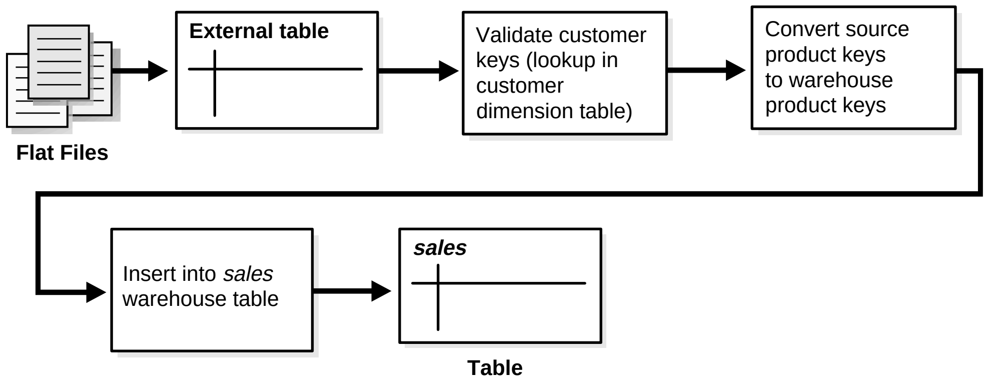
Pipelined Data Transformation

With the introduction of Oracle9*i*, Oracle's database capabilities have been significantly enhanced to address specifically some of the tasks in ETL environments. The ETL process flow can be changed dramatically and the database becomes an integral part of the ETL solution.

The new functionality renders some of the former necessary process steps obsolete whilst some others can be remodeled to enhance the data flow and the data transformation to become more scalable and non-interruptive. The task shifts from serial transform-then-load process (with most of the tasks done outside the database) or load-then-transform process, to an enhanced transform-while-loading.

Oracle9*i* offers a wide variety of new capabilities to address all the issues and tasks relevant in an ETL scenario. It is important to understand that the database offers toolkit functionality rather than trying to address a one-size-fits-all solution. The underlying database has to enable the most appropriate ETL process flow for a specific customer need, and not dictate or constrain it from a technical perspective. Figure 13–2 illustrates the new functionality, which is discussed throughout later sections.

Figure 13–2 Pipelined Data Transformation


External table
Validate customer keys (lookup in customer dimension table)
Convert source product keys to warehouse product keys
Flat Files
Insert into *sales* warehouse table
sales
Table

Loading Mechanisms

You can use the following mechanisms for loading a warehouse:

- SQL*Loader
- External Tables
- OCI and Direct-path APIs
- Export/Import

SQL*Loader

Before any data transformations can occur within the database, the raw data must become accessible for the database. One approach is to load it into the database. Chapter 12, "Transportation in Data Warehouses", discusses several techniques for transporting data to an Oracle data warehouse. Perhaps the most common technique for transporting data is by way of flat files.

SQL*Loader is used to move data from flat files into an Oracle data warehouse. During this data load, SQL*Loader can also be used to implement basic data transformations. When using direct-path SQL*Loader, basic data manipulation, such as datatype conversion and simple `NULL` handling, can be automatically resolved during the data load. Most data warehouses use direct-path loading for performance reasons.

Oracle's conventional-path loader provides broader capabilities for data transformation than a direct-path loader: SQL functions can be applied to any column as those values are being loaded. This provides a rich capability for transformations during the data load. However, the conventional-path loader is slower than direct-path loader. For these reasons, the conventional-path loader should be considered primarily for loading and transforming smaller amounts of data.

> **See Also:** *Oracle9i Database Utilities* for more information on SQL*Loader

The following is a simple example of a SQL*Loader controlfile to load data into the sales fact table of the `Sales History` schema from an external file `sh_sales.dat`. The external flat file `sh_sales.dat` consists of sales transaction data, aggregated on a daily level. Not all columns of this external file are loaded into the sales table. This external file will also be used as source for loading the second fact table cost of the `Sales History` schema, which is done using an external table:

The following shows the controlfile (`sh_sales.ctl`) to load the `sales` table:

```
LOAD DATA
INFILE sh_sales.dat
APPEND INTO TABLE sales
FIELDS TERMINATED BY "|"
( PROD_ID, CUST_ID, TIME_ID, CHANNEL_ID, PROMO_ID,
 QUANTITY_SOLD, AMOUNT_SOLD)
```

It can be loaded with the following command:

```
$  sqlldr sh/sh control=sh_sales.ctl direct=true
```

External Tables

Another approach for handling external data sources is using external tables. Oracle9*i*'s external table feature enables you to use external data as a virtual table that can be queried and joined directly and in parallel without requiring the external data to be first loaded in the database. You can then use SQL, PL/SQL, and Java to access the external data.

External tables enable the pipelining of the loading phase with the transformation phase. The transformation process can be merged with the loading process without any interruption of the data streaming. It is no longer necessary to stage the data inside the database for further processing inside the database, such as comparison or transformation. For example, the conversion functionality of a conventional load can be used for a direct-path `INSERT AS SELECT` statement in conjunction with the `SELECT` from an external table.

The main difference between external tables and regular tables is that externally organized tables are read-only. No DML operations (`UPDATE`/`INSERT`/`DELETE`) are possible and no indexes can be created on them.

Oracle9*i*'s external tables are a complement to the existing SQL*Loader functionality, and are especially useful for environments where the complete external source has to be joined with existing database objects and transformed in a complex manner, or where the external data volume is large and used only once. SQL*Loader, on the other hand, might still be the better choice for loading of data where additional indexing of the staging table is necessary. This is true for operations where the data is used in independent complex transformations or the data is only partially used in further processing.

> **See Also:** *Oracle9i SQL Reference* for a complete description of external table syntax and restrictions and *Oracle9i Database Utilities* for usage examples

You can create an external table named `sales_transactions_ext`, representing the structure of the complete sales transaction data, represented in the external file `sh_sales.dat`. The product department is especially interested in a cost analysis on product and time. We thus create a fact table named `cost` in the `sales history` schema. The operational source data is the same as for the `sales` fact table. However, because we are not investigating every dimensional information that is provided, the data in the cost fact table has a coarser granularity than in the sales fact table, for example, all different distribution channels are aggregated.

We cannot load the data into the cost fact table without applying the above mentioned aggregation of the detailed information, due to the suppression of some of the dimensions.

Oracle’s external table framework offers a solution to solve this. Unlike SQL*Loader, where we would have to load the data before applying the aggregation, we can combine the loading and transformation within a single SQL DML statement, as shown below. We do not have to stage the data temporarily before inserting into the target table.

The Oracle object directories must already exist, and point to the directory containing the `sh_sales.dat` file as well as the directory containing the bad and log files.

```
CREATE TABLE sales_transactions_ext
(
  PROD_ID NUMBER(6),
  CUST_ID NUMBER,
  TIME_ID DATE,
  CHANNEL_ID CHAR(1),
  PROMO_ID NUMBER(6),
  QUANTITY_SOLD NUMBER(3),
  AMOUNT_SOLD NUMBER(10,2),
  UNIT_COST NUMBER(10,2),
  UNIT_PRICE NUMBER(10,2)
)
ORGANIZATION external
(
  TYPE oracle_loader
  DEFAULT DIRECTORY data_file_dir
  ACCESS PARAMETERS
  (
    RECORDS DELIMITED BY NEWLINE CHARACTERSET US7ASCII
    BADFILE log_file_dir:'sh_sales.bad_xt'
    LOGFILE log_file_dir:'sh_sales.log_xt'
    FIELDS TERMINATED BY "|" LDRTRIM
  )
  location
  (
    'sh_sales.dat'
  )
)REJECT LIMIT UNLIMITED;
```

The external table can now be used from within the database, accessing some columns of the external data only, grouping the data, and inserting it into the `costs` fact table:

```
INSERT /*+ APPEND */ INTO COSTS
(
  TIME_ID,
  PROD_ID,
  UNIT_COST,
  UNIT_PRICE
)
SELECT
  TIME_ID,
  PROD_ID,
  SUM(UNIT_COST),
  SUM(UNIT_PRICE)
FROM sales_transactions_ext
GROUP BY time_id, prod_id;
```

OCI and Direct-path APIs

OCI and direct-path APIs are frequently used when the transformation and computation are done outside the database and there is no need for flat file staging.

Export/Import

Export and import are used when the data is inserted as is into the target system. No large volumes of data should be handled and no complex extractions are possible.

> **See Also:** Chapter 11, "Extraction in Data Warehouses" for further information

Transformation Mechanisms

You have the following choices for transforming data inside the database:

- Transformation Using SQL
- Transformation Using PL/SQL
- Transformation Using Table Functions

Transformation Using SQL

Once data is loaded into an Oracle9*i* database, data transformations can be executed using SQL operations. There are four basic techniques for implementing SQL data transformations within Oracle9*i*:

- The CREATE TABLE ... AS SELECT and INSERT /*+APPEND*/ AS SELECT Statements
- The UPDATE Statement
- The MERGE Statement
- The Multitable INSERT Statement

1. The CREATE TABLE ... AS SELECT Statement

The CREATE TABLE ... AS SELECT statement (CTAS) is a very powerful tool for manipulating large sets of data. As shown in the example below, many data transformations can be expressed in standard SQL, and CTAS provides a mechanism for efficiently executing a SQL query and storing the results of that query in a new database table. The INSERT /*+APPEND*/ ... AS SELECT statement offers the same capabilities with existing database tables.

In a data warehouse environment, CTAS is typically run in parallel using NOLOGGING mode for best performance.

A simple and common type of data transformation is data substitution. In a data substitution transformation, some or all of the values of a single column are modified. For example, our sales table has a channel_id column. This column indicates whether a given sales transaction was made by a company's own sales force (a direct sale) or by a distributor (an indirect sale).

You may receive data from multiple source systems foryour data warehouse. Suppose that one of those source systems processes only direct sales, and thus the source system does not know indirect sales channels. When the data warehouse initially receives sales data from this system, all sales records have a NULL value for the sales.channel_id field. These NULL values must be set to the proper key value. For example, You can do this efficiently using a SQL function as part of the insertion into the target sales table statement:

The structure of source table `sales_activity_direct` is as follows:

```
SQL> DESC sales_activity_direct
Name          Null?    Type
------------  -----    ----------------
SALES_DATE             DATE
PRODUCT_ID             NUMBER
CUSTOMER_ID            NUMBER
PROMOTION_ID           NUMBER
AMOUNT                 NUMBER
QUANTITY               NUMBER

INSERT /*+ APPEND NOLOGGING PARALLEL */
INTO sales
SELECT product_id, customer_id, TRUNC(sales_date), 'S',
  promotion_id, quantity, amount
FROM  sales_activity_direct;
```

2. The `UPDATE` Statement

Another technique for implementing a data substitution is to use an `UPDATE` statement to modify the `sales.channel_id` column. An `UPDATE` will provide the correct result. However, if the data substitution transformations require that a very large percentage of the rows (or all of the rows) be modified, then, it may be more efficient to use a CTAS statement than an `UPDATE`.

3. The `MERGE` Statement

Oracle's merge functionality extends SQL, by introducing the SQL keyword `MERGE`, in order to provide the ability to update or insert a row conditionally into a table or out of line single table views. Conditions are specified in the `ON` clause. This is, besides pure bulk loading, one of the most common operations in data warehouse synchronization.

Prior to Oracle9*i*, merges were expressed either as a sequence of DML statements or as PL/SQL loops operating on each row. Both of these approaches suffer from deficiencies in performance and usability. The new merge functionality overcomes these deficiencies with a new SQL statement. This syntax has been proposed as part of the upcoming SQL standard.

When to Use Merge

There are several benefits of the new MERGE statement as compared with the two other existing approaches.

- The entire operation can be expressed much more simply as a single SQL statement.
- You can parallelize statements transparently.
- You can use bulk DML.
- Performance will improve becasue your statements will require fewer scans of the source table.

Merge Examples

The following discusses various implementations of a merge. The examples assume that new data for the dimension table products is propagated to the data warehouse and has to be either inserted or updated. The table `products_delta` has the same structure as `products`.

Example 13–1 Merge Operation Using SQL in Oracle9i

```
MERGE INTO products t
USING products_delta s
ON (t.prod_id=s.prod_id)
WHEN MATCHED THEN
UPDATE SET
t.prod_list_price=s.prod_list_price,
t.prod_min_price=s.prod_min_price
WHEN NOT MATCHED THEN
INSERT
(prod_id, prod_name, prod_desc,
prod_subcategory, prod_subcat_desc, prod_category,
prod_cat_desc, prod_status, prod_list_price, prod_min_price)
VALUES
(s.prod_id, s.prod_name, s.prod_desc,
s.prod_subcategory, s.prod_subcat_desc,
s.prod_category, s.prod_cat_desc,
s.prod_status, s.prod_list_price, s.prod_min_price);
```

Example 13–2 Merge Operation Using SQL Prior to Oracle9i

A regular join between source `products_delta` and target `products`.

```
UPDATE products t
SET
(prod_name, prod_desc, prod_subcategory, prod_subcat_desc, prod_category,
prod_cat_desc, prod_status, prod_list_price,
prod_min_price) =
(SELECT prod_name, prod_desc, prod_subcategory, prod_subcat_desc,
prod_category, prod_cat_desc, prod_status, prod_list_price,
prod_min_price from products_delta s WHERE s.prod_id=t.prod_id);
```

An antijoin between source `products_delta` and target `products`.

```
INSERT INTO products t
SELECT * FROM products_delta s
WHERE s.prod_id NOT IN
(SELECT prod_id FROM products);
```

The advantage of this approach is its simplicity and lack of new language extensions. The disadvantage is its performance. It requires an extra scan and a join of both the `products_delta` and the `products` tables.

Example 13–3 Pre-9i Merge Using PL/SQL

```
CREATE OR REPLACE PROCEDURE merge_proc
IS
CURSOR cur IS
SELECT prod_id, prod_name, prod_desc, prod_subcategory, prod_subcat_desc,
       prod_category, prod_cat_desc, prod_status, prod_list_price,
       prod_min_price
FROM products_delta;
crec cur%rowtype;
BEGIN
  OPEN cur;
  LOOP
    FETCH cur INTO crec;
    EXIT WHEN cur%notfound;
    UPDATE products SET
          prod_name = crec.prod_name, prod_desc = crec.prod_desc,
          prod_subcategory = crec.prod_subcategory,
          prod_subcat_desc = crec.prod_subcat_desc,
          prod_category = crec.prod_category,
          prod_cat_desc = crec.prod_cat_desc,
          prod_status = crec.prod_status,
          prod_list_price = crec.prod_list_price,
          prod_min_price = crec.prod_min_price
      WHERE crec.prod_id = prod_id;

    IF SQL%notfound THEN
    INSERT INTO products
    (prod_id, prod_name, prod_desc, prod_subcategory,
     prod_subcat_desc, prod_category,
     prod_cat_desc, prod_status, prod_list_price, prod_min_price)
    VALUES
    (crec.prod_id, crec.prod_name, crec.prod_desc, crec.prod_subcategory,
     crec.prod_subcat_desc, crec.prod_category,
     crec.prod_cat_desc, crec.prod_status, crec.prod_list_price, crec.prod_min_
price);
    END IF;
  END LOOP;
  CLOSE cur;
END merge_proc;
/
```

4. A Multitable `INSERT` Statement

Many times, external data sources have to be segregated based on logical attributes for insertion into different target objects. It's also frequent in data warehouse environments to fan out the same source data into several target objects. Multitable inserts provide a new SQL statement for these kinds of transformations, where data can either end up in several or exactly one target, depending on the business transformation rules. This insertion can be done conditionally based on business rules or unconditionally.

It offers the benefits of the `INSERT` ... `SELECT` statement when multiple tables are involved as targets. In doing so, it avoids the drawbacks of the alternatives available to you using functionality prior to Oracle9*i*. You either had to deal with *n* independent `INSERT` … `SELECT` statements, thus processing the same source data *n* times and increasing the transformation workload *n* times. Alternatively, you had to choose a procedural approach with a per-row determination how to handle the insertion. This solution lacked direct access to high-speed access paths available in SQL.

As with the existing `INSERT` ... `SELECT` statement, the new statement can be parallelized and used with the direct-load mechanism for faster performance.

Example 13–4 Unconditional Insert

The following statement aggregates the transactional sales information, stored in `sales_activity_direct`, on a per daily base and inserts into both the sales and the cost fact table for the current day.

```
INSERT ALL
   INTO sales VALUES (product_id, customer_id, today, 'S', promotion_id,
                   quantity_per_day, amount_per_day)
   INTO cost VALUES (product_id, today, product_cost, product_price)
SELECT TRUNC(s.sales_date) as today,
   s.product_id, s.customer_id, s.promotion_id,
   SUM(s.amount) as amount_per_day, SUM(s.quantity) quantity_per_day,
   p.product_cost, p.product_price
   FROM sales_activity_direct s, product_information p
   WHERE s.product_id = p.product_id
   AND trunc(sales_date)=trunc(sysdate)
   GROUP BY trunc(sales_date), s.product_id,
            s.customer_id, s.promotion_id, p.product_cost, p.product_price;
```

Example 13–5 Conditional ALL Insert

The following statement inserts a row into the `sales` and `cost` tables for all sales transactions with a valid promotion and stores the information about multiple identical orders of a customer in a separate table `cum_sales_activity`. It is possible two rows will be inserted for some sales transactions, and none for others.

```
INSERT ALL
WHEN promotion_id IN (SELECT promo_id FROM promotions) THEN
   INTO sales VALUES (product_id, customer_id, today, 'S', promotion_id,
                    quantity_per_day, amount_per_day)
   INTO cost VALUES (product_id, today, product_cost, product_price)
WHEN num_of_orders > 1 THEN
   INTO cum_sales_activity VALUES (today, product_id, customer_id,
                           promotion_id, quantity_per_day, amount_per_day,
                           num_of_orders)
SELECT TRUNC(s.sales_date) AS today, s.product_id, s.customer_id,
       s.promotion_id, SUM(s.amount) AS amount_per_day, SUM(s.quantity)
       quantity_per_day, COUNT(*) num_of_orders,
       p.product_cost, p.product_price
FROM sales_activity_direct s, product_information p
WHERE s.product_id = p.product_id
AND TRUNC(sales_date) = TRUNC(sysdate)
GROUP BY TRUNC(sales_date), s.product_id, s.customer_id,
            s.promotion_id, p.product_cost, p.product_price;
```

Example 13–6 Conditional FIRST Insert

The following statement inserts into an appropriate shipping manifest according to the total quantity and the weight of a product order. An exception is made for high value orders, which are also sent by express, unless their weight classification is not too high. It assumes the existence of appropriate tables `large_freight_shipping`, `express_shipping`, and `default_shipping`.

```
INSERT FIRST
   WHEN (sum_quantity_sold > 10 AND prod_weight_class < 5) OR
        (sum_quantity_sold > 5 AND prod_weight_class > 5) THEN
      INTO large_freight_shipping VALUES
          (time_id, cust_id, prod_id, prod_weight_class, sum_quantity_sold)
   WHEN sum_amount_sold > 1000 THEN
      INTO express_shipping VALUES
          (time_id, cust_id, prod_id, prod_weight_class,
           sum_amount_sold, sum_quantity_sold)
   ELSE
      INTO default_shipping VALUES
          (time_id, cust_id, prod_id, sum_quantity_sold)
SELECT s.time_id, s.cust_id, s.prod_id, p.prod_weight_class,
       SUM(amount_sold) AS sum_amount_sold,
       SUM(quantity_sold) AS sum_quantity_sold
FROM sales s, products p
WHERE s.prod_id = p.prod_id
AND s.time_id = TRUNC(sysdate)
GROUP BY s.time_id, s.cust_id, s.prod_id, p.prod_weight_class;
```

Example 13–7 Mixed Conditional and Unconditional Insert

The following example inserts new customers into the customers table and stores all new customers with `cust_credit_limit` higher then 4500 in an additional, separate table for further promotions.

```
INSERT FIRST
  WHEN cust_credit_limit >= 4500 THEN
     INTO customers
     INTO customers_special VALUES (cust_id, cust_credit_limit)
  ELSE
     INTO customers
SELECT * FROM customers_new;
```

Transformation Using PL/SQL

In a data warehouse environment, you can use procedural languages such as PL/SQL to implement complex transformations in the Oracle9*i* database. Whereas CTAS operates on entire tables and emphasizes parallelism, PL/SQL provides a row-based approached and can accommodate very sophisticated transformation rules. For example, a PL/SQL procedure could open multiple cursors and read data from multiple source tables, combine this data using complex business rules, and finally insert the transformed data into one or more target table. It would be difficult or impossible to express the same sequence of operations using standard SQL statements.

Using a procedural language, a specific transformation (or number of transformation steps) within a complex ETL processing can be encapsulated, reading data from an intermediate staging area and generating a new table object as output. A previously generated transformation input table and a subsequent transformation will consume the table generated by this specific transformation. Alternatively, these encapsulated transformation steps within the complete ETL process can be integrated seamlessly, thus streaming sets of rows between each other without the necessity of intermediate staging. You can use Oracle9*i*'s table functions to implement such behavior.

Transformation Using Table Functions

Oracle9*i*'s table functions provide the support for pipelined and parallel execution of transformations implemented in PL/SQL, C, or Java. Scenarios as mentioned above can be done without requiring the use of intermediate staging tables, which interrupt the data flow through various transformations steps.

What is a Table Function?

A table function is defined as a function that can produce a set of rows as output. Additionally, table functions can take a set of rows as input. Prior to Oracle9*i*, PL/SQL functions:

- Could not take cursors as input
- Could not be parallelized or pipelined

Starting with Oracle9*i*, functions are not limited in these ways. Table functions extend database functionality by allowing:

- Multiple rows to be returned from a function

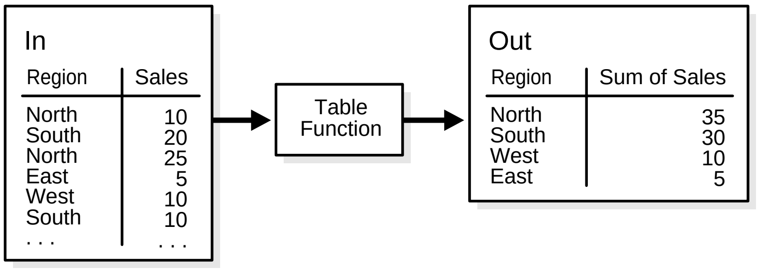
- Results of SQL subqueries (that select multiple rows) to be passed directly to functions
- Functions take cursors as input
- Functions can be parallelized
- Returning result sets incrementally for further processing as soon as they are created. This is called incremental pipelining

Table functions can be defined in PL/SQL using a native PL/SQL interface, or in Java or C using the Oracle Data Cartridge Interface (ODCI).

> **See Also:** *PL/SQL User's Guide and Reference* for further information and *Oracle9i Data Cartridge Developer's Guide*

Figure 13–3 illustrates a typical aggregation where you input a set of rows and output a set of rows, in that case, after performing a `SUM` operation:

Figure 13–3 Table Function Example



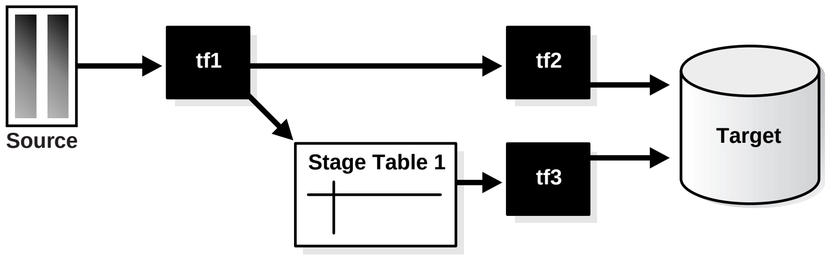
The pseudocode for the above operation would be similar to:

```
INSERT INTO out
SELECT * FROM ("Table Function"(SELECT * FROM in));
```

The table function takes the result of the `SELECT` on `In` as input and delivers a set of records in a different format as output for a direct insertion into `Out`.

Additionally, a table function can fan out data within the scope of an atomic transaction. This can be used for many occasions like an efficient logging mechanism or a fan out for other independent transformations. In such a scenario, a single staging table will be needed.

Figure 13–4 Pipelined Parallel Transformation with Fanout



The pseudocode for the above would be similar to:

```
INSERT INTO target SELECT * FROM (tf2(SELECT *
FROM (tf1(SELECT * FROM source))));
```

This will insert into `target` and, as part of `tf1`, into `Stage Table 1` within the scope of an atomic transaction.

```
INSERT INTO target SELECT * FROM tf3(SELT * FROM stage_table1);
```

Example 13–8 Table Functions Fundamentals-Examples

The following examples demonstrate the fundamentals of table functions, without the usage of complex business rules implemented inside those functions. They are chosen for demonstration purposes only, and are all implemented in PL/SQL.

Table functions return sets of records and can take cursors as input. Besides the `Sales History` schema, you have to set up the following database objects before using the examples:

```
REM object types
CREATE TYPE product_t AS OBJECT (
    prod_id             NUMBER(6),
    prod_name           VARCHAR2(50),
    prod_desc           VARCHAR2(4000),
    prod_subcategory    VARCHAR2(50),
    prod_subcat_desc    VARCHAR2(2000).
    prod_category       VARCHAR2(50),
    prod_cat_desc       VARCHAR2(2000),
    prod_weight_class   NUMBER(2),
    prod_unit_of_measure VARCHAR2(20),
    prod_pack_size      VARCHAR2(30),
    supplier_id         NUMBER(6),
    prod_status         VARCHAR2(20),
    prod_list_price      NUMBER(8,2),
    prod_min_price       NUMBER(8,2)
);
/
CREATE TYPE product_t_table AS TABLE OF product_t;
/
COMMIT;

REM package of all cursor types
REM we have to handle the input cursor type and the output cursor collection
REM type
CREATE OR REPLACE PACKAGE cursor_PKG as
  TYPE product_t_rec IS RECORD (
     prod_id              NUMBER(6),
     prod_name            VARCHAR2(50),
     prod_desc            VARCHAR2(4000),
     prod_subcategory     VARCHAR2(50),
     prod_subcat_desc     VARCHAR2(2000),
     prod_category        VARCHAR2(50),
     prod_cat_desc        VARCHAR2(2000),
     prod_weight_class    NUMBER(2),
     prod_unit_of_measure VARCHAR2(20),
     prod_pack_size       VARCHAR2(30),
     supplier_id          NUMBER(6),
     prod_status          VARCHAR2(20),
     prod_list_price      NUMBER(8,2),
     prod_min_price       NUMBER(8,2));
  TYPE product_t_rectab IS TABLE OF product_t_rec;
  TYPE strong_refcur_t IS REF CURSOR RETURN product_t_rec;
  TYPE refcur_t IS REF CURSOR;
END;
/

REM artificial help table, used to demonstrate figure 13-4
CREATE TABLE obsolete_products_errors (prod_id NUMBER, msg VARCHAR2(2000));
```

The following example demonstrates a simple filtering; it shows all obsolete products except the `prod_category` `Boys`. The table function returns the result set as a set of records and uses a weakly typed ref cursor as input.

```
CREATE OR REPLACE FUNCTION obsolete_products(cur cursor_pkg.refcur_t)
   RETURN product_t_table
IS
    prod_id              NUMBER(6);
    prod_name            VARCHAR2(50);
    prod_desc           VARCHAR2(4000);
    prod_subcategory    VARCHAR2(50);
    prod_subcat_desc    VARCHAR2(2000);
    prod_category       VARCHAR2(50);
    prod_cat_desc       VARCHAR2(2000);
    prod_weight_class   NUMBER(2);
    prod_unit_of_measure VARCHAR2(20);
    prod_pack_size      VARCHAR2(30);
    supplier_id         NUMBER(6);
    prod_status         VARCHAR2(20);
    prod_list_price     NUMBER(8,2);
    prod_min_price      NUMBER(8,2);
  sales NUMBER:=0;
  objset product_t_table := product_t_table();
  i NUMBER := 0;
BEGIN
   LOOP
     -- Fetch from cursor variable
     FETCH cur INTO prod_id, prod_name, prod_desc, prod_subcategory,
     prod_subcat_desc,   prod_category, prod_cat_desc, prod_weight_class,
     prod_unit_of_measure,  prod_pack_size, supplier_id, prod_status,
     prod_list_price, prod_min_price;
     EXIT WHEN cur%NOTFOUND; -- exit when last row is fetched
     IF prod_status='obsolete' AND prod_category != 'Boys' THEN
     -- append to collection
     i:=i+1;
     objset.extend;
     objset(i):=product_t( prod_id, prod_name, prod_desc, prod_subcategory,
prod_subcat_desc,  prod_category, prod_cat_desc, prod_weight_class, prod_unit_
of_measure,  prod_pack_size, supplier_id, prod_status, prod_list_price, prod_
min_price);
     END IF;
   END LOOP;
   CLOSE cur;
   RETURN objset;
END;
/
```

You can use the table function in a SQL statement to show the results. Here we use additional SQL functionality for the output.

```
SELECT DISTINCT UPPER(prod_category), prod_status
FROM TABLE(obsolete_products(CURSOR(SELECT * FROM products)));

UPPER(PROD_CATEGORY)      PROD_STATUS
--------------------      -----------
GIRLS                     obsolete
MEN                       obsolete

2 rows selected.
```

The following example implements the same filtering than the first one. The main differences between those two are:

- This example uses a strong typed REF cursor as input and can be parallelized based on the objects of the strong typed cursor, as shown in one of the following examples.
- The table function returns the result set incrementally as soon as records are created.

```
REM Same example, pipelined implementation
REM strong ref cursor (input type is defined)
REM a table without a strong typed input ref cursor cannot be parallelized
REM
CREATE OR
REPLACE FUNCTION obsolete_products_pipe(cur cursor_pkg.strong_refcur_t)
RETURN product_t_table
PIPELINED
PARALLEL_ENABLE (PARTITION cur BY ANY) IS
    prod_id             NUMBER(6);
    prod_name           VARCHAR2(50);
    prod_desc           VARCHAR2(4000);
    prod_subcategory    VARCHAR2(50);
    prod_subcat_desc    VARCHAR2(2000);
    prod_category       VARCHAR2(50);
    prod_cat_desc       VARCHAR2(2000);
    prod_weight_class   NUMBER(2);
    prod_unit_of_measure VARCHAR2(20);
    prod_pack_size      VARCHAR2(30);
    supplier_id         NUMBER(6);
    prod_status         VARCHAR2(20);
    prod_list_price     NUMBER(8,2);
    prod_min_price      NUMBER(8,2);
```

```
  sales NUMBER:=0;
BEGIN
   LOOP
     -- Fetch from cursor variable
     FETCH cur INTO prod_id, prod_name, prod_desc, prod_subcategory, prod_
subcat_desc, prod_category, prod_cat_desc, prod_weight_class, prod_unit_of_
measure, prod_pack_size, supplier_id, prod_status, prod_list_price, prod_min_
price;
     EXIT WHEN cur%NOTFOUND; -- exit when last row is fetched
     IF prod_status='obsolete' AND prod_category !='Boys' THEN
       PIPE ROW (product_t(prod_id, prod_name, prod_desc, prod_subcategory,
prod_subcat_desc, prod_category, prod_cat_desc, prod_weight_class, prod_unit_of_
measure, prod_pack_size, supplier_id, prod_status, prod_list_price, prod_min_
price));
     END IF;
   END LOOP;
   CLOSE cur;
   RETURN;
END;
/
```

You can use the table function as follows:

```
SELECT DISTINCT prod_category, DECODE(prod_status, 'obsolete', 'NO LONGER
AVAILABLE', 'N/A')
FROM TABLE(obsolete_products_pipe(CURSOR(SELECT * FROM products)));

PROD_CATEGORY    DECODE(PROD_STATUS,
-------------    -------------------
Girls            NO LONGER AVAILABLE
Men              NO LONGER AVAILABLE

2 rows selected.
```

We now change the degree of parallelism for the input table products and issue the same statement again

```
ALTER TABLE products PARALLEL 4;
```

The session statistics show that the statement has been parallelized

```
SELECT * FROM V$PQ_SESSTAT WHERE statistic='Queries Parallelized';

STATISTIC              LAST_QUERY  SESSION_TOTAL
--------------------   ----------  -------------
Queries Parallelized            1              3

1 row selected.
```

Table functions are also capable to fan-out results into persistent table structures. This is demonstrated in the next example. The function filters returns all obsolete products except a those of a specific `prod_category` (default `Men`), which was set to status obsolete by error. The detected wrong `prod_id`'s are stored in a separate table structure. Its result set consists of all other obsolete product categories. It furthermore demonstrates how normal variables can be used in conjunction with table functions:

```
CREATE OR REPLACE FUNCTION obsolete_products_dml(cur cursor_pkg.strong_refcur_t,
prod_cat VARCHAR2 DEFAULT 'Men') RETURN product_t_table
PIPELINED
PARALLEL_ENABLE (PARTITION cur BY ANY) IS
    PRAGMA AUTONOMOUS_TRANSACTION;
    prod_id              NUMBER(6);
    prod_name            VARCHAR2(50);
    prod_desc            VARCHAR2(4000);
    prod_subcategory     VARCHAR2(50);
    prod_subcat_desc     VARCHAR2(2000);
    prod_category        VARCHAR2(50);
    prod_cat_desc        VARCHAR2(2000);
    prod_weight_class    NUMBER(2);
    prod_unit_of_measure VARCHAR2(20);
    prod_pack_size       VARCHAR2(30);
    supplier_id          NUMBER(6);
    prod_status          VARCHAR2(20);
    prod_list_price      NUMBER(8,2);
    prod_min_price       NUMBER(8,2);
  sales NUMBER:=0;
BEGIN
   LOOP
     -- Fetch from cursor variable
     FETCH cur INTO prod_id, prod_name, prod_desc, prod_subcategory, prod_
subcat_desc,  prod_category, prod_cat_desc, prod_weight_class, prod_unit_of_
measure,  prod_pack_size, supplier_id, prod_status, prod_list_price, prod_min_
price;
```

```
     EXIT WHEN cur%NOTFOUND; -- exit when last row is fetched
     IF prod_status='obsolete' THEN
       IF prod_category=prod_cat THEN
          INSERT INTO obsolete_products_errors VALUES
          (prod_id, 'correction: category '||UPPER(prod_cat)||' still
available');
       ELSE
       PIPE ROW (product_t( prod_id, prod_name, prod_desc, prod_subcategory,
prod_subcat_desc, prod_category, prod_cat_desc, prod_weight_class, prod_unit_of_
measure, prod_pack_size, supplier_id, prod_status, prod_list_price, prod_min_
price));
       END IF;
     END IF;
   END LOOP;
   COMMIT;
   CLOSE cur;
   RETURN;
END;
/
```

The following query shows all obsolete product groups except the `prod_category` `Men`, which was wrongly set to status `obsolete`.

```
SELECT DISTINCT prod_category, prod_status FROM TABLE(obsolete_products_
dml(CURSOR(SELECT * FROM products)));
PROD_CATEGORY            PROD_STATUS
-------------            -----------
Boys                     obsolete
Girls                    obsolete

2 rows selected.
```

As you can see, there are some products of the `prod_category` `Men` that were obsoleted by accident:

```
SELECT DISTINCT msg FROM obsolete_products_errors;

MSG
----------------------------------------
correction: category MEN still available

1 row selected.
```

Taking advantage of the second input variable changes the result set as follows:

```
SELECT DISTINCT prod_category, prod_status FROM TABLE(obsolete_products_
dml(CURSOR(SELECT * FROM products), 'Boys'));

PROD_CATEGORY    PROD_STATUS
-------------    -----------
Girls            obsolete
Men              obsolete

2 rows selected.

SELECT DISTINCT msg FROM obsolete_products_errors;

MSG
-----------------------------------------
correction: category BOYS still available

1 row selected.
```

Since table functions can be used like a normal table, they can be nested, as shown in the next example:

```
SELECT DISTINCT prod_category, prod_status
FROM TABLE(obsolete_products_dml(CURSOR(SELECT *
        FROM TABLE(obsolete_products_pipe(CURSOR(SELECT *   FROM products))))));

PROD_CATEGORY       PROD_STATUS
-------------       -----------
Girls               obsolete

1 row selected.
```

Because the table function `obsolete_products_pipe` filters out all products of the `prod_category` `Boys`, our result does no longer include products of the `prod_category` `Boys`. The `prod_category` `Men` is still set to be obsolete by accident.

```
SELECT COUNT(*) FROM obsolete_products_errors;
MSG
----------------------------------------
correction: category MEN still available
```

The biggest advantage of Oracle9*i* ETL is its toolkit functionality, where you can combine any of the latter discussed functionality to improve and speed up your ETL processing. For example, you can take an external table as input, join it with an existing table and use it as input for a parallelized table function to process complex business logic. This table function can be used as input source for a `MERGE` operation, thus streaming the new information for the data warehouse, provided in a flat file within one single statement through the complete ETL process.

Loading and Transformation Scenarios

The following sections offer examples of typical loading and transformation tasks:

- Parallel Load Scenario
- Key Lookup Scenario
- Exception Handling Scenario
- Pivoting Scenarios

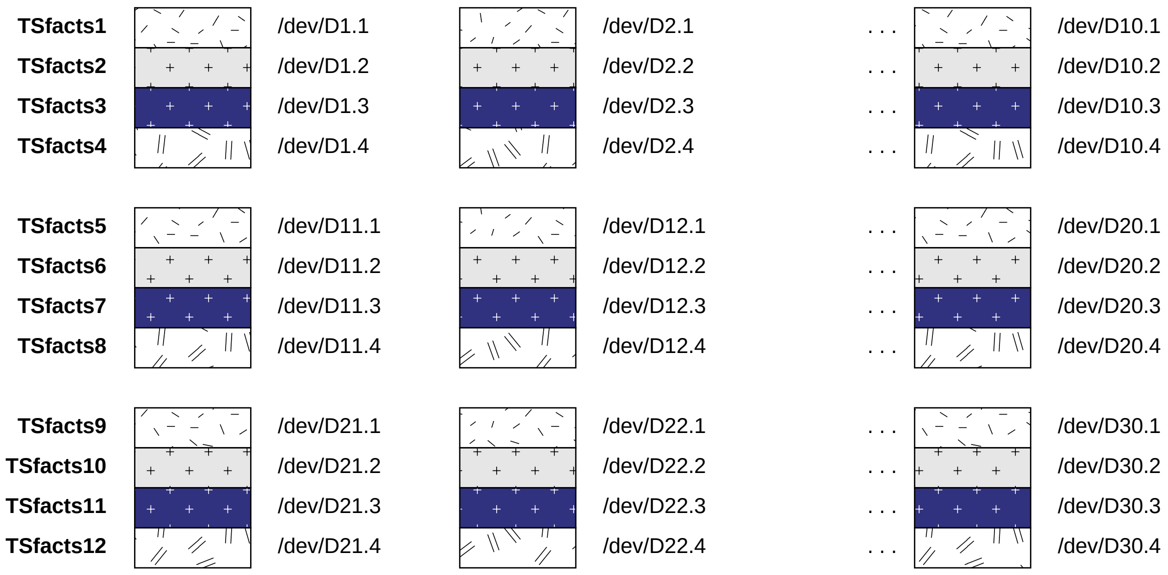
Parallel Load Scenario

This section presents a case study illustrating how to create, load, index, and analyze a large data warehouse fact table with partitions in a typical star schema. This example uses SQL*Loader to explicitly stripe data over 30 disks.

- The example 120 GB table is named `facts`.
- The system is a 10-CPU shared memory computer with more than 100 disk drives.
- Thirty disks (4 GB each) are used for base table data, 10 disks for indexes, and 30 disks for temporary space. Additional disks are needed for rollback segments, control files, log files, possible staging area for loader flat files, and so on.
- The `facts` table is partitioned by month into 12 partitions. To facilitate backup and recovery, each partition is stored in its own tablespace.
- Each partition is spread evenly over 10 disks, so a scan accessing few partitions or a single partition can proceed with full parallelism. Thus there can be intra-partition parallelism when queries restrict data access by partition pruning.

- Each disk has been further subdivided using an operating system utility into 4 operating system files with names like `/dev/D1.1, /dev/D1.2, ... , /dev/D30.4`.
- Four tablespaces are allocated on each group of 10 disks. To better balance I/O and parallelize table space creation (because Oracle writes each block in a datafile when it is added to a tablespace), it is best if each of the four tablespaces on each group of 10 disks has its first datafile on a different disk. Thus the first tablespace has `/dev/D1.1` as its first datafile, the second tablespace has `/dev/D4.2` as its first datafile, and so on, as illustrated in Figure 13–5.

Figure 13–5 Datafile Layout for Parallel Load Example



Step 1: Create the Tablespaces and Add Datafiles in Parallel

Below is the command to create a tablespace named `Tsfacts1`. Other tablespaces are created with analogous commands. On a 10-CPU machine, it should be possible to run all 12 CREATE TABLESPACE statements together. Alternatively, it might be better to run them in two batches of 6 (two from each of the three groups of disks).

```
CREATE TABLESPACE TSfacts1
DATAFILE /dev/D1.1'  SIZE 1024MB REUSE,
DATAFILE /dev/D2.1'  SIZE 1024MB REUSE,
DATAFILE /dev/D3.1'  SIZE 1024MB REUSE,
DATAFILE /dev/D4.1'  SIZE 1024MB REUSE,
DATAFILE /dev/D5.1'  SIZE 1024MB REUSE,
DATAFILE /dev/D6.1'  SIZE 1024MB REUSE,
DATAFILE /dev/D7.1'  SIZE 1024MB REUSE,
DATAFILE /dev/D8.1'  SIZE 1024MB REUSE,
DATAFILE /dev/D9.1'  SIZE 1024MB REUSE,
DATAFILE /dev/D10.1  SIZE 1024MB REUSE,
DEFAULT STORAGE (INITIAL 100MB NEXT 100MB PCTINCREASE 0);
...

CREATE TABLESPACE TSfacts2
DATAFILE /dev/D4.2'  SIZE 1024MB REUSE,
DATAFILE /dev/D5.2'  SIZE 1024MB REUSE,
DATAFILE /dev/D6.2'  SIZE 1024MB REUSE,
DATAFILE /dev/D7.2'  SIZE 1024MB REUSE,
DATAFILE /dev/D8.2'  SIZE 1024MB REUSE,
DATAFILE /dev/D9.2'  SIZE 1024MB REUSE,
DATAFILE /dev/D10.2  SIZE 1024MB REUSE,
DATAFILE /dev/D1.2'  SIZE 1024MB REUSE,
DATAFILE /dev/D2.2'  SIZE 1024MB REUSE,
DATAFILE /dev/D3.2'  SIZE 1024MB REUSE,
DEFAULT STORAGE (INITIAL 100MB NEXT 100MB PCTINCREASE 0);
...
CREATE TABLESPACE TSfacts4
DATAFILE /dev/D10.4' SIZE 1024MB REUSE,
DATAFILE /dev/D1.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D2.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D3.4   SIZE 1024MB REUSE,
DATAFILE /dev/D4.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D5.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D6.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D7.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D8.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D9.4'  SIZE 1024MB REUSE,
DEFAULT STORAGE (INITIAL 100MB NEXT 100MB PCTINCREASE 0);
...
CREATE TABLESPACE TSfacts12
DATAFILE /dev/D30.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D21.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D22.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D23.4   SIZE 1024MB REUSE,
DATAFILE /dev/D24.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D25.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D26.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D27.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D28.4'  SIZE 1024MB REUSE,
DATAFILE /dev/D29.4'  SIZE 1024MB REUSE,
DEFAULT STORAGE (INITIAL 100MB NEXT 100MB PCTINCREASE 0);
```

Extent sizes in the STORAGE clause should be multiples of the multiblock read size, where blocksize * MULTIBLOCK_READ_COUNT = multiblock read size.

INITIAL and NEXT should normally be set to the same value. In the case of parallel load, make the extent size large enough to keep the number of extents reasonable, and to avoid excessive overhead and serialization due to bottlenecks in the data dictionary. When PARALLEL=TRUE is used for parallel loader, the INITIAL extent is not used. In this case you can override the INITIAL extent size specified in the tablespace default storage clause with the value specified in the loader control file, for example, 64KB.

Tables or indexes can have an unlimited number of extents, provided you have set the COMPATIBLE initialization parameter to match the current release number, and use the MAXEXTENTS keyword on the CREATE or ALTER statement for the tablespace or object. In practice, however, a limit of 10,000 extents per object is reasonable. A table or index has an unlimited number of extents, so set the PERCENT_INCREASE parameter to zero to have extents of equal size.

Note: If possible, do not allocate extents faster than about 2 or 3 per minute. Thus, each process should get an extent that lasts for 3 to 5 minutes. Normally, such an extent is at least 50 MB for a large object. Too small an extent size incurs significant overhead, which affects performance and scalability of parallel operations. The largest possible extent size for a 4 GB disk evenly divided into 4 partitions is 1 GB. 100 MB extents should perform well. Each partition will have 100 extents. You can then customize the default storage parameters for each object created in the tablespace, if needed.

Step 2: Create the Partitioned Table

We create a partitioned table with 12 partitions, each in its own tablespace. The table contains multiple dimensions and multiple measures. The partitioning column is named dim_2 and is a date. There are other columns as well.

```
CREATE TABLE facts (dim_1 NUMBER, dim_2 DATE, ...
  meas_1 NUMBER, meas_2 NUMBER, ... )
PARALLEL
PARTITION BY RANGE (dim_2)
(PARTITION jan95 VALUES LESS THAN ('02-01-1995') TABLESPACE
TSfacts1,
PARTITION feb95 VALUES LESS THAN ('03-01-1995') TABLESPACE
TSfacts2,
...
PARTITION dec95 VALUES LESS THAN ('01-01-1996') TABLESPACE
TSfacts12);
```

Step 3: Load the Partitions in Parallel

This section describes four alternative approaches to loading partitions in parallel. The different approaches to loading help you manage the ramifications of the PARALLEL=TRUE keyword of SQL*Loader that controls whether individual partitions are loaded in parallel. The PARALLEL keyword entails the following restrictions:

- Indexes cannot be defined.
- You must set a small initial extent, because each loader session gets a new extent when it begins, and it does not use any existing space associated with the object.
- Space fragmentation issues arise.

However, regardless of the setting of this keyword, if you have one loader process per partition, you are still effectively loading into the table in parallel.

Example 13–9 Loading Partitions in Parallel Case 1

In this approach, assume 12 input files are partitioned in the same way as your table. The DBA has one input file per partition of the table to be loaded. The DBA starts 12 SQL*Loader sessions concurrently in parallel, entering statements like these:

```
SQLLDR DATA=jan95.dat DIRECT=TRUE CONTROL=jan95.ctl
SQLLDR DATA=feb95.dat DIRECT=TRUE CONTROL=feb95.ctl
 . . .
SQLLDR DATA=dec95.dat DIRECT=TRUE CONTROL=dec95.ctl
```

In the example, the keyword PARALLEL=TRUE is *not* set. A separate control file per partition is necessary because the control file must specify the partition into which the loading should be done. It contains a statement such as:

```
LOAD INTO facts partition(jan95)
```

The advantage of this approach is that local indexes are maintained by SQL*Loader. You still get parallel loading, but on a partition level—without the restrictions of the PARALLEL keyword.

A disadvantage is that you must partition the input prior to loading manually.

Example 13–10 Loading Partitions in Parallel Case 2

In another common approach, assume an arbitrary number of input files that are not partitioned in the same way as the table. You can adopt a strategy of performing parallel load for each input file individually. Thus if there are seven input files, you can start seven SQL*Loader sessions, using statements like the following:

```
SQLLDR DATA=file1.dat DIRECT=TRUE PARALLEL=TRUE
```

Oracle partitions the input data so that it goes into the correct partitions. In this case all the loader sessions can share the same control file, so there is no need to mention it in the statement.

The keyword PARALLEL=TRUE must be used, because each of the seven loader sessions can write into every partition. In Case 1, every loader session would write into only one partition, because the data was partitioned prior to loading. Hence all the PARALLEL keyword restrictions are in effect.

In this case, Oracle attempts to spread the data evenly across all the files in each of the 12 tablespaces—however an even spread of data is not guaranteed. Moreover, there could be I/O contention during the load when the loader processes are attempting to write to the same device simultaneously.

Example 13–11 Loading Partitions in Parallel Case 3

In this example, you want precise control over the load. To achieve this, you must partition the input data in the same way as the datafiles are partitioned in Oracle.

This example uses 10 processes loading into 30 disks. To accomplish this, you must split the input into 120 files beforehand. The 10 processes will load the first partition in parallel on the first 10 disks, then the second partition in parallel on the second 10 disks, and so on through the 12th partition. You then run the following commands concurrently as background processes:

```
SQLLDR DATA=jan95.file1.dat DIRECT=TRUE PARALLEL=TRUE FILE=/dev/D1.1
...
SQLLDR DATA=jan95.file10.dat DIRECT=TRUE PARALLEL=TRUE FILE=/dev/D10.1
WAIT;
...
SQLLDR DATA=dec95.file1.dat DIRECT=TRUE PARALLEL=TRUE FILE=/dev/D30.4
...
SQLLDR DATA=dec95.file10.dat DIRECT=TRUE PARALLEL=TRUE FILE=/dev/D29.4
```

For Oracle Real Application Clusters, divide the loader session evenly among the nodes. The datafile being read should always reside on the same node as the loader session.

The keyword `PARALLEL=TRUE` must be used, because multiple loader sessions can write into the same partition. Hence all the restrictions entailed by the `PARALLEL` keyword are in effect. An advantage of this approach, however, is that it guarantees that all of the data is precisely balanced, exactly reflecting your partitioning.

Note: Although this example shows parallel load used with partitioned tables, the two features can be used independent of one another.

Example 13–12 Loading Partitions in Parallel Case 4

For this approach, all partitions must be in the same tablespace. You need to have the same number of input files as datafiles in the tablespace, but you do not need to partition the input the same way in which the table is partitioned.

For example, if all 30 devices were in the same tablespace, then you would arbitrarily partition your input data into 30 files, then start 30 SQL*Loader sessions in parallel. The statement starting up the first session would be similar to the following:

```
SQLLDR DATA=file1.dat DIRECT=TRUE PARALLEL=TRUE FILE=/dev/D1
. . .
SQLLDR DATA=file30.dat DIRECT=TRUE PARALLEL=TRUE FILE=/dev/D30
```

The advantage of this approach is that as in Case 3, you have control over the exact placement of datafiles because you use the `FILE` keyword. However, you are not required to partition the input data by value because Oracle does that for you.

A disadvantage is that this approach requires all the partitions to be in the same tablespace. This minimizes availability.

Example 13–13 Loading External Data Example

This is probably the most basic use of external tables where the data volume is large and no transformations are applied to the external data. The load process is performed as follows:

1. You create the external table. Most likely, the table will be declared as parallel to perform the load in parallel. Oracle will dynamically perform load balancing between the parallel execution servers involved in the query.
2. Once the external table is created (remember that this only creates the metadata in the dictionary), data can be converted, moved and loaded into the database using either a `PARALLEL CREATE TABLE AS SELECT` or a `PARALLEL INSERT` statement.

```
CREATE TABLE products_ext
(prod_id NUMBER, prod_name VARCHAR2(50), ...,
 price NUMBER(6.2), discount NUMBER(6.2))
ORGANIZATION EXTERNAL
(
DEFAULT DIRECTORY (stage_dir)
ACCESS PARAMETERS
( RECORDS FIXED 30
BADFILE 'bad/bad_products_ext'
LOGFILE 'log/log_products_ext'
( prod_id POSITION (1:8) CHAR,
  prod_name POSITION (*,+50) CHAR,
  prod_desc  POSITION (*,+200) CHAR,
  . . .)
LOCATION ('new/new_prod1.txt','new/new_prod2.txt'))
PARALLEL 5
REJECT LIMIT 200;

# load it in the database using a parallel insert
ALTER  SESSION ENABLE PARALLEL DML;
INSERT INTO TABLE products SELECT * FROM products_ext;
```

In the above example, `stage_dir` is a directory where the external flat files reside.

Note that loading data in parallel can be performed in Oracle9*i* by using SQL*Loader. But external tables are probably easier to use and the parallel load is automatically coordinated. Unlike SQL*Loader, dynamic load balancing between parallel execution servers will be performed as well because there will be intra-file parallelism. The latter implies that the user will not have to manually split input files before starting the parallel load. This will be accomplished dynamically.

Key Lookup Scenario

Another simple transformation is a key lookup. For example, suppose that sales transaction data has been loaded into a retail data warehouse. Although the data warehouse's `sales` table contains a `product_id` column, the sales transaction data extracted from the source system contains Uniform Price Codes (UPC) instead of product IDs. Therefore, it is necessary to transform the UPC codes into product IDs before the new sales transaction data can be inserted into the `sales` table.

In order to execute this transformation, a lookup table must relate the `product_id` values to the UPC codes. This table might be the `product` dimension table, or perhaps another table in the data warehouse that has been created specifically to support this transformation. For this example, we assume that there is a table named `product`, which has a `product_id` and an `upc_code` column.

This data substitution transformation can be implemented using the following CTAS statement:

```
CREATE TABLE temp_sales_step2
   NOLOGGING PARALLEL AS
   SELECT
      sales_transaction_id,
      product.product_id sales_product_id,
      sales_customer_id,
      sales_time_id,
      sales_channel_id,
      sales_quantity_sold,
      sales_dollar_amount
   FROM  temp_sales_step1, product
   WHERE temp_sales_step1.upc_code = product.upc_code;
```

This CTAS statement will convert each valid UPC code to a valid `product_id` value. If the ETL process has guaranteed that each UPC code is valid, then this statement alone may be sufficient to implement the entire transformation.

Exception Handling Scenario

In the preceding example, if you must also handle new sales data that does not have valid UPC codes, you can use an additional CTAS statement to identify the invalid rows:

```
CREATE TABLE temp_sales_step1_invalid NOLOGGING PARALLEL AS
   SELECT * FROM temp_sales_step1
   WHERE temp_sales_step1.upc_code NOT IN (SELECT upc_code FROM product);
```

This invalid data is now stored in a separate table, `temp_sales_step1_invalid`, and can be handled separately by the ETL process.

Another way to handle invalid data is to modify the original CTAS to use an outer join:

```
CREATE TABLE temp_sales_step2
   NOLOGGING PARALLEL AS
   SELECT
        sales_transaction_id,
        product.product_id sales_product_id,
        sales_customer_id,
        sales_time_id,
        sales_channel_id,
        sales_quantity_sold,
        sales_dollar_amount
   FROM  temp_sales_step1, product
   WHERE temp_sales_step1.upc_code = product.upc_code (+);
```

Using this outer join, the sales transactions that originally contained invalidated UPC codes will be assigned a `product_id` of `NULL`. These transactions can be handled later.

Additional approaches to handling invalid UPC codes exist. Some data warehouses may choose to insert null-valued `product_id` values into their `sales` table, while other data warehouses may not allow any new data from the entire batch to be inserted into the `sales` table until all invalid UPC codes have been addressed. The correct approach is determined by the business requirements of the data warehouse. Regardless of the specific requirements, exception handling can be addressed by the same basic SQL techniques as transformations.

Pivoting Scenarios

A data warehouse can receive data from many different sources. Some of these source systems may not be relational databases and may store data in very different formats from the data warehouse. For example, suppose that you receive a set of sales records from a nonrelational database having the form:

```
product_id, customer_id, weekly_start_date, sales_sun, sales_mon, sales_tue,
  sales_wed, sales_thu, sales_fri, sales_sat
```

The input table looks like this:

```
SELECT * FROM sales_input_table;

PRODUCT_ID CUSTOMER_ID WEEKLY_ST  SALES_SUN  SALES_MON  SALES_TUE  SALES_WED SALES_THU  SALES_FRI  SALES_SAT
---------- ----------- ---------- ---------- ---------- ---------- -------------------- ---------- ----------
       111         222 01-OCT-00         100        200        300        400       500        600        700
       222         333 08-OCT-00         200        300        400        500       600        700        800
       333         444 15-OCT-00         300        400        500        600       700        800        900
```

In your data warehouse, you would want to store the records in a more typical relational form in a fact table `sales` of the `Sales History` schema:

```
prod_id, cust_id, time_id, amount_sold
```

Note: A number of constraints on the `sales` table have been disabled for purposes of this example, because the example ignores a number of table columns for the sake of brevity.

Thus, you need to build a transformation such that each record in the input stream must be converted into seven records for the data warehouse's `sales` table. This operation is commonly referred to as **pivoting**, and Oracle offers several ways to do this.

The result of the above will resemble the following:

```
SELECT prod_id, cust_id, time_id, amount_sold FROM sales;

   PROD_ID    CUST_ID   TIME_ID   AMOUNT_SOLD
---------- ----------   --------- -----------
       111        222   01-OCT-00         100
       111        222   02-OCT-00         200
       111        222   03-OCT-00         300
       111        222   04-OCT-00         400
       111        222   05-OCT-00         500
       111        222   06-OCT-00         600
       111        222   07-OCT-00         700
       222        333   08-OCT-00         200
       222        333   09-OCT-00         300
       222        333   10-OCT-00         400
       222        333   11-OCT-00         500
       222        333   12-OCT-00         600
       222        333   13-OCT-00         700
       222        333   14-OCT-00         800
```

```
333         444   15-OCT-00         300
333         444   16-OCT-00         400
333         444   17-OCT-00         500
333         444   18-OCT-00         600
333         444   19-OCT-00         700
333         444   20-OCT-00         800
333         444   21-OCT-00         900
```

Pre-Oracle9i Pivoting

The pre-Oracle9*i* way of doing this involved using CTAS (or parallel `INSERT AS SELECT`) or PL/SQL, as shown in Example 13–14 and Example 13–15.

Example 13–14 Pre-Oracle9i Pivoting Example Using a CTAS Statement

```
CREATE table temp_sales_step2 NOLOGGING PARALLEL AS
   SELECT product_id, customer_id, time_id, amount_sold
   FROM
   (SELECT product_id, customer_id, weekly_start_date, time_id,
          sales_sun amount_sold FROM sales_input_table
    UNION ALL
    SELECT product_id, customer_id, weekly_start_date+1, time_id,
           sales_mon amount_sold FROM sales_input_table
    UNION ALL
    SELECT product_id, cust_id, weekly_start_date+2, time_id,
           sales_tue amount_sold FROM sales_input_table
    UNION ALL
    SELECT product_id, customer_id, weekly_start_date+3, time_id,
           sales_web amount_sold FROM sales_input_table
    UNION ALL
    SELECT product_id, customer_id, weekly_start_date+4, time_id,
           sales_thu amount_sold FROM sales_input_table
    UNION ALL
    SELECT product_id, customer_id, weekly_start_date+5, time_id,
           sales_fri amount_sold FROM sales_input_table
    UNION ALL
    SELECT product_id, customer_id, weekly_start_date+6, time_id,
           sales_sat amount_sold FROM sales_input_table);
```

Like all CTAS operations, this operation can be fully parallelized. However, the CTAS approach also requires seven separate scans of the data, one for each day of the week. Even with parallelism, the CTAS approach can be time-consuming.

Example 13–15 Pre-Oracle9i Pivoting Example Using PL/SQL

PL/SQL offers an alternative implementation. A basic PL/SQL function to implement a pivoting operation is:

```
DECLARE
   CURSOR c1 is
      SELECT product_id, customer_id, weekly_start_date, sales_sun,
      sales_mon, sales_tue, sales_wed, sales_thu, sales_fri, sales_sat
      FROM sales_input_table;
BEGIN
   FOR crec IN c1 LOOP
      INSERT INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (crec.product_id, crec.customer_id, crec.weekly_start_date,
             crec.sales_sun );
      INSERT INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (crec.product_id, crec.customer_id, crec.weekly_start_date+1,
             crec.sales_mon );
      INSERT INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (crec.product_id, crec.customer_id, crec.weekly_start_date+2,
              crec.sales_tue );
      INSERT INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (crec.product_id, crec.customer_id, crec.weekly_start_date+3,
              crec.sales_wed );
      INSERT INTO sales (prod_id, cust_id, time_id, amount_sold)
       VALUES (crec.product_id, crec.customer_id, crec.weekly_start_date+4,
               crec.sales_thu );
       INSERT INTO sales (prod_id, cust_id, time_id, amount_sold)
       VALUES (crec.product_id, crec.customer_id, crec.weekly_start_date+5,
               crec.sales_fri );
       INSERT INTO sales (prod_id, cust_id, time_id, amount_sold)
       VALUES (crec.product_id, crec.customer_id, crec.weekly_start_date+6,
               crec.sales_sat );
    END LOOP;
    COMMIT;
END;
```

This PL/SQL procedure can be modified to provide even better performance. Array inserts can accelerate the insertion phase of the procedure. Further performance can be gained by parallelizing this transformation operation, particularly if the `temp_sales_step1` table is partitioned, using techniques similar to the parallelization of data unloading described in Chapter 11, "Extraction in Data Warehouses". The primary advantage of this PL/SQL procedure over a CTAS approach is that it requires only a single scan of the data.

Oracle9i Pivoting

Oracle9*i* offers a faster way of pivoting your data by using a multitable insert, as in Example 13–16.

Example 13–16 Oracle9i Pivoting Example

The following example uses the multitable insert syntax to insert into the demo table `sh.sales` some data from an input table with a different structure.

The multitable insert statement looks like this:

```
INSERT ALL
      INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (product_id, customer_id, weekly_start_date, sales_sun)
      INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (product_id, customer_id, weekly_start_date+1, sales_mon)
      INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (product_id, customer_id, weekly_start_date+2, sales_tue)
      INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (product_id, customer_id, weekly_start_date+3, sales_wed)
      INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (product_id, customer_id, weekly_start_date+4, sales_thu)
      INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (product_id, customer_id, weekly_start_date+5, sales_fri)
      INTO sales (prod_id, cust_id, time_id, amount_sold)
      VALUES (product_id, customer_id, weekly_start_date+6, sales_sat)
SELECT product_id, customer_id, weekly_start_date, sales_sun,
      sales_mon, sales_tue, sales_wed, sales_thu, sales_fri, sales_sat
FROM sales_input_table;
```

The above statement only scans the source table once and then inserts the appropriate data for each day.

14 Maintaining the Data Warehouse

This chapter discusses how to load and refresh a data warehouse, and discusses:

- Using Partitioning to Improve Data Warehouse Refresh
- Optimizing DML Operations During Refresh
- Refreshing Materialized Views
- Using Materialized Views With Partitioned Tables

Using Partitioning to Improve Data Warehouse Refresh

ETL (Extraction, Transformation and Loading) is done on a scheduled basis to reflect changes made to the original source system. During this step, you physically insert the new, clean data into the production data warehouse schema, and take all of the other steps necessary (such as building indexes, validating constraints, taking backups) to make this new data available to the end users. Once all of this data has been loaded into the data warehouse, the materialized views have to be updated to reflect the latest data.

The partitioning scheme of the data warehouse is often crucial in determining the efficiency of refresh operations in the data warehouse load process. In fact, the load process is often the primary consideration in choosing the partitioning scheme of data warehouse tables and indexes.

The partitioning scheme of the largest data warehouse tables (for example, the fact table in a star schema) should be based upon the loading paradigm of the data warehouse.

Most data warehouses are loaded with new data on a regular schedule. For example, every night, week, or month, new data is brought into the data warehouse. The data being loaded at the end of the week or month typically corresponds to the transactions for the week or month. In this very common scenario, the data warehouse is being loaded by time. This suggests that the data warehouse tables should be partitioned on a date column. In our data warehouse example, suppose the new data is loaded into the `sales` table every month. Furthermore, the `sales` table has been partitioned by month. These steps show how the load process will proceed to add the data for a new month (January 2001) to the table `sales`:

1. Place the new data into a separate table, `sales_01_2001`. This data can be directly loaded into `sales_01_2001` from outside the data warehouse, or this data can be the result of previous data transformation operations that have already occurred in the data warehouse. `sales_01_2001` has the exact same columns, datatypes, and so forth, as the `sales` table. Gather statistics on the `sales_01_2001` table.
2. Create indexes and add constraints on `sales_01_2001`. Again, the indexes and constraints on `sales_01_2001` should be identical to the indexes and constraints on `sales`. Indexes can be built in parallel and should use the `NOLOGGING` and the `COMPUTE STATISTICS` options. For example:

```
CREATE BITMAP INDEX sales_01_2001_customer_id_bix
  ON sales_01_2001(customer_id)
      TABLESPACE sales_idx NOLOGGING PARALLEL 8 COMPUTE STATISTICS;
```

Apply all constraints to the sales_01_2001 table that are present on the sales table. This includes referential integrity constraints. A typical constraint would be:

```
ALTER TABLE sales_01_2001 ADD CONSTRAINT sales_customer_id
      REFERENCES customer(customer_id) ENABLE NOVALIDATE;
```

If the partitioned table sales has a primary or unique key that is enforced with a global index structure, please ensure that the constraint on sales_jan01 is validated without the creation of an index structure, like:

```
ALTER TABLE sales_01_2001 ADD CONSTRAINT sales_pk_jan01
PRIMARY KEY (sales_transaction_id) DISABLE VALIDATE;
```

The creation of the constraint with ENABLE clause would cause the creation of a unique index, which does not match a local index structure of the partitioned table. The exchange command would fail.

3. Add the sales_01_2001 table to the sales table.

   In order to add this new data to the sales table, we need to do two things. First, we need to add a new partition to the sales table. We will use the ALTER TABLE ... ADD PARTITION statement. This will add an empty partition to the sales table:

```
ALTER TABLE sales ADD PARTITION sales_01_2001
VALUES LESS THAN (TO_DATE('01-FEB-2001', 'DD-MON-YYYY'));
```

   Then, we can add our newly created table to this partition using the EXCHANGE PARTITION operation. This will exchange the new, empty partition with the newly loaded table.

```
ALTER TABLE sales EXCHANGE PARTITION sales_01_2001 WITH TABLE sales_01_2001
INCLUDING INDEXES WITHOUT VALIDATION UPDATE GLOBAL INDEXES;
```

   The EXCHANGE operation will preserve the indexes and constraints that were already present on the sales_01_2001 table. For unique constraints (such as the unique constraint on sales_transaction_id), you can use the UPDATE GLOBAL INDEXES clause, as shown above. This will automatically maintain your global index structures as part of the partition maintenance operation and keep them accessible throughout the whole process. If there were only foreign-key constraints, the exchange operation would be instantaneous.

The benefits of this partitioning technique are significant. First, the new data is loaded with minimal resource utilization. The new data is loaded into an entirely separate table, and the index processing and constraint processing are applied only to the new partition. If the `sales` table was 50 GB and had 12 partitions, then a new month's worth of data contains approximately 4 GB. Only the new month's worth of data needs to be indexed. None of the indexes on the remaining 46 GB of data needs to be modified at all. This partitioning scheme additionally ensures that the load processing time is directly proportional to the amount of new data being loaded, not to the total size of the `sales` table.

Second, the new data is loaded with minimal impact on concurrent queries. All of the operations associated with data loading are occurring on a separate `sales_01_2001` table. Therefore, none of the existing data or indexes of the `sales` table is affected during this data refresh process. The `sales` table and its indexes remain entirely untouched throughout this refresh process.

Third, in case of the existence of any global indexes, those are incrementally maintained as part of the exchange command. This maintenance does not affect the availability of the existing global index structures.

The exchange operation can be viewed as a **publishing** mechanism. Until the data warehouse administrator exchanges the `sales_01_2001` table into the `sales` table, end users cannot see the new data. Once the exchange has occurred, then any end user query accessing the `sales` table will immediately be able to see the `sales_01_2001` data.

Partitioning is useful not only for adding new data but also for removing data. Many data warehouses maintain a **rolling window** of data. For example, the data warehouse stores the most recent 36 months of `sales` data. Just as a new partition can be added to the `sales` table (as described above), an old partition can be quickly (and independently) removed from the `sales` table. The above two benefits (reduced resources utilization and minimal end-user impact) are just as pertinent to removing a partition as they are to adding a partition.

This example is a simplification of the data warehouse load scenario. Real-world data warehouse refresh characteristics are always more complex. However, the advantages of this rolling window approach are not diminished in more complex scenarios.

Consider two typical scenarios:

1. Data is loaded daily. However, the data warehouse contains two years of data, so that partitioning by day might not be desired.

   Solution: Partition by week or month (as appropriate). Use `INSERT` to add the new data to an existing partition. The `INSERT` operation only affects a single partition, so the benefits described above remain intact. The `INSERT` operation could occur while the partition remains a part of the table. Inserts into a single partition can be parallelized:

```
INSERT INTO sales PARTITION (sales_01_2001) SELECT * FROM new_sales;
```

The indexes of this `sales` partition will be maintained in parallel as well. An alternative is to use the `EXCHANGE` operation. You can do this by exchanging the `sales_01_2001` partition of the `sales` table and then using an `INSERT` operation. You might prefer this technique when dropping and rebuilding indexes is more efficient than maintaining them.

2. New data feeds, although consisting primarily of data for the most recent day, week, and month, also contain some data from previous time periods.

   Solution 1: Use parallel SQL operations (such as `CREATE TABLE ... AS SELECT`) to separate the new data from the data in previous time periods. Process the old data separately using other techniques.

   New data feeds are not solely time based. You can also feed new data into a data warehouse with data from multiple operational systems on a business need basis. For example, the sales data from direct channels may come into the data warehouse separately from the data from indirect channels. For business reasons, it may furthermore make sense to keep the direct and indirect data in separate partitions.

   Solution 2: Oracle supports concatenated partitioning keys. The `sales` table could be partitioned by month and channel. Care must be taken with this approach to ensure that the partition pruning techniques (when querying the `sales` table) are understood prior to implementation.

   Another possibility is composite (range/hash) partitioning. This approach is feasible only if the second key has a high cardinality. In this example, `channel` has only two possible values, so that it would not be a good candidate for a hash-partitioning key.

Optimizing DML Operations During Refresh

You can optimize DML performance through the techniques listed in this section.

Implementing an Efficient Merge

Commonly, the data that is extracted from a source system is not simply a list of new records that needs to be inserted into the data warehouse. Instead, this new data set is a combination of new records as well as modified records. For example, suppose that most of data extracted from the OLTP systems will be new sales transactions. These records will be inserted into the warehouse's `sales` table, but some records may reflect modifications of previous transactions, such as returned merchandise or transactions that were incomplete or incorrect when initially loaded into the data warehouse. These records require updates to the `sales` table.

As a typical scenario, suppose that there is a table called `new_sales` that contains both inserts and updates that will be applied to the `sales` table. When designing the entire data warehouse load process, it was determined that the `new_sales` table would contain records with the following semantics:

- If a given `sales_transaction_id` of a record in `new_sales` already exists in `sales`, then update the `sales` table by adding the `sales_dollar_amount` and `sales_quantity_sold` values from the `new_sales` table to the existing row in the `sales` table.
- Otherwise, insert the entire new record from the `new_sales` table into the `sales` table.

This `UPDATE-ELSE-INSERT` operation is often called an **upsert** or **merge**. A merge can be executed using one SQL statement in Oracle9*i*, though it required two earlier.

Example 14–1   Merge Operation Example Prior to Oracle9i

The first SQL statement updates the appropriate rows in the `sales` tables, while the second SQL statement inserts the rows:

```
UPDATE
  (SELECT
   s.sales_quantity_sold AS s_quantity,
   s.sales_dollar_amount AS s_dollar,
   n.sales_quantity_sold AS n_quantity,
   n.sales_dollar_amount AS n_dollar
   FROM sales s, new_sales n
   WHERE s.sales_transaction_id = n.sales_transaction_id) sales_view
 SET s_quantity = s_quantity + n_quantity, s_dollar = s_dollar + n_dollar;

INSERT INTO sales
SELECT * FROM new_sales s
WHERE NOT EXISTS
(SELECT 'x' FROM FROM sales t
 WHERE s.sales_transaction_id = t.sales_transaction_id);
```

The new, faster way of upserting data is shown below.

Example 14–2 Merge Operation Example in Oracle9i

```
MERGE INTO sales s
USING new_sales n
ON (s.sales_transaction_id = n.sales_transaction_id)
WHEN MATCHED THEN
UPDATE s_quantity = s_quantity + n_quantity, s_dollar = s_dollar + n_dollar
WHEN NOT MATCHED THEN
INSERT (sales_quantity_sold, sales_dollar_amount)
VALUES (n.sales_quantity_sold, n.sales_dollar_amount);
```

An alternative implementation of upserts is to utilize a PL/SQL package, which successively reads each row of the `new_sales` table and applies if-then logic to either update or insert the new row into the `sales` table. A PL/SQL-based implementation is effective when the `new_sales` table is small, although the SQL approach will often be more efficient for larger data volumes.

Maintaining Referential Integrity

In some data warehousing environments, you might want to insert new data into tables in order to guarantee referential integrity. For example, a data warehouse may derive `sales` from an operational system that retrieves data directly from cash registers. `sales` is refreshed nightly. However, the data for the `product` dimension table may be derived from a separate operational system. The `product` dimension table may only be refreshed once per week, because the `product` table changes relatively slowly. If a new product was introduced on Monday, then it is possible for that product's `product_id` to appear in the `sales` data of the data warehouse before that `product_id` has been inserted into the data warehouses `product` table.

Although the sales transactions of the new product may be valid, this sales data will not satisfy the referential integrity constraint between the `product` dimension table and the `sales` fact table. Rather than disallow the new sales transactions, you might choose to insert the sales transactions into the `sales` table.

However, you might also wish to maintain the referential integrity relationship between the `sales` and `product` tables. This can be accomplished by inserting new rows into the `product` table as placeholders for the unknown products.

As in previous examples, we assume that the new data for the `sales` table will be staged in a separate table, `new_sales`. Using a single `INSERT` statement (which can be parallelized), the `product` table can be altered to reflect the new products:

```
INSERT INTO PRODUCT_ID
  (SELECT sales_product_id, 'Unknown Product Name', NULL, NULL ...
   FROM new_sales WHERE sales_product_id NOT IN
  (SELECT product_id FROM product));
```

Purging Data

Occasionally, it is necessary to remove large amounts of data from a data warehouse. A very common scenario is the rolling window discussed previously, in which older data is rolled out of the data warehouse to make room for new data.

However, sometimes other data might need to be removed from a data warehouse. Suppose that a retail company has previously sold products from MS Software, and that MS Software has subsequently gone out of business. The business users of the warehouse may decide that they are no longer interested in seeing any data related to MS Software, so this data should be deleted.

One approach to removing a large volume of data is to use parallel delete:

```
DELETE FROM sales WHERE sales_product_id IN
  (SELECT product_id
   FROM product WHERE product_category = 'MS Software');
```

This SQL statement will spawn one parallel process per partition. This approach will be much more efficient than a serial DELETE statement, and none of the data in the sales table will need to be moved.

However, this approach also has some disadvantages. When removing a large percentage of rows, the DELETE statement will leave many empty row-slots in the existing partitions. If new data is being loaded using a rolling window technique (or is being loaded using direct-path INSERT or load), then this storage space will not be reclaimed. Moreover, even though the DELETE statement is parallelized, there might be more efficient methods. An alternative method is to re-create the entire sales table, keeping the data for all product categories except MS Software.

```
CREATE TABLE sales2 AS
SELECT * FROM sales, product
WHERE sales.sales_product_id = product.product_id
AND product_category <> 'MS Software'
NOLOGGING PARALLEL (DEGREE 8)
#PARTITION ... ;
#create indexes, constraints, and so on
DROP TABLE SALES;
RENAME SALES2 TO SALES;
```

This approach may be more efficient than a parallel delete. However, it is also costly in terms of the amount of disk space, because the `sales` table must effectively be instantiated twice.

An alternative method to utilize less space is to re-create the `sales` table one partition at a time:

```
CREATE TABLE sales_temp AS SELECT * FROM sales WHERE 1=0;
INSERT INTO sales_temp PARTITION (sales_99jan)
SELECT * FROM sales, product
WHERE sales.sales_product_id = product.product_id
AND product_category <> 'MS Software';
<create appropriate indexes and constraints on sales_temp>
ALTER TABLE sales EXCHANGE PARTITION sales_99jan WITH TABLE sales_temp;
```

Continue this process for each partition in the `sales` table.

Refreshing Materialized Views

When creating a materialized view, you have the option of specifying whether the refresh occurs `ON DEMAND` or `ON COMMIT`. In the case of `ON COMMIT`, the materialized view is changed every time a transaction commits, which changes data used by the materialized view, thus ensuring that the materialized view always contains the latest data. Alternatively, you can control the time when refresh of the materialized views occurs by specifying `ON DEMAND`. In this case, the materialized view can only be refreshed by calling one of the procedures in the `DBMS_MVIEW` package.

`DBMS_MVIEW` provides three different types of refresh operations.

- `DBMS_MVIEW.REFRESH`

  Refresh one or more materialized views.

- `DBMS_MVIEW.REFRESH_ALL_MVIEWS`

  Refresh all materialized views.

- `DBMS_MVIEW.REFRESH_DEPENDENT`

  Refresh all table-based materialized views that depend on a specified detail table or list of detail tables.

> **See Also:** "Manual Refresh Using the DBMS_MVIEW Package" on page 14-11 for more information about this package

Performing a refresh operation requires temporary space to rebuild the indexes and can require additional space for performing the refresh operation itself. Some sites might prefer not to refresh all of their materialized views at the same time: as soon as some underlying detail data has been updated, all materialized views using this data will become stale. Therefore, if you defer refreshing your materialized views, you can either rely on your chosen rewrite integrity level whether or not a stale materialized view can be used for query rewrite, or you can temporarily disable query rewrite with an `ALTER SYSTEM SET QUERY_REWRITE_ENABLED = FALSE` statement. After refreshing the materialized views, you can reenable query rewrite as the default for all sessions in the current database instance by specifying `ALTER SYSTEM SET QUERY_REWRITE_ENABLED` as `TRUE`. Refreshing a materialized view automatically updates all of its indexes. In the case of full refresh, this requires temporary sort space to rebuild all indexes during refresh. This is because the full refresh truncates or deletes the table before inserting the new full data volume. If insufficient temporary space is available to rebuild the indexes, then you must explicitly drop each index or mark it `UNUSABLE` prior to performing the refresh operation.

If you anticipate performing insert, update or delete operations on tables referenced by a materialized view concurrently with the refresh of that materialized view, and that materialized view includes joins and aggregation, Oracle recommends you use `ON COMMIT` fast refresh rather than `ON DEMAND` fast refresh.

Complete Refresh

A complete refresh occurs when the materialized view is initially defined as `BUILD IMMEDIATE`, unless the materialized view references a prebuilt table. For materialized views using `BUILD DEFERRED`, a complete refresh must be requested before it can be used for the first time. A complete refresh may be requested at any time during the life of any materialized view. The refresh involves reading the detail tables to compute the results for the materialized view. This can be a very time-consuming process, especially if there are huge amounts of data to be read and processed. Therefore, you should always consider the time required to process a complete refresh before requesting it.

However, there are cases when the only refresh method available for an already built materialized view is complete refresh because the materialized view does not satisfy the conditions specified in the following section for a fast refresh.

Fast Refresh

Most data warehouses have periodic incremental updates to their detail data. As described in "Schema Design Guidelines for Materialized Views" on page 8-8, you can use the SQL*Loader or any bulk load utility to perform incremental loads of detail data. Fast refresh of your materialized views is usually efficient, because instead of having to recompute the entire materialized view, the changes are applied to the existing data. Thus, processing only the changes can result in a very fast refresh time.

ON COMMIT Refresh

A materialized view can be refreshed automatically using the `ON COMMIT` method. Therefore, whenever a transaction commits which has updated the tables on which a materialized view is defined, those changes will be automatically reflected in the materialized view. The advantage of using this approach is you never have to remember to refresh the materialized view. The only disadvantage is the time required to complete the commit will be slightly longer because of the extra processing involved. However, in a data warehouse, this should not be an issue because there is unlikely to be concurrent processes trying to update the same table.

Manual Refresh Using the DBMS_MVIEW Package

When a materialized view is refreshed `ON DEMAND`, one of three refresh methods can be specified as shown in the following table. You can define a default option during the creation of the materialized view.

Refresh Option	Parameter	Description
`COMPLETE`	C	Refreshes by recalculating the defining query of the materialized view
`FAST`	F	Refreshes by incrementally applying changes to the materialized view
`FORCE`	?	Attempts a fast refresh. If that is not possible, it does a complete refresh

Three refresh procedures are available in the `DBMS_MVIEW` package for performing `ON DEMAND` refresh. Each has its own unique set of parameters.

See Also: *Oracle9i Supplied PL/SQL Packages and Types Reference* for detailed information about the DBMS_MVIEW package and *Oracle9i Replication* explains how to use it in a replication environment

Refresh Specific Materialized Views with REFRESH

Use the DBMS_MVIEW.REFRESH procedure to refresh one or more materialized views. Some parameters are used only for replication, so they are not mentioned here. The required parameters to use this procedure are:

- The comma-delimited list of materialized views to refresh
- The refresh method: F-Fast, ?-Force, C-Complete
- The rollback segment to use
- Refresh after errors (TRUE or FALSE)

  A Boolean parameter. If set to TRUE, the number_of_failures output parameter will be set to the number of refreshes that failed, and a generic error message will indicate that failures occurred. The alert log for the instance will give details of refresh errors. If set to FALSE, the default, then refresh will stop after it encounters the first error, and any remaining materialized views in the list will not be refreshed.
- The following four parameters are used by the replication process. For warehouse refresh, set them to FALSE, 0,0,0.
- Atomic refresh (TRUE or FALSE)

  If set to TRUE, then all refreshes are done in one transaction. If set to FALSE, then the refresh of each specified materialized view is done in a separate transaction.

For example, to perform a fast refresh on the materialized view cal_month_sales_mv, the DBMS_MVIEW package would be called as follows:

```
DBMS_MVIEW.REFRESH('CAL_MONTH_SALES_MV', 'F', '', TRUE, FALSE, 0,0,0, FALSE);
```

Multiple materialized views can be refreshed at the same time, and they do not all have to use the same refresh method. To give them different refresh methods, specify multiple method codes in the same order as the list of materialized views (without commas). For example, the following specifies that cal_month_sales_mv be completely refreshed and fweek_pscat_sales_mv receive a fast refresh.

```
DBMS_MVIEW.REFRESH('CAL_MONTH_SALES_MV, FWEEK_PSCAT_SALES_MV', 'CF', '',
  TRUE, FALSE, 0,0,0, FALSE);
```

If the refresh method is not specified, the default refresh method as specified in the materialized view definition will be used.

Refresh All Materialized Views with REFRESH_ALL_MVIEWS

An alternative to specifying the materialized views to refresh is to use the procedure `DBMS_MVIEW.REFRESH_ALL_MVIEWS`. This procedure refreshes all materialized views. If any of the materialized views fails to refresh, then the number of failures is reported.

The parameters for this procedure are:

- The number of failures (this is an `OUT` variable)
- The refresh method: F-Fast, ?-Force, C-Complete
- Refresh after errors (`TRUE` or `FALSE`)

  A Boolean parameter. If set to `TRUE`, the `number_of_failures` output parameter will be set to the number of refreshes that failed, and a generic error message will indicate that failures occurred. The alert log for the instance will give details of refresh errors. If set to `FALSE`, the default, then refresh will stop after it encounters the first error, and any remaining materialized views in the list will not be refreshed.
- Atomic refresh (`TRUE` or `FALSE`)

  If set to `TRUE`, then all refreshes are done in one transaction. If set to `FALSE`, then the refresh of each specified materialized view is done in a separate transaction.

An example of refreshing all materialized views is:

```
DBMS_MVIEW.REFRESH_ALL_MVIEWS(failures,'C','',FALSE,FALSE);
```

Refresh Dependent Materialized Views with REFRESH_DEPENDENT

The third procedure, `DBMS_MVIEW.REFRESH_DEPENDENT`, refreshes only those materialized views that depend on a specific table or list of tables. For example, suppose the changes have been received for the `orders` table but not for `customer` payments. The refresh dependent procedure can be called to refresh only those materialized views that reference the `orders` table.

The parameters for this procedure are:

- The number of failures (this is an OUT variable)
- The dependent table
- The refresh method: F-Fast, ?-Force, C-Complete
- The rollback segment to use
- Refresh after errors (TRUE or FALSE)

  A Boolean parameter. If set to TRUE, the number_of_failures output parameter will be set to the number of refreshes that failed, and a generic error message will indicate that failures occurred. The alert log for the instance will give details of refresh errors. If set to FALSE, the default, then refresh will stop after it encounters the first error, and any remaining materialized views in the list will not be refreshed.
- Atomic refresh (TRUE or FALSE)

  If set to TRUE, then all refreshes are done in one transaction. If set to FALSE, then the refresh of each specified materialized view is done in a separate transaction.

In order to perform a full refresh on all materialized views that reference the customers table, specify:

```
DBMS_MVIEW.REFRESH_DEPENDENT(failures, 'CUSTOMERS', 'C', '', FALSE, FALSE );
```

To obtain the list of materialized views that are directly dependent on a given object (table or materialized view), use the procedure DBMS_MVIEW.GET_MV_DEPENDENCIES to determine the dependent materialized views for a given table, or for deciding the order to refresh nested materialized views.

```
DBMS_MVIEW.GET_MV_DEPENDENCIES(mvlist IN  VARCHAR2, deplist OUT  VARCHAR2)
```

The input to the above function is the name or names of the materialized view. The output is a comma separated list of the materialized views that are defined on it. For example:

```
GET_MV_DEPENDENCIES("JOHN.SALES_REG, SCOTT.PROD_TIME", deplist)
```

populates deplist with the list of materialized views defined on the input arguments. For example:

```
deplist <= "JOHN.SUM_SALES_WEST, JOHN.SUM_SALES_EAST, SCOTT.SUM_PROD_MONTH".
```

Using Job Queues for Refresh

Job queues can be used to refresh multiple materialized views in parallel. If queues are not available, fast refresh will sequentially refresh each view in the foreground process. The order in which the materialized views are refreshed cannot be guaranteed. To make queues available, you must set the JOB_QUEUE_PROCESSES parameter. This parameter defines the number of background job queue processes and determines how many materialized views can be refreshed concurrently. This parameter is only effective when atomic_refresh is set to FALSE.

If the process that is executing DBMS_MVIEW.REFRESH is interrupted or the instance is shut down, any refresh jobs that were executing in job queue processes will be requeued and will continue running. To remove these jobs, use the DBMS_JOB.REMOVE procedure.

When Refresh is Possible

Not all materialized views may be fast refreshable. Therefore, use the package DBMS_MVIEW.EXPLAIN_MVIEW to determine what refresh methods are available for a materialized view.

Recommended Initialization Parameters for Parallelism

Set the following parameters:

- PARALLEL_MAX_SERVERS should be set high enough to take care of parallelism. You need to consider the number of slaves needed for the refresh statement. For example, with a DOP of eight, you need 16 slave processes.
- PGA_AGGREGATE_TARGET should be set for the instance to manage the memory usage for sorts and joins automatically. If the memory parameters are set manually, SORT_AREA_SIZE should be less than HASH_AREA_SIZE.
- OPTIMIZER_MODE should equal ALL_ROWS (cost-based optimization).

Remember to analyze all tables and indexes for better cost-based optimization.

Monitoring a Refresh

While a job is running, you can query the V$SESSION_LONGOPS view to tell you the progress of each materialized view being refreshed.

```
SELECT * FROM V$SESSION_LONGOPS;
```

To look at the progress of which jobs are on which queue, use:

```
SELECT * FROM DBA_JOBS_RUNNING;
```

Checking the Status of a Materialized View

Three views are provided for checking the status of a materialized view:

- USER_MVIEWS
- DBA_MVIEWS
- ALL_MVIEWS

To check if a materialized view is fresh or stale, issue the following statement:

```
SELECT MVIEW_NAME, STALENESS, LAST_REFRESH_TYPE, COMPILE_STATE
FROM USER_MVIEWS ORDER BY MVIEW_NAME;

MVIEW_NAME           STALENESS LAST_REF COMPILE_STATE
----------           --------- -------- -------------
CUST_MTH_SALES_MV    FRESH     FAST     NEEDS_COMPILE
PROD_YR_SALES_MV     FRESH     FAST     VALID
```

If the `compile_state` column shows `NEEDS COMPILE`, the other displayed column values cannot be trusted as reflecting the true status. Use

```
ALTER MATERIALIZED VIEW [materialized_view_name] COMPILE;
```

to revalidate the materialized view and then reissue the `SELECT` statement.

Tips for Refreshing Materialized Views with Aggregates

Following are some guidelines for using the refresh mechanism for materialized views with aggregates.

1. For fast refresh, create materialized view logs on all detail tables involved in a materialized view with the `ROWID`, `SEQUENCE` and `INCLUDING NEW VALUES` clauses.

   Include all columns from the table likely to be used in materialized views in the materialized view logs.

   Fast refresh may be possible even if the `SEQUENCE` option is omitted from the materialized view log. If it can be determined that only inserts or deletes will occur on all the detail tables, then the materialized view log does not require the `SEQUENCE` clause. However, if updates to multiple tables are likely or required or if the specific update scenarios are unknown, make sure the `SEQUENCE` clause is included.

2. Use Oracle's bulk loader utility or direct-path `INSERT` (`INSERT` with the `APPEND` hint for loads).

   This is a lot more efficient than conventional insert. During loading, disable all constraints and re-enable when finished loading. Note that materialized view logs are required regardless of whether you use direct load or conventional DML.

   Try to optimize the sequence of conventional mixed DML operations, direct-path `INSERT` and the fast refresh of materialized views. You can use fast refresh with a mixture of conventional DML and direct loads. Fast refresh can perform significant optimizations if it finds that only direct loads have occurred, as shown below:

   1. Direct-path `INSERT` (SQL*Loader or `INSERT /*+ APPEND */`) into the detail table
   2. Refresh materialized view
   3. Conventional mixed DML
   4. Refresh materialized view

   You can use fast refresh with conventional mixed DML (`INSERT`, `UPDATE`, and `DELETE`) to the detail tables. However, fast refresh will be able to perform significant optimizations in its processing if it detects that only inserts or deletes have been done to the tables, such as:

   - DML `INSERT` or `DELETE` to the detail table
   - Refresh materialized views
   - DML Update to the detail table
   - Refresh materialized view

   Even more optimal is the separation of `INSERT` and `DELETE`.

   If possible, refresh should be performed after each type of data change (as shown above) rather than issuing only one refresh at the end. If that is not possible, restrict the conventional DML to the table to inserts only, to get much better refresh performance. Avoid mixing deletes and direct loads.

   Furthermore, for refresh `ON COMMIT`, Oracle keeps track of the type of DML done in the committed transaction. Therefore, do not perform direct-path

INSERT and DML to other tables in the same transaction, as Oracle may not be able to optimize the refresh phase.

For ON COMMIT materialized views, where refreshes automatically occur at the end of each transaction, it may not be possible to isolate the DML statements, in which case keeping the transactions short will help. However, if you plan to make numerous modifications to the detail table, it may be better to perform them in one transaction, so that refresh of the materialized view will be performed just once at commit time rather than after each update.

3. Oracle recommends partitioning the tables because it enables you to use:

   - Parallel DML

     For large loads or refresh, enabling parallel DML will help shorten the length of time for the operation.

   - Partition Change Tracking (PCT) fast refresh

     You can refresh your materialized views fast after partition maintenance operations on the detail tables. "Partition Change Tracking" on page 8-34 for details on enabling PCT for materialized views.

   Partitioning the materialized view will also help refresh performance as refresh can update the materialized view using parallel DML. For example, assume that the detail tables and materialized view are partitioned and have a parallel clause. The following sequence would enable Oracle to parallelize the refresh of the materialized view.

   1. Bulk load into the detail table
   2. Enable parallel DML with an ALTER SESSION ENABLE PARALLEL DML statement
   3. Refresh the materialized view

   See Also: Chapter 5, "Parallelism and Partitioning in Data Warehouses"

4. For a complete refresh using DBMS_MVIEW.REFRESH, set the parameter atomic to FALSE. This will use TRUNCATE to delete existing rows in the materialized view, which is faster than a delete.

5. When using DBMS_MVIEW.REFRESH with JOB_QUEUES, remember to set atomic to FALSE. Otherwise, JOB_QUEUES will not get used. Set the number of job queue processes greater than the number of processors.

If job queues are enabled and there are many materialized views to refresh, it is faster to refresh all of them in a single command than to call them individually.

6. Use REFRESH FORCE to ensure getting a refreshed materialized view that can definitely be used for query rewrite. If a fast refresh cannot be done, a complete refresh will be performed.

Tips for Refreshing Materialized Views Without Aggregates

If a materialized view contains joins but no aggregates, then having an index on each of the join column rowids in the detail table will enhance refresh performance greatly, because this type of materialized view tends to be much larger than materialized views containing aggregates. For example, consider the following materialized view:

```
CREATE MATERIALIZED VIEW  detail_fact_mv
BUILD IMMEDIATE
 AS
 SELECT
   s.rowid "sales_rid", t.rowid "times_rid", c.rowid "cust_rid",
   c.cust_state_province, t.week_ending_day, s.amount_sold
 FROM sales s, times t, customers c
 WHERE s.time_id = t.time_id AND
       s.cust_id = c.cust_id;
```

Indexes should be created on columns `sales_rid`, `times_rid` and `cust_rid`. Partitioning is highly recommended, as is enabling parallel DML in the session before invoking refresh, because it will greatly enhance refresh performance.

This type of materialized view can also be fast refreshed if DML is performed on the detail table. It is recommended that the same procedure be applied to this type of materialized view as for a single table aggregate. That is, perform one type of change (direct-path INSERT or DML) and then refresh the materialized view. This is because Oracle can perform significant optimizations if it detects that only one type of change has been done.

Also, Oracle recommends that the refresh be invoked after each table is loaded, rather than load all the tables and then perform the refresh.

For refresh ON COMMIT, Oracle keeps track of the type of DML done in the committed transaction. Oracle therefore recommends that you do not perform direct-path and conventional DML to other tables in the same transaction because Oracle may not be able to optimize the refresh phase. For example, the following is not recommended:

1. Direct load new data into the `fact` table
2. DML into the `store` table
3. Commit

Also, try not to mix different types of conventional DML statements if possible. This would again prevent using various optimizations during fast refresh. For example, try to avoid the following:

1. Insert into the `fact` table
2. Delete from the `fact` table
3. Commit

If many updates are needed, try to group them all into one transaction because refresh will be performed just once at commit time, rather than after each update.

When you use the `DBMS_MVIEW` package to refresh a number of materialized views containing only joins with the `ATOMIC` parameter set to `TRUE`, if you disable parallel DML, refresh performance may degrade.

In a data warehousing environment, assuming that the materialized view has a parallel clause, the following sequence of steps is recommended:

1. Bulk load into the `fact` table
2. Enable parallel DML
3. An `ALTER SESSION ENABLE PARALLEL DML` statement
4. Refresh the materialized view

Tips for Refreshing Nested Materialized Views

Refreshing materialized views containing joins only and single-table aggregate materialized views uses the same algorithms irrespective of whether or not the views are nested. All underlying objects are treated as ordinary tables. If the `ON COMMIT` refresh option is specified, then all the materialized views are refreshed in the appropriate order at commit time.

Consider the schema in Figure 8–3. Assume all the materialized views are defined for `ON COMMIT` refresh. If table `fact` changes, then at commit time you could refresh `join_fact_store_time` first, and then `sum_sales_store_time` and `join_fact_store_time_prod`. No specific order for `sum_sales_store_time` and `join_fact_store_time_prod`, because they do not have any dependencies between them.

In other words, Oracle builds a partially ordered set of materialized views and refreshes them such that, after the successful completion of the refresh, all the materialized views are fresh. The status of the materialized views can be checked by querying the appropriate `USER_`, `DBA_`, or `ALL_MVIEWS` view.

If any of the materialized views are defined as `ON DEMAND` refresh (irrespective of whether the refresh method is `FAST`, `FORCE`, or `COMPLETE`), you will need to refresh them in the correct order (taking into account the dependencies between the materialized views) because the nested materialized view will be refreshed with respect to the current state of the other materialized views (whether fresh or not).

If a refresh fails during commit time, the list of materialized views that has not been refreshed is written to the alert log, and you must manually refresh them along with all their dependent materialized views.

Use the same `DBMS_MVIEW` procedures on nested materialized views that you use on regular materialized views.

These procedures have the following behavior when used with nested materialized views:

- If `REFRESH` is applied to a materialized view `my_mv` that is built on other materialized views, then `my_mv` will be refreshed with respect to the current state of the other materialized views (that is, they will not be made fresh first).
- If `REFRESH_DEPENDENT` is applied to materialized view `my_mv`, then only materialized views that directly depend on `my_mv` will be refreshed (that is, a materialized view that depends on a materialized view that depends on `my_mv` will not be refreshed).
- If `REFRESH_ALL_MVIEWS` is used, the order in which the materialized views will be refreshed is not guaranteed.
- `GET_MV_DEPENDENCIES` provides a list of the immediate (or direct) materialized view dependencies for an object.

Tips After Refreshing Materialized Views

After you have performed a load or incremental load and rebuilt the detail table indexes, you need to re-enable integrity constraints (if any) and refresh the materialized views and materialized view indexes that are derived from that detail data. In a data warehouse environment, referential integrity constraints are normally enabled with the `NOVALIDATE` or `RELY` options. An important decision to make before performing a refresh operation is whether the refresh needs to be recoverable. Because materialized view data is redundant and can always be reconstructed from the detail tables, it might be preferable to disable logging on the materialized view. To disable logging and run incremental refresh non-recoverably, use the ALTER MATERIALIZED VIEW ... NOLOGGING statement prior to refreshing.

If the materialized view is being refreshed using the ON COMMIT method, then, following refresh operations, consult the alert log alert_<SID>.log and the trace file ora_<SID>_number.trc to check that no errors have occurred.

Using Materialized Views With Partitioned Tables

A major maintenance component of a data warehouse is synchronizing (refreshing) the materialized views when the detail data changes. Partitioning the underlying detail tables can reduce the amount of time taken to perform the refresh task. This is possible because partitioning enables refresh to use parallel DML to update the materialized view. Also, it enables the use of Partition Change Tracking (PCT).

Fast Refresh with Partition Change Tracking

In a data warehouse, changes to the detail tables can often entail partition maintenance operations, such as DROP, EXCHANGE, MERGE, and ADD PARTITION. To maintain the materialized view after such operations in Oracle8*i* required the use of manual maintenance (see also CONSIDER FRESH) or complete refresh. Oracle9*i* introduces an addition to fast refresh known as Partition Change Tracking (PCT) refresh.

For PCT to be available, the detail tables must be partitioned. The partitioning of the materialized view itself has no bearing on this feature. If PCT refresh is possible, it will occur automatically and no user intervention is required in order for it to occur.

> **See Also:** "Partition Change Tracking" on page 8-34 for the requirements for PCT

The following examples will illustrate the use of this feature. In "PCT Fast Refresh Scenario 1", assume sales is a partitioned table using the time_id column and products is partitioned by the prod_category column. The table times is not a partitioned table.

PCT Fast Refresh Scenario 1

1. All detail tables must have materialized view logs. To avoid redundancy, only the materialized view log for the `sales` table is provided below.

   ```
   CREATE materialized view LOG on SALES
   WITH ROWID, SEQUENCE
     (prod_id, time_id, quantity_sold, amount_sold)
   INCLUDING NEW VALUES;
   ```

2. The following materialized view satisfies requirements for PCT.

   ```
   CREATE MATERIALIZED VIEW cust_mth_sales_mv
   BUILD IMMEDIATE
   REFRESH FAST ON DEMAND
     ENABLE QUERY REWRITE
     AS
     SELECT s.time_id, s.prod_id, SUM(s.quantity_sold), SUM(s.amount_sold),
           p.prod_name, t.calendar_month_name, COUNT(*),
           COUNT(s.quantity_sold), COUNT(s.amount_sold)
     FROM sales s, products p, times t
     WHERE  s.time_id = t.time_id AND
            s.prod_id = p.prod_id
     GROUP BY t.calendar_month_name, s.prod_id, p.prod_name, s.time_id;
   ```

3. You can use the `DBMS_MVIEW.EXPLAIN_MVIEW` procedure to determine which tables will allow PCT refresh.

   See Also: "Analyzing Materialized View Capabilities" on page 8-43 for how to use this procedure

```
MVNAME               CAPABILITY_NAME   POSSIBLE  RELATED_TEXT  MSGTXT
-----------------    ---------------   --------  ------------  ----------------
CUST_MTH_SALES_MV    PCT               Y         SALES
CUST_MTH_SALES_MV    PCT_TABLE         Y         SALES
CUST_MTH_SALES_MV    PCT_TABLE         N         PRODUCTS      no partition key or PMARKER
                                                               in SELECT list
CUST_MTH_SALES_MV    PCT_TABLE         N         TIMES         relation is not a
                                                               partitioned table
```

As can be seen from the partial sample output from `EXPLAIN_MVIEW`, any partition maintenance operation performed on the `sales` table will allow PCT fast refresh. However, PCT is not possible after partition maintenance operations or updates to the `products` table as there is insufficient information contained in `cust_mth_sales_mv` for PCT refresh to be possible. Note that the `times` table is not partitioned and hence can never allow for PCT refresh. Oracle will apply PCT refresh if it can determine that the materialized view has sufficient information to support PCT for all the updated tables.

4. Suppose at some later point, a `SPLIT` operation of one partition in the sales table becomes necessary.

```
ALTER TABLE SALES
SPLIT PARTITION month3 AT (TO_DATE('05-02-1998', 'DD-MM-YYYY'))
  INTO (
  PARTITION month3_1
  TABLESPACE summ,
  PARTITION month3
      TABLESPACE summ
  );
```

5. Insert some data into the `sales` table.

6. Fast refresh `cust_mth_sales_mv` using the `DBMS_MVIEW.REFRESH` procedure.

```
EXECUTE DBMS_MVIEW.REFRESH('CUST_MTH_SALES_MV', 'F',
   '',TRUE,FALSE,0,0,0,FALSE);
```

Fast refresh will automatically do a PCT refresh as it is the only fast refresh possible in this scenario. However, fast refresh will not occur if a partition maintenance operation occurs when any update has taken place to a table on which PCT is not enabled. This is shown in "PCT Fast Refresh Scenario 2".

"PCT Fast Refresh Scenario 1" would also be appropriate if the materialized view was created using the `PMARKER` clause as illustrated below.

```
CREATE MATERIALIZED VIEW cust_sales_marker_mv
       BUILD IMMEDIATE
       REFRESH FAST ON DEMAND
       ENABLE QUERY REWRITE
       AS
       SELECT DBMS_MVIEW.PMARKER(s.rowid) s_marker,
              SUM(s.quantity_sold), SUM(s.amount_sold),
                  p.prod_name, t.calendar_month_name, COUNT(*),
              COUNT(s.quantity_sold), COUNT(s.amount_sold)
       FROM sales s, products p, times t
       WHERE  s.time_id = t.time_id AND
              s.prod_id = p.prod_id
       GROUP BY DBMS_MVIEW.PMARKER(s.rowid),
              p.prod_name, t.calendar_month_name;
```

PCT Fast Refresh Scenario 2

In "PCT Fast Refresh Scenario 2", the first three steps are the same as in "PCT Fast Refresh Scenario 1" on page 14-23. Then, the `SPLIT` partition operation to the `sales` table is performed, but before the materialized view refresh occurs, records are inserted into the `times` table.

1. The same as in "PCT Fast Refresh Scenario 1".
2. The same as in "PCT Fast Refresh Scenario 1".
3. The same as in "PCT Fast Refresh Scenario 1".
4. The same as in "PCT Fast Refresh Scenario 1".
5. After issuing the same `SPLIT` operation, as shown in "PCT Fast Refresh Scenario 1", some data will be inserted into the `times` table.

   ```
   ALTER TABLE SALES
     SPLIT PARTITION month3 AT (TO_DATE('05-02-1998', 'DD-MM-YYYY'))
     INTO (
        PARTIITION month3_1
        TABLESPACE summ,
        PARTITION month3
        TABLESPACE summ);
   ```

6. Refresh `cust_mth_sales_mv`.

   ```
   EXECUTE DBMS_MVIEW.REFRESH('CUST_MTH_SALES_MV', 'F',
       '',TRUE,FALSE,0,0,0,FALSE);
   ORA-12052: cannot fast refresh materialized view SH.CUST_MTH_SALES_MV
   ```

The materialized view is not fast refreshable because DML has occurred to a table on which PCT fast refresh is not possible. To avoid this occurring, Oracle recommends performing a fast refresh immediately after any partition maintenance operation on detail tables for which partition tracking fast refresh is available.

If the situation in "PCT Fast Refresh Scenario 2" occurs, there are two possibilities; perform a complete refresh or switch to the `CONSIDER FRESH` option outlined below, if suitable. However, it should be noted that `CONSIDER FRESH` and partition change tracking fast refresh are not compatible. Once the `ALTER MATERIALIZED VIEW cust_mth_sales_mv CONSIDER FRESH` statement has been issued, PCT refresh will not longer be applied to this materialized view, until a complete refresh is done.

A common situation in a warehouse is the use of rolling windows of data. In this case, the detail table and the materialized view may contain say the last 12 months of data. Every month, new data for a month is added to the table and the oldest month is deleted (or maybe archived). PCT refresh provides a very efficient mechanism to maintain the materialized view in this case.

PCT Fast Refresh Scenario 3

1. The new data is usually added to the detail table by adding a new partition and exchanging it with a table containing the new data.

   ```
   ALTER TABLE sales ADD PARTITION month_new ...
   ALTER TABLE sales EXCHANGE PARTITION month_new month_new_table
   ```

2. Next, the oldest partition is dropped or truncated.

   ```
   ALTER TABLE sales DROP PARTITION month_oldest;
   ```

3. Now, if the materialized view satisfies all conditions for PCT refresh.

   ```
   EXECUTE DBMS_MVIEW.REFRESH('CUST_MTH_SALES_MV', 'F', '',
      TRUE, FALSE,0,0,0,FALSE);
   ```

Fast refresh will automatically detect that PCT is available and perform a PCT refresh.

Fast Refresh with CONSIDER FRESH

If the materialized view and a detail table have the same partitioning criteria, then you could use `CONSIDER FRESH` to maintain the materialized view after partition maintenance operations.

The following example demonstrates how you can manually maintain an unsynchronized detail table and materialized view. Assume the sales table and the `cust_mth_sales_mv` are partitioned identically, and contain say 12 months of data, one month in each partition.

1. Suppose the oldest month is to be removed from the table.

   ```
   ALTER TABLE sales DROP PARTITION month_oldest;
   ```

2. You could manually resynchronize the materialized view by doing a corresponding partition operation on the materialized view.

   ```
   ALTER MATERIALIZED VIEW cust_mth_sales_mv DROP PARTITION month_oldest;
   ```

3. Use `CONSIDER FRESH` to declare that the materialized view has been refreshed.

   ```
   ALTER MATERIALIZED VIEW cust_mth_sales_mv CONSIDER FRESH;
   ```

In a data warehouse, you may often wish to accumulate historical information in the materialized view even though this information is no longer in the detailed tables. In this case, you could maintain the materialized view using the `ALTER MATERIALIZED VIEW <materialized view name> CONSIDER FRESH` statement.

Note that `CONSIDER FRESH` declares that the contents of the materialized view are `FRESH` (in sync with the detail tables). Care must be taken when using this option in this scenario in conjunction with query rewrite because you may see unexpected results.

After using `CONSIDER FRESH` in an historical scenario, you will be able to apply traditional fast refresh after DML and direct loads to the materialized view, but not PCT fast refresh. This is because if the detail table partition at one time contained data that is currently kept in aggregated form in the materialized view, PCT refresh in attempting to resynchronize the materialized view with that partition could delete historical data which cannot be recomputed.

Assume the `sales` table stores the prior year's data and the `cust_mth_sales_mv` keeps the prior 10 years of data in aggregated form.

1. Remove old data from a partition in the `sales` table:

   ```
   ALTER TABLE sales TRUNCATE PARTITION month1;
   ```

   The materialized view is now considered stale and requires a refresh because of the partition operation. However, as the detail table no longer contains all the data associated with the partition fast refresh cannot be attempted.

2. Therefore, alter the materialized view to tell Oracle to consider it fresh.

   ```
   ALTER MATERIALIZED VIEW cust_mth_sales_mv CONSIDER FRESH;
   ```

   This statement informs Oracle that `cust_mth_sales_mv` is fresh for your purposes. However, the materialized view now has a status that is neither known fresh nor known stale. Instead, it is `UNKNOWN`. If the materialized view has query rewrite enabled in `QUERY_REWRITE_INTEGRITY=STALE_TOLERATED` mode it will be used for rewrite.

3. Insert data into `sales`.

4. Refresh the materialized view.

```
EXECUTE DBMS_MVIEW.REFRESH('CUST_MTH_SALES_MV', 'F',
   '', TRUE, FALSE,0,0,0,FALSE);
```

Because the fast refresh detects that only `INSERT` statements occurred against the sales table it will update the materialized view with the new data. However, the status of the materialized view will remain `UNKNOWN`. The only way to return the materialized view to `FRESH` status is with a complete refresh which, also will remove the historical data from the materialized view.

15 Change Data Capture

Oracle Change Data Capture efficiently identifies and *captures* data that has been added to, updated, or removed from, Oracle relational tables, and makes the *change data* available for use by applications. Change Data Capture is provided as an Oracle database server component with Oracle9*i*.

This chapter introduces Change Data Capture in the following sections:

See Also: *Oracle9i Supplied PL/SQL Packages and Types Reference* for more information about the Change Data Capture publish and subscribe PL/SQL packages.

About Oracle Change Data Capture

Oftentimes, data warehousing involves the extraction and transportation of relational data from one or more source databases into the data warehouse for analysis. Oracle Change Data Capture quickly identifies and processes only the data that has changed, not entire tables, and makes the change data available for further use.

Without Change Data Capture, database extraction is a cumbersome process in which you move the entire contents of tables into flat files, and then load the files into the data warehouse. This ad hoc approach is expensive in a number of ways.

Change Data Capture does not depend on intermediate flat files to stage the data outside of the relational database. It captures the change data resulting from `INSERT`, `UPDATE`, and `DELETE` operations made to user tables. The change data is then stored in a database object called a change table, and the change data is made available to applications in a controlled way.

Table 15–1 describes the advantages of performing database extraction with Change Data Capture.

Table 15–1 Database Extraction With and Without Change Data Capture

Database Extraction		
	With Change Data Capture	**Without Change Data Capture**
Extraction	Database extraction from `INSERT`, `UPDATE`, and `DELETE` operations occurs immediately, at the same time the changes occur to the source tables.	Database extraction is marginal at best for `INSERT` operations, and problematic for `UPDATE` and `DELETE` operations, because the data is no longer in the table.
Staging	Stages data directly to relational tables; there is no need to use flat files.	The entire contents of tables are moved into flat files.
Interface	Provides an easy-to-use publish and subscribe interface using `DBMS_LOGMNR_CDC_PUBLISH` and `DBMS_LOGMNR_CDC_SUBSCRIBE` packages.	Error prone and manpower intensive to administer.
Cost	Supplied with the Oracle9*i* (and later) database server. Reduces overhead cost by simplifying the extraction of change data.	Expensive because you must write and maintain the capture software yourself, or purchase it from a third-party vendors.

A Change Data Capture system is based on the interaction of a publisher and subscribers to capture and distribute change data, as described in the next section.

Publish and Subscribe Model

Most Change Data Capture systems have one publisher that captures and publishes change data for any number of Oracle source tables. There can be multiple subscribers accessing the change data. Change Data Capture provides PL/SQL packages to accomplish the publish and subscribe tasks.

Publisher

The **publisher** is usually a database administrator (DBA) who is in charge of creating and maintaining schema objects that make up the Change Data Capture system. The publisher performs these tasks:

- Determines the relational tables (called source tables) from which the data warehouse application is interested in capturing change data.
- Uses the Oracle supplied package, `DBMS_LOGMNR_CDC_PUBLISH`, to set up the system to capture data from one or more source tables.
- Publishes the change data in the form of change tables.
- Allows controlled access to subscribers by using the SQL `GRANT` and `REVOKE` statements to grant and revoke the `SELECT` privilege on change tables for users and roles.

Subscribers

The **subscribers**, usually applications, are consumers of the published change data. Subscribers subscribe to one or more sets of columns in source tables. Subscribers perform the following tasks:

- Use the Oracle supplied package, `DBMS_LOGMNR_CDC_SUBSCRIBE`, to subscribe to source tables for controlled access to the published change data for analysis.
- Extend the subscription window and create a new subscriber view when the subscriber is ready to receive a set of change data.
- Use `SELECT` statements to retrieve change data from the subscriber views.
- Drop the subscriber view and purge the subscription window when finished processing a block of changes.
- Drop the subscription when the subscriber no longer needs its change data.

Example of a Change Data Capture System

The Change Data Capture system captures the effects of DML statements, including `INSERT`, `DELETE`, and `UPDATE`, when they are performed on the source table. As these operations are performed, the change data is captured and published to corresponding change tables.

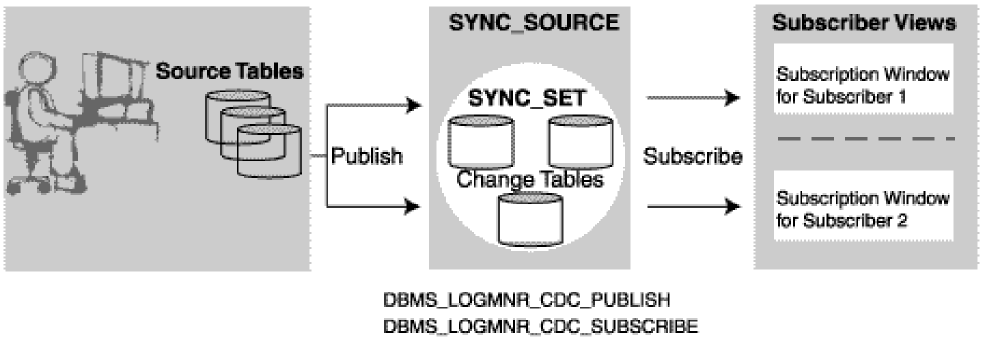
To capture change data, the publisher creates and administers change tables, which are special database tables that capture change data from a source table.

For example, for each source table for which you want to capture data, the publisher creates a corresponding change table. Change Data Capture ensures that none of the updates are missed or duplicated.

Each subscriber has its own view of the change data. This makes it possible for multiple subscribers to simultaneously subscribe to the same change table without interfering with one another.

Figure 15–1 shows the publish and subscribe model in a Change Data Capture system.

Figure 15–1 Publish and Subscribe Model in a Change Data Capture System



For example, assume that the change tables in Figure 15–1 contains all of the changes that occurred between Monday and Friday, and also assume that:

- Subscriber 1 is viewing and processing data from Tuesday.
- Subscriber 2 is viewing and processing data from Wednesday to Thursday.

Subscribers 1 and 2 each have a unique **subscription window** that contains a block of transactions. Oracle Change Data Capture manages the subscription window for each subscriber by creating a subscriber view that returns a range of transactions of interest to that subscriber. The subscriber accesses the change data by performing SELECT statements on the subscriber view that was generated by Change Data Capture.

When a subscriber needs to read additional change data, the subscriber makes procedure calls to *extend* the window and to create a new subscriber view. Each subscriber can *walk* through the data at its own pace, while Oracle Change Data Capture manages the data storage. As each subscriber finishes processing the data in its subscription window, it calls procedures to drop the subscriber view and *purge* the contents of the subscription window. Extending and purging windows is necessary to prevent the change table from growing indefinitely, and to prevent the subscriber from seeing the same data again.

Thus, Oracle Change Data Capture provides the following benefits for subscribers:

- Guarantees that each subscriber sees all of the changes, does not miss any changes, and does not see the same change data more than once.
- Keeps track of multiple subscribers and gives each subscriber shared access to change data.
- Handles all of the storage management, automatically removing data from change tables when it is no longer required by any of the subscribers.

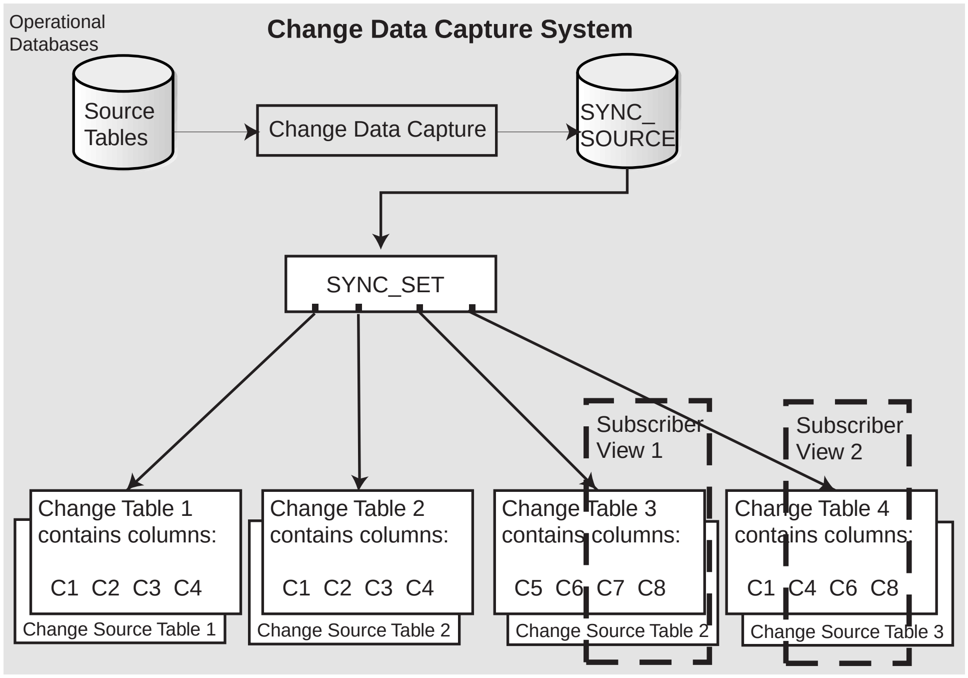
Components and Terminology for Synchronous Change Data Capture

This section describes the Change Data Capture components shown in Figure 15–2. The publisher is responsible for all of the components shown in Figure 15–2, except for the subscriber views. The publisher creates and maintains all of the schema objects that make up the Change Data Capture system, and publishes change data so that subscribers can use it.

Subscribers are the consumers of change data and are granted controlled access to the change data by the publisher. Subscribers subscribe to one or more columns in source tables.

With synchronous data capture, the change data is generated as data manipulation language (DML) operations are made to the source table. Every time a DML operation occurs on a source table, a record of that operation is written to the change table.

Figure 15–2 Components in a Synchronous Change Data Capture System


Operational Databases
Change Data Capture System
Source Tables
Change Data Capture
SYNC_SOURCE
SYNC_SET
Subscriber View 1
Subscriber View 2
Change Table 1 contains columns: C1 C2 C3 C4
Change Table 2 contains columns: C1 C2 C3 C4
Change Table 3 contains columns: C5 C6 C7 C8
Change Table 4 contains columns: C1 C4 C6 C8
Change Source Table 1
Change Source Table 2
Change Source Table 2
Change Source Table 3

The following subsections describe Change Data Capture components in more detail.

Source System

A source system is a production database that contains source tables for which Change Data Capture will capture changes.

Source Table

A source table is a database table that resides on the source system that contains the data you want to capture. Changes made to the source table are immediately reflected in the change table.

Change Source

A change source represents a source system. There is a system-generated change source named `SYNC_SOURCE`.

Change Set

A change set represents the collection of change tables. There is a system-generated change set named SYNC_SET.

Change Table

A change table contains the change data resulting from DML statements made to a single source table. A change table consists of two things: the change data itself, which is stored in a database table, and the system metadata necessary to maintain the change table. A given change table can capture changes from only one source table. In addition to published columns, the change table contains control columns that are managed by Change Data Capture. See the "Columns in a Change Table" section for more information.

Publication

A publication provides a way for publishers to publish multiple change tables on the same source table, and control subscriber access to the published change data. For example, Publication A consists of a change table that contains all the columns from the EMPLOYEE source table, while Publication B contains all the columns except the salary column from the EMPLOYEE source table. Because each change table is a separate publication, the publisher can implement security on the salary column by allowing only selected subscribers to access Publication A.

Subscriber View

A subscriber view is a view created by Change Data Capture that returns all of the rows in the subscription window. In Figure 15–2, the subscribers have created two views: one on columns 7 and 8 of Source Table 3 and one on columns 4, 6, and 8 of Source Table 4 The columns included in the view are based on the actual columns that the subscribers subscribed to in the source table.

Subscription Window

A subscription window defines the time range of change rows that the subscriber can currently see. The oldest row in the window is the low watermark; the newest row in the window is the high watermark. Each subscriber has a subscription window.

Installation and Implementation

Oracle Change Data Capture comes pre-packaged with the appropriate Oracle9*i* drivers already installed with which you can implement synchronous data capture.

In addition, note that Oracle Change Data Capture uses Java. Therefore, when you install the Oracle9*i* database server, ensure that Java is enabled.

Security

You grant privileges for a change table separately from the privileges you grant for a source table. For example, a subscriber that has privileges to perform a `SELECT` operation on a source table might not have privileges to perform a `SELECT` operation on a change table.

The publisher controls subscribers' access to change data by using the SQL `GRANT` and `REVOKE` statements to grant and revoke the `SELECT` privilege on change tables for users and roles. The publisher must grant the `SELECT` privilege before a user or application can subscribe to the change table.

The publisher must not grant any DML access (using either the `INSERT`, `UPDATE`, or `DELETE` statements) to the subscribers on the change tables because of the risk that a subscriber might inadvertently change the data in the change table, making it inconsistent with its source. Furthermore, the publisher should avoid creating change tables in schemas to which users have DML access.

Columns in a Change Table

A change table contains the change data resulting from DML statements. A change table consists of two things: the change data itself, which is stored in a database table and the system metadata necessary to maintain the change table.

The change table contains control columns that are managed by Change Data Capture. Table 15–2 describes the contents of a change table.

Table 15–2 Control Columns for a Change Table

Column	Datatype	Null-able?	Description
`RSID$`	`NUMBER`	N	Unique row sequence ID.

Table 15–2 (Cont.) Control Columns for a Change Table

Column	Datatype	Null-able?	Description
`OPERATION$`	`CHAR(2)`	N	<u>**Value**</u> <u>**Description**</u> I Insert UO or UU Update old value UN Update new value UL Update LOB D Delete
`CSCN$`	`NUMBER`	N	Commit SCN.
`COMMIT_TIMESTAMP$`	`DATE`	Y	Commit time of this transaction.
`SOURCE_COLMAP$`	`NUMBER`	N	Bit mask of updated columns; source table relative (optional column).
`TARGET_COLMAP$`	`NUMBER`	N	Bit mask of updated columns; change table relative (optional column).
`USERNAME$`	`VARCHAR2(30)`	N	Name of the user who caused the operation (optional column).
`TIMESTAMP$`	`DATE`	N	Time when the operation occurred in the source table (optional column).
`ROW_ID$`	`ROW_ID`	N	Row ID of affected row in source table (optional column).
`SYS_NC_OID$`	`RAW(16)`	Y	Object ID (optional column).

Views

Information about the Change Data Capture environment is provided in the views described in Table 15–3.

Note: See also the *Oracle9i Database Reference* for complete information about views.

Table 15–3 View Names for Oracle Change Data Capture

View Name	Description
CHANGE_SOURCES	Allows a publisher to see existing change sources.
CHANGE_SETS	Allows a publisher to see existing change sets.
CHANGE_TABLES	Allows a publisher to see existing change tables.
DBA_SOURCE_TABLES	Allows a publisher to see all of the existing (published) source tables.
ALL_SOURCE_TABLES	Allows subscribers to see all of the published source tables for which the subscribers have privileges to subscribe.
USER_SOURCE_TABLES	Allows the user to see all of the published source tables for which this user has privileges to subscribe.
DBA_PUBLISHED_COLUMNS	Allows a publisher to see all of the existing (published) source table columns.
ALL_PUBLISHED_COLUMNS	Allows a subscriber to see all of the published source table columns for which the subscriber has privileges.
USER_PUBLISHED_COLUMNS	Allows a user to see all of the published source table columns for which the user has privileges.
DBA_SUBSCRIPTIONS	Allows a publisher to see all of the subscriptions.
USER_SUBSCRIPTIONS	Allows a subscriber to see all of their current subscriptions.
DBA_SUBSCRIBED_TABLES	Allows a publisher to see all of the published tables to which subscribers have subscribed.
USER_SUBSCRIBED_TABLES	Allows a subscriber to see all of the published tables to which the subscriber has subscribed.
DBA_SUBSCRIBED_COLUMNS	Allows a publisher to see all of the columns of published tables to which subscribers have subscribed.
USER_SUBSCRIBED_COLUMNS	Allows a publisher to see all of the columns of published tables to which the subscriber has subscribed.

Synchronous Mode of Data Capture

Synchronous data capture provides up-to-the-second accuracy because the changes are being captured continuously and in real time on the production system. The change tables are populated after DML operations occur on the source table.

While synchronous mode data capture adds overhead to the system at capture time, it can reduce cost by simplifying the extraction of change data.

Publishing Change Data

This section provides step-by-step instructions for setting up an Oracle Change Data Capture system to capture and publish data from one or more Oracle relational source tables. Change Data Capture captures and publishes only committed data.

Note: To use the `DBMS_LOGMNR_CDC_PUBLISH` package, you must have the `EXECUTE_CATALOG_ROLE` privilege, and you must have the `SELECT_CATALOG_ROLE` privilege to look at all of the views. Also, you must be able to `GRANT SELECT` in the change tables to subscribers.

Step 1 Decide which Oracle instance will be the source system that will provide the change data.

The publisher needs to gather requirements from the subscribers and determine which source system contains the relevant source tables.

Step 2 Create the change tables that will contain the changes to individual source tables.

Use the `DBMS_LOGMNR_CDC_PUBLISH.CREATE_CHANGE_TABLE` procedure to create change tables.

Note: For synchronous data capture, Change Data Capture automatically generates a change source, called SYNC_SOURCE, and a change set called SYNC_SET. Change tables are contained in the predefined SYNC_SET change set.

Create a change table for each source table to be published, and decide which columns should be included. For update operations, decide whether to capture old values, new values, or both.

The publisher can set the `options_string` field of the `DBMS_LOGMNR_CDC_PUBLISH.CREATE_CHANGE_TABLE` procedure to have more control over the physical properties and tablespace properties of the change tables. The `options_string` field can contain any option available on the `CREATE TABLE DDL` statement.

Example 1 Creating a Change Table

The following example creates a change table that captures changes that happen to a source table. The example uses the sample table `SCOTT.EMP`.

```
EXECUTE DBMS_LOGMNR_CDC_PUBLISH.CREATE_CHANGE_TABLE (OWNER => 'cdc',\
    CHANGE_TABLE_NAME => 'emp_ct', \
    CHANGE_SET_NAME => 'SYNC_SET', \
    SOURCE_SCHEMA => 'scott', \
    SOURCE_TABLE => 'emp',\
    COLUMN_TYPE_LIST =. 'empno number, ename varchar2(10), job varchar2(9), mgr
    number, hiredate date, deptno number', \
    CAPTURE_VALUES => 'both', \
    RS_ID => 'y' \
    ROW_ID => 'n', \
    USER_ID => 'n', \
    TIMESTAMP => 'n', \
    OBJECT_ID => 'n', \
    SOURCE_COLMAP => 'y', \
    TARGET_COLMAP => 'y', \
    OPTIONS_STRING => null);
```

This statement creates a change table named `emp_ct` within the change set `SYNC_SET`. The `column_type_list` parameter identifies the columns captured by the change table. The `source_schema` and `source_table` parameters identify the schema and source table that reside on the production system.

The capture_values setting in the example indicates that for UPDATE operations, the change data will contain two separate rows for each row that changed: one row will contain the row values before the update occurred, and the other row will contain the row values after the update occurred.

Subscribing to Change Data

The subscribers, typically applications, register their interest in one or more source tables, and obtain subscriptions to these tables. Assuming sufficient access privileges, the subscribers may subscribe to any source tables that the publisher has published.

Steps Required to Subscribe to Change Data

The primary role of the subscriber is to access and use the change data. To do this, the subscriber must first determine which source tables are of interest, and then call the procedures in the DBMS_LOGMNR_CDC_SUBSCRIBE package to access them.

Step 1 Find the source tables for which the subscriber has access privileges.

Query the ALL_SOURCE_TABLES view to see all of the published source tables for which the subscriber has access privileges.

Step 2 Obtain a subscription handle.

Call the DBMS_LOGMNR_CDC_SUBSCRIBE.GET_SUBSCRIPTION_HANDLE procedure to create a subscription.

The following example shows how the subscriber first names the change set of interest (SYNC_SET), and then returns a unique subscription handle that will be used throughout the session.

```
EXECUTE SYS.DBMS_LOGMNR_CDC_SUBSCRIBE.GET_SUBSCRIPTION_HANDLE ( \
    CHANGE_SET => 'SYNC_SET',\
    DESCRIPTION => 'Change data for emp',\
    SUBSCRIPTION_HANDLE => :subhandle);
```

Step 3 Subscribe to a source table and columns in the source table.

Use the DBMS_LOGMNR_CDC_SUBSCRIBE.SUBSCRIBE procedure to specify which columns of the source tables are of interest to the subscriber and are to be captured.

The subscriber identifies the columns of the source table that are of interest. A subscription can contain one source table or multiple tables from the same change set. To see all of the published source table columns for which the subscriber has privileges, query the ALL_PUBLISHED_COLUMNS view.

In the following example, the subscriber wants to see only one source table.

```
EXECUTE SYS.DBMS_LOGMNR_CDC_SUBSCRIBE.SUBSCRIBE (\
    SUBSCRIPTION_HANDLE => :subhandle, \
    SOURCE_SCHEMA => 'scott', \
    SOURCE_TABLE => 'emp', \
    COLUMN_LIST => 'empno, ename, hiredate');
```

Step 4 Activate the subscription.

Use the DBMS_LOGMNR_CDC_SUBSCRIBE.ACTIVATE_SUBSCRIPTION procedure to activate the subscription.

Subscribers call this procedure when they are finished subscribing to source tables, and are ready to receive change data. Whether subscribing to one or multiple source tables, the subscriber needs to call the ACTIVATE_SUBSCRIPTION procedure only once.

In the following example, the ACTIVATE_SUBSCRIPTION procedure sets the subscription window to empty. At this point, no additional source tables can be added to the subscription.

```
EXECUTE SYS.DBMS_LOGMNR_CDC_SUBSCRIBE.ACTIVATE_SUBSCRIPTION ( \
    SUBSCRIPTION_HANDLE => :subhandle);
```

Step 5 Set the boundaries to see new data.

Call the DBMS_LOGMNR_CDC_SUBSCRIBE.EXTEND_WINDOW procedure to set the upper boundary (called a high-water mark) for a subscription window.

For example:

```
EXECUTE SYS.DBMS_LOGMNR_CDC_SUBSCRIBE.EXTEND_WINDOW (\
    SUBSCRIPTION_HANDLE => :subhandle);
```

At this point, the subscriber has created a new window that begins where the previous window ends. The new window contains any data that was added to the change table. If no new data has been added, the EXTEND_WINDOW procedure has no effect. To access the new change data, the subscriber must call the CREATE_SUBSCRIBER_VIEW procedure, and select from the new subscriber view that is generated by Change Data Capture.

Step 6 Prepare a subscriber view.

Use the DBMS_LOGMNR_CDC_SUBSCRIBE.PREPARE_SUBSCRIBER_VIEW procedure to create and prepare a subscriber view. (You must do this for each change table in the subscription.)

Subscribers do not access data directly from a change table; subscribers see the change data through subscriber views and perform SELECT operations against them. The reason for this is because Change Data Capture generates a view that restricts the data to only the columns to which the application has subscribed, and returns only the rows that the application has not viewed previously. The contents of the subscriber view will not change.

The following example shows how to prepare a subscriber view:

```
EXECUTE SYS.DBMS_LOGMNR_CDC_SUBSCRIBE.PREPARE_SUBSCRIBER_VIEW ( \
    SUBSCRIPTION_HANDLE => :subhandle, \
    SOURCE_SCHEMA => 'scott',\
    SOURCE_TABLE => 'emp', \
    VIEW_NAME => :viewname);
```

Step 7 Read and query the contents of the change tables.

Use the SQL SELECT statement on the subscriber view to read and query the contents of change tables (within the boundaries of the subscription window). You must do this for each change table in the subscription. For example:

```
SELECT * FROM CDC#CV$119490;
```

The subscriber view name, CDC#CV$119490, is a generated name.

Step 8 Drop the subscriber view.

Use the DBMS_LOGMNR_CDC_SUBSCRIBE.DROP_SUBSCRIBER_VIEW procedure to drop the subscriber views.

Change Data Capture guarantees not to change the subscriber view, even if new data has been added. Subscribers continue to have access to a subscriber view until calling the DROP_SUBSCRIBER_VIEW procedure, which indicates the subscriber is finished using the view. For example:

```
EXECUTE SYS.DBMS_LOGMNR_CDC_SUBSCRIBE.DROP_SUBSCRIBER_VIEW (\
SUBSCRIPTION_HANDLE => :subhandle, \
SOURCE_SCHEMA => 'scott', \
SOURCE_TABLE => 'emp');
```

Step 9 Empty the old data from the subscription window.

Use the `DBMS_LOGMNR_CDC_SUBSCRIBE.PURGE_WINDOW` procedure to let the Change Data Capture software know that the subscriber no longer needs the data in the current subscription window.

For example:

```
EXECUTE SYS.DBMS_LOGMNR_CDC_SUBSCRIBE.PURGE_WINDOW (\
    SUBSCRIPTION_HANDLE => :subhandle);
```

Step 10 Repeat steps 5 through 9.

Repeat steps 5 though 9 as long as you are interested in additional change data.

Step 11 End the subscription.

Use the `DBMS_LOGMNR_CDC_SUBSCRIBE.DROP_SUBSCRIPTION` procedure to end the subscription. This is necessary to prevent the change tables from growing without bound. For example:

```
EXECUTE SYS.DBMS_LOGMNR_CDC_SUBSCRIBE.DROP_SUBSCRIPTION (\
SUBSCRIPTION_HANDLE => :subhandle);
```

What Happens to Subscriptions When the Publisher Makes Changes

The Change Data Capture environment is dynamic in nature. The publisher can add and drop change tables at any time. The publisher can also add to and drop columns from existing change tables at any time. The following list describes how changes to the Change Data Capture environment affect subscriptions:

- Subscribers do not get explicit notification if the publisher adds a new change table. The views can be checked to see if new change tables have been added, and whether or not you have access to them.
- If a publisher drops a change table that is currently being subscribed to, the publisher must use the force flag to get a successful drop. It is expected that the publisher will warn subscribers before the force flag is actually used. If the subscribers are unaware of the dropped table, then when the subscriber calls `PREPARE_SUBSCRIBER_VIEW` procedure, an appropriate exception is generated. This becomes the notification mechanism.
- If the publisher adds a user column to a change table and a new subscription includes this column, then the subscription window starts at the point the column was added.

- If the publisher adds a user column to a change table and a new subscription does not include this newly added column, then the subscription window starts at the low-water mark for the change table thus enabling the subscriber to see the entire table.
- If the publisher adds a user column to a change table, and old subscriptions exist, then the subscription windows remain unchanged.
- Subscribers subscribe to source columns and never to control columns. They can see the control columns that were present at the time of the subscription.
- If the publisher adds a control column to a change table and there is a new subscription, then the subscription window starts at the low-water mark for the change table. The subscription can see the control column immediately. All rows that existed in the change table prior to adding the control column will have the value `NULL` for the newly added control column field.
- If the publisher adds a control column to a change table, then any existing subscriptions can see the new control column when the window is extended (`DBMS_LOGMNR_CDC_PUBLISH.EXTEND_WINDOW` procedure) such that the low watermark for the window crosses over the point when the control column was added.

Export and Import Considerations

When exporting or importing change tables for Change Data Capture, consider the following information:

- When change tables are imported, the job queue is checked for a Change Data Capture purge job. If no purge job is found, then one is submitted automatically (using the `DBMS_CDC_PUBLISH.PURGE` procedure). If a change table is imported, but no subscriptions are taken out before the purge job runs (24 hours later, by default), then all rows in the table will be purged.

  Choose one of the following methods to prevent the purging of data from a change table:

  – Suspend the purge job using the `DBMS_JOB` package to either disable the job (using the `BROKEN` procedure) or execute the job sometime in the future when there are subscriptions (using the `NEXT_DATE` procedure).

Note: If you disable the purge job by marking it as broken, you need to remember to reset it once subscriptions have been activated. This prevents the change table from growing without bound.

  – Take out a *dummy* subscription to preserve the change table data until real subscriptions appear. Then, you can drop the dummy subscription.

- When importing data into a source table for which a change table already exists, the imported data is also recorded in any associated change tables.

  Assume that you have a source table Employees that has an associated change table "CT_Employees." When you import data into Employees, that data is also recorded in CT_Employees.

- When importing a source table and its change table to a database where the tables did not previously exist, Change Data Capture for that source table will not be established until the import process completes. This protects you from duplicating activity in the change table.

- When exporting a source table and its associated change table, and then importing them into a new instance, the imported source table data is not recorded in the change table because it is already in the change table.

- When importing a change table having the optional control `ROW_ID` column, the `ROW_ID` columns stored in the change table have meaning only if the associated source table has *not* been imported. If a source table is re-created or imported, each row will have a new `ROW_ID` that is unrelated to the `ROW_ID` that was previously recorded in a change table.

- Any time a table is exported from one database and imported to another, there is a risk that the import target already has tables or objects with the same name. Moving a change table to a different database where a table exists that has the same name as the source table may result in import errors.

- If you need to move a synchronous change table or its source table, then move both tables together and check the import log for error messages.

16 Summary Advisor

This chapter illustrates how to use the Summary Advisor, a tool for choosing and understanding materialized views. The chapter contains:

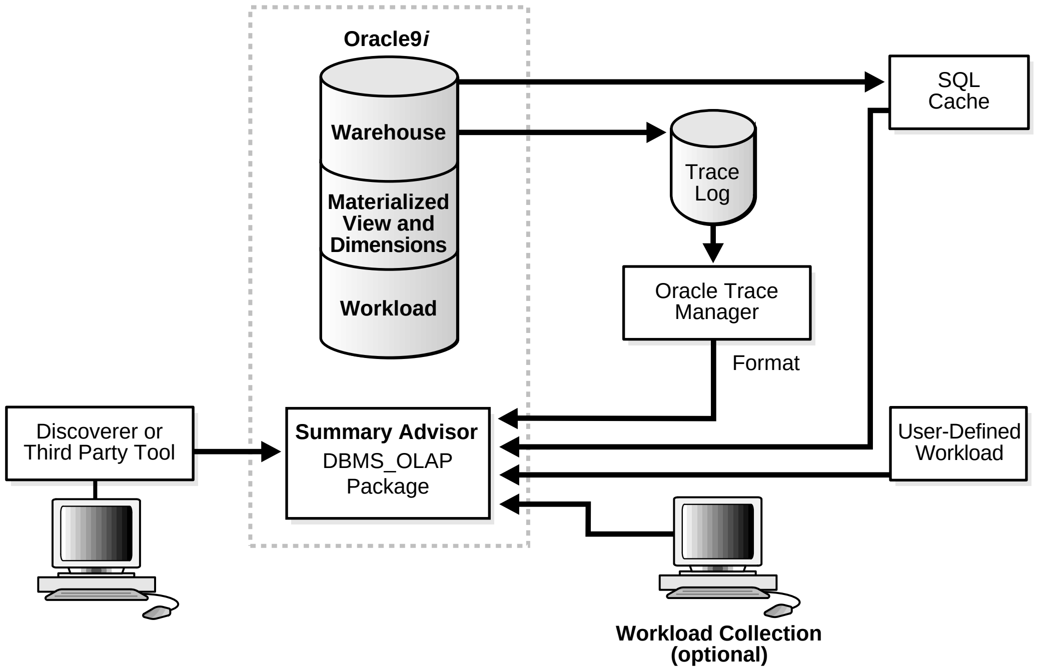
Overview of the Summary Advisor in the DBMS_OLAP Package

Materialized views provide high performance for complex, data-intensive queries. The Summary Advisor helps you achieve this performance benefit by choosing the proper set of materialized views for a given workload. In general, as the number of materialized views and space allocated to materialized views is increased, query performance improves. But the additional materialized views have some cost: they consume additional storage space and must be refreshed, which increases maintenance time. The Summary Advisor considers these costs and makes the most cost-effective trade-offs when recommending the creation of new materialized views and evaluating the performance of existing materialized views.

To help you select from among the many possible materialized views in your schema, Oracle provides a collection of materialized view analysis and advisory functions and procedures in the `DBMS_OLAP` package. Collectively, these functions are called the Summary Advisor, and they are callable from any PL/SQL program. Figure 16–1 shows how the Summary Advisor recommends materialized views from a hypothetical or user-defined workload or one obtained from the SQL cache, or Oracle Trace. You can run the Summary Advisor from Oracle Enterprise Manager or by invoking the `DBMS_OLAP` package. You must have Java enabled to use the Summary Advisor.

All data and results generated by the Summary Advisor is stored in a set of tables referred to as the Summary Advisor repository. These tables are owned by `SYSTEM` and start with `MVIEW$_ADV_*`. Only DBAs can access these tables directly, but other users can access the data relevant to them using a set of read-only views. These views start with `MVIEW_`. Thus, the table `MVIEW$_ADV_WORKLOAD` stores the workload of all users, but a user accesses his workload through the `MVIEW_WORKLOAD` view.

Figure 16–1 Materialized Views and the Summary Advisor



Using the Summary Advisor or the `DBMS_OLAP` package, you can:

- Estimate the size of a materialized view
- Recommend a materialized view
- Recommend materialized views based on collected workload information
- Report actual utilization of materialized views based on collected workload
- Define a filter to use against a workload
- Load and validate a workload
- Purge filters, workloads, and results
- Generate a unique identifier (for example, run ID, filter ID, or workload ID)

All of these tasks can be performed independently of one another. However, sometimes you need to use several procedures from the `DBMS_OLAP` package to complete a task. For example, to recommend a set of materialized views based on a workload, you have to first load the workload and then generate the set of recommendations.

Before you can use any of these procedures, you must create a unique identifier for the data they are about to create. This number is obtained by calling the procedure `CREATE_ID` and the unique number is known subsequently as a run ID, workload ID or filter ID depending on the procedure it is given.

The identifier is used to store the Advisor artifacts in the repository. Each activity in the Advisor requires a unique identifier to distinguish it from other objects. For example, when you add a filter item, you associate the item with a filter ID. When you load a workload, the data gets stored using the unique workload ID. In addition, when you run `RECOMMEND_MVIEW_STRATEGY` or `EVALUATE_MVIEW_STRATEGY`, a unique ID is associated with the run.

Because the ID is just a unique number, Oracle uses the same `CREATE_ID` function to acquire the value. It is only when a specific operation is performed (such as a load workload) that the ID is identified as a workload ID.

You can use the Summary Advisor with or without a workload, but better results are achieved if a workload is provided. This can be supplied by:

- The user
- Oracle Trace
- The current SQL cache contents

Once the workload is loaded into the Advisor workload repository or at the time the materialized view recommendations are generated, a filter can be applied to the workload to restrict what is analyzed. This provides the ability to generate different sets of recommendations based on different workload scenarios.

These filters are created using the procedure `ADD_FILTER_ITEM`. You can create any number of filters, and use more than one at a time to filter a workload. See "Using Filters with the Summary Advisor" on page 16-18 for further details.

The Summary Advisor uses four types of schema objects, some of which are defined in the user's schema and some are in the system schema:

- User Schema

  For both V-table and workload tables, before the workload is available to the recommendation process. It must be loaded into the advisor workload repository.

  - V-tables

  V-tables are generated by Oracle Trace for storing results of formatting server-collected trace. Please note that these V-tables are different from the V$ tables.

  - Workload Tables

    Workload tables are user tables that store workload information, and can reside in any schema.

- System Schema
  - Result Tables

    Result tables are internal tables that store both intermediate and final results from all Summary Advisor components.

  - Read-only Views

    Read-only views allow you to access recommendations, filters and workloads.These views are MVIEW_RECOMMENDATIONS, MVIEW_EVALUATIONS, MVIEW_FILTER, and MVIEW_WORKLOAD.

    Whenever the Summary Advisor is run, the results, with the exception of estimated size, are placed in internal tables, which can be accessed from read-only views in the database. These results can be queried, so you do not have to keep running the Advisor process.

If you want to view the results of the last materialized view recommendation, you can issue the following statement:

```
SELECT MVIEW_OWNER, MVIEW_NAME, RECOMMENDED_ACTION, PCT_PERFORMANCE_GAIN,
   BENEFIT_TO_COST_RATIO
FROM SYSTEM.MVIEW_RECOMMENDATIONS
WHERE RUNID= (SELECT MAX(RUNID) FROM MVIEW_RECOMMENDATIONS)
  ORDER BY RECOMMENDATION_NUMBER ASC
```

The advisory functions and procedures of the DBMS_OLAP package require you to gather structural statistics about fact and dimension table cardinalities, and the distinct cardinalities of every dimension level column, JOIN KEY column, and fact table key column. You do this by loading your data warehouse, then gathering either exact or estimated statistics with the DBMS_STATS package or the ANALYZE TABLE statement. Because gathering statistics is time-consuming and extreme statistical accuracy is not required, it is generally preferable to estimate statistics.

Using information from the system workload table, schema metadata and statistical information generated by the DBMS_STATS package, the Advisor engine generates summary recommendations and summary usage evaluations and stores the results in result tables.

To use the Summary Advisor with a workload, some or all of the following steps must be followed:

1. Optionally obtain an identifier number as a filter ID and define one or more filter items.
2. Obtain an identifier number as a workload ID and load a workload. If a filter was defined in step 1, then it can be used during the operation to refine the SQL statements as they are collected from the workload source. Load the workload.
3. Call the procedure `RECOMMEND_MVIEW_STRATEGY` to generate the recommendations.

These steps can be repeated several times with different workloads to see the effect on the materialized views.

Summary Advisor Wizard

The Summary Advisor Wizard in Oracle Enterprise Manager provides an interactive environment to recommend and build materialized views. Using the Wizard, you will be asked where the materialized views are to be placed, which fact tables to use, and which of the existing materialized views are to be retained. If a workload exists, it may be automatically selected. Otherwise, the Wizard will display the recommendations that are generated from the `RECOMMEND_MVIEW_STRATEGY` procedure.

All of the steps required to maintain your materialized views can be completed by answering the Wizard's questions. No subsequent DML operations are required.

> **See Also:** *Oracle Enterprise Manager Configuration Guide* for further information regarding the Summary Advisor

Using the Summary Advisor

The following sections will help you use the Advisor:

- Identifier Numbers
- Workload Management
- Loading a User-Defined Workload
- Loading a Trace Workload

- Loading a SQL Cache Workload
- Validating a Workload
- Removing a Workload
- Using Filters with the Summary Advisor
- Removing a Filter
- Recommending Materialized Views
- Summary Data Report
- When Recommendations are no Longer Required
- Stopping the Recommendation Process
- ESTIMATE_MVIEW_SIZE Parameters
- DBMS_OLAP.EVALUATE_MVIEW_STRATEGY Procedure

Identifier Numbers

Most of the `DBMS_OLAP` procedures require a unique identifier as one of their parameters. You obtain this by calling the procedure `CREATE_ID`, which is shown below.

DBMS_OLAP.CREATE_ID Procedure

Table 16–1 DBMS_OLAP.CREATE_ID Procedure Parameters

Parameter	Datatype	Description
id	NUMBER	The unique identifier that can be used to create a filter, load a workload, or create an analysis

With a SQL utility such as SQL*Plus:

1. Declare an output variable to receive the new identifier:

```
VARIABLE MY_ID NUMBER;
```

2. Call the `CREATE_ID` function to generate a new identifier:

```
CALL DBMS_OLAP.CREATE_ID(:MY_ID);
```

Workload Management

The Advisor performs best when a workload based on usage is available. The Advisor Workload Repository is capable of storing multiple workloads, so that the different uses of a real-world data warehousing environment can be viewed over a long period of time and across the life cycle of database instance startup and shutdown.

To facilitate wider use of the Summary Advisor, three types of workload are supported:

- Current contents of the SQL cache
- Oracle Trace collection
- User-specified Workload

When the workload is loaded using the appropriate `load_workload` procedure, it is stored in a new workload repository in the `SYSTEM` schema called `MVIEW_WORKLOAD` whose format is shown in Table 16–2. A specific workload can be removed by calling the `PURGE_WORKLOAD` routine and passing it a valid workload ID. To remove all workloads for the current user, call `PURGE_WORKLOAD` and pass the constant value `DBMS_OLAP.WORKLOAD_ALL`.

Table 16–2 MVIEW_WORKLOAD

Column	Datatype	Description
APPLICATION	VARCHAR2(30)	Optional application name for the query
CARDINALITY	NUMBER	Total cardinality of all of tables in query
WORKLOADID	NUMBER	Workload id identifying a unique sampling
FREQUENCY	NUMBER	Number of times query executed
IMPORT_TIME	DATE	Date at which item was collected
LASTUSE	DATE	Last date of execution
OWNER	VARCHAR2(30)	User who last executed query
PRIORITY	NUMBER	User-supplied ranking of query
QUERY	LONG	Query text
QUERYID	NUMBER	Id number identifying a unique query

Table 16–2 MVIEW_WORKLOAD

Column	Datatype	Description
RESPONSETIME	NUMBER	Execution time in seconds
RESULTSIZE	NUMBER	Total bytes selected by the query

Once the workload has been collected using the appropriate LOAD_WORKLOAD routine, there is also a filter mechanism that may be applied, this lets you specify the portion of workload that is to be loaded into the repository. You can also use the same filter mechanism to restrict workload-based summary recommendation and evaluation to a subset of the queries contained in the workload repository. Once the workload has been loaded, the Summary Advisor is run by calling the procedure RECOMMEND_MVIEW_STRATEGY. A major benefit of this approach is that it is easy to model different workloads by simply modifying the frequency column, removing some SQL queries, or adding new queries.

Summary Advisor can retrieve workload information from the SQL cache as well as Oracle Trace. If the collected data was retrieved from a server with the instance parameter cursor_sharing set to SIMILAR or FORCE, then user queries with embedded literal values will be converted to a statement that contains system-generated bind variables.

In Oracle9*i*, it is not possible to retrieve the bind-variable data in order to reconstruct the statement in the form originally submitted by the user. This will, in turn, cause Summary Advisor to not consider the query for rewrite and potentially miss a critical statement in the user's workload. As a work-around, if the Advisor will be used to recommend materialized views, then the server should set the instance parameter CURSOR_SHARING to EXACT.

Loading a User-Defined Workload

A user-defined workload is loaded using the procedure LOAD_WORKLOAD_USER. The workload_id is obtained by calling the procedure CREATE_ID. The value of the flags parameter determines whether the workload is considered to be new, should be used to overwrite an existing workload, or should be appended to an existing workload. The optional filter_id can be supplied to specify the filter that is to be used against this workload. Where the filter would have been defined using the ADD_FILTER_ITEM procedure.

DBMS_OLAP.LOAD_WORKLOAD_USER Procedure

Table 16–3 DBMS_OLAP.LOAD_WORKLOAD_USER Procedure Parameters

Parameter	Datatype	Description
`workload_id`	`NUMBER`	The required workload id that was returned by the create_id call

`flags`	`NUMBER`	Can take one of the following values:
		`DBMS_OLAP.WORKLOAD_OVERWRITE`
		The load routine will explicitly remove any existing queries from the workload that are owned by the specified collection ID
		`DBMS_OLAP.WORKLOAD_APPEND`
		The load routine preserves any existing queries in the workload. Any queries collected by the load operation will be appended to the end of the specified workload
		`DBMS_OLAP.WORKLOAD_NEW`
		The load routine assumes there are no existing queries in the workload. If it finds an existing workload element, the call will fail with an error
		Note: the flags have the same behavior irrespective of the `LOAD_WORKLOAD` operation

`filter_id`	`NUMBER`	Specify filter for the workload to be loaded
`owner_name`	`VARCHAR2`	The schema that contains the user supplied table or view
`table_name`	`VARCHAR2`	The table or view name containing valid workload data

The actual workload is defined in a separate table and the two parameters `owner_name` and `table_name` describe where it is stored. There is no restriction on which schema the workload resides in, the name for the table, or how many of these user-defined tables exist. The only restriction is that the format of the user table must correspond to the `USER_WORKLOAD` table, as described in Table 16–4 below:

Table 16–4 USER_WORKLOAD

Column	Datatype	Optional/ Required	Description
QUERY	Can be any VARCHAR or LONG type. All character types are supported	Required	SQL statement
OWNER	VARCHAR2(30)	Required	User who last executed query
APPLICATION	VARCHAR2(30)	Optional	Application name for the query
FREQUENCY	NUMBER	Optional	Number of times query executed
LASTUSE	DATE	Optional	Last date of execution
PRIORITY	NUMBER	Optional	User-supplied ranking of query
RESPONSETIME	NUMBER	Optional	Execution time in seconds
RESULTSIZE	NUMBER	Optional	Total bytes selected by the query
SQL_ADDR	NUMBER	Optional	Cache address
SQL_HASH	NUMBER	Optional	Cache hash value

The following is an example of loading a user workload:

1. Declare an output variable to receive the new identifier:

```
VARIABLE MY_ID NUMBER;
```

2. Call the CREATE_ID function to generate a new identifier:

```
CALL DBMS_OLAP.CREATE_ID(:MY_ID);
```

3. Load the workload from a target table or view:

```
CALL DBMS_OLAP.LOAD_WORKLOAD_USER(:MY_ID, DBMS_OLAP.WORKLOAD_NEW,
   DBMS_OLAP.FILTER_NONE, 'SH', 'MY_WORKLOAD');
```

Loading a Trace Workload

Alternatively, you can collect a Trace workload from Oracle Enterprise Manager to gather dynamic information about your query workload, which can be used by an advisory function. If Oracle Trace is available, consider using it to collect materialized view usage. Doing so enables you to see which materialized views are in use. It also lets the Advisor detect any unusual query requests from users that would result in recommending some different materialized views.

A workload collected by Oracle Trace is loaded using the procedure LOAD_WORKLOAD_TRACE described below. You obtain workload_id by calling the procedure CREATE_ID. The value of the flags parameter will determine whether the workload is considered new, should be used to overwrite an existing workload or should be appended to an existing workload. The optional filter ID can be supplied to specify the filter that is to be used against this workload. In addition, you can specify an application name to describe this workload and give every query a default priority. The application name is simply a tag that enables you to classify the workload query. The name can later be used to filter the workload during a RECOMMEND_MVIEW_STRATEGY or EVALUATE_MVIEW_STRATEGY operation.

The priority is an important piece of information. It tells the Advisor how important the query is to the business. When recommendations are formed, the priority will determine its value and will cause the Advisor to make decisions that favor higher ranking queries.

If the owner_name parameter is not defined, then the procedure will expect to find the formatted trace tables in the schema for the current user.

DBMS_OLAP.LOAD_WORKLOAD_TRACE Procedure

Table 16–5 DBMS_OLAP.LOAD_WORKLOAD_TRACE Procedure Parameters

Parameter	Datatype	Description
workload_id	NUMBER	The required id that was returned by the CREATE_ID call

Table 16–5 DBMS_OLAP.LOAD_WORKLOAD_TRACE Procedure Parameters

Parameter	Datatype	Description
flags	NUMBER	Can take one of the following values: DBMS_OLAP.WORKLOAD_OVERWRITE The load routine will explicitly remove any existing queries from the workload that are owned by the specified collection ID DBMS_OLAP.WORKLOAD_APPEND; The load routine preserves any existing queries in the workload. Any queries collected by the load operation will be appended to the end of the specified workload DBMS_OLAP.WORKLOAD_NEW: The load routine assumes there are no existing queries in the workload. If it finds an existing workload element, the call will fail with an error Note: the flags have the same behavior irrespective of the LOAD_WORKLOAD operation
filter_id	NUMBER	Specify filter for the workload to be loaded
application	VARCHAR2	The default business application name. This value will be used for a query if one is not found in the target workload
priority	NUMBER	The default business priority to be assigned to every query in the target workload
owner_name	VARCHAR2	The schema that contains the Oracle Trace data. If omitted, the current user will be used

Oracle Trace collects two types of data. One is a duration event which causes a data item to be collected twice: once at the start of the operation and once at the end of the operation. The duration of the data item is the difference between the start and end of the operation. For example, execution time is collected as a duration event. It first collects the clock time when the operation starts. Then it collects the clock time when the operation ends. Execution time is calculated by subtracting the start time from the end time.

A point event is a static data item that doesn't change over time. For example, an owner name is a static data item that would be the same at the start and the end of an operation.

To collect, analyze and load the summary event set, you must do the following:

1. Set six initialization parameters to collect data using Oracle Trace. Enabling these parameters incurs some additional overhead at database connection, but is otherwise transparent.

   - `ORACLE_TRACE_COLLECTION_NAME = oraclesm or oraclee`

     `ORACLEE` is the Oracle Expert collection which contains Summary Advisor data and additional data that is only used by Oracle Expert.

     `ORACLESM` is the Summary Advisor collection that contains only Summary Advisor data and is the preferred collection type.

   - `ORACLE_TRACE_COLLECTION_PATH =` <location of collection files>
   - `ORACLE_TRACE_COLLECTION_SIZE = 0`
   - `ORACLE_TRACE_ENABLE = TRUE`
   - `ORACLE_TRACE_FACILITY_NAME = oraclesm` or `oralcee`
   - `ORACLE_TRACE_FACILITY_PATH =` <location of trace facility files>

     See Also: *Oracle Enterprise Manager Oracle Trace User's Guide* for further information regarding these parameters

2. Run the Oracle Trace Manager, specify a collection name, and select the `SUMMARY_EVENT` set. Oracle Trace Manager reads information from the associated configuration file and registers events to be logged with Oracle. While collection is enabled, the workload information defined in the event set gets written to a flat log file.

3. When collection is complete, Oracle Trace automatically formats the Oracle Trace log file into a set of relations, which have the predefined synonyms beginning with `V_192216243_`. Alternatively, the collection file, which usually has an extension of .CDF, can be formatted manually using the `otrcfmt` utility, as shown in this example:

   ```
   otrcfmt    collection_name.cdf    user/password@database
   ```

   The trace data can be formatted in any schema. The `LOAD_WORKLOAD_TRACE` call lets you specify the location of the data.

4. Run the `GATHER_TABLE_STATS` procedure of the `DBMS_STATS` package or `ANALYZE...ESTIMATE STATISTICS` to collect cardinality statistics on all fact tables, dimension tables, and key columns (any column that appears in a dimension `LEVEL` clause or `JOIN` clause of a `CREATE DIMENSION` statement).

5. Run the CREATE_ID procedure of the DBMS_OLAP package to get a unique workload_id for this workload.
6. Run the LOAD_WORKLOAD_TRACE procedure of the DBMS_OLAP package to load this workload into the repository.

Once these six steps have been completed, you will be ready to make recommendations about your materialized views. An example of how to load a trace workload is shown below.

1. Declare an output variable to receive the new identifier:

```
VARIABLE MY_ID NUMBER:
```

2. Call the CREATE_ID function to generate a new identifier:

```
CALL DBMS_OLAP.CREATE_ID(:MY_ID);
```

3. Load the workload from the formatted trace collection:

```
CALL DBMS_OLAP.LOAD_WORKLOAD_TRACE(:MY_ID, DBMS_OLAP.WORKLOAD_NEW, DBMS_
OLAP.FILTER_NONE,  'myapp', 7,  'SH');
```

Loading a SQL Cache Workload

You obtain a SQL cache workload using the procedure LOAD_WORKLOAD_CACHE described below. At the time this procedure is called, the current contents of the SQL cache are analyzed and placed into the read-only view SYSTEM.MVIEW_ WORKLOAD.

You obtain the workload_id by calling the procedure CREATE_ID. The value of the flags parameter determines whether the workload is treated as new, should be used to overwrite an existing workload, or should be appended to an existing workload. The optional filter ID can be supplied to specify the filter that is to be used against this workload. Where the filter would have been defined using the ADD_FILTER_ITEM procedure. In addition, you can specify an application name to describe this workload and give every query a default priority.

DBMS_OLAP.LOAD_WORKLOAD_CACHE Procedure

Table 16–6 DBMS_OLAP.LOAD_WORKLOAD_CACHE Procedure Parameters

Parameter	Datatype	Description
workload_id	NUMBER	The required ID that was returned by the CREATE_ID call

Table 16–6 DBMS_OLAP.LOAD_WORKLOAD_CACHE Procedure Parameters

Parameter	Datatype	Description

`flags`	`NUMBER`	Can take one of the following values:
		`DBMS_OLAP.WORKLOAD_OVERWRITE`
		The load routine will explicitly remove any existing queries from the workload that are owned by the specified collection ID
		`DBMS_OLAP.WORKLOAD_APPEND:`
		The load routine preserves any existing queries in the workload. Any queries collected by the load operation will be appended to the end of the specified workload
		`DBMS_OLAP.WORKLOAD_NEW:`
		The load routine assumes there are no existing queries in the workload. If it finds an existing workload element, the call will fail with an error
		Note: the flags have the same behavior irrespective of the `LOAD_WORKLOAD` operation

`filter_id`	`NUMBER`	Specify filter for the workload to be loaded. The value `DBMS_OLAP.FILTER_NONE` indicates no filtering
`application`	`VARCHAR2`	String workload's application column. Not used by SQL Cache workload
`priority`	`NUMBER`	The default business priority to be assigned to every query in the target workload

An example of how to load a SQL Cache workload is shown below.

1. Declare an output variable to receive the new identifier:

   ```
   VARIABLE MY_ID NUMBER:
   ```

2. Call the `CREATE_ID` function to generate a new identifier:

   ```
   CALL DBMS_OLAP.CREATE_ID(:MY_ID);
   ```

3. Load the workload from the SQL cache:

   ```
   CALL DBMS_OLAP.LOAD_WORKLOAD_CACHE(:MY_ID, DBMS_OLAP.WORKLOAD_NEW, DBMS_
   OLAP.FILTER_NONE, 'Payroll', 7);
   ```

Validating a Workload

Prior to loading a workload, one of the three `VALIDATE_WORKLOAD` procedures:

- `VALIDATE_WORKLOAD_USER`
- `VALIDATE_WORKLOAD_CACHE`
- `VALIDATE_WORKLOAD_TRACE`

may be called to check that the workload exists. This procedure does not check that the contents of the workload are valid, it merely checks that the workload exists.

The following are examples of validating the three types of workload:

```
DECLARE
  isitgood      NUMBER;
  err_text      VARCHAR2(200);
BEGIN
  DBMS_OLAP.VALIDATE_WORKLOAD_CACHE (isitgood, err_text);
END;

DECLARE
  isitgood      NUMBER;
  err_text      VARCHAR2(200);
BEGIN
  DBMS_OLAP.VALIDATE_WORKLOAD_TRACE ('SH', isitgood, err_text);
END;
DECLARE
  isitgood      NUMBER;
  err_text      VARCHAR2(200);
BEGIN
  DBMS_OLAP.VALIDATE_WORKLOAD_USER ('SH', 'USER_WORKLOAD', isitgood, err_text);
END;
```

Removing a Workload

When workloads are no longer needed, they can be removed using the procedure PURGE_WORKLOAD. You can delete all workloads or a specific collection.

DBMS_OLAP.PURGE_WORKLOAD Procedure

Table 16–7 DBMS_OLAP.PURGE_WORKLOAD Procedure Parameters

Parameter	Datatype	Description
workload_id	NUMBER	An ID number originally assigned by the create_id call. If the value of workload_id is set to DBMS_OLAP.WORKLOAD_ALL, then all workload collections for the current user will be deleted

The following is an example of removing a specific workload

```
VARIABLE workload_id NUMBER;
DBMS_OLAP.PURGE_WORKLOAD(:workload_id);
```

This example removes all workloads.

```
EXECUTE  DBMS_OLAP.PURGE_WORKLOAD(DBMS_OLAP.WORKLOAD_ALL);
```

Using Filters with the Summary Advisor

The entire contents of a workload do not have to be used during the recommendation process. Any workload can be filtered by creating a filter item using the procedure ADD_FILTER_ITEM, which is described is Table 16–8.

DBMS_OLAP.ADD_FILTER_ITEM Procedure

Table 16–8 DBMS_OLAP.ADD_FILTER_ITEM Procedure Parameters

Parameter	Datatype	Description
filter_id	NUMBER	An ID that uniquely describes the filter. It is generated by the create_id call

Table 16–8 DBMS_OLAP.ADD_FILTER_ITEM Procedure Parameters

Parameter	Datatype	Description

`filter_name`	VARCHAR2	`APPLICATION`
		String-workload's application column. An example of how to load a SQL Cache workload is shown below.
		
		`BASETABLE`
		String-base tables referenced by workload queries. Name must be fully qualified including owner and table name (`SH.SALES`)
		
		`CARDINALITY`
		Numerical-sum of cardinality of the referenced base tables
		
		`FREQUENCY`
		Numerical-workload's frequency column
		
		`LASTUSE`
		Date-workload's lastuse column. Not used by SQL Cache workload.
		
		`OWNER`
		String-workload's owner column. Expected in uppercase unless owner defined explicitly to be not all in uppercase.
		
		`PRIORITY`
		Numerical-workload's priority column. Not used by SQL Cache workload.
		
		`RESPONSETIME`
		Numerical-workload's responsetime column. Not used by SQL Cache workload.
		
		`TRACENAME`
		String-list of oracle trace collection names. Only used by a Trace Workload

`string_list`	VARCHAR2	A comma-separated list of strings
`number_min`	NUMBER	The lower bound of a numerical range. `NULL` represents the lowest possible value
`number_max`	NUMBER	The upper bound of a numerical range, `NULL` for no upper bound. `NULL` represents the highest possible value
`date_min`	VARCHAR2	The lower bound of a date range. `NULL` represents the lowest possible date value
`date_max`	VARCHAR2	The upper bound of a date range. `NULL` represents the highest possible date value

The Advisor supports nine different filter item types. For each filter item, Oracle stores an attribute that tells Advisor how to apply the selection rule. For example, an `APPLICATION` item requires a string attribute that can be either a single name as in `GREG`, or it can be a comma-separated list of names like `GREG`, `ROSE`, `KALLIE`, `HANNAH`. For a single name, the Advisor takes the value and only accept the workload query if the application name exactly matches the supplied name. For a list of names, the queries application name must appear in the list. Referring to my example, a query whose application name is `GREG` would match either a single application filter item containing `GREG` or the list `GREG`, `ROSE`, `KALLIE`, `HANNAH`. Conversely, a query whose application is `KALLIE` will only match the filter item list `GREG`, `ROSE`, `KALLIE`, `HANNAH`.

For numeric filter items such as `CARDINALITY`, the attribute represents a possible range of values. Advisor will determine if the filter item represents a bounded range such as 500 to 1000000, or it could be an exact match like 1000 to 1000. When the range value is specified as `NULL`, then the value is infinitely small or large, depending upon which attribute is set.

Data filters, such as `LASTUSE` behave similar to numeric filter except Advisor treats the range test as two dates. A `NULL` value indicates infinity.

You can define a number of different types of filter as shown in Table 16–9:

Table 16–9 Workload Filters and Attribute Types

Filter Item Name	string_list	number_ min	number_ max	date_min	date_max	Description
`APPLICATION`	Required	N/A	N/A	N/A	N/A	Query should be from the list applications defined in string_list. Multiple application names must separated by commas
`CARDINALITY`	N/A	Required	Required	N/A	N/A	Sum of cardinalities of base tables found in a query
`LASTUSE`	N/A	N/A	N/A	Required	Required	Last execution date of the query
`FREQUENCY`	N/A	Required	Required	N/A	N/A	Number of executions for the query
`OWNER`	Required	N/A	N/A	N/A	N/A	List of database users who executed queries. Multiple owners must be separated by commas

Table 16–9 Workload Filters and Attribute Types

Filter Item Name	string_list	number_ min	number_ max	date_min	date_max	Description
PRIORITY	N/A	Required	Required	N/A	N/A	User-supplied priority value
BASETABLE	Required	N/A	N/A	N/A	N/A	List of fully qualified tables that appear in a candidate query. Multiple tables must be separated by commas
RESPONSETIME	N/A	Required	Required	N/A	N/A	Query response time in seconds
TRACENAME	Required	N/A	N/A	N/A	N/A	List of Oracle Trace collection names. If this filter is not used, then the collection operation will choose the entire Oracle Trace collection, regardless of it collection name. Multiple names must be separated by commas

When dealing with a workload, the client can optionally attach a filter to reduce or refine the set of target SQL statements. If no filter is attached, then all target SQL statements will be collected or used.

A new filter can be created with the `CREATE_ID` call. Filter items can be added to the filter by using the `ADD_FILTER_ITEM` call. When a filter is created, an entry is stored in the read-only view `SYSTEM.MVIEW_FILTER`.

Below is an example illustrating how to add three different types of filter

1. Declare an output variable to receive the new identifier:

   ```
   VARIABLE MY_ID NUMBER:
   ```

2. Call the `CREATE_ID` function to generate a new identifier:

   ```
   CALL DBMS_OLAP.CREATE_ID(:MY_ID);
   ```

3. Add filter items:

```
CALL DBMS_OLAP.ADD_FILTER_ITEM(:MY_ID,'BASETABLE', 'SCOTT.EMP',
                                NULL, NULL, NULL, NULL);
CALL DBMS_OLAP.ADD_FILTER_ITEM(:MY_ID, 'OWNER', 'SCOTT,PAYROLL,PERSONNEL',
                                NULL, NULL, NULL, NULL);
CALL DBMS_OLAP.ADD_FILTER_ITEM(:MY_ID, 'FREQUENCY', NULL,
                                500, NULL, NULL, NULL);
```

The above example defines a filter with three filter items. The first filter will only allow queries that reference the table SCOTT.EMP. The second item will accept queries that were executed by one of the users SCOTT, PAYROLL or PERSONNEL. Finally, the third filter item accepts queries that execute at least 500 times.

Note, all filter items must match for a single query to be accepted. If any of the items fail to match, then the query will not be accepted.

In the previous example, three filters will be applied against the data. However, each filter item could have created with its only unique filter id, thus creating three different filters as shown below:

```
VARIABLE MY_ID NUMBER:
CALL DBMS_OLAP.CREATE_ID(:MY_ID);
CALL DBMS_OLAP.ADD_FILTER_ITEM(:MY_ID,'BASETABLE',
   'SCOTT.EMP', NULL, NULL, NULL, NULL);
CALL DBMS_OLAP.CREATE_ID(:MY_ID);
CALL DBMS_OLAP.ADD_FILTER_ITEM(:MY_ID, 'OWNER',
  'SCOTT, PAYROLL,PERSONNEL', NULL, NULL, NULL, ULL);
CALL DBMS_OLAP.CREATE_ID(:MY_ID);
CALL DBMS_OLAP.ADD_FILTER_ITEM(:MY_ID, 'FREQUENCY', NULL, 500,NULL, NULL,NULL);
```

Removing a Filter

A filter can be removed at anytime by calling the procedure PURGE_FILTER which is described below. You can delete a specific filter or all filters. You can remove all filters using the purge_filter call by specifying DBMS_OLAP.FILTER_ALL as the filter ID.

DBMS_OLAP.PURGE_FILTER Procedure

Table 16–10 DBMS_OLAP.PURGE_FILTER Procedure Parameters

Parameter	Datatype	Description
`filterid`	`NUMBER`	A filter ID number used to identify the filter to be deleted

DBMS_OLAP.PURGE_FILTER Example

```
VARIABLE   MY_FILTER_ID NUMBER:
CALL DBMS_OLAP.PURGE_FILTER(:MY_FILTER_ID);
CALL DBMS_OLAP.PURGE_FILTER(DBMS_OLAP.FILTER_ALL);
```

Recommending Materialized Views

The analysis and advisory procedure for materialized views is `RECOMMEND_MVIEW_STRATEGY` in the `DBMS_OLAP` package. This procedure automatically recommends which materialized view to create, retain, or drop. `RECOMMEND_MVIEW_STRATEGY` uses structural statistics and optionally workload statistics.

You can call this procedure to obtain a list of materialized view recommendations that you can select, modify, or reject. Alternatively, you can use the `DBMS_OLAP` package directly in your PL/SQL programs for the same purpose.

In order to use the Summary advisor, you must have the `SELECT ANY TABLE` privilege.

> **See Also:** *Oracle9i Supplied PL/SQL Packages and Types Reference* for detailed information about the `DBMS_OLAP` package

This procedure has the following parameters:

RECOMMEND_MVIEW_STRATEGY Procedure Parameters

Table 16–11 RECOMMEND_MVIEW_STRATEGY Parameters

Parameter	I/O	Datatype	Description
`run_id`	`IN`	`NUMBER`	A return value that uniquely identifies the current operation
`workoad_id`	`IN`	`NUMBER`	An optional workload ID that maps to a workload in the current repository

Table 16–11 RECOMMEND_MVIEW_STRATEGY Parameters

Parameter	I/O	Datatype	Description
`filter_id`	IN	NUMBER	An optional filter ID that maps to a set of user-supplied filter items
`storage_in_bytes`	IN	NUMBER	Maximum storage, in bytes, that can be used for storing materialized views. This number must be non-negative
`retention_pct`	IN	NUMBER	Number between 0 and 100 that specifies the percent of existing materialized view storage that must be retained, based on utilization on the actual or hypothetical workload. A materialized view is retained if the cumulative space, ranked by utilization, is within the retention threshold specified (or if it is explicitly listed in `retention_list`). Materialized views that have a `NULL` utilization (for example, non-dimensional materialized views) are always retained.
`retention_list`	IN	VARCHAR2	Comma-separated list of materialized view table names A drop recommendation is not made for any materialized view that appears in this list
`fact_table_filter`	IN	VARCHAR2	Comma-separated list of fact table names to analyze, or `NULL` to analyze all fact tables

The results from calling this package are put in the table `SYSTEM.MVIEW_RECOMMENDATIONS` shown in Table 16–12. The output can be queried directly using the `MVIEW_RECOMMENDATION` table or a structured report can be generated using the `DBMS_OLAP.GENERATE_MVIEW_REPORT` procedure.

Table 16–12 MVIEW_RECOMMENDATIONS

Column	Datatype	Description
`RUNID`	`NUMBER`	Run ID identifying a unique advisor call
`FACT_TABLES`	`VARCHAR2(1000)`	A comma-separated list of fully qualified table names for structured recommendations
`GROUPING_LEVELS`	`VARCHAR2(2000)`	A comma-separated list of grouping levels, if any, for structured recommendations

Table 16–12 MVIEW_RECOMMENDATIONS

Column	Datatype	Description
QUERY_TEXT	LONG	Query text of materialized view if RECOMMENDED_ACTION is CREATE; NULL otherwise
RECOMMENDATION_ NUMBER	NUMBER	Unique identifier for this recommendation
RECOMMENDED_ACTION	VARCHAR(6)	CREATE, RETAIN, or DROP
MVIEW_OWNER	VARCHAR2(30)	Owner of the materialized view summary if RECOMMENDED_ACTION is RETAIN or DROP; NULL otherwise
MVIEW_NAME	VARCHAR2(30)	Name of the materialized view if RECOMMENDED_ACTION is RETAIN or DROP; NULL otherwise
STORAGE_IN_BYTES	NUMBER	Actual or estimated storage in bytes Storage
PCT_PERFORMANCE_GAIN	NUMBER	The expected incremental improvement in performance obtained by accepting this recommendation relative to the initial condition, assuming that all previous recommendations have been accepted, or NULL if unknown. Performance gain
BENEFIT_TO_COST_ RATIO	NUMBER	Ratio of the incremental improvement in performance to the size of the materialized view in bytes, or NULL if unknown. Benefit / Cost

Below are several examples of how you can use the Advisor recommendation process:

In this example, a workload is loaded from the table USER_WORKLOAD and no filtering is applied to the workload. The fact table is called sales.

```
DECLARE
  workload_id       NUMBER;
  run_id            NUMBER;

BEGIN
-- load the workload
  DBMS_OLAP.CREATE_ID (workload_id);
  DBMS_OLAP.LOAD_WORKLOAD_USER(workload_id, DBMS_OLAP.WORKLOAD_NEW,
         DBMS_OLAP.FILTER_NONE,'SH','USER_WORKLOAD' );
-- run recommend_mv
  DBMS_OLAP.CREATE_ID (run_id);
  DBMS_OLAP.RECOMMEND_MVIEW_STRATEGY(run_id, workload_id, NULL, 1000000, 100,
NULL, 'sales');
END;
```

In this example, the workload is derived from the current contents of the SQL cache and then filtered for only the application called `sales_hist`:

```
DECLARE
  workload_id      NUMBER;
  filter_id        NUMBER;
  run_id           NUMBER;
BEGIN
-- add a filter for application sales_hist
  DBMS_OLAP.CREATE_ID(filter_id);
  DBMS_OLAP.ADD_FILTER_ITEM(filter_id, 'APPLICATION', 'sales_hist', NULL, NULL,
NULL, NULL);
-- load the workload
  DBMS_OLAP.CREATE_ID(workload_id);
  DBMS_OLAP.LOAD_WORKLOAD_CACHE (workload_id, DBMS_OLAP.WORKLOAD_NEW, DBMS_
OLAP.FILTER_NONE, NULL
,NULL);
-- run recommend_mv
  DBMS_OLAP.CREATE_ID (run_id );
  DBMS_OLAP.RECOMMEND_MVIEW_STRATEGY(run_id, workload_id, NULL, 1000000, 100,
NULL, 'sales');
END;
```

In this example, the workload is from Oracle Trace without filtering.

```
DECLARE
  workload_id    NUMBER;
  run_id         NUMBER;
BEGIN
  DBMS_OLAP.CREATE_ID (workload_id);
  DBMS_OLAP.LOAD_WORKLOAD_TRACE (workload_id, DBMS_OLAP.WORKLOAD_NEW, DBMS_
OLAP.FILTER_NONE, NULL,NULL,NULL );
-- run recommend_mv
  DBMS_OLAP.CREATE_ID(run_id);
  DBMS_OLAP.RECOMMEND_MVIEW_STRATEGY(run_id, workload_id, NULL,10000000, 100,
NULL, 'sales');
END;
```

SQL Script Generation

When the Summary Advisor is run using Oracle Enterprise Manager the facility is provided to implement the advisors recommendations. But when the procedure RECOMMEND_MVIEW_STRATEGY is called directly the procedure GENERATE_ MVIEW_SCRIPT must be used to create a script which will implement the advisors recommendations. The parameters are as follows:

```
GENERATE_MVIEW_SCRIPT (filename VARCHAR2, id NUMBER, tablespace_name VARCHAR2)
```

- filename

  Contains the fully-specified output file name

- id

  Contains the Advisor run ID for which the script will be created

- tablespace_name

  Contains an optional tablespace in which new materialized views will be placed.

The resulting script is a executable SQL file that can contain DROP and CREATE statements for materialized views. For new materialized views, the name of the materialized views is auto-generated by combining the user-specified ID and the Rank value of the materialized views. It is recommended that the user review the generated SQL script before attempting to execute it.

The filename specification requires the same security model as described in the GENERATE_MVIEW_REPORT routine.

Example 16–1 Summary Advisor Sample Output

```
/*****************************************************************************
**  Oracle Summary Advisor 9i - Production
**
**  Summary Advisor Recommendation Script
*****************************************************************************/
/*****************************************************************************
**  Recommendations for run ID #9999
*****************************************************************************/
/*****************************************************************************
**  Rank 1
**  Storage 0 bytes
**  Gain 0.00%
**  Benefit Ratio 0.00
**  SELECT COUNT(*), AVG(dollar_cost)
**      FROM sales
**      GROUP BY store_key
*****************************************************************************/

CREATE MATERIALIZED VIEW mv_id_9999_rank_1
  TABLESPACE user
  BUILD IMMEDIATE
  REFRESH COMPLETE
  ENABLE QUERY REWRITE AS
    SELECT COUNT(*),AVG(dollar_cost) FROM sales GROUP BY store_key;

/*****************************************************************************

**  Rank 2
**  Storage 6,000 bytes
**  Gain 13.00%
**  Benefit Ratio 874.00
*****************************************************************************/

DROP MATERIALIZED VIEW sh.mview_fact_01;

/*****************************************************************************

**  Rank 3
**  Storage 6,000 bytes
**  Gain 76.00%
**  Benefit Ratio 8,744.00
**
**  SELECT COUNT(*), MAX(dollar_cost), MIN(dollar_cost)
**      FROM sh.sales
**      WHERE store_key IN (10, 23)
**        AND unit_sales > 5000
**      GROUP BY store_key, promotion_key
*****************************************************************************/

CREATE MATERIALIZED VIEW mv_id_9999_rank_3
  TABLESPACE user
  BUILD IMMEDIATE
  REFRESH COMPLETE
  ENABLE QUERY REWRITE AS
    SELECT COUNT(*), MAX(dollar_cost), MIN(dollar_cost) FROM sh.sales
    WHERE store_key IN (10,23) AND unit_sales > 5000 GROUP BY
       store_key, promotion_key;
```

Summary Data Report

A Summary Data Report offers you data about workloads and filters, and then generates recommendations. The report format is HTML and the contents are

- Activity Journal Details

  This section describes the recorded data. A journal is simply a mechanism to permit the Advisor to record any interesting event that may occur during processing. During processing, many decisions can made by the Advisor that are not necessarily visible to you. The journal enables you to see the internal processes and steps taken by the Summary Advisor. It contains work-in-progress messages, debugging messages and error messages for a particular Advisor element

- Activity Log Details

  This section describes the various Advisor activities that have been executed by the current user. Activities include workload filter maintenance, workload collections and analysis operations

- Materialized View Recommendations

  This section contains detail information regarding Advisor analysis sessions. It presents various recommendations on the creation of new materialized views as well as the removal of inappropriate or expensive materialized views

- Materialized View Usage

  This section describes the Advisor's results from an evaluation of existing materialized views

- Workload Collection Details

  The workload report lists the details of each SQL query for the current user's workload collections. The report is arranged by table references

- Workload Filter Details

  The workload filter report lists details of workload filters for the current user

- Workload Query Details

  This report contains the actual SQL queries for the current user's workload collections. Each query can be linked back to an entry in the Workload report

PL/SQL Interface Syntax

```
PROCEDURE GENERATE_MVIEW_REPORT
   (file_name IN VARCHAR2,
    id        IN NUMBER,
    flags     IN NUMBER)
```

Parameters

- file_name

  A valid output file specification. Note, the Oracle9*i* restricts file access within Oracle Stored Procedures. This means that file locations and names must adhere to the known file permissions in the Policy Table. See the Security and Performance section of the *Oracle9i Java Developer's Guide* for more information on file permissions.

- id

  The Advisor ID number used to collect or analyze data. `NULL` indicates all data for the requested section.

- flags

  Report flags to indicate required detail sections. Multiple sections can be selected by referencing the following constants.

  `RPT_ALL`

  `RPT_ACTIVITY`

  `RPT_JOURNAL`

  `RPT_RECOMMENDATION`

  `RPT_USAGE`

  `RPT_WORKLOAD_DETAIL`

  `RPT_WORKLOAD_FILTER`

  `RPT_WORKLOAD_QUERY`

Because of the Oracle security model, report output file directories must be granted read and write permission prior to executing this call. The call is described in the the *Oracle9i Java Developer's Guide* and is as follows:

```
CALL DBMS_JAVA.GRANT_PERMISSION('Oracle-user-goes-here',
  'java.io.FilePermission', 'directory-spec-goes-here/*', 'read, write');
```

Below is a example of how to call this report

```
CALL DBMS_OLAP.GENERATE_MVIEW_REPORT(
    '/usr/mydev/myname/report.html', 0, DBMS_OLAP.RPT_ALL);
```

This produces the HTML file `/usr/mydev/myname/report.html`. In this example, `report.html` is the Table of Contents for the report. It will contain links to each section of the report, which are found in external files with names derived from the original filename. Because no ID was specified for the second parameter, all data for the current user will be reported. If, for example, you want only a report on a particular recommendation run, then that run ID should be passed into the call. The report can generate the following HTML files:

- `xxxx.html`

  Table of Contents
- `xxxx_log.html`

  Activity Section
- `xxxx_jou.html`

  Journal Section
- `xxxx_fil.html`

  Workload Filter Section
- `xxxx_wrk.html`

  Workload Section
- `xxxx_rec.html`

  Materialized View Recommendation Section
- `xxxx_usa.html`

  Materialized View Usage Section

`xxxx` is the filename portion of the user-supplied file specification.

All files appear in the same directory, which is the one you specify.

When Recommendations are no Longer Required

Every time the Summary Advisor is run, a new set of recommendations is created. When they are no longer required, they should be removed using the procedure `PURGE_RESULTS`. You can remove all results or those for a specific run.

DBMS_OLAP.PURGE_RESULTS Procedure

Table 16–13 DBMS_OLAP.PURGE_RESULTS Procedure Parameters

Parameter	Datatype	Description
run_id	NUMBER	An ID used to identify the results to delete

```
CALL DBMS_OLAP.PURGE_RESULTS (DBMS_OLAP.RUNID_ALL);
```

Stopping the Recommendation Process

If the Summary Advisor takes too long to make its recommendations using the procedure RECOMMEND_MVIEW_STRATEGY, you can stop it by calling the procedure SET_CANCELLED and passing in the run_id for this recommendation process.

DBMS_OLAP.SET_CANCELLED Procedure

Table 16–14 DBMS_OLAP.SET_CANCELLED Procedure Parameters

Parameter	Datatype	Description
run_id	NUMBER	Id that uniquely identifies an advisor analysis operation. This call can be used to cancel a long running workload collection as well as an Advisor analysis session

Sample Sessions

Here are some complete examples of how to use the Summary Advisor.

```
REM===============================================================
REM Setup for demos
REM===============================================================
CONNECT system/manager
GRANT SELECT ON mview_recommendations to sh;
GRANT SELECT ON mview_workload to sh;
GRANT SELECT ON mview_filter to sh;
DISCONNECT
```

```
REM***************************************************************
REM * Demo 1: Materialized View Recommendation With User Workload*
REM***************************************************************
REM===============================================================
REM Step 1. Define user workload table and add artificial workload queries.
REM===============================================================
CONNECT sh/sh
CREATE TABLE user_workload(
  query         VARCHAR2(40),
  owner         VARCHAR2(40),
  application   VARCHAR2(30),
  frequency     NUMBER,
  lastuse       DATE,
  priority      NUMBER,
  responsetime  NUMBER,
  resultsize    NUMBER
)
/
INSERT INTO user_workload values
(
  'SELECT SUM(s.quantity_sold)
   FROM sales s, products p
   WHERE s.prod_id = p.prod_id and p.prod_category = ''Boys''
   GROUP BY p.prod_category',  'SH', 'app1', 10, NULL, 5, NULL, NULL
)
/
INSERT INTO user_workload values
(
  'SELECT SUM(s.amount)
   FROM sales s, products p
   WHERE s.prod_id = p.prod_id AND
     p.prod_category = ''Girls''
   GROUP BY p.prod_category',
  'SH', 'app1', 10, NULL, 6, NULL, NULL
)
/
INSERT INTO user_workload values
(
  'SELECT SUM(quantity_sold)
   FROM sales s, products p
   WHERE s.prod_id = p.prod_id and
     p.prod_category = ''Men''
   GROUP BY p.prod_category
  ',
  'SH', 'app1', 11, NULL, 3, NULL, NULL
)
/
INSERT INTO user_workload VALUES
(
  'SELECT SUM(quantity_sold)
   FROM sales s, products p
   WHERE s.prod_id = p.prod_id and
     p.prod_category in (''Women'', ''Men'')
   GROUP BY p.prod_category  ', 'SH', 'app1', 1, NULL, 8, NULL, NULL
)
/

REM===============================================================
REM Step 2. Create a new identifier to identify a new collection in the
REM         internal repository and load the user-defined workload into the
REM         workload collection without filtering the workload.
REM
=================================================================
VARIABLE WORKLOAD_ID NUMBER;
EXECUTE DBMS_OLAP.CREATE_ID(:workload_id);
EXECUTE DBMS_OLAP.LOAD_WORKLOAD_USER(:workload_id,\
   DBMS_OLAP.WORKLOAD_NEW,\
   DBMS_OLAP.FILTER_NONE, 'SH', 'USER_WORKLOAD');
SELECT COUNT(*) FROM SYSTEM.MVIEW_WORKLOAD
   WHERE workloadid = :workload_id;

REM================================================================
REM Step 3. Create a new identifier to identify a new filter object. Add
REM         two filter items such that the filter can filter out workload
REM         queries with priority >= 5 and frequency <= 10.
REM=================================================================
VARIABLE filter_id NUMBER;
EXECUTE DBMS_OLAP.CREATE_ID(:filter_id);
EXECUTE DBMS_OLAP.ADD_FILTER_ITEM(:filter_id, 'PRIORITY',
   NULL, 5, NULL, NULL, NULL);
EXECUTE DBMS_OLAP.ADD_FILTER_ITEM(:filter_id, 'FREQUENCY',   NULL,
   NULL, 10, NULL, NULL);
SELECT COUNT(*) FROM SYSTEM.MVIEW_FILTER
WHERE filterid = :filter_id;

REM=================================================================
REM Step 4. Recommend materialized views with part of the previous workload
REM         collection that satisfy the filter conditions. Create a new
REM         identifier to identify the recommendation output.
REM===============================================================
VARIABLE RUN_ID NUMBER;
EXECUTE DBMS_OLAP.CREATE_ID(:run_id);
EXECUTE DBMS_OLAP.RECOMMEND_MVIEW_STRATEGY(:run_id, :workload_id, :filter_id,
100000, 100, NULL, NULL);
SELECT COUNT(*) FROM SYSTEM.MVIEW_RECOMMENDATIONS;

REM===============================================================
REM Step 5. Generate HTML reports on the output.
REM===============================================================
EXECUTE DBMS_OLAP.GENERATE_MVIEW_REPORT('/tmp/output1.html', :run_id, DBMS_
OLAP.RPT_RECOMMENDATION);

REM================================================================
REM Step 6. Cleanup current output, filter and workload collection
REM         FROM the internal repository, truncate the user workload table
REM         for new user workloads.
REM================================================================
EXECUTE DBMS_OLAP.PURGE_RESULTS(:run_id);
EXECUTE DBMS_OLAP.PURGE_FILTER(:filter_id);
EXECUTE DBMS_OLAP.PURGE_WORKLOAD(:workload_id);
SELECT COUNT(*) FROM SYSTEM.MVIEW_WORKLOAD
   WHERE workloadid = :WORKLOAD_ID;
TRUNCATE TABLE user_workload;

DROP TABLE user_workload;
DISCONNECT

REM***************************************************************
REM * Demo 2: Materialized View Recommendation With SQL Cache.  *
REM***************************************************************
CONNECT sh/sh

REM===============================================================
REM Step 1. Run some applications or some SQL queries, so that the
REM         Oracle SQL Cache is populated with target queries.
REM===============================================================
REM Clear Pool of SQL queries

ALTER SYSTEM FLUSH SHARED_POOL;

SELECT SUM(s.quantity_sold)
FROM sales s, products p
WHERE s.prod_id = p.prod_id
 GROUP BY p.prod_category;
```

```
SELECT SUM(s.amount)
FROM sales s, products p
WHERE s.prod_id = p.prod_id
GROUP BY p.prod_category;

SELECT t.calendar_month_desc, SUM(s.amount) AS dollars
FROM sales s, times t
WHERE s.time_id = t.time_id
GROUP BY t.calendar_month_desc;

SELECT t.calendar_month_desc, SUM(s.amount) AS dollars
FROM sales s, times t
WHERE s.time_id = t.time_id
GROUP BY t.calendar_month_desc;

REM===============================================================
REM Step 2. Create a new identifier to identify a new collection in the
REM         internal repository and grab a snapshot of the Oracle SQL cache
REM         into the new collection.
REM===============================================================
EXECUTE DBMS_OLAP.CREATE_ID(:WORKLOAD_ID);
EXECUTE DBMS_OLAP.LOAD_WORKLOAD_CACHE(:WORKLOAD_ID,
   DBMS_OLAP.WORKLOAD_NEW, DBMS_OLAP.FILTER_NONE, NULL, 1);
SELECT COUNT(*) FROM SYSTEM.MVIEW_WORKLOAD
   WHERE workloadid = :WORKLOAD_ID;

REM===============================================================
REM Step 3. Recommend materialized views with all of the workload workload
REM         and no filtering.
REM================================================================
EXECUTE DBMS_OLAP.RECOMMEND_MVIEW_STRATEGY(:run_id, :workload_id, DBMS_
OLAP.FILTER_NONE, 10000000, 100,  NULL, NULL);
SELECT COUNT(*) FROM SYSTEM.MVIEW_RECOMMENDATIONS;

REM==============================================================
REM Step 4. Generate HTML reports on the output.
REM===============================================================
EXECUTE DBMS_OLAP.GENERATE_MVIEW_REPORT('/tmp/output2.html', :run_id,
   DBMS_OLAP.RPT_RECOMMENDATION);

REM===============================================================
REM Step 5. Evaluate materialized views.
REM===============================================================
EXECUTE DBMS_OLAP.CREATE_ID(:run_id);
EXECUTE DBMS_OLAP.EVALUATE_MVIEW_STRATEGY(:run_id, workload_id, DBMS_
OLAP.FILTER_NONE);
REM===============================================================
REM Step 5. Cleanup current output, and workload collection
REM         FROM the internal repository.
REM================================================================
EXECUTE DBMS_OLAP.PURGE_RESULTS(:run_id);
EXECUTE DBMS_OLAP.PURGE_WORKLOAD(:workload_id);
DISCONNECT

REM================================================================
REM Cleanup for demos.
REM================================================================
CONNECT system/manager
REVOKE SELECT ON MVIEW_RECOMMENDATIONS FROM sh;
REVOKE SELECT ON MVIEW_WORKLOAD FROM sh;
REVOKE SELECT ON MVIEW_FILTER FROM sh;
DISCONNECT
```

Estimating Materialized View Size

A materialized view occupies storage space in the database, so it is helpful to know how much space will be required before it is created. Rather than guess or wait until it has been created and then discover that insufficient space is available in the tablespace, use the procedure ESTIMATE_MVIEW_SIZE. Calling this procedure instantly returns an estimate of the size in bytes for the materialized view. Table 16–15 lists the parameters to this procedure.

ESTIMATE_MVIEW_SIZE Parameters

Table 16–15 ESTIMATE_MVIEW_SIZE Procedure Parameters

Parameter	Description
stmt_id	Arbitrary string used to identify the statement in an EXPLAIN PLAN.
select_clause	The SELECT statement to be analyzed.
num_rows	Estimated cardinality.
num_bytes	Estimated number of bytes.

ESTIMATE_SUMMARY_SIZE returns:

- The number of rows it expects in the materialized view
- The size of the materialized view in bytes

In the example shown below, the query specified in the materialized view is passed into the ESTIMATE_SUMMARY_SIZE procedure. Note that the SQL statement is passed in without a semicolon at the end.

```
DBMS_OLAP.ESTIMATE_SUMMARY_SIZE ('simple_store',
   'SELECT  product_key1, product_key2,
    SUM(dollar_sales) AS sum_dollar_sales,
    SUM(unit_sales) AS sum_unit_sales,
    SUM(dollar_cost) AS sum_dollar_cost,
    SUM(customer_count) AS no_of_customers
    FROM fact GROUP BY product_key1, product_key2', no_of_rows, mv_size );
```

The procedure returns two values: an estimate for the number of rows, and the size of the materialized view in bytes, as shown below.

```
No of Rows: 17284
Size of Materialized view (bytes): 2281488
```

Is a Materialized View Being Used?

One of the major administrative problems with materialized views is knowing whether they are being used. Some materialized views might be in regular use. Others could have been created for a one-time problem that has now been resolved. However, the users who requested this level of analysis might never have told you that it was no longer required, so the materialized views remain in the database occupying storage space and possibly being regularly refreshed.

If a workload is available, then it can advise you which materialized views are in use. The workload will report only on materialized views that were used while it was collecting statistics. Therefore, if too small a window is chosen, not all the materialized views that are in use will be reported. To obtain the information, the procedure EVALUATE_MVIEW_STRATEGY is called. It analyzes the data and then the results can be viewed through the SYSTEM_MVIEW_EVALUATIONS view.

DBMS_OLAP.EVALUATE_MVIEW_STRATEGY Procedure

Table 16–16 DBMS_OLAP.EVALUATE_MVIEW_STRATEGY Procedure Parameters

Parameter	Datatype	Description
`run_id`	`NUMBER`	The Advisor-assigned id for the current session
`workload_id`	`NUMBER`	An optional workload id that maps to a user-supplied workload
`filter_id`	`NUMBER`	The optional filter id is used to identify a filter against the target workload

In the example below, the utilization of materialized views is analyzed and the results are displayed.

```
DBMS_OLAP.EVALUATE_MVIEW_STRATEGY(:run_id, NULL, DBMS_OLAP.FILTER_NONE);
```

Shown below is a sample output obtained by querying the view `SYSTEM.MVIEW_EVALUATIONS`, which provides the following information:

- Materialized view owner and name
- Rank of this materialized view in descending benefit-to-cost ratio
- Size of the materialized view in bytes
- The number of times the materialized view appears in the workload
- The cumulative benefit (calculated each time the materialized view is used)
- The benefit-to-cost ratio (calculated as the incremental improvement in performance to the size of the materialized view)

```
MVIEW_OWNER MVIEW_NAME           RANK   SIZE FREQ CUMULATIVE    BENEFIT
----------- ------------------- ----- ------ ---- ---------- ----------
GROCERY     STORE_MIN_SUM           1    340    1       9001 26.4735294
GROCERY     STORE_MAX_SUM           2    380    1       9001 23.6868421
GROCERY     STORE_STDCNT_SUM        3   3120    1 3000.38333 .961661325
GROCERY     QTR_STORE_PROMO_SUM     4 196020    2          0          0
GROCERY     STORE_SALES_SUM         5    340    1          0          0
GROCERY     STORE_SUM               6     21   10          0          0
```

Part V
Warehouse Performance

This section deals with ways to improve your data warehouse's performance, and contains the following chapters:

17 Schema Modeling Techniques

The following topics provide information about schemas in a data warehouse:

- Schemas in Data Warehouses
- Optimizing Star Queries

Schemas in Data Warehouses

A **schema** is a collection of database objects, including tables, views, indexes, and synonyms.

There is a variety of ways of arranging schema objects in the schema models designed for data warehousing. The most common data-warehouse schema model is a star schema. For this reason, the `Sales History` schema (the basis for most of the examples in this book) uses a star schema. However, a significant but smaller number of data warehouses use third normal form (3NF) schemas, or other schemas that are more highly normalized than star schemas. These 3NF data warehouses are typically very large data warehouses, which are used primarily for loading data, feeding data marts, and executing longer-running queries.

Some features of the Oracle9*i* database, such as the **star transformation** feature described in this chapter, are specific to star schemas. However, the vast majority of Oracle's data warehousing features are equally applicable to both star schemas and other schemas.

Star Schemas

The **star schema** is the simplest data warehouse schema. It is called a star schema because the entity-relationship diagram of this schema resembles a star, with points radiating from a central table. The center of the star consists of one or more fact tables and the points of the star are the dimension tables.

A star schema is characterized by one or more very large **fact** tables that contain the primary information in the data warehouse and a number of much smaller **dimension** tables (or **lookup** tables), each of which contains information about the entries for a particular attribute in the fact table.

A **star query** is a join between a fact table and a number of dimension tables. Each dimension table is joined to the fact table using a primary key to foreign key join, but the dimension tables are not joined to each other.

The cost-based optimizer recognizes star queries and generates efficient execution plans for them. Star queries are not recognized by the rule-based optimizer.

A typical fact table contains **keys** and **measures**. For example, in the `Sales History` schema, the fact table, `sales`, contain the measures `quantity_sold`, `amount`, and `cost`, and the keys `cust_id`, `time_id`, `prod_id`, `channel_id`, and `promo_id`. The dimension tables are `customers`, `times`, `products`, `channels`, and `promotions`. The `product` dimension table, for example, contains information about each product number that appears in the fact table.

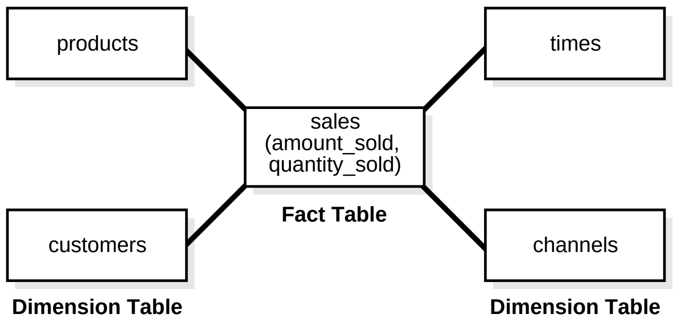
A **star join** is a primary key to foreign key join of the dimension tables to a fact table.

The main advantages of star schemas are that they:

- Provide a direct and intuitive mapping between the business entities being analyzed by end users and the schema design.
- Provide highly optimized performance for typical data warehouse queries.

Figure 17–1 presents a graphical representation of a star schema.

Figure 17–1 Star Schema

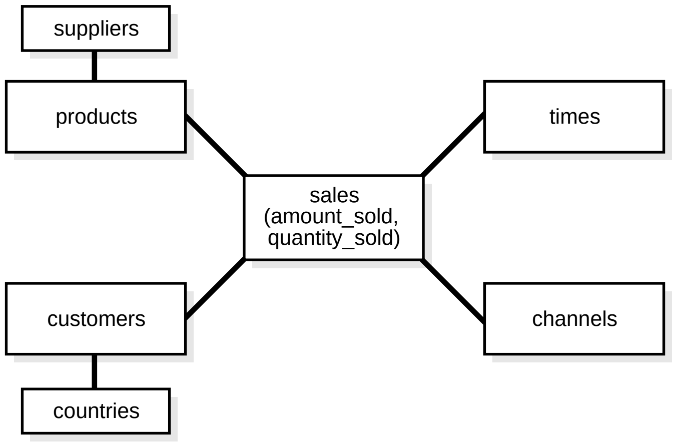


Snowflake Schemas

The snowflake schema is a more complex data warehouse model than a star schema, and is a type of star schema. It is called a snowflake schema because the diagram of the schema resembles a snowflake.

Snowflake schemas normalize dimensions to eliminate redundancy. That is, the dimension data has been grouped into multiple tables instead of one large table. For example, a product dimension table in a star schema might be normalized into a `products` table, a `product_category` table, and a `product_manufacturer` table in a snowflake schema. While this saves space, it increases the number of dimension tables and requires more foreign key joins. The result is more complex queries and reduced query performance. Figure 17–2 presents a graphical representation of a snowflake schema.

Figure 17–2 Snowflake Schema



Note: Oracle Corporation recommends you choose a star schema over a snowflake schema unless you have a clear reason not to.

Optimizing Star Queries

You should consider the following when using star queries:

- Tuning Star Queries
- Using Star Transformation

Tuning Star Queries

To get the best possible performance for star queries, it is important to follow some basic guidelines:

- A bitmap index should be built on each of the foreign key columns of the fact table or tables.
- The initialization parameter `STAR_TRANSFORMATION_ENABLED` should be set to `TRUE`. This enables an important optimizer feature for star-queries. It is set to `FALSE` by default for backwards-compatibility.
- The cost-based optimizer should be used. This does not apply solely to star schemas: all data warehouses should always use the cost-based optimizer.

When a data warehouse satisfies these conditions, the majority of the star queries running in the data warehouse will use a query execution strategy known as the star transformation. The star transformation provides very efficient query performance for star queries.

Using Star Transformation

The star transformation is a powerful optimization technique that relies upon implicitly rewriting (or transforming) the SQL of the original star query. The end user never needs to know any of the details about the star transformation. Oracle's cost-based optimizer automatically chooses the star transformation where appropriate.

The star transformation is a cost-based query transformation aimed at executing star queries efficiently. Oracle processes a star query using two basic phases. The first phase retrieves exactly the necessary rows from the fact table (the **result set**). Because this retrieval utilizes bitmap indexes, it is very efficient. The second phase joins this result set to the dimension tables. An example of an end user query is: "What were the sales and profits for the grocery department of stores in the west and southwest sales districts over the last three quarters?" This is a simple star query.

Note: Bitmap indexes are available only if you have purchased the Oracle9*i* Enterprise Edition. In Oracle9*i* Standard Edition, bitmap indexes and star transformation are not available.

Star Transformation with a Bitmap Index

A prerequisite of the star transformation is that there be a single-column bitmap index on every join column of the fact table. These join columns include all foreign key columns.

For example, the sales table of the `Sales History` schema has bitmap indexes on the `time_id`, `channel_id`, `cust_id`, `prod_id`, and `promo_id` columns.

Consider the following star query:

```
SELECT ch.channel_class, c.cust_city, t.calendar_quarter_desc,
   SUM(s.amount_sold) sales_amount
FROM sales s, times t, customers c, channels ch
WHERE s.time_id = t.time_id
AND   s.cust_id = c.cust_id
AND   s.channel_id = ch.channel_id
AND   c.cust_state_province = 'CA'
AND   ch.channel_desc in ('Internet','Catalog')
AND   t.calendar_quarter_desc IN ('1999-Q1','1999-Q2')
GROUP BY ch.channel_class, c.cust_city, t.calendar_quarter_desc;
```

Oracle processes this query in two phases. In the first phase, Oracle uses the bitmap indexes on the foreign key columns of the fact table to identify and retrieve only the necessary rows from the fact table. That is, Oracle will retrieve the result set from the fact table using essentially the following query:

```
SELECT ... FROM sales
WHERE time_id IN
  (SELECT time_id FROM times
   WHERE calendar_quarter_desc IN('1999-Q1','1999-Q2'))
   AND cust_id IN
  (SELECT cust_id FROM customers WHERE cust_state_province='CA')
   AND channel_id IN
  (SELECT channel_id FROM channels WHERE channel_desc IN('Internet','Catalog'));
```

This is the transformation step of the algorithm, because the original star query has been transformed into this subquery representation. This method of accessing the fact table leverages the strengths of Oracle's bitmap indexes. Intuitively, bitmap indexes provide a set-based processing scheme within a relational database. Oracle has implemented very fast methods for doing set operations such as AND (an intersection in standard set-based terminology), OR (a set-based union), MINUS, and COUNT.

In this star query, a bitmap index on time_id is used to identify the set of all rows in the fact table corresponding to sales in 1999-Q1. This set is represented as a bitmap (a string of 1's and 0's that indicates which rows of the fact table are members of the set).

A similar bitmap is retrieved for the fact table rows corresponding to the sale from 1999-Q2. The bitmap OR operation is used to combine this set of Q1 sales with the set of Q2 sales.

Additional set operations will be done for the customer dimension and the product dimension. At this point in the star query processing, there are three bitmaps. Each bitmap corresponds to a separate dimension table, and each bitmap represents the set of rows of the fact table that satisfy that individual dimension's constraints.

These three bitmaps are combined into a single bitmap using the bitmap AND operation. This final bitmap represents the set of rows in the fact table that satisfy all of the constraints on the dimension table. This is the result set, the exact set of rows from the fact table needed to evaluate the query. Note that none of the actual data in the fact table has been accessed. All of these operations rely solely on the bitmap indexes and the dimension tables. Because of the bitmap indexes' compressed data representations, the bitmap set-based operations are extremely efficient.

Once the result set is identified, the bitmap is used to access the actual data from the sales table. Only those rows that are required for the end user's query are retrieved from the fact table. At this point, Oracle has effectively joined all of the dimension tables to the fact table using bitmap indexes. This technique provides excellent performance because Oracle is joining all of the dimension tables to the fact table with one logical join operation, rather than joining each dimension table to the fact table independently.

The second phase of this query is to join these rows from the fact table (the result set) to the dimension tables. Oracle will use the most efficient method for accessing and joining the dimension tables. Many dimension are very small, and table scans are typically the most efficient access method for these dimension tables. For large dimension tables, table scans may not be the most efficient access method. In the example above, a bitmap index on `product.department` can be used to quickly identify all of those products in the grocery department. Oracle's cost-based optimizer automatically determines which access method is most appropriate for a given dimension table, based upon the cost-based optimizer's knowledge about the sizes and data distributions of each dimension table.

The specific join method (as well as indexing method) for each dimension table will likewise be intelligently determined by the cost-based optimizer. A hash join is often the most efficient algorithm for joining the dimension tables. The final answer is returned to the user once all of the dimension tables have been joined. The query technique of retrieving only the matching rows from one table and then joining to another table is commonly known as a semi-join.

Execution Plan for a Star Transformation with a Bitmap Index

The following typical execution plan might result from "Star Transformation with a Bitmap Index" on page 17-5:

```
SELECT STATEMENT
 SORT GROUP BY
  HASH JOIN
   TABLE ACCESS FULL                          CHANNELS
   HASH JOIN
    TABLE ACCESS FULL                         CUSTOMERS
```

```
HASH JOIN
 TABLE ACCESS FULL                        TIMES
 PARTITION RANGE ITERATOR
  TABLE ACCESS BY LOCAL INDEX ROWID       SALES
   BITMAP CONVERSION TO ROWIDS
    BITMAP AND
     BITMAP MERGE
      BITMAP KEY ITERATION
       BUFFER SORT
        TABLE ACCESS FULL                 CUSTOMERS
       BITMAP INDEX RANGE SCAN            SALES_CUST_BIX
     BITMAP MERGE
      BITMAP KEY ITERATION
       BUFFER SORT
        TABLE ACCESS FULL                 CHANNELS
       BITMAP INDEX RANGE SCAN            SALES_CHANNEL_BIX
     BITMAP MERGE
      BITMAP KEY ITERATION
       BUFFER SORT
        TABLE ACCESS FULL                 TIMES
       BITMAP INDEX RANGE SCAN            SALES_TIME_BIX
```

In this plan, the fact table is accessed through a bitmap access path based on a bitmap AND, of three merged bitmaps. The three bitmaps are generated by the BITMAP MERGE row source being fed bitmaps from row source trees underneath it. Each such row source tree consists of a BITMAP KEY ITERATION row source which fetches values from the subquery row source tree, which in this example is a full table access. For each such value, the BITMAP KEY ITERATION row source retrieves the bitmap from the bitmap index. After the relevant fact table rows have been retrieved using this access path, they are joined with the dimension tables and temporary tables to produce the answer to the query.

Star Transformation with a Bitmap Join Index

In addition to bitmap indexes, you can use a bitmap join index during star transformations. Assume you have the following additional index structure:

```
CREATE BITMAP INDEX sales_c_state_bjix
ON sales(customers.cust_state_province)
FROM sales, customers
WHERE sales.cust_id = customers.cust_id;
```

The processing of the same star query using the bitmap join index is similiar to the previous example. The only difference is that Oracle will utilize the join index, instead of a single-table bitmap index, to access the customer data in the first phase of the star query.

Execution Plan for a Star Transformation with a Bitmap Join Index

The following typical execution plan might result from "Execution Plan for a Star Transformation with a Bitmap Join Index" on page 17-9:

```
SELECT STATEMENT
 SORT GROUP BY
  HASH JOIN
   TABLE ACCESS FULL                           CHANNELS
   HASH JOIN
    TABLE ACCESS FULL                          CUSTOMERS
    HASH JOIN
     TABLE ACCESS FULL                         TIMES
     PARTITION RANGE ALL
      TABLE ACCESS BY LOCAL INDEX ROWID        SALES
       BITMAP CONVERSION TO ROWIDS
        BITMAP AND
         BITMAP INDEX SINGLE VALUE             SALES_C_STATE_BJIX
         BITMAP MERGE
          BITMAP KEY ITERATION
           BUFFER SORT
            TABLE ACCESS FULL                  CHANNELS
           BITMAP INDEX RANGE SCAN             SALES_CHANNEL_BIX
         BITMAP MERGE
          BITMAP KEY ITERATION
           BUFFER SORT
            TABLE ACCESS FULL                  TIMES
           BITMAP INDEX RANGE SCAN             SALES_TIME_BIX
```

The difference between this plan as compared to the previous one is that the inner part of the bitmap index scan for the `customer` dimension has no subselect. This is because the join predicate information on `customer.cust_state_province` can be satisfied with the bitmap join index `sales_c_state_bjix`.

How Oracle Chooses to Use Star Transformation

The star transformation is a cost-based transformation in the following sense. The optimizer generates and saves the best plan it can produce without the transformation. If the transformation is enabled, the optimizer then tries to apply it to the query and, if applicable, generates the best plan using the transformed query. Based on a comparison of the cost estimates between the best plans for the two versions of the query, the optimizer will then decide whether to use the best plan for the transformed or untransformed version.

If the query requires accessing a large percentage of the rows in the fact table, it might be better to use a full table scan and not use the transformations. However, if the constraining predicates on the dimension tables are sufficiently selective that only a small portion of the fact table needs to be retrieved, the plan based on the transformation will probably be superior.

Note that the optimizer generates a subquery for a dimension table only if it decides that it is reasonable to do so based on a number of criteria. There is no guarantee that subqueries will be generated for all dimension tables. The optimizer may also decide, based on the properties of the tables and the query, that the transformation does not merit being applied to a particular query. In this case the best regular plan will be used.

Star Transformation Restrictions

Star transformation is not supported for tables with any of the following characteristics:

- Queries with a table hint that is incompatible with a bitmap access path
- Queries that contain bind variables
- Tables with too few bitmap indexes. There must be a bitmap index on a fact table column for the optimizer to generate a subquery for it.
- Remote fact tables. However, remote dimension tables are allowed in the subqueries that are generated.
- Anti-joined tables
- Tables that are already used as a dimension table in a subquery
- Tables that are really unmerged views, which are not view partitions

The star transformation may not be chosen by the optimizer for the following cases:

- Tables that have a good single-table access path
- Tables that are too small for the transformation to be worthwhile

In addition, temporary tables will not be used by star transformation under the following conditions:

- The database is in read-only mode
- The star query is part of a transaction that is in serializable mode

18

SQL for Aggregation in Data Warehouses

This chapter discusses aggregation of SQL, a basic aspect of data warehousing. It contains these topics:

Overview of SQL for Aggregation in Data Warehouses

Aggregation is a fundamental part of data warehousing. To improve aggregation performance in your warehouse, Oracle provides the following extensions to the `GROUP BY` clause:

- `CUBE` and `ROLLUP` Extensions to the `GROUP BY` Clause
- The Three `GROUPING` Functions
- `GROUPING SETS` Expression

The `CUBE`, `ROLLUP`, and `GROUPING SETS` extensions to SQL make querying and reporting easier and faster. `ROLLUP` calculates aggregations such as `SUM`, `COUNT`, `MAX`, `MIN`, and `AVG` at increasing levels of aggregation, from the most detailed up to a grand total. `CUBE` is an extension similar to `ROLLUP`, enabling a single statement to calculate all possible combinations of aggregations. `CUBE` can generate the information needed in cross-tabulation reports with a single query.

`CUBE`, `ROLLUP`, and the `GROUPING SETS` extension let you specify exactly the groupings of interest in the `GROUP BY` clause. This allows efficient analysis across multiple dimensions without performing a `CUBE` operation. Computing a full cube creates a heavy processing load, so replacing cubes with grouping sets can significantly increase performance. `CUBE`, `ROLLUP`, and grouping sets produce a single result set that is equivalent to a `UNION ALL` of differently grouped rows.

To enhance performance, `CUBE`, `ROLLUP`, and `GROUPING SETS` can be parallelized: multiple processes can simultaneously execute all of these statements. These capabilities make aggregate calculations more efficient, thereby enhancing database performance, and scalability.

The three `GROUPING` functions help you identify the group each row belongs to and enable sorting subtotal rows and filtering results.

See Also: *Oracle9i SQL Reference* for further details

Analyzing Across Multiple Dimensions

One of the key concepts in decision support systems is multidimensional analysis: examining the enterprise from all necessary combinations of dimensions. We use the term **dimension** to mean any category used in specifying questions. Among the most commonly specified dimensions are time, geography, product, department, and distribution channel, but the potential dimensions are as endless as the varieties of enterprise activity. The events or entities associated with a particular set of dimension values are usually referred to as **facts**. The facts might be sales in units or local currency, profits, customer counts, production volumes, or anything else worth tracking.

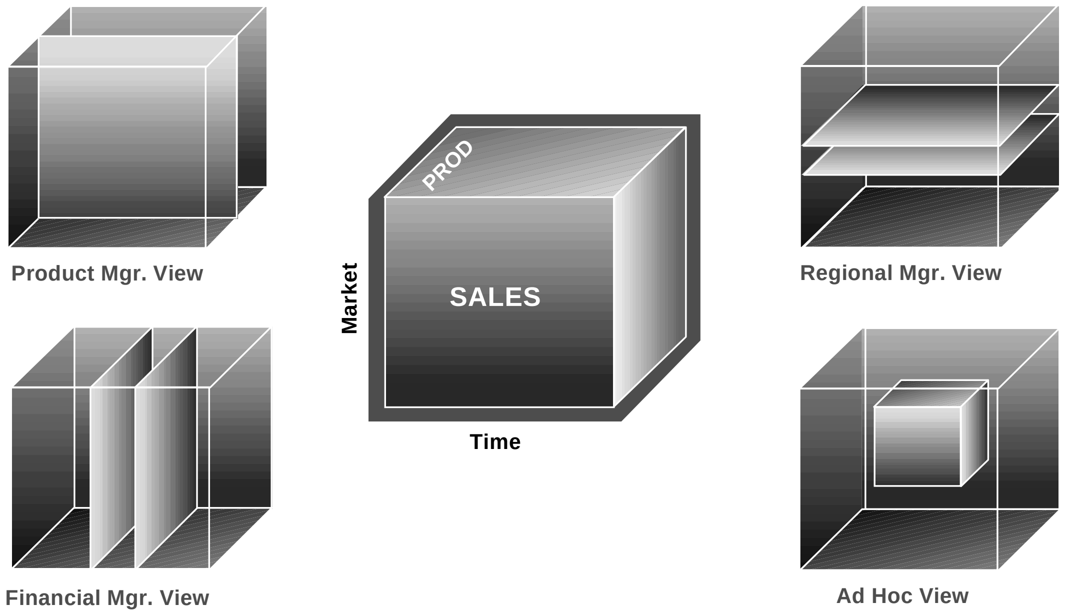
Here are some examples of multidimensional requests:

- Show total sales across all products at increasing aggregation levels for a geography dimension, from state to country to region, for 1999 and 2000.
- Create a cross-tabular analysis of our operations showing expenses by territory in South America for 1999 and 2000. Include all possible subtotals.
- List the top 10 sales representatives in Asia according to 2000 sales revenue for automotive products, and rank their commissions.

All the requests above involve multiple dimensions. Many multidimensional questions require aggregated data and comparisons of data sets, often across time, geography or budgets.

To visualize data that has many dimensions, analysts commonly use the analogy of a data cube, that is, a space where facts are stored at the intersection of *n* dimensions. Figure 18–1 shows a data cube and how it can be used differently by various groups. The cube stores sales data organized by the dimensions of `product`, `market`, and `time`. Note that this is only a metaphor: the actual data is physically stored in normal tables. The cube data consists of both detail and aggregated data.

Figure 18–1 Logical Cubes and Views by Different Users



You can retrieve **slices** of data from the cube. These correspond to cross-tabular reports such as the one shown in Table 18–1. Regional managers might study the data by comparing slices of the cube applicable to different markets. In contrast, product managers might compare slices that apply to different products. An ad hoc user might work with a wide variety of constraints, working in a subset cube.

Answering multidimensional questions often involves accessing and querying huge quantities of data, sometimes in millions of rows. Because the flood of detailed data generated by large organizations cannot be interpreted at the lowest level, aggregated views of the information are essential. Aggregations, such as sums and counts, across many dimensions are vital to multidimensional analyses. Therefore, analytical tasks require convenient and efficient data aggregation.

Optimized Performance

Not only multidimensional issues, but all types of processing can benefit from enhanced aggregation facilities. Transaction processing, financial and manufacturing systems—all of these generate large numbers of production reports needing substantial system resources. Improved efficiency when creating these reports will reduce system load. In fact, any computer process that aggregates data from details to higher levels will benefit from optimized aggregation performance.

Oracle9*i* extensions provide aggregation features and bring many benefits, including:

- Simplified programming requiring less SQL code for many tasks
- Quicker and more efficient query processing
- Reduced client processing loads and network traffic because aggregation work is shifted to servers
- Opportunities for caching aggregations because similar queries can leverage existing work

An Aggregate Scenario

To illustrate the use of the `GROUP BY` extension, this chapter uses the `Sales History` data of the common schema. All the examples refer to data from this scenario. The hypothetical company has sales across the world and tracks sales by both dollars and quantities information. Because there are many rows of data, the queries shown here typically have tight constraints on their `WHERE` clauses to limit the results to a small number of rows.

Example 18–1 Simple Cross-Tabular Report, with Subtotals

Example 18–1 is a sample cross-tabular report showing the total sales by `country_id` and `channel_desc` for the US and UK through the Internet and Direct Sales in September 2000:

Table 18–1 Simple Cross-Tabular Report, with Subtotals Shaded

Country

Channel

	UK	**US**	**Total**
Direct Sales	1,378,126	2,835,557	4,213,683
Internet	911,739	1,732,240	2,643,979
Total	2,289,865	4,567,797	6,857,662

Consider that even a simple report like Example 18–1, with just nine values in its grid, generates four subtotals and a grand total. The subtotals are the shaded numbers. Half of the values needed for this report would not be calculated with a query that requested `SUM(amount_sold)` and did a `GROUP BY(channel_desc, country_id)`. To get the higher-level aggregates would require additional queries. Database commands that offer improved calculation of subtotals bring major benefits to querying, reporting, and analytical operations.

```
SELECT channel_desc,  country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc='2000-09'
   AND country_id IN ('UK', 'US')
GROUP BY CUBE(channel_desc, country_id);

CHANNEL_DESC         CO SALES$
-------------------- -- --------------
Direct Sales         UK      1,378,126
Direct Sales         US      2,835,557
Direct Sales                 4,213,683
Internet             UK        911,739
Internet             US      1,732,240
Internet                     2,643,979
                     UK      2,289,865
                     US      4,567,797
                             6,857,662
```

Interpreting NULLs in Examples

`NULLs` returned by the `GROUP BY` extensions are not always the traditional null meaning value unknown. Instead, a `NULL` may indicate that its row is a subtotal. For instance, the first `NULL` value shown in Example 18–1 is in the `Calendar_month_desc` column. This `NULL` means that the row is a subtotal for "All Months" returned by this query for the `Direct Sales` channel, which is a subtotal for September and October 2000. To avoid introducing another non-value in the database system, these subtotal values are not given a special tag.

See "GROUPING Functions" on page 18-13 for details on how the `NULLs` representing subtotals are distinguished from `NULLs` stored in the data.

ROLLUP Extension to GROUP BY

ROLLUP enables a SELECT statement to calculate multiple levels of subtotals across a specified group of dimensions. It also calculates a grand total. ROLLUP is a simple extension to the GROUP BY clause, so its syntax is extremely easy to use. The ROLLUP extension is highly efficient, adding minimal overhead to a query.

The action of ROLLUP is straightforward: it creates subtotals that **roll up** from the most detailed level to a grand total, following a grouping list specified in the ROLLUP clause. ROLLUP takes as its argument an ordered list of grouping columns. First, it calculates the standard aggregate values specified in the GROUP BY clause. Then, it creates progressively higher-level subtotals, moving from right to left through the list of grouping columns. Finally, it creates a grand total.

ROLLUP creates subtotals at n+1 levels, where n is the number of grouping columns. For instance, if a query specifies ROLLUP on grouping columns of time, region, and department (n=3), the result set will include rows at four aggregation levels.

When to Use ROLLUP

Use the ROLLUP extension in tasks involving subtotals.

- It is very helpful for subtotaling along a hierarchical dimension such as time or geography. For instance, a query could specify a ROLLUP(y, m, day) or ROLLUP(country, state, city).
- For data warehouse administrators using summary tables, ROLLUP can simplify and speed up the maintenance of summary tables.

ROLLUP Syntax

ROLLUP appears in the GROUP BY clause in a SELECT statement. Its form is:

```
SELECT … GROUP BY ROLLUP(grouping_column_reference_list)
```

Example 18–2 ROLLUP Example

This example uses the data in the sales history store data, the same data as was used in Example 18–1. The ROLLUP is across three dimensions.

```
SELECT channel_desc, calendar_month_desc, country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY ROLLUP(channel_desc, calendar_month_desc, country_id);

CHANNEL_DESC         CALENDAR CO SALES$
-------------------- -------- -- --------------
Direct Sales         2000-09  UK      1,378,126
Direct Sales         2000-09  US      2,835,557
Direct Sales         2000-09          4,213,683
Direct Sales         2000-10  UK      1,388,051
Direct Sales         2000-10  US      2,908,706
Direct Sales         2000-10          4,296,757
Direct Sales                          8,510,440
Internet             2000-09  UK        911,739
Internet             2000-09  US      1,732,240
Internet             2000-09          2,643,979
Internet             2000-10  UK        876,571
Internet             2000-10  US      1,893,753
Internet             2000-10          2,770,324
Internet                              5,414,303
                                     13,924,743
```

Note that results do not always add due to rounding.

This query returns the following sets of rows:

- Regular aggregation rows that would be produced by `GROUP BY` without using `ROLLUP`
- First-level subtotals aggregating across `country_id` for each combination of `channel_desc` and `calendar_month`
- Second-level subtotals aggregating across `calendar_month_desc` and `country_id` for each `channel_desc` value
- A grand total row

Partial Rollup

You can also roll up so that only some of the sub-totals will be included. This **partial rollup** uses the following syntax:

```
GROUP BY expr1, ROLLUP(expr2, expr3);
```

In this case, the GROUP BY clause creates subtotals at (2+1=3) aggregation levels. That is, at level (expr1, expr2, expr3), (expr1, expr2), and (expr1).

Example 18–3 Partial ROLLUP Example

```
SELECT channel_desc, calendar_month_desc, country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY channel_desc, ROLLUP(calendar_month_desc, country_id);

CHANNEL_DESC         CALENDAR CO SALES$
-------------------- -------- -- --------------
Direct Sales         2000-09  UK      1,378,126
Direct Sales         2000-09  US      2,835,557
Direct Sales         2000-09          4,213,683
Direct Sales         2000-10  UK      1,388,051
Direct Sales         2000-10  US      2,908,706
Direct Sales         2000-10          4,296,757
Direct Sales                          8,510,440
Internet             2000-09  UK        911,739
Internet             2000-09  US      1,732,240
Internet             2000-09          2,643,979
Internet             2000-10  UK        876,571
Internet             2000-10  US      1,893,753
Internet             2000-10          2,770,324
Internet                              5,414,303
```

This query returns the following sets of rows:

- Regular aggregation rows that would be produced by GROUP BY without using ROLLUP
- First-level subtotals aggregating across country_id for each combination of channel_desc and calendar_month_desc
- Second-level subtotals aggregating across calendar_month_desc and country_id for each channel_desc value
- It does *not* produce a grand total row

CUBE Extension to GROUP BY

CUBE takes a specified set of grouping columns and creates subtotals for all of their possible combinations. In terms of multidimensional analysis, CUBE generates all the subtotals that could be calculated for a data cube with the specified dimensions. If you have specified CUBE(time, region, department), the result set will include all the values that would be included in an equivalent ROLLUP statement plus additional combinations. For instance, in Example 18–1, the departmental totals across regions (279,000 and 319,000) would not be calculated by a ROLLUP(time, region, department) clause, but they would be calculated by a CUBE(time, region, department) clause. If *n* columns are specified for a CUBE, there will be 2 to the *n* combinations of subtotals returned. Example 18–3 on page 18-9 gives an example of a three-dimension cube.

When to Use CUBE

Consider Using CUBE in any situation requiring cross-tabular reports. The data needed for cross-tabular reports can be generated with a single SELECT using CUBE. Like ROLLUP, CUBE can be helpful in generating summary tables. Note that population of summary tables is even faster if the CUBE query executes in parallel.

See Also: Chapter 21, "Using Parallel Execution" for information on parallel execution

CUBE is typically most suitable in queries that use columns from multiple dimensions rather than columns representing different levels of a single dimension. For instance, a commonly requested cross-tabulation might need subtotals for all the combinations of month, state, and product. These are three independent dimensions, and analysis of all possible subtotal combinations is commonplace. In contrast, a cross-tabulation showing all possible combinations of year, month, and day would have several values of limited interest, because there is a natural hierarchy in the time dimension. Subtotals such as profit by day of month summed across year would be unnecessary in most analyses. Relatively few users need to ask "What were the total sales for the 16th of each month across the year?" See "Hierarchy Handling in ROLLUP and CUBE" on page 18-28 for an example of handling rollup calculations efficiently.

CUBE Syntax

CUBE appears in the GROUP BY clause in a SELECT statement. Its form is:

```
SELECT …  GROUP BY CUBE (grouping_column_reference_list)
```

Example 18–4 CUBE Example

```
SELECT channel_desc, calendar_month_desc, country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY CUBE(channel_desc, calendar_month_desc, country_id);

CHANNEL_DESC         CALENDAR CO SALES$
-------------------- -------- -- --------------
Direct Sales         2000-09  UK      1,378,126
Direct Sales         2000-09  US      2,835,557
Direct Sales         2000-09          4,213,683
Direct Sales         2000-10  UK      1,388,051
Direct Sales         2000-10  US      2,908,706
Direct Sales         2000-10          4,296,757
Direct Sales                  UK      2,766,177
Direct Sales                  US      5,744,263
Direct Sales                          8,510,440
Internet             2000-09  UK        911,739
Internet             2000-09  US      1,732,240
Internet             2000-09          2,643,979
Internet             2000-10  UK        876,571
Internet             2000-10  US      1,893,753
Internet             2000-10          2,770,324
Internet                      UK      1,788,310
Internet                      US      3,625,993
Internet                              5,414,303
                     2000-09  UK      2,289,865
                     2000-09  US      4,567,797
                     2000-09          6,857,662
                     2000-10  UK      2,264,622
                     2000-10  US      4,802,459
                     2000-10          7,067,081
                              UK      4,554,487
                              US      9,370,256
                                     13,924,743
```

This query illustrates `CUBE` aggregation across three dimensions

Partial CUBE

Partial CUBE resembles partial ROLLUP in that you can limit it to certain dimensions and precede it with columns outside the CUBE operator. In this case, subtotals of all possible combinations are limited to the dimensions within the cube list (in parentheses), and they are combined with the preceding items in the GROUP BY list.

Partial CUBE Syntax

```
GROUP BY expr1, CUBE(expr2, expr3)
```

The above syntax example calculates 2*2, or 4, subtotals. That is:

- (expr1, expr2, expr3)
- (expr1, expr2)
- (expr1, expr3)
- (expr1)

Example 18–5 Partial CUBE Example

Using the sales database, you can issue the following statement:

```
SELECT channel_desc, calendar_month_desc, country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY channel_desc, CUBE(calendar_month_desc, country_id);

CHANNEL_DESC         CALENDAR CO SALES$
-------------------- -------- -- --------------
Direct Sales         2000-09  UK      1,378,126
Direct Sales         2000-09  US      2,835,557
Direct Sales         2000-09          4,213,683
Direct Sales         2000-10  UK      1,388,051
Direct Sales         2000-10  US      2,908,706
Direct Sales         2000-10          4,296,757
Direct Sales                  UK      2,766,177
Direct Sales                  US      5,744,263
Direct Sales                          8,510,440
```

```
Internet             2000-09  UK       911,739
Internet             2000-09  US     1,732,240
Internet             2000-09         2,643,979
Internet             2000-10  UK       876,571
Internet             2000-10  US     1,893,753
Internet             2000-10         2,770,324
Internet                      UK     1,788,310
Internet                      US     3,625,993
Internet                             5,414,303
```

Calculating Subtotals without CUBE

Just as for ROLLUP, multiple SELECT statements combined with UNION ALL statements could provide the same information gathered through CUBE. However, this might require many SELECT statements. For an n-dimensional cube, 2 to the *n* SELECT statements are needed. In the three-dimension example, this would mean issuing SELECT statements linked with UNION ALL. So many SELECT statements yield inefficient processing and very lengthy SQL.

Consider the impact of adding just one more dimension when calculating all possible combinations: the number of SELECT statements would double to 16. The more columns used in a CUBE clause, the greater the savings compared to the UNION ALL approach.

GROUPING Functions

Two challenges arise with the use of ROLLUP and CUBE. First, how can you programmatically determine which result set rows are subtotals, and how do you find the exact level of aggregation for a given subtotal? You often need to use subtotals in calculations such as percent-of-totals, so you need an easy way to determine which rows are the subtotals. Second, what happens if query results contain both stored NULL values and "NULL" values created by a ROLLUP or CUBE? How can you differentiate between the two?

GROUPING Function

GROUPING handles these problems. Using a single column as its argument, GROUPING returns 1 when it encounters a NULL value created by a ROLLUP or CUBE operation. That is, if the NULL indicates the row is a subtotal, GROUPING returns a 1. Any other type of value, including a stored NULL, returns a 0.

GROUPING Syntax

`GROUPING` appears in the selection list portion of a `SELECT` statement. Its form is:

```
SELECT …  [GROUPING(dimension_column)…]  …
  GROUP BY …    {CUBE | ROLLUP}  (dimension_column)
```

Example 18–6 GROUPING Example

This example uses `GROUPING` to create a set of mask columns for the result set shown in Example 18–3. The mask columns are easy to analyze programmatically.

```
SELECT channel_desc, calendar_month_desc, country_id,
   TO_CHAR(SUM(amount_sold), ’9,999,999,999’) SALES$,
   GROUPING(channel_desc) as Ch,
   GROUPING(calendar_month_desc) AS Mo,
   GROUPING(country_id) AS Co
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY ROLLUP(channel_desc, calendar_month_desc, country_id);

CHANNEL_DESC         CALENDAR CO SALES$                CH        MO        CO
-------------------- -------- -- -------------- --------- --------- ---------
Direct Sales         2000-09  UK      1,378,126         0         0         0
Direct Sales         2000-09  US      2,835,557         0         0         0
Direct Sales         2000-09          4,213,683         0         0         1
Direct Sales         2000-10  UK      1,388,051         0         0         0
Direct Sales         2000-10  US      2,908,706         0         0         0
Direct Sales         2000-10          4,296,757         0         0         1
Direct Sales                          8,510,440         0         1         1
Internet             2000-09  UK        911,739         0         0         0
Internet             2000-09  US      1,732,240         0         0         0
Internet             2000-09          2,643,979         0         0         1
Internet             2000-10  UK        876,571         0         0         0
Internet             2000-10  US      1,893,753         0         0         0
Internet             2000-10          2,770,324         0         0         1
Internet                              5,414,303         0         1         1
                                     13,924,743         1         1         1
```

A program can easily identify the detail rows above by a mask of "0 0 0" on the T, R, and D columns. The first level subtotal rows have a mask of "0 0 1", the second level subtotal rows have a mask of "0 1 1", and the overall total row has a mask of "1 1 1".

You can resolve ambiguity in result sets by using the GROUPING and other functions as shown in the code below.

Example 18–7 GROUPING Example

```
SELECT DECODE(GROUPING(channel_desc), 1, 'All Channels', channel_desc) AS
Channel,
    DECODE(GROUPING(country_id), 1, 'All Countries', country_id) AS Country,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc= '2000-09'
   AND country_id IN ('UK', 'US')
GROUP BY CUBE(channel_desc, country_id);

CHANNEL              COUNTRY       SALES$
-------------------- ------------- --------------
Direct Sales         UK                 1,378,126
Direct Sales         US                 2,835,557
Direct Sales         All Countries      4,213,683
Internet             UK                   911,739
Internet             US                 1,732,240
Internet             All Countries      2,643,979
All Channels         UK                 2,289,865
All Channels         US                 4,567,797
All Channels         All Countries      6,857,662
```

These results include text values clarifying which rows have aggregations.

Grouping function used to differentiate aggregate-based "NULL" from stored NULL values.

To understand the SQL statement above, note its first column specification, which handles the channel_desc column. In the first line of the SQL code above:

```
SELECT DECODE(GROUPING(channel_desc), 1, ’All Channels’, channel_desc)
  AS Channel,
```

The `channel_desc` value is determined with a `DECODE` function that contains a `GROUPING` function. The `GROUPING` function returns a 1 if a row value is an aggregate created by `ROLLUP` or `CUBE`, otherwise it returns a 0. The `DECODE` function then operates on the `GROUPING` function's results. It returns the text "All Channels" if it receives a 1 and the `channel_desc` value from the database if it receives a 0. Values from the database will be either a real value such as "Internet" or a stored `NULL`. The second column specification, displaying `country_id`, works the same way.

When to Use GROUPING

The `GROUPING` function is not only useful for identifying `NULL`s, it also enables sorting subtotal rows and filtering results. In Example 18–8, you retrieve a subset of the subtotals created by a `CUBE` and none of the base-level aggregations. The `HAVING` clause constrains columns that use `GROUPING` functions.

Example 18–8 GROUPING Example

```
SELECT channel_desc, calendar_month_desc, country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$,
   GROUPING(channel_desc) CH, GROUPING(calendar_month_desc)  MO,
GROUPING(country_id) CO
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY CUBE(channel_desc, calendar_month_desc, country_id)
HAVING
    (GROUPING(channel_desc)=1 AND GROUPING(calendar_month_desc)= 1 AND
      GROUPING(country_id)=1) OR
    (GROUPING(channel_desc)=1 AND GROUPING(calendar_month_desc)= 1) OR
    (GROUPING(country_id)=1 AND GROUPING(calendar_month_desc)= 1);

CHANNEL_DESC         C CO SALES$                CH        MO        CO
-------------------- - -- -------------- --------- --------- ---------
                       UK      4,554,487         1         1         0
                       US      9,370,256         1         1         0
Direct Sales                   8,510,440         0         1         1
Internet                       5,414,303         0         1         1
                              13,924,743         1         1         1
```

Compare the result set of Example 18–8 with that in Example 18–3 on page 18-9 to see how Example 18–8 is a precisely specified group: it contains only the yearly totals, regional totals aggregated over `time` and `department`, and the grand total.

GROUPING_ID Function

To find the GROUP BY level of a particular row, a query must return GROUPING function information for each of the GROUP BY columns. If we do this using the GROUPING function, every GROUP BY column requires another column using the GROUPING function. For instance, a four-column GROUP BY clause needs to be analyzed with four GROUPING functions. This is inconvenient to write in SQL and increases the number of columns required in the query. When you want to store the query result sets in tables, as with materialized views, the extra columns waste storage space.

To address these problems, Oracle9*i* introduces the GROUPING_ID function. GROUPING_ID returns a single number that enables you to determine the exact GROUP BY level. For each row, GROUPING_ID takes the set of 1's and 0's that would be generated if you used the appropriate GROUPING functions and concatenates them, forming a bit vector. The bit vector is treated as a binary number, and the number's base-10 value is returned by the GROUPING_ID function. For instance, if you group with the expression `CUBE(a, b)` the possible values are as shown in Table 18–2:

Table 18–2 GROUPING_ID Example for CUBE(a, b)

Aggregation Level	Bit Vector	GROUPING_ID
a, b	0 0	0
a	0 1	1
b	1 0	2
Grand Total	1 1	3

GROUPING_ID clearly distinguishes groupings created by grouping set specification, and it is very useful during refresh and rewrite of materialized views.

GROUP_ID Function

While the extensions to GROUP BY offer power and flexibility, they also allow complex result sets that can include duplicate groupings. The GROUP_ID function lets you distinguish among duplicate groupings. If there are multiple sets of rows calculated for a given level, GROUP_ID assigns the value of 0 to all the rows in the first set. All other sets of duplicate rows for a particular grouping are assigned higher values, starting with 1. For example, consider the following query, which generates a duplicate grouping:

Example 18–9 GROUP_ID Example

```
SELECT country_id, cust_state_province, SUM(amount_sold),
  GROUPING_ID(country_id, cust_state_province) GROUPING_ID, GROUP_ID()
FROM sales, customers, times
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   times.time_id= '30-OCT-00'
   AND country_id IN ('FR', 'ES')
GROUP BY GROUPING SETS (country_id, ROLLUP(country_id, cust_state_province));

CO CUST_STATE_PROVINCE     SUM(AMOUNT_SOLD) GROUPING_ID      GROUP_ID()
-- ---------------------------------------- --------------- ----------
ES Alicante                            8939               0          0
ES Almeria                              1053               0          0
ES Barcelona                            6312               0          0
ES Girona                              220                0          0
ES Malaga                               8137               0          0
ES Salamanca                             324               0          0
ES Valencia                             7588               0          0
FR Alsace                               5099               0          0
FR Aquitaine                           13183               0          0
FR Brittany                             3938               0          0
FR Centre                               2968               0          0
FR Ile-de-France                       16449               0          0
FR Languedoc-Roussillon                20228               0          0
FR Midi-Pyrenees                        2322               0          0
FR Pays de la Loire                     1096               0          0
FR Provence-Alpes-Cote d’Azur           1208               0          0
FR Rhtne-Alpes                          7637               0          0
                                      106701               3          0
ES                                     32573               1          0
FR                                     74128               1          0
ES                                     32573               1          1
FR                                     74128               1          1
```

The query above generates the following groupings: (country_id, cust_state_province), (country_id), (country_id), and (). Note that the grouping (country_id) is repeated twice. The syntax for GROUPING SETS is explained in "GROUPING SETS Expression" on page 18-19.

This function helps you filter out duplicate groupings from the result. For example, you can filter out duplicate (region) groupings from the above example by adding a HAVING clause condition GROUP_ID()=0 to the query.

GROUPING SETS Expression

You can selectively specify the set of groups that you want to create using a GROUPING SETS expression within a GROUP BY clause. This allows precise specification across multiple dimensions without computing the whole CUBE. For example, you can say:

```
SELECT channel_desc, calendar_month_desc, country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY GROUPING SETS((channel_desc, calendar_month_desc, country_id),
    (channel_desc, country_id), (calendar_month_desc, country_id));
```

Note that this statement uses composite columns, described in "Composite Columns" on page 18-21. This statement calculates aggregates over three groupings:

- (channel_desc, calendar_month_desc, country_id)
- (channel_desc, country_id)
- (calendar_month_desc, country_id)

Compare the above statement with the alternative below, which uses the CUBE operation and the GROUPING_ID function to return the desired rows:

```
SELECT channel_desc, calendar_month_desc, country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$,
   GROUPING_ID(channel_desc, calendar_month_desc, country_id)  gid
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY CUBE(channel_desc, calendar_month_desc, country_id)
HAVING GROUPING_ID(channel_desc, calendar_month_desc, country_id)=0
  OR GROUPING_ID(channel_desc, calendar_month_desc, country_id)=2
  OR GROUPING_ID(channel_desc, calendar_month_desc, country_id)=4;;
```

The above statement computes all the 8 (2 *2 *2) groupings, though only the above 3 groups are of interest to you.

Another alternative is the following statement, which is lengthy due to several unions. This statement requires three scans of the base table, making it inefficient. CUBE and ROLLUP can be thought of as grouping sets with very specific semantics. The following equivalences show this fact:

```
CUBE(a, b, c)
```

is equivalent to

```
GROUPING SETS ((a, b, c), (a, b), (a, c), (b, c), (a), (b), (c), ())
```

```
ROLLUP(a, b, c)
```

is equivalent to

```
GROUPING SETS ((a, b, c), (a, b), ())
```

GROUPING SETS Syntax

GROUPING SETS syntax lets you define multiple groupings in the same query. GROUP BY computes all the groupings specified and combines them with UNION ALL. For example,

```
GROUP BY GROUPING sets (channel_desc, calendar_month_desc, country_id )
```

is equivalent to:

```
GROUP BY channel_desc
UNION ALL
GROUP BY calendar_month_desc
UNION ALL country_id
```

Table 18–3 shows grouping sets specification and equivalent GROUP BY specification. Note that some examples use composite columns.

Table 18–3 GROUPING SETS Statements and Equivalent GROUP BY Statements

GROUPING SETS Statements	Equivalent GROUP BY Statements

`GROUP BY GROUPING SETS(a, b, c)`	`GROUP BY a UNION ALL`
	`GROUP BY b UNION ALL`
	`GROUP BY c`

`GROUP BY GROUPING SETS(a, b, (b, c))`	`GROUP BY a UNION ALL`
	`GROUP BY b UNION ALL`
	`GROUP BY b, c`

`GROUP BY GROUPING SETS((a, b, c))`	`GROUP BY a, b, c`

`GROUP BY GROUPING SETS(a, (b), ())`	`GROUP BY a UNION ALL`
	`GROUP BY b UNION ALL`
	`GROUP BY ()`

`GROUP BY GROUPING SETS(a, ROLLUP(b, c))`	`GROUP BY a UNION ALL`
	`GROUP BY ROLLUP(b, c)`

In the absence of an optimizer that looks across query blocks to generate the execution plan, a query based on `UNION` would need multiple scans of the base table, sales. This could be very inefficient as fact tables will normally be huge. Using `GROUPING SETS` statements, all the groupings of interest are available in the same query block.

Composite Columns

A composite column is a collection of columns that are treated as a unit during the computation of groupings. You specify the columns in parentheses as in the following statement:

```
ROLLUP (year, (quarter, month), day)
```

In this statement, the data is not rolled up across year and quarter, but is instead equivalent to the following groupings of a `UNION ALL`:

- (`year`, `quarter`, `month`, `day`),
- (`year`, `quarter`, `month`),
- (`year`)
- ()

Here, (`quarter`, `month`) form a composite column and are treated as a unit. In general, composite columns are useful in `ROLLUP`, `CUBE`, `GROUPING SETS`, and concatenated groupings. For example, in `CUBE` or `ROLLUP`, composite columns would mean skipping aggregation across certain levels. That is,

```
GROUP BY ROLLUP(a, (b, c))
```

is equivalent to

```
GROUP BY a, b, c UNION ALL
GROUP BY a UNION ALL
GROUP BY ()
```

Here, `(b, c)` are treated as a unit and rollup will not be applied across `(b, c)`. It is as if you have an alias, for example z, for `(b, c)` and the `GROUP BY` expression reduces to `GROUP BY ROLLUP(a, z)`. Compare this with the normal rollup as in:

```
GROUP BY ROLLUP(a, b, c)
```

which would be

```
GROUP BY a, b, c UNION ALL
GROUP BY a, b UNION ALL
GROUP BY a UNION ALL
GROUP BY ().
```

Similarly,

```
GROUP BY CUBE((a, b), c)
would be equivalent to
GROUP BY a, b, c UNION ALL
GROUP BY a, b UNION ALL
GROUP BY c UNION ALL
GROUP By ()
```

In `GROUPING SETS`, a composite column is used to denote a particular level of `GROUP BY`. See Table 18–3 for more examples of composite columns.

Example 18–10 Composite Columns Example

You do not have full control over what aggregation levels you want with CUBE and ROLLUP. For example, the following statement:

```
SELECT channel_desc, calendar_month_desc, country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
      channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY ROLLUP(channel_desc, calendar_month_desc, country_id);
```

results in Oracle computing the following groupings:

- (channel_desc, calendar_month_desc, country_id)
- (channel_desc, calendar_month_desc)
- (channel_desc)
- ()

If you are just interested in grouping of lines (1), (3) and (4) in the above, you cannot limit the calculation to those groupings without using composite columns. With composite columns, this is possible by treating month and country as a single unit while rolling up. Columns enclosed in parentheses are treated as a unit while computing CUBE and ROLLUP. Thus, you would say:

```
SELECT channel_desc, calendar_month_desc, country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id  AND
      channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY ROLLUP(channel_desc, (calendar_month_desc, country_id));
```

Concatenated Groupings

Concatenated groupings offer a concise way to generate useful combinations of groupings. Groupings specified with concatenated groupings yield the cross-product of groupings from each grouping set. The cross-product operation enables even a small number of concatenated groupings to generate a large number of final groups. The concatenated groupings are specified simply by listing multiple grouping sets, cubes, and rollups, and separating them with commas. Here is an example of concatenated grouping sets:

```
GROUP BY GROUPING SETS(a, b), GROUPING SETS(c, d)
```

The SQL above defines the following groupings:

```
(a, c), (a, d), (b, c), (b, d)
```

Concatenation of grouping sets is very helpful for these reasons:

- Ease of query development - you need not enumerate all groupings manually
- Use by applications - SQL generated by OLAP applications often involves concatenation of grouping sets, with each grouping set defining groupings needed for a dimension

Example 18–11 Concatenated Groupings Example 1

You can also specify more than one grouping in the `GROUP BY` clause. For example, if you want aggregated sales values for each product rolled up across all levels in the `time` dimension (`year`, `month` and `day`), and across all levels in the `geography` dimension (`region`), you can issue the following statement:

```
SELECT channel_desc, calendar_year, calendar_quarter_desc, country_id,
   cust_state_province,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
      channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY
    channel_desc,
    GROUPING SETS (ROLLUP(calendar_year, calendar_quarter_desc),
                    ROLLUP(country_id, cust_state_province)) ;
```

This results in the following groupings:

- (channel_desc, calendar_year, calendar_quarter_desc)
- (channel_desc, calendar_year)
- (channel_desc)
- (channel_desc, country_id, cust_state_province)
- (channel_desc, country_id)
- (channel_desc)

This is the cross-product of the following:

1. The expression, channel_desc
2. ROLLUP(calendar_year, calendar_quarter_desc), which is equivalent to ((calendar_year, calendar_quarter_desc), (calendar_year), ())
3. ROLLUP(country_id, cust_state_province), which is equivalent to ((country_id, cust_state_province), (country_id), ())

Note that the output above contains two occurrences of (channel_desc) group. To filter out the extra (channel_desc) group, the query could use a GROUP_ID function.

Another concatenated join example is given below, showing the cross product of two grouping sets:

Example 18–12 Concatenated Groupings Example 2

```
SELECT   country_id,  cust_state_province,
    calendar_year, calendar_quarter_desc,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
   AND country_id IN ('UK', 'US')
GROUP BY
  GROUPING SETS (country_id, cust_state_province),
  GROUPING SETS (calendar_year, calendar_quarter_desc);
```

This statement results in the computation of groupings:

- (country_id, year), (country_id, calendar_quarter_desc), (cust_state_province, year) and (cust_state_province, calendar_quarter_desc)

Concatenated Groupings and Hierarchical Data Cubes

One of the most important uses for concatenated groupings is to generate the aggregates needed for a hierarchical cube of data. A hierarchical cube is a data set where the data is aggregated along the rollup hierarchy of each of its dimensions and these aggregations are combined across dimensions. It includes the typical set of aggregations needed for business intelligence queries. By using concatenated groupings, you can generate all the aggregations needed by a hierarchical cube with just *n* ROLLUPs (where *n* is the number of dimensions), and avoid generating unwanted aggregations.

Consider just three of the dimensions in the Sales History data set, each of which has a multilevel hierarchy:

- time: year, quarter, month, day (week is in a separate hierarchy)
- product: category, subcategory, prod_name
- geography: region, subregion, country, state, city

This data is represented using a column for each level of the hierarchies, creating a total of twelve columns for dimensions, plus the columns holding sales figures.

For our business intelligence needs, we would like to calculate and store certain aggregates of the various combinations of dimensions. In Example 18–13 on page 18-27, we create the aggregates for all levels, except for "day", which would create too many rows. In particular, we want to use ROLLUP within each dimension to generate useful aggregates. Once we have the ROLLUP-based aggregates within each dimension, we want to combine them with the other dimensions. This will generate our hierarchical cube. Note that this is not at all the same as a CUBE using all twelve of the dimension columns: that would create 2 to the 12th power (4,096) aggregation groups, of which we need only a small fraction. Concatenated grouping sets make it easy to generate exactly the aggregations we need. Below we show GROUP BY clause needed:

Example 18–13   Concatenated Groupings and Hierarchical Cubes Example

```
SELECT
  calendar_year, calendar_quarter_desc,
  calendar_month_desc, country_region, country_subregion, countries.country_id,
  cust_state_province, cust_city,
   prod_cat_desc, prod_subcat_desc, prod_name,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$
FROM sales, customers, times, channels, countries, products
WHERE
   sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   sales.prod_id=products.prod_id  AND
   customers.country_id=countries.country_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc IN ('2000-09', '2000-10')  AND
   prod_name IN ('Ruckpart Eclipse', 'Ukko Plain Gortex Boot') AND
   countries.country_id IN ('UK', 'US')
GROUP BY
  ROLLUP(calendar_year, calendar_quarter_desc,
         calendar_month_desc),
  ROLLUP(country_region, country_subregion, countries.country_id,
         cust_state_province, cust_city),
  ROLLUP(prod_cat_desc, prod_subcat_desc, prod_name);
```

The ROLLUPs in the GROUP BY specification above generate the following groups, four for each dimension:

Table 18–4   Hierarchical CUBE Example

ROLLUP by time	ROLLUP by product	ROLLUP by geography
year, quarter, month	category, subcategory, name	region, subregion, country, state, city
		region, subregion, country, state
		region, subregion, country
year, quarter	category, subcategory	region, subregion
year	category	region
all times	all products	all geographies

The concatenated grouping sets specified in the SQL above will take the ROLLUP aggregations listed in the table and perform a cross-product on them. The cross-product will create the 96 (4x4x6) aggregate groups needed for a hierarchical cube of the data. There are major advantages in using three ROLLUP expressions to replace what would otherwise require 96 grouping set expressions: the concise SQL is far less error-prone to develop and far easier to maintain, and it enables much better query optimization. You can picture how a cube with more dimensions and more levels would make the use of concatenated groupings even more advantageous.

Considerations when Using Aggregation

This section discusses the following topics.

- Hierarchy Handling in ROLLUP and CUBE
- Column Capacity in ROLLUP and CUBE
- HAVING Clause Used with GROUP BY Extensions
- ORDER BY Clause Used with GROUP BY Extensions
- Using Other Aggregate Functions with ROLLUP and CUBE

Hierarchy Handling in ROLLUP and CUBE

The ROLLUP and CUBE extensions work independently of any hierarchy metadata in your system. Their calculations are based entirely on the columns specified in the SELECT statement in which they appear. This approach enables CUBE and ROLLUP to be used whether or not hierarchy metadata is available. The simplest way to handle levels in hierarchical dimensions is by using the ROLLUP extension and indicating levels explicitly through separate columns. The code below shows a simple example of this with months rolled up to quarters and quarters rolled up to years.

Example 18–14 ROLLUP and CUBE Hierarchy Handling Example

```
SELECT calendar_year, calendar_quarter_number,
       calendar_month_number, SUM(amount_sold)
FROM sales, times, products, customers
WHERE sales.time_id=times.time_id AND
  sales.prod_id=products.prod_id AND
  sales.cust_id=customers.cust_id AND
 prod_name IN ('Ruckpart Eclipse', 'Ukko Plain Gortex Boot')
```

```
    AND country_id = 'US'
    AND calendar_year=1999
GROUP BY ROLLUP(calendar_year, calendar_quarter_number, calendar_month_number);

CALENDAR_YEAR CALENDAR_QUARTER_NUMBER CALENDAR_MONTH_NUMBER SUM(AMOUNT_SOLD)
------------- ----------------------- --------------------- ----------------
         1999                       1                     2            79652
         1999                       1                     3           156738
         1999                       1                                 236390
         1999                       2                     4            97802
         1999                       2                     5           116282
         1999                       2                     6            85914
         1999                       2                                 299998
         1999                       3                     7           113256
         1999                       3                     8            79270
         1999                       3                     9           103200
         1999                       3                                 295726
         1999                                                         832114
                                                                      832114
```

Column Capacity in ROLLUP and CUBE

CUBE, ROLLUP, and GROUPING SETS do not restrict the GROUP BY clause column capacity. The GROUP BY clause, with or without the extensions, can work with up to 255 columns. However, the combinatorial explosion of CUBE makes it unwise to specify a large number of columns with the CUBE extension. Consider that a 20-column list for CUBE would create 2 to the 20 combinations in the result set. A very large CUBE list could strain system resources, so any such query needs to be tested carefully for performance and the load it places on the system.

HAVING Clause Used with GROUP BY Extensions

The HAVING clause of SELECT statements is unaffected by the use of GROUP BY. Note that the conditions specified in the HAVING clause apply to both the subtotal and non-subtotal rows of the result set. In some cases a query may need to exclude the subtotal rows or the non-subtotal rows from the HAVING clause. This can be achieved by using a GROUPING or GROUPING_ID function together with the HAVING clause. See Example 18–8 on page 18-16 and its associated SQL statement for an example.

ORDER BY Clause Used with GROUP BY Extensions

In many cases, a query needs to order the rows in a certain way, and this is done with the ORDER BY clause. The ORDER BY clause of a SELECT statement is unaffected by the use of GROUP BY, since the ORDER BY clause is applied after the GROUP BY calculations are complete.

Note that the ORDER BY specification makes no distinction between aggregate and non-aggregate rows of the result set. For instance, you might wish to list sales figures in declining order, but still have the subtotals at the end of each group. Simply ordering sales figures in descending sequence will not be sufficient, since that will place the subtotals (the largest values) at the start of each group. Therefore, it is essential that the columns in the ORDER BY clause include columns that differentiate aggregate from non-aggregate columns. This requirement means that queries using ORDER BY along with aggregation extensions to GROUP BY will generally need to use one or more of the GROUPING functions.

Using Other Aggregate Functions with ROLLUP and CUBE

The examples in this chapter show ROLLUP and CUBE used with the SUM function. While this is the most common type of aggregation, these extensions can also be used with all other functions available to the GROUP BY clause, for example, COUNT, AVG, MIN, MAX, STDDEV, and VARIANCE. COUNT, which is often needed in cross-tabular analyses, is likely to be the second most commonly used function.

Computation Using the WITH Clause

The WITH clause (formally known as subquery_factoring_clause) enables you to reuse the same query block in a SELECT statement when it occurs more than once within a complex query. WITH is a part of the SQL-99 standard. This is particularly useful when a query has multiple references to the same query block and there are joins and aggregations. Using the WITH clause, Oracle retrieves the results of a query block and stores them in the user's temporary tablespace. Note that Oracle9*i* does not support recursive use of the WITH clause.

The following query is an example of where you can improve performance and write SQL more simply by using the WITH clause. The query calculates the sum of sales for each channel and holds it under the name channel_summary. Then it checks each channel's sales total to see if any channel's sales are greater than one third of the total sales. By using the WITH clause, the channel_summary data is calculated just once, avoiding an extra scan through the large sales table.

Example 18–15 WITH Clause Example

```
WITH  channel_summary AS (
SELECT channels.channel_desc, SUM(amount_sold) AS channel_total
FROM sales, channels
WHERE sales.channel_id = channels.channel_id
GROUP BY channels.channel_desc
)
SELECT channel_desc, channel_total
FROM channel_summary
WHERE channel_total > (
SELECT SUM(channel_total) * 1/3
FROM channel_summary);

CHANNEL_DESC         CHANNEL_TOTAL
-------------------- -------------
Direct Sales             312829530
```

Note that the example above could also be performed efficiently using the reporting aggregate functions described in Chapter 19, "SQL for Analysis in Data Warehouses".

See Also: *Oracle9i SQL Reference* for further details

19

SQL for Analysis in Data Warehouses

The following topics provide information about how to improve analytical SQL queries in a data warehouse:

Overview of SQL for Analysis in Data Warehouses

Oracle has enhanced SQL's analytical processing capabilities by introducing a new family of analytic SQL functions. These analytic functions enable you to calculate:

- Rankings and percentiles
- Moving window calculations
- Lag/Lead analysis
- First/last analysis
- Linear regression statistics

Ranking functions include cumulative distributions, percent rank, and N-tiles. Moving window calculations allow you to find moving and cumulative aggregations, such as sums and averages. Lag/lead analysis enables direct inter-row references so you can calculate period-to-period changes. First/last analysis enables you to find the first or last value in an ordered group.

Other enhancements to SQL include the `CASE` expression. `CASE` expressions provide if-then logic useful in many situations.

To enhance performance, analytic functions can be parallelized: multiple processes can simultaneously execute all of these statements. These capabilities make calculations easier and more efficient, thereby enhancing database performance, scalability, and simplicity.

See Also: *Oracle9i SQL Reference* for further details

Analytic functions are classified in the following categories:

Table 19–1 Analytic Functions and Their Uses

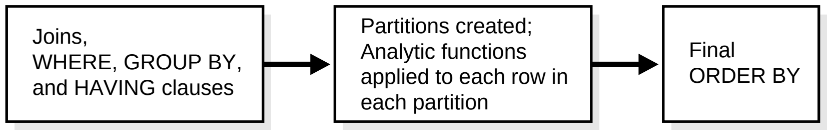
Type	Used for
Ranking	Calculating ranks, percentiles, and n-tiles of the values in a result set.
Windowing	Calculating cumulative and moving aggregates. Works with these functions: `SUM`, `AVG`, `MIN`, `MAX`, `COUNT`, `VARIANCE`, `STDDEV`, `FIRST_VALUE`, `LAST_VALUE`, and new statistical functions

Table 19–1 Analytic Functions and Their Uses

Type	Used for
Reporting	Calculating shares, for example, market share. Works with these functions: SUM, AVG, MIN, MAX, COUNT (with / without DISTINCT), VARIANCE, STDDEV, RATIO_TO_REPORT, and new statistical functions
LAG / LEAD	Finding a value in a row a specified number of rows from a current row.
FIRST / LAST	First or last value in an ordered group.
Linear Regression	Calculating linear regression and other statistics (slope, intercept, and so on).
Inverse Percentile	The value in a data set that corresponds to a specified percentile.
Hypothetical Rank and Distribution	The rank or percentile that a row would have if inserted into a specified data set.

To perform these operations, the analytic functions add several new elements to SQL processing. These elements build on existing SQL to allow flexible and powerful calculation expressions. With just a few exceptions, the analytic functions have these new elements. The processing flow is represented in Figure 19–1.

Figure 19–1 Processing Order


Joins, WHERE, GROUP BY, and HAVING clauses
Partitions created; Analytic functions applied to each row in each partition
Final ORDER BY

The essential concepts used in analytic functions are:

- Processing Order - Query processing using analytic functions takes place in three stages. First, all joins, WHERE, GROUP BY and HAVING clauses are performed. Second, the result set is made available to the analytic functions, and all their calculations take place. Third, if the query has an ORDER BY clause at its end, the ORDER BY is processed to allow for precise output ordering. The processing order is shown in Figure 19–1.

- Result Set Partitions - The analytic functions allow users to divide query result sets into groups of rows called partitions. Note that the term **partitions** used with analytic functions is unrelated to Oracle's table partitions feature. Throughout this chapter, the term partitions refers to only the meaning related to analytic functions. Partitions are created after the groups defined with `GROUP BY` clauses, so they are available to any aggregate results such as sums and averages. Partition divisions may be based upon any desired columns or expressions. A query result set may be partitioned into just one partition holding all the rows, a few large partitions, or many small partitions holding just a few rows each.

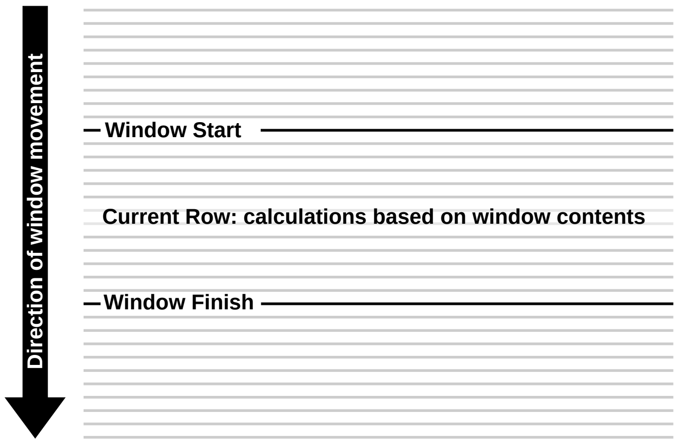
- Window - For each row in a partition, you can define a sliding window of data. This window determines the range of rows used to perform the calculations for the **current row**. Window sizes can be based on either a physical number of rows or a logical interval such as time. The window has a starting row and an ending row. Depending on its definition, the window may move at one or both ends. For instance, a window defined for a cumulative sum function would have its starting row fixed at the first row of its partition, and its ending row would slide from the starting point all the way to the last row of the partition. In contrast, a window defined for a moving average would have both its starting and end points slide so that they maintain a constant physical or logical range.

  A window can be set as large as all the rows in a partition or just a sliding window of one row within a partition. When a window is near a border, the function returns results for only the available rows, rather than warning you that the results are not what you want.

  When using window functions, the current row is included during calculations, so you should only specify (*n*-1) when you are dealing with *n* items.

- Current Row - Each calculation performed with an analytic function is based on a current row within a partition. The current row serves as the reference point determining the start and end of the window. For instance, a centered moving average calculation could be defined with a window that holds the current row, the six preceding rows, and the following six rows. This would create a sliding window of 13 rows, as shown in Figure 19–2.

Figure 19–2 Sliding Window Example


Direction of window movement
Window Start
Current Row: calculations based on window contents
Window Finish

Ranking Functions

A ranking function computes the rank of a record compared to other records in the dataset based on the values of a set of measures. The types of ranking function are:

- `RANK` and `DENSE_RANK`
- `CUME_DIST` and `PERCENT_RANK`
- `NTILE`
- `ROW_NUMBER`

RANK and DENSE_RANK

The `RANK` and `DENSE_RANK` functions allow you to rank items in a group, for example, finding the top three products sold in California last year. There are two functions that perform ranking, as shown by the following syntax:

```
RANK() OVER (
  [PARTITION BY <value expression1> [, ...]]
  ORDER BY <value expression2> [collate clause] [ASC|DESC]
     [NULLS FIRST|NULLS LAST] [, ...]
   )
```

```
DENSE_RANK() OVER (
  [PARTITION BY <value expression1> [, ...]]
  ORDER BY <value expression2> [collate clause] [ASC|DESC]
  [NULLS FIRST|NULLS LAST] [, ...]
  )
```

The difference between RANK and DENSE_RANK is that DENSE_RANK leaves no gaps in ranking sequence when there are ties. That is, if you were ranking a competition using DENSE_RANK and had three people tie for second place, you would say that all three were in second place and that the next person came in third. The RANK function would also give three people in second place, but the next person would be in fifth place.

The following are some relevant points about RANK:

- Ascending is the default sort order, which you canThe expressions in the optional PARTITION BY clause divide the query result set into groups within which the RANK function operates. That is, RANK gets reset whenever the group changes. In effect, the value expressions of the PARTITION BY clause define the reset boundaries.
- If the PARTITION BY clause is missing, then ranks are computed over the entire query result set.
- *value_expression1* can be any valid expression involving column references, constants, aggregates, or expressions invoking these items.
- The ORDER BY clause specifies the measures (<value expression>s) on which ranking is done and defines the order in which rows are sorted in each group (or partition). Once the data is sorted within each partition, ranks are given to each row starting from 1.
- *value_expression2* can be any valid expression involving column references, aggregates, or expressions invoking these items.
- The NULLS FIRST | NULLS LAST clause indicates the position of NULLs in the ordered sequence, either first or last in the sequence. The order of the sequence would make NULLs compare either high or low with respect to non-NULL values. If the sequence were in ascending order, then NULLS FIRST implies that NULLs are smaller than all other non-NULL values and NULLS LAST implies they are larger than non-NULL values. It is the opposite for descending order. See the example in "Treatment of NULLs" on page 19-11.
- If the NULLS FIRST | NULLS LAST clause is omitted, then the ordering of the null values depends on the ASC or DESC arguments. Null values are considered larger than any other values. If the ordering sequence is ASC, then nulls will

appear last; nulls will appear first otherwise. Nulls are considered equal to other nulls and, therefore, the order in which nulls are presented is non-deterministic.

Ranking Order

The following example shows how the [ASC | DESC] option changes the ranking order.

Example 19–1 Ranking Order Example

```
SELECT channel_desc,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$,
   RANK() OVER (ORDER BY SUM(amount_sold) ) AS default_rank,
   RANK() OVER (ORDER BY SUM(amount_sold) DESC NULLS LAST) AS custom_rank
FROM sales, products, customers, times, channels
WHERE sales.prod_id=products.prod_id AND
   sales.cust_id=customers.cust_id AND
   sales.time_id=times.time_id AND
   sales.channel_id=channels.channel_id AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
    AND country_id='US'
GROUP BY channel_desc;

CHANNEL_DESC         SALES$         DEFAULT_RANK CUSTOM_RANK
-------------------- -------------- ------------ -----------
Direct Sales              5,744,263            5           1
Internet                  3,625,993            4           2
Catalog                   1,858,386            3           3
Partners                  1,500,213            2           4
Tele Sales                  604,656            1           5
```

While the data in this result is ordered on the measure SALES$, in general, it is not guaranteed by the RANK function that the data will be sorted on the measures. If you want the data to be sorted on SALES$ in your result, you must specify it explicitly with an ORDER BY clause, at the end of the SELECT statement.

Ranking on Multiple Expressions

Ranking functions need to resolve ties between values in the set. If the first expression cannot resolve ties, the second expression is used to resolve ties and so on. For example, here is a query ranking four of the sales channels over two months based on their dollar sales, breaking ties with the unit sales. (Note that the TRUNC function is used here only to create tie values for this query.)

Example 19–2 Ranking On Multiple Expressions Example

```
SELECT channel_desc, calendar_month_desc,
   TO_CHAR(TRUNC(SUM(amount_sold),-6), '9,999,999,999') SALES$,
   TO_CHAR(SUM(quantity_sold), '9,999,999,999') SALES_Count,
   RANK() OVER (ORDER BY trunc(SUM(amount_sold), -6) DESC, SUM(quantity_sold)
DESC) AS col_rank
FROM sales, products, customers, times, channels
WHERE sales.prod_id=products.prod_id AND
   sales.cust_id=customers.cust_id AND
   sales.time_id=times.time_id AND
   sales.channel_id=channels.channel_id AND
   times.calendar_month_desc IN ('2000-09', '2000-10') AND
   channels.channel_desc<>'Tele Sales'
GROUP BY channel_desc, calendar_month_desc;

CHANNEL_DESC         CALENDAR SALES$         SALES_COUNT     COL_RANK
-------------------- -------- -------------- -------------- ---------
Direct Sales         2000-10      10,000,000        192,551         1
Direct Sales         2000-09       9,000,000        176,950         2
Internet             2000-10       6,000,000        123,153         3
Internet             2000-09       6,000,000        113,006         4
Catalog              2000-10       3,000,000         59,782         5
Catalog              2000-09       3,000,000         54,857         6
Partners             2000-10       2,000,000         50,773         7
Partners             2000-09       2,000,000         46,220         8
```

The `sales_count` column breaks the ties for three pairs of values.

RANK and DENSE_RANK Difference

The difference between RANK and DENSE_RANK functions is illustrated below:

Example 19–3 RANK and DENSE_RANK Example

```
SELECT channel_desc, calendar_month_desc,
   TO_CHAR(TRUNC(SUM(amount_sold),-6), '9,999,999,999') SALES$,
      RANK() OVER (ORDER BY trunc(SUM(amount_sold),-6) DESC)
               AS RANK,
DENSE_RANK() OVER (ORDER BY TRUNC(SUM(amount_sold),-6) DESC)
               AS DENSE_RANK
FROM sales, products, customers, times, channels
WHERE sales.prod_id=products.prod_id AND
   sales.cust_id=customers.cust_id AND
   sales.time_id=times.time_id AND
   sales.channel_id=channels.channel_id AND
   times.calendar_month_desc IN ('2000-09', '2000-10') AND
   channels.channel_desc<>'Tele Sales'
GROUP BY channel_desc, calendar_month_desc;

CHANNEL_DESC         CALENDAR SALES$              RANK DENSE_RANK
-------------------- -------- -------------- --------- ----------
Direct Sales         2000-10     10,000,000          1          1
Direct Sales         2000-09      9,000,000          2          2
Internet             2000-09      6,000,000          3          3
Internet             2000-10      6,000,000          3          3
Catalog              2000-09      3,000,000          5          4
Catalog              2000-10      3,000,000          5          4
Partners             2000-09      2,000,000          7          5
Partners             2000-10      2,000,000          7          5
```

Note that, in the case of DENSE_RANK, the largest rank value gives the number of distinct values in the dataset.

Per Group Ranking

The RANK function can be made to operate within groups, that is, the rank gets reset whenever the group changes. This is accomplished with the PARTITION BY clause. The group expressions in the PARTITION BY subclause divide the dataset into groups within which RANK operates. For example, to rank products within each channel by their dollar sales, you say:

Example 19–4 Per Group Ranking Example 1

```
SELECT channel_desc, calendar_month_desc,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$,
      RANK() OVER (PARTITION BY channel_desc
      ORDER BY SUM(amount_sold) DESC) AS RANK_BY_CHANNEL
FROM sales, products, customers, times, channels
WHERE sales.prod_id=products.prod_id AND
   sales.cust_id=customers.cust_id AND
   sales.time_id=times.time_id AND
   sales.channel_id=channels.channel_id AND
   times.calendar_month_desc IN ('2000-08', '2000-09', '2000-10', '2000-11') AND
   channels.channel_desc IN ('Direct Sales', 'Internet')
GROUP BY channel_desc, calendar_month_desc;
```

A single query block can contain more than one ranking function, each partitioning the data into different groups (that is, reset on different boundaries). The groups can be mutually exclusive. The following query ranks products based on their dollar sales within each month (`rank_of_product_per_region`) and within each channel (`rank_of_product_total`).

Example 19–5 Per Group Ranking Example 2

```
SELECT channel_desc, calendar_month_desc,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$,
RANK() OVER (PARTITION BY calendar_month_desc
       ORDER BY SUM(amount_sold) DESC) AS RANK_WITHIN_MONTH,
 RANK() OVER (PARTITION BY channel_desc
       ORDER BY SUM(amount_sold) DESC) AS RANK_WITHIN_CHANNEL
FROM sales, products, customers, times, channels
WHERE sales.prod_id=products.prod_id AND
   sales.cust_id=customers.cust_id AND
   sales.time_id=times.time_id AND
   sales.channel_id=channels.channel_id AND
   times.calendar_month_desc IN ('2000-08', '2000-09', '2000-10', '2000-11')
    AND
   channels.channel_desc IN ('Direct Sales', 'Internet')
GROUP BY channel_desc, calendar_month_desc;
```

```
CHANNEL_DESC          CALENDAR   SALES$         RANK_WITHIN_MONTH RANK_WITHIN_CHANNEL
--------------------  --------   -------------- ----------------- -------------------
Direct Sales          2000-08         9,588,122                 1                   4
Internet              2000-08         6,084,390                 2                   4
Direct Sales          2000-09         9,652,037                 1                   3
Internet              2000-09         6,147,023                 2                   3
Direct Sales          2000-10        10,035,478                 1                   2
Internet              2000-10         6,417,697                 2                   2
Direct Sales          2000-11        12,217,068                 1                   1
Internet              2000-11         7,821,208                 2                   1
```

Per Cube- and Rollup-group Ranking

Analytic functions, `RANK` for example, can be reset based on the groupings provided by a `CUBE`, `ROLLUP`, or `GROUPING SETS` operator. It is useful to assign ranks to the groups created by `CUBE`, `ROLLUP`, and `GROUPING SETS` queries.

> **See Also:** Chapter 18, "SQL for Aggregation in Data Warehouses" for further information about the `GROUPING` function

A sample `CUBE` and `ROLLUP` query is:

Example 19–6 Per Cube and Rollup Group Example

```
SELECT channel_desc,  country_id,
   TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$,
   RANK() OVER (PARTITION BY GROUPING_ID(channel_desc, country_id)
              ORDER BY SUM(amount_sold) DESC) AS RANK_PER_GROUP
FROM sales, customers, times, channels
WHERE sales.time_id=times.time_id AND
   sales.cust_id=customers.cust_id AND
   sales.channel_id= channels.channel_id AND
   channels.channel_desc IN ('Direct Sales', 'Internet') AND
   times.calendar_month_desc='2000-09'
   AND country_id IN ('UK', 'US', 'JP')
GROUP BY CUBE( channel_desc, country_id);

CHANNEL_DESC         CO SALES$         RANK_PER_GROUP
-------------------- -- -------------- --------------
Direct Sales         US      2,835,557              1
Internet             US      1,732,240              2
Direct Sales         UK      1,378,126              3
Internet             UK        911,739              4
Direct Sales         JP         91,124              5
Internet             JP         57,232              6
Direct Sales                 4,304,807              1
Internet                     2,701,211              2
                     US      4,567,797              1
                     UK      2,289,865              2
                     JP        148,355              3
                             7,006,017              1
```

Treatment of NULLs

NULLs are treated like normal values. Also, for rank computation, a NULL value is assumed to be equal to another NULL value. Depending on the ASC | DESC options provided for measures and the NULLS FIRST | NULLS LAST clause, NULLs will either sort low or high and hence, are given ranks appropriately. The following example shows how NULLs are ranked in different cases:

Example 19–7 Treatment of NULLs Example

```
SELECT calendar_year AS YEAR, calendar_quarter_number AS QTR,
            calendar_month_number AS MO, SUM(amount_sold),
RANK()  OVER (ORDER BY SUM(amount_sold)  ASC NULLS FIRST) AS NFIRST,
RANK()  OVER (ORDER BY SUM(amount_sold)  ASC NULLS LAST) AS NLASST,
RANK()  OVER (ORDER BY SUM(amount_sold)  DESC NULLS FIRST) AS NFIRST_DESC,
RANK()  OVER (ORDER BY SUM(amount_sold)  DESC NULLS LAST) AS NLAST_DESC
FROM (
       SELECT sales.time_id, sales.amount_sold, products.*, customers.*
       FROM sales, products, customers
       WHERE
         sales.prod_id=products.prod_id AND
         sales.cust_id=customers.cust_id AND
         prod_name IN ('Ruckpart Eclipse', 'Ukko Plain Gortex Boot')
         AND country_id ='UK') v, times
 WHERE v.time_id (+) =times.time_id AND
      calendar_year=1999
 GROUP BY calendar_year, calendar_quarter_number, calendar_month_number;

YEAR       QTR        MO SUM(AMOUNT_SOLD)    NFIRST    NLASST NFIRST_DESC NLAST_DESC
------------ --------- --------- ---------------- --------- --------- ----------- ----------
 1999         1         3           51820        12         8           5          1
 1999         2         6           45360        11         7           6          2
 1999         3         9           43950        10         6           7          3
 1999         3         8           41180         8         4           9          5
 1999         2         5           27431         7         3          10          6
 1999         2         4           20602         6         2          11          7
 1999         3         7           15296         5         1          12          8
 1999         1         1                         1         9           1          9
 1999         4        10                         1         9           1          9
 1999         4        11                         1         9           1          9
 1999         4        12                         1         9           1          9
```

If the value for two rows is `NULL`, the next group expression is used to resolve the tie. If they cannot be resolved even then, the next expression is used and so on till the tie is resolved or else the two rows are given the same rank. For example:

Top N Ranking

You can easily obtain top N ranks by enclosing the `RANK` function in a subquery and then applying a filter condition outside the subquery. For example, to obtain the top five countries in sales for a specific month, you can issue:

Example 19–8   Top N Ranking Example

```
SELECT * FROM
  (SELECT country_id,
     TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$,
     RANK() OVER (ORDER BY SUM(amount_sold)  DESC ) AS COUNTRY_RANK
   FROM sales, products, customers, times, channels
   WHERE sales.prod_id=products.prod_id AND
     sales.cust_id=customers.cust_id AND
     sales.time_id=times.time_id AND
     sales.channel_id=channels.channel_id AND
     times.calendar_month_desc='2000-09'
   GROUP BY country_id)
WHERE COUNTRY_RANK <= 5;

CO SALES$         COUNTRY_RANK
-- -------------- ------------
US      6,517,786            1
NL      3,447,121            2
UK      3,207,243            3
DE      3,194,765            4
FR      2,125,572            5
```

Bottom N Ranking

Bottom N is similar to top N except for the ordering sequence within the rank expression. Using the previous example, you can order SUM(s_amount) ascending instead of descending.

CUME_DIST

The CUME_DIST function (defined as the inverse of percentile in some statistical books) computes the position of a specified value relative to a set of values. The order can be ascending or descending. Ascending is the default. The range of values for CUME_DIST is from greater than 0 to 1. To compute the CUME_DIST of a value x in a set S of size N, you use the formula:

```
CUME_DIST(x) =  number of values in S coming before and including x
    in the specified order/ N
```

Its syntax is:

```
CUME_DIST() OVER
  ([PARTITION BY <value expression1> [, ...]]
   ORDER BY <value expression2> [collate clause] [ASC|DESC]
       [NULLS FIRST | NULLS LAST] [, ...])
```

The semantics of various options in the CUME_DIST function are similar to those in the RANK function. The default order is ascending, implying that the lowest value gets the lowest CUME_DIST (as all other values come later than this value in the order). NULLs are treated the same as they are in the RANK function. They are counted towards both the numerator and the denominator as they are treated like non-NULL values. The example below finds cumulative distribution of sales by channel within each month:

Example 19–9   CUME_DIST Example

```
SELECT calendar_month_desc AS MONTH, channel_desc,
     TO_CHAR(SUM(amount_sold) , '9,999,999,999') SALES$ ,
     CUME_DIST() OVER ( PARTITION BY calendar_month_desc ORDER BY
         SUM(amount_sold) ) AS
     CUME_DIST_BY_CHANNEL
   FROM sales, products, customers, times, channels
   WHERE sales.prod_id=products.prod_id AND
     sales.cust_id=customers.cust_id AND
     sales.time_id=times.time_id AND
     sales.channel_id=channels.channel_id AND
     times.calendar_month_desc IN ('2000-09', '2000-07','2000-08')
   GROUP BY calendar_month_desc, channel_desc;

MONTH    CHANNEL_DESC         SALES$         CUME_DIST_BY_CHANNEL
-------- -------------------- -------------- --------------------
2000-07  Tele Sales                1,012,954                   .2
2000-07  Partners                  2,495,662                   .4
2000-07  Catalog                   2,946,709                   .6
2000-07  Internet                  6,045,609                   .8
2000-07  Direct Sales              9,563,664                    1
2000-08  Tele Sales                1,008,703                   .2
2000-08  Partners                  2,552,945                   .4
2000-08  Catalog                   3,061,381                   .6
2000-08  Internet                  6,084,390                   .8
2000-08  Direct Sales              9,588,122                    1
2000-09  Tele Sales                1,017,149                   .2
2000-09  Partners                  2,570,666                   .4
2000-09  Catalog                   3,025,309                   .6
2000-09  Internet                  6,147,023                   .8
2000-09  Direct Sales              9,652,037                    1
```

PERCENT_RANK

PERCENT_RANK is similar to CUME_DIST, but it uses rank values rather than row counts in its numerator. Therefore, it returns the percent rank of a value relative to a group of values. The function is available in many popular spreadsheets. PERCENT_RANK of a row is calculated as:

```
(rank of row in its partition - 1) / (number of rows in the partition - 1)
```

PERCENT_RANK returns values in the range zero to one. The row(s) with a rank of 1 will have a PERCENT_RANK of zero.

Its syntax is:

```
PERCENT_RANK() OVER
  ([PARTITION BY <value expression1> [, ...]]
   ORDER BY <value expression2> [collate clause] [ASC|DESC]
       [NULLS FIRST | NULLS LAST] [, ...])
```

NTILE

NTILE allows easy calculation of tertiles, quartiles, deciles and other common summary statistics. This function divides an ordered partition into a specified number of groups called **buckets** and assigns a bucket number to each row in the partition. NTILE is a very useful calculation because it lets users divide a data set into fourths, thirds, and other groupings.

The buckets are calculated so that each bucket has exactly the same number of rows assigned to it or at most 1 row more than the others. For instance, if you have 100 rows in a partition and ask for an NTILE function with four buckets, 25 rows will be assigned a value of 1, 25 rows will have value 2, and so on. These buckets are referred to as equiheight buckets.

If the number of rows in the partition does not divide evenly (without a remainder) into the number of buckets, then the number of rows assigned per bucket will differ by one at most. The extra rows will be distributed one per bucket starting from the lowest bucket number. For instance, if there are 103 rows in a partition which has an NTILE(5) function, the first 21 rows will be in the first bucket, the next 21 in the second bucket, the next 21 in the third bucket, the next 20 in the fourth bucket and the final 20 in the fifth bucket.

The NTILE function has the following syntax:

```
NTILE(N) OVER
  ([PARTITION BY <value expression1> [, ...]]
    ORDER BY <value expression2> [collate clause] [ASC|DESC]
      [NULLS FIRST | NULLS LAST] [, ...])
```

where the N in NTILE(N) can be a constant (for example, 5) or an expression.

This function, like RANK and CUME_DIST, has a PARTITION BY clause for *per group* computation, an ORDER BY clause for specifying the measures and their sort order, and NULLS FIRST | NULLS LAST clause for the specific treatment of NULLs. For example, Here is an example assigning each month's sales total into one of 4 buckets:

Example 19–10 NTILE Example

```
SELECT calendar_month_desc AS MONTH ,
     TO_CHAR(SUM(amount_sold), '9,999,999,999') SALES$,
     NTILE(4) OVER (ORDER BY SUM(amount_sold)) AS TILE4
   FROM sales, products, customers, times, channels
   WHERE sales.prod_id=products.prod_id AND
     sales.cust_id=customers.cust_id AND
     sales.time_id=times.time_id AND
     sales.channel_id=channels.channel_id AND
     times.calendar_year=1999 AND
     prod_category= 'Men'
   GROUP BY calendar_month_desc;

MONTH    SALES$             TILE4
-------- -------------- ---------
1999-10      4,373,102          1
1999-01      4,754,622          1
1999-11      5,367,943          1
1999-12      6,082,226          2
1999-07      6,161,638          2
1999-02      6,518,877          2
1999-06      6,634,401          3
1999-04      6,772,673          3
1999-08      6,954,221          3
1999-03      6,968,928          4
1999-09      7,030,524          4
1999-05      8,018,174          4
```

NTILE ORDER BY statements must be fully specified to yield reproducible results. Equal values can get distributed across adjacent buckets (75 is assigned to buckets 2 and 3 in the example above) and buckets 1, 2, and 3 in the example above have 3 elements - one more than the size of bucket 4. In the above table, JEANS could as well be assigned to bucket 2 (instead of 3) and SWEATERS to bucket 3 (instead of 2), because there is no ordering on the p_product_key column. To ensure deterministic results, you must order on a unique key.

ROW_NUMBER

The ROW_NUMBER function assigns a unique number (sequentially, starting from 1, as defined by ORDER BY) to each row within the partition. It has the following syntax:

```
ROW_NUMBER() OVER
  ([PARTITION BY <value expression1> [, ...]]
    ORDER BY <value expression2> [collate clause] [ASC|DESC]
      [NULLS FIRST | NULLS LAST] [, ...])
```

Example 19–11 ROW_NUMBER Example

```
SELECT channel_desc, calendar_month_desc,
   TO_CHAR(TRUNC(SUM(amount_sold), -6), '9,999,999,999') SALES$,
   ROW_NUMBER() OVER (ORDER BY TRUNC(SUM(amount_sold), -6) DESC)
     AS ROW_NUMBER
FROM sales, products, customers, times, channels
WHERE sales.prod_id=products.prod_id AND
   sales.cust_id=customers.cust_id AND
   sales.time_id=times.time_id AND
   sales.channel_id=channels.channel_id AND
   times.calendar_month_desc IN ('2000-09', '2000-10')
GROUP BY channel_desc, calendar_month_desc;

CHANNEL_DESC         CALENDAR SALES$         ROW_NUMBER
-------------------- -------- -------------- ----------
Direct Sales         2000-10      10,000,000          1
Direct Sales         2000-09       9,000,000          2
Internet             2000-09       6,000,000          3
Internet             2000-10       6,000,000          4
Catalog              2000-09       3,000,000          5
Catalog              2000-10       3,000,000          6
Partners             2000-09       2,000,000          7
Partners             2000-10       2,000,000          8
Tele Sales           2000-09       1,000,000          9
Tele Sales           2000-10       1,000,000         10
```

Note that there are three pairs of tie values in these results. Like NTILE, ROW_NUMBER is a non-deterministic function, so each tied value could have its row number switched. To ensure deterministic results, you must order on a unique key. Inmost cases, that will require adding a new tie breaker column to the query and using it in the ORDER BY specification.

Windowing Aggregate Functions

Windowing functions can be used to compute cumulative, moving, and centered aggregates. They return a value for each row in the table, which depends on other rows in the corresponding window. These functions include moving sum, moving average, moving min/max, cumulative sum, as well as statistical functions. They can be used only in the SELECT and ORDER BY clauses of the query. Two other functions are available: FIRST_VALUE, which returns the first value in the window; and LAST_VALUE, which returns the last value in the window. These functions provide access to more than one row of a table without a self-join. The syntax of the windowing functions is:

```
{SUM|AVG|MAX|MIN|COUNT|STDDEV|VARIANCE|FIRST_VALUE|LAST_VALUE}
  ({<value expression1> | *}) OVER
    ([PARTITION BY <value expression2>[,...]]
      ORDER BY <value expression3> [collate clause>]
                [ASC| DESC] [NULLS FIRST | NULLS LAST] [,...]
    ROWS | RANGE
      {{UNBOUNDED PRECEDING | <value expression4> PRECEDING}
      | BETWEEN
          {UNBOUNDED PRECEDING_| <value expression4> PRECEDING}
     AND{CURRENT ROW | <value expression4> FOLLOWING}}
```

See Also: *Oracle9i SQL Reference* for further information regarding syntax and restrictions

Treatment of NULLs as Input to Window Functions

Window functions' NULL semantics match the NULL semantics for SQL aggregate functions. Other semantics can be obtained by user-defined functions, or by using the DECODE or a CASE expression within the window function.

Windowing Functions with Logical Offset

A logical offset can be specified with constants such as RANGE 10 PRECEDING, or an expression that evaluates to a constant, or by an interval specification like RANGE INTERVAL N DAY/MONTH/YEAR PRECEDING or an expression that evaluates to an interval. With logical offset, there can only be one expression in the ORDER BY expression list in the function, with type compatible to NUMERIC if offset is numeric, or DATE if an interval is specified.

Cumulative Aggregate Function

The following is an example of cumulative amount_sold by customer ID by quarter in 1999.

Example 19–12 Cumulative Aggregate Example

```
SELECT c.cust_id, t.calendar_quarter_desc,
TO_CHAR (SUM(amount_sold), '9,999,999,999') AS Q_SALES,
TO_CHAR(SUM(SUM(amount_sold)) OVER (PARTITION BY
c.cust_id ORDER BY c.cust_id, t.calendar_quarter_desc ROWS UNBOUNDED
PRECEDING), '9,999,999,999') AS CUM_SALES
FROM sales s, times t, customers c
WHERE
s.time_id=t.time_id AND
s.cust_id=c.cust_id AND
t.calendar_year=1999 AND
c.cust_id IN (6380, 6510)
GROUP BY c.cust_id, t.calendar_quarter_desc
ORDER BY c.cust_id, t.calendar_quarter_desc;

  CUST_ID CALENDA Q_SALES        CUM_SALES
--------- ------- -------------- --------------
     6380 1999-Q1         60,621         60,621
     6380 1999-Q2         68,213        128,834
     6380 1999-Q3         75,238        204,072
     6380 1999-Q4         57,412        261,484
     6510 1999-Q1         63,030         63,030
     6510 1999-Q2         74,622        137,652
     6510 1999-Q3         69,966        207,617
     6510 1999-Q4         63,366        270,983
```

In this example, the analytic function SUM defines, for each row, a window that starts at the beginning of the partition (UNBOUNDED PRECEDING) and ends, by default, at the current row.

Nested SUMs are needed in this example since we are performing a SUM over a value that is itself a SUM. Nested aggregations are used very often in analytic aggregate functions.

Moving Aggregate Function

This example of a time-based window shows, for one customer, the moving average of sales for the current month and preceding two months:

Example 19–13 Moving Aggregate Example

```
SELECT c.cust_id, t.calendar_month_desc,
TO_CHAR (SUM(amount_sold), '9,999,999,999') as SALES ,
TO_CHAR(AVG(SUM(amount_sold)) OVER (ORDER BY c.cust_id,
t.calendar_month_desc
ROWS 2 PRECEDING), '9,999,999,999') as MOVING_3_MONTH_AVG
FROM sales s, times t, customers c
WHERE
s.time_id=t.time_id AND
s.cust_id=c.cust_id AND
t.calendar_year=1999 AND
c.cust_id IN (6380)
GROUP BY c.cust_id, t.calendar_month_desc
ORDER BY c.cust_id, t.calendar_month_desc;

  CUST_ID CALENDAR SALES          MOVING_3_MONTH
--------- -------- -------------- --------------
     6380 1999-01          19,642         19,642
     6380 1999-02          19,324         19,483
     6380 1999-03          21,655         20,207
     6380 1999-04          27,091         22,690
     6380 1999-05          16,367         21,704
     6380 1999-06          24,755         22,738
     6380 1999-07          31,332         24,152
     6380 1999-08          22,835         26,307
     6380 1999-09          21,071         25,079
     6380 1999-10          19,279         21,062
     6380 1999-11          18,206         19,519
     6380 1999-12          19,927         19,137
```

Note that the first two rows for the three month moving average calculation in the data above are based on a smaller interval size than specified because the window calculation cannot reach past the data retrieved by the query. You need to consider the different window sizes found at the borders of result sets. In other words, you may need to modify the query to include exactly what you want.

Centered Aggregate Function

Calculating windowing aggregate functions centered around the current row is straightforward. This example computes for a customer a centered moving average of the sales total for the one day preceding the current row and one day following the current row including the current row as well.

Example 19–14 Centered Aggregate Example

```
SELECT cust_id, t.time_id,
TO_CHAR (SUM(amount_sold), '9,999,999,999') AS SALES,
TO_CHAR(AVG(SUM(amount_sold)) OVER
(PARTITION BY s.cust_id ORDER BY t.time_id
RANGE BETWEEN INTERVAL '1' DAY PRECEDING AND INTERVAL '1' DAY FOLLOWING),
'9,999,999,999') AS CENTERED_3_DAY_AVG
FROM sales s, times t
WHERE
s.time_id=t.time_id AND
t.calendar_week_number IN (51) AND
calendar_year=1999 AND
cust_id IN (6380, 6510)
GROUP BY cust_id, t.time_id
ORDER BY cust_id, t.time_id;

  CUST_ID TIME_ID   SALES          CENTERED_3_DAY
--------- --------- -------------- --------------
     6380 20-DEC-99          2,240          1,136
     6380 21-DEC-99             32            873
     6380 22-DEC-99            348            148
     6380 23-DEC-99             64            302
     6380 24-DEC-99            493            212
     6380 25-DEC-99             80            423
     6380 26-DEC-99            696            388
     6510 20-DEC-99            196            106
     6510 21-DEC-99             16            155
     6510 22-DEC-99            252            143
     6510 23-DEC-99            160            305
     6510 24-DEC-99            504            240
     6510 25-DEC-99             56            415
     6510 26-DEC-99            684            370
```

The starting and ending rows for each product's centered moving average calculation in the data above are based on just two days, since the window calculation cannot reach past the data retrieved by the query. Users need to consider the different window sizes found at the borders of result sets: the query may need to be adjusted.

Windowing Aggregate Functions with Logical Offsets

The following example illustrates how window aggregate functions compute values in the presence of duplicates. Note that the data is hypothetical.

Example 19–15 Windowing Aggregate Functions with Logical Offsets Example

```
SELECT r_rkey, p_pkey, s_amt
    SUM(s_amt) OVER
        (ORDER BY p_pkey RANGE BETWEEN 1 PRECEDING AND CURRENT ROW) AS current_group_sum
FROM product, region, sales
WHERE r_rkey = s_rkey AND p_pkey = s_pkey AND r_rkey = 'east'
ORDER BY r_rkey, p_pkey;

R_RKEY   P_PKEY     S_AMT      CURRENT_GROUP_SUM  /*Source numbers for the current_group_sum column*/
------   ------     -----      -----------------  /*-------                */
EAST          1       130      130                /* 130                  */
EAST          2        50      180                /*130+50                */
EAST          3        80      265                /*50+(80+75+60)         */
EAST          3        75      265                /*50+(80+75+60)         */
EAST          3        60      265                /*50+(80+75+60)         */
EAST          4        20      235                /*80+75+60+20           */
```

Values within parentheses indicate ties.

Let us consider the row with the output of "EAST, 3, 75" from the above table. In this case, all the other rows with p_pkey of 3 (ties) are considered to belong to one group. So, it should include itself (that is, 75) to the window and its ties (that is, 80, 60). Hence the result 50 + (80 + 75 + 60). This is only true because you used RANGE rather than ROWS. It is important to note that the value returned by the window aggregate function with logical offsets is deterministic in all the cases. In fact, all the windowing functions (except FIRST_VALUE and LAST_VALUE) with logical offsets are deterministic.

Variable Sized Window

Assume that you want to calculate the moving average of stock price over 3 working days. If you have an equal number of rows for each day for all working days and no non-working days are stored, then you can use a physical window function. However, if the conditions noted are not met, you can still calculate a moving average by using an expression in the window size parameters.

Expressions in a window size specification can be made in several different sources. the expression could be a reference to a column in a table, such as a time table. It could also be a function that returns the appropriate boundary for the window based on values in the current row. The following statement for a hypothetical stock price database uses a user-defined function in its RANGE clause to set window size:

```
SELECT t_timekey,
    AVG(stock_price)
        OVER (ORDER BY t_timekey RANGE fn(t_timekey) PRECEDING) av_price
```

```
FROM stock, time
WHERE st_timekey = t_timekey
ORDER BY t_timekey;
```

In the statement above, `t_timekey` is a date field. Here, *fn* could be a PL/SQL function with the following specification:

`fn(t_timekey)` returns

- 4 if `t_timekey` is Monday, Tuesday
- 2 otherwise
- If any of the previous days are holidays, it adjusts the count appropriately.

Note that, when window is specified using a number in a window function with `ORDER BY` on a date column, then it is converted to mean the number of days. You could have also used the interval literal conversion function, as:

```
NUMTODSINTERVAL(fn(t_timekey), 'DAY')
```

instead of just

```
fn(t_timekey)
```

to mean the same thing. You can also write a PL/SQL function that returns an `INTERVAL` datatype value.

Windowing Aggregate Functions with Physical Offsets

For windows expressed in rows, the ordering expressions should be unique to produce deterministic results. For example, the query below is not deterministic because `time_id` is not unique in this result set.

Example 19–16 Windowing Aggregate Functions with Physical Offsets Example

```
SELECT t.time_id,
TO_CHAR(amount_sold, '9,999,999,999') AS INDIV_SALE ,
TO_CHAR(SUM(amount_sold) OVER
(PARTITION BY t.time_id ORDER BY t.time_id
ROWS UNBOUNDED PRECEDING), '9,999,999,999') AS CUM_SALES
FROM sales s, times t, customers c
WHERE
s.time_id=t.time_id AND
s.cust_id=c.cust_id AND
t.time_id IN (TO_DATE('11-DEC-1999'), TO_DATE('12-DEC-1999') )
  AND
```

```
c.cust_id BETWEEN 6500 AND 6600
ORDER BY t.time_id;

TIME_ID   INDIV_SALE     CUM_SALES
--------- -------------- --------------
11-DEC-99          1,036          1,036
11-DEC-99          1,932          2,968
11-DEC-99            588          3,556
12-DEC-99            504            504
12-DEC-99            429            933
12-DEC-99          1,160          2,093
```

Or it could yield:

```
TIME_ID   INDIV_SALE     CUM_SALES
--------- -------------- --------------
11-DEC-99          1,932          2,968
11-DEC-99            588          3,556
11-DEC-99          1,036          1,036
12-DEC-99            504            504
12-DEC-99          1,160          2,093
12-DEC-99            429            933
```

One way to handle this problem would be to add the `prod_id` column to the result set and order on both `time_id` and `prod_id`.

FIRST_VALUE and LAST_VALUE

The `FIRST_VALUE` and `LAST_VALUE` functions allow you to select the first and last rows from a window. These rows are especially valuable because they are often used as the baselines in calculations. For instance, with a partition holding sales data ordered by day, you might ask "How much was each day's sales compared to the first sales day (`FIRST_VALUE`) of the period?" Or you might wish to know, for a set of rows in increasing sales order, "What was the percentage size of each sale in the region compared to the largest sale (`LAST_VALUE`) in the region?"

Reporting Aggregate Functions

After a query has been processed, aggregate values like the number of resulting rows or an average value in a column can be easily computed within a partition and made available to other reporting functions. Reporting aggregate functions return the same aggregate value for every row in a partition. Their behavior with respect to `NULLs` is the same as the SQL aggregate functions. The syntax is:

```
{SUM | AVG | MAX | MIN | COUNT | STDDEV | VARIANCE}
   ([ALL | DISTINCT] {<value expression1> | *})
       OVER ([PARTITION BY <value expression2>[,...]])
```

where

- An asterisk (*) is only allowed in `COUNT(*)`
- `DISTINCT` is supported only if corresponding aggregate functions allow it
- `<value expression1>` and `<value expression2>` can be any valid expression involving column references or aggregates.
- The `PARTITION BY` clause defines the groups on which the windowing functions would be computed. If the `PARTITION BY` clause is absent, then the function is computed over the whole query result set.

Reporting functions can appear only in the `SELECT` clause or the `ORDER BY` clause. The major benefit of reporting functions is their ability to do multiple passes of data in a single query block and speed up query performance. Queries such as "Count the number of salesmen with sales more than 10% of city sales" do not require joins between separate query blocks.

For example, consider the question "For each product category, find the region in which it had maximum sales". The equivalent SQL query using the `MAX` reporting aggregate function would be:

Example 19–17 Reporting Aggregate Example 1

```
SELECT prod_category, country_region, sales FROM
(SELECT substr(p.prod_category,1,8), co.country_region, SUM(amount_sold)
  AS sales,
MAX(SUM(amount_sold)) OVER (partition BY prod_category) AS MAX_REG_SALES
FROM sales s, customers c, countries co, products p
WHERE s.cust_id=c.cust_id AND
c.country_id=co.country_id AND
s.prod_id=p.prod_id AND
s.time_id=to_DATE('11-OCT-2000')
GROUP BY prod_category, country_region)
WHERE sales=MAX_REG_SALES;
```

The inner query with the reporting aggregate function `MAX(SUM(amount_sold))` returns:

```
SUBSTR(P COUNTRY_REGION           SALES MAX_REG_SALES
-------- ------------------- --------- -------------
Boys     Africa                    594         41974
Boys     Americas                20353         41974
Boys     Asia                     2258         41974
Boys     Europe                  41974         41974
Boys     Oceania                  1402         41974
Girls    Americas                13869         52963
Girls    Asia                     1657         52963
Girls    Europe                  52963         52963
Girls    Middle East               303         52963
Girls    Oceania                   380         52963
Men      Africa                   1705        123253
Men      Americas                69304        123253
Men      Asia                     6153        123253
Men      Europe                 123253        123253
Men      Oceania                  2646        123253
Women    Africa                   4037        255109
Women    Americas               145501        255109
Women    Asia                    20394        255109
Women    Europe                 255109        255109
Women    Middle East               350        255109
Women    Oceania                 17408        255109
```

Full query results:

```
PROD_CATEGORY        COUNTRY_REGION    SALES
-------------        --------------    ------
Boys                 Europe             41974
Girls                Europe             52963
Men                  Europe            123253
Women                Europe            255109
```

Reporting Aggregate Example

Reporting aggregates combined with nested queries enable you to answer complex queries efficiently. For instance, what if we want to know the best selling products in our most significant product subcategories? We have 4 product categories which contain a total of 37 product subcategories, and there are 10,000 unique products. Here is a query which finds the 5 top-selling products for each product subcategory that contributes more than 20% of the sales within its product category.

Example 19–18 Reporting Aggregate Example 2

```
SELECT SUBSTR(prod_category,1,8) AS CATEG, prod_subcategory, prod_id, SALES FROM
  (SELECT p.prod_category, p.prod_subcategory, p.prod_id,
      SUM(amount_sold) as SALES,
      SUM(SUM(amount_sold)) OVER (partition by p.prod_category) AS CAT_SALES,
      AUM(SUM(amount_sold)) OVER
         (partition by p.prod_subcategory) AS SUBCAT_SALES,
      RANK() OVER  (partition by p.prod_subcategory
         ORDER BY SUM(amount_sold) ) AS RANK_IN_LINE
     FROM sales s, customers c, countries co, products p
     WHERE s.cust_id=c.cust_id AND
        c.country_id=co.country_id AND  s.prod_id=p.prod_id AND
        s.time_id=to_DATE('11-OCT-2000')
     GROUP BY p.prod_category, p.prod_subcategory, p.prod_id
     ORDER BY prod_category, prod_subcategory)
  WHERE SUBCAT_SALES>0.2*CAT_SALES AND RANK_IN_LINE<=5;
```

RATIO_TO_REPORT

The RATIO_TO_REPORT function computes the ratio of a value to the sum of a set of values. If the expression value expression evaluates to NULL, RATIO_TO_REPORT also evaluates to NULL, but it is treated as zero for computing the sum of values for the denominator. Its syntax is:

```
RATIO_TO_REPORT
(<value expression1>) OVER
        ([PARTITION BY <value expression2>[,...]])
```

where

- <value expression1> and <value expression2> can be any valid expression involving column references or aggregates.
- The PARTITION BY clause defines the groups on which the RATIO_TO_REPORT function is to be computed. If the PARTITION BY clause is absent, then the function is computed over the whole query result set.

Example 19–19 RATIO_TO_REPORT Example

To calculate RATIO_TO_REPORT of sales per channel, you might use the following syntax:

```
SELECT ch.channel_desc,
    TO_CHAR(SUM(amount_sold),'9,999,999') as SALES,
    TO_CHAR(SUM(SUM(amount_sold)) OVER (), '9,999,999')
```

```
        AS TOTAL_SALES,
    TO_CHAR(RATIO_TO_REPORT(SUM(amount_sold)) OVER (), '9.999')
        AS RATIO_TO_REPORT
     FROM sales s, channels ch
     WHERE s.channel_id=ch.channel_id  AND
        s.time_id=to_DATE('11-OCT-2000')
     GROUP BY ch.channel_desc ;

CHANNEL_DESC         SALES      TOTAL_SALE RATIO_
-------------------- ---------- ---------- ------
Catalog                 111,103    781,613   .142
Direct Sales            335,409    781,613   .429
Internet                212,314    781,613   .272
Partners                 91,352    781,613   .117
Tele Sales               31,435    781,613   .040
```

LAG/LEAD Functions

The `LAG` and `LEAD` functions are useful for comparing values when the relative positions of rows can be known reliably. They work by specifying the count of rows which separate the target row from the current row. Since the functions provide access to more than one row of a table at the same time without a self-join, they can enhance processing speed. The `LAG` function provides access to a row at a given offset prior to the current position, and the `LEAD` function provides access to a row at a given offset after the current position.

LAG/LEAD Syntax

The functions have the following syntax:

```
{LAG | LEAD}
   (<value expression1>, [<offset> [, <default>]]) OVER
      ([PARTITION BY <value expression2>[,...]]
       ORDER BY <value expression3> [collate clause>]
      [ASC | DESC] [NULLS FIRST | NULLS LAST] [,...])
```

`<offset>` is an optional parameter and defaults to 1. `<default>` is an optional parameter and is the value returned if the `<offset>` falls outside the bounds of the table or partition.

Example 19–20 LAG/LEAD Example

```
SELECT  time_id, TO_CHAR(SUM(amount_sold),'9,999,999') AS SALES,
TO_CHAR(LAG(SUM(amount_sold),1) OVER (ORDER BY time_id),'9,999,999') AS LAG1,
TO_CHAR(LEAD(SUM(amount_sold),1) OVER (ORDER BY time_id),'9,999,999') AS LEAD1
FROM sales
WHERE
time_id>=TO_DATE('10-OCT-2000') AND
time_id<=TO_DATE('14-OCT-2000')
GROUP BY time_id;

TIME_ID   SALES      LAG1       LEAD1
--------- ---------- ---------- ----------
10-OCT-00    773,921               781,613
11-OCT-00    781,613    773,921    744,351
12-OCT-00    744,351    781,613    757,356
13-OCT-00    757,356    744,351    791,960
14-OCT-00    791,960    757,356
```

FIRST/LAST Functions

The FIRST/LAST aggregate functions allow you to return the result of an aggregate applied over a set of rows that rank as the first or last with respect to a given order specification. FIRST/LAST lets you order on column A but return an result of an aggregate applied on column B. This is valuable because it avoids the need for a self-join or subquery, thus improving performance. These functions begin with a tiebreaker function, which is a regular aggregate function (MIN, MAX, SUM, AVG, COUNT, VARIANCE, STDDEV) that produces the return value. The tiebreraker function is performed on the set rows (1 or more rows) that rank as first or last respect to the order specification to return a single value.

To specify the ordering used within each group, the FIRST/LAST functions add a new clause starting with the word KEEP.

FIRST/LAST Syntax

```
[MIN | MAX | COUNT | SUM | AVG | STDDEV | VARIANCE ] (<expression>)
KEEP ( DENSE_RANK [FIRST | LAST] ORDER BY <order by expression> [, ...]
[ASC|DESC] [NULLS FIRST| NULLS LAST] )
```

Note that the ORDER BY clause can take multiple expressions.

FIRST/LAST As Regular Aggregates

You can use the FIRST / LAST family of aggregates as regular aggregate functions.

Example 19–21 FIRST/LAST Example 1

The following query lets us compare minimum price and list price of our products. For each product subcategory within the Men's clothing category, it returns the following:

- list price of the product with the lowest minimum price
- lowest minimum price
- list price of the product with the highest minimum price
- highest minimum price

```
SELECT prod_subcategory, MIN(prod_list_price)
  KEEP (DENSE_RANK FIRST ORDER BY (prod_min_price))
AS LP_OF_LO_MINP,
MIN(prod_min_price) AS LO_MINP,
MAX(prod_list_price) KEEP (DENSE_RANK LAST ORDER BY (prod_min_price))
   AS LP_OF_HI_MINP,
MAX(prod_min_price) AS HI_MINP
FROM products
WHERE prod_category='Men'
GROUP BY prod_subcategory;

PROD_SUBCATEGORY     LP_OF_LO_MINP   LO_MINP    LP_OF_HI_MINP    HI_MINP
----------------     -------------   -------    -------------    -------
Casual Shirts - Men           39.9     16.92               88       59.4
Dress Shirts - Men            42.5     17.34             59.9      41.51
Jeans - Men                     38     17.33             69.9      62.28
Outerwear - Men               44.9     19.76              495     334.12
Shorts - Men                  34.9     15.36              195     103.54
Sportcoats - Men               195     96.53              595     390.92
Sweaters - Men                29.9     14.59              140      97.02
Trousers - Men                  38      15.5              135     120.29
Underwear And Socks - Men     10.9      4.45             39.5      27.02
```

A query like this can be useful for understanding the sales patterns of your different channels. For instance, the result set here highlights that Telesales sell relatively small volumes.

FIRST/LAST As Reporting Aggregates

You can also use the FIRST/LAST family of aggregates as reporting aggregate functions. An example is calculating which months had the greatest and least increase in head count throughout the year. The syntax for these functions is similar to the syntax for any other reporting aggregate.

Consider the example in Example 19–21 for FIRST/LAST. What if we wanted to find the list prices of individual products and compare them to the list prices of the products in their subcategory that had the highest and lowest minimum prices?

The query below lets us find that information for the Sportcoats - Men subcategory by using FIRST/LAST as reporting aggregates. Because there are over 100 products in this subcategory, we show only the first few rows of results.

Example 19–22 FIRST/LAST Example 2

```
SELECT prod_id, prod_list_price,
MIN(prod_list_price) KEEP (DENSE_RANK FIRST ORDER BY (prod_min_price))
  OVER(PARTITION BY (prod_subcategory)) AS LP_OF_LO_MINP,
MAX(prod_list_price) KEEP (DENSE_RANK LAST ORDER BY (prod_min_price))
  OVER(PARTITION BY (prod_subcategory)) AS  LP_OF_HI_MINP
FROM products
WHERE prod_subcategory='Sportcoats - Men';

PROD_ID     PROD_LIST_PRICE      LP_OF_LO_MINP     LP_OF_HI_MINP
-------     ---------------      -------------     -------------
    730                 365                195               595
   1165                 365                195               595
   1560                 595                195               595
   2655                 195                195               595
   2660                 195                195               595
   3840                 275                195               595
   3865                 275                195               595
   4035               319.9                195               595
   4075                 395                195               595
   4245                 195                195               595
   4790                 365                195               595
   4800                 365                195               595
   5560                 425                195               595
   5575                 425                195               595
   5625                 595                195               595
   7915                 275                195               595
      ....  and so on
```

Using the `FIRST` and `LAST` functions as reporting aggregates makes it easy to include the results in calculations such "Salary as a percent of the highest salary."

Linear Regression Functions

The regression functions support the fitting of an ordinary-least-squares regression line to a set of number pairs. You can use them as both aggregate functions or windowing or reporting functions.

The functions are:

- `REGR_COUNT`
- `REGR_AVGX`
- `REGR_AVGY`
- `REGR_SLOPE`
- `REGR_INTERCEPT`
- `REGR_R2`
- `REGR_SXX`
- `REGR_SYY`
- `REGR_SXY`

Oracle applies the function to the set of (`e1`, `e2`) pairs after eliminating all pairs for which either of `e1` or `e2` is null. e1 is interpreted as a value of the dependent variable (a "y value"), and `e2` is interpreted as a value of the independent variable (an "x value"). Both expressions must be numbers.

The regression functions are all computed simultaneously during a single pass through the data. They are frequently combined with the `COVAR_POP`, `COVAR_SAMP`, and `CORR` functions.

> **See Also:** *Oracle9i SQL Reference* for further information regarding syntax and semantics

REGR_COUNT

`REGR_COUNT` returns the number of non-null number pairs used to fit the regression line. If applied to an empty set (or if there are no (e1, e2) pairs where neither of `e1` or `e2` is null), the function returns 0.

REGR_AVGY and REGR_AVGX

REGR_AVGY and REGR_AVGX compute the averages of the dependent variable and the independent variable of the regression line, respectively. REGR_AVGY computes the average of its first argument (e1) after eliminating (e1, e2) pairs where either of e1 or e2 is null. Similarly, REGR_AVGX computes the average of its second argument (e2) after null elimination. Both functions return NULL if applied to an empty set.

REGR_SLOPE and REGR_INTERCEPT

The REGR_SLOPE function computes the slope of the regression line fitted to non-null (e1, e2) pairs.

The REGR_INTERCEPT function computes the y-intercept of the regression line. REGR_INTERCEPT returns NULL whenever slope or the regression averages are NULL.

REGR_R2

The REGR_R2 function computes the coefficient of determination (usually called "R-squared" or "goodness of fit") for the regression line.

REGR_R2 returns values between 0 and 1 when the regression line is defined (slope of the line is not null), and it returns NULL otherwise. The closer the value is to 1, the better the regression line fits the data.

REGR_SXX, REGR_SYY, and REGR_SXY

REGR_SXX, REGR_SYY and REGR_SXY functions are used in computing various diagnostic statistics for regression analysis. After eliminating (e1, e2) pairs where either of e1 or e2 is null, these functions make the following computations:

```
REGR_SXX:    REGR_COUNT(e1,e2) * VAR_POP(e2)

REGR_SYY:    REGR_COUNT(e1,e2) * VAR_POP(e1)

REGR_SXY:    REGR_COUNT(e1,e2) * COVAR_POP(e1, e2)
```

Linear Regression Statistics Examples

Some common diagnostic statistics that accompany linear regression analysis are given in Table 19–2, "Common Diagnostic Statistics and Their Expressions". Note that Oracle's new functions allow you to calculate all of these.

Table 19–2 Common Diagnostic Statistics and Their Expressions

Type of Statistic	Expression
Adjusted R2	`1-((1 - REGR_R2)*((REGR_COUNT-1)/(REGR_COUNT-2)))`
Standard error	`SQRT((REGR_SYY-(POWER(REGR_SXY,2)/REGR_SXX))/(REGR_COUNT-2))`
Total sum of squares	`REGR_SYY`
Regression sum of squares	`POWER(REGR_SXY,2) / REGR_SXX`
Residual sum of squares	`REGR_SYY` - (`POWER(REGR_SXY,2)/REGR_SXX)`
t statistic for slope	`REGR_SLOPE * SQRT(REGR_SXX)` / (Standard error)
t statistic for y-intercept	`REGR_INTERCEPT` / ((Standard error) `* SQRT((1/REGR_COUNT)+(POWER(REGR_AVGX,2)/REGR_SXX))`

Sample Linear Regression Calculation

In this example, we compute an ordinary-least-squares regression line that expresses the quantity sold of a product as a linear function of the product's list price. The calculations are grouped by sales channel. The values SLOPE, INTCPT, RSQR are slope, intercept, and coefficient of determination of the regression line, respectively. The (integer) value COUNT is the number of products in each channel for whom both quantity sold and list price data are available.

Example 19–23 Linear Regression Example

```
SELECT s.channel_id,
REGR_SLOPE(s.quantity_sold, p.prod_list_price) SLOPE,
REGR_INTERCEPT(s.quantity_sold, p.prod_list_price) INTCPT,
REGR_R2(s.quantity_sold, p.prod_list_price) RSQR,
REGR_COUNT(s.quantity_sold, p.prod_list_price) COUNT,
REGR_AVGX(s.quantity_sold, p.prod_list_price) AVGLISTP,
REGR_AVGY(s.quantity_sold, p.prod_list_price) AVGQSOLD
FROM sales s, products p
WHERE s.prod_id=p.prod_id
  AND p.prod_category='Men' AND s.time_id=to_DATE('10-OCT-2000')
GROUP BY s.channel_id;
```

```
C     SLOPE    INTCPT      RSQR     COUNT  AVGLISTP  AVGQSOLD
- --------- --------- --------- --------- --------- ---------
C -.0683687 16.627808 .05134258        20    65.495     12.15
I  .0197103 14.811392 .00163149        46 51.480435 15.826087
P -.0124736 12.854546 .01703979        30     81.87 11.833333
S .00615589 13.991924 .00089844        83 69.813253 14.421687
T -.0041131 5.2271721 .00813224        27 82.244444 4.8888889
```

Inverse Percentile Functions

Using the CUME_DIST function, you can find the cumulative distribution (percentile) of a set of values. However, the inverse operation (finding what value computes to a certain percentile) is neither easy to do nor efficiently computed. To overcome this difficulty, Oracle introduced the PERCENTILE_CONT and PERCENTILE_DISC functions. These can be used both as window reporting functions as well as normal aggregate functions.

These functions need a sort specification and a parameter that takes a percentile value between 0 and 1. The sort specification is handled by using an ORDER BY clause with one expression. When used as a normal aggregate function, it returns a single value per ordered set.

PERCENTILE_CONT, which is a continuous function computed by interpolation, and PERCENTILE_DISC, which is a step function that assumes discrete values. Like other aggregates, PERCENTILE_CONT and PERCENTILE_DISC operate on a group of rows in a grouped query, but with the following differences:

- They require a parameter between 0 and 1 (inclusive). A parameter specified out of this range will result in error. This parameter should be specified as an expression that evaluates to a constant.
- They require a sort specification. This sort specification is an ORDER BY clause with a single expression. Multiple expressions are not allowed.

Normal Aggregate Syntax

```
[PERCENTILE_CONT | PERCENTILE_DISC]( <constant expression> )
   WITHIN GROUP ( ORDER BY <single order by expression>
[ASC|DESC] [NULLS FIRST| NULLS LAST])
```

Example 19–24   Inverse Percentile Example

We use the following query to return the 17 rows of data used in the examples of this section:

```
SELECT cust_id, cust_credit_limit, cume_dist()
   OVER (ORDER BY cust_credit_limit) AS cume_dist
FROM customers WHERE cust_city='Marshal';

CUST_ID   CUST_CREDIT_LIMIT CUME_DIST
--------- ----------------- ---------
   171630              1500 .23529412
   346070              1500 .23529412
   420830              1500 .23529412
   383450              1500 .23529412
   165400              3000 .35294118
   227700              3000 .35294118
    28340              5000 .52941176
   215240              5000 .52941176
   364760              5000 .52941176
   184090              7000 .70588235
   370990              7000 .70588235
   408370              7000 .70588235
   121790              9000 .76470588
    22110             11000 .94117647
   246390             11000 .94117647
    40800             11000 .94117647
   464440             15000         1
```

PERCENTILE_DISC(x) is computed by scanning up the CUME_DIST values in each group till you find the first one greater than or equal to x, where x is the specified percentile value. For the example query where PERCENTILE_DISC(0.5), the result is 5,000 as shown below.

```
SELECT PERCENTILE_DISC(0.5) WITHIN GROUP
  (ORDER BY cust_credit_limit) AS perc_disc,
   PERCENTILE_CONT(0.5) WITHIN GROUP
  (ORDER BY cust_credit_limit) AS perc_cont
 FROM customers WHERE cust_city='Marshal';

PERC_DISC   PERC_CONT
---------   ---------
     5000        5000
```

The result of PERCENTILE_CONT is computed by linear interpolation between rows after ordering them. To compute PERCENTILE_CONT(x), we first compute the row number = RN= (1+x*(n-1)), where *n* is the number of rows in the group and *x* is the specified percentile value. The final result of the aggregate function is computed by linear interpolation between the values from rows at row numbers CRN = CEILING(RN) and FRN = FLOOR(RN).

The final result will be: PERCENTILE_CONT(X) = if (CRN = FRN = RN), then (value of expression from row at RN) else (CRN - RN) * (value of expression for row at FRN) + (RN -FRN) * (value of expression for row at CRN).

Consider the example query above where we compute PERCENTILE_CONT(0.5). Here *n* is 17. The row number RN = (1 + 0.5*(n-1))= 9 for both groups. Putting this into the formula, (FRN=CRN=9), we return the value from row 9 as the result.

Another example is, if you want to compute PERCENTILE_CONT(0.66). The computed row number RN=(1 + 0.66*(n-1))= (1 + 0.66*16)= 11.67. PERCENTILE_CONT(0.66) = (12-11.67)*(value of row 11)+(11.67-11)*(value of row 12). These results are:

```
SELECT PERCENTILE_DISC(0.66) WITHIN GROUP
  (ORDER BY cust_credit_limit) AS perc_disc,
   PERCENTILE_CONT(0.66) WITHIN GROUP
  (ORDER BY cust_credit_limit) AS perc_cont
 FROM customers WHERE cust_city='Marshal';

PERC_DISC   PERC_CONT
---------   ---------
     7000        7000
```

Inverse distribution aggregate functions can appear in the HAVING clause of a query like other existing aggregate functions.

As Reporting Aggregates

You can also use the aggregate functions PERCENTILE_CONT, PERCENTILE_DISC as reporting aggregate functions. When used as reporting aggregate functions, the syntax is similar to those of other reporting aggregates.

```
[PERCENTILE_CONT | PERCENTILE_DISC]( <constant expression> )
WITHIN GROUP ( ORDER BY <single order by expression>
[ASC|DESC] [NULLS FIRST| NULLS LAST])
OVER ( [PARTITION BY <value expression> [,...]] )
```

This query computes the same thing (median credit limit for customers in this result set, but reports the result for every row in the result set, as shown in the output below.

Example 19–25   Reporting Aggregates Example

```
SELECT cust_id, cust_credit_limit,
   PERCENTILE_DISC(0.5) WITHIN GROUP
```

```
     (ORDER BY cust_credit_limit) OVER () AS perc_disc,
   PERCENTILE_CONT(0.5) WITHIN GROUP
     (ORDER BY cust_credit_limit) OVER () AS perc_cont
 FROM customers WHERE cust_city='Marshal';

CUST_ID   CUST_CREDIT_LIMIT PERC_DISC PERC_CONT
--------- ----------------- --------- ---------
   171630              1500      5000      5000
   346070              1500      5000      5000
   420830              1500      5000      5000
   383450              1500      5000      5000
   165400              3000      5000      5000
   227700              3000      5000      5000
    28340              5000      5000      5000
   215240              5000      5000      5000
   364760              5000      5000      5000
   184090              7000      5000      5000
   370990              7000      5000      5000
   408370              7000      5000      5000
   121790              9000      5000      5000
    22110             11000      5000      5000
   246390             11000      5000      5000
    40800             11000      5000      5000
   464440             15000      5000      5000
```

Inverse Percentile Restrictions

For PERCENTILE_DISC, the expression in the ORDER BY clause can be of any data type that you can sort (numeric, string, date, and so on). However, the expression in the ORDER BY clause must be a numeric or datetime type (including intervals) because linear interpolation is used to evaluate PERCENTILE_CONT. If the expression is of type DATE, the interpolated result is rounded to the smallest unit for the type. For a DATE type, the interpolated value will be rounded to the nearest second, for interval types to the nearest second (INTERVAL DAY TO SECOND) or to the month(INTERVAL YEAR TO MONTH).

Like other aggregates, the inverse distribution functions ignore NULLs in evaluating the result. For example, when you want to find the median value in a set, Oracle ignores the NULLs and finds the median among the non-null values. You can use the NULLS FIRST/NULLS LAST option in the ORDER BY clause, but they will be ignored as NULLs are ignored.

Hypothetical Rank and Distribution Functions

These functions provide functionality useful for what-if analysis. As an example, what would be the rank of a row, if the row was **hypothetically** inserted into a set of other rows?

This family of aggregates takes one or more arguments of a hypothetical row and an ordered group of rows, returning the RANK, DENSE_RANK, PERCENT_RANK or CUME_DIST of the row as if it was hypothetically inserted into the group.

Hypothetical Rank and Distribution Syntax

```
[RANK | DENSE_RANK | PERCENT_RANK | CUME_DIST]( <constant expression> [, ...] )
WITHIN GROUP ( ORDER BY <order by expression> [ASC|DESC] [NULLS FIRST|NULLS
LAST][, ...] )
```

Here, <constant expression> refers to an expression that evaluates to a constant, and there may be more than one such expressions that are passed as arguments to the function. The ORDER BY clause can contain one or more expressions that define the sorting order on which the ranking will be based. ASC, DESC, NULLS FIRST, NULLS LAST options will be available for each expression in the ORDER BY.

Example 19–26 Hypothetical Rank and Distribution Example 1

Using the list price data from the products table used throughout this section, you can calculate the RANK, PERCENT_RANK and CUME_DIST for a hypothetical sweater with a price of $50 for how it fits within each of the sweater subcategories. The query and results are:

```
SELECT prod_subcategory,
 RANK(50) WITHIN GROUP  (ORDER BY prod_list_price DESC) as HRANK,
  TO_CHAR(PERCENT_RANK(50) WITHIN GROUP
      (ORDER BY prod_list_price),'9.999') AS HPERC_RANK,
  TO_CHAR(CUME_DIST (50) WITHIN GROUP
      (ORDER BY prod_list_price),'9.999') AS HCUME_DIST
FROM products
WHERE prod_subcategory LIKE 'Sweater%'
GROUP BY prod_subcategory;

PROD_SUBCATEGORY               HRANK   HPERC_RANK   HCUME_DIST
----------------               -----   ----------   ----------
Sweaters - Boys                   16         .911         .912
Sweaters - Girls                   1        1.000        1.000
Sweaters - Men                   240         .351         .352
Sweaters - Women                  21         .783         .785
```

Unlike the inverse percentile aggregates, the ORDER BY clause in the sort specification for hypothetical rank and distribution functions may take multiple expressions. The number of arguments and the expressions in the ORDER BY clause should be the same and the arguments must be constant expressions of the same or compatible type to the corresponding ORDER BY expression. Below is an example using 2 arguments in several hypothetical ranking functions.

Example 19–27 Hypothetical Rank and Distribution Example 1

```
SELECT prod_subcategory,
 RANK(45,30) WITHIN GROUP  (ORDER BY prod_list_price DESC,prod_min_price) as
HRANK,
  TO_CHAR(PERCENT_RANK(45,30) WITHIN GROUP
      (ORDER BY prod_list_price, prod_min_price),'9.999') as HPERC_RANK,
  TO_CHAR(CUME_DIST (45,30) WITHIN GROUP
      (ORDER BY prod_list_price, prod_min_price),'9.999') as HCUME_DIST
FROM products
WHERE prod_subcategory LIKE 'Sweater%'
GROUP BY prod_subcategory;

PROD_SUBCATEGORY              HRANK     HPERC_RANK  HCUME_DIST
----------------              -----     ----------  ----------
Sweaters - Boys                  21           .858        .859
Sweaters - Girls                  1          1.000       1.000
Sweaters - Men                  340           .079        .081
Sweaters - Women                 72           .228        .237
```

These functions can appear in the HAVING clause of a query just like other aggregate functions. They cannot be used as either reporting aggregate functions or windowing aggregate functions.

WIDTH_BUCKET Function

For a given expression, the WIDTH_BUCKET function returns the bucket number that the result of this expression will be assigned after it is evaluated. You can generate equiwidth histograms with this function. Equiwidth histograms divide data sets into buckets whose interval size (highest value to lowest value) is equal. The number of rows held by each bucket will vary. A related function, NTILE, creates equiheight buckets.

Equiwidth histograms can be generated only for numeric, date or datetime types. So the first three parameters should be all numeric expressions or all date expressions. Other types of expressions are not allowed. If the first parameter is NULL, the result is NULL. If the second or the third parameter is NULL, an error message is returned, as a NULL value cannot denote any end point (or any point) for a range in a date or numeric value dimension. The last parameter (number of buckets) should be a numeric expression that evaluates to a positive integer value; 0, NULL, or a negative value will result in an error.

Buckets are numbered from 0 to (n+1). Bucket 0 holds the count of values less than the minimum. Bucket(n+1) holds the count of values greater than or equal to the maximum specified value.

WIDTH_BUCKET Syntax

The WIDTH_BUCKET takes four expressions as parameters. The first parameter is the expression that the equiwidth histogram is for. The second and third parameters are expressions that denote the end points of the acceptable range for the first parameter. The fourth parameter denotes the number of buckets.

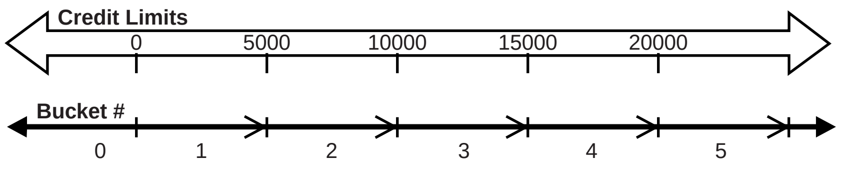
```
WIDTH_BUCKET(<expression>, <minval expression>, <maxval expression>,
   <num buckets>)
```

Consider the following data from table customers, that shows the credit limits of 17 customers. This data is gathered in the query shown in Example 19–28 on page 19-43.

```
CUST_ID  CUST_CREDIT_LIMIT
-------- -----------------
   22110             11000
   28340              5000
   40800             11000
  121790              9000
  165400              3000
  171630              1500
  184090              7000
  215240              5000
  227700              3000
  246390             11000
  346070              1500
  364760              5000
  370990              7000
  383450              1500
  408370              7000
  420830                1500
  464440               15000
```

In the table customers, the column `cust_credit_limit` contains values between 1500 and 15000, and we can assign the values to four equiwidth buckets, numbered from 1 to 4, by using `WIDTH_BUCKET (cust_credit_limit, 0, 20000, 4)`. Ideally each bucket is a closed-open interval of the real number line, for example, bucket number 2 is assigned to scores between 5000.0000 and 9999.9999..., sometimes denoted [5000, 10000) to indicate that 5,000 is included in the interval and 10,000 is excluded. To accommodate values outside the range [0, 20,000), values less than 0 are assigned to a designated underflow bucket which is numbered 0, and values greater than or equal to 20,000 are assigned to a designated overflow bucket which is numbered 5 (num buckets + 1 in general). See Figure 19–3 for a graphical illustration of how the buckets are assigned.

Figure 19–3 Bucket Assignments



You can specify the bounds in the reverse order, for example, `WIDTH_BUCKET` (`cust_credit_limit`, `20000`, `0`, `4`). When the bounds are reversed, the buckets will be open-closed intervals. In this example, bucket number 1 is (`15000,20000`], bucket number 2 is (`10000,15000`], and bucket number 4, is (`0`,5000]. The overflow bucket will be numbered 0 (`20000`, +`infinity`), and the underflow bucket will be numbered 5 (-`infinity`, `0`].

It is an error if the bucket count parameter is 0 or negative.

Example 19–28 WIDTH_BUCKET Example

The following query shows the bucket numbers for the credit limits in the customers table for both cases where the boundaries are specified in regular or reverse order. We use a range of 0 to 20,000.

```
SELECT cust_id, cust_credit_limit,
  WIDTH_BUCKET(cust_credit_limit,0,20000,4) AS WIDTH_BUCKET_UP,
  WIDTH_BUCKET(cust_credit_limit,20000, 0, 4) AS WIDTH_BUCKET_DOWN
FROM customers WHERE cust_city = 'Marshal';

  CUST_ID CUST_CREDIT_LIMIT WIDTH_BUCKET_UP WIDTH_BUCKET_DOWN
  ------- ----------------- --------------- -----------------
    22110             11000               3                 2
    28340              5000               2                 4
    40800             11000               3                 2
   121790              9000               2                 3
   165400              3000               1                 4
   171630              1500               1                 4
   184090              7000               2                 3
   215240              5000               2                 4
   227700              3000               1                 4
   246390             11000               3                 2
   346070              1500               1                 4
   364760              5000               2                 4
   370990              7000               2                 3
   383450              1500               1                 4
   408370              7000               2                 3
   420830              1500               1                 4
   464440             15000               4                 2
```

User-Defined Aggregate Functions

Oracle offers a facility for creating your own functions, called **user-defined aggregate functions**. These functions are written in programming languages such as PL/SQL, Java, and C, and can be used as analytic functions or aggregates in materialized views.

See Also: *Oracle9i Data Cartridge Developer's Guide* for further information regarding syntax and restrictions

The advantages of these functions are:

- Highly complex functions can be programmed using a fully procedural language.
- Higher scalability than other techniques when user-defined functions are programmed for parallel processing.
- Object datatypes can be processed.

As a simple example of a user-defined aggregate function, consider the skew statistic. This calculation measures if a data set has a lopsided distribution about its mean. It will tell you if one tail of the distribution is significantly larger than the other. If you created a user-defined aggregate called `udskew` and applied it to the credit limit data in the prior example, the SQL statement and results might look like this:

```
SELECT USERDEF_SKEW(cust_credit_limit)
FROM customers WHERE cust_city='Marshal';

USERDEF_SKEW
============
0.583891
```

Before building user-defined aggregate functions, you should consider if your needs can be met in regular SQL. Many complex calculations are possible directly in SQL, particularly by using the `CASE` expression.

Staying with regular SQL will enable simpler development, and many query operations are already well-parallelized in SQL. Even the example above, the skew statistic, can be created using standard, albeit lengthy, SQL.

CASE Expressions

Oracle now supports **simple** and **searched** `CASE` statements. `CASE` statements are similar in purpose to the Oracle `DECODE` statement, but they offer more flexibility and logical power. They are also easier to read than traditional `DECODE` statements, and offer better performance as well. They are commonly used when breaking categories into buckets like age (for example, 20-29, 30-39, and so on). The syntax for simple statements is:

```
CASE value expression t
  WHEN <value expression 1> THEN <result 1>
  WHEN <value expression 2> THEN <result 2>
  ...
  ELSE result n + 1
END
```

The syntax for searched statements is:

```
CASE
  WHEN <search condition 1> THEN <result 1>
  WHEN <search condition 2> THEN <result 2>
  ...
  ELSE result n + 1
END
```

You can specify only 255 arguments and each `WHEN` ... `THEN` pair counts as two arguments. For a workaround to this limit, see *Oracle9i SQL Reference*.

Example 19–29 CASE Example

Suppose you wanted to find the average salary of all employees in the company. If an employee's salary is less than $2000, you want the query to use $2000 instead. With a `CASE` statement, you would have to write this query as follows,

```
SELECT AVG(foo(e.sal)) FROM emps e;
```

where `foo` is a function that returns its input if the input is greater than 2000, and returns 2000 otherwise. The query has performance implications because it needs to invoke a function for each row. Writing custom functions can also add to the development load.

Using `CASE` expressions in the database without PL/SQL, the above query can be rewritten as:

```
SELECT AVG(CASE when e.sal > 2000 THEN e.sal ELSE 2000 end) FROM emps e;
```

Using a `CASE` expression lets you avoid developing custom functions and can also perform faster.

Creating Histograms with User-defined Buckets

You can use the `CASE` statement when you want to obtain histograms with user-defined buckets (both in number of buckets and width of each bucket). Below are two examples of histograms created with `CASE` statements. In the first example, the histogram totals are shown in multiple columns and a single row is returned. In the second example, the histogram is shown with a label column and a single column for totals, and multiple rows are returned.

Example 19–30 Histogram Example 1

```
SELECT
SUM(CASE WHEN cust_credit_limit BETWEEN  0 AND 3999 THEN 1 ELSE 0 END)
  AS "0-3999",
SUM(CASE WHEN cust_credit_limit BETWEEN  4000 AND 7999 THEN 1 ELSE 0 END)
  AS "4000-7999",
SUM(CASE WHEN cust_credit_limit BETWEEN  8000 AND 11999 THEN 1 ELSE 0 END)
  AS "8000-11999",
SUM(CASE WHEN cust_credit_limit BETWEEN  12000 AND 16000 THEN 1 ELSE 0 END)
  AS "12000-16000"
FROM customers WHERE cust_city='Marshal';

   0-3999 4000-7999 8000-11999 12000-16000
--------- --------- ---------- -----------
        6         6          4           1
```

Example 19–31 Histogram Example 2

```
SELECT
 (CASE WHEN cust_credit_limit BETWEEN  0 AND 3999
    THEN  ' 0 - 3999'
   WHEN cust_credit_limit BETWEEN  4000 AND 7999 THEN ' 4000 - 7999'
   WHEN cust_credit_limit BETWEEN  8000 AND 11999 THEN  ' 8000 - 11999'
   WHEN cust_credit_limit BETWEEN  12000 AND 16000 THEN '12000 - 16000' END)
  AS BUCKET,
  COUNT(*) AS Count_in_Group
FROM customers
WHERE cust_city = 'Marshal'
GROUP BY
 (CASE WHEN cust_credit_limit BETWEEN  0 AND 3999
    THEN ' 0 - 3999'
 WHEN cust_credit_limit BETWEEN  4000 AND 7999 THEN ' 4000 - 7999'
 WHEN cust_credit_limit BETWEEN  8000 AND 11999 THEN  ' 8000 - 11999'
 WHEN cust_credit_limit BETWEEN  12000 AND 16000 THEN '12000 - 16000'
 END)
;

BUCKET        COUNT_IN_GROUP
------------- --------------
 0 - 3999                  6
 4000 - 7999               6
 8000 - 11999              4
12000 - 16000              1
```

20

Advanced Analytic Services

The following topics provide an introduction to Oracle's Advanced Analytic Services:

- OLAP
- Data Mining

OLAP

Oracle9*i* OLAP adds the query performance and calculation capability previously found only in multidimensional databases to Oracle's relational platform. In addition, it provides a Java OLAP API that is appropriate for the development of internet-ready analytical applications. Unlike other combinations of OLAP and RDBMS technology, Oracle9*i* OLAP is not a multidimensional database using bridges to move data from the relational data store to a multidimensional data store. Instead, it is truly an OLAP-enabled relational database. As a result, Oracle9*i* provides the benefits of a multidimensional database along with the scalability, accessibility, security, manageability, and high availability of the Oracle9*i* database. The Java OLAP API, which is specifically designed for internet-based analytical applications, offers productive data access.

See Also: *Oracle OLAP* documentation for further information

Benefits of OLAP and RDBMS Integration

Basing an OLAP system directly on the Oracle server offers the following benefits:

- Scalability
- Availability
- Manageability
- Backup and Recovery
- Security

Scalability

Oracle9*i* OLAP is highly scalable. In today's environment, there is tremendous growth along three dimensions of analytic applications: number of users, size of data, complexity of analyses. There are more users of analytical applications, and they need access to more data to perform more sophisticated analysis and target marketing. For example, a telephone company might want a customer dimension to include detail such as all telephone numbers as part of an application that is used to analyze customer turnover. This would require support for multi-million row dimension tables and very large volumes of fact data. Oracle9*i* can handle very large data sets using parallel execution and partitioning, as well as offering support for advanced hardware and clustering.

Availability

Oracle9*i* includes many features that support high availability. One of the most significant is partitioning, which allows management of precise subsets of tables and indexes, so that management operations affect only small pieces of these data structures. By partitioning tables and indexes, data management processing time is reduced, thus minimizing the time data is unavailable. Another feature supporting high availability is transportable tablespaces. With transportable tablespaces, large data sets, including tables and indexes, can be added with almost no processing to other databases. This enables extremely rapid data loading and updates.

Manageability

Oracle enables you to precisely control resource utilization. The Database Resource Manager, for example, provides a mechanism for allocating the resources of a data warehouse among different sets of end-users. Consider an environment where the marketing department and the sales department share an OLAP system. Using the Database Resource Manager, you could specify that the marketing department receive at least 60 percent of the CPU resources of the machines, while the sales department receive 40 percent of the CPU resources. You can also further specify limits on the total number of active sessions, and the degree of parallelism of individual queries for each department.

Another resource management facility is the progress monitor, which gives end users and administrators the status of long-running operations. Oracle9*i* maintains statistics describing the percent-complete of these operations. Oracle Enterprise Manager enables you to view a bar-graph display of these operations showing what percent complete they are. Moreover, any other tool or any database administrator can also retrieve progress information directly from the Oracle data server, using system views.

Backup and Recovery

Oracle provides a server-managed infrastructure for backup, restore, and recovery tasks that enables simpler, safer operations at terabyte scale. Some of the highlights are:

- Details related to backup, restore, and recovery operations are maintained by the server in a recovery catalog and automatically used as part of these operations. This reduces administrative burden and minimizes the possibility of human errors.

- Backup and recovery operations are fully integrated with partitioning. Individual partitions, when placed in their own tablespaces, can be backed up and restored independently of the other partitions of a table.
- Oracle includes support for incremental backup and recovery, enabling operations to be completed efficiently within times proportional to the amount of changes, rather than the overall size of the database.
- The backup and recovery technology is highly scalable, and provides tight interfaces to industry-leading media management subsystems. This provides for efficient operations that can scale up to handle very large volumes of data. Open Platforms for more hardware options & enterprise-level platforms

Security

Just as the demands of real-world transaction processing required Oracle to develop robust features for scalability, manageability and backup and recovery, they lead Oracle to create industry-leading security features. The security features in Oracle have reached the highest levels of U.S. government certification for database trustworthiness. Oracle's fine grained access control feature, enables cell-level security for OLAP users. Fine grained access control works with minimal burden on query processing, and it enables efficient centralized security management.

Data Mining

Oracle enables data mining inside the database for performance and scalability. Some of the capabilities are:

- An API that provides programmatic control and application integration
- Analytical capabilities with OLAP and statistical functions in the database
- Multiple Algorithms: Naïve Bayes and Association Rules
- Real-time and Batch Scoring modes
- Multiple Prediction types
- Association insights

See Also: *Oracle Data Mining* documentation for further information

Enabling Data Mining Applications

Oracle9*i* Data Mining provides a Java API to exploit the data mining functionality that is embedded within the Oracle9*i* database.

By delivering complete programmatic control of the database in data mining, Oracle Data Mining (ODM) delivers powerful, scalable modeling and real-time scoring. This enables e-businesses to incorporate predictions and classifications in all processes and decision points throughout the business cycle.

ODM is designed to meet the challenges of vast amounts of data, delivering accurate insights completely integrated into e-business applications. This integrated intelligence enables the automation and decision speed that e-businesses require in order to compete today.

Predictions and Insights

ODM uses data mining algorithms to sift through the large volumes of data generated by e-businesses to produce, evaluate, and deploy predictive models. It alos enriches mission critical applications in CRM, manufacturing control, inventory management, customer service and support, Web portals, wireless devices and other fields with context-specific recommendations and predictive monitoring of critical processes. ODM delivers real-time answers to questions such as:

- Which N items is person A most likely to buy or like?
- What is the likelihood that this product will be returned for repair?

Mining Within the Database Architecture

ODM performs all the phases of data mining within the database. In each data mining phase, this architecture results in significant improvements including performance, automation, and integration.

Data Preparation

Data preparation can create new tables or views of existing data. Both options perform faster than moving data to an external data mining utility and offer the programmer the option of snap-shots or real-time updates.

ODM provides utilities for complex, data mining-specific tasks. Binning improves model build time and model performance, so ODM provides a utility for user-defined binning. ODM accepts data in either single record format or in transactional format and performs mining on transactional formats. Single record format is most common in applications, so ODM provides a utility for transforming single record format.

Associated analysis for preparatory data exploration and model evaluation is extended by Oracle’s statistical functions and OLAP capabilities. Because these also operate within the database, they can all be incorporated into a seamless application that shares database objects. This allows for more functional and faster applications.

Model Building

ODM provides Naïve Bayes for prediction and rating. This algorithm can predict binary outcomes in which the prediction might be either yes or no. It can also predict multi-class outcomes in which the prediction might be one or more of a set of possible outcomes. ODM also provides Association Rules for market basket analysis and other association problems. For example, the possible outcomes of a loyalty prediction might include: increase use, remain stable, decrease use, and defect. All model building takes place inside the database. Once again, the data does not need to move and the process is accelerated.

Model Evaluation

Models are stored in the database and directly accessible for evaluation, reporting, and further analysis by a wide variety of tools and application functions. ODM provides APIs for calculating traditional confusion matrixes and lift charts. It stores the models, the underlying data, and these analysis results together in the database to allow further analysis, reporting and application specific model management.

Scoring

ODM provides both batch and real-time scoring. In batch mode, ODM takes a table as input. It scores every record, and returns a scored table as a result. In real-time mode, parameters for a single record are passed in and the scores are returned in a Java object.

In both modes, ODM can deliver a variety of scores. It can return a rating or probability of a specific outcome. Alternatively it can return a predicted outcome and the probability of that outcome occurring. Some examples follow.

- How likely is this event to end in outcome A?
- Which outcome is most likely to result from this event?
- What is the probability of each possible outcome for this event?

Java API

The Oracle Data Mining API lets you build analytical models and deliver real-time predictions in any application that supports Java. The API is based on the emerging JSR-073 standard.

21

Using Parallel Execution

This chapter covers tuning in a parallel execution environment and discusses:

Introduction to Parallel Execution Tuning

Parallel execution dramatically reduces response time for data-intensive operations on large databases typically associated with decision support systems (DSS) and data warehouses. You can also implement parallel execution on certain types of online transaction processing (OLTP) and hybrid systems. Parallel execution improves processing for:

- Queries requiring large table scans, joins, or partitioned index scans
- Creation of large indexes
- Creation of large tables (including materialized views)
- Bulk inserts, updates, merges, and deletes

You can also use parallel execution to access object types within an Oracle database. For example, you can use parallel execution to access large objects (LOBs).

Parallel execution benefits systems with all of the following characteristics:

- Symmetric multiprocessors (SMPs), clusters, or massively parallel systems
- Sufficient I/O bandwidth
- Underutilized or intermittently used CPUs (for example, systems where CPU usage is typically less than 30%)
- Sufficient memory to support additional memory-intensive processes, such as sorts, hashing, and I/O buffers

If your system lacks any of these characteristics, parallel execution might not significantly improve performance. In fact, parallel execution may reduce system performance on overutilized systems or systems with small I/O bandwidth.

When to Implement Parallel Execution

Parallel execution provides the greatest performance improvements in DSS and data warehousing environments. OLTP systems also benefit from parallel execution, but usually only during batch processing.

During the day, most OLTP systems should probably not use parallel execution. During off-hours, however, parallel execution can effectively process high-volume batch operations. For example, a bank might use parallelized batch programs to perform millions of updates to apply interest to accounts.

Operations That Can Be Parallelized

The Oracle server can use parallel execution for any of the following:

1. Access Methods

   Table Scans, Index Full Scans, and Partitioned Index Range Scans

2. Join Methods

   Nested Loop, Sort Merge, Hash, and Star Transformation

3. DDL Statements

   `CREATE TABLE AS SELECT`, `CREATE INDEX`, `REBUILD INDEX`, `REBUILD INDEX PARTITION`, and `MOVE SPLIT COALESCE PARTITION`

4. DML Statements

   Inserts as Select, Updates, Deletes, and Merges

5. Miscellaneous SQL Operations

   `GROUP BY`, `NOT IN`, `SELECT DISTINCT`, `UNION`, `UNION ALL`, `CUBE`, and `ROLLUP`, as well as Aggregate and Table Functions

The Parallel Execution Server Pool

When an instance starts up, Oracle creates a pool of parallel execution servers which are available for any parallel operation. The initialization parameter `PARALLEL_MIN_SERVERS` specifies the number of parallel execution servers that Oracle creates at instance startup.

When executing a parallel operation, the parallel execution coordinator obtains parallel execution servers from the pool and assigns them to the operation. If necessary, Oracle can create additional parallel execution servers for the operation. These parallel execution servers remain with the operation throughout job execution, then become available for other operations. After the statement has been processed completely, the parallel execution servers return to the pool.

Note: The parallel execution coordinator and the parallel execution servers can only service one statement at a time. A parallel execution coordinator cannot coordinate, for example, a parallel query and a parallel DML statement at the same time.

When a user issues a SQL statement, the optimizer decides whether to execute the operations in parallel and determines the degree of parallelism (DOP) for each operation. You can specify the number of parallel execution servers required for an operation in various ways.

If the optimizer targets the statement for parallel processing, the following sequence of events takes place:

1. The SQL statement's foreground process becomes a parallel execution coordinator.
2. The parallel execution coordinator obtains as many parallel execution servers as needed (determined by the DOP) from the server pool or creates new parallel execution servers as needed.
3. Oracle executes the statement as a sequence of operations. Each operation is performed in parallel, if possible.
4. When statement processing is completed, the coordinator returns any resulting data to the user process that issued the statement and returns the parallel execution servers to the server pool.

The parallel execution coordinator calls upon the parallel execution servers during the execution of the SQL statement, not during the parsing of the statement. Therefore, when parallel execution is used with the shared server, the server process that processes the EXECUTE call of a user's statement becomes the parallel execution coordinator for the statement.

See Also: "Setting the Degree of Parallelism" on page 21-32

Variations in the Number of Parallel Execution Servers

If the number of parallel operations processed concurrently by an instance changes significantly, Oracle automatically changes the number of parallel execution servers in the pool.

If the number of parallel operations increases, Oracle creates additional parallel execution servers to handle incoming requests. However, Oracle never creates more parallel execution servers for an instance than the value specified by the initialization parameter PARALLEL_MAX_SERVERS.

If the number of parallel operations decreases, Oracle terminates any parallel execution servers that have been idle for a threshold period of time. Oracle does not reduce the size of the pool below the value of PARALLEL_MIN_SERVERS, no matter how long the parallel execution servers have been idle.

Processing Without Enough Parallel Execution Servers

Oracle can process a parallel operation with fewer than the requested number of processes.

If all parallel execution servers in the pool are occupied and the maximum number of parallel execution servers has been started, the parallel execution coordinator switches to serial processing.

See Also:

- "Minimum Number of Parallel Execution Servers" on page 21-36 for information about using the initialization parameter `PARALLEL_MIN_PERCENT`
- *Oracle9i Database Performance Guide and Reference* for information about monitoring an instance's pool of parallel execution servers and determining the appropriate values for the initialization parameters

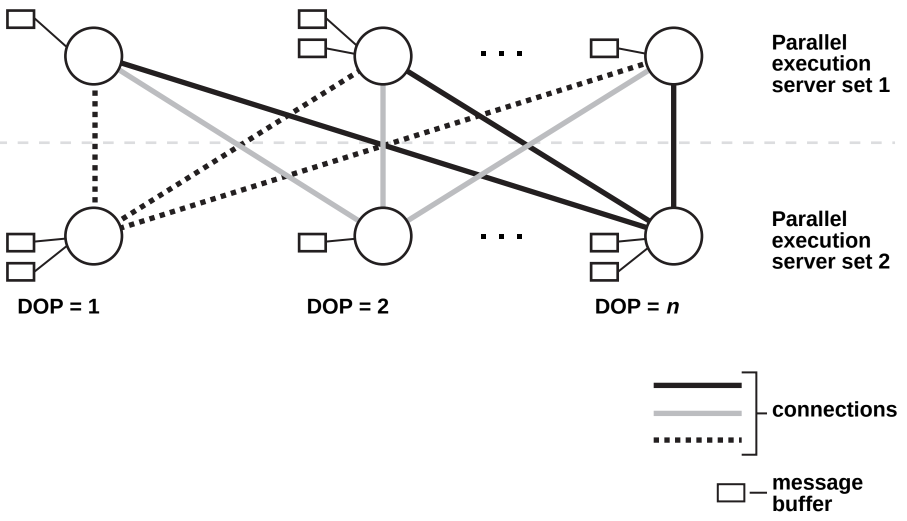
How Parallel Execution Servers Communicate

To execute a query in parallel, Oracle generally creates a producer queue server and a consumer server. The producer queue server retrieves rows from tables and the consumer server performs operations such as join, sort, DML, and DDL on these rows. Each server in the producer execution process set has a connection to each server in the consumer set. This means that the number of virtual connections between parallel execution servers increases as the square of the DOP.

Each communication channel has at least one, and sometimes up to four memory buffers. Multiple memory buffers facilitate asynchronous communication among the parallel execution servers.

A single-instance environment uses at most three buffers per communication channel. An Oracle Real Application Cluster environment uses at most four buffers per channel. Figure 21–1 illustrates message buffers and how producer parallel execution servers connect to consumer parallel execution servers.

Figure 21–1 Parallel Execution Server Connections and Buffers


Parallel execution server set 1
Parallel execution server set 2
DOP = 1
DOP = 2
DOP = *n*
connections
message buffer

When a connection is between two processes on the same instance, the servers communicate by passing the buffers back and forth. When the connection is between processes in different instances, the messages are sent using external high-speed network protocols. In Figure 21–1, the DOP is equal to the number of parallel execution servers, which in this case is *n*. Figure 21–1 does not show the parallel execution coordinator. Each parallel execution server actually has an additional connection to the parallel execution coordinator.

Parallelizing SQL Statements

Each SQL statement undergoes an optimization and parallelization process when it is parsed. When the data changes, if a more optimal execution or parallelization plan becomes available, Oracle can automatically adapt to the new situation.

After the optimizer determines the execution plan of a statement, the parallel execution coordinator determines the parallelization method for each operation in the plan. For example, the parallelization method might be to parallelize a full table scan by block range or parallelize an index range scan by partition. The coordinator must decide whether an operation can be performed in parallel and, if so, how many parallel execution servers to enlist. The number of parallel execution servers is the DOP.

See Also:

- "Setting the Degree of Parallelism" on page 21-32
- "Parallelization Rules for SQL Statements" on page 21-38

Dividing Work Among Parallel Execution Servers

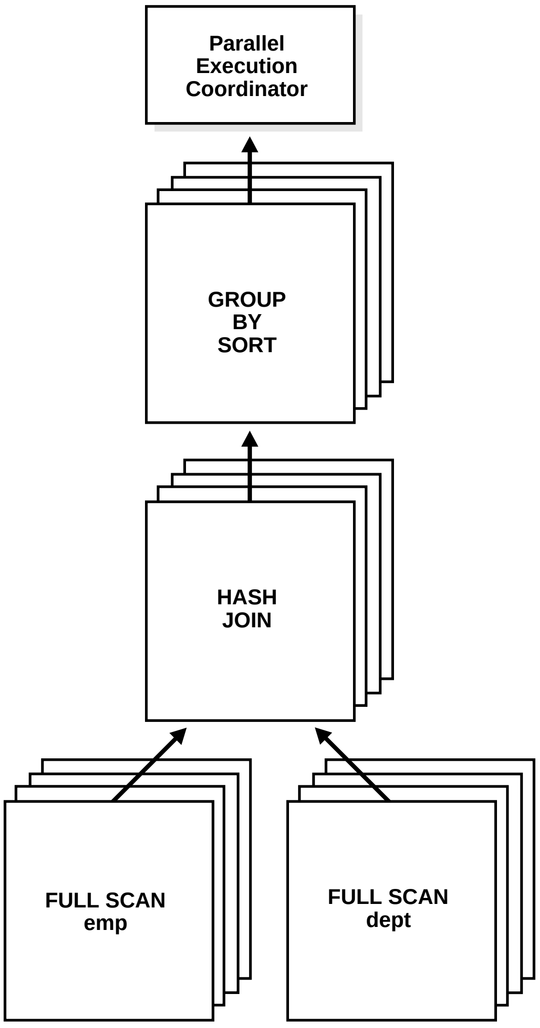
The parallel execution coordinator examines the redistribution requirements of each operation. An operation's redistribution requirement is the way in which the rows operated on by the operation must be divided or redistributed among the parallel execution servers.

After determining the redistribution requirement for each operation in the execution plan, the optimizer determines the order in which the operations must be performed. With this information, the optimizer determines the data flow of the statement.

Figure 21–2 illustrates the data flow for a query to join the `emp` and `dept` tables:

```
SELECT dname, MAX(sal), AVG(sal)
FROM emp, dept
WHERE emp.deptno = dept.deptno
GROUP BY dname;
```

Figure 21–2 Data Flow Diagram for a Join of the EMP and DEPT Tables



Parallelism Between Operations

Operations that require the output of other operations are known as parent operations. In Figure 21–2 the `GROUP BY SORT` operation is the parent of the `HASH JOIN` operation because `GROUP BY SORT` requires the `HASH JOIN` output.

Parent operations can begin consuming rows as soon as the child operations have produced rows. In the previous example, while the parallel execution servers are producing rows in the FULL SCAN dept operation, another set of parallel execution servers can begin to perform the HASH JOIN operation to consume the rows.

Each of the two operations performed concurrently is given its own set of parallel execution servers. Therefore, both query operations and the data flow tree itself have parallelism. The parallelism of an individual operation is called intraoperation parallelism and the parallelism between operations in a data flow tree is called interoperation parallelism.

Due to the producer-consumer nature of the Oracle server's operations, only two operations in a given tree need to be performed simultaneously to minimize execution time.

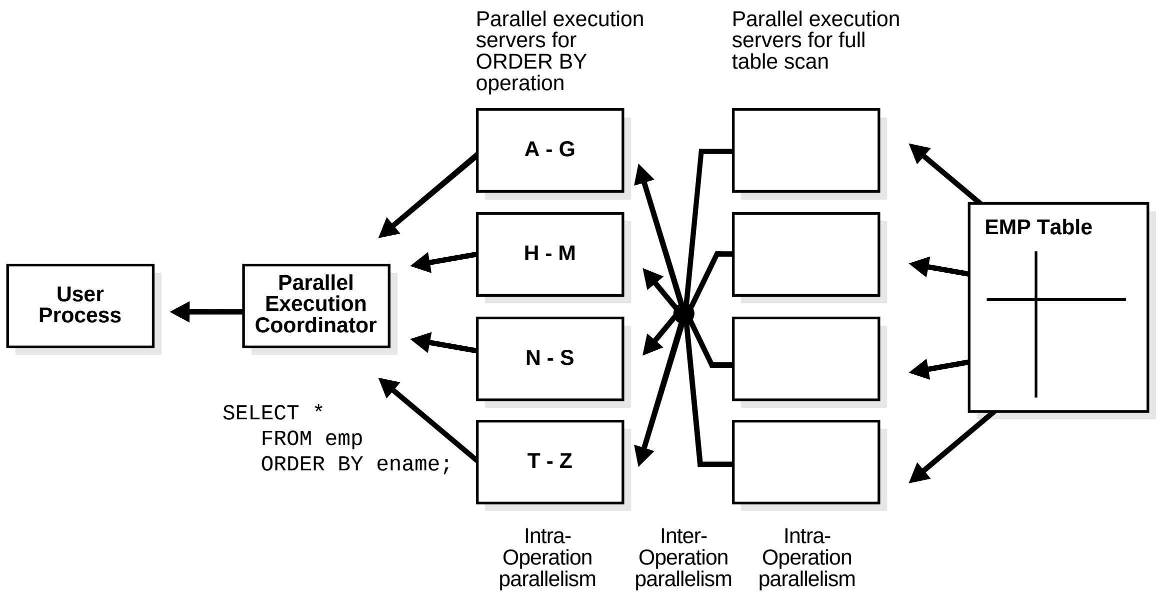
To illustrate intraoperation and interoperation parallelism, consider the following statement:

```
SELECT * FROM emp ORDER BY ename;
```

The execution plan implements a full scan of the emp table. This operation is followed by a sorting of the retrieved rows, based on the value of the ename column. For the sake of this example, assume the ename column is not indexed. Also assume that the DOP for the query is set to 4, which means that four parallel execution servers can be active for any given operation.

Figure 21–3 illustrates the parallel execution of the example query.

Figure 21–3 Interoperation Parallelism and Dynamic Partitioning


Parallel execution servers for ORDER BY operation
Parallel execution servers for full table scan
A - G
H - M
N - S
T - Z
EMP Table
User Process
Parallel Execution Coordinator
SELECT *
FROM emp
ORDER BY ename;
Intra-Operation parallelism
Inter-Operation parallelism
Intra-Operation parallelism

As you can see from Figure 21–3, there are actually eight parallel execution servers involved in the query even though the DOP is 4. This is because a parent and child operator can be performed at the same time (interoperation parallelism).

Also note that all of the parallel execution servers involved in the scan operation send rows to the appropriate parallel execution server performing the `SORT` operation. If a row scanned by a parallel execution server contains a value for the `ename` column between `A` and `G`, that row gets sent to the first `ORDER BY` parallel execution server. When the scan operation is complete, the sorting processes can return the sorted results to the coordinator, which, in turn, returns the complete query results to the user.

Note: When a set of parallel execution servers completes its operation, it moves on to operations higher in the data flow. For example, in Figure 21–3 on page 21-10, if there was another `ORDER BY` operation after the `ORDER BY`, the parallel execution servers performing the table scan would perform the second `ORDER BY` operation after completing the table scan.

Types of Parallelism

The following types of parallelism are discussed in this section:

- Parallel Query
- Parallel DDL
- Parallel DML
- Parallel Execution of Functions
- Other Types of Parallelism

Parallel Query

You can parallelize queries and subqueries in `SELECT` statements. You can also parallelize the query portions of DDL statements and DML statements (`INSERT`, `UPDATE`, and `DELETE`).

However, you cannot parallelize the query portion of a DDL or DML statement if it references a remote object. When you issue a parallel DML or DDL statement in which the query portion references a remote object, the operation is automatically executed serially.

See Also:

- "Operations That Can Be Parallelized" on page 21-3 for information on the query operations that Oracle can parallelize
- "Parallelizing SQL Statements" on page 21-6 for an explanation of how the processes perform parallel queries
- "Distributed Transaction Restrictions" on page 21-27 for examples of queries that reference a remote object
- "Rules for Parallelizing Queries" on page 21-38 for information on the conditions for parallelizing a query and the factors that determine the DOP

Parallel Queries on Index-Organized Tables

The following parallel scan methods are supported on index-organized tables:

- Parallel fast full scan of a nonpartitioned index-organized table
- Parallel fast full scan of a partitioned index-organized table
- Parallel index range scan of a partitioned index-organized table

These scan methods can be used for index-organized tables with overflow areas and for index-organized tables that contain LOBs.

Nonpartitioned Index-Organized Tables

Parallel query on a nonpartitioned index-organized table uses parallel fast full scan. The DOP is determined, in decreasing order of priority, by:

1. A PARALLEL hint (if present)
2. An ALTER SESSION FORCE PARALLEL QUERY statement
3. The parallel degree associated with the table, if the parallel degree is specified in the CREATE TABLE or ALTER TABLE statement

The allocation of work is done by dividing the index segment into a sufficiently large number of block ranges and then assigning the block ranges to parallel execution servers in a demand-driven manner. The overflow blocks corresponding to any row are accessed in a demand-driven manner only by the process which owns that row.

Partitioned Index-Organized Tables

Both index range scan and fast full scan can be performed in parallel. For parallel fast full scan, parallelization is exactly the same as for nonpartitioned index-organized tables. For parallel index range scan on partitioned index-organized tables, the DOP is the minimum of the degree picked up from the above priority list (like in parallel fast full scan) and the number of partitions in the index-organized table. Depending on the DOP, each parallel execution server gets one or more partitions (assigned in a demand-driven manner), each of which contains the primary key index segment and the associated overflow segment, if any.

Parallel Queries on Object Types

Parallel queries can be performed on object type tables and tables containing object type columns. Parallel query for object types supports all of the features that are available for sequential queries on object types, including:

- Methods on object types
- Attribute access of object types
- Constructors to create object type instances
- Object views

- PL/SQL and OCI queries for object types

There are no limitations on the size of the object types for parallel queries.

The following restrictions apply to using parallel query for object types.

- A MAP function is needed to parallelize queries involving joins and sorts (through ORDER BY, GROUP BY, or set operations). In the absence of a MAP function, the query will automatically be executed serially.
- Parallel queries on nested tables are not supported. Even if the table has a parallel attribute or parallel hints, the query will execute serially.
- Parallel DML and parallel DDL are not supported with object types. DML and DDL statements are always performed serially.

In all cases where the query cannot execute in parallel because of any of the above restrictions, the whole query executes serially without giving an error message.

Parallel DDL

This section includes the following topics on parallelism for DDL statements:

- DDL Statements That Can Be Parallelized
- CREATE TABLE ... AS SELECT in Parallel
- Recoverability and Parallel DDL
- Space Management for Parallel DDL

DDL Statements That Can Be Parallelized

You can parallelize DDL statements for tables and indexes that are nonpartitioned or partitioned. Table 21–3 on page 21-45 summarizes the operations that can be parallelized in DDL statements.

The parallel DDL statements for nonpartitioned tables and indexes are:

- CREATE INDEX
- CREATE TABLE ... AS SELECT
- ALTER INDEX ... REBUILD

The parallel DDL statements for partitioned tables and indexes are:

- CREATE INDEX
- CREATE TABLE ... AS SELECT

- ALTER TABLE ... MOVE PARTITION
- ALTER TABLE ... SPLIT PARTITION
- ALTER TABLE ... COALESCE PARTITION
- ALTER INDEX ... REBUILD PARTITION
- ALTER INDEX ... SPLIT PARTITION
  - This statement can be executed in parallel only if the (global) index partition being split is usable.

All of these DDL operations can be performed in no-logging mode for either parallel or serial execution.

CREATE TABLE for an index-organized table can be parallelized either with or without an AS SELECT clause.

Different parallelism is used for different operations (see Table 21–3 on page 21-45). Parallel CREATE TABLE ... AS SELECT statements on partitioned tables and parallel CREATE INDEX statements on partitioned indexes execute with a DOP equal to the number of partitions.

Partition parallel analyze table is made less necessary by the ANALYZE {TABLE, INDEX} PARTITION statements, since parallel analyze of an entire partitioned table can be constructed with multiple user sessions.

Parallel DDL cannot occur on tables with object columns or LOB columns.

See Also:

- *Oracle9i SQL Reference* for information about the syntax and use of parallel DDL statements
- *Oracle9i Application Developer's Guide - Large Objects (LOBs)* for information about LOB restrictions

CREATE TABLE ... AS SELECT in Parallel

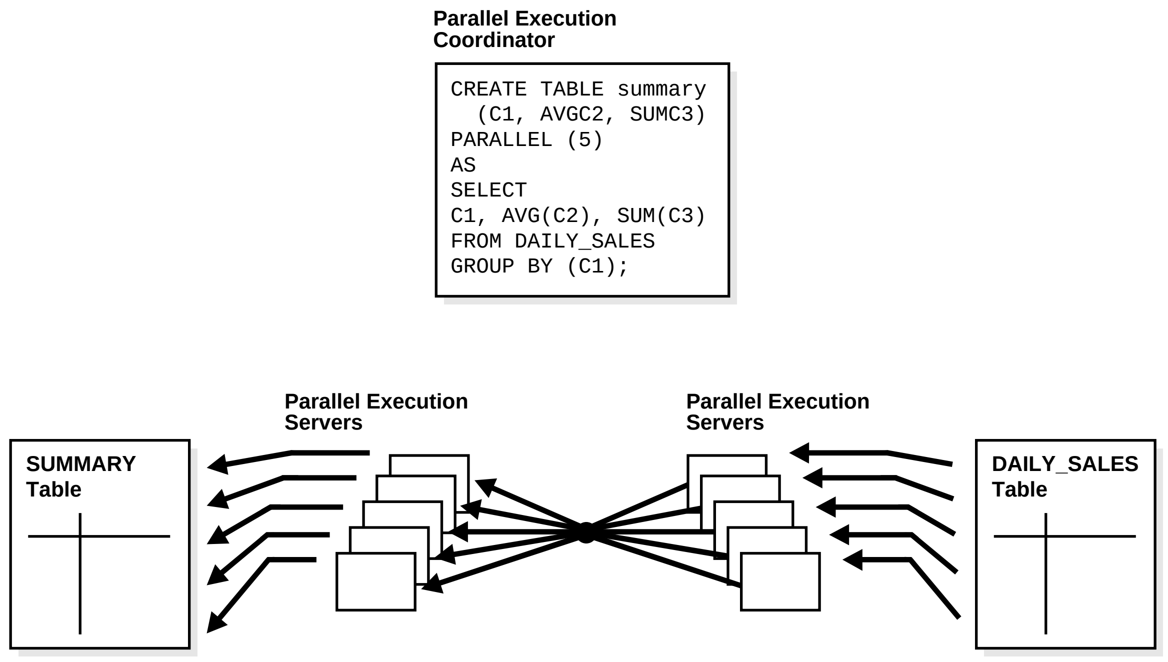
For performance reasons, decision support applications often require large amounts of data to be summarized or rolled up into smaller tables for use with ad hoc, decision support queries. Rollup occurs regularly (such as nightly or weekly) during a short period of system inactivity.

Parallel execution lets you parallelize the query and create operations of creating a table as a subquery from another table or set of tables.

Figure 21–4 illustrates creating a table from a subquery in parallel.

Note: Clustered tables cannot be created and populated in parallel.

Figure 21–4 Creating a Summary Table in Parallel



Recoverability and Parallel DDL

When summary table data is derived from other tables' data, recoverability from media failure for the smaller summary table may not be important and can be turned off during creation of the summary table.

If you disable logging during parallel table creation (or any other parallel DDL operation), you should back up the tablespace containing the table once the table is created to avoid loss of the table due to media failure.

Use the `NOLOGGING` clause of the `CREATE TABLE`, `CREATE INDEX`, `ALTER TABLE`, and `ALTER INDEX` statements to disable undo and redo log generation.

See Also: *Oracle9i Database Administrator's Guide* for information about recoverability of tables created in parallel

Space Management for Parallel DDL

Creating a table or index in parallel has space management implications that affect both the storage space required during a parallel operation and the free space available after a table or index has been created.

Storage Space When Using Dictionary-Managed Tablespaces

When creating a table or index in parallel, each parallel execution server uses the values in the `STORAGE` clause of the `CREATE` statement to create temporary segments to store the rows. Therefore, a table created with a `NEXT` setting of 5 MB and a `PARALLEL DEGREE` of 12 consumes at least 60 megabytes (MB) of storage during table creation because each process starts with an extent of 5 MB. When the parallel execution coordinator combines the segments, some of the segments may be trimmed, and the resulting table may be smaller than the requested 60 MB.

See Also:

- *Oracle9i SQL Reference* for a discussion of the syntax of the `CREATE TABLE` statement
- *Oracle9i Database Administrator's Guide* for information about dictionary-managed tablespaces

Free Space and Parallel DDL

When you create indexes and tables in parallel, each parallel execution server allocates a new extent and fills the extent with the table or index data. Thus, if you create an index with a DOP of 3, the index will have at least three extents initially. Allocation of extents is the same for rebuilding indexes in parallel and for moving, splitting, or rebuilding partitions in parallel.

Serial operations require the schema object to have at least one extent. Parallel creations require that tables or indexes have at least as many extents as there are parallel execution servers creating the schema object.

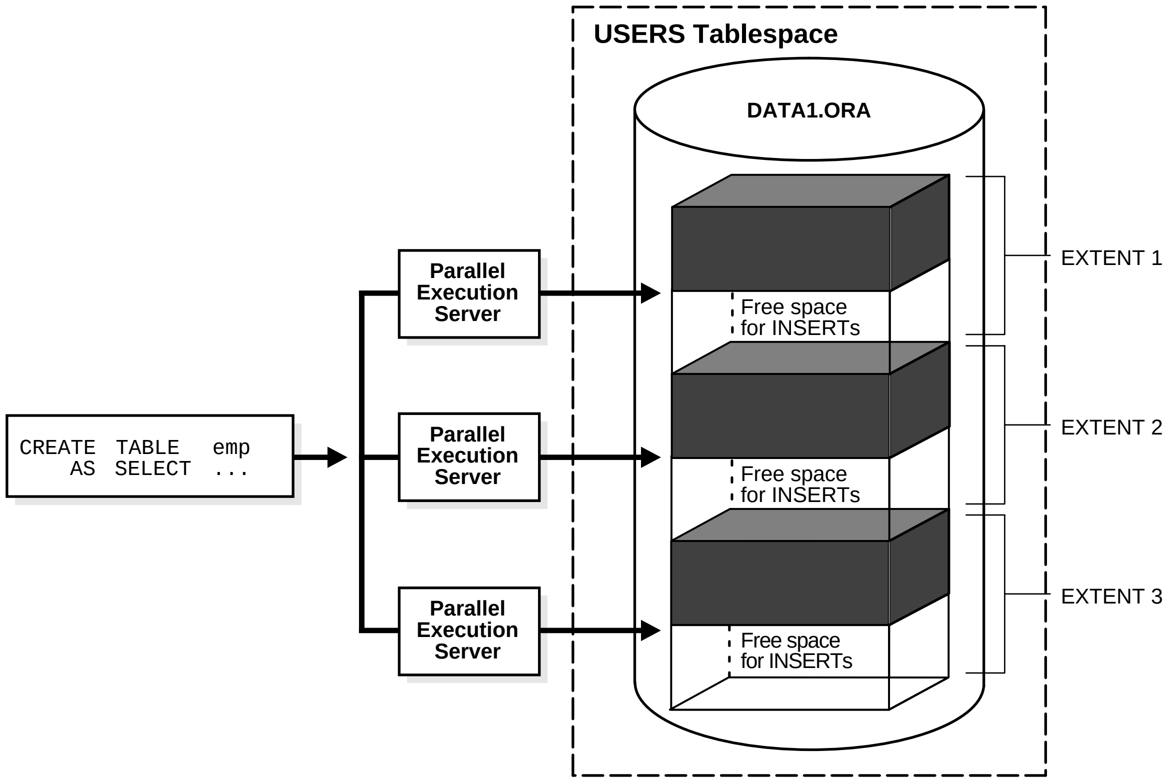
When you create a table or index in parallel, it is possible to create pockets of free space—either external or internal fragmentation. This occurs when the temporary segments used by the parallel execution servers are larger than what is needed to store the rows.

- If the unused space in each temporary segment is larger than the value of the `MINIMUM EXTENT` parameter set at the tablespace level, then Oracle trims the unused space when merging rows from all of the temporary segments into the table or index. The unused space is returned to the system free space and can be allocated for new extents, but it cannot be coalesced into a larger segment because it is not contiguous space (external fragmentation).
- If the unused space in each temporary segment is smaller than the value of the `MINIMUM EXTENT` parameter, then unused space cannot be trimmed when the rows in the temporary segments are merged. This unused space is not returned to the system free space; it becomes part of the table or index (internal fragmentation) and is available only for subsequent inserts or for updates that require additional space.

For example, if you specify a DOP of 3 for a `CREATE TABLE ... AS SELECT` statement, but there is only one datafile in the tablespace, then internal fragmentation may occur, as shown in Figure 21–5 on page 21-18. The pockets of free space within the internal table extents of a datafile cannot be coalesced with other free space and cannot be allocated as extents.

> **See Also:** *Oracle9i Database Performance Guide and Reference* for more information about creating tables and indexes in parallel

Figure 21–5 Unusable Free Space (Internal Fragmentation)



Parallel DML

Parallel DML (`PARALLEL`, `INSERT`, `UPDATE`, and `DELETE`) uses parallel execution mechanisms to speed up or scale up large DML operations against large database tables and indexes.

Note: Although DML generally includes queries, in this chapter the term DML refers only to inserts, updates, and deletes.

Also note that the partitioning option must be installed to enable parallel DML.

This section discusses the following parallel DML topics:

- Advantages of Parallel DML over Manual Parallelism
- When to Use Parallel DML
- Enabling Parallel DML
- Transaction Restrictions for Parallel DML
- Rollback Segments
- Recovery for Parallel DML
- Space Considerations for Parallel DML
- Lock and Enqueue Resources for Parallel DML
- Restrictions on Parallel DML

Advantages of Parallel DML over Manual Parallelism

You can parallelize DML operations manually by issuing multiple DML statements simultaneously against different sets of data. For example, you can parallelize manually by:

- Issuing multiple `INSERT` statements to multiple instances of an Oracle Real Application Cluster to make use of free space from multiple free list blocks.
- Issuing multiple `UPDATE` and `DELETE` statements with different key value ranges or rowid ranges.

However, manual parallelism has the following disadvantages:

- Difficult to use. You have to open multiple sessions (possibly on different instances) and issue multiple statements.
- Lack of transactional properties. The DML statements are issued at different times; and, as a result, the changes are done with inconsistent snapshots of the database. To get atomicity, the commit or rollback of the various statements must be coordinated manually (maybe across instances).
- Work division complexity. You may have to query the table in order to find out the rowid or key value ranges to correctly divide the work.
- Calculation complexity. The calculation of the degree of parallelism can be complex.
- Lack of affinity and resource information. You need to know affinity information to issue the right DML statement at the right instance when

running an Oracle Real Application Cluster. You also have to find out about current resource usage to balance workload across instances.

Parallel DML removes these disadvantages by performing inserts, updates, and deletes in parallel automatically.

When to Use Parallel DML

Parallel DML operations are mainly used to speed up large DML operations against large database objects. Parallel DML is useful in a DSS environment where the performance and scalability of accessing large objects are important. Parallel DML complements parallel query in providing you with both querying and updating capabilities for your DSS databases.

The overhead of setting up parallelism makes parallel DML operations infeasible for short OLTP transactions. However, parallel DML operations can speed up batch jobs running in an OLTP database.

Some of the scenarios where parallel DML is used include:

- Refreshing Tables in a Data Warehouse System
- Creating Intermediate Summary Tables
- Using Scoring Tables
- Updating Historical Tables
- Running Batch Jobs

Refreshing Tables in a Data Warehouse System In a data warehouse system, large tables need to be refreshed (updated) periodically with new or modified data from the production system. You can do this efficiently by using parallel DML combined with updatable join views. You can also use the `MERGE` statement.

The data that needs to be refreshed is generally loaded into a temporary table before starting the refresh process. This table contains either new rows or rows that have been updated since the last refresh of the data warehouse. You can use an updatable join view with parallel `UPDATE` to refresh the updated rows, and you can use an anti-hash join with parallel `INSERT` to refresh the new rows.

See Also: Chapter 14, "Maintaining the Data Warehouse" for further information

Creating Intermediate Summary Tables In a DSS environment, many applications require complex computations that involve constructing and manipulating many large intermediate summary tables. These summary tables are often temporary and frequently do not need to be logged. Parallel DML can speed up the operations against these large intermediate tables. One benefit is that you can put incremental results in the intermediate tables and perform parallel update.

In addition, the summary tables may contain cumulative or comparison information which has to persist beyond application sessions; thus, temporary tables are not feasible. Parallel DML operations can speed up the changes to these large summary tables.

Using Scoring Tables Many DSS applications score customers periodically based on a set of criteria. The scores are usually stored in large DSS tables. The score information is then used in making a decision, for example, inclusion in a mailing list.

This scoring activity queries and updates a large number of rows in the large table. Parallel DML can speed up the operations against these large tables.

Updating Historical Tables Historical tables describe the business transactions of an enterprise over a recent time interval. Periodically, the DBA deletes the set of oldest rows and inserts a set of new rows into the table. Parallel `INSERT` ... `SELECT` and parallel `DELETE` operations can speed up this rollover task.

Although you can also use parallel direct loader (SQL*Loader) to insert bulk data from an external source, parallel `INSERT` ... `SELECT` is faster for inserting data that already exists in another table in the database.

Dropping a partition can also be used to delete old rows. However, to do this, the table has to be partitioned by date and with the appropriate time interval.

Running Batch Jobs Batch jobs executed in an OLTP database during off hours have a fixed time window in which the jobs must complete. A good way to ensure timely job completion is to parallelize their operations. As the work load increases, more machine resources can be added; the scaleup property of parallel operations ensures that the time constraint can be met.

Enabling Parallel DML

A DML statement can be parallelized only if you have explicitly enabled parallel DML in the session with the `ENABLE PARALLEL DML` clause of the `ALTER SESSION` statement. This mode is required because parallel DML and serial DML have different locking, transaction, and disk space requirements.

The default mode of a session is `DISABLE PARALLEL DML`. When parallel DML is disabled, no DML will be executed in parallel even if the `PARALLEL` hint is used.

When parallel DML is enabled in a session, all DML statements in this session will be considered for parallel execution. However, even if parallel DML is enabled, the DML operation may still execute serially if there are no parallel hints or no tables with a parallel attribute or if restrictions on parallel operations are violated.

The session's `PARALLEL DML` mode does not influence the parallelism of `SELECT` statements, DDL statements, and the query portions of DML statements. Thus, if this mode is not set, the DML operation is not parallelized, but scans or join operations within the DML statement may still be parallelized.

See Also:

- "Space Considerations for Parallel DML" on page 21-24
- "Lock and Enqueue Resources for Parallel DML" on page 21-24
- "Restrictions on Parallel DML" on page 21-24

Transaction Restrictions for Parallel DML

To execute a DML operation in parallel, the parallel execution coordinator acquires or spawns parallel execution servers, and each parallel execution server executes a portion of the work under its own parallel process transaction.

- Each parallel execution server creates a different parallel process transaction.
- To reduce contention on the rollback segments, only a few parallel process transactions should reside in the same rollback segment. See "Rollback Segments" on page 21-23.

The coordinator also has its own coordinator transaction, which can have its own rollback segment. In order to ensure user-level transactional atomicity, the coordinator uses a two-phase commit protocol to commit the changes performed by the parallel process transactions.

A session that is enabled for parallel DML may put transactions in the session in a special mode: If any DML statement in a transaction modifies a table in parallel, no subsequent serial or parallel query or DML statement can access the same table again in that transaction. This means that the results of parallel modifications cannot be seen during the transaction.

Serial or parallel statements that attempt to access a table that has already been modified in parallel within the same transaction are rejected with an error message.

If a PL/SQL procedure or block is executed in a parallel DML enabled session, then this rule applies to statements in the procedure or block.

Rollback Segments

Oracle assigns transactions to rollback segments that have the fewest active transactions. To speed up both forward and undo operations, you should create and bring online enough rollback segments so that at most two parallel process transactions are assigned to one rollback segment.

The `SET TRANSACTION USE ROLLBACK SEGMENT` statement is ignored when parallel DML is used because parallel DML requires more than one rollback segment for performance.

You should create the rollback segments in tablespaces that have enough space for them to extend when necessary. You can then set the `MAXEXTENTS` storage parameters for the rollback segments to `UNLIMITED`. Also, set the `OPTIMAL` value for the rollback segments so that after the parallel DML transactions commit, the rollback segments are shrunk to the `OPTIMAL` size.

Recovery for Parallel DML

The time required to roll back a parallel DML operation is roughly equal to the time it takes to perform the forward operation.

Oracle supports parallel rollback after transaction and process failures, and after instance and system failures. Oracle can parallelize both the rolling forward stage and the rolling back stage of transaction recovery.

> **See Also:** *Oracle9i Backup and Recovery Concepts* for details about parallel rollback

Transaction Recovery for User-Issued Rollback A user-issued rollback in a transaction failure due to statement error is performed in parallel by the parallel execution coordinator and the parallel execution servers. The rollback takes approximately the same amount of time as the forward transaction.

Process Recovery Recovery from the failure of a parallel execution coordinator or parallel execution server is performed by the `PMON` process. If a parallel execution server or a parallel execution coordinator fails, `PMON` rolls back the work from that process and all other processes in the transaction roll back their changes.

System Recovery Recovery from a system failure requuires a new startup. Recovery is performed by the SMON process and any recovery server processes spawned by SMON. Parallel DML statements may be recovered using parallel rollback. If the initialization parameter COMPATIBLE is set to 8.1.3 or greater, Fast-Start On-Demand Rollback enables dead transactions to be recovered, on demand one block at a time.

Instance Recovery (Oracle Real Application Clusters) Recovery from an instance failure in an Oracle Real Application Cluster is performed by the recovery processes (that is, the SMON processes and any recovery server processes they spawn) of other live instances. Each recovery process of the live instances can recover the parallel execution coordinator or parallel execution server transactions of the failed instance independently.

Space Considerations for Parallel DML

Parallel UPDATE uses the space in the existing object, while direct-path INSERT gets new segments for the data.

Space usage characteristics may be different in parallel than sequential execution because multiple concurrent child transactions modify the object.

Lock and Enqueue Resources for Parallel DML

A parallel DML operation's lock and enqueue resource requirements are very different from the serial DML requirements. Parallel DML holds many more locks, so you should increase the starting value of the ENQUEUE_RESOURCES and DML_LOCKS parameters.

See Also: "DML_LOCKS" on page 21-63

Restrictions on Parallel DML

The following restrictions apply to parallel DML (including direct-path INSERT):

- UPDATE, MERGE, and DELETE operations are not parallelized on nonpartitioned tables.
- A transaction can contain multiple parallel DML statements that modify different tables, but after a parallel DML statement modifies a table, no subsequent serial or parallel statement (DML or query) can access the same table again in that transaction.

  - This restriction also exists after a serial direct-path `INSERT` statement: no subsequent SQL statement (DML or query) can access the modified table during that transaction.
  - Queries that access the same table are allowed before a parallel DML or direct-path `INSERT` statement, but not after.
  - Any serial or parallel statements attempting to access a table that has already been modified by a parallel `UPDATE`, `DELETE`, or `MERGE`, or a direct-path `INSERT` during the same transaction are rejected with an error message.
- If the initialization parameter `ROW_LOCKING` is set to `INTENT`, then inserts, updates, merges, and deletes are not parallelized (regardless of the serializable mode).
- Parallel DML operations cannot be done on tables with triggers.
- Replication functionality is not supported for parallel DML.
- Parallel DML cannot occur in the presence of certain constraints: self-referential integrity, delete cascade, and deferred integrity. In addition, for direct-path `INSERT`, there is no support for any referential integrity.
- Parallel DML can be done on tables with object or `LOB` columns as long as you are not touching the objects or `LOB`s.
- A transaction involved in a parallel DML operation cannot be or become a distributed transaction.
- Clustered tables are not supported.

Violations of these restrictions cause the statement to execute serially without warnings or error messages (except for the restriction on statements accessing the same table in a transaction, which can cause error messages). For example, an update is serialized if it is on a nonpartitioned table.

> **See Also:** *Oracle9i Application Developer's Guide - Large Objects (LOBs)* for more information about LOB restrictions

Partitioning Key Restriction You can only update the partitioning key of a partitioned table to a new value if the update does not cause the row to move to a new partition. The update is possible if the table is defined with the row movement clause enabled.

Function Restrictions The function restrictions for parallel DML are the same as those for parallel DDL and parallel query.

> **See Also:** "Parallel Execution of Functions" on page 21-28

Data Integrity Restrictions

This section describes the interactions of integrity constraints and parallel DML statements.

NOT NULL and CHECK These types of integrity constraints are allowed. They are not a problem for parallel DML because they are enforced on the column and row level, respectively.

UNIQUE and PRIMARY KEY These types of integrity constraints are allowed.

FOREIGN KEY (Referential Integrity) Restrictions for referential integrity occur whenever a DML operation on one table could cause a recursive DML operation on another table. These restrictions also apply when, in order to perform an integrity check, it is necessary to see simultaneously all changes made to the object being modified.

Table 21–1 lists all of the operations that are possible on tables that are involved in referential integrity constraints.

Table 21–1 Referential Integrity Restrictions

DML Statement	Issued on Parent	Issued on Child	Self-Referential
`INSERT`	(Not applicable)	Not parallelized	Not parallelized
`MERGE`	(Not applicable)	Not parallelized	Not parallelized
`UPDATE` No Action	Supported	Supported	Not parallelized
`DELETE` No Action	Supported	Supported	Not parallelized
`DELETE` Cascade	Not parallelized	(Not applicable)	Not parallelized

Delete Cascade Delete on tables having a foreign key with delete cascade is not parallelized because parallel execution servers will try to delete rows from multiple partitions (parent and child tables).

Self-Referential Integrity DML on tables with self-referential integrity constraints is not parallelized if the referenced keys (primary keys) are involved. For DML on all other columns, parallelism is possible.

Deferrable Integrity Constraints If any deferrable constraints apply to the table being operated on, the DML operation will not be parallelized.

Trigger Restrictions

A DML operation will not be parallelized if the affected tables contain enabled triggers that may get fired as a result of the statement. This implies that DML statements on tables that are being replicated will not be parallelized.

Relevant triggers must be disabled in order to parallelize DML on the table. Note that, if you enable or disable triggers, the dependent shared cursors are invalidated.

Distributed Transaction Restrictions

A DML operation cannot be parallelized if it is in a distributed transaction or if the DML or the query operation is against a remote object.

Example 21–1 Distributed Transaction Parallelization: Example 1

In this example, the DML statement queries a remote object:

```
INSERT /* APPEND PARALLEL (t3,2) */ INTO t3 SELECT * FROM t4@dblink;
```

The query operation is executed serially without notification because it references a remote object.

Example 21–2 Distributed Transaction Parallelization: Example 2

In this example, the DML operation is applied to a remote object:

```
DELETE /*+ PARALLEL (t1, 2) */ FROM t1@dblink;
```

The `DELETE` operation is not parallelized because it references a remote object.

Example 21–3 Distributed Transaction Parallelization: Example 3

In this example, the DML operation is in a distributed transaction:

```
SELECT * FROM t1@dblink;
DELETE /*+ PARALLEL (t2,2) */ FROM t2;
COMMIT;
```

The `DELETE` operation is not parallelized because it occurs in a distributed transaction (which is started by the `SELECT` statement).

Parallel Execution of Functions

SQL statements can contain user-defined functions written in PL/SQL, in Java, or as external procedures in C that can appear as part of the SELECT list, SET clause, or WHERE clause. When the SQL statement is parallelized, these functions are executed on a per-row basis by the parallel execution server. Any PL/SQL package variables or Java static attributes used by the function are entirely private to each individual parallel execution process and are newly initialized when each row is processed, rather than being copied from the original session. Because of this, not all functions will generate correct results if executed in parallel.

User-written table functions can appear in the statement's FROM list. These functions act like source tables in that they output rows. Table functions are initialized once during the statement at the start of each parallel execution process. As above, any variables are entirely private to the parallel execution process.

Functions in Parallel Queries

In a SELECT statement or a subquery in a DML or DDL statement, a user-written function may be executed in parallel if it has been declared with the PARALLEL_ENABLE keyword, if it is declared in a package or type and has a PRAGMA RESTRICT_REFERENCES that indicates all of WNDS, RNPS, and WNPS, or if it is declared with CREATE FUNCTION and the system can analyze the body of the PL/SQL code and determine that the code neither writes to the database nor reads or modifies package variables.

Other parts of a query or subquery can sometimes execute in parallel even if a given function execution must remain serial.

See Also:

- *Oracle9i Application Developer's Guide - Fundamentals* for information about the PRAGMA RESTRICT_REFERENCES
- *Oracle9i SQL Reference* for information about CREATE FUNCTION

Functions in Parallel DML and DDL Statements

In a parallel DML or DDL statement, as in a parallel query, a user-written function may be executed in parallel if it has been declared with the PARALLEL_ENABLE keyword, if it is declared in a package or type and has a PRAGMA RESTRICT_REFERENCES that indicates all of RNDS, WNDS, RNPS, and WNPS, or if it is declared with CREATE FUNCTION and the system can analyze the body of the PL/SQL code and determine that the code neither reads nor writes to the database or reads nor modifies package variables.

For a parallel DML statement, any function call that cannot be executed in parallel causes the entire DML statement to be executed serially.

For an `INSERT ... SELECT` or `CREATE TABLE ... AS SELECT` statement, function calls in the query portion are parallelized according to the parallel query rules in the prior paragraph. The query may be parallelized even if the remainder of the statement must execute serially, or vice versa.

Other Types of Parallelism

In addition to parallel SQL execution, Oracle can use parallelism for the following types of operations:

- Parallel recovery
- Parallel propagation (replication)
- Parallel load (the SQL*Loader utility)

Like parallel SQL, parallel recovery and propagation are performed by a parallel execution coordinator and multiple parallel execution servers. Parallel load, however, uses a different mechanism.

The behavior of the parallel execution coordinator and parallel execution servers may differ, depending on what kind of operation they perform (SQL, recovery, or propagation). For example, if all parallel execution servers in the pool are occupied and the maximum number of parallel execution servers has been started:

- In parallel SQL, the parallel execution coordinator switches to serial processing.
- In parallel propagation, the parallel execution coordinator returns an error.

For a given session, the parallel execution coordinator coordinates only one kind of operation. A parallel execution coordinator cannot coordinate, for example, parallel SQL and parallel recovery or propagation at the same time.

See Also:

- *Oracle9i Database Utilities* for information about parallel load and SQL*Loader
- *Oracle9i User-Managed Backup and Recovery Guide* for information about parallel media recovery
- *Oracle9i Database Performance Guide and Reference* for information about parallel instance recovery
- *Oracle9i Replication* for information about parallel propagation

Initializing and Tuning Parameters for Parallel Execution

You can initialize and automatically tune parallel execution by setting the initialization parameter `PARALLEL_AUTOMATIC_TUNING` to `TRUE`. Once enabled, automated parallel execution controls values for all parameters related to parallel execution. These parameters affect several aspects of server processing, namely, the DOP, the adaptive multiuser feature, and memory sizing.

With parallel automatic tuning enabled, Oracle determines parameter settings for each environment based on the number of CPUs on your system at database startup and the value set for `PARALLEL_THREADS_PER_CPU`. The default values Oracle sets for parallel execution processing when `PARALLEL_AUTOMATIC_TUNING` is `TRUE` are usually optimal for most environments. In most cases, Oracle's automatically derived settings are at least as effective as manually derived settings.

You can also manually tune parallel execution parameters; however, Oracle recommends using automated parallel execution. Manual tuning of parallel execution is more complex than using automated tuning for two reasons: manual parallel execution tuning requires more attentive administration than automated tuning, and manual tuning is prone to user-load and system-resource miscalculations.

Initializing and tuning parallel execution involves the following steps:

- Selecting Automated or Manual Tuning of Parallel Execution
- Using Automatically Derived Parameter Settings
- Setting the Degree of Parallelism
- How Oracle Determines the Degree of Parallelism for Operations
- Balancing the Workload

- Parallelization Rules for SQL Statements
- Enabling Parallelism for Tables and Queries
- Degree of Parallelism and Adaptive Multiuser: How They Interact
- Forcing Parallel Execution for a Session
- Controlling Performance with the Degree of Parallelism

Selecting Automated or Manual Tuning of Parallel Execution

There are several ways to initialize and tune parallel execution. You can make your environment fully automated for parallel execution. As mentioned, by setting PARALLEL_AUTOMATIC_TUNING to TRUE. You can further customize this type of environment by overriding some of the automatically derived values.

You can also leave PARALLEL_AUTOMATIC_TUNING at its default value of FALSE and manually set the parameters that affect parallel execution. For most OLTP environments and other types of systems that would not benefit from parallel execution, do not enable parallel execution.

Note: Well-established, manually tuned systems that achieve desired resource-use patterns might not benefit from automated parallel execution.

Using Automatically Derived Parameter Settings

When PARALLEL_AUTOMATIC_TUNING is TRUE, Oracle automatically sets other parameters, as shown in Table 21–2. For most systems, you do not need to make further adjustments to have an adequately tuned, fully automated parallel execution environment.

Table 21–2 Parameters Affected by PARALLEL_AUTOMATIC_TUNING

Parameter	Default	Default if PARALLEL_AUTOMATIC_ TUNING = TRUE	Comments
PARALLEL_ ADAPTIVE_ MULTI_USER	FALSE	TRUE	
PROCESSES	6	The greater of: 1.2 x PARALLEL_MAX_SERVERS or PARALLEL_MAX_SERVERS + 6 + 5 + (CPUs x 4)	Value is forced up to minimum if PARALLEL_AUTOMATIC_TUNING is TRUE.
SESSIONS	(PROCESSES x 1.1) + 5	(PROCESSES x 1.1) + 5	Automatic parallel tuning indirectly affects SESSIONS. If you do not set SESSIONS, Oracle sets it based on the value for PROCESSES.
PARALLEL_MAX_ SERVERS	5	CPU x 10	Use this limit to maximize the number of processes that parallel execution uses. The value for this parameter is port-specific so processing can vary from system to system.
LARGE_POOL_SIZE	None	PARALLEL_EXECUTION_POOL + Shared Server heap requirements + Backup buffer requests + 600 KB	Oracle does not allocate parallel execution buffers from the SHARED_POOL when PARALLEL_ AUTOMATIC_TUNING is set to TRUE.
PARALLEL_ EXECUTION_ MESSAGE_SIZE	2 KB (port specific)	4 KB (port specific)	Default increases because Oracle allocates memory from the LARGE_ POOL.

As mentioned, you can manually adjust the parameters shown in Table 21–2, even if you set PARALLEL_AUTOMATIC_TUNING to TRUE. You might need to do this if you have a highly customized environment or if your system does not perform optimally using the completely automated settings.

Setting the Degree of Parallelism

The parallel execution coordinator may enlist two or more of the instance's parallel execution servers to process a SQL statement. The number of parallel execution servers associated with a single operation is known as the degree of parallelism.

The DOP is specified in the following ways:

- At the statement level:
  - With hints
  - With the PARALLEL clause
- At the session level by issuing the ALTER SESSION FORCE PARALLEL statement
- At the table level in the table's definition
- At the index level in the index's definition

The following example shows a statement that sets the DOP to 4 on a table:

```
ALTER TABLE emp PARALLEL 4;
```

This next example sets the DOP on an index to 4:

```
ALTER INDEX iemp PARALLEL 4;
```

This last example sets a hint to 4 on a query:

```
SELECT /*+ PARALLEL(emp, 4) */ COUNT(*) FROM emp;
```

Note that the DOP applies directly only to intraoperation parallelism. If interoperation parallelism is possible, the total number of parallel execution servers for a statement can be twice the specified DOP. No more than two operations can be performed simultaneously.

Parallel execution is designed to effectively use multiple CPUs and disks to answer queries quickly. When multiple users employ parallel execution at the same time, available CPU, memory, and disk resources may be quickly exhausted. Oracle provides several ways to deal with resource utilization in conjunction with parallel execution, including:

- The adaptive multiuser algorithm, which reduces the DOP as the load on the system increases. You can turn this option on with the PARALLEL_ADAPTIVE_ MULTI_USER parameter of the ALTER SYSTEM statement or in your initialization file.
- User resource limits and profiles, which allow you to set limits on the amount of various system resources available to each user as part of a user's security domain.
- The Database Resource Manager, which enables you to allocate resources to different groups of users.

See Also:

- *Oracle9i Database Reference* and *Oracle9i Database Performance Guide and Reference* for information about the syntax of the SELECT and ALTER statements
- *Oracle9i SQL Reference* for the syntax of the ALTER SYSTEM statement
- "Forcing Parallel Execution for a Session" on page 21-47

How Oracle Determines the Degree of Parallelism for Operations

The parallel execution coordinator determines the DOP by considering several specifications. The coordinator:

1. Checks for hints or a PARALLEL clause specified in the SQL statement itself
2. Checks for a session value set by the ALTER SESSION FORCE PARALLEL statement
3. Looks at the table's or index's definition

After a DOP is found in one of these specifications, it becomes the DOP for the operation.

Hints, PARALLEL clauses, table or index definitions, and default values only determine the number of parallel execution servers that the coordinator requests for a given operation. The actual number of parallel execution servers used depends upon how many processes are available in the parallel execution server pool and whether interoperation parallelism is possible.

See Also:

- "The Parallel Execution Server Pool" on page 21-3
- "Parallelism Between Operations" on page 21-8
- "Default Degree of Parallelism" on page 21-35
- "Parallelization Rules for SQL Statements" on page 21-38

Hints

You can specify hints in a SQL statement to set the DOP for a table or index and for the caching behavior of the operation.

- The PARALLEL hint is used only for operations on tables. You can use it to parallelize queries and DML statements (INSERT, UPDATE, and DELETE).
- The PARALLEL_INDEX hint parallelizes an index range scan of a partitioned index. (In an index operation, the PARALLEL hint is not valid and is ignored.)

> **See Also:** *Oracle9i Database Performance Guide and Reference* for information about using hints in SQL statements and the specific syntax for the PARALLEL, NOPARALLEL, PARALLEL_INDEX, CACHE, and NOCACHE hints

Table and Index Definitions

You can specify the DOP within a table or index definition by using one of the following statements: CREATE TABLE, ALTER TABLE, CREATE INDEX, or ALTER INDEX.

> **See Also:** *Oracle9i SQL Reference* for information about the complete syntax of SQL statements

Default Degree of Parallelism

The default DOP is used when you ask to parallelize an operation but you do not specify a DOP in a hint or within the definition of a table or index. The default DOP is appropriate for most applications.

The default DOP for a SQL statement is determined by the following factors:

- The number of CPUs for all Oracle Real Application Cluster instances in the system, and the value of the parameter PARALLEL_THREADS_PER_CPU.
- For parallelizing by partition, the number of partitions that will be accessed, based on partition pruning.
- For parallel DML operations with global index maintenance, the minimum number of transaction free lists among all the global indexes to be updated. The minimum number of transaction free lists for a partitioned global index is the minimum number across all index partitions. This is a requirement to prevent self-deadlock.

> **Note:** Oracle obtains the information about CPUs from the operating system.

The above factors determine the default number of parallel execution servers to use. However, the actual number of processes used is limited by their availability on the requested instances during run time. The initialization parameter PARALLEL_MAX_SERVERS sets an upper limit on the total number of parallel execution servers that an instance can have.

If a minimum fraction of the desired parallel execution servers is not available (specified by the initialization parameter PARALLEL_MIN_PERCENT), a user error is produced. The user can then retry the query with less parallelism.

> **See Also:** *Oracle9i Database Performance Guide and Reference* for information about adjusting the DOP

Adaptive Multiuser Algorithm

When the adaptive multiuser algorithm is enabled, the parallel execution coordinator varies the DOP according to the system load. The Database Resource Manager determines the load by calculating the number of allocated threads. If the number of threads currently allocated is larger than the optimal number of threads, given the number of available CPUs, the algorithm reduces the DOP. This reduction improves throughput by avoiding overallocation of resources.

Minimum Number of Parallel Execution Servers

Oracle can perform an operation in parallel as long as at least two parallel execution servers are available. If too few parallel execution servers are available, your SQL statement may execute slower than expected. You can specify the minimum percentage of requested parallel execution servers that must be available in order for the operation to execute. This strategy ensures that your SQL statement executes with a minimum acceptable parallel performance. If the minimum percentage of requested parallel execution servers is not available, the SQL statement does not execute and returns an error.

The initialization parameter PARALLEL_MIN_PERCENT specifies the desired minimum percentage of requested parallel execution servers. This parameter affects DML and DDL operations as well as queries.

For example, if you specify 50 for this parameter, then at least 50 percent of the parallel execution servers requested for any parallel operation must be available in order for the operation to succeed. If 20 parallel execution servers are requested, then at least 10 must be available or an error is returned to the user. If PARALLEL_MIN_PERCENT is set to null, then all parallel operations will proceed as long as at least two parallel execution servers are available for processing.

Limiting the Number of Available Instances

In an Oracle Real Application Cluster, instance groups can be used to limit the number of instances that participate in a parallel operation. You can create any number of instance groups, each consisting of one or more instances. You can then specify which instance group is to be used for any or all parallel operations. Parallel execution servers will only be used on instances which are members of the specified instance group.

> **See Also:** *Oracle9i Real Application Clusters Administration* and *Oracle9i Real Application Clusters Deployment and Performance* for more information about instance groups

Balancing the Workload

To optimize performance, all parallel execution servers should have equal work loads. For SQL statements parallelized by block range or by parallel execution servers, the workload is dynamically divided among the parallel execution servers. This minimizes workload skewing, which occurs when some parallel execution servers perform significantly more work than the other processes.

For SQL statements parallelized by partitions, if the workload is evenly distributed among the partitions, you can optimize performance by matching the number of parallel execution servers to the number of partitions or by choosing a DOP in which the number of partitions is a multiple of the number of processes.

For example, suppose a table has 10 partition, and a parallel operation divides the work evenly among them. You can use 10 parallel execution servers (DOP equals 10) to do the work in approximately one-tenth the time that one process would take. You might also use five processes to do the work in one-fifth the time, or two processes to do the work in one-half the time.

If, however, you use nine processes to work on 10 partitions, the first process to finish its work on one partition then begins work on the 10th partition; and as the other processes finish their work, they become idle. This configuration does not provide good performance when the work is evenly divided among partitions. When the work is unevenly divided, the performance varies depending on whether the partition that is left for last has more or less work than the other partitions.

Similarly, suppose you use four processes to work on 10 partitions and the work is evenly divided. In this case, each process works on a second partition after finishing its first partition, but only two of the processes work on a third partition while the other two remain idle.

In general, you cannot assume that the time taken to perform a parallel operation on a given number of partitions (N) with a given number of parallel execution servers (P) will be N / P. This formula does not take into account the possibility that some processes might have to wait while others finish working on the last partitions. By choosing an appropriate DOP, however, you can minimize the workload skew and optimize performance.

See Also: "Affinity and Parallel DML" on page 21-78 for information about balancing the workload with disk affinity

Parallelization Rules for SQL Statements

A SQL statement can be parallelized if it includes a parallel hint or if the table or index being operated on has been declared `PARALLEL` with a `CREATE` or `ALTER` statement. In addition, a DDL statement can be parallelized by using the `PARALLEL` clause. However, not all of these methods apply to all types of SQL statements.

Parallelization has two components: the decision to parallelize and the DOP. These components are determined differently for queries, DDL operations, and DML operations.

To determine the DOP, Oracle looks at the reference objects:

- Parallel query looks at each table and index, in the portion of the query being parallelized, to determine which is the reference table. The basic rule is to pick the table or index with the largest DOP.
- For parallel DML (`INSERT`, `UPDATE`, `MERGE`, and `DELETE`), the reference object that determines the DOP is the table being modified by an insert, update, or delete operation. Parallel DML also adds some limits to the DOP to prevent deadlock. If the parallel DML statement includes a subquery, the subquery's DOP is the same as the DML operation.
- For parallel DDL, the reference object that determines the DOP is the table, index, or partition being created, rebuilt, split, or moved. If the parallel DDL statement includes a subquery, the subquery's DOP is the same as the DDL operation.

Rules for Parallelizing Queries

Decision to Parallelize A `SELECT` statement can be parallelized only if the following conditions are satisfied:

1. The query includes a parallel hint specification (PARALLEL or PARALLEL_INDEX) or the schema objects referred to in the query have a PARALLEL declaration associated with them.
2. At least one of the tables specified in the query requires one of the following:
   - A full table scan
   - An index range scan spanning multiple partitions

Degree of Parallelism The DOP for a query is determined by the following rules:

1. The query uses the maximum DOP taken from all of the table declarations involved in the query and all of the potential indexes that are candidates to satisfy the query (the reference objects). That is, the table or index that has the greatest DOP determines the query's DOP (maximum query directive).
2. If a table has both a parallel hint specification in the query and a parallel declaration in its table specification, the hint specification takes precedence over parallel declaration specification. See Table 21–3 on page 21-45 for precedence rules.

Rules for Parallelizing UPDATE, MERGE, and DELETE

UPDATE, MERGE, and DELETE operations are parallelized by partition or subpartition. Updates, merges, and deletes can only be parallelized on partitioned tables. Update, merge, and delete parallelism are not possible within a partition, nor on a nonpartitioned table.

You have two ways to specify parallel directives for UPDATE, MERGE, and DELETE operations (assuming that PARALLEL DML mode is enabled):

1. Use a parallel clause in the definition of the table being updated or deleted (the reference object).
2. Use an update, merge, or delete parallel hint in the statement.

Parallel hints are placed immediately after the UPDATE, MERGE, or DELETE keywords in UPDATE, MERGE, and DELETE statements. The hint also applies to the underlying scan of the table being changed.

You can use the ALTER SESSION FORCE PARALLEL DML statement to override parallel clauses for subsequent UPDATE, MERGE, and DELETE statements in a session. Parallel hints in UPDATE, MERGE, and DELETE statements override the ALTER SESSION FORCE PARALLEL DML statement.

Decision to Parallelize The following rule determines whether the UPDATE, MERGE, or DELETE operation should be parallelized:

> The UPDATE or DELETE operation will be parallelized if and only if at least one of the following is true:
>
> - The table being updated or deleted has a PARALLEL specification.
> - The PARALLEL hint is specified in the DML statement.
> - An ALTER SESSION FORCE PARALLEL DML statement has been issued previously during the session.

If the statement contains subqueries or updatable views, then they may have their own separate parallel hints or clauses. However, these parallel directives do not affect the decision to parallelize the UPDATE, MERGE, or DELETE.

The parallel hint or clause on the tables is used by both the query and the UPDATE, MERGE, DELETE portions to determine parallelism, the decision to parallelize the UPDATE, MERGE, or DELETE portion is made independently of the query portion, and vice versa.

Degree of Parallelism The DOP is determined by the same rules as for the queries. Note that in the case of UPDATE and DELETE operations, only the target table to be modified (the only reference object) is involved. Thus, the UPDATE or DELETE parallel hint specification takes precedence over the parallel declaration specification of the target table. In other words, the precedence order is: MERGE, UPDATE, DELETE hint > Session > Parallel declaration specification of target table

See Table 21–3 on page 21-45 for precedence rules.

The maximum DOP you can achieve is equal to the number of partitions (or subpartitions in the case of composite subpartitions) in the table. A parallel execution server can update or merge into, or delete from multiple partitions, but each partition can only be updated or deleted by one parallel execution server.

If the DOP is less than the number of partitions, then the first process to finish work on one partition continues working on another partition, and so on until the work is finished on all partitions. If the DOP is greater than the number of partitions involved in the operation, then the excess parallel execution servers will have no work to do.

Example 21–4 Parallelization: Example 1

```
UPDATE tbl_1 SET c1=c1+1 WHERE c1>100;
```

If `tbl_1` is a partitioned table and its table definition has a parallel clause, then the update operation is parallelized even if the scan on the table is serial (such as an index scan), assuming that the table has more than one partition with `c1` greater than 100.

Example 21–5 Parallelization: Example 2

```
UPDATE /*+ PARALLEL(tbl_2,4) */ tbl_2 SET c1=c1+1;
```

Both the scan and update operations on `tbl_2` will be parallelized with degree four.

Rules for Parallelizing INSERT ... SELECT

An `INSERT` ... `SELECT` statement parallelizes its `INSERT` and `SELECT` operations independently, except for the DOP.

You can specify a parallel hint after the `INSERT` keyword in an `INSERT` ... `SELECT` statement. Because the tables being queried are usually not the same as the table being inserted into, the hint enables you to specify parallel directives specifically for the insert operation.

You have the following ways to specify parallel directives for an `INSERT` ... `SELECT` statement (assuming that `PARALLEL DML` mode is enabled):

- `SELECT` parallel hints specified at the statement
- Parallel clauses specified in the definition of tables being selected
- `INSERT` parallel hint specified at the statement
- Parallel clause specified in the definition of tables being inserted into

You can use the `ALTER SESSION FORCE PARALLEL DML` statement to override parallel clauses for subsequent `INSERT` operations in a session. Parallel hints in insert operations override the `ALTER SESSION FORCE PARALLEL DML` statement.

Decision to Parallelize The following rule determines whether the `INSERT` operation should be parallelized in an `INSERT` ... `SELECT` statement:

> The `INSERT` operation will be parallelized if and only if at least one of the following is true:

- The PARALLEL hint is specified after the INSERT in the DML statement.
- The table being inserted into (the reference object) has a PARALLEL declaration specification.
- An ALTER SESSION FORCE PARALLEL DML statement has been issued previously during the session.

The decision to parallelize the INSERT operation is made independently of the SELECT operation, and vice versa.

Degree of Parallelism Once the decision to parallelize the SELECT or INSERT operation is made, one parallel directive is picked for deciding the DOP of the whole statement, using the following precedence rule Insert hint directive > Session> Parallel declaration specification of the inserting table > Maximum query directive.

In this context, maximum query directive means that among multiple tables and indexes, the table or index that has the maximum DOP determines the parallelism for the query operation.

The chosen parallel directive is applied to both the SELECT and INSERT operations.

Example 21–6 Parallelization: Example 3

The DOP used is 2, as specified in the INSERT hint:

```
INSERT /*+ PARALLEL(tbl_ins,2) */ INTO tbl_ins
SELECT /*+ PARALLEL(tbl_sel,4) */ * FROM tbl_sel;
```

Rules for Parallelizing DDL Statements

Decision to Parallelize DDL operations can be parallelized if a PARALLEL clause (declaration) is specified in the syntax. In the case of CREATE INDEX and ALTER INDEX ... REBUILD or ALTER INDEX ... REBUILD PARTITION, the parallel declaration is stored in the data dictionary.

You can use the ALTER SESSION FORCE PARALLEL DDL statement to override the parallel clauses of subsequent DDL statements in a session.

Degree of Parallelism The DOP is determined by the specification in the PARALLEL clause, unless it is overridden by an ALTER SESSION FORCE PARALLEL DDL statement. A rebuild of a partitioned index is never parallelized.

Parallel clauses in CREATE TABLE and ALTER TABLE statements specify table parallelism. If a parallel clause exists in a table definition, it determines the parallelism of DDL statements as well as queries. If the DDL statement contains explicit parallel hints for a table, however, those hints override the effect of parallel clauses for that table. You can use the ALTER SESSION FORCE PARALLEL DDL statement to override parallel clauses.

Rules for Parallelizing CREATE INDEX, REBUILD INDEX, MOVE or SPLIT PARTITION

Parallel CREATE INDEX or ALTER INDEX ... REBUILD The CREATE INDEX and ALTER INDEX ... REBUILD statements can be parallelized only by a PARALLEL clause or an ALTER SESSION FORCE PARALLEL DDL statement.

ALTER INDEX ... REBUILD can be parallelized only for a nonpartitioned index, but ALTER INDEX ... REBUILD PARTITION can be parallelized by a PARALLEL clause or an ALTER SESSION FORCE PARALLEL DDL statement.

The scan operation for ALTER INDEX ... REBUILD (nonpartitioned), ALTER INDEX ... REBUILD PARTITION, and CREATE INDEX has the same parallelism as the REBUILD or CREATE operation and uses the same DOP. If the DOP is not specified for REBUILD or CREATE, the default is the number of CPUs.

Parallel MOVE PARTITION or SPLIT PARTITION The ALTER INDEX ... MOVE PARTITION and ALTER INDEX ... SPLIT PARTITION statements can be parallelized only by a PARALLEL clause or an ALTER SESSION FORCE PARALLEL DDL statement. Their scan operations have the same parallelism as the corresponding MOVE or SPLIT operations. If the DOP is not specified, the default is the number of CPUs.

Rules for Parallelizing CREATE TABLE AS SELECT

The CREATE TABLE ... AS SELECT statement contains two parts: a CREATE part (DDL) and a SELECT part (query). Oracle can parallelize both parts of the statement. The CREATE part follows the same rules as other DDL operations.

Decision to Parallelize (Query Part) The query part of a CREATE TABLE ... AS SELECT statement can be parallelized only if the following conditions are satisfied:

1. The query includes a parallel hint specification (PARALLEL or PARALLEL_INDEX) or the CREATE part of the statement has a PARALLEL clause specification or the schema objects referred to in the query have a PARALLEL declaration associated with them.

2. At least one of the tables specified in the query requires one of the following:
   - A full table scan
   - An index range scan spanning multiple partitions

Degree of Parallelism (Query Part) The DOP for the query part of a CREATE TABLE ... AS SELECT statement is determined by one of the following rules:

- The query part uses the values specified in the PARALLEL clause of the CREATE part.
- If the PARALLEL clause is not specified, the default DOP is the number of CPUs.
- If the CREATE is serial, then the DOP is determined by the query.

Note that any values specified in a hint for parallelism are ignored.

See Also: "Rules for Parallelizing Queries" on page 21-38

Decision to Parallelize (CREATE Part) The CREATE operation of CREATE TABLE ... AS SELECT can be parallelized only by a PARALLEL clause or an ALTER SESSION FORCE PARALLEL DDL statement.

When the CREATE operation of CREATE TABLE ... AS SELECT is parallelized, Oracle also parallelizes the scan operation if possible. The scan operation cannot be parallelized if, for example:

- The SELECT clause has a NOPARALLEL hint
- The operation scans an index of a nonpartitioned table

When the CREATE operation is not parallelized, the SELECT can be parallelized if it has a PARALLEL hint or if the selected table (or partitioned index) has a parallel declaration.

Degree of Parallelism (CREATE Part) The DOP for the CREATE operation, and for the SELECT operation if it is parallelized, is specified by the PARALLEL clause of the CREATE statement, unless it is overridden by an ALTER SESSION FORCE PARALLEL DDL statement. If the PARALLEL clause does not specify the DOP, the default is the number of CPUs.

Summary of Parallelization Rules

Table 21–3 shows how various types of SQL statements can be parallelized and indicates which methods of specifying parallelism take precedence.

- The priority (1) specification overrides priority (2) and priority (3).
- The priority (2) specification overrides priority (3).

See Also: *Oracle9i SQL Reference* for information about parallel clauses and hints in SQL statements

Table 21–3 Parallelization Rules

Parallel Operation	Parallelized by Clause, Hint, or Underlying Table/Index Declaration (priority order: 1, 2, 3)			
	PARALLEL Hint	PARALLEL Clause	ALTER SESSION	Parallel Declaration
Parallel query table scan (partitioned or nonpartitioned table)	(1) PARALLEL		(2) FORCE PARALLEL QUERY	(3) of table
Parallel query index range scan (partitioned index)	(1) PARALLEL_ INDEX		(2) FORCE PARALLEL QUERY	(2) of index
Parallel UPDATE or DELETE (partitioned table only)	(1) PARALLEL		(2) FORCE PARALLEL DML	(3) of table being updated or deleted from
INSERT operation of parallel INSERT... SELECT (partitioned or nonpartitioned table)	(1) PARALLEL of insert		(2) FORCE PARALLEL DML	(3) of table being inserted into
SELECT operation of INSERT ... SELECT when INSERT is parallel	takes degree from INSERT statement			
SELECT operation of INSERT ... SELECT when INSERT is serial	(1) PARALLEL			(2) of table being selected from
CREATE operation of parallel CREATE TABLE ... AS SELECT (partitioned or nonpartitioned table)	(Note: Hint in select clause does not affect the create operation.)	(2)	(1) FORCE PARALLEL DDL	
SELECT operation of CREATE TABLE ... AS SELECT when CREATE is parallel	takes degree from CREATE statement			
SELECT operation of CREATE TABLE ... AS SELECT when CREATE is serial	(1) PARALLEL or PARALLEL_ INDEX			(2) of querying tables or partitioned indexes

Table 21–3 Parallelization Rules(Cont.)

Parallel Operation	**Parallelized by Clause, Hint, or Underlying Table/Index Declaration (priority order: 1, 2, 3)**			
	PARALLEL Hint	**PARALLEL Clause**	**ALTER SESSION**	**Parallel Declaration**
Parallel `CREATE INDEX` (partitioned or nonpartitioned index)		(2)	(1) `FORCE PARALLEL DDL`	
Parallel `REBUILD INDEX` (nonpartitioned index)		(2)	(1) `FORCE PARALLEL DDL`	
`REBUILD INDEX` (partitioned index)—never parallelized			—	—
Parallel `REBUILD INDEX` partition		(2)	(1) `FORCE PARALLEL DDL`	
Parallel `MOVE` or `SPLIT` partition		(2)	(1) `FORCE PARALLEL DDL`	

Enabling Parallelism for Tables and Queries

The DOP of tables involved in parallel operations affect the DOP for operations on those tables. Therefore, after setting parallel tuning parameters, you must also enable parallel execution for each table you want parallelized, using the `PARALLEL` clause of the `CREATE TABLE` or `ALTER TABLE` statements. You can also use the `PARALLEL` hint with SQL statements to enable parallelism for that operation only, or use the `FORCE` option of the `ALTER SESSION` statement to enable parallelism for all subsequent operations in the session.

When you parallelize tables, you can also specify the DOP or allow Oracle to use a default DOP. The value of the default DOP is derived automatically, based on the value of `PARALLEL_THREADS_PER_CPU` and the number of CPUs available to Oracle.

```
ALTER TABLE emp PARALLEL;    -- uses default DOP
ALTER TABLE emp PARALLEL 4;  -- users DOP of 4
```

Degree of Parallelism and Adaptive Multiuser: How They Interact

The DOP specifies the number of available processes, or threads, used in parallel operations. Each parallel thread can use one or two query processes, depending on the query's complexity.

The adaptive multiuser feature adjusts the DOP based on user load. For example, you might have a table with a DOP of 5. This DOP might be acceptable with 10 users. However, if 10 more users enter the system and you enable the `PARALLEL_ADAPTIVE_MULTI_USER` feature, Oracle reduces the DOP to spread resources more evenly according to the perceived system load.

Note: Once Oracle determines the DOP for a query, the DOP does not change for the duration of the query.

It is best to use the parallel adaptive multiuser feature when users process simultaneous parallel execution operations. If you enable `PARALLEL_AUTOMATIC_TUNING`, Oracle automatically sets `PARALLEL_ADAPTIVE_MULTI_USER` to `TRUE`.

Note: Disable adaptive multiuser for single-user, batch processing systems or if your system already provides optimal performance.

How the Adaptive Multiuser Algorithm Works

The adaptive multiuser algorithm has several inputs. The algorithm first considers the number of allocated threads as calculated by the Database Resource Manager. The algorithm then considers the default settings for parallelism as set in the initialization parameter file, as well as parallelism options used in `CREATE TABLE` and `ALTER TABLE` statements and SQL hints.

When a system is overloaded and the input DOP is larger than the default DOP, the algorithm uses the default degree as input. The system then calculates a reduction factor that it applies to the input DOP. For example, using a 16-CPU system, when the first user enters the system and it is idle, it will be granted a DOP of 32. The next user will be give a DOP of eight, the next four, and so on. If the system settles into a steady state of eight users issuing queries, all the users will eventually be given a DOP of 4, thus dividing the system evenly among all the parallel users.

Forcing Parallel Execution for a Session

If you are sure you want to execute in parallel and want to avoid setting the DOP for a table or modifying the queries involved, you can force parallelism with the following statement:

```
ALTER SESSION FORCE PARALLEL QUERY;
```

All subsequent queries will be executed in parallel provided no restrictions are violated. You can also force DML and DDL statements. This clause overrides any parallel clause specified in subsequent statements in the session, but is overridden by a parallel hint.

In typical OLTP environments, for example, the tables are not set parallel, but nightly batch scripts may want to collect data from these tables in parallel. By setting the DOP in the session, the user avoids altering each table in parallel and then altering it back to serial when finished.

> **See Also:** *Oracle9i Database Administrator's Guide* for additional information on forcing parallel execution

Controlling Performance with the Degree of Parallelism

The initialization parameter PARALLEL_THREADS_PER_CPU affects algorithms controlling both the DOP and the adaptive multiuser feature. Oracle multiplies the value of PARALLEL_THREADS_PER_CPU by the number of CPUs per instance to derive the number of threads to use in parallel operations.

The adaptive multiuser feature also uses the default DOP to compute the target number of query server processes that should exist in a system. When a system is running more processes than the target number, the adaptive algorithm reduces the DOP of new queries as required. Therefore, you can also use PARALLEL_THREADS_PER_CPU to control the adaptive algorithm.

PARALLEL_THREADS_PER_CPU enables you to adjust for hardware configurations with I/O subsystems that are slow relative to the CPU speed and for application workloads that perform few computations relative to the amount of data involved. If the system is neither CPU-bound nor I/O-bound, then the PARALLEL_THREADS_PER_CPU value should be increased. This increases the default DOP and allow better utilization of hardware resources. The default for PARALLEL_THREADS_PER_CPU on most platforms is 2. However, the default for machines with relatively slow I/O subsystems can be as high as eight.

Tuning General Parameters for Parallel Execution

This section discusses the following topics:

- Parameters Establishing Resource Limits for Parallel Operations
- Parameters Affecting Resource Consumption
- Parameters Related to I/O

Parameters Establishing Resource Limits for Parallel Operations

The parameters that establish resource limits are:

- PARALLEL_MAX_SERVERS
- PARALLEL_MIN_SERVERS
- LARGE_POOL_SIZE or SHARED_POOL_SIZE
- SHARED_POOL_SIZE
- PARALLEL_MIN_PERCENT
- CLUSTER_DATABASE_INSTANCES

PARALLEL_MAX_SERVERS

The recommended value for the PARALLEL_MAX_SEVERS parameter is:

```
2 x DOP x NUMBER_OF_CONCURRENT_USERS
```

The PARALLEL_MAX_SEVERS parameter sets a resource limit on the maximum number of processes available for parallel execution. If you set PARALLEL_AUTOMATIC_TUNING to FALSE, you need to manually specify a value for PARALLEL_MAX_SERVERS.

Most parallel operations need at most twice the number of query server processes as the maximum DOP attributed to any table in the operation.

If PARALLEL_AUTOMATIC_TUNING is FALSE, the default value for PARALLEL_MAX_SERVERS is 5. This is sufficient for some minimal operations, but not enough for effective use of parallel execution. If you manually set the PARALLEL_MAX_SERVERS parameter, set it to 16 times the number of CPUs. This is a reasonable starting value that will allow you to run four parallel queries simultaneously, assuming that each query is using a DOP of eight.

If the hardware system is neither CPU bound nor I/O bound, then you can increase the number of concurrent parallel execution users on the system by adding more query server processes. When the system becomes CPU- or I/O-bound, however, adding more concurrent users becomes detrimental to the overall performance. Careful setting of PARALLEL_MAX_SERVERS is an effective method of restricting the number of concurrent parallel operations.

If users initiate too many concurrent operations, Oracle might not have enough query server processes. In this case, Oracle executes the operations sequentially or displays an error if PARALLEL_MIN_PERCENT is set to a value other than the default value of 0 (zero).

This condition can be verified through the GV$SYSSTAT view by comparing the statistics for parallel operations not downgraded and parallel operations downgraded to serial. For example:

```
SELECT * FROM GV$SYSSTAT WHERE name LIKE 'Parallel operation%';
```

When Users Have Too Many Processes When concurrent users have too many query server processes, memory contention (paging), I/O contention, or excessive context switching can occur. This contention can reduce system throughput to a level lower than if parallel execution were not used. Increase the PARALLEL_MAX_SERVERS value only if the system has sufficient memory and I/O bandwidth for the resulting load.

You can use operating system performance monitoring tools to determine how much memory, swap space and I/O bandwidth are free. Look at the runq lengths for both your CPUs and disks, as well as the service time for I/Os on the system. Verify that the machine has sufficient swap space exists on the machine to add more processes. Limiting the total number of query server processes might restrict the number of concurrent users who can execute parallel operations, but system throughput tends to remain stable.

Increasing the Number of Concurrent Users

To increase the number of concurrent users, you can restrict the number of concurrent sessions that resource consumer groups can have. For example:

- You can enable PARALLEL_ADAPTIVE_MULTI_USER.
- You can set a large limit for users running batch jobs.
- You can set a medium limit for users performing analyses.
- You can prohibit a particular class of user from using parallelism.

> **See Also:** *Oracle9i Database Administrator's Guide* and *Oracle9i Database Concepts* for more information about resource consumer groups and the Database Resource Manager

Limiting the Number of Resources for a User

You can limit the amount of parallelism available to a given user by establishing a resource consumer group for the user. Do this to limit the number of sessions, concurrent logons, and the number of parallel processes that any one user or group of users can have.

Each query server process working on a parallel execution statement is logged on with a session ID. Each process counts against the user's limit of concurrent sessions. For example, to limit a user to 10 parallel execution processes, set the user's limit to 11. One process is for the parallel coordinator and the other 10 consist of two sets of query server servers. This would allow one session for the parallel coordinator and 10 sessions for the parallel execution processes.

See Also:

- *Oracle9i Database Administrator’s Guide* for more information about managing resources with user profiles
- *Oracle9i Real Application Clusters Administration* for more information on querying GV$ views

PARALLEL_MIN_SERVERS

The recommended value for the PARALLEL_MIN_SERVERS parameter is 0 (zero), which is the default.

This parameter is used at startup and lets you specify in a single instance the number of processes to be started and reserved for parallel operations. The syntax is:

```
PARALLEL_MIN_SERVERS=n
```

The *n* variable is the number of processes you want to start and reserve for parallel operations.

Setting PARALLEL_MIN_SERVERS balances the startup cost against memory usage. Processes started using PARALLEL_MIN_SERVERS do not exit until the database is shut down. This way, when a query is issued the processes are likely to be available. It is desirable, however, to recycle query server processes periodically since the memory these processes use can become fragmented and cause the high water mark to slowly increase. When you do not set PARALLEL_MIN_SERVERS, processes exit after they are idle for five minutes.

LARGE_POOL_SIZE or SHARED_POOL_SIZE

The following discussion of how to tune the large pool also applies to tuning the shared pool, except as noted in "SHARED_POOL_SIZE" on page 21-56. You must also increase the value for this memory setting by the amount you determine.

Parallel execution requires additional memory resources in addition to those required by serial SQL execution. Additional memory is used for communication and passing data between query server processes and the query coordinator.

There is no recommended value for LARGE_POOL_SIZE. Instead, Oracle recommends leaving this parameter unset and having Oracle set it for you by setting the PARALLEL_AUTOMATIC_TUNING parameter to TRUE. The exception to this is when the system-assigned value is inadequate for your processing requirements.

Note: When PARALLEL_AUTOMATIC_TUNING is set to TRUE, Oracle allocates parallel execution buffers from the large pool. When this parameter is FALSE, Oracle allocates parallel execution buffers from the shared pool.

Oracle automatically computes LARGE_POOL_SIZE if PARALLEL_AUTOMATIC_TUNING is TRUE. To manually set a value for LARGE_POOL_SIZE, query the V$SGASTAT view and increase or decrease the value for LARGE_POOL_SIZE depending on your needs. For example, suppose Oracle displays the following error on startup:

```
ORA-27102: out of memory
SVR4 Error: 12: Not enough space
```

You should reduce the value for LARGE_POOL_SIZE low enough so your database starts. After reducing the value of LARGE_POOL_SIZE, you might see the error:

```
ORA-04031: unable to allocate 16084 bytes of shared memory ("large
pool","unknown object","large pool heap","PX msg pool")
```

If so, execute the following query to determine why Oracle could not allocate the 16,084 bytes:

```
SELECT NAME, SUM(BYTES)
FROM V$SGASTAT
WHERE POOL='LARGE POOL'
  GROUP BY ROLLUP (NAME);
```

Your output should resemble the following:

```
NAME                       SUM(BYTES)
-------------------------- ----------
PX msg pool                   1474572
free memory                    562132
                              2036704
3 rows selected.
```

If you specify LARGE_POOL_SIZE and the amount of memory you need to reserve is bigger than the pool, Oracle does not allocate all the memory it can get. Instead, it leaves some space. When the query runs, Oracle tries to get what it needs. Oracle uses the 560 KB and needs another 16KB when it fails. The error does not report the cumulative amount that is needed. The best way of determining how much more memory is needed is to use the formulas in "Adding Memory for Message Buffers" on page 21-53.

To resolve the problem in the current example, increase the value for LARGE_POOL_SIZE. As shown in the sample output, the LARGE_POOL_SIZE is about 2 MB. Depending on the amount of memory available, you could increase the value of LARGE_POOL_SIZE to 4 MB and attempt to start your database. If Oracle continues to display an ORA-4031 message, gradually increase the value for LARGE_POOL_SIZE until startup is successful.

Computing Additional Memory Requirements for Message Buffers

After you determine the initial setting for the large or shared pool, you must calculate additional memory requirements for message buffers and determine how much additional space you need for cursors.

Adding Memory for Message Buffers You must increase the value for the LARGE_POOL_SIZE or the SHARED_POOL_SIZE parameters to accommodate message buffers. The message buffers allow query server processes to communicate with each other. If you enable automatic parallel tuning, Oracle allocates space for the message buffer from the large pool. Otherwise, Oracle allocates space from the shared pool.

Oracle uses a fixed number of buffers per virtual connection between producer query servers and consumer query servers. Connections increase as the square of the DOP increases. For this reason, the maximum amount of memory used by parallel execution is bound by the highest DOP allowed on your system. You can control this value by using either the PARALLEL_MAX_SERVERS parameter or by using policies and profiles.

To calculate the amount of memory required, use one of the following formulas:

- For SMP systems:

  `mem in bytes = (3 x size x users x groups x connections)`

- For SMP Real Application Clusters and MPP systems:

  `mem in bytes = ((3 x local) + (2 x remote) x (size x users x groups))`

Each instance uses the memory computed by the formula.

The terms are:

- `SIZE` = `PARALLEL_EXECUTION_MESSAGE_SIZE`
- `USERS` = the number of concurrent parallel execution users that you expect to have running with the optimal DOP
- `GROUPS` = the number of query server process groups used per query

  A simple SQL statement requires only one group. However, if your queries involve subqueries which will be processed in parallel, then Oracle uses an additional group of query server processes.
- `CONNECTIONS` = (DOP^2 + 2 x DOP)

  If your system is a cluster or MPP, then you should account for the number of instances because this will increase the DOP. In other words, using a DOP of 4 on a two instance cluster results in a DOP of 8. A value of `PARALLEL_MAX_SERVERS` times the number of instances divided by four is a conservative estimate to use as a starting point.
- `LOCAL` = `CONNECTIONS`/`INSTANCES`
- `REMOTE` = `CONNECTIONS` - `LOCAL`

Add this amount to your original setting for the large or shared pool. However, before setting a value for either of these memory structures, you must also consider additional memory for cursors, as explained in the following section.

Calculating Additional Memory for Cursors Parallel execution plans consume more space in the SQL area than serial execution plans. You should regularly monitor shared pool resource use to ensure that the memory used by both messages and cursors can accommodate your system's processing requirements.

Adjusting Memory After Processing Begins

The formulas in this section are just starting points. Whether you are using automated or manual tuning, you should monitor usage on an on-going basis to make sure the size of memory is not too large or too small. To do this, tune the large and shared pools after examining the size of structures in the large pool, using the following query:

```
SELECT POOL, NAME, SUM(BYTES)
FROM V$SGASTAT
WHERE POOL LIKE '%pool%'
  GROUP BY ROLLUP (POOL, NAME);
```

Your output should resemble the following:

```
POOL        NAME                       SUM(BYTES)
----------- -------------------------- ----------
large pool  PX msg pool                  38092812
large pool  free memory                    299988
large pool                               38392800
shared pool Checkpoint queue                38496
shared pool KGFF heap                        1964
shared pool KGK heap                         4372
shared pool KQLS heap                     1134432
shared pool LRMPD SGA Table                 23856
shared pool PLS non-lib hp                   2096
shared pool PX subheap                     186828
shared pool SYSTEM PARAMETERS               55756
shared pool State objects                 3907808
shared pool character set memory            30260
shared pool db_block_buffers               200000
shared pool db_block_hash_buckets           33132
shared pool db_files                       122984
shared pool db_handles                      52416
shared pool dictionary cache               198216
shared pool dlm shared memory             5387924
shared pool enqueue_resources               29016
shared pool event statistics per sess      264768
shared pool fixed allocation callback        1376
shared pool free memory                  26329104
shared pool gc_*                            64000
shared pool latch nowait fails or sle       34944
shared pool library cache                 2176808
shared pool log_buffer                      24576
shared pool log_checkpoint_timeout          24700
shared pool long op statistics array        30240
shared pool message pool freequeue         116232
shared pool miscellaneous                  267624
shared pool processes                       76896
shared pool session param values          41424
shared pool sessions                     170016
shared pool sql area                    9549116
shared pool table columns                148104
shared pool trace_buffers_per_process   1476320
shared pool transactions                  18480
shared pool trigger inform                24684
shared pool                            52248968
                                       90641768
41 rows selected.
```

Evaluate the memory used as shown in your output, and alter the setting for LARGE_POOL_SIZE based on your processing needs.

To obtain more memory usage statistics, execute the following query:

```
SELECT * FROM V$PX_PROCESS_SYSSTAT WHERE STATISTIC LIKE 'Buffers%';
```

Your output should resemble the following:

```
STATISTIC                           VALUE
-------------------                 -----
Buffers Allocated                   23225
Buffers Freed                       23225
Buffers Current                         0
Buffers HWM                          3620
4 Rows selected.
```

The amount of memory used appears in the Buffers Current and Buffers HWM statistics. Calculate a value in bytes by multiplying the number of buffers by the value for PARALLEL_EXECUTION_MESSAGE_SIZE. Compare the high water mark to the parallel execution message pool size to determine if you allocated too much memory. For example, in the first output, the value for large pool as shown in px msg pool is 38,092,812 or 38 MB. The Buffers HWM from the second output is 3,620, which when multiplied by a parallel execution message size of 4,096 is 14,827,520, or approximately 15 MB. In this case, the high water mark has reached approximately 40 percent of its capacity.

SHARED_POOL_SIZE

As mentioned earlier, if PARALLEL_AUTOMATIC_TUNING is FALSE, Oracle allocates query server processes from the shared pool. In this case, tune the shared pool as described under the previous heading for large pool, with the following exceptions:

- Allow for other clients of the shared pool, such as shared cursors and stored procedures
- Remember that larger values improve performance in multiuser systems, but smaller values use less memory

You must also take into account that using parallel execution generates more cursors. Look at statistics in the `V$SQLAREA` view to determine how often Oracle recompiles cursors. If the cursor hit ratio is poor, increase the size of the pool. This happens only when you have a large number of distinct queries.

You can then monitor the number of buffers used by parallel execution in the same way as explained previously, and compare the `shared pool PX msg pool` to the current high water mark reported in output from the view `V$PX_PROCESS_SYSSTAT`.

PARALLEL_MIN_PERCENT

The recommended value for the `PARALLEL_MIN_PERCENT` parameter is 0 (zero).

This parameter allows users to wait for an acceptable DOP, depending on the application in use. Setting this parameter to values other than 0 (zero) causes Oracle to return an error when the requested DOP cannot be satisfied by the system at a given time.

For example, if you set `PARALLEL_MIN_PERCENT` to 50, which translates to 50 percent, and the DOP is reduced by 50 percent or greater because of the adaptive algorithm or because of a resource limitation, then Oracle returns `ORA-12827`. For example:

```
SELECT /*+ PARALLEL(e, 8, 1) */ d.deptno, SUM(SAL)
FROM emp e, dept d WHERE e.deptno = d.deptno
GROUP BY d.deptno ORDER BY d.deptno;
```

Oracle responds with this message:

```
ORA-12827: insufficient parallel query slaves available
```

CLUSTER_DATABASE_INSTANCES

The `CLUSTER_DATABASE_INSTANCES` parameter should be set to a value that is equal to the number of instances in your Real Application Cluster environment.

The `CLUSTER_DATABASE_INSTANCES` parameter specifies the number of instances configured in an Oracle Real Application Cluster environment. Oracle uses the value of this parameter to compute values for LARGE_POOL_SIZE when PARALLEL_AUTOMATIC_TUNING is set to TRUE.

Parameters Affecting Resource Consumption

The first group of parameters discussed in this section affects memory and resource consumption for all parallel operations, in particular, for parallel execution. These parameters are:

- HASH_AREA_SIZE
- SORT_AREA_SIZE
- PARALLEL_EXECUTION_MESSAGE_SIZE
- PARALLEL_BROADCAST_ENABLE

A second subset of parameters discussed in this section explains parameters affecting parallel DML and DDL.

To control resource consumption, you should configure memory at two levels:

- At the Oracle level, so the system uses an appropriate amount of memory from the operating system.
- At the operating system level for consistency. On some platforms, you might need to set operating system parameters that control the total amount of virtual memory available, summed across all processes.

The SGA is typically part of real physical memory. The SGA is static and of fixed size; if you want to change its size, shut down the database, make the change, and restart the database. Oracle allocates the large and shared pools out of the SGA.

> **See Also:** *Oracle9i Database Concepts* for further details regarding the SGA

A large percentage of the memory used in data warehousing operations is more dynamic. This memory comes from process memory, and both the size of process memory and the number of processes can vary greatly. This memory is controlled by the HASH_AREA_SIZE and SORT_AREA_SIZE parameters. Together, these parameters affect the amount of virtual memory used by Oracle.

Process memory comes from virtual memory. Total virtual memory should be somewhat larger than available real memory, which is the physical memory minus the size of the SGA. Virtual memory generally should not exceed twice the size of the physical memory minus the SGA size. If you set virtual memory to a value several times greater than real memory, the paging rate might increase when the machine is overloaded.

As a general rule for memory sizing, each process requires adequate address space for hash joins. A dominant factor in high volume data warehousing operations is the relationship between memory, the number of processes, and the number of hash join operations. Hash joins and large sorts are memory-intensive operations, so you might want to configure fewer processes, each with a greater limit on the amount of memory it can use.

HASH_AREA_SIZE

You can improve hash join performance with a relatively high value for the `HASH_AREA_SIZE` parameter. If you use a relatively high value, you will increase your memory requirements.

Set `HASH_AREA_SIZE` using one of two approaches. The first approach examines how much memory is available after configuring the SGA and calculating the amount of memory processes the system uses during normal loads.

The total amount of memory that Oracle processes are allowed to use should be divided by the number of processes during the normal load. These processes include parallel execution servers. This number determines the total amount of working memory per process. This amount then needs to be shared among different operations in a given query. For example, setting `HASH_AREA_SIZE` or `SORT_AREA_SIZE` to one-half or one-third of this number is reasonable.

Set these parameters to the highest number that does not cause swapping. After setting these parameters as described, you should watch for swapping and free memory. If swapping occurs, decrease the values for these parameters. If a significant amount of free memory remains, you can increase the values for these parameters.

The second approach to setting `HASH_AREA_SIZE` requires a thorough understanding of the types of hash joins you execute and an understanding of the amount of data you will be querying against. If the queries and query plans you execute are well understood, this approach is reasonable.

The value for `HASH_AREA_SIZE` should be approximately half of the square root of *S*, where *S* is the size in megabytes of the smaller of the inputs to the join operation. In any case, the value for `HASH_AREA_SIZE` should not be less than 1 MB.

This relationship can be expressed as follows:

$$HASH\_AREA\_SIZE \;>=\; \frac{\sqrt{S}}{2}$$

For example, if *S* equals 16 MB, a minimum appropriate value for HASH_AREA_SIZE might be 2 MB, summed over all parallel processes. Thus, if you have two parallel processes, a minimum value for HASH_AREA_SIZE might be 1 MB. A smaller hash area is not advisable.

For a large data warehouse, HASH_AREA_SIZE can range from 8 MB to 32 MB or more. This parameter provides for adequate memory for hash joins. Each process performing a parallel hash join uses an amount of memory equal to HASH_AREA_SIZE.

Hash join performance is more sensitive to HASH_AREA_SIZE than sort performance is to SORT_AREA_SIZE. As with SORT_AREA_SIZE, too large a hash area can cause the system to run out of memory.

The hash area does not cache blocks in the buffer cache; even low values of HASH_AREA_SIZE will not cause this to occur. Too small a setting, however, could adversely affect performance.

HASH_AREA_SIZE is relevant to parallel execution operations and to the query portion of DML or DDL statements.

SORT_AREA_SIZE

The recommended values for this parameter range from 256 KB to 4 MB.

This parameter specifies the amount of memory to allocate per query server process for sort operations. If you have a lot of system memory, you can benefit from setting SORT_AREA_SIZE to a large value. This can dramatically increase the performance of sort operations because the entire process is more likely to be performed in memory. However, if memory is a concern for your system, you might want to limit the amount of memory allocated for sort and hash operations.

If the sort area is too small, an excessive amount of I/O is required to merge a large number of sort runs. If the sort area size is smaller than the amount of data to sort, the sort will move to disk, creating sort runs. These must then be merged again using the sort area. If the sort area size is very small, there will be many runs to merge, and multiple passes might be necessary. The amount of I/O increases as SORT_AREA_SIZE decreases.

If the sort area is too large, the operating system paging rate will be excessive. The cumulative sort area adds up quickly because each query server process can allocate this amount of memory for each sort. For such situations, monitor the operating system paging rate to see if too much memory is being requested.

`SORT_AREA_SIZE` is relevant to parallel execution operations and to the query portion of DML or DDL statements. All `CREATE INDEX` statements must do some sorting to generate the index. Commands that require sorting include:

- `CREATE INDEX`
- Direct-path `INSERT` (if an index is involved)
- `ALTER INDEX ... REBUILD`

See Also: "HASH_AREA_SIZE" on page 21-59

PARALLEL_EXECUTION_MESSAGE_SIZE

The recommended value for `PARALLEL_EXECUTION_MESSAGE_SIZE` is 4 KB. If `PARALLEL_AUTOMATIC_TUNING` is `TRUE`, the default is 4 KB. If `PARALLEL_AUTOMATIC_TUNING` is `FALSE`, the default is slightly greater than 2 KB.

The `PARALLEL_EXECUTION_MESSAGE_SIZE` parameter specifies the upper limit for the size of parallel execution messages. The default value is operating system specific and this value should be adequate for most applications. Larger values for `PARALLEL_EXECUTION_MESSAGE_SIZE` require larger values for `LARGE_POOL_SIZE` or `SHARED_POOL_SIZE`, depending on whether you have enabled parallel automatic tuning.

While you might experience significantly improved response time by increasing the value for `PARALLEL_EXECUTION_MESSAGE_SIZE`, memory use also drastically increases. For example, if you double the value for `PARALLEL_EXECUTION_MESSAGE_SIZE`, parallel execution requires a message source pool that is twice as large.

Therefore, if you set `PARALLEL_AUTOMATIC_TUNING` to `FALSE`, you must adjust the `SHARED_POOL_SIZE` to accommodate parallel execution messages. If you have set `PARALLEL_AUTOMATIC_TUNING` to `TRUE`, but have set `LARGE_POOL_SIZE` manually, then you must adjust the `LARGE_POOL_SIZE` to accommodate parallel execution messages.

PARALLEL_BROADCAST_ENABLE

The default value for the PARALLEL_BROADCAST_ENABLE parameter is FALSE.

Set PARALLEL_BROADCAST_ENABLE to TRUE if you are joining a very large join result set with a very small result set (size being measured in bytes, rather than number of rows). In this case, the optimizer has the option of broadcasting the small set's rows to each of the query server processes that are processing the rows of the larger set. The result is enhanced performance. If the result set is large, the optimizer will not broadcast, which avoids excessive communication overhead.

Parameters Affecting Resource Consumption for Parallel DML and Parallel DDL

The parameters that affect parallel DML and parallel DDL resource consumption are:

- TRANSACTIONS
- ROLLBACK_SEGMENTS
- FAST_START_PARALLEL_ROLLBACK
- LOG_BUFFER
- DML_LOCKS
- ENQUEUE_RESOURCES

Parallel inserts, updates, and deletes require more resources than serial DML operations. Similarly, PARALLEL CREATE TABLE ... AS SELECT and PARALLEL CREATE INDEX can require more resources. For this reason, you may need to increase the value of several additional initialization parameters. These parameters do *not* affect resources for queries.

TRANSACTIONS For parallel DML and DDL, each query server process starts a transaction. The parallel coordinator uses the two-phase commit protocol to commit transactions; therefore, the number of transactions being processed increases by the DOP. As a result, you might need to increase the value of the TRANSACTIONS initialization parameter.

The TRANSACTIONS parameter specifies the maximum number of concurrent transactions. The default assumes no parallelism. For example, if you have a DOP of 20, you will have 20 more new server transactions (or 40, if you have two server sets) and 1 coordinator transaction. In this case, you should increase TRANSACTIONS by 21 (or 41) if the transactions are running in the same instance. If you do not set this parameter, Oracle sets it to a value equal to 1.1 x SESSIONS.

ROLLBACK_SEGMENTS The increased number of transactions for parallel DML and DDL requires more rollback segments. For example, one command with a DOP of five uses 5 server transactions distributed among different rollback segments. The rollback segments should belong to tablespaces that have free space. The rollback segments should also be unlimited, or you should specify a high value for the `MAXEXTENTS` parameter of the `STORAGE` clause. In this way, the rollback segments can extend and not run out of space.

FAST_START_PARALLEL_ROLLBACK If a system crashes when there are uncommitted parallel DML or DDL transactions, you can speed up transaction recovery during startup by using the `FAST_START_PARALLEL_ROLLBACK` parameter.

This parameter controls the DOP used when recovering **dead transactions**. Dead transactions are transactions that are active before a system crash. By default, the DOP is chosen to be at most two times the value of the `CPU_COUNT` parameter.

If the default DOP is insufficient, set the parameter to the `HIGH`. This gives a maximum DOP of at most four times the value of the `CPU_COUNT` parameter. This feature is available by default.

LOG_BUFFER Check the statistic `redo buffer allocation retries` in the `V$SYSSTAT` view. If this value is high relative to `redo blocks written`, try to increase the `LOG_BUFFER` size. A common `LOG_BUFFER` size for a system generating numerous logs is 3 MB to 5 MB. If the number of retries is still high after increasing `LOG_BUFFER` size, a problem might exist with the disk on which the log files reside. In that case, tune the I/O subsystem to increase the I/O rates for redo. One way of doing this is to use fine-grained striping across multiple disks. For example, use a stripe size of 16 KB. A simpler approach is to isolate redo logs on their own disk.

DML_LOCKS This parameter specifies the maximum number of DML locks. Its value should equal the total number of locks on all tables referenced by all users. A parallel DML operation's lock and enqueue resource requirement is very different from serial DML. Parallel DML holds many more locks, so you should increase the value of the `ENQUEUE_RESOURCES` and `DML_LOCKS` parameters by equal amounts.

Table 21–4 shows the types of locks acquired by coordinator and parallel execution server processes for different types of parallel DML statements. Using this information, you can determine the value required for these parameters.

Table 21–4 Locks Acquired by Parallel DML Statements

Type of statement	Coordinator process acquires:	Each parallel execution server acquires:
Parallel UPDATE or DELETE into partitioned table; WHERE clause pruned to a subset of partitions or subpartitions	1 table lock SX	1 table lock SX
	1 partition lock X per pruned (sub)partition	1 partition lock NULL per pruned (sub)partition owned by the query server process
		1 partition-wait lock S per pruned (sub)partition owned by the query server process
Parallel row-migrating UPDATE into partitioned table; WHERE clause pruned to a subset of (sub)partitions	1 table lock SX	1 table lock SX
	1 partition X lock per pruned (sub)partition	1 partition lock NULL per pruned (sub)partition owned by the query server process
		1 partition-wait lock S per pruned partition owned by the query server process
	1 partition lock SX for all other (sub)partitions	1 partition lock SX for all other (sub)partitions
Parallel UPDATE, MERGE, DELETE, or INSERT into partitioned table	1 table lock SX	1 table lock SX
	Partition locks X for all (sub)partitions	1 partition lock NULL per (sub)partition owned by the query server process
		1 partition-wait lock S per (sub)partition owned by the query server process
Parallel INSERT into partitioned table; destination table with partition or subpartition clause	1 table lock SX	1 table lock SX
	1 partition lock X per specified (sub)partition	1 partition lock NULL per specified (sub)partition owned by the query server process
		1 partition-wait lock S per specified (sub)partition owned by the query server process
Parallel INSERT into nonpartitioned table	1 table lock X	None

---

Note: Table, partition, and partition-wait DML locks all appear as TM locks in the V$LOCK view.

Consider a table with 600 partitions running with a DOP of 100. Assume all partitions are involved in a parallel UPDATE or DELETE statement with no row-migrations.

The coordinator acquires:	1 table lock SX
	600 partition locks X
Total server processes acquire:	100 table locks SX
	600 partition locks NULL
	600 partition-wait locks S

ENQUEUE_RESOURCES This parameter sets the number of resources that can be locked by the lock manager. Parallel DML operations require many more resources than serial DML. Oracle allocates more enqueue resources as needed.

See Also: "DML_LOCKS" on page 21-63

Parameters Related to I/O

The parameters that affect I/O are:

- DB_BLOCK_BUFFERS
- DB_BLOCK_SIZE
- DB_FILE_MULTIBLOCK_READ_COUNT
- DISK_ASYNCH_IO and TAPE_ASYNCH_IO

These parameters also affect the optimizer which ensures optimal performance for parallel execution I/O operations.

DB_BLOCK_BUFFERS

When you perform parallel updates, merges, and deletes, the buffer cache behavior is very similar to any OLTP system running a high volume of updates.

DB_BLOCK_SIZE

The recommended value for this parameter is 8 KB or 16 KB.

Set the database block size when you create the database. If you are creating a new database, use a large block size such as 8 KB or 16 KB.

DB_FILE_MULTIBLOCK_READ_COUNT

The recommended value for this parameter is eight for 8 KB block size, or four for 16 KB block size. The default is 8.

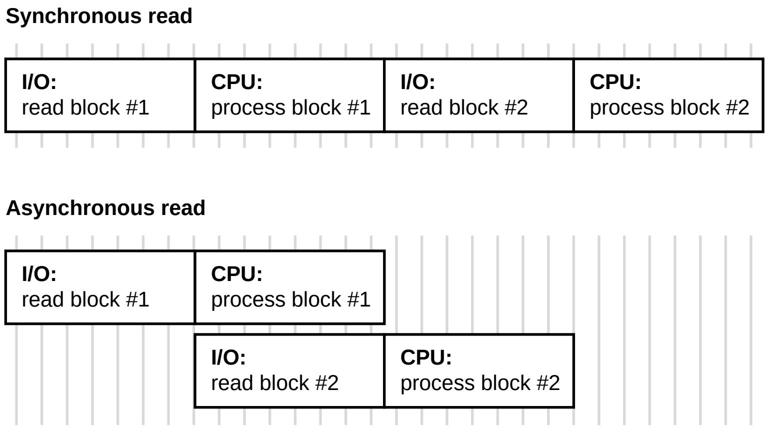
This parameter determines how many database blocks are read with a single operating system `READ` call. The upper limit for this parameter is platform-dependent. If you set `DB_FILE_MULTIBLOCK_READ_COUNT` to an excessively high value, your operating system will lower the value to the highest allowable level when you start your database. In this case, each platform uses the highest value possible. Maximum values generally range from 64 KB to 1 MB.

DISK_ASYNCH_IO and TAPE_ASYNCH_IO

The recommended value for both of these parameters is `TRUE`.

These parameters enable or disable the operating system's asynchronous I/O facility. They allow query server processes to overlap I/O requests with processing when performing table scans. If the operating system supports asynchronous I/O, leave these parameters at the default value of `TRUE`.

Figure 21–6 Asynchronous Read



Asynchronous operations are currently supported for parallel table scans, hash joins, sorts, and serial table scans. However, this feature can require operating system specific configuration and may not be supported on all platforms. Check your Oracle operating system-specific documentation.

Monitoring and Diagnosing Parallel Execution Performance

You should do the following tasks when diagnosing parallel execution performance problems:

- Quantify your performance expectations to determine whether there is a problem.
- Determine whether a problem pertains to optimization, such as inefficient plans that might require reanalyzing tables or adding hints, or whether the problem pertains to execution, such as simple operations like scanning, loading, grouping, or indexing running much slower than published guidelines.
- Determine whether the problem occurs when running in parallel, such as load imbalance or resource bottlenecks, or whether the problem is also present for serial operations.

Performance expectations are based on either prior performance metrics (for example, the length of time a given query took last week or on the previous version of Oracle) or scaling and extrapolating from serial execution times (for example, serial execution took 10 minutes while parallel execution took 5 minutes). If the performance does not meet your expectations, consider the following questions:

- Did the execution plan change?

  If so, you should gather statistics and decide whether to use index-only access and a CREATE TABLE AS SELECT statement. You should use index hints if your system is CPU-bound.

  You should also study the EXPLAIN PLAN output.

- Did the data set change?

  If so, you should gather statistics to evaluate any differences.

- Is the hardware overtaxed?

  If so, you should check CPU, I/O, and swap memory.

After setting your basic goals and answering these questions, you need to consider the following topics:

- Is There Regression?
- Is There a Plan Change?
- Is There a Parallel Plan?
- Is There a Serial Plan?
- Is There Parallel Execution?
- Is The Workload Evenly Distributed?

Is There Regression?

Does parallel execution's actual performance deviate from what you expected? If performance is as you expected, could there be an underlying performance problem? Perhaps you have a desired outcome in mind to which you are comparing the current outcome. Perhaps you have justifiable performance expectations that the system does not achieve. You might have achieved this level of performance or a particular execution plan in the past, but now, with a similar environment and operation, the system is not meeting this goal.

If performance is not as you expected, can you quantify the deviation? For data warehousing operations, the execution plan is key. For critical data warehousing operations, save the EXPLAIN PLAN results. Then, as you analyze and reanalyze the data, upgrade Oracle, and load new data, over time you can compare new execution plans with old plans. Take this approach either proactively or reactively.

Alternatively, you might find that plan performance improves if you use hints. You might want to understand why hints are necessary and determine how to get the optimizer to generate the desired plan without hints. Try increasing the statistical sample size: better statistics can give you a better plan.

> **See Also:** *Oracle9i Database Performance Guide and Reference* for information on preserving plans throughout changes to your system, using plan stability and outlines

Is There a Plan Change?

If there has been a change in the execution plan, determine whether the plan is or should be parallel or serial.

Is There a Parallel Plan?

If the execution plan is or should be parallel, study the `EXPLAIN PLAN` output. Did you analyze all the tables? Perhaps you need to use hints in a few cases. Verify that the hint provides better performance.

Is There a Serial Plan?

If the execution plan is or should be serial, consider the following strategies:

- Use an index. Sometimes adding an index can greatly improve performance. Consider adding an extra column to the index. Perhaps your operation could obtain all its data from the index, and not require a table scan. Perhaps you need to use hints in a few cases. Verify that the hint provides better results.
- Compute statistics. If you do not analyze often and you can spare the time, it is a good practice to compute statistics. This is particularly important if you are performing many joins, and it will result in better plans. Alternatively, you can estimate statistics.

> **Note:** Using different sample sizes can cause the plan to change. Generally, the higher the sample size, the better the plan.

- Use histograms for nonuniform distributions.
- Check initialization parameters to be sure the values are reasonable.

- Replace bind variables with literals unless CURSOR_SHARING is set to FORCE or SIMILAR.
- Determine whether execution is I/O- or CPU-bound. Then check the optimizer cost model.
- Convert subqueries to joins.
- Use the CREATE TABLE ... AS SELECT statement to break a complex operation into smaller pieces. With a large query referencing five or six tables, it may be difficult to determine which part of the query is taking the most time. You can isolate bottlenecks in the query by breaking it into steps and analyzing each step.

Is There Parallel Execution?

If the cause of regression cannot be traced to problems in the plan, the problem must be an execution issue. For data warehousing operations, both serial and parallel, consider how the plan uses memory. Check the paging rate and make sure the system is using memory as effectively as possible. Check buffer, sort, and hash area sizing. After you run a query or DML operation, look at the V$SESSTAT, V$PX_SESSTAT, and V$PQ_SYSSTAT views to see the number of server processes used and other information for the session and system.

Is The Workload Evenly Distributed?

If you are using parallel execution, is there unevenness in workload distribution? For example, if there are 10 CPUs and a single user, you can see whether the workload is evenly distributed across CPUs. This can vary over time, with periods that are more or less I/O intensive, but in general each CPU should have roughly the same amount of activity.

The statistics in V$PQ_TQSTAT show rows produced and consumed per parallel execution server. This is a good indication of skew and does not require single user operation.

Operating system statistics show you the per-processor CPU utilization and per-disk I/O activity. Concurrently running tasks make it harder to see what is going on, however. It may be useful to run in single-user mode and check operating system monitors that show system level CPU and I/O activity.

If I/O problems occur, you might need to reorganize your data by spreading it over more devices. If parallel execution problems occur, check to be sure you have followed the recommendation to spread data over at least as many devices as CPUs.

If there is no skew in workload distribution, check for the following conditions:

- Is there device contention?
- Is there controller contention?
- Is the system I/O-bound with too little parallelism? If so, consider increasing parallelism up to the number of devices.
- Is the system CPU-bound with too much parallelism? Check the operating system CPU monitor to see whether a lot of time is being spent in system calls. The resource might be overcommitted, and too much parallelism might cause processes to compete with themselves.
- Are there more concurrent users than the system can support?

Monitoring Parallel Execution Performance with Dynamic Performance Views

After your system has run for a few days, monitor parallel execution performance statistics to determine whether your parallel processing is optimal. Do this using any of the views discussed in this section.

In Oracle Real Application Cluster, global versions of the views described in this section aggregate statistics from multiple instances. The global views have names beginning with `G`, such as `GV$FILESTAT` for `V$FILESTAT`, and so on.

V$PX_SESSION

The `V$PX_SESSION` view shows data about query server sessions, groups, sets, and server numbers. It also displays real-time data about the processes working on behalf of parallel execution. This table includes information about the requested DOP and the actual DOP granted to the operation.

V$PX_SESSTAT

The `V$PX_SESSTAT` view provides a join of the session information from `V$PX_SESSION` and the `V$SESSTAT` table. Thus, all session statistics available to a normal session are available for all sessions performed using parallel execution.

V$PX_PROCESS

The `V$PX_PROCESS` view contains information about the parallel processes, including status, session ID, process ID, and other information.

V$PX_PROCESS_SYSSTAT

The V$PX_PROCESS_SYSSTAT view shows the status of query servers and provides buffer allocation statistics.

V$PQ_SESSTAT

The V$PQ_SESSTAT view shows the status of all current server groups in the system such as data about how queries allocate processes and how the multiuser and load balancing algorithms are affecting the default and hinted values. V$PQ_SESSTAT will be obsolete in a future release.

You might need to adjust some parameter settings to improve performance after reviewing data from these views. In this case, refer to the discussion of "Tuning General Parameters for Parallel Execution" on page 21-48. Query these views periodically to monitor the progress of long-running parallel operations.

Note: For many dynamic performance views, you must set the parameter TIMED_STATISTICS to TRUE in order for Oracle to collect statistics for each view. You can use the ALTER SYSTEM or ALTER SESSION statements to turn TIMED_STATISTICS on and off.

V$FILESTAT

The V$FILESTAT view sums read and write requests, the number of blocks, and service times for every datafile in every tablespace. Use V$FILESTAT to diagnose I/O and workload distribution problems.

You can join statistics from V$FILESTAT with statistics in the DBA_DATA_FILES view to group I/O by tablespace or to find the filename for a given file number. Using a ratio analysis, you can determine the percentage of the total tablespace activity used by each file in the tablespace. If you make a practice of putting just one large, heavily accessed object in a tablespace, you can use this technique to identify objects that have a poor physical layout.

You can further diagnose disk space allocation problems using the DBA_EXTENTS view. Ensure that space is allocated evenly from all files in the tablespace. Monitoring V$FILESTAT during a long-running operation and then correlating I/O activity to the EXPLAIN PLAN output is a good way to follow progress.

V$PARAMETER

The V$PARAMETER view lists the name, current value, and default value of all system parameters. In addition, the view shows whether a parameter is a session parameter that you can modify online with an ALTER SYSTEM or ALTER SESSION statement.

V$PQ_TQSTAT

As a simple example, consider a hash join between two tables, with a join on a column with only 2 distinct values. At best, this hash function will have one value hash to parallel execution server A and the other to parallel execution server B. A DOP of two is fine, but, if it is 4, then at least 2 parallel execution servers have no work. To discover this type of skew, use a query similar to the following example:

```
SELECT dfo_number, tq_id, server_type, process, num_rows
FROM V$PQ_TQSTAT
ORDER BY dfo_number DESC, tq_id, server_type, process;
```

The best way to resolve thie problem might be to choose a different join method; a nested loop join might be the best option. Alternatively, if one of the join tables is small relative to the other, it can be broadcast if PARALLEL_BROADCAST_ENABLED=TRUE or a PQ_DISTRIBUTE hint is used.

Now, assume that you have a join key with high cardinality, but one of the values contains most of the data, for example, lava lamp sales by year. The only year that had big sales was 1968, and thus, the parallel execution server for the 1968 records will be overwhelmed. You should use the same corrective actions as described above.

The V$PQ_TQSTAT view provides a detailed report of message traffic at the table queue level. V$PQ_TQSTAT data is valid only when queried from a session that is executing parallel SQL statements. A table queue is the pipeline between query server groups, between the parallel coordinator and a query server group, or between a query server group and the coordinator. Table queues are represented in EXPLAIN PLAN output by the row labels of PARALLEL_TO_PARALLEL, SERIAL_TO_PARALLEL, or PARALLEL_TO_SERIAL, respectively.

V$PQ_TQSTAT has a row for each query server process that reads from or writes to in each table queue. A table queue connecting 10 consumer processes to 10 producer processes has 20 rows in the view. Sum the bytes column and group by TQ_ID, the table queue identifier, to obtain the total number of bytes sent through each table queue. Compare this with the optimizer estimates; large variations might indicate a need to analyze the data using a larger sample.

Compute the variance of bytes grouped by TQ_ID. Large variances indicate workload imbalances. You should investigate large variances to determine whether the producers start out with unequal distributions of data, or whether the distribution itself is skewed. If the data itself is skewed, this might indicate a low cardinality, or low number of distinct values.

Note: The V$PQ_TQSTAT view will be renamed in a future release to V$PX_TQSTSAT.

V$SESSTAT and V$SYSSTAT

The V$SESSTAT view provides parallel execution statistics for each session. The statistics include total number of queries, DML and DDL statements executed in a session and the total number of intrainstance and interinstance messages exchanged during parallel execution during the session.

V$SYSSTAT provides the same statistics as V$SESSTAT, but for the entire system.

Monitoring Session Statistics

These examples use the dynamic performance views described in "Monitoring Parallel Execution Performance with Dynamic Performance Views" on page 21-71.

Use GV$PX_SESSION to determine the configuration of the server group executing in parallel. In this example, sessions 9 is the query coordinator, while sessions 7 and 21 are in the first group, first set. Sessions 18 and 20 are in the first group, second set. The requested and granted DOP for this query is 2, as shown by Oracle's response to the following query:

```
SELECT QCSID, SID, INST_ID "Inst",
  SERVER_GROUP "Group", SERVER_SET "Set",
  DEGREE "Degree", REQ_DEGREE "Req Degree"
FROM GV$PX_SESSION ORDER BY QCSID, QCINST_ID, SERVER_GROUP, SERVER_SET;
```

Your output should resemble the following:

```
QCSID      SID        Inst       Group      Set        Degree     Req Degree
---------- ---------- ---------- ---------- ---------- ---------- ----------
         9          9          1
         9          7          1          1          1          2          2
         9         21          1          1          1          2          2
         9         18          1          1          2          2          2
         9         20          1          1          2          2          2
5 rows selected.
```

Note: For a single instance, use SELECT FROM V$PX_SESSION and do not include the column name Instance ID.

The processes shown in the output from the previous example using GV$PX_SESSION collaborate to complete the same task. The next example shows the execution of a join query to determine the progress of these processes in terms of physical reads. Use this query to track any specific statistic:

```
SELECT QCSID, SID, INST_ID "Inst",
  SERVER_GROUP "Group", SERVER_SET "Set",
  NAME "Stat Name", VALUE
FROM GV$PX_SESSTAT A, V$STATNAME B
WHERE A.STATISTIC# = B.STATISTIC#
  AND NAME LIKE 'PHYSICAL READS'
  AND VALUE > 0
ORDER BY QCSID, QCINST_ID, SERVER_GROUP, SERVER_SET;
```

Your output should resemble the following:

```
QCSID  SID   Inst   Group  Set    Stat Name          VALUE
------ ----- ------ ------ ------ ------------------ ----------
     9     9      1               physical reads           3863
     9     7      1      1      1 physical reads              2
     9    21      1      1      1 physical reads              2
     9    18      1      1      2 physical reads              2
     9    20      1      1      2 physical reads              2
5 rows selected.
```

Use the previous type of query to track statistics in V$STATNAME. Repeat this query as often as required to observe the progress of the query server processes.

The next query uses V$PX_PROCESS to check the status of the query servers.

```
SELECT * FROM V$PX_PROCESS;
```

Your output should resemble the following:

```
SERV STATUS    PID    SPID      SID    SERIAL
---- --------- ------ --------- ------ ------
P002 IN USE        16     16955     21   7729
P003 IN USE        17     16957     20   2921
P004 AVAILABLE     18     16959
P005 AVAILABLE     19     16962
P000 IN USE        12      6999     18   4720
```

```
P001 IN USE        13      7004      7    234
6 rows selected.
```

See Also: *Oracle9i Database Reference* for more information about these views

Monitoring System Statistics

The V$SYSSTAT and V$SESSTAT views contain several statistics for monitoring parallel execution. Use these statistics to track the number of parallel queries, DMLs, DDLs, data flow operators (DFOs), and operations. Each query, DML, or DDL can have multiple parallel operations and multiple DFOs.

In addition, statistics also count the number of query operations for which the DOP was reduced, or downgraded, due to either the adaptive multiuser algorithm or the depletion of available parallel execution servers.

Finally, statistics in these views also count the number of messages sent on behalf of parallel execution. The following syntax is an example of how to display these statistics:

```
SELECT NAME, VALUE FROM GV$SYSSTAT
WHERE UPPER (NAME) LIKE '%PARALLEL OPERATIONS%'
OR UPPER (NAME) LIKE '%PARALLELIZED%'
OR UPPER (NAME) LIKE '%PX%';
```

Your output should resemble the following:

```
NAME                                               VALUE
-------------------------------------------------- ----------
queries parallelized                                      347
DML statements parallelized                                 0
DDL statements parallelized                                 0
DFO trees parallelized                                    463
Parallel operations not downgraded                         28
Parallel operations downgraded to serial                   31
Parallel operations downgraded 75 to 99 pct               252
Parallel operations downgraded 50 to 75 pct               128
Parallel operations downgraded 25 to 50 pct                43
Parallel operations downgraded 1 to 25 pct                 12
PX local messages sent                                  74548
PX local messages recv'd                                74128
PX remote messages sent                                     0
PX remote messages recv'd                                   0

14 rows selected.
```

Monitoring Operating System Statistics

There is considerable overlap between information available in Oracle and information available though operating system utilities (such as `sar` and `vmstat` on UNIX-based systems). Operating systems provide performance statistics on I/O, communication, CPU, memory and paging, scheduling, and synchronization primitives. The V$SESSTAT view provides the major categories of operating system statistics as well.

Typically, operating system information about I/O devices and semaphore operations is harder to map back to database objects and operations than is Oracle information. However, some operating systems have good visualization tools and efficient means of collecting the data.

Operating system information about CPU and memory usage is very important for assessing performance. Probably the most important statistic is CPU usage. The goal of low-level performance tuning is to become CPU bound on all CPUs. Once this is achieved, you can work at the SQL level to find an alternate plan that might be more I/O intensive but use less CPU.

Operating system memory and paging information is valuable for fine tuning the many system parameters that control how memory is divided among memory-intensive warehouse subsystems like parallel communication, sort, and hash join.

Affinity and Parallel Operations

Note: The features described in this section are available only if you have purchased Oracle9*i* Enterprise Edition with the Real Application Cluster Option. See *Oracle9i Database New Features* for information about the features and options available with Oracle9*i* Enterprise Edition.

In a shared-disk cluster or MPP configuration, an instance of the Oracle Real Application Cluster is said to have **affinity** for a device if the device is directly accessed from the processors on which the instance is running. Similarly, an instance has affinity for a file if it has affinity for the devices on which the file is stored.

Determination of affinity may involve arbitrary determinations for files that are striped across multiple devices. Somewhat arbitrarily, an instance is said to have affinity for a tablespace (or a partition of a table or index within a tablespace) if the instance has affinity for the first file in the tablespace.

Oracle considers affinity when allocating work to parallel execution servers. The use of affinity for parallel execution of SQL statements is transparent to users.

Affinity and Parallel Queries

Affinity in parallel queries increases the speed of scanning data from disk by doing the scans on a processor that is near the data. This can provide a substantial performance increase for machines that do not naturally support shared disks.

The most common use of affinity is for a table or index partition to be stored in one file on one device. This configuration provides the highest availability by limiting the damage done by a device failure and makes the best use of partition-parallel index scans.

DSS customers might prefer to stripe table partitions over multiple devices (probably a subset of the total number of devices). This configuration allows some queries to prune the total amount of data being accessed using partitioning criteria and still obtain parallelism through rowid-range parallel table (partition) scans. If the devices are configured as a RAID, availability can still be very good. Even when used for DSS, indexes should probably be partitioned on individual devices.

Other configurations (for example, multiple partitions in one file striped over multiple devices) will yield correct query results, but you may need to use hints or explicitly set object attributes to select the correct DOP.

Affinity and Parallel DML

For parallel DML (inserts, updates, and deletes), affinity enhancements improve cache performance by routing the DML operation to the node that has affinity for the partition.

Affinity determines how to distribute the work among the set of instances or parallel execution servers to perform the DML operation in parallel. Affinity can improve performance of queries in several ways:

- For certain MPP architectures, Oracle uses device-to-node affinity information to determine on which nodes to spawn parallel execution servers (parallel process allocation) and which work granules (rowid ranges or partitions) to send to particular nodes (work assignment). Better performance is achieved by having nodes mainly access local devices, giving a better buffer cache hit ratio for every node and reducing the network overhead and I/O latency.

- For SMP, cluster, and MPP architectures, process-to-device affinity is used to achieve device isolation. This reduces the chances of having multiple parallel execution servers accessing the same device simultaneously. This process-to-device affinity information is also used in implementing stealing between processes.

For partitioned tables and indexes, partition-to-node affinity information determines process allocation and work assignment. For shared-nothing MPP systems, the Oracle Real Application Cluster tries to assign partitions to instances, taking the disk affinity of the partitions into account. For shared-disk MPP and cluster systems, partitions are assigned to instances in a round-robin manner.

Affinity is only available for parallel DML when running in an Oracle Real Application Cluster configuration. Affinity information which persists across statements improves buffer cache hit ratios and reduces block pings between instances.

See Also: *Oracle9i Real Application Clusters Concepts*

Miscellaneous Parallel Execution Tuning Tips

This section contains some ideas for improving performance in a parallel execution environment and includes the following topics:

- Formula for Memory, Users, and Parallel Execution Server Processes
- Setting Buffer Pool Size for Parallel Operations
- Balancing the Formula
- Parallel Execution Space Management Issues
- Overriding the Default Degree of Parallelism
- Rewriting SQL Statements

- Creating and Populating Tables in Parallel
- Creating Temporary Tablespaces for Parallel Sort and Hash Join
- Executing Parallel SQL Statements
- Using EXPLAIN PLAN to Show Parallel Operations Plans
- Additional Considerations for Parallel DML
- Creating Indexes in Parallel
- Parallel DML Tips
- Incremental Data Loading in Parallel
- Using Hints with Cost-Based Optimization

Formula for Memory, Users, and Parallel Execution Server Processes

A key to the tuning of parallel operations is an understanding of the relationship between memory requirements, the number of users (processes) a system can support, and the maximum number of parallel execution servers. The goal is to obtain the dramatic performance enhancements made possible by parallelizing certain operations and by using hash joins rather than sort merge joins. You must balance this performance goal with the need to support multiple users.

In considering the maximum number of processes a system can support, it is useful to divide the processes into three classes, based on their memory requirements. Table 21–5 on page 21-81 defines high, medium, and low memory processes.

Analyze the maximum number of processes that can fit in memory by using the following formula:

Figure 21–7 Formula for Memory/Users/Server Relationship

$$\begin{array}{l} \quad \textit{sga\_size} \\ + \; (\#\ \textit{low\_memory\_processes} * \textit{low\_memory\_required}) \\ + \; (\#\ \textit{medium\_memory\_processes} * \textit{medium\_memory\_required}) \\ + \; (\#\ \textit{high\_memory\_processes} * \textit{high\_memory\_required}) \\ \hline \quad \textit{total memory required} \end{array}$$

Table 21–5 Memory Requirements for Three Classes of Process

Class	Description
Low Memory Processes: 100 KB to 1 MB	Low memory processes include table scans, index lookups, index nested loop joins; single-row aggregates (such as sum or average with no GROUP BY clauses, or very few groups), and sorts that return only a few rows; and direct loading. This class of data warehousing process is similar to OLTP processes in the amount of memory required. Process memory may be as low as a few hundred kilobytes of fixed overhead. You could potentially support thousands of users performing this kind of operation. You can take this requirement even lower and support even more users by using the shared server.
Medium Memory Processes: 1 MB to 10 MB	Medium Memory Processes include large sorts, sort merge join, GROUP BY or ORDER BY operations returning a large number of rows, parallel insert operations that involve index maintenance, and index creation. These processes require the fixed overhead needed by a low memory process, plus one or more sort areas, depending on the operation. For example, a typical sort merge join would sort both its inputs—resulting in two sort areas. GROUP BY or ORDER BY operations with many groups or rows also require sort areas. Look at the EXPLAIN PLAN output for the operation to identify the number and type of joins, and the number and type of sorts. Optimizer statistics in the plan show the size of the operations. When planning joins, remember that you have several choices. The EXPLAIN PLAN statement is described in *Oracle9i Database Performance Guide and Reference*.
High Memory Processes: 10 MB to 100 MB	High memory processes include one or more hash joins, or a combination of one or more hash joins with large sorts. These processes require the fixed overhead needed by a low memory process, plus hash area. The hash area size required might range from 8 MB to 32 MB, and you might need two of them. If you are performing two or more serial hash joins, each process uses 2 hash areas. In a parallel operation, each parallel execution server does at most 1 hash join at a time; therefore, you would need one hash area size per server. In summary, the amount of hash join memory for an operation equals the DOP multiplied by hash area size, multiplied by the lesser of either 2 or the number of hash joins in the operation.

Note: The process memory requirements of parallel DML and parallel DDL operations also depend upon the query portion of the statement.

The formula to calculate the maximum number of processes your system can support (referred to here as MAX_PROCESSES) is:

Figure 21–8 Formula for Calculating the Maximum Number of Processes

$$\begin{array}{rl} & \#\ low\_memory\_processes \\ + & \#\ medium\_memory\_processes \\ + & \#\ high\_memory\_processes \\ \hline & max\_processes \end{array}$$

In general, if the value for `MAX_PROCESSES` is much larger than the number of users, consider using parallel operations. If `MAX_PROCESSES` is considerably less than the number of users, consider other alternatives, such as those described in the following section on "Balancing the Formula".

Setting Buffer Pool Size for Parallel Operations

With the exception of parallel update and delete, parallel operations do not generally benefit from larger buffer pool sizes. Parallel update and delete benefit from a larger buffer pool when they update indexes. This is because index updates have a random access pattern, and I/O activity can be reduced if an entire index or its interior nodes can be kept in the buffer pool. Other parallel operations can benefit only if you increase the size of the buffer pool and thereby accommodate the inner table or index for a nested loop join.

Balancing the Formula

Use the following technique to balance the formula provided in Figure 21–7.

You can permit the potential workload to exceed the limits recommended in the formula. Total memory required, minus the SGA size, can be multiplied by a factor of 1.2, to allow for 20 percent oversubscription. Thus, if you have 1 GB of memory, you may be able to support 1.2 GB of demand: the other 20 percent could be handled by the paging system.

You must, however, verify that a particular degree of oversubscription is viable on your system. Do this by monitoring the paging rate and making sure you are not spending more than a very small percent of the time waiting for the paging subsystem. Your system might perform acceptably even if oversubscribed by 60 percent, if, on average, not all of the processes are performing hash joins concurrently. Users might then try to access more than the available memory, so you must continually monitor paging activity in such a situation. If paging dramatically increases, consider other alternatives.

On average, no more than 5 percent of the time should be spent simply waiting in the operating system on page faults. A wait time of more than 5 percent indicates your paging subsystem is I/O-bound. Use your operating system monitor to check wait time.

If wait time for paging devices exceeds 5 percent, you can reduce memory requirements in one of the following ways:

- Reduce the memory required for each class of process.
- Reduce the number of processes in memory-intensive classes.
- Add memory.

If the wait time indicates an I/O bottleneck in the paging subsystem, you could resolve this by striping.

Parallel Execution Space Management Issues

This section describes space management issues that occur when using parallel execution. These issues are:

- ST Enqueue for Sorts and Temporary Data
- External Fragmentation
- Free Space

These problems become particularly important for parallel operations in an Oracle Real Application Cluster environment. The more nodes that are involved, the more critical tuning becomes.

If you can implement locally managed tablespaces, you can avoid these issues altogether.

> **See Also:** *Oracle9i Database Administrator's Guide* for more information about locally managed tablespaces

ST Enqueue for Sorts and Temporary Data

Every space management transaction in the database (such as creation of temporary segments in `PARALLEL CREATE TABLE`, or parallel direct-path `INSERT`s of non-partitioned tables) is controlled by a single space transaction enqueue. A high transaction rate, for example, more than two or three transactions per minute, on ST enqueues can result in poor scalability on Oracle Real Application Clusters with many nodes, or a timeout waiting for space management resources. Use the `V$ROWCACHE` and `V$LIBRARYCACHE` views to locate this type of contention.

Try to minimize the number of space management transactions, in particular:

- The number of sort space management transactions
- The creation and removal of objects
- Transactions caused by fragmentation in a tablespace

To optimize space management for sorts, use locally managed tablespaces for temporary data. This is particularly beneficial on Oracle Real Application Clusters. You can monitor this using `V$SORT_SEGMENT`.

External Fragmentation

External fragmentation is a concern for parallel load, direct-path `INSERT`, and `PARALLEL CREATE TABLE ... AS SELECT`. Memory tends to become fragmented as extents are allocated and data is inserted and deleted. This can result in a fair amount of free space that is unusable because it consists of small, noncontiguous chunks of memory.

To reduce external fragmentation on partitioned tables, set all extents to the same size. Set the value for `NEXT` equal to the value for `INITIAL`, and set `PERCENT_INCREASE` to `0`. The system can handle this well with a few thousand extents per object. Therefore, set `MAXEXTENTS` to, for example, 1,000 to 3,000. Never attempt to use a value for `MAXEXTENTS` in excess of 10,000. For tables that are not partitioned, the initial extent should be small. In general, the smaller the extent, the better utilization of space. The trade-off is that your system will spend more time getting new extents.

Free Space

Schema objects from an OLTP database are often duplicated in the data warehouse. However, these objects will probably not be subject to the same mix of insert versus update activity in the data warehouse as in the OLTP environment. The `PCTFREE` storage clause can be reduced in the data warehouse environment if the data is loaded and then very seldomly updated. The default value is 10, which reserves 10 percent of each block that is loaded for future updates. An OLTP environment may use higher values, so care should be taken when importing schema DDL from OLTP systems.

Overriding the Default Degree of Parallelism

The default DOP is appropriate for reducing response time while guaranteeing use of CPU and I/O resources for any parallel operations.

If it is memory-bound, or if several concurrent parallel operations are running, you might want to decrease the default DOP.

Oracle uses the default DOP for tables that have PARALLEL attributed to them in the data dictionary or that have the PARALLEL hint specified. If a table does not have parallelism attributed to it, or has NOPARALLEL (the default) attributed to it, and parallelism is not being forced through ALTER SESSION FORCE PARALLEL, then that table is never scanned in parallel. This override occurs regardless of the default DOP indicated by the number of CPUs, instances, and devices storing that table.

You can adjust the DOP by using the following guidelines:

- Modify the default DOP by changing the value for the PARALLEL_THREADS_PER_CPU parameter.
- Adjust the DOP either by using ALTER TABLE, ALTER SESSION, or by using hints.
- To increase the number of concurrent parallel operations, reduce the DOP, or set the parameter PARALLEL_ADAPTIVE_MULTI_USER to TRUE.

Rewriting SQL Statements

The most important issue for parallel execution is ensuring that all parts of the query plan that process a substantial amount of data execute in parallel. Use EXPLAIN PLAN to verify that all plan steps have an OTHER_TAG of PARALLEL_TO_PARALLEL, PARALLEL_TO_SERIAL, PARALLEL_COMBINED_WITH_PARENT, or PARALLEL_COMBINED_WITH_CHILD. Any other keyword (or null) indicates serial execution and a possible bottleneck.

You can also use the utlxplp.sql script to present the EXPLAIN PLAN output with all relevant parallel information.

See Also: *Oracle9i Database Performance Guide and Reference* for more information on using EXPLAIN PLAN

You can increase the optimizer's ability to generate parallel plans converting subqueries, especially correlated subqueries, into joins. Oracle can parallelize joins more efficiently than subqueries. This also applies to updates.

See Also: "Updating the Table in Parallel" on page 21-98

Creating and Populating Tables in Parallel

Oracle cannot return results to a user process in parallel. If a query returns a large number of rows, execution of the query might indeed be faster. However, the user process can only receive the rows serially. To optimize parallel execution performance for queries that retrieve large result sets, use PARALLEL CREATE TABLE ... AS SELECT or direct-path INSERT to store the result set in the database. At a later time, users can view the result set serially.

> **Note:** Performing the SELECT in parallel does not influence the CREATE statement. If the CREATE is parallel, however, the optimizer tries to make the SELECT run in parallel also.

When combined with the NOLOGGING option, the parallel version of CREATE TABLE ... AS SELECT provides a very efficient intermediate table facility, for example:

```
CREATE TABLE summary PARALLEL NOLOGGING
  AS SELECT dim_1, dim_2 ..., SUM (meas_1)
     FROM facts
  GROUP BY dim_1, dim_2;
```

These tables can also be incrementally loaded with parallel INSERT. You can take advantage of intermediate tables using the following techniques:

- Common subqueries can be computed once and referenced many times. This can allow some queries against star schemas (in particular, queries without selective WHERE-clause predicates) to be better parallelized. Note that star queries with selective WHERE-clause predicates using the star-transformation technique can be effectively parallelized automatically without any modification to the SQL.
- Decompose complex queries into simpler steps in order to provide application-level checkpoint or restart. For example, a complex multitable join on a database 1 terabyte in size could run for dozens of hours. A crash during this query would mean starting over from the beginning. Using CREATE TABLE ... AS SELECT or PARALLEL INSERT AS SELECT, you can rewrite the query as a sequence of simpler queries that run for a few hours each. If a system failure occurs, the query can be restarted from the last completed step.
- Implement manual parallel deletes efficiently by creating a new table that omits the unwanted rows from the original table, and then dropping the original

table. Alternatively, you can use the convenient parallel delete feature, which directly deletes rows from the original table.

- Create summary tables for efficient multidimensional drill-down analysis. For example, a summary table might store the sum of revenue grouped by month, brand, region, and salesman.
- Reorganize tables, eliminating chained rows, compressing free space, and so on, by copying the old table to a new table. This is much faster than export/import and easier than reloading.

Note: Be sure to use the DBMS_STATS package on newly created tables. Also consider creating indexes. To avoid I/O bottlenecks, specify a tablespace with at least as many devices as CPUs. To avoid fragmentation in allocating space, the number of files in a tablespace should be a multiple of the number of CPUs. See Chapter 4, "Hardware and I/O Considerations in Data Warehouses", for more information about bottlenecks.

Creating Temporary Tablespaces for Parallel Sort and Hash Join

For optimal space management performance, use dedicated temporary tablespaces. As with the TStemp tablespace, first add a single datafile and later add the remainder in parallel, as in this example:

```
CREATE TABLESPACE TStemp TEMPORARY DATAFILE '/dev/D31'
SIZE 4096MB REUSE
DEFAULT STORAGE (INITIAL 10MB NEXT 10MB PCTINCREASE 0);
```

Size of Temporary Extents

Temporary extents are all the same size because the server ignores the PCTINCREASE and INITIAL settings and only uses the NEXT setting for temporary extents. This helps avoid fragmentation.

As a general rule, temporary extents should be smaller than permanent extents because there are more demands for temporary space, and parallel processes or other operations running concurrently must share the temporary tablespace. Normally, temporary extents should be in the range of 1 MB to 10 MB. Once you allocate an extent, it is available for the duration of an operation. If you allocate a large extent but only need to use a small amount of space, the unused space in the extent is tied up.

At the same time, temporary extents should be large enough that processes do not have to wait for space. Temporary tablespaces use less overhead than permanent tablespaces when allocating and freeing a new extent. However, obtaining a new temporary extent still requires the overhead of acquiring a latch and searching through the SGA structures, as well as SGA space consumption for the sort extent pool. Also, if extents are too small, SMON might take a long time dropping old sort segments when new instances start up.

Operating System Striping of Temporary Tablespaces

Operating system striping is an alternative technique you can use with temporary tablespaces. Media recovery, however, offers subtle challenges for large temporary tablespaces. It does not make sense to mirror, use RAID, or back up a temporary tablespace. If you lose a disk in an operating system striped temporary space, you will probably have to drop and re-create the tablespace. This could take several hours for the 120 GB example. With Oracle striping, simply remove the defective disk from the tablespace. For example, if `/dev/D50` fails, enter:

```
ALTER DATABASE DATAFILE '/dev/D50' RESIZE 1K;
ALTER DATABASE DATAFILE '/dev/D50' OFFLINE;
```

Because the dictionary sees the size as 1 KB, which is less than the extent size, the corrupt file is not accessed. Eventually, you might wish to re-create the tablespace.

To make your temporary tablespace available for use, enter:

```
ALTER USER scott TEMPORARY TABLESPACE TStemp;
```

See Also: For MPP systems, see your platform-specific documentation regarding the advisability of disabling disk affinity when using operating system striping

Executing Parallel SQL Statements

After analyzing your tables and indexes, you should see performance improvements based on the DOP used.

As a general process, you should start with simple parallel operations and evaluate their total I/O throughput with a `SELECT COUNT(*) FROM facts` statement. Then, evaluate total CPU power by adding a complex `WHERE` clause to the statement. An I/O imbalance might suggest a better physical database layout. After you understand how simple scans work, add aggregation, joins, and other operations that reflect individual aspects of the overall workload. In particular, you should look for bottlenecks.

Besides query performance, you should also monitor parallel load, parallel index creation, and parallel DML, and look for good utilization of I/O and CPU resources.

Using EXPLAIN PLAN to Show Parallel Operations Plans

Use the `EXPLAIN PLAN` statement to see the execution plans for parallel queries. `EXPLAIN PLAN` output shows optimizer information in the `COST`, `BYTES`, and `CARDINALITY` columns. You can also use the `utlxplp.sql` script to present the `EXPLAIN PLAN` output with all relevant parallel information.

> **See Also:** *Oracle9i Database Performance Guide and Reference* for more information on using `EXPLAIN PLAN`

There are several ways to optimize the parallel execution of join statements. You can alter system configuration, adjust parameters as discussed earlier in this chapter, or use hints, such as the `DISTRIBUTION` hint.

The key points when using `EXPLAIN PLAN` are to:

- Verify optimizer selectivity estimates. If the optimizer thinks that only one row will be produced from a query, it tends to favor using a nested loop. This could be an indication that the tables are not analyzed or that the optimizer has made an incorrect estimate about the correlation of multiple predicates on the same table. A hint may be required to force the optimizer to use another join method. Consequently, if the plan says only one row is produced from any particular stage and this is incorrect, consider hints or gather statistics.
- Use hash join on low cardinality join keys. If a join key has few distinct values, then a hash join may not be optimal. If the number of distinct values is less than the DOP, then some parallel query servers may be unable to work on the particular query.
- Consider data skew. If a join key involves excessive data skew, a hash join may require some parallel query servers to work more than others. Consider setting `PARALLEL_BROADCAST_ENBALED` to `TRUE` or using a hint to cause a broadcast.

Additional Considerations for Parallel DML

When you want to refresh your data warehouse database using parallel insert, update, or delete on a data warehouse, there are additional issues to consider when designing the physical database. These considerations do not affect parallel execution operations. These issues are:

- PDML and Direct-Path Restrictions
- Limitation on the Degree of Parallelism
- Using Local and Global Striping
- Increasing INITRANS and MAXTRANS
- Limitation on Available Number of Transaction Free Lists for Segments in Dictionary-Managed Tablespaces
- Using Multiple Archivers
- Database Writer Process (DBWn) Workload
- [NO]LOGGING Clause

PDML and Direct-Path Restrictions

If a parallel restriction is violated, the operation is simply performed serially. If a direct-path `INSERT` restriction is violated, then the `APPEND` hint is ignored and a conventional insert is performed. No error message is returned.

Limitation on the Degree of Parallelism

If you are performing parallel `UPDATE`, `MERGE`, or `DELETE` operations, the DOP is equal to or less than the number of partitions in the table.

Using Local and Global Striping

Parallel updates and deletes work only on partitioned tables. They can generate a high number of random I/O requests during index maintenance.

For local index maintenance, local striping is most efficient in reducing I/O contention because one server process only goes to its own set of disks and disk controllers. Local striping also increases availability in the event of one disk failing.

For global index maintenance (partitioned or nonpartitioned), globally striping the index across many disks and disk controllers is the best way to distribute the number of I/Os.

Increasing INITRANS and MAXTRANS

If you have global indexes, a global index segment and global index blocks are shared by server processes of the same parallel DML statement. Even if the operations are not performed against the same row, the server processes can share the same index blocks. Each server transaction needs one transaction entry in the index block header before it can make changes to a block. Therefore, in the `CREATE`

INDEX or ALTER INDEX statements, you should set INITRANS, the initial number of transactions allocated within each data block, to a large value, such as the maximum DOP against this index. Leave MAXTRANS, the maximum number of concurrent transactions that can update a data block, at its default value, which is the maximum your system can support. This value should not exceed 255.

If you run a DOP of 10 against a table with a global index, all 10 server processes might attempt to change the same global index block. For this reason, you must set MAXTRANS to at least 10 so all server processes can make the change at the same time. If MAXTRANS is not large enough, the parallel DML operation fails.

Limitation on Available Number of Transaction Free Lists for Segments in Dictionary-Managed Tablespaces

Once a segment has been created, the number of process and transaction free lists is fixed and cannot be altered. If you specify a large number of process free lists in the segment header, you might find that this limits the number of transaction free lists that are available. You can abate this limitation the next time you re-create the segment header by decreasing the number of process free lists; this leaves more room for transaction free lists in the segment header.

For UPDATE and DELETE operations, each server process can require its own transaction free list. The parallel DML DOP is thus effectively limited by the smallest number of transaction free lists available on any of the global indexes the DML statement must maintain. For example, if you have two global indexes, one with 50 transaction free lists and one with 30 transaction free lists, the DOP is limited to 30.

The FREELISTS parameter of the STORAGE clause is used to set the number of process free lists. By default, no process free lists are created.

The default number of transaction free lists depends on the block size. For example, if the number of process free lists is not set explicitly, a 4 KB block has about 80 transaction free lists by default. The minimum number of transaction free lists is 25.

Using Multiple Archivers

Parallel DDL and parallel DML operations can generate a large amount of redo logs. A single ARCH process to archive these redo logs might not be able to keep up. To avoid this problem, you can spawn multiple archiver processes. This can be done manually or by using a job queue.

Database Writer Process (DBWn) Workload

Parallel DML operations dirty a large number of data, index, and undo blocks in the buffer cache during a short period of time. For example, suppose you see a high number of `free_buffer_waits` after querying the `V$SYSTEM_EVENT` view, as in the following syntax:

```
SELECT TOTAL_WAITS FROM V$SYSTEM_EVENT WHERE EVENT = 'FREE BUFFER WAITS';
```

In this case, you should consider increasing the DBW*n* processes. If there are no waits for free buffers, the query will not return any rows.

[NO]LOGGING Clause

The `[NO]LOGGING` clause applies to tables, partitions, tablespaces, and indexes. Virtually no log is generated for certain operations (such as direct-path `INSERT`) if the `NOLOGGING` clause is used. The `NOLOGGING` attribute is not specified at the `INSERT` statement level but is instead specified when using the `ALTER` or `CREATE` statement for a table, partition, index, or tablespace.

When a table or index has `NOLOGGING` set, neither parallel nor serial direct-path `INSERT` operations generate undo or redo logs. Processes running with the `NOLOGGING` option set run faster because no redo is generated. However, after a `NOLOGGING` operation against a table, partition, or index, if a media failure occurs before a backup is taken, then all tables, partitions, and indexes that have been modified might be corrupted.

Note: Direct-path `INSERT` operations (except for dictionary updates) never generate undo logs. The `NOLOGGING` attribute does not affect undo, only redo. To be precise, `NOLOGGING` allows the direct-path `INSERT` operation to generate a negligible amount of redo (range-invalidation redo, as opposed to full image redo).

For backward compatibility, `[UN]RECOVERABLE` is still supported as an alternate keyword with the `CREATE TABLE` statement. This alternate keyword might not be supported, however, in future releases.

At the tablespace level, the logging clause specifies the default logging attribute for all tables, indexes, and partitions created in the tablespace. When an existing tablespace logging attribute is changed by the `ALTER TABLESPACE` statement, then all tables, indexes, and partitions created after the `ALTER` statement will have the new logging attribute; existing ones will not change their logging attributes. The tablespace-level logging attribute can be overridden by the specifications at the table, index, or partition level.

The default logging attribute is LOGGING. However, if you have put the database in NOARCHIVELOG mode, by issuing ALTER DATABASE NOARCHIVELOG, then all operations that can be done without logging will not generate logs, regardless of the specified logging attribute.

Creating Indexes in Parallel

Multiple processes can work together simultaneously to create an index. By dividing the work necessary to create an index among multiple server processes, Oracle can create the index more quickly than if a single server process created the index sequentially.

Parallel index creation works in much the same way as a table scan with an ORDER BY clause. The table is randomly sampled and a set of index keys is found that equally divides the index into the same number of pieces as the DOP. A first set of query processes scans the table, extracts key-rowid pairs, and sends each pair to a process in a second set of query processes based on key. Each process in the second set sorts the keys and builds an index in the usual fashion. After all index pieces are built, the parallel coordinator simply concatenates the pieces (which are ordered) to form the final index.

Parallel local index creation uses a single server set. Each server process in the set is assigned a table partition to scan and for which to build an index partition. Because half as many server processes are used for a given DOP, parallel local index creation can be run with a higher DOP.

You can optionally specify that no redo and undo logging should occur during index creation. This can significantly improve performance but temporarily renders the index unrecoverable. Recoverability is restored after the new index is backed up. If your application can tolerate a window where recovery of the index requires it to be re-created, then you should consider using the NOLOGGING clause.

The PARALLEL clause in the CREATE INDEX statement is the only way in which you can specify the DOP for creating the index. If the DOP is not specified in the parallel clause of CREATE INDEX, then the number of CPUs is used as the DOP. If there is no PARALLEL clause, index creation is done serially.

Note: When creating an index in parallel, the STORAGE clause refers to the storage of each of the subindexes created by the query server processes. Therefore, an index created with an INITIAL of 5 MB and a DOP of 12 consumes at least 60 MB of storage during index creation because each process starts with an extent of 5 MB. When the query coordinator process combines the sorted subindexes, some of the extents might be trimmed, and the resulting index might be smaller than the requested 60 MB.

When you add or enable a UNIQUE or PRIMARY KEY constraint on a table, you cannot automatically create the required index in parallel. Instead, manually create an index on the desired columns, using the CREATE INDEX statement and an appropriate PARALLEL clause, and then add or enable the constraint. Oracle then uses the existing index when enabling or adding the constraint.

Multiple constraints on the same table can be enabled concurrently and in parallel if all the constraints are already in the ENABLE NOVALIDATE state. In the following example, the ALTER TABLE ... ENABLE CONSTRAINT statement performs the table scan that checks the constraint in parallel:

```
CREATE TABLE a (a1 NUMBER CONSTRAINT ach CHECK (a1 > 0) ENABLE NOVALIDATE)
PARALLEL;
INSERT INTO a values (1);
COMMIT;
ALTER TABLE a ENABLE CONSTRAINT ach;
```

See Also: *Oracle9i Database Concepts* for more information on how extents are allocated when using parallel execution

Parallel DML Tips

This section provides an overview of parallel DML functionality. The topics covered include:

- INSERT
- Direct-path INSERT
- Parallelizing INSERT, MERGE, UPDATE, and DELETE

See Also: *Oracle9i Database Concepts* for a detailed discussion of parallel DML and DOP

INSERT

Oracle INSERT functionality can be summarized as follows:

Table 21–6 Summary of INSERT Features

Insert Type	Parallel	Serial	NOLOGGING
Conventional	No	Yes	No
Direct-path INSERT (Append)	Yes: requires: ■ ALTER SESSION ENABLE PARALLEL DML ■ Table PARALLEL attribute or PARALLEL hint ■ APPEND hint (optional)	Yes: requires: ■ APPEND hint	Yes: requires: ■ NOLOGGING attribute set for table or partition

If parallel DML is enabled and there is a PARALLEL hint or PARALLEL attribute set for the table in the data dictionary, then inserts are parallel and appended, unless a restriction applies. If either the PARALLEL hint or PARALLEL attribute is missing, the insert is performed serially.

Direct-path INSERT

Append mode is the default during a parallel insert: data is always inserted into a new block which is allocated to the table. Therefore the APPEND hint is optional. You should use append mode to increase the speed of INSERT operations, but not when space utilization needs to be optimized. You can use NOAPPEND to override append mode.

The APPEND hint applies to both serial and parallel insert: even serial inserts are faster if you use this hint. APPEND, however, does require more space and locking overhead.

You can use NOLOGGING with APPEND to make the process even faster. NOLOGGING means that no redo log is generated for the operation. NOLOGGING is never the default; use it when you wish to optimize performance. It should not normally be used when recovery is needed for the table or partition. If recovery is needed, be sure to take a backup immediately after the operation. Use the ALTER TABLE [NO]LOGGING statement to set the appropriate value.

Parallelizing INSERT, MERGE, UPDATE, and DELETE

When the table or partition has the PARALLEL attribute in the data dictionary, that attribute setting is used to determine parallelism of INSERT, UPDATE, and DELETE statements as well as queries. An explicit PARALLEL hint for a table in a statement overrides the effect of the PARALLEL attribute in the data dictionary.

You can use the NOPARALLEL hint to override a PARALLEL attribute for the table in the data dictionary. In general, hints take precedence over attributes.

DML operations are considered for parallelization only if the session is in a PARALLEL DML enabled mode. (Use ALTER SESSION ENABLE PARALLEL DML to enter this mode.) The mode does not affect parallelization of queries or of the query portions of a DML statement.

> **See Also:** *Oracle9i Database Concepts* for more information on parallel INSERT, UPDATE and DELETE

Parallelizing INSERT ... SELECT In the INSERT ... SELECT statement you can specify a PARALLEL hint after the INSERT keyword, in addition to the hint after the SELECT keyword. The PARALLEL hint after the INSERT keyword applies to the INSERT operation only, and the PARALLEL hint after the SELECT keyword applies to the SELECT operation only. Thus, parallelism of the INSERT and SELECT operations are independent of each other. If one operation cannot be performed in parallel, it has no effect on whether the other operation can be performed in parallel.

The ability to parallelize inserts causes a change in existing behavior if the user has explicitly enabled the session for parallel DML and if the table in question has a PARALLEL attribute set in the data dictionary entry. In that case, existing INSERT ... SELECT statements that have the select operation parallelized can also have their insert operation parallelized.

If you query multiple tables, you can specify multiple SELECT PARALLEL hints and multiple PARALLEL attributes.

Example 21–7 Parallelizing INSERT ... SELECT Example

Add the new employees who were hired after the acquisition of ACME.

```
INSERT /*+ PARALLEL(EMP) */ INTO EMP
SELECT /*+ PARALLEL(ACME_EMP) */ *
FROM ACME_EMP;
```

The APPEND keyword is not required in this example because it is implied by the PARALLEL hint.

Parallelizing UPDATE and DELETE The PARALLEL hint (placed immediately after the UPDATE or DELETE keyword) applies not only to the underlying scan operation, but also to the UPDATE or DELETE operation. Alternatively, you can specify UPDATE or DELETE parallelism in the PARALLEL clause specified in the definition of the table to be modified.

If you have explicitly enabled parallel DML for the session or transaction, UPDATE or DELETE statements that have their query operation parallelized can also have their UPDATE or DELETE operation parallelized. Any subqueries or updatable views in the statement can have their own separate PARALLEL hints or clauses, but these parallel directives do not affect the decision to parallelize the update or delete. If these operations cannot be performed in parallel, it has no effect on whether the UPDATE or DELETE portion can be performed in parallel.

Tables must be partitioned in order to support parallel UPDATE and DELETE.

Example 21–8 Parallelizing UPDATE and DELETE: Example 1

Give a 10 percent salary raise to all clerks in Dallas.

```
UPDATE /*+ PARALLEL(EMP) */ EMP
SET SAL=SAL * 1.1
  WHERE JOB='CLERK' AND
  DEPTNO IN
  (SELECT DEPTNO FROM DEPT WHERE LOCATION='DALLAS');
```

The PARALLEL hint is applied to the UPDATE operation as well as to the scan.

Example 21–9 Parallelizing UPDATE and DELETE: Example 2

Remove all products in the grocery category because the grocery business line was recently spun off into a separate company.

```
DELETE /*+ PARALLEL(PRODUCTS) */ FROM PRODUCTS
WHERE PRODUCT_CATEGORY ='GROCERY';
```

Again, the parallelism is applied to the scan as well as UPDATE operation on table emp.

Incremental Data Loading in Parallel

Parallel DML combined with the updatable join views facility provides an efficient solution for refreshing the tables of a data warehouse system. To refresh tables is to update them with the differential data generated from the OLTP production system.

In the following example, assume that you want to refresh a table named customer that has columns c_key, c_name, and c_addr. The differential data contains either new rows or rows that have been updated since the last refresh of the data warehouse. In this example, the updated data is shipped from the production system to the data warehouse system by means of ASCII files. These files must be loaded into a temporary table, named `diff_customer`, before starting the refresh process. You can use SQL*Loader with both the parallel and direct options to efficiently perform this task.

Once `diff_customer` is loaded, the refresh process can be started. It can be performed in two phases or with a newer technique:

- Updating the Table in Parallel
- Inserting the New Rows into the Table in Parallel
- Merging in Parallel

Updating the Table in Parallel

A straightforward SQL implementation of the update uses subqueries:

```
UPDATE customer
SET(c_name, c_addr) =
  (SELECT c_name, c_addr
   FROM diff_customer
   WHERE diff_customer.c_key = customer.c_key)
   WHERE c_key IN(SELECT c_key FROM diff_customer);
```

Unfortunately, the two subqueries in this statement affect performance.

An alternative is to rewrite this query using updatable join views. To do this, you must first add a primary key constraint to the `diff_customer` table to ensure that the modified columns map to a key-preserved table:

```
CREATE UNIQUE INDEX diff_pkey_ind ON diff_customer(c_key)
  PARALLEL NOLOGGING;
ALTER TABLE diff_customer ADD PRIMARY KEY (c_key);
```

You can then update the `customer` table with the following SQL statement:

```
UPDATE /*+ PARALLEL(cust_joinview) */
(SELECT /*+ PARALLEL(customer) PARALLEL(diff_customer) */
CUSTOMER.c_name as c_name
CUSTOMER.c_addr as c_addr,
diff_customer.c_name as c_newname, diff_customer.c_addr as c_newaddr
   WHERE customer.c_key = diff_customer.c_key) cust_joinview
   SET c_name = c_newname, c_addr = c_newaddr;
```

The base scans feeding the join view `cust_joinview` are done in parallel. You can then parallelize the update to further improve performance, but only if the `customer` table is partitioned.

See Also:

- "Rewriting SQL Statements" on page 21-85
- *Oracle9i Application Developer's Guide - Fundamentals* for information about key-preserved tables

Inserting the New Rows into the Table in Parallel

The last phase of the refresh process consists of inserting the new rows from the `diff_customer` temporary table to the `customer` table. Unlike the update case, you cannot avoid having a subquery in the `INSERT` statement:

```
INSERT /*+PARALLEL(customer)*/ INTO customer
SELECT * FROM diff_customer
WHERE diff_customer.c_key NOT IN (SELECT /*+ HASH_AJ */ KEY FROM customer);
```

However, youcan guarantee that the subquery is transformed into an anti-hash join by using the `HASH_AJ` hint. Doing so enables you to use parallel `INSERT` to execute the preceding statement efficiently. Parallel `INSERT` is applicable even if the table is not partitioned.

Merging in Parallel

In Oracle9*i*, you combine the previous updates and inserts into one statement, commonly known as an **upsert** or **merge**. The following statement achieves the same result as all of the statements in "Updating the Table in Parallel" on page 21-98 and "Inserting the New Rows into the Table in Parallel" on page 21-99:

```
MERGE INTO customer USING diff_customer
ON (diff_customer.c_key = customer.c_key)
WHEN MATCHED THEN
  UPDATE SET (c_name, c_addr) = (SELECT c_name, c_addr
  FROM diff_customer
  WHERE diff_customer.c_key = customer.c_key)
WHEN NOT MATCHED THEN
  INSERT VALUES (diff_customer.c_key,diff_customer.c_data);
```

Using Hints with Cost-Based Optimization

Cost-based optimization is a sophisticated approach to finding the best execution plan for SQL statements. Oracle automatically uses cost-based optimization with parallel execution.

Note: You must use the `DBMS_STATS` package to gather current statistics for cost-based optimization. In particular, tables used in parallel should always be analyzed. Always keep your statistics current by using the `DBMS_STATS` package.

Use discretion in employing hints. If used, hints should come as a final step in tuning and only when they demonstrate a necessary and significant performance advantage. In such cases, begin with the execution plan recommended by cost-based optimization, and go on to test the effect of hints only after you have quantified your performance expectations. Remember that hints are powerful. If you use them and the underlying data changes, you might need to change the hints. Otherwise, the effectiveness of your execution plans might deteriorate.

Always use cost-based optimization unless you have an existing application that has been hand-tuned for rule-based optimization. If you must use rule-based optimization, rewriting a SQL statement can greatly improve application performance.

Note: If any table in a query has a DOP greater than one (including the default DOP), Oracle uses the cost-based optimizer for that query, even if `OPTIMIZER_MODE` is set to `RULE` or if there is a `RULE` hint in the query itself.

---

22 Query Rewrite

This chapter discusses how Oracle rewrites queries. It contains:

Overview of Query Rewrite

One of the major benefits of creating and maintaining materialized views is the ability to take advantage of query rewrite, which transforms a SQL statement expressed in terms of tables or views into a statement accessing one or more materialized views that are defined on the detail tables. The transformation is transparent to the end user or application, requiring no intervention and no reference to the materialized view in the SQL statement. Because query rewrite is transparent, materialized views can be added or dropped just like indexes without invalidating the SQL in the application code.

Before the query is rewritten, it is subjected to several checks to determine whether it is a candidate for query rewrite. If the query fails any of the checks, then the query is applied to the detail tables rather than the materialized view. This can be costly in terms of response time and processing power.

The Oracle optimizer uses two different methods to recognize when to rewrite a query in terms of one or more materialized views. The first method is based on matching the SQL text of the query with the SQL text of the materialized view definition. If the first method fails, the optimizer uses the more general method in which it compares joins, selections, data columns, grouping columns, and aggregate functions between the query and a materialized view.

Query rewrite operates on queries and subqueries in the following types of SQL statements:

- `SELECT`
- `CREATE TABLE … AS SELECT`
- `INSERT INTO … SELECT`

It also operates on subqueries in the set operators `UNION`, `UNION ALL`, `INTERSECT`, and `MINUS`, and subqueries in DML statements such as `INSERT`, `DELETE`, and `UPDATE`.

Several factors affect whether or not a given query is rewritten to use one or more materialized views:

- Enabling or disabling query rewrite
  - by the `CREATE` or `ALTER` statement for individual materialized views
  - by the initialization parameter `QUERY_REWRITE_ENABLED`
  - by the `REWRITE` and `NOREWRITE` hints in SQL statements

- Rewrite integrity levels
- Dimensions and constraints

There is also an explain rewrite procedure which will advise whether query rewrite is possible on a query and if so, which materialized views will be used.

Cost-Based Rewrite

Query rewrite is available with cost-based optimization. Oracle optimizes the input query with and without rewrite and selects the least costly alternative. The optimizer rewrites a query by rewriting one or more query blocks, one at a time.

If the rewrite logic has a choice between multiple materialized views to rewrite a query block, it will select one to optimize the ratio of the sum of the cardinality of the tables in the rewritten query block to that in the original query block. Therefore, the materialized view selected would be the one which can result in reading in the least amount of data.

After a materialized view has been picked for a rewrite, the optimizer performs the rewrite, and then tests whether the rewritten query can be rewritten further with another materialized view. This process continues until no further rewrites are possible. Then the rewritten query is optimized and the original query is optimized. The optimizer compares these two optimizations and selects the least costly alternative.

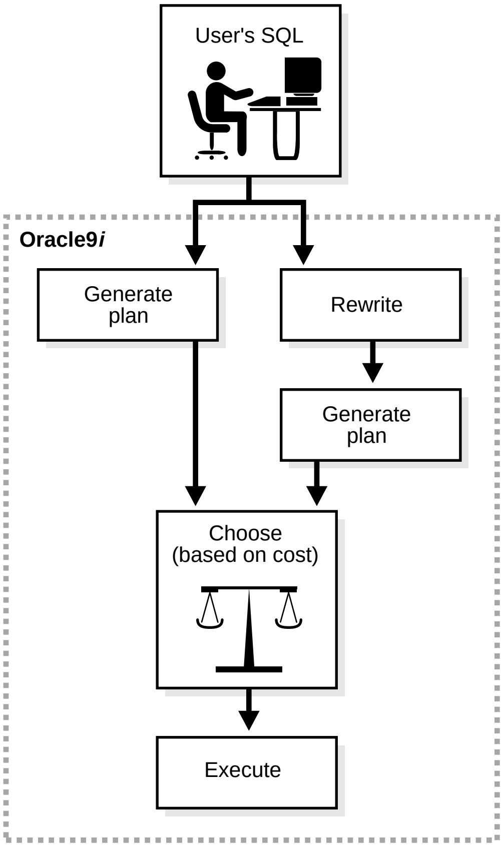
Since optimization is based on cost, it is important to collect statistics both on tables involved in the query and on the tables representing materialized views. Statistics are fundamental measures, such as the number of rows in a table, that are used to calculate the cost of a rewritten query. They are created by using the `DBMS_STATS` package.

Queries that contain in-line or named views are also candidates for query rewrite. When a query contains a named view, the view name is used to do the matching between a materialized view and the query. When a query contains an inline view, the inline view can be merged into the query before matching between a materialized view and the query occurs.

In addition, if the inline view's text definition exactly matches with that of an inline view present in any eligible materialized view, general rewrite may be possible. This is because, whenever a materialized view contains exactly identical inline view text to the one present in a query, query rewrite treats such an inline view like a named view or a table.

The following presents a graphical view of the cost-based approach.

Figure 22–1 The Query Rewrite Process



When Does Oracle Rewrite a Query?

A query is rewritten only when a certain number of conditions are met:

- Query rewrite must be enabled for the session.
- A materialized view must be enabled for query rewrite.
- The rewrite integrity level should allow the use of the materialized view. For example, if a materialized view is not fresh and query rewrite integrity is set to `ENFORCED`, then the materialized view will not be used.

- Either all or part of the results requested by the query must be obtainable from the precomputed result stored in the materialized view.

To determine this, the optimizer may depend on some of the data relationships declared by the user using constraints and dimensions. Such data relationships include hierarchies, referential integrity, and uniqueness of key data, and so on.

Sample Schema and Materialized Views

The following sections use an example schema and a few materialized views to illustrate how the optimizer uses data relationships to rewrite queries. Oracle's `Sales History` demo schema consists of these tables:

```
CUSTOMERS (cust_id, cust_last_name, cust_city,
           cust_state_province, cust_country, country_id)
PRODUCTS  (prod_id, prod_name, prod_category, prod_subcategory)
TIMES     (time_id, week_ending_day, time_week, time_month, calendar_month_desc)
SALES     (amount, channel_id, promo_id, time_id, cust_id)
```

See Also: Appendix B, "Sample Data Warehousing Schema", for details regarding the `Sales History` demo schema

The query rewrite examples in this chapter mainly refer to the following materialized views. Note that those materialized views does not necessarily represent the most efficient implementation for the `Sales History` business example rather than the base for demonstrating Oracle's rewrite capabilities. Further examples demonstrating specific functionality can be found in the specific context.

Materialized views containing joins and aggregates:

```
CREATE MATERIALIZED VIEW sum_sales_pscat_week_mv
  ENABLE QUERY REWRITE
  AS
SELECT p.prod_subcategory, t.week_ending_day,
       SUM(s.amount_sold) AS sum_amount_sold
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id=p.prod_id
GROUP BY p.prod_subcategory, t.week_ending_day;

CREATE MATERIALIZED VIEW sum_sales_prod_week_mv
  ENABLE QUERY REWRITE
  AS
SELECT p.prod_id, t.week_ending_day, s.cust_id,
       SUM(s.amount_sold) AS sum_amount_sold
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id=p.prod_id
GROUP BY p.prod_id, t.week_ending_day, s.cust_id;

CREATE MATERIALIZED VIEW sum_sales_pscat_month_city_mv
  ENABLE QUERY REWRITE
  AS
SELECT p.prod_subcategory, t.calendar_month_desc, c.cust_city,
       SUM(s.amount_sold) AS sum_amount_sold,
       COUNT(s.amount_sold) AS count_amount_sold
FROM   sales s, products p, times t, customers c
WHERE  s.time_id=t.time_id
AND    s.prod_id=p.prod_id
AND    s.cust_id=c.cust_id
GROUP BY p.prod_subcategory, t.calendar_month_desc, c.cust_city;
```

Materialized views containing joins only:

```
CREATE MATERIALIZED VIEW join_sales_time_product_mv
  ENABLE QUERY REWRITE
  AS
SELECT p.prod_id, p.prod_name, t.time_id, t.week_ending_day,
       s.channel_id, s.promo_id, s.cust_id,
       s.amount_sold
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id = p.prod_id;

CREATE MATERIALIZED VIEW join_sales_time_product_oj_mv
  ENABLE QUERY REWRITE
  AS
SELECT p.prod_id, p.prod_name, t.time_id, t.week_ending_day,
       s.channel_id, s.promo_id, s.cust_id,
       s.amount_sold
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id=p.prod_id(+);
```

You must collect statistics on the materialized views so that the optimizer can determine whether to rewrite the queries. You can do this either on a per object base or for all newly created objects without statistics.

On a per object base, shown for `JOIN_SALES_TIME_PRODUCT_MV`:

```
EXECUTE DBMS_STATS.GATHER_TABLE_STATS ('SH','JOIN_SALES_TIME_PRODUCT_MV',
      estimate_percent=>20,block_sample=>TRUE,cascade=>TRUE);
```

For all newly created objects without statistics, on schema level:

```
EXECUTE DBMS_STATS.GATHER_SCHEMA_STATS('SH', options => 'GATHER EMPTY',
      estimate_percent=>20, block_sample=>TRUE, cascade=>TRUE);
```

> **See Also:** *Oracle9i Supplied PL/SQL Packages and Types Reference* for further information about using the `DBMS_STATS` package to maintain statistics

Enabling Query Rewrite

Several steps must be followed to enable query rewrite:

1. Individual materialized views must have the `ENABLE QUERY REWRITE` clause.
2. The initialization parameter `QUERY_REWRITE_ENABLED` must be set to `TRUE`.
3. Cost-based optimization must be used either by setting the initialization parameter `OPTIMIZER_MODE` to `ALL_ROWS` or `FIRST_ROWS`, or by analyzing the tables and setting `OPTIMIZER_MODE` to `CHOOSE`.
4. The initialization parameter `OPTIMIZER_FEATURES_ENABLE` should be left unset for query rewrite to be possible. However, if it is given a value, then it must be set to at least 8.1.6 or query rewrite and explain rewrite will not be possible.

If step 1 has not been completed, a materialized view will never be eligible for query rewrite. `ENABLE QUERY REWRITE` can be specified either when the materialized view is created, as illustrated below, or with the `ALTER MATERIALIZED VIEW` statement.

```
CREATE MATERIALIZED VIEW join_sales_time_product_mv
ENABLE QUERY REWRITE
AS
SELECT p.prod_id, p.prod_name, t.time_id, t.week_ending_day,
       s.channel_id, s.promo_id, s.cust_id,
       s.amount_sold
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id = p.prod_id;
```

You can use the initialization parameter `QUERY_REWRITE_ENABLED` to disable query rewrite for all materialized views, or to enable it again for all materialized views that are individually enabled. However, the QUERY_REWRITE_ENABLED parameter cannot enable query rewrite for materialized views that have disabled it with the CREATE or ALTER statement.

The NOREWRITE hint disables query rewrite in a SQL statement, overriding the QUERY_REWRITE_ENABLED parameter, and the REWRITE hint (when used with mv_name) restricts the eligible materialized views to those named in the hint.

Initialization Parameters for Query Rewrite

Query rewrite requires the following initialization parameter settings:

- OPTIMIZER_MODE = ALL_ROWS, FIRST_ROWS, or CHOOSE
- QUERY_REWRITE_ENABLED = TRUE
- COMPATIBLE = 8.1.0 (or greater)

The QUERY_REWRITE_INTEGRITY parameter is optional, but must be set to STALE_TOLERATED, TRUSTED, or ENFORCED if it is specified (see "Accuracy of Query Rewrite" on page 22-10). It defaults to ENFORCED if it is undefined.

Because the integrity level is set by default to ENFORCED, all constraints must be validated. Therefore, if you use ENABLE NOVALIDATE, certain types of query rewrite might not work. To enable query rewrite in this environment, you should set your integrity level to a lower level of granularity such as TRUSTED or STALE_TOLERATED.

See Also: "View Constraints" on page 22-14 for details regarding view constraints and query rewrite

With OPTIMIZER_MODE set to CHOOSE, a query will not be rewritten unless at least one table referenced by it has been analyzed. This is because the rule-based optimizer is used when OPTIMIZER_MODE is set to CHOOSE and none of the tables referenced in a query have been analyzed.

Controlling Query Rewrite

A materialized view is only eligible for query rewrite if the ENABLE QUERY REWRITE clause has been specified, either initially when the materialized view was first created or subsequently with an ALTER MATERIALIZED VIEW statement.

The initialization parameters described above can be set using the ALTER SYSTEM SET statement. For a given user's session, ALTER SESSION can be used to disable or enable query rewrite for that session only. For example:

```
ALTER SESSION SET QUERY_REWRITE_ENABLED = TRUE;
```

You can set the level of query rewrite for a session, thus allowing different users to work at different integrity levels. The possible statements are:

```
ALTER SESSION SET QUERY_REWRITE_INTEGRITY = STALE_TOLERATED;
ALTER SESSION SET QUERY_REWRITE_INTEGRITY = TRUSTED;
ALTER SESSION SET QUERY_REWRITE_INTEGRITY = ENFORCED;
```

Rewrite Hints

Hints can be included in SQL statements to control whether query rewrite occurs. Using the `NOREWRITE` hint in a query prevents the optimizer from rewriting it.

The `REWRITE` hint with no argument in a query forces the optimizer to use a materialized view (if any) to rewrite it regardless of the cost.

The `REWRITE(mv1,mv2,...)` hint with arguments forces rewrite to select the most suitable materialized view from the list of names specified.

To prevent a rewrite, you can use the following statement:

```
SELECT /*+ NOREWRITE */ p.prod_subcategory, SUM(s.amount_sold)
FROM   sales s, products p
WHERE  s.prod_id=p.prod_id
GROUP BY p.prod_subcategory;
```

To force a rewrite using `sum_sales_pscat_week_mv`, you can use the following statement:

```
SELECT /*+ REWRITE (sum_sales_pscat_week_mv) */ p.prod_subcategory,
SUM(s.amount_sold)
FROM   sales s, products p
WHERE  s.prod_id=p.prod_id
GROUP BY p.prod_subcategory;
```

Note that the scope of a rewrite hint is a query block. If a SQL statement consists of several query blocks (`SELECT` clauses), you might need to specify a rewrite hint on each query block to control the rewrite for the entire statement.

Privileges for Enabling Query Rewrite

Use of a materialized view based not on privileges the user has on that materialized view, but on privileges the user has on detail tables or views in the query.

The system privilege GRANT REWRITE lets you enable materialized views in your own schema for query rewrite only if all tables directly referenced by the materialized view are in that schema. The GRANT GLOBAL REWRITE privilege allows you to enable materialized views for query rewrite even if the materialized view references objects in other schemas.

The privileges for using materialized views for query rewrite are similar to those for definer-rights procedures.

> **See Also:** *PL/SQL User's Guide and Reference* for further information

Accuracy of Query Rewrite

Query rewrite offers three levels of rewrite integrity that are controlled by the initialization parameter QUERY_REWRITE_INTEGRITY, which can either be set in your parameter file or controlled using an ALTER SYSTEM or ALTER SESSION statement. The three values it can take are:

- ENFORCED

  This is the default mode. The optimizer will only use materialized views that it knows contain fresh data and only use those relationships that are based on ENABLED VALIDATED primary / unique / foreign key constraints.

- TRUSTED

  In TRUSTED mode, the optimizer trusts that the data in the materialized views is fresh and the relationships declared in dimensions and RELY constraints are correct. In this mode, the optimizer will also use prebuilt materialized views or materialized views based on views, and it will use relationships that are not enforced as well as those that are enforced. In this mode, the optimizer also 'trusts' declared but not ENABLED VALIDATED primary / unique key constraints and data relationships specified using dimensions.

- STALE_TOLERATED

  In STALE_TOLERATED mode, the optimizer uses materialized views that are valid but contain stale data as well as those that contain fresh data. This mode offers the maximum rewrite capability but creates the risk of generating inaccurate results.

If rewrite integrity is set to the safest level, ENFORCED, the optimizer uses only enforced primary key constraints and referential integrity constraints to ensure that the results of the query are the same as the results when accessing the detail tables directly. If the rewrite integrity is set to levels other than ENFORCED, there are several situations where the output with rewrite can be different from that without it.

1. A materialized view can be out of synchronization with the master copy of the data. This generally happens because the materialized view refresh procedure is pending following bulk load or DML operations to one or more detail tables of a materialized view. At some data warehouse sites, this situation is desirable because it is not uncommon for some materialized views to be refreshed at certain time intervals.
2. The relationships implied by the dimension objects are invalid. For example, values at a certain level in a hierarchy do not roll up to exactly one parent value.
3. The values stored in a prebuilt materialized view table might be incorrect.
4. Partition operations such as `DROP` and `MOVE PARTITION` on the detail table could affect the results of the materialized view.
5. A wrong answer can occur because of bad data relationships defined by unenforced table or view constraints.

How Oracle Rewrites Queries

The optimizer uses a number of different methods to rewrite a query. The first, most important step is to determine if all or part of the results requested by the query can be obtained from the precomputed results stored in a materialized view.

The simplest case occurs when the result stored in a materialized view exactly matches what is requested by a query. The Oracle optimizer makes this type of determination by comparing the text of the query with the text of the materialized view definition. This method is most straightforward but the number of queries eligible for this type of query rewrite will be minimal.

When the text comparison test fails, the Oracle optimizer performs a series of generalized checks based on the joins, selections, grouping, aggregates, and column data fetched. This is accomplished by individually comparing various clauses (`SELECT`, `FROM`, `WHERE`, `HAVING`, or `GROUP BY`) of a query with those of a materialized view.

Text Match Rewrite Methods

The optimizer uses two methods:

- Full Text Match
- Partial Text Match

In full text match, the entire text of a query is compared against the entire text of a materialized view definition (that is, the entire `SELECT` expression), ignoring the white space during text comparison. Given the following query:

```
SELECT p.prod_subcategory, t.calendar_month_desc, c.cust_city,
       SUM(s.amount_sold) AS sum_amount_sold,
       COUNT(s.amount_sold) AS count_amount_sold
FROM   sales s, products p, times t, customers c
WHERE  s.time_id=t.time_id
AND    s.prod_id=p.prod_id
AND    s.cust_id=c.cust_id
GROUP BY p.prod_subcategory, t.calendar_month_desc, c.cust_city;
```

This query matches `sum_sales_pscat_month_city_mv` (white space excluded) and is rewritten as:

```
SELECT prod_subcategory, calendar_month_desc, cust_city,
       sum_amount_sold, count_amount_sold
FROM   sum_sales_pscat_month_city_mv;
```

When full text match fails, the optimizer then attempts a partial text match. In this method, the text starting from the `FROM` clause of a query is compared against the text starting with the `FROM` clause of a materialized view definition. Therefore, this query:

```
SELECT p.prod_subcategory, t.calendar_month_desc, c.cust_city,
       AVG(s.amount_sold)
FROM   sales s, products p, times t, customers c
WHERE  s.time_id=t.time_id
AND    s.prod_id=p.prod_id
AND    s.cust_id=c.cust_id
GROUP BY p.prod_subcategory, t.calendar_month_desc, c.cust_city;
```

is rewritten as:

```
SELECT prod_subcategory, calendar_month_desc, cust_city,
       sum_amount_sold/count_amount_sold
FROM   sum_sales_pscat_month_city_mv;
```

Note that, under the partial text match rewrite method, the average of sales aggregate required by the query is computed using the sum of sales and count of sales aggregates stored in the materialized view.

When neither text match succeeds, the optimizer uses a general query rewrite method.

Also note that text comparison is case sensitive, so keywords like `FROM` must be in the same case.

General Query Rewrite Methods

Oracle employs a number of checks to determine if a query can be rewritten to use a materialized view. These checks are:

- Selection Compatibility
- Join Compatibility
- Data Sufficiency
- Grouping Compatibility
- Aggregate Computability

Table 22–1 illustrates how Oracle makes these five checks depending on the type of materialized view. Note that, depending on the composition of the materialized view, some or all of the checks may be made.

Table 22–1 Materialized View Types and General Query Rewrite Methods

	MV with Joins Only	MV with Joins and Aggregates	MV with Aggregates on a Single Table
Selection Compatibility	X	X	X
Join Compatibility	X	X	-
Data Sufficiency	X	X	X
Grouping Compatibility	-	X	X
Aggregate Computability	-	X	X

To perform these checks, the optimizer uses data relationships on which it can depend. For example, primary key and foreign key relationships tell the optimizer that each row in the foreign key table joins with at most one row in the primary key table. Furthermore, if there is a `NOT NULL` constraint on the foreign key, it indicates that each row in the foreign key table must join to exactly one row in the primary key table.

Data relationships such as these are very important for query rewrite because they tell what type of result is produced by joins, grouping, or aggregation of data. Therefore, to maximize the rewritability of a large set of queries when such data relationships exist in a database, they should be declared by the user.

When are Constraints and Dimensions Needed?

To clarify when dimensions and constraints are required for the different types of query rewrite, refer to Table 22–2.

Table 22–2 Dimension and Constraint Requirements for Query Rewrite

Rewrite Checks	Dimensions		Primary Key/Foreign Key/Not Null Constraints
Matching SQL Text	Not Required		Not Required
Join Compatibility	Not Required		Required
Data Sufficiency	Required	OR	Required
Grouping Compatibility	Required		Required
Aggregate Computability	Not Required		Not Required

View Constraints

Data warehouse applications recognize multi-dimensional cubes in the database by identifying integrity constraints in the relational schema. Integrity constraints represent primary and foreign key relationships between fact and dimension tables. By querying the data dictionary, applications can recognize integrity constraints and hence the cubes in the database. However, this does not work in an environment where DBAs, for schema complexity or security reasons, define views on fact and dimension tables. In such environments, applications cannot identify the cubes properly. By allowing constraint definitions between views, you can propagate base table constraints to the views, thereby allowing applications to recognize cubes even in a restricted environment.

View constraint definitions are declarative in nature, but operations on views are subject to the integrity constraints defined on the underlying base tables, and constraints on views can be enforced through constraints on base tables. Defining constraints on base tables is necessary, not only for data correctness and cleanliness, but also for materialized view query rewrite purposes using the original base objects.

Materialized view rewrite extensively uses constraints for query rewrite. They are used for determining lossless joins, which, in turn, determine if joins in the materialized view are compatible with joins in the query and thus if rewrite is possible.

DISABLE NOVALIDATE is the only valid state for a view constraint. However, you can choose RELY or NORELY as the view constraint state to enable more sophisticated query rewrites. For example, a view constraint in the RELY state allows query rewrite to occur when the query integrity level is set to TRUSTED. Table 22–3 illustrates when view constraints are used for determining lossless joins.

Note that view constraints cannot be used for query rewrite integrity level TRUSTED. This level enforces the highest degree of constraint enforcement ENABLE VALIDATE.

Table 22–3 View Constraints and Rewrite Integrity Modes

Constraint States	RELY	NORELY
ENFORCED	No	No
TRUSTED	Yes	No
STALE_TOLERATED	Yes	No

Example 22–1 View Constraints Example

To demonstrate the rewrite capabilities on views, you have to extend the Sales History schema as follows:

```
CREATE VIEW time_view AS
SELECT time_id, TO_NUMBER(TO_CHAR(time_id, 'ddd')) AS day_in_year FROM times;
```

You can now establish a foreign-primary key relationship (in RELY ON) mode between the view and the fact table, and thus rewrite will take place as described in Table 22–3, by adding the following constraints. Rewrite will then work for example in TRUSTED mode.

```
ALTER VIEW time_view ADD (CONSTRAINT time_view_pk
   PRIMARY KEY (time_id) DISABLE NOVALIDATE);
ALTER VIEW time_view MODIFY CONSTRAINT time_view_pk RELY;
ALTER TABLE sales ADD (CONSTRAINT time_view_fk FOREIGN key (time_id)
   REFERENCES time_view(time_id) DISABLE NOVALIDATE);
ALTER TABLE sales MODIFY CONSTRAINT time_view_fk RELY;
```

Consider the following materialized view definition:

```
CREATE MATERIALIZED VIEW sales_pcat_cal_day_mv
ENABLE QUERY REWRITE
AS
SELECT p.prod_category, t.day_in_year,
       SUM(s.amount_sold) as sum_amount_sold
FROM time_view t, sales s, products p
WHERE t.time_id = s.time_id
AND   p.prod_id = s.prod_id
GROUP BY p.prod_category, t.day_in_year;
```

The following query, omitting the dimension table `products`, will also be rewritten without the primary key/foreign key relationships, because the suppressed join between `sales` and `products` is known to be lossless.

```
SELECT t.day_in_year,
       SUM(s.amount_sold) AS sum_amount_sold
FROM time_view t, sales s
WHERE t.time_id = s.time_id
GROUP BY t.day_in_year;
```

However, if the materialized view `sales_pcat_cal_day_mv` above were defined only in terms of the view `time_view`, then you could not rewrite the following query, suppressing then join between `sales` and `time_view`, because there is no basis for losslessness of the delta materialized view join. With the additional constraints as shown above, this query will also rewrite.

```
SELECT p.prod_category,
       SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, products p
WHERE p.prod_id = s.prod_id
GROUP BY p.prod_category;
```

To revert the changes you have made to the sales history schema, apply the following SQL commands:

```
ALTER TABLE sales DROP CONSTRAINT time_view_fk;
DROP VIEW time_view;
```

View Constraints Restrictions If the referential constraint definition involves a view, that is, either the foreign key or the referenced key resides in a view, the constraint can only be in `DISABLE NOVALIDATE` mode.

A `RELY` constraint on a view is allowed only if the referenced `UNIQUE` or `PRIMARY KEY` constraint in `DISABLE NOVALIDATE` mode is also a `RELY` constraint.

The specification of ON DELETE actions associated with a referential Integrity constraint, is not allowed (for example, DELETE cascade). However, DELETE, UPDATE, and INSERT operations are allowed on views and their base tables as view constraints are in DISABLE NOVALIDATE mode.

Expression Matching

An expression that appears in a query can be replaced with a simple column in a materialized view provided the materialized view column represents a precomputed expression that matches with the expression in the query. If a query can be rewritten to use a materialized view, it will be faster. This is because materialized views contain precomputed calculations and do not need to perform expression computation.

The expression matching is done by first converting the expressions into canonical forms and then comparing them for equality. Therefore, two different expressions will be matched as long as they are equivalent to each other. Further, if the entire expression in a query fails to match with an expression in a materialized view, then subexpressions of it are tried to find a match. The subexpressions are tried in a top-down order to get maximal expression matching.

Consider a query that asks for sum of sales by age brackets (1-10, 11-20, 21-30, and so on).

```
CREATE MATERIALIZED VIEW sales_by_age_bracket_mv
ENABLE QUERY REWRITE
AS
SELECT TO_CHAR((2000-c.cust_year_of_birth)/10-0.5,999) AS age_bracket,
       SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, customers c
WHERE  s.cust_id=c.cust_id
GROUP BY TO_CHAR((2000-c.cust_year_of_birth)/10-0.5,999);
```

The following query rewrites, using expression matching:

```
SELECT TO_CHAR(((2000-c.cust_year_of_birth)/10)-0.5,999),
       SUM(s.amount_sold)
FROM sales s, customers c
WHERE  s.cust_id=c.cust_id
GROUP BY TO_CHAR((2000-c.cust_year_of_birth)/10-0.5,999);
```

The above query is rewritten in terms of sum_sales_mv based on the matching of the canonical forms of the age bracket expressions (that is, 2000 - c.cust_year_of_birth)/10-0.5), as follows.

```
SELECT age_bracket, sum_amount_sold
FROM sales_by_age_bracket_mv;
```

Date Folding

Date folding rewrite is a specific form of expression matching rewrite. In this type of rewrite, a date range in a query is folded into an equivalent date range representing higher date granules. The resulting expressions representing higher date granules in the folded date range are matched with equivalent expressions in a materialized view. The folding of date range into higher date granules such as months, quarters, or years is done when the underlying datatype of the column is an Oracle DATE. The expression matching is done based on the use of canonical forms for the expressions.

DATE is a built-in datatype which represents ordered time units such as seconds, days, and months, and incorporates a time hierarchy (second -> minute -> hour -> day -> month -> quarter -> year). This hard-coded knowledge about DATE is used in folding date ranges from lower-date granules to higher-date granules. Specifically, folding a date value to the beginning of a month, quarter, year, or to the end of a month, quarter, year is supported. For example, the date value 1-jan-1999 can be folded into the beginning of either year 1999 or quarter 1999-1 or month 1999-01. And, the date value 30-sep-1999 can be folded into the end of either quarter 1999-03 or month 1999-09.

Because date values are ordered, any range predicate specified on date columns can be folded from lower level granules into higher level granules provided the date range represents an integral number of higher level granules. For example, the range predicate date_col BETWEEN '1-jan-1999' AND '30-jun-1999' can be folded into either a month range or a quarter range using the TO_CHAR function, which extracts specific date components from a date value.

The advantage of aggregating data by folded date values is the compression of data achieved. Without date folding, the data is aggregated at the lowest granularity level, resulting in increased disk space for storage and increased I/O to scan the materialized view.

Consider a query that asks for the sum of sales by product types for the years 1991, 1992, and 1993.

```
SELECT p.prod_category, SUM(s.amount_sold)
FROM sales s, products p
WHERE s.prod_id=p.prod_id
AND s.time_id >=  TO_DATE('01-jan-1998', 'dd-mon-yyyy')
AND s.time_id <= TO_DATE('31-dec-1998', 'dd-mon-yyyy')
GROUP BY p.prod_category;

CREATE MATERIALIZED VIEW sum_sales_pcat_monthly_mv
ENABLE QUERY REWRITE
AS
SELECT p.prod_category, TO_CHAR(s.time_id,'YYYY-MM') AS month,
       SUM(s.amount) AS sum_amount
FROM sales s, products p
WHERE s.prod_id=p.prod_id
GROUP BY p.prod_category, TO_CHAR(s.time_id, 'YYYY-MM');

SELECT p.prod_category, SUM(s.amount)
FROM sales s, products p
WHERE s.prod_id=p.prod_id
AND TO_CHAR(s.time_id, 'YYYY-MM')
-- BETWEEN TO_CHAR('01-jan-1998','YYYY-MM') AND TO_CHAR('31-dec-1998','YYYY-MM')
BETWEEN '01-jan-1998' AND '31-dec-1998'
GROUP BY p.prod_category;

SELECT mv.prod_category, mv.sum_amount
FROM sum_sales_pcat_monthly_mv mv
WHERE month
-- BETWEEN TO_CHAR('1-jan-1998','YYYY-MM') AND TO_CHAR('31-dec-1998','YYYY-MM')
BETWEEN '01-jan-1998' AND '31-dec-1998';
```

The range specified in the query represents an integral number of years, quarters, or months. Assume that there is a materialized view `mv3` that contains pre-summarized sales by `prod_type` and is defined as follows:

```
CREATE MATERIALIZED VIEW mv3
  ENABLE QUERY REWRITE
AS
SELECT prod_type, TO_CHAR(sale_date,'yyyy-mm') AS month, SUM(sales) AS sum_sales
FROM fact, product
WHERE fact.prod_id = product.prod_id
GROUP BY prod_type, TO_CHAR(sale_date, 'yyyy-mm');
```

The query can be rewritten by first folding the date range into the month range and then matching the expressions representing the months with the month expression in mv3. This rewrite is shown below in two steps (first folding the date range followed by the actual rewrite).

```
SELECT prod_type, SUM(sales) AS sum_sales
FROM fact, product
WHERE fact.prod_id = product.prod_id AND
      TO_CHAR(sale_date, 'yyyy-mm') BETWEEN
      TO_CHAR('01-jan-1991', 'yyyy-mm') AND TO_CHAR('31-dec-1993', 'yyyy-mm')
GROUP BY prod_type;

SELECT prod_type, sum_sales
FROM mv3
WHERE month BETWEEN
      TO_CHAR('01-jan-1991', 'yyyy-mm') AND TO_CHAR('31-dec-1993', 'yyyy-mm');
GROUP BY prod_type;
```

If mv3 had pre-summarized sales by prod_type and year instead of prod_type and month, the query could still be rewritten by folding the date range into year range and then matching the year expressions.

Selection Compatibility

Oracle supports rewriting of queries so that they will use materialized views in which the HAVING or WHERE clause of the materialized view contains a selection of a subset of the data in a table or tables. A materialized view's WHERE or HAVING clause can contain a join, a selection, or both, and still be used by a rewritten query. Predicate clauses containing expressions, or selecting rows based on the values of particular columns, are examples of non-join predicates.

To perform this type of query rewrite, Oracle must determine if the data requested in the query is contained in, or is a subset of, the data stored in the materialized view. This problem is sometimes referred to as the data containment problem or, in more general terms, the problem of a restricted subset of data in a materialized view. The following sections detail the conditions where Oracle can solve this problem and thus rewrite a query to use a materialized view that contains a restricted portion of the data in the detail table.

Selection compatibility is performed when both the query and the materialized view contain selections (non-joins). A selection compatibility check is done on the WHERE as well as the HAVING clause. If the materialized view contains selections and the query does not, then selection compatibility check fails because the materialized view is more restrictive than the query. If the query has selections and the materialized view does not then selection compatibility check is not needed. Regardless, selections and any columns mentioned in them must pass the data sufficiency check.

Definitions

The following definitions are introduced to help the discussion:

- `<join relop>`

  Is one of the following `(=, <, <=, >, >=)`

- `<selection relop>`

  Is `(=, <, <=, >, >=, !=, [NOT] BETWEEN | IN| LIKE |NULL)`

- `<join predicate>`

  Is of the form `(<column1> <join relop> <column2>)`, where columns are from different tables within the same `FROM` clause in the current query block. So, for example, there cannot be an outer reference.

- `<selection predicate>`

  Is of the form `<LHS-expression><relop><RHS-expression>`, where LHS means left-hand side and RHS means right-hand side. All non-join predicates are selection predicates. The left-hand side usually contains a column and the right-hand side contains the values. For example, `color='red'` means the left-hand side is `color` and the right-hand side is `'red'` and the relational operator is `(=)`.

- `<LHS-constrained>`

  When comparing a selection from the query with a selection from the materialized view, the left-hand side of the selection is compared with the left-hand side of the query. If they match, they are said to be LHS-constrained or just constrained for short.

- `<RHS-constrained>`

  When comparing a selection from the query with a selection from the materialized view, the right-hand side of the selection is compared with the right-hand side of the query. If they match, they are said to be RHS-constrained or just constrained. Note that before comparing the selections, the LHS/RHS-expression is converted to a canonical form and then the comparison is done. This means that expressions such as `<column1 + 5>` and `<5 + column1>` will match and be constrained.

Although selection compatibility does not restrict the general form of the WHERE, there is an optimal pattern and normally most queries fall into this pattern as follows:

```
(<join predicate> AND <join predicate> AND ....)  AND
 (<selection predicate>  AND|OR  <selection predicate> .... )
```

The join compatibility check operates on the joins and the selection compatibility operates on the selections. If the WHERE clause has an OR at the top, then the optimizer first checks for common predicates under the OR. If found, the common predicates are factored out from under the OR then joined with an AND back to the OR. This helps to put the WHERE into the optimal pattern. This is done only if OR occurs at the top of the WHERE clause. For example, if the WHERE clause is:

```
(sales.prod_id = prod.prod_id AND prod.prod_name = 'Kids Polo Shirt')
  OR (sales.prod_id = prod.prod_id  AND prod.prod_name = 'Kids Shorts')
```

The join is factored out and the WHERE becomes:

```
(sales.prod_id = prod.prod_id) AND (prod.prod_name = 'Kids Polo Shirt'
  OR prod.prod_name = 'Kids Shorts')
```

Thus putting the WHERE into the most optimal pattern.

If the WHERE is so complex that factoring cannot be done, all predicates under the OR are treated as selections and join compatibility is not performed but selection compatibility is still performed. In the HAVING clause, all predicates are considered selections.

Selection compatibility categorizes selections into the following cases:

- Simple

  Simple selections are of the form `<expression> <relop> <constant>`.

- Complex

  Complex selections are of the form `<expression> <relop> <expression>`.

- Range

  Range selections are such as `WHERE (cust_last_name BETWEEN 'abacrombe' AND 'anakin')`.

  Note that simple selections with relational operators `(<,<=,>,>=)` are also considered range selections.

- IN lists

  Single and multi-column IN lists such as WHERE(prod_id) IN (102, 233, ...).

  Note that selections of the form (column1='v1' OR column1='v2' OR column1='v3' OR ....) are treated as a group and classified as an IN list.

- IS [NOT] NULL
- [NOT] LIKE
- Other

  Other selections are when selection compatibility cannot determine containment of data. For example, EXISTS.

When comparing a selection from the query with a selection from the materialized view, the left-hand side of the selection is compared with the left-hand side of the query. If they match, they are said to be LHS-constrained or constrained for short.

If the selections are constrained, then the right-hand side values are checked for containment. That is, the RHS values of the query selection must be contained by right-hand side values of the materialized view selection. For example:

Example 22–2 Selection Compatibility: Example 1

With a query of:

```
WHERE prod_id = 102
```

And a materialized view of:

```
WHERE prod_id BETWEEN 0 AND 200
```

In the above example, the selections are constrained on prod_id and the right-hand side value of the query 102 is within the range of the materialized view.

Example 22–3 Selection Compatibility: Example 2

A selection can be a bounded range (a range with an upper and lower value), for example:

With a query of:

```
WHERE prod_id > 10 AND prod_id < 50
```

And a materialized view of:

```
WHERE prod_id BETWEEN 0 AND 200
```

In the above example, the selections are constrained on `prod_id` and the query range is within the materialized view range. In this example, we notice that both query selections are constrained by the same materialized view selection. The left-hand side can be an expression.

Example 22–4 Selection Compatibility: Example 3

With a query of:

```
WHERE (sales.amount_sold * .07) BETWEEN 1.00 AND 100.00
```

And a materialized view of:

```
WHERE (sales.amount_sold * .07) BETWEEN 0.0 AND 200.00
```

In the above example, the selections are constrained on `(sales.amount_sold *.07)` and the right-hand side value of the query is within the range of the materialized view. Complex selections require that both the left-hand side and right-hand side be matched (for example, when the left-hand side and the right-hand side are constrained). For example:

Example 22–5 Selection Compatibility: Example 4

With a query of:

```
WHERE (cost.unit_price * 0.95) > (cost_unit_cost  * 1.25)
```

And a materialized view of:

```
WHERE (cost.unit_price * 0.95) > (cost_unit_cost  * 1.25)
```

If the left-hand side and the right-hand side are constrained and the `<selection relop>` is the same, then generally the selection can be dropped from the rewritten query. Otherwise, the selection must be keep to filter out extra data from the materialized view.

If query rewrite can drop the selection from the rewritten query, then any columns from the selection may not have to be in the materialized view so more rewrites can be done with less data.

Selection compatibility requires that all selections in the materialized view be LHS-constrained with some selection in the query. This ensures that the materialized view data is not more restrictive that the query.

Example 22–6 Selection Compatibility: Example 5

Selections in the query do not have to be constrained by any selections in the materialized view but if they are then the right-hand side values must be contained by the materialized view. For example,

With a query of:

```
WHERE prod_name = 'Shorts' AND prod_category = 'Men'
```

And a materialized view of:

```
WHERE prod_category = 'Men'
```

In the above example, selection with `prod_category` is constrained. The query has an extra selection that is not constrained but this is acceptable because the materialized view does have the data. However, the following example fails selection compatibility check:

Example 22–7 Selection Compatibility: Example 6

With a query of:

```
WHERE prod_category = 'Men'
```

And a materialized view of:

```
WHERE prod_name = 'Shorts' AND prod_category = 'Men'
```

In the above example, the materialized view selection with `prod_name` is not constrained. The materialized view is more restrictive that the query because it only contains the product `Shorts`, therefore, query rewrite will not occur.

Example 22–8 Selection Compatibility: Example 7

Selection compatibility also checks for cases where the query has a multi-column in list where the columns are fully constrained by individual columns from the materialized view single column in lists. For example:

With a query of:

```
WHERE (prod_id, cust_id) IN ((1022, 1000), (1033, 2000))
```

And a materialized view of:

```
WHERE prod_id IN (1022,1033) AND cust_id IN (1000, 2000)
```

In the above example, the materialized view `IN` lists are constrained by the columns in the query multi-column in list. Furthermore, the right-hand side values of the query selection are contained by the materialized view so that rewrite will occur.

Example 22–9 Selection Compatibility: Example 8

Selection compatibility also checks for cases where the materialized view has a multi-column in list where the columns are fully constrained by individual columns or columns from in lists in the query. For example:

With a query of:

```
WHERE prod_id = 1022 AND cust_id IN (1000, 2000)
```

And a materialized view of:

```
WHERE (prod_id, cust_id) IN ((1022, 1000), (1022, 2000))
```

In the above example, the materialized view `IN` list columns are fully constrained by the columns in the query selections. Furthermore, the right-hand side values of the query selection are contained by the materialized view. However, the following example fails selection compatibility check:

Example 22–10 Selection Compatibility: Example 9

With a query of:

```
WHERE (prod_id = 1022 AND cust_id IN (1000, 2000)
```

And a materialized view of:

```
WHERE (prod_id, cust_id, cust_city)
  IN ((1022, 1000, 'Boston'), (1022, 2000, 'Nashua'))
```

In the above example, the materialized view in list column `cust_city` is not constrained so the materialized view is more restrictive than the query. Selection compatibility also works with complex `OR`s. If we assume that the shape of the `WHERE` is as follows:

```
(selection AND selection AND ...) OR (selection AND selection AND ...)
```

Each group of selections separated by `AND` is related and the group is called a **disjunct**. The disjuncts are separated by `OR`s. Selection compatibility requires that every disjunct in the query be contained by some disjunct in the materialized view. Otherwise, the materialized view is more restrictive than the query. The materialized view disjuncts do not have to match any query disjunct. This just means that the materialized view has more data than the query requires. When comparing a disjunct from the query with a disjunct of the materialized view, the normal selection compatibility rules apply as specified in the previous discussion. For example:

Example 22–11 Selection Compatibility: Example 10

With a query of:

```
WHERE (city_population > 15000 AND city_population < 25000
   AND state_name = 'New Hampshire')
```

And a materialized view of:

```
WHERE (city_population < 5000 AND state_name = 'New York') OR
   (city_population BETWEEN 10000 AND 50000 AND state_name = 'New Hampshire')
```

In the above example, the query has a single disjunct (group of selections separated by `AND`). The materialized view has two disjuncts separated by `OR`. The query disjunct is contained by the second materialized view disjunct so selection compatibility succeeds. It is clear that the materialized view contains more data than needed by the query so the query can be rewritten.

For example, here is a simple materialized view definition:

```
CREATE MATERIALIZED VIEW cal_month_sales_id_mv
BUILD IMMEDIATE
REFRESH FORCE
ENABLE QUERY REWRITE
AS
SELECT    t.calendar_month_desc,
          SUM(s.amount_sold) AS dollars
FROM      sales s,
          times t
WHERE    s.time_id = t.time_id AND s.cust_id = 10
GROUP BY t.calendar_month_desc;
```

The following query could be rewritten to use this materialized view because the query asks for the amount where the customer ID is 10 and this is contained in the materialized view.

```
SELECT   t.calendar_month_desc, SUM(s.amount_sold) AS dollars
FROM     times t, sales s
```

```
WHERE    s.time_id = t.time_id AND s.cust_id = 10
GROUP BY t.calendar_month_desc;
```

Because the predicate `s.cust_id` = `10` selects the same data in the query and in the materialized view, it is dropped from the rewritten query. This means the rewritten query looks like:

```
SELECT mv.calendar_month_desc, mv.dollars FROM cal_month_sales_id_mv mv;
```

Query rewrite can also occur when the query specifies a range of values, such as `s.prod_id > 10000` and `s.prod_id < 20000`, as long as the range specified in the query is within the range specified in the materialized view. For example, if there is a materialized view defined as:

```
CREATE MATERIALIZED VIEW product_sales_mv
   BUILD IMMEDIATE
   REFRESH FORCE
   ENABLE QUERY REWRITE
   AS
   SELECT p.prod_name, SUM(s.amount_sold) AS dollar_sales
   FROM products p, sales s
   WHERE p.prod_id = s.prod_id
   GROUP BY prod_name
   HAVING SUM(s.amount_sold) BETWEEN 5000 AND 50000;
```

Then a query such as:

```
SELECT p.prod_name, SUM(s.amount_sold) AS dollar_sales
   FROM products p, sales s
   WHERE p.prod_id = s.prod_id
   GROUP BY prod_name
   HAVING SUM(s.amount_sold) BETWEEN 10000 AND 20000;
```

would be rewritten as:

```
SELECT prod_name, dollar_sales FROM product_sales_mv
WHERE dollar_sales > 10000 AND dollar_sales < 20000;
```

Rewrite with select expressions is also supported when the expression evaluates to a constant, such as `TO_DATE('12-SEP-1999','DD-Mon-YYYY')`. For example, if an existing materialized view is defined as:

```
CREATE MATERIALIZED VIEW sales_on_valentines_day_99_mv
BUILD IMMEDIATE
REFRESH FORCE
ENABLE QUERY REWRITE
```

```
AS
  SELECT prod_id, cust_id, amount_sold
  FROM sales s, times t
  WHERE s.time_id = t.time_id
  AND t.time_id = TO_DATE('04-FEB-1999', 'DD-MON-YYYY');
```

Then the query:

```
SELECT prod_id, cust_id, amount_sold
  FROM sales s, times t
  WHERE s.time_id = t.time_id
  AND t.time_id = TO_DATE('14-FEB-1999', 'DD-MON-YYYY');
```

would be rewritten to:

```
SELECT * FROM sales_on_valentines_day_99_mv;
```

Rewrite can also occur against a materialized view when the selection is contained in an `IN` expression. For example, given the following materialized view definition,

```
CREATE MATERIALIZED VIEW popular_promo_sales_mv
BUILD IMMEDIATE
REFRESH FORCE
ENABLE QUERY REWRITE
AS
  SELECT p.promo_name, SUM(s.amount_sold) AS sum_amount_sold
  FROM  promotions p, sales s
  WHERE s.promo_id = p.promo_id
  AND promo_name IN ('coupon', 'premium', 'giveaway')
  GROUP BY promo_name;
```

The query,

```
SELECT p.promo_name, SUM(s.amount_sold)
FROM  promotions p, sales s
WHERE s.promo_id = p.promo_id
AND promo_name IN ('coupon', 'premium')
GROUP BY promo_name;
```

is rewritten to:

```
SELECT * FROM popular_promo_sales_mv WHERE promo_name IN ('coupon', 'premium');
```

You can also use expressions in selection predicates. This process looks like the following example:

```
<expression> <relational operator> <constant>
```

where <`expression`> can be any arbitrary arithmetic expression allowed by Oracle. The expression in the materialized view and the query must match. Oracle attempts to discern expressions that are logically equivalent, such as `A+B` and `B+A`, and will always recognize identical expressions as being equivalent.

You can also use queries with an expression on both sides of the operator or user-defined functions as operators. Query rewrite occurs when the complex predicate in the materialized view and the query are logically equivalent. This means that, unlike exact text match, terms could be in a different order and rewrite can still occur, as long as the expressions are equivalent.

In addition, selection predicates can be joined with an `AND` operator in a query and the query can still be rewritten to use a materialized view as long as every restriction on the data selected by the query is matched by a restriction in the definition of the materialized view. Again, this does not mean an exact text match, but that the restrictions on the data selected must be a logical match. Also, the query may be more restrictive in its selection of data and still be eligible, but it can never be less restrictive than the definition of the materialized view and still be eligible for rewrite.

For example, given the preceding materialized view definition, a query such as:

```
SELECT p.promo_name, SUM(s.amount_sold)
FROM  promotions p, sales s
WHERE s.promo_id = p.promo_id
AND promo_name  = 'coupon'
  GROUP BY promo_name
  HAVING SUM(s.amount_sold) > 1000;
```

would be rewritten to

```
SELECT * FROM popular_promo_sales_mv
WHERE promo_name = 'coupon' AND sum_amount_sold > 1000;
```

This is an example where the query is more restrictive than the definition of the materialized view, so rewrite can occur. However, if the query had selected `promo_category`, then it could not have been rewritten against the materialized view, because the materialized view definition does not contain that column.

For another example, if the definition of a materialized view restricts a city name column to `Boston`, then a query that selects `Seattle` as a value for this column can never be rewritten with that materialized view, but a query that restricts city name to `Boston` and restricts a column value that is not restricted in the materialized view could be rewritten to use the materialized view.

All the rules noted previously also apply when predicates are combined with an `OR` operator. The simple predicates, or simple predicates connect by `AND`s, are considered separately. Each predicate in the query must appear in the materialized view if rewrite is to occur.

For example, the query could have a restriction like `city='Boston' OR city ='Seattle'` and to be eligible for rewrite, the materialized view that the query might be rewritten against must have the same restriction. In fact, the materialized view could have additional restrictions, such as `city='Boston' OR city='Seattle' OR city='Cleveland'` and rewrite might still be possible.

Note, however, that the reverse is not true. If the query had the restriction `city = 'Boston' OR city='Seattle' OR city='Cleveland'` and the materialized view only had the restriction `city='Boston' OR city='Seattle'`, then rewrite would not be possible since the query seeks more data than is contained in the restricted subset of data stored in the materialized view.

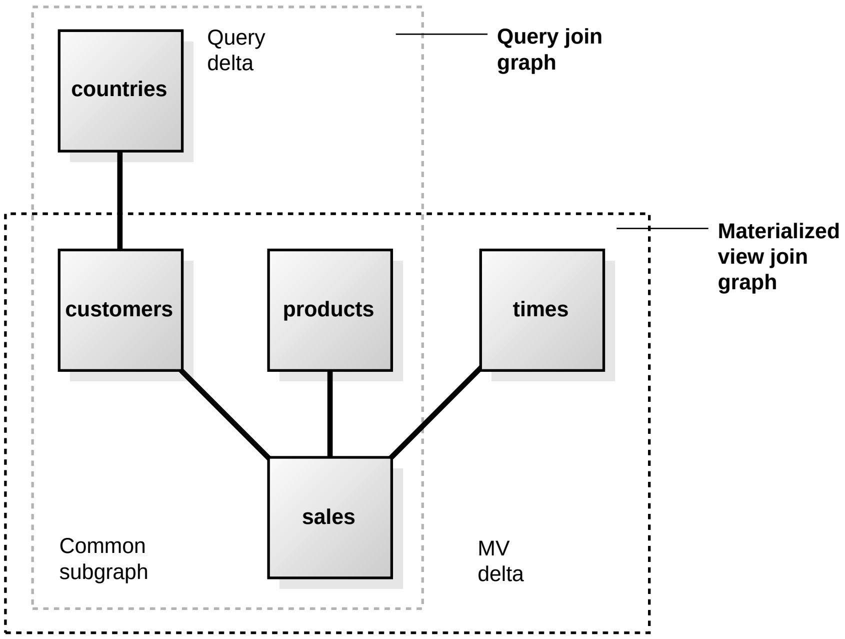
Join Compatibility Check

In this check, the joins in a query are compared against the joins in a materialized view. In general, this comparison results in the classification of joins into three categories:

1. Common joins that occur in both the query and the materialized view. These joins form the common subgraph.
2. Delta joins that occur in the query but not in the materialized view. These joins form the query delta subgraph.
3. Delta joins that occur in the materialized view but not in the query. These joins form the materialized view delta subgraph.

They can be visualized as shown in Figure 22–2:

Figure 22–2 Query Rewrite Subgraphs



Common Joins The common join pairs between the two must be of the same type, or the join in the query must be derivable from the join in the materialized view. For example, if a materialized view contains an outer join of table A with table B, and a query contains an inner join of table A with table B, the result of the inner join can be derived by filtering the anti-join rows from the result of the outer join.

For example, consider this query:

```
SELECT p.prod_name, t.week_ending_day,
       SUM(amount_sold)
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id = p.prod_id
AND    t. week_ending_day BETWEEN TO_DATE('01-AUG-1999', 'DD-MON-YYYY')
                          AND     TO_DATE('10-AUG-1999', 'DD-MON-YYYY')
GROUP BY prod_name, week_ending_day;
```

The common joins between this query and the materialized view `join_sales_time_product_mv` are:

```
s.time_id = t.time_id AND s.prod_id = p.prod_id
```

They match exactly and the query can be rewritten as:

```
SELECT prod_name, week_ending_day,
       SUM(amount_sold)
FROM   join_sales_time_product_mv
WHERE  week_ending_day BETWEEN TO_DATE('01-AUG-1999','DD-MON-YYYY')
                         AND     TO_DATE('10-AUG-1999','DD-MON-YYYY')
GROUP BY prod_name, week_ending_day;
```

The query could also be answered using the `join_sales_time_product_oj_mv` materialized view where inner joins in the query can be derived from outer joins in the materialized view. The rewritten version will (transparently to the user) filter out the anti-join rows. The rewritten query will have the structure:

```
SELECT prod_name, week_ending_day,
       SUM(amount_sold)
FROM   join_sales_time_product_oj_mv
WHERE  week_ending_day BETWEEN TO_DATE('01-AUG-1999','DD-MON-YYYY')
                       AND     TO_DATE('10-AUG-1999','DD-MON-YYYY')
AND    prod_id IS NOT NULL
GROUP BY prod_name, week_ending_day;
```

In general, if you use an outer join in a materialized view containing only joins, you should put in the materialized view either the primary key or the rowid on the right side of the outer join. For example, in the previous example, `join_sales_time_product_oj_mv`, there is a primary key on both `sales` and `products`.

Another example of when a materialized view containing only joins is used is the case of a semi-join rewrites. That is, a query contains either an `EXISTS` or an `IN` subquery with a single table.

Consider this query, which reports the products that had sales greater than $1,000.

```
SELECT DISTINCT prod_name
FROM products p
WHERE EXISTS
  (SELECT *
   FROM sales s
   WHERE p.prod_id=s.prod_id
     AND s.amount_sold > 1000);
```

This query could also be seen as:

```
SELECT DISTINCT prod_name
FROM products p
WHERE p.prod_id IN (SELECT s.prod_id
                    FROM sales s
                    WHERE s.amount_sold > 1000
                       );
```

This query contains a semi-join between the product and the sales table:

```
s.prod_id = p.prod_id
```

This query can be rewritten to use either the `join_sales_time_product_mv` materialized view, if foreign key constraints are active or `join_sales_time_product_oj_mv` materialized view, if primary keys are active. Observe that both materialized views contain `s.prod_id=p.prod_id`, which can be used to derive the semi-join in the query.

The query is rewritten with `join_sales_time_product_mv` as follows:

```
SELECT prod_name
FROM (SELECT DISTINCT prod_name
      FROM  join_sales_time_product_mv
      WHERE amount_sold > 1000
      );
```

If the materialized view `join_sales_time_product_mv` is partitioned by `time_id`, then this query is likely to be more efficient than the original query because the original join between `sales` and `products` has been avoided.

The query could be rewritten using `join_sales_time_product_oj_mv` as follows.

```
SELECT prod_name
FROM (SELECT DISTINCT prod_name
      FROM  join_sales_time_product_oj_mv
      WHERE amount_sold > 1000
      AND prod_id IS NOT NULL
      );
```

Rewrites with semi-joins are currently restricted to materialized views with joins only and are not available for materialized views with joins and aggregates.

Query Delta Joins A **query delta join** is a join that appears in the query but not in the materialized view. Any number and type of delta joins in a query are allowed and they are simply retained when the query is rewritten with a materialized view. Upon rewrite, the materialized view is joined to the appropriate tables in the query delta.

For example, consider this query:

```
SELECT p.prod_name, t.week_ending_day, c.cust_city,
       SUM(s.amount_sold)
FROM   sales s, products p, times t, customers c
WHERE  s.time_id=t.time_id
AND    s.prod_id = p.prod_id
AND    s.cust_id = c.cust_id
GROUP BY prod_name, week_ending_day, cust_city;
```

Using the materialized view `join_sales_time_product_mv`, common joins are: `s.time_id=t.time_id` and `s.prod_id=p.prod_id`. The delta join in the query is `s.cust_id=c.cust_id`.

The rewritten form will then join the `join_sales_time_product_mv` materialized view with the product table as follows:

```
SELECT mv.prod_name, mv.week_ending_day, c.cust_city,
       SUM(mv.amount_sold)
FROM   join_sales_time_product_mv mv, customers c
WHERE  mv.cust_id = c.cust_id
GROUP BY prod_name, week_ending_day, cust_city;
```

Materialized View Delta Joins A **materialized view delta join** is a join that appears in the materialized view but not the query. All delta joins in a materialized view are required to be lossless with respect to the result of common joins. A lossless join guarantees that the result of common joins is not restricted. A **lossless** join is one where, if two tables called A and B are joined together, rows in table A will always match with rows in table B and no data will be lost, hence the term lossless join. For example, every row with the foreign key matches a row with a primary key provided no nulls are allowed in the foreign key. Therefore, to guarantee a lossless join, it is necessary to have FOREIGN KEY, PRIMARY KEY, and NOT NULL constraints on appropriate join keys. Alternatively, if the join between tables A and B is an outer join (A being the outer table), it is lossless as it preserves all rows of table A.

All delta joins in a materialized view are required to be non-duplicating with respect to the result of common joins. A non-duplicating join guarantees that the result of common joins is not duplicated. For example, a non-duplicating join is one where, if table A and table B are joined together, rows in table A will match with at most one row in table B and no duplication occurs. To guarantee a non-duplicating join, the key in table B must be constrained to unique values by using a primary key or unique constraint.

Consider this query that joins sales and times:

```
SELECT t.week_ending_day,
       SUM(s.amount_sold)
FROM   sales s, times t
WHERE  s.time_id = t.time_id
AND    t.week_ending_day BETWEEN TO_DATE('01-AUG-1999', 'DD-MON-YYYY')
                         AND     TO_DATE('10-AUG-1999', 'DD-MON-YYYY')
GROUP BY week_ending_day;
```

The materialized view join_sales_time_product_mv has an additional join (s.prod_id=p.prod_id) between sales and products. This is the delta join in join_sales_time_product_mv. You can rewrite the query if this join is lossless and non-duplicating. This is the case if s.prod_id is a foreign key to p.prod_id and is not null. The query is therefore rewritten as:

```
SELECT week_ending_day,
       SUM(amount_sold)
FROM   join_sales_time_product_mv
WHERE  week_ending_day BETWEEN TO_DATE('01-AUG-1999', 'DD-MON-YYYY')
                       AND     TO_DATE('10-AUG-1999', 'DD-MON-YYYY')
GROUP BY week_ending_day;
```

The query can also be rewritten with the materialized view join_sales_time_product_mv_oj where foreign key constraints are not needed. This view contains an outer join (s.prod_id=p.prod_id(+)) between sales and products. This makes the join lossless. If p.prod_id is a primary key, then the non-duplicating condition is satisfied as well and optimizer will rewrite the query as:

```
SELECT week_ending_day,
       SUM(amount_sold)
FROM   join_sales_time_product_oj_mv
WHERE  week_ending_day BETWEEN TO_DATE('01-AUG-1999', 'DD-MON-YYYY')
  AND  TO_DATE('10-AUG-1999', 'DD-MON-YYYY')
GROUP BY week_ending_day;
```

Note that the outer join in the definition of join_sales_time_product_mv_oj is not necessary, because the parent key - foreign key relationship between sales and products in the Sales History schema is already lossless. It is used for demonstration purposes only, and would be necessary if sales.prod_id is nullable, thus violating the losslessness of the join condition sales.prod_id = products.prod_id.

Current limitations restrict most rewrites with outer joins to materialized views with joins only. There is limited support for rewrites with materialized aggregate views with outer joins, so those views should rely on foreign key constraints to assure losslessness of materialized view delta joins.

Data Sufficiency Check

In this check, the optimizer determines if the necessary column data requested by a query can be obtained from a materialized view. For this, the equivalence of one column with another is used. For example, if an inner join between table A and table B is based on a join predicate A.X = B.X, then the data in column A.X will equal the data in column B.X in the result of the join. This data property is used to match column A.X in a query with column B.X in a materialized view or vice versa. For example, consider this query:

```
SELECT p.prod_name, s.time_id, t.week_ending_day,
       SUM(s.amount_sold)
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id = p.prod_id
GROUP BY p.prod_name, s.time_id, t.week_ending_day;
```

This query can be answered with join_sales_time_product_mv even though the materialized view does not have s.time_id. Instead, it has t.time_id, which, through a join condition s.time_id=t.time_id, is equivalent to s.time_id.

Thus, the optimizer might select this rewrite:

```
SELECT prod_name, time_id, week_ending_day,
       SUM(amount_sold)
FROM   join_sales_time_product_mv
GROUP BY prod_name, time_id, week_ending_day;
```

If some column data requested by a query cannot be obtained from a materialized view, the optimizer further determines if it can be obtained based on a data relationship called functional dependency. When the data in a column can determine data in another column, such a relationship is called functional dependency or functional determinance. For example, if a table contains a primary key column called prod_id and another column called prod_name, then, given a prod_id value, it is possible to look up the corresponding prod_name. The opposite is not true, which means a prod_name value need not relate to a unique prod_id.

When the column data required by a query is not available from a materialized view, such column data can still be obtained by joining the materialized view back to the table that contains required column data provided the materialized view contains a key that functionally determines the required column data.

For example, consider this query:

```
SELECT p.prod_category, t.week_ending_day,
       SUM(s.amount_sold)
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id=p.prod_id
AND    p.prod_category='CD'
GROUP BY p.prod_category, t.week_ending_day;
```

The materialized view `sum_sales_pscat_week_mv` contains `p.prod_id`, but not `p.prod_category`. However, we can join `sum_sales_pscat_week_mv` back to `products` to retrieve `prod_brand` because `prod_id` functionally determines `prod_category`. The optimizer rewrites this query using `sum_sales_prod_week_mv` as:

```
SELECT p.prod_category, mv.week_ending_day,
       SUM(mv.sum_amount_sold)
FROM   sum_sales_prod_week_mv mv, products p
WHERE  mv.prod_id=p.prod_id
AND    p.prod_category='Men'
GROUP BY p.prod_category, mv.week_ending_day;
```

Here the `products` table is called a joinback table because it was originally joined in the materialized view but joined again in the rewritten query.

There are two ways to declare functional dependency:

- Using the primary key constraint (as shown in the example above)
- Using the `DETERMINES` clause of a dimension

The `DETERMINES` clause of a dimension definition might be the only way you could declare functional dependency when the column that determines another column cannot be a primary key. For example, the `products` table is a denormalized dimension table that has columns `prod_id`, `prod_name`, and `prod_subcategory`, and `prod_subcategory` functionally determines `prod_subcat_desc` and `prod_category` determines `prod_cat_desc`.

The first functional dependency can be established by declaring `prod_id` as the primary key, but not the second functional dependency because the `prod_` subcategory column contains duplicate values. In this situation, you can use the DETERMINES clause of a dimension to declare the second functional dependency.

The following dimension definition illustrates how the functional dependencies are declared.

```
CREATE DIMENSION products_dim
        LEVEL product          IS (products.prod_id)
        LEVEL subcategory      IS (products.prod_subcategory)
        LEVEL category         IS (products.prod_category)
        HIERARCHY prod_rollup (
                product        CHILD OF
                subcategory    CHILD OF
                category
        )
        ATTRIBUTE product DETERMINES products.prod_name
        ATTRIBUTE product DETERMINES products.prod_desc
        ATTRIBUTE subcategory DETERMINES products.prod_subcat_desc
        ATTRIBUTE category    DETERMINES products.prod_cat_desc;
```

The hierarchy prod_rollup declares hierarchical relationships that are also 1:n functional dependencies. The 1:1 functional dependencies are declared using the DETERMINES clause, as seen when prod_subcategory functionally determines prod_subcat_desc.

The following query:

```
SELECT p.prod_subcat_desc, t.week_ending_day,
       SUM(s.amount_sold)
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id=p.prod_id
AND    p.prod_subcat_desc LIKE '%Men'
GROUP BY p.prod_subcat_desc, t.week_ending_day;
```

can be rewritten by joining sum_sales_pscat_week_mv to the products table so that prod_subcat_desc is available to evaluate the predicate. But the join will be based on the prod_subcategory column, which is not a primary key in the products table; therefore, it allows duplicates. This is accomplished by using an inline view that selects distinct values and this view is joined to the materialized view as shown in the rewritten query below.

```
SELECT iv.prod_subcat_desc, mv.week_ending_day,
       SUM(mv.sum_amount_sold)
FROM   sum_sales_pscat_week_mv mv,
       (SELECT DISTINCT prod_subcategory, prod_subcat_desc
        FROM products) iv
WHERE  mv.prod_subcategory=iv.prod_subcategory
AND    iv.prod_subcat_desc LIKE '%Men'
GROUP BY iv.prod_subcat_desc, mv.week_ending_day;
```

This type of rewrite is possible because of the fact that `prod_subcategory` functionally determines `prod_subcat_desc` as declared in the dimension.

Grouping Compatibility Check

This check is required only if both the materialized view and the query contain a `GROUP BY` clause. The optimizer first determines if the grouping of data requested by a query is exactly the same as the grouping of data stored in a materialized view. In other words, the level of grouping is the same in both the query and the materialized view. For example, a query requests data grouped by `prod_category` and a materialized view stores data grouped by `prod_subcategory` and `prod_subcat_desc`. The grouping is the same in both provided `prod_subcategory` functionally determines `prod_subcat_desc`, such as the functional dependency shown in the dimension example above.

If the grouping of data requested by a query is at a coarser level compared to the grouping of data stored in a materialized view, the optimizer can still use the materialized view to rewrite the query. For example, the materialized view `sum_sales_pscat_week_mv` groups by `week_ending_day`, and `prod_subcategory`. This query groups by `prod_subcategory`, a coarser grouping granularity:

```
SELECT p.prod_subcategory, SUM(s.amount_sold) AS sum_amount
FROM   sales s, products p
WHERE  s.prod_id=p.prod_id
GROUP BY p.prod_subcategory;
```

Therefore, the optimizer will rewrite this query as:

```
SELECT p.prod_subcategory, SUM(sum_amount_sold)
FROM   sum_sales_pscat_week_mv mv,
GROUP BY p.prod_subcategory;
```

In another example, a query requests data grouped by `prod_category` whereas a materialized view stores data grouped by `prod_subcategory`. If `prod_subcategory` is a `CHILD OF` `prod_category` (see the dimension example above), the grouped data stored in the materialized view can be further grouped by `prod_category` when the query is rewritten. In other words, aggregates at `prod_` subcategory level (finer granularity) stored in a materialized view can be rolled up into aggregates at prod_category level (coarser granularity).

For example, consider the following query:

```
SELECT p.prod_category, t.week_ending_day,
       SUM(s.amount_sold) AS sum_amount
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id=p.prod_id
GROUP BY p.prod_category, t.week_ending_day;
```

Because prod_subcategory functionally determines prod_category, sum_sales_pscat_week_mv can be used with a joinback to products to retrieve prod_category column data, and then aggregates can be rolled up to prod_category level, as shown below:

```
SELECT pv.prod_subcategory, mv.week_ending_day, SUM(mv.sum_amount_sold)
FROM   sum_sales_pscat_week_mv mv,
       (SELECT DISTINCT prod_subcategory, prod_category
        FROM products) pv
WHERE mv.prod_subcategory=mv.prod_subcategory
GROUP BY pv.prod_subcategory, mv.week_ending_day;
```

Note that, for this rewrite, the data sufficiency check determines that a joinback to the products table is necessary, and the grouping compatibility check determines that aggregate rollup is necessary.

Aggregate Computability Check

This check is required only if both the query and the materialized view contain aggregates. Here the optimizer determines if the aggregates requested by a query can be derived or computed from one or more aggregates stored in a materialized view. For example, if a query requests AVG(X) and a materialized view contains SUM(X) and COUNT(X), then AVG(X) can be computed as SUM(X)/COUNT(X).

If the grouping compatibility check determined that the rollup of aggregates stored in a materialized view is required, then the aggregate computability check determines if it is possible to roll up each aggregate requested by the query using aggregates in the materialized view.

For example, SUM(sales) at the city level can be rolled up to SUM(sales) at the state level by summing all SUM(sales) aggregates in a group with the same state value. However, AVG(sales) cannot be rolled up to a coarser level unless COUNT(sales) is also available in the materialized view. Similarly, VARIANCE(sales) or STDDEV(sales) cannot be rolled up unless COUNT(sales) and SUM(sales) are also available in the materialized view. For example, given the query:

```
SELECT  p.prod_subcategory, AVG(s.amount_sold) AS avg_sales
FROM    sales s, products p
WHERE   s.prod_id = p.prod_id
GROUP BY p.prod_subcategory;
```

The above can be rewritten with materialized view sum_sales_pscat_month_city_mv provided the join between sales and times and sales and customers are lossless and non-duplicating. Further, the query groups by prod_subcategory whereas the materialized view groups by prod_subcategory, calendar_month_desc and cust_city, which means the aggregates stored in the materialized view will have to be rolled up. The optimizer will rewrite the query as:

```
SELECT mv.prod_subcategory, SUM(mv.sum_amount_sold)/SUM(mv.count_amount_sold)
  AS avg_sales
FROM sum_sales_pscat_month_city_mv mv
GROUP BY mv.prod_subcategory;
```

The argument of an aggregate such as SUM can be an arithmetic expression like A+B. The optimizer will try to match an aggregate SUM(A+B) in a query with an aggregate SUM(A+B) or SUM(B+A) stored in a materialized view. In other words, expression equivalence is used when matching the argument of an aggregate in a query with the argument of a similar aggregate in a materialized view. To accomplish this, Oracle converts the aggregate argument expression into a canonical form such that two different but equivalent expressions convert into the same canonical form. For example, A*(B-C), A*B-C*A, (B-C)*A, and -A*C+A*B all convert into the same canonical form and, therefore, they are successfully matched.

Query Rewrite with Inline Views Oracle supports general query rewrite when the user query contains an inline view, or a subquery in the FROM list. Query rewrite matches inline views in the materialized view with inline views in the request query when the text of the two inline views exactly match. In this case, rewrite treats the matching inline view as it would a named view, and general rewrite processing is possible.

Query rewrite now matches inline views in the materialized view with inline views in the request query when the text of the two inline views exactly match. In this case, rewrite treats the matching inline view as it would a named view, and general rewrite processing is possible.

Here is an example where the materialized view contains an inline view, and the query has the same inline view, but the aliases for these views are different. Previously, this query could not be rewritten because neither exact text match nor partial text match is possible.

Here is the materialized view definition:

```
CREATE MATERIALIZED VIEW inline_example
ENABLE QUERY REWRITE AS
SELECT t.calendar_month_name, t.calendar_year  p.prod_category,
  SUM(V1.revenue) AS sum_revenue
FROM times t, products p,
     (SELECT time_id, prod_id, amount_sold*0.2 as revenue FROM sales) V1
WHERE t.time_id = V1.time_id
AND   p.prod_id = V1.prod_id
GROUP BY calendar_month_name, calendar_year, prod_category ;
```

And here is the query that will be rewritten to use the materialized view:

```
SELECT t.calendar_month_name, t.calendar_year, p.prod_category,
   SUM(X1.revenue) AS sum_revenue
FROM times t, products p,
     (SELECT time_id, prod_id, amount_sold*0.2 AS revenue FROM sales) X1
WHERE t.time_id = X1.time_id
AND   p.prod_id = X1.prod_id
GROUP BY calendar_month_name, calendar_year, prod_category ;
```

Query Rewrite with Selfjoins Query rewrite of queries which contain multiple references to the same tables, or self joins are possible, to the extent that general rewrite can occur when the query and the materialized view definition have the same aliases for the multiple references to a table. This allows Oracle to provide a distinct identity for each table reference and this in turn allows query rewrite.

Below is an example of a materialized view and a query. In this example, the query is missing a reference to a column in a table so an exact text match will not work. But general query rewrite can occur because the aliases for the table references match.

To demonstrate the self-join rewriting possibility with the `Sales History` schema, we are assuming the following addition to include the actual shipping and payment date in the fact table, referencing the same dimension table times. This is for demonstration purposes only and will not return any results:

```
ALTER TABLE sales ADD (time_id_ship DATE);
ALTER TABLE sales ADD (CONSTRAINT time_id_book_fk FOREIGN key (time_id_ship)
REFERENCES times(time_id) ENABLE NOVALIDATE);
```

```
ALTER TABLE sales MODIFY CONSTRAINT time_id_book_fk RELY;
ALTER TABLE sales ADD (time_id_paid DATE);
ALTER TABLE sales ADD (CONSTRAINT time_id_paid_fk FOREIGN key (time_id_paid)
REFERENCES times(time_id) ENABLE NOVALIDATE);
ALTER TABLE sales MODIFY CONSTRAINT time_id_paid_fk RELY;
```

To reverse the changes, you can simply drop the columns:

```
ALTER TABLE sales DROP COLUMN time_id_ship;
ALTER TABLE sales DROP COLUMN time_id_paid;
```

Now, we can define a materialized view as follows:

```
CREATE MATERIALIZED VIEW sales_shipping_lag_mv
ENABLE QUERY REWRITE
AS
  SELECT t1.fiscal_week_number, s.prod_id,
         t2.fiscal_week_number - t1.fiscal_week_number as lag
  FROM times t1, sales s, times t2
  WHERE t1.time_id = s.time_id
  AND   t2.time_id = s.time_id_ship;
```

The following query fails the exact text match test but is rewritten because the aliases for the table references match:

```
SELECT s.prod_id,
       t2.fiscal_week_number - t1.fiscal_week_number AS lag
FROM times t1, sales s, times t2
WHERE t1.time_id = s.time_id
AND   t2.time_id = s.time_id_ship;
```

Note that Oracle performs other checks to insure the correct match of an instance of a multiply instanced table in the request query with the corresponding table instance in the materialized view. For instance, in the following example, Oracle correctly determines that the matching alias names used for the multiple instances of table `time` does not establish a match between the multiple instances of table `time` in the materialized view:

The following query cannot be rewritten using `sales_shipping_lag_mv` even though the alias names of the multiply instanced table `time` match because the joins are not compatible between the instances of `time` aliased by `t2`:

```
SELECT s.prod_id,
       t2.fiscal_week_number - t1.fiscal_week_number AS lag
FROM times t1, sales s, times t2
WHERE t1.time_id = s.time_id AND   t2.time_id = s.time_id_paid;
```

The request query above joins the instance of the `time` table aliased by `t2` on the `s.time_id_paid` column, while the materialized views joins the instance of the `time` table aliased by `t2` on the `s.time_id_ship` column. Because the join conditions differ, Oracle correctly determines that rewrite cannot occur.

Special Cases for Query Rewrite

There are a few special cases when using query rewrite:

- Query Rewrite Using Partially Stale Materialized Views
- Query Rewrite Using Complex Materialized Views
- Query Rewrite Using Nested Materialized Views
- Query Rewrite Using Nested Materialized Views
- Query Rewrite with CUBE, ROLLUP, and Grouping Sets

Query Rewrite Using Partially Stale Materialized Views

In Oracle9*i*, when a certain partition of the detail table is updated, only specific sections of the materialized view are marked stale. The materialized view must have information that can identify the partition of the table corresponding to a particular row or group of the materialized view. The simplest scenario is when the partitioning key of the table is available in the `SELECT` list of the materialized view because this is the easiest way to map a row to a stale partition. The key points when using partially stale materialized views are:

- Query rewrite can use an materialized view in `ENFORCED` or `TRUSTED` mode if the rows from the materialized view used to answer the query are known to be `FRESH`.
- The fresh rows in the materialized view are identified by adding selection predicates to the materialized view's `WHERE` clause. We will rewrite a query with this materialized view if its answer is contained within this (restricted) materialized view. Note that support for materialized views with selection predicates is a prerequisite for this type of rewrite.

The fact table `sales` is partitioned based on ranges of store ID as follows:

```
PARTITION BY RANGE (time_id)
(PARTITION SALES_Q1_1998
          VALUES LESS THAN (TO_DATE('01-APR-1998', 'DD-MON-YYYY')),
 PARTITION SALES_Q2_1998
          VALUES LESS THAN (TO_DATE('01-JUL-1998', 'DD-MON-YYYY')),
 PARTITION SALES_Q3_1998
           VALUES LESS THAN (TO_DATE('01-OCT-1998', 'DD-MON-YYYY')), ...
```

Suppose you have a materialized view grouping by `store_id` as follows:

```
CREATE MATERIALIZED VIEW sum_sales_per_city_mv
AS
SELECT s.time_id, p.prod_subcategory, c.cust_city,
       SUM(s.amount_sold) as sum_amount_sold
FROM sales s, products p, customers c
WHERE s.cust_id = c.cust_id
AND   s.prod_id = p.prod_id
GROUP BY time_id, prod_subcategory, cust_city;
```

Suppose new data will be inserted for December 2000, which will end up in the partition `SALES_Q4_2000`.

Until a refresh is done, the materialized view is stale and cannot be used for rewrite in enforced mode. The fresh rows in the materialized view, that means the data of all partitions where Oracle knows that no changes have occurred, can be represented by modifying the materialized view's defining query as follows:

```
SELECT s.time_id, p.prod_subcategory, c.cust_city,
       SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, products p, customers c
WHERE s.cust_id = c.cust_id
AND   s.prod_id = p.prod_id
AND   s.time_id < TO_DATE('01-OCT-2000','DD-MON-YYYY')
GROUP BY time_id, prod_subcategory, cust_city;
```

Please note that the freshness of partially stale materialized views is tracked on a per partition base, and not on a logical base. Since the partitioning strategy of the sales fact table is on a quarterly base, changes in December 2000 causes the complete partition `SALES_Q4_2000` to become stale.

Consider the following query which asks for sales in quarter 1 and 2 of 2000:

```
SELECT s.time_id, p.prod_subcategory, c.cust_city,
       SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, products p, customers c
WHERE s.cust_id = c.cust_id
AND   s.prod_id = p.prod_id
AND   s.time_id BETWEEN TO_DATE('01-JAN-2000', 'DD-MON-YYYY')
AND TO_DATE('01-JUL-2000', 'DD-MON-YYYY')
GROUP BY time_id, prod_subcategory, cust_city;
```

Oracle knows that those ranges of rows in the materialized view are fresh and can therefore rewrite the above query with the materialized view. The rewritten query looks as follows:

```
SELECT time_id, prod_subcategory, cust_city, sum_amount_sold
FROM sum_sales_per_city_mv
WHERE time_id BETWEEN TO_DATE('01-JAN-2000', 'DD-MON-YYYY')
AND TO_DATE('01-JUL-2000', 'DD-MON-YYYY');
```

Instead of the partitioning key, a partition marker (a function that identifies the partition given a rowid) can be present in the select (and `GROUP BY` list) of the materialized view. You can use the materialized view to rewrite queries that require data from only certain partitions (identifiable by the partition-marker), for instance, queries that reference a partition-extended table-name or queries that have a predicate specifying ranges of the partitioning keys containing entire partitions. See Chapter 8, "Materialized Views", for details regarding the supplied partition marker function `DBMS_MVIEW.PMARKER`.

The following example illustrates the use of a partition marker in the materialized view instead of the direct usage of the partition key column.

```
CREATE MATERIALIZED VIEW sum_sales_per_city_2_mv
ENABLE QUERY REWRITE
AS
SELECT DBMS_MVIEW.PMARKER(s.rowid) AS pmarker,
       t.fiscal_quarter_desc, p.prod_subcategory, c.cust_city,
       SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, products p, customers c, times t
WHERE s.cust_id = c.cust_id
AND   s.prod_id = p.prod_id
AND   s.time_id = t.time_id
GROUP BY DBMS_MVIEW.PMARKER(s.rowid),
         prod_subcategory, cust_city, fiscal_quarter_desc;C
```

Suppose you know that the partition `SALES_Q1_2000` is fresh. You can rewrite the following query using the above materialized view. This query restricts the data to the partition `SALES_Q1_2000`, that means only the first quarter of 2000, and selects only certain values of `cust_city`.

```
SELECT s.city, SUM(f.dollar_sales)
FROM store s, fact f
WHERE s.store_id < 25
AND s.store_name = 'Sears'
GROUP BY s.city;
```

Assuming the value of `p_marker` for partition `store_id_1_to_24` is `P1`, the query can be rewritten as:

```
SELECT m.city, SUM(m.sum_sales)
FROM store_id_sales m
WHERE m.p_marker = 'P1'
  AND m.store_name = 'Sears'
GROUP BY m.city;
```

The same query could have been expressed with a partition-extended file name as in the following statement:

```
SELECT s.city, SUM(f.dollar_sales)
FROM store s, fact partition(store_id_1_to_24) f
WHERE s.store_name = 'Sears'
GROUP BY s.city;
```

So the query can be rewritten against the materialized view without accessing stale data.

Query Rewrite Using Complex Materialized Views

Complex materialized views are views that are not uniquely resolvable for query rewrite. Rewrite capability with complex materialized views is restricted to text match-based rewrite (partial or full). You can define a materialized view using arbitrarily complex SQL query expressions, but such a materialized view is treated as complex by query rewrite.

For example some of the constructs that make a materialized view complex are: set operators (`UNION`, `UNION ALL`, `INTERSECT`, `MINUS`), `START WITH` clause, `CONNECT BY` clause, and so on. Oracle currently supports general rewrite with inline views and self-joins on certain cases. These are the cases when the texts of inline view in the query and materialized view exactly match and the aliases of the duplicate tables in both the query and materialized view exactly match. All other cases involving inline views and self-joins will make a materialized view complex.

Query Rewrite Using Nested Materialized Views

Query rewrite is attempted iteratively to take advantage of nested materialized views. Oracle first tries to rewrite a query with a materialized view having aggregates and joins, then with a materialized join view. If any of the rewrites succeeds, Oracle repeats that process again until no rewrites have occurred.

For example, assume that you had created a materialized views `join_sales_time_product_mv` and `sum_sales_time_product_mv`:

```
CREATE MATERIALIZED VIEW join_sales_time_product_mv
ENABLE QUERY REWRITE
AS
SELECT p.prod_id, p.prod_name, t.time_id, t.week_ending_day,
       s.channel_id, s.promo_id, s.cust_id,
       s.amount_sold
FROM   sales s, products p, times t
WHERE  s.time_id=t.time_id
AND    s.prod_id = p.prod_id;

CREATE MATERIALIZED VIEW sum_sales_time_product_mv
ENABLE QUERY REWRITE
AS
SELECT mv.prod_name, mv.week_ending_day,
       COUNT(*) cnt_all,
       SUM(mv.amount_sold) sum_amount_sold,
       COUNT(mv.amount_sold) cnt_amount_sold
FROM join_sales_time_product_mv mv
GROUP BY mv.prod_name, mv.week_ending_day;
```

Consider this query:

```
SELECT p.prod_name, t.week_ending_day, SUM(s.amount_sold)
FROM sales s, products p, times t
WHERE s.time_id=t.time_id
AND s.prod_id=p.prod_id
GROUP BY p.prod_name, t.week_ending_day;
```

Oracle first tries to rewrite it with a materialized aggregate view and finds there is none eligible (note that single-table aggregate materialized view `sum_sales_store_time_mv` cannot yet be used), and then tries a rewrite with a materialized join view and finds that `join_sales_time_product_mv` is eligible for rewrite. The rewritten query has this form:

```
SELECT mv.prod_name, mv.week_ending_day, SUM(mv.amount_sold)
FROM join_sales_time_product_mv mv
GROUP BY mv.prod_name, mv.week_ending_day;
```

Because a rewrite occurred, Oracle tries the process again. This time the above query can be rewritten with single-table aggregate materialized view `sum_sales_store_time` into this form:

```
SELECT mv.prod_name, mv.week_ending_day, mv.sum_amount_sold
FROM sum_sales_time_product_mv mv;
```

Query Rewrite with CUBE, ROLLUP, and Grouping Sets

Oracle rewrites queries in the presence of extended GROUP BY clauses (CUBE, ROLLUP, Grouping Sets, or a concatenation of them) in materialized views or queries. The following scenarios arise during the rewrite process:

Materialized View has Simple GROUP BY and Query has Extended GROUP BY

When the query contains CUBE, ROLLUP, or concatenation of them, it can be rewritten in terms of materialized view if all the GROUP BY expressions in the query either match or functionally dependent on the GROUP BY expressions of the materialized view. For example, the query:

```
SELECT c.cust_city, p.prod_subcategory, AVG(s.amount_sold) AS avg_sales_sold
FROM sales s, customers c, products p
WHERE s.prod_id = p.prod_id AND s.cust_id = c.cust_id
GROUP BY CUBE(c.cust_city, p.prod_subcategory);
```

This query can be rewritten in terms of the materialized view sum_sales_pscat_month_city_mv as:

```
SELECT mv.cust_city, mv.prod_subcategory,
DECODE(SUM(mv.count_amount_sold), 0, NULL,
       SUM(mv.sum_amount_sold)/SUM(mv.count_amount_sold)) AS avg_sales_sold
FROM sum_sales_pscat_month_city_mv mv
GROUP BY CUBE(mv.cust_city, mv.prod_subcategory);
```

When a query contains grouping sets or a concatenation of grouping sets, it can be rewritten if every grouping in the query can be rewritten using the materialized view. For example, the query:

```
SELECT p.prod_subcategory, t.calendar_month_desc, c.cust_city,
SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, customers c, products p, times t
WHERE s.time_id=t.time_id
AND s.prod_id = p.prod_id AND s.cust_id = c.cust_id
GROUP BY GROUPING SETS ((p.prod_subcategory, t.calendar_month_desc),
   (c.cust_city, p.prod_subcategory));
```

can be rewritten in terms of materialized view sum_sales_pscat_month_city_mv as:

```
SELECT mv.prod_subcategory, mv.calendar_month_desc, mv.cust_city,
SUM(mv.sum_amount_sold) AS sum_amount_sold
FROM sum_sales_pscat_month_city_mv mv
GROUP BY GROUPING SETS ((mv.prod_subcategory, mv.calendar_month_desc),
  (mv.cust_city, mv.prod_subcategory);
```

Materialized View has Extended GROUP BY and Query has Simple GROUP BY

To rewrite queries in this scenario, Oracle requires the materialized view satisfy two additional conditions:

- to contain a grouping distinguisher, which is the `GROUPING_ID` function on all `GROUP BY` expressions. For example, if the `GROUP BY` clause of the materialized view is `GROUP BY CUBE(a, b)`, then the `SELECT` list should contain `GROUPING_ID(a, b)`

  and

- the `GROUP BY` clause of the materialized view should not result in any duplicate groupings. For example, `GROUP BY GROUPING SETS ((a, b), (a,b))` would disqualify an materialized view from general rewrite.

Oracle finds the grouping with the lowest cost from which the query can be computed and uses that for rewrite. For example, consider the materialized view:

```
CREATE MATERIALIZED VIEW sum_grouping_set_mv
ENABLE QUERY REWRITE
AS
SELECT p.prod_category, p.prod_subcategory, c.cust_state_province, c.cust_city,
  GROUPING_ID(p.prod_category,p.prod_subcategory,
    c.cust_state_province,c.cust_city) AS gid,
SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, products p, customers c
WHERE s.prod_id = p.prod_id AND s.cust_id = c.cust_id
GROUP BY GROUPING SETS
(
(p.prod_category, p.prod_subcategory, c.cust_city),
(p.prod_category, p.prod_subcategory, c.cust_state_province, c.cust_city),
(p.prod_category, p.prod_subcategory)
);
```

The following query:

```
SELECT p.prod_subcategory, c.cust_city,
SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, products p, customers c
WHERE s.prod_id = p.prod_id AND s.cust_id = c.cust_id
GROUP BY p.prod_subcategory, c.cust_city;
```

will be rewritten as:

```
SELECT prod_subcategory, cust_city, SUM(sum_amount_sold) AS sum_amount_sold
FROM sum_grouping_set_mv
WHERE gid = <grouping identifier of (prod_category,
   prod_subcategory, cust_city)>
   GROUP BY prod_subcategory, cust_city;
```

Both Materialized View and Query have Extended GROUP BY

In the most general case of materialized view and the query both containing extended GROUP BY clause, a materialized view that contains all groupings of the query is selected for rewrite. For example, given a materialized view,

```
CREATE MATERIALIZED VIEW sum_ext_grouping_set_mv
AS
SELECT p.prod_category, p.prod_subcategory, c.cust_state_province, c.cust_city,
GROUPING_ID(p.prod_category, p.prod_subcategory, c.cust_state_province,
  c.cust_city)
    AS gid,
SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, products p, customers c
WHERE s.prod_id = p.prod_id AND s.cust_id = c.cust_id
GROUP BY GROUPING SETS
(
(p.prod_category, p.prod_subcategory, c.cust_state_province, c.cust_city),
(p.prod_category, p.prod_subcategory),
(c.cust_state_province, c.cust_city)
);
```

The following query:

```
SELECT p.prod_category, p.prod_subcategory, c.cust_state_province, c.cust_city,
SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, products p, customers c
WHERE s.prod_id = p.prod_id AND s.cust_id = c.cust_id
GROUP BY GROUPING SETS
(
(p.prod_category, p.prod_subcategory),
(c.cust_state_province, c.cust_city)
);
```

can be rewritten in terms of materialized view `sum_ext_grouping_set_mv`, as in the following example:

```
SELECT prod_category, prod_subcategory, cust_state_province,
   cust_city, sum_amount_sold
FROM sum_ext_grouping_set_mv
WHERE gid IN (<grouping identifier of (prod_category, prod_subcategory)>,
<grouping identifier of (cust_country, cust_city)>);
```

For this type of rewrite to occur, the predicates in the WHERE clause of the materialized view and the query must match (answers could otherwise be incorrect).

This type of rewrite is useful for OLAP applications where queries ask for aggregations from multiple levels of a cube. For example, you can construct a sales cube with two dimensions: product and customers. The product dimension has two levels: prod_category and prod_subcategory and the customer dimension two levels: cust_state_province and cust_city. In a cube, we use a concatenated rollup of the dimensions. The rollup is arranged with decreasing hierarchy levels. So the sales cube can be represented as a view:

```
CREATE VIEW sales_cube_view
AS
SELECT p.prod_category, p.prod_subcategory, c.cust_state_province,
   c.cust_city, SUM(s.amount_sold) as sum_amount_sold
FROM sales s, products p, customers c
WHERE s.prod_id = p.prod_id AND s.cust_id = c.cust_id
GROUP BY ROLLUP(p.prod_category, p.prod_subcategory),
ROLLUP(c.cust_state_province, c.cust_city);
```

To support that cube, you would build corresponding materialized view:

```
CREATE MATERIALIZED VIEW sales_cube_mv
ENABLE QUERY REWRITE
AS
SELECT p.prod_category, p.prod_subcategory, c.cust_state_province, c.cust_city,
GROUPING_ID(p.prod_category,p.prod_subcategory,c.cust_state_province,
   c.cust_city) AS gid,
   SUM(s.amount_sold) as sum_amount_sold,
   COUNT(s.amount_sold) AS count_amount_sold,
   COUNT(*) AS cnt_star
FROM sales s, products p, customers c
WHERE s.prod_id = p.prod_id AND s.cust_id = c.cust_id
GROUP BY ROLLUP(p.prod_category, p.prod_subcategory),
ROLLUP(c.cust_state_province, c.cust_city);
```

Using the sales_cube_view, OLAP queries can ask for multiple levels of aggregations using a single query. For example, this query asks for sums sales of product category Men in San Francisco by prod_category and prod_ subcategory, that is, asks for these two groupings: (p.prod_category, p.prod_subcategory, c.cust_state_province, c.cust_city) and (p.prod_category, c.cust_state_province, c.cust_city).

```
SELECT prod_category, prod_subcategory, cust_state_province,
   cust_city, sum_amount_sold
FROM sales_cube_view
WHERE prod_category = 'Men' AND cust_city = 'San Francisco';
```

This query will be rewritten using materialized view mv_sales_cube as follows:

```
SELECT prod_category, prod_subcategory, cust_state_province,
   cust_city, sum_amount_sold
FROM sales_cube_mv
WHERE prod_category = 'Men' AND cust_city = 'San Francisco'
   AND gid IN (<grouping identifier of (prod_category, prod_subcategory,
      cust_country, cust_city)>, <grouping identifier of (prod_category,
      cust_country, cust_city)>);
```

Note that the rewrite requires simple selection from the materialized view container table. No rollup is required.

If none of the materialized views contain all groupings of the query, then the materialized view containing the smallest grouping from which all groupings of the query can be computed is selected for rewrite. As an example, Oracle rewrites the query:

```
SELECT p.prod_category, p.prod_subcategory, c.cust_city,
SUM(s.amount_sold) AS sum_amount_sold
FROM sales s, products p, customers c
WHERE s.prod_id = p.prod_id AND s.cust_id = c.cust_id
GROUP BY GROUPING SETS
(
(p.prod_category, c.cust_city),
(p.prod_subcategory, c.cust_city));
```

as:

```
SELECT prod_category, prod_subcategory, cust_city,
SUM(sum_amount_sold) AS sum_amount_sold
FROM sum_grouping_set_mv
WHERE gid = <grouping identifier of (prod_category,
   prod_subcategory, cust_city)>
GROUP BY GROUPING SETS ((prod_category, cust_city),
   (prod_subcategory, cust_city));
```

Did Query Rewrite Occur?

Because query rewrite occurs transparently, special steps have to be taken to verify that a query has been rewritten. Of course, if the query runs faster, this should indicate that rewrite has occurred, but that is not proof. Therefore, to confirm that query rewrite does occur, use the EXPLAIN PLAN statement or the DBMS_MVIEW.EXPLAIN_REWRITE procedure.

Explain Plan

The EXPLAIN PLAN facility is used as described in *Oracle9i SQL Reference*. For query rewrite, all you need to check is that the object_name column in PLAN_TABLE contains the materialized view name. If it does, then query rewrite will occur when this query is executed.

In this example, the materialized view cal_month_sales_mv has been created.

```
CREATE MATERIALIZED VIEW cal_month_sales_mv
ENABLE QUERY REWRITE
AS
SELECT  t.calendar_month_desc, SUM(s.amount_sold) AS dollars
FROM  sales s, times t
WHERE  s.time_id = t.time_id
GROUP BY t.calendar_month_desc;
```

If EXPLAIN PLAN is used on the following SQL statement, the results are placed in the default table PLAN_TABLE. However, PLAN_TABLE must first be created using the utlxplan.sql script.

```
EXPLAIN PLAN
FOR
SELECT  t.calendar_month_desc, SUM(s.amount_sold)
FROM  sales s, times t
WHERE  s.time_id = t.time_id
GROUP BY t.calendar_month_desc;
```

For the purposes of query rewrite, the only information of interest from PLAN_TABLE is the OBJECT_NAME, which identifies the objects that will be used to execute this query. Therefore, you would expect to see the object name CALENDAR_MONTH_SALES_MV in the output as illustrated below.

```
SELECT  object_name FROM plan_table;

OBJECT_NAME
-----------------------
CALENDAR_MONTH_SALES_MV

2 rows selected.
```

DBMS_MVIEW.EXPLAIN_REWRITE Procedure

It can be difficult to understand why a query did not rewrite. The rules governing query rewrite eligibility are quite complex, involving various factors such as constraints, dimensions, query rewrite integrity modes, freshness of the materialized views, and the types of queries themselves. In addition, you may want to know why query rewrite chose a particular materialized view instead of another. To help with this matter, Oracle provides a PL/SQL procedure (DBMS_MVIEW.EXPLAIN_REWRITE) to advise you when a query can be rewritten and, if not, why not. Using the results from DBMS_MVIEW.EXPLAIN_REWRITE, you can take the appropriate action needed to make a query rewrite if at all possible.

Note: The query specified in the EXPLAIN_REWRITE statement is never actually executed.

DBMS_MVIEW.EXPLAIN_REWRITE Syntax

You can obtain the output from DBMS_MVIEW.EXPLAIN_REWRITE in two ways. The first is to use a table, while the second is to create a varray. The following shows the basic syntax for using an output table:

```
DBMS_MVIEW.EXPLAIN_REWRITE (
    QUERY           VARCHAR2(2000),
    MV              VARCHAR2(30),
    STATEMENT_ID    VARCHAR2(30)
  );
```

You can create an output table named REWRITE_TABLE by executing the Oracle-supplied script utlxrw.sql.

The QUERY_TXT parameter is a text string representing the SQL query. The parameter, MV, is a fully qualified materialized view name in the form of SCHEMA.MV. This is an optional parameter. When it is not specified, EXPLAIN_REWRITE returns any relevant error messages regarding all the materialized views considered for rewriting the given query. When SCHEMA is omitted and only MV is specified, EXPLAIN_REWRITE looks for the materialized view in the current schema.

Therefore, to call the EXPLAIN_REWRITE procedure using an output table is as follows:

```
 DBMS_MVIEW.EXPLAIN_REWRITE (
     QUERY           VARCHAR2(2000),
     MV              VARCHAR2(30),
     STATEMENT_ID    VARCHAR2(30)
   );
```

If you want to direct the output of EXPLAIN_REWRITE to a varray instead of a table, you should call the procedure as follows:

```
DBMS_MVIEW.EXPLAIN_REWRITE (
    QUERY           VARCHAR2(2000),
    MV              VARCHAR2(30),
    OUTPUT_ARRAY    SYS.RewriteArrayType
  );
```

Using REWRITE_TABLE

Output of EXPLAIN_REWRITE can be directed to a table named REWRITE_TABLE. You can create this output table by running the Oracle-supplied script utlxrw.sql. This script can be found in the admin directory. The format of REWRITE_TABLE is given below.

```
CREATE TABLE REWRITE_TABLE(
  statement_id          VARCHAR2(30),  -- ID for the query
  mv_owner              VARCHAR2(30),  -- MV's schema
  mv_name               VARCHAR2(30),  -- Name of the MV
  sequence              INTEGER,       -- Seq # of error msg
  query                 VARCHAR2(2000),-- user query
  message               VARCHAR2(512), -- EXPLAIN_REWRITE error msg
  pass                  VARCHAR2(3),   -- Query Rewrite pass no
  flags                 INTEGER,       -- For future use
  reserved1             INTEGER,       -- For future use
  reserved2             VARCHAR2(256); -- For future use
);
```

Example 22–12 EXPLAIN_REWRITE Example Using REWRITE_TABLE

An example PL/SQL invocation is:

```
EXECUTE DBMS_MVIEW.EXPLAIN_REWRITE \
('SELECT p.prod_name, SUM(amount_sold) ' ||\
'FROM sales s, products p ' ||\
'WHERE s.prod_id = p.prod_id ' ||\
' AND prod_name > ''B%'' ' ||\
' AND prod_name < ''C%'' ' ||\
'GROUP BY prod_name', \
'TestXRW.PRODUCT_SALES_MV', \
'SH');

SELECT message FROM rewrite_table ORDER BY sequence;
MESSAGE
--------------------------------------------------------------------------------
QSM-01033: query rewritten with materialized view, PRODUCT_SALES_MV
1 row selected.
```

Here is another example where you can see a more detailed explanation of why some materialized views were not considered and eventually the materialized view `sales_mv` was chosen as the best one.

```
DECLARE
    qrytext VARCHAR2(500)  :='SELECT cust_first_name, cust_last_name,
SUM(amount) AS dollar_sales FROM sales s, customers c WHERE s.cust_id= c.cust_id
GROUP BY cust_first_name, cust_last_name';
    idno    VARCHAR2(30) :='ID1';
BEGIN
DBMS_MVIEW.EXPLAIN_REWRITE(querytxt, '', idno);
END;
/
SELECT message FROM rewrite_table ORDER BY sequence;
```

```
SQL> MESSAGE
--------------------------------------------------------------------------------
QSM-01082: Joining materialized view, CAL_MONTH_SALES_MV, with table, SALES, not possible
QSM-01022: a more optimal materialized view than PRODUCT_SALES_MV was used to rewrite
QSM-01022: a more optimal materialized view than FWEEK_PSCAT_SALES_MV was used to rewrite
QSM-01033: query rewritten with materialized view, SALES_MV
```

Using a VARRAY

You can save the output of EXPLAIN_REWRITE in a PL/SQL varray. The elements of this array are of the type RewriteMessage, which is defined in the SYS schema as shown below:

```
TYPE RewriteMessage IS record(
  mv_owner             VARCHAR2(30),  -- MV's schema
  mv_name              VARCHAR2(30),  -- Name of the MV
  sequence             INTEGER,       -- Seq # of error msg
  query                VARCHAR2(2000),-- user query
  message              VARCHAR2(512), -- EXPLAIN_REWRITE error msg
  pass                 VARCHAR2(3),   -- Query Rewrite pass no
  flags                INTEGER,       -- For future use
  reserved1            INTEGER,       -- For future use
  reserved2            VARCHAR2(256); -- For future use
);
```

The array type, RewriteArrayType, which is a varray of RewriteMessage objects, is defined in SYS schema as follows:

- TYPE RewriteArrayType AS VARRAY(256) OF RewriteMessage;

  Using this array type, now you can declare an array variable and specify it in the EXPLAIN_REWRITE statement.

- Each RewriteMessage record provides a message concerning rewrite processing.

  The parameters are the same as for REWRITE_TABLE, except for STATEMENT_ID, which is not used when using a varray as output.

- The MV_OWNER field defines the owner of materialized view that is relevant to the message.
- The MV_NAME field defines the name of a materialized view that is relevant to the message.
- The SEQUENCE field defines the sequence in which messages should be ordered.
- The QUERY_TEXT field contains the first 2000 characters of the query text under analysis.
- The MESSAGE field contains the text of message relevant to rewrite processing of QUERY_TEXT.
- The FLAGS, RESERVED1, and RESERVED2 fields are reserved for future use.

Example 22–13 EXPLAIN_REWRITE Example Using VARRAY

Consider the following query:

```
    SELECT c.cust_state_province,
           AVG(s.amount_sold)
     FROM sales s, customers c
     WHERE s.cust_id = c.cust_id
     GROUP BY c.cust_state_province;
```

and the following materialized view:

```
     CREATE MATERIALIZED VIEW avg_sales_city_state_mv
     ENABLE QUERY REWRITE
     AS
     SELECT c.cust_city, c.cust_state_province,
            AVG(s.amount_sold)
     FROM sales s, customers c
     WHERE s.cust_id = c.cust_id
     GROUP BY c.cust_city, c.cust_state_province;
```

The query will not rewrite with this materialized view. This can be quite confusing to a novice user as it seems like all information required for rewrite is present in the materialized view. The user can find out from DBMS_MVIEW.EXPLAIN_REWRITE that AVG cannot be computed from the given materialized view. The problem is that a ROLLUP is required here and AVG requires a COUNT or a SUM to do ROLLUP.

An example PL/SQL block for the above query, using a varray as its output medium, is as follows:

```
SET SERVEROUTPUT ON
DECLARE
  Rewrite_Array SYS.RewriteArrayType  := SYS.RewriteArrayType();
  querytxt VARCHAR2(1500) := 'SELECT S.CITY, AVG(F.DOLLAR_SALES)
          FROM STORE S, FACT F WHERE S.STORE_KEY = F.STORE_KEY
          GROUP BY S.CITY';
  i NUMBER;
BEGIN
  DBMS_MVIEW.Explain_Rewrite(querytxt, 'MV_CITY_STATE', Rewrite_Array);
  FOR i IN 1..Rewrite_Array.count
  LOOP
DBMS_OUTPUT.PUT_LINE(Rewrite_Array(i).message);
  END LOOP;
END;
/
```

Following is the output of the above `EXPLAIN_REWRITE` statement:

```
>> MV_NAME  : MV_CITY_STATE
>> QUERY    : SELECT S.CITY, AVG(F.DOLLAR_SALES) FROM STORE S, FACT F
              WHERE S.ST ORE_KEY = F.STORE_KEY GROUP BY S.CITY
>> MESSAGE  : QSM-01065: materialized view, MV_CITY_STATE, cannot compute
              measure, AVG, in the query

DBMS_MVIEW.Explain_Rewrite(querytxt, 'ID1', 'MV_CITY_STATE',
     user_name, Rewrite_Array);
```

Design Considerations for Improving Query Rewrite Capabilities

The following design considerations will help in getting the maximum benefit from query rewrite. They are not mandatory for using query rewrite and rewrite is not guaranteed if you follow them. They are general rules of thumb.

Constraints

Make sure all inner joins referred to in a materialized view have referential integrity (foreign key - primary key constraints) with additional `NOT NULL` constraints on the foreign key columns. Since constraints tend to impose a large overhead, you could make them `NO VALIDATE` and `RELY` and set the parameter `QUERY_REWRITE_INTEGRITY` to `STALE_TOLERATED` or `TRUSTED`. However, if you set `QUERY_REWRITE_INTEGRITY` to `ENFORCED`, all constraints must be enforced to get maximum rewritability.

Dimensions

You can express the hierarchical relationships and functional dependencies in normalized or denormalized dimension tables using the `HIERARCHY` and `DETERMINES` clauses of a dimension. Dimensions can express intra-table relationships which cannot be expressed by any constraints. Set the parameter `QUERY_REWRITE_INTEGRITY` to `TRUSTED` or `STALE_TOLERATED` for query rewrite to take advantage of the relationships declared in dimensions.

Outer Joins

Another way of avoiding constraints is to use outer joins in the materialized view. Query rewrite will be able to derive an inner join in the query, such as `(A.a=B.b)`, from an outer join in the materialized view `(A.a = B.b(+))`, as long as the rowid of `B` or column `B.b` is available in the materialized view. Most of the support for rewrites with outer joins is provided for materialized views with joins only. To exploit it, a materialized view with outer joins should store the rowid or primary key of the inner table of an outer join. For example, the materialized view `join_sales_time_product_mv_oj` stores the primary keys `prod_id` and `time_id` of the inner tables of outer joins.

Text Match

If you need to speed up an extremely complex, long-running query, you could create a materialized view with the exact text of the query. Then the materialized view would contain the query results, thus eliminating the time required to perform any complex joins and search through all the data for that which is required.

Aggregates

To get the maximum benefit from query rewrite, make sure that all aggregates which are needed to compute ones in the targeted set of queries are present in the materialized view. The conditions on aggregates are quite similar to those for incremental refresh. For instance, if `AVG(x)` is in the query, then you should store `COUNT(x)` and `AVG(x)` or store `SUM(x)` and `COUNT(x)` in the materialized view.

> **See Also:** "General Restrictions on Fast Refresh" on page 8-27 for requirements for fast refresh

Grouping Conditions

Aggregating data at lower levels in the hierarchy is better than aggregating at higher levels because lower levels can be used to rewrite more queries. Note, however, that doing so will also take up more space. For example, instead of grouping on state, group on city (unless space constraints prohibit it).

Instead of creating multiple materialized views with overlapping or hierarchically related `GROUP BY` columns, create a single materialized view with all those `GROUP BY` columns. For example, instead of using a materialized view that groups by city and another materialized view that groups by month, use a materialized view that groups by city and month.

Use `GROUP BY` on columns which correspond to levels in a dimension but not on columns that are functionally dependent, because query rewrite will be able to use the functional dependencies automatically based on the `DETERMINES` clause in a dimension. For example, instead of grouping on `prod_name`, group on `prod_id` (as long as there is a dimension which indicates that the attribute `prod_id` determines prod_name, you will enable the rewrite of a query involving prod_name).

Expression Matching

If several queries share the same common subexpression, it is advantageous to create a materialized view with the common subexpression as one of its SELECT columns. This way, the performance benefit due to precomputation of the common subexpression can be obtained across several queries.

Date Folding

When creating a materialized view which aggregates data by folded date granules such as months or quarters or years, always use the year component as the prefix but not as the suffix. For example, TO_CHAR(date_col, 'yyyy-q') folds the date into quarters, which collate in year order, whereas TO_CHAR(date_col, 'q-yyyy') folds the date into quarters, which collate in quarter order. The former preserves the ordering while the latter does not. For this reason, any materialized view created without a year prefix will not be eligible for date folding rewrite.

Statistics

Optimization with materialized views is based on cost and the optimizer needs statistics of both the materialized view and the tables in the query to make a cost-based choice. Materialized views should thus have statistics collected using the DBMS_STATS package.

Part VI
Miscellaneous

This section deals with other topics of interest in a data warehousing environment.

It contains the following chapters:

A Glossary

additive

Describes a fact (or measure) that can be summarized through addition. An additive fact is the most common type of fact. Examples include Sales, Cost, and Profit. Contrast with *nonadditive, semi-additive.*

advisor

The Summary Advisor recommends which materialized views to retain, create, and drop. It helps database administrators manage materialized views. It is a GUI in Oracle Enterprise Manager, and has similar capabilities to the `DBMS_OLAP` package.

attribute

A descriptive characteristic of one or more levels. Attributes represent logical groupings that enable end users to select data based on like characteristics. Note that in relational modeling, an attribute is defined as a characteristic of an entity. In Oracle9*i*, an attribute is a column in a dimension that characterizes elements of a single level.

aggregation

The process of consolidating data values into a single value. For example, sales data could be collected on a daily basis and then be aggregated to the week level, the week data could be aggregated to the month level, and so on. The data can then be referred to as *aggregate data. Aggregation* is synonymous with *summarization*, and *aggregate data* is synonymous with *summary data.*

aggregate

Summarized data. For example, unit sales of a particular product could be aggregated by day, month, quarter and yearly sales.

ancestor

A value at any level above a given value in a hierarchy. For example, in a Time dimension, the value `1999` might be the ancestor of the values `Q1-99` and `Jan-99`. See also *descendant, hierarchy, level.*

attribute

A descriptive characteristic of one or more levels. For example, the Product dimension for a clothing manufacturer might contain a level called Item, one of whose attributes is Color. Attributes represent logical groupings that enable end users to select data based on like characteristics.

Note that in relational modeling, an attribute is defined as a characteristic of an entity. In Oracle9*i*, an attribute is a column in a dimension that characterizes elements of a single level.

child

A value at the level below a given value in a hierarchy. For example, in a Time dimension, the value `Jan-99` might be the child of the value `Q1-99`. A value can be a child for more than one parent if the child value belongs to multiple hierarchies. See also *hierarchy, level, parent.*

cleansing

The process of resolving inconsistencies and fixing the anomalies in source data, typically as part of the ETL process. See also *ETL.*

Common Warehouse Metadata (CWM)

A repository standard used by Oracle data warehousing, decision support, and OLAP tools including Oracle Warehouse Builder. The CWM repository schema is a standalone product that other products can share—each product owns only the objects within the CWM repository that it creates.

cross product

A procedure for combining the elements in multiple sets. For example, given two columns, each element of the first column is matched with every element of the second column. A simple example is shown below:

```
Col1   Col2   Cross Product
----   ----   -------------
a      c      ac
b      d      ad
              bc
              bd
```

Cross products are performed when grouping sets are concatenated, as described in Chapter 18, "SQL for Aggregation in Data Warehouses".

data source

A database, application, repository, or file that contributes data to a warehouse.

data mart

A data warehouse that is designed for a particular line of business, such as sales, marketing, or finance. In a dependent data mart, the data can be derived from an enterprise-wide data warehouse. In an independent data mart, data can be collected directly from sources. See also *data warehouse.*

data warehouse

A relational database that is designed for query and analysis rather than transaction processing. A data warehouse usually contains historical data that is derived from transaction data, but it can include data from other sources. It separates analysis workload from transaction workload and enables a business to consolidate data from several sources.

In addition to a relational database, a data warehouse environment often consists of an ETL solution, an OLAP engine, client analysis tools, and other applications that manage the process of gathering data and delivering it to business users. See also *ETL, OLAP.*

denormalize

The process of allowing redundancy in a table so that it can remain flat. Contrast with *normalize.*

derived fact (or measure)

A fact (or measure) that is generated from existing data using a mathematical operation or a data transformation. Examples include averages, totals, percentages, and differences.

dimension

A structure, often composed of one or more hierarchies, that categorizes data. Several distinct dimensions, combined with measures, enable end users to answer business questions. Commonly used dimensions are Customer, Product, and Time. In Oracle 9*i*, a dimension is a database object that defines hierarchical (parent/child) relationships between pairs of column sets. In Oracle Express, a dimension is a database object that consists of a list of values.

dimension value

One element in the list that makes up a dimension. For example, a computer company might have dimension values in the Product dimension called `LAPPC` and `DESKPC`. Values in the Geography dimension might include `Boston` and `Paris`. Values in the Time dimension might include `MAY96` and `JAN97`.

drill

To navigate from one item to a set of related items. Drilling typically involves navigating up and down through the levels in a hierarchy. When selecting data, you can expand or collapse a hierarchy by drilling down or up in it, respectively. See also *drill down*, *drill up*.

drill down

To expand the view to include child values that are associated with parent values in the hierarchy. (See also *drill, drill up*.)

drill up

To collapse the list of descendant values that are associated with a parent value in the hierarchy.

element

An object or process. For example, a dimension is an object, a mapping is a process, and both are elements.

ETL

Extraction, transformation, and loading. ETL refers to the methods involved in accessing and manipulating source data and loading it into a data warehouse. The order in which these processes are performed varies.

Note that ETT (extraction, transformation, transportation) and ETM (extraction, transformation, move) are sometimes used instead of ETL. (See also *data warehouse, extraction, transformation, transportation*.)

extraction

The process of taking data out of a source as part of an initial phase of ETL. (See also *ETL*.)

fact table

A table in a star schema that contains facts. A fact table typically has two types of columns: those that contain facts and those that are foreign keys to dimension tables. The primary key of a fact table is usually a composite key that is made up of all of its foreign keys.

A fact table might contain either detail level facts or facts that have been aggregated (fact tables that contain aggregated facts are often instead called *summary tables*). A fact table usually contains facts with the same level of aggregation.

fact/measure

Data, usually numeric and additive, that can be examined and analyzed. Values for facts or measures are usually not known in advance; they are observed and stored. Examples include Sales, Cost, and Profit. *Fact* and *measure* are synonymous; *fact* is more commonly used with relational environments, *measure* is more commonly used with multidimensional environments. See also *derived fact*.

fast refresh

An operation that applies only the data changes to a materialized view, thus eliminating the need to rebuild the materialized view from scratch.

file-to-table mapping

Maps data from flat files to tables in the warehouse.

hierarchy

A logical structure that uses ordered levels as a means of organizing data. A hierarchy can be used to define data aggregation; for example, in a Time dimension, a hierarchy might be used to aggregate data from the `Month` level to the `Quarter` level to the `Year` level. A hierarchy can also be used to define a navigational drill path, regardless of whether the levels in the hierarchy represent aggregated totals. See also *dimension*, *level*.

hub module

The metadata container for process data.

level

A position in a hierarchy. For example, a Time dimension might have a hierarchy that represents data at the `Month`, `Quarter`, and `Year` levels.

(See also *hierarchy*.)

level value table

A database table that stores the values or data for the levels you created as part of your dimensions and hierarchies.

mapping

The definition of the relationship and data flow between source and target objects.

materialized view

A pre-computed table comprising aggregated and/or joined data from fact and possibly dimension tables. Also known as a summary or aggregate table.

metadata

Data that describes data and other structures, such as objects, business rules, and processes. For example, the schema design of a data warehouse is typically stored in a repository as metadata, which is used to generate scripts used to build and populate the data warehouse. A repository contains metadata.

Examples include: for data, the definition of a source to target transformation that is used to generate and populate the data warehouse; for information, definitions of tables, columns and associations that are stored inside a relational modeling tool; for business rules, discount by 10 percent after selling 1,000 items.

model

An object that represents something to be made. A representative style, plan, or design. Metadata that defines the structure of the data warehouse.

nonadditive

Describes a fact (or measure) that cannot be summarized through addition. An example includes Average. Contrast with *additive, semi-additive.*

normalize

In a relational database, the process of removing redundancy in data by separating the data into multiple tables. Contrast with denormalize.

The process of removing redundancy in data by separating the data into multiple tables.

operational data store (ODS)

The cleaned, transformed data from a particular source database.

OLAP

Online analytical processing. OLAP functionality is characterized by dynamic, multidimensional analysis of historical data, which supports activities such as the following:

- Calculating across dimensions and through hierarchies
- Analyzing trends
- Drilling up and down through hierarchies
- Rotating to change the dimensional orientation

OLAP tools can run against a multidimensional database or interact directly with a relational database.

parent

A value at the level above a given value in a hierarchy. For example, in a Time dimension, the value `Q1-99` might be the parent of the value `Jan-99`. See also *child, hierarchy, level.*

refresh

The mechanism whereby materialized views are populated with data.

schema

A collection of related database objects. Relational schemas are grouped by database user ID and include tables, views, and other objects. See also *snowflake schema, star schema*. Whenever possible, a demo schema called `Sales History` is used throughout this Guide.

semi-additive

Describes a fact (or measure) that can be summarized through addition along some, but not all, dimensions. Examples include Headcount and On Hand Stock. Contrast with *additive, nonadditive.*

snowflake schema

A type of star schema in which the dimension tables are partly or fully normalized. See also *schema, star schema.*

source

A database, application, file, or other storage facility from which the data in a data warehouse is derived.

star schema

A relational schema whose design represents a multidimensional data model. The star schema consists of one or more fact tables and one or more dimension tables that are related through foreign keys. See also *schema, snowflake schema.*

subject area

A classification system that represents or distinguishes parts of an organization or areas of knowledge. A data mart is often developed to support a subject area such as sales, marketing, or geography. See also *data mart*.

table

A layout of data in columns.

target

Holds the intermediate or final results of any part of the ETL process. The target of the entire ETL process is the data warehouse. See also *data warehouse, ETL*.

transformation

The process of manipulating data. Any manipulation beyond copying is a transformation. Examples include cleansing, aggregating, and integrating data from multiple sources.

transportation

The process of moving copied or transformed data from a source to a data warehouse. See also *transformation*.

validation

The process of verifying metadata definitions and configuration parameters.

versioning

The ability to create new versions of a data warehouse project for new requirements and changes.

B
Sample Data Warehousing Schema

This appendix introduces a common schema (`Sales History`) that is used in this guide. Most of the examples throughout this book use the same, simple star schema. This schema consists of four dimension tables and a single fact table (called `sales`) partitioned by month. The definitions of these tables follow:

```
CREATE TABLE times
(
  time_id                 DATE,
  day_name                VARCHAR2(9)
      CONSTRAINT             tim_day_name_nn            NOT NULL,
  day_number_in_week      NUMBER(1)
      CONSTRAINT             tim_day_in_week_nn         NOT NULL,
  day_number_in_month     NUMBER(2)
      CONSTRAINT             tim_day_in_month_nn        NOT NULL,
  calendar_week_number    NUMBER(2)
      CONSTRAINT             tim_cal_week_nn            NOT NULL,
  fiscal_week_number      NUMBER(2)
      CONSTRAINT             tim_fis_week_nn            NOT NULL,
  week_ending_day         DATE
      CONSTRAINT             tim_week_ending_day_nn     NOT NULL,
  calendar_month_number   NUMBER(2)
      CONSTRAINT             tim_cal_month_number_nn    NOT NULL,
  fiscal_month_number     NUMBER(2)
      CONSTRAINT             tim_fis_month_number_nn    NOT NULL,
  calendar_month_desc     VARCHAR2(8)
      CONSTRAINT             tim_cal_month_desc_nn      NOT NULL,
  fiscal_month_desc       VARCHAR2(8)
      CONSTRAINT             tim_fis_month_desc_nn      NOT NULL,
  days_in_cal_month       NUMBER
      CONSTRAINT             tim_days_cal_month_nn      NOT NULL,
  days_in_fis_month       NUMBER
      CONSTRAINT             tim_days_fis_month_nn      NOT NULL,
  end_of_cal_month        DATE
      CONSTRAINT             tim_end_of_cal_month_nn   NOT NULL,
  end_of_fis_month        DATE
      CONSTRAINT             tim_end_of_fis_month_nn   NOT NULL,
  calendar_month_name     VARCHAR2(9)
      CONSTRAINT             tim_cal_month_name_nn     NOT NULL,
  fiscal_month_name       VARCHAR2(9)
      CONSTRAINT             tim_fis_month_name_nn     NOT NULL,
  calendar_quarter_desc   CHAR(7)
      CONSTRAINT             tim_cal_quarter_desc_nn   NOT NULL,
  fiscal_quarter_desc     CHAR(7)
      CONSTRAINT             tim_fis_quarter_desc_nn   NOT NULL,
  days_in_cal_quarter     NUMBER
      CONSTRAINT             tim_days_cal_quarter_nn   NOT NULL,
  days_in_fis_quarter     NUMBER
      CONSTRAINT             tim_days_fis_quarter_nn   NOT NULL,
  end_of_cal_quarter      DATE
      CONSTRAINT             tim_end_of_cal_quarter_nn NOT NULL,
  end_of_fis_quarter      DATE
      CONSTRAINT             tim_end_of_fis_quarter_nn NOT NULL,
  calendar_quarter_number NUMBER(1)
      CONSTRAINT             tim_cal_quarter_number_nn NOT NULL,
  fiscal_quarter_number   NUMBER(1)
      CONSTRAINT             tim_fis_quarter_number_nn NOT NULL,
  calendar_year           NUMBER(4)
      CONSTRAINT             tim_cal_year_nn           NOT NULL,
  fiscal_year             NUMBER(4)
      CONSTRAINT             tim_fis_year_nn           NOT NULL,
  days_in_cal_year        NUMBER
      CONSTRAINT             tim_days_cal_year_nn      NOT NULL,
  days_in_fis_year        NUMBER
      CONSTRAINT             tim_days_fis_year_nn      NOT NULL,
  end_of_cal_year         DATE
      CONSTRAINT             tim_end_of_cal_year_nn    NOT NULL,
  end_of_fis_year         DATE
      CONSTRAINT             tim_end_of_fis_year_nn    NOT NULL
  );
```

```
REM creation of dimension table CHANNELS ...
CREATE TABLE channels
(
   channel_id       CHAR(1),
   channel_desc     VARCHAR2(20)
        CONSTRAINT     chan_desc_nn NOT NULL,
   channel_class    VARCHAR2(20)
  );

REM creation of dimension table PROMOTIONS ...
CREATE TABLE promotions
(
   promo_id           NUMBER(6),
   promo_name         VARCHAR2(20)
        CONSTRAINT      promo_name_nn       NOT NULL,
   promo_subcategory  VARCHAR2(30)
        CONSTRAINT      promo_subcat_nn     NOT NULL,
   promo_category     VARCHAR2(30)
        CONSTRAINT      promo_cat_nn        NOT NULL,
   promo_cost         NUMBER(10,2)
        CONSTRAINT      promo_cost_nn       NOT NULL,
   promo_begin_date   DATE
        CONSTRAINT      promo_begin_date_nn NOT NULL,
   promo_end_date     DATE
        CONSTRAINT      promo_end_date_nn   NOT NULL
 );

REM creation of dimension table COUNTRIES ...
CREATE TABLE countries
(
  country_id         CHAR(2),
  country_name       VARCHAR2(40)
        CONSTRAINT     country_country_name_nn NOT NULL,
  country_subregion  VARCHAR2(30),
  country_region     VARCHAR2(20)
 );
```

```
CREATE TABLE customers
(
   cust_id                NUMBER,
   cust_first_name        VARCHAR2(20)
        CONSTRAINT           customer_fname_nn      NOT NULL,
   cust_last_name         VARCHAR2(40)
        CONSTRAINT           customer_lname_nn      NOT NULL,
   cust_gender            CHAR(1),
   cust_year_of_birth     NUMBER(4),
   cust_marital_status    VARCHAR2(20),
   cust_street_address    VARCHAR2(40)
        CONSTRAINT           customer_st_addr_nn    NOT NULL,
   cust_postal_code       VARCHAR2(10)
        CONSTRAINT           customer_pcode_nn      NOT NULL,
   cust_city              VARCHAR2(30)
        CONSTRAINT           customer_city_nn       NOT NULL,
   cust_state_province    VARCHAR2(40),
   country_id             CHAR(2)
        CONSTRAINT           customer_country_id_nn NOT NULL,
   cust_main_phone_number VARCHAR2(25),
   cust_income_level      VARCHAR2(30),
   cust_credit_limit      NUMBER,
   cust_email             VARCHAR2(30)
);

REM creation of dimension table PRODUCTS ...
CREATE TABLE products
(
  prod_id               NUMBER(6),
  prod_name             VARCHAR2(50)
      CONSTRAINT            products_prod_name_nn     NOT NULL,
  prod_desc             VARCHAR2(4000)
      CONSTRAINT            products_prod_desc_nn     NOT NULL,
  prod_subcategory      VARCHAR2(50)
      CONSTRAINT            products_prod_subcat_nn   NOT NULL,
  prod_subcat_desc      VARCHAR2(2000)
      CONSTRAINT            products_prod_subcatd_nn  NOT NULL,
  prod_category         VARCHAR2(50)
      CONSTRAINT            products_prod_cat_nn      NOT NULL,
  prod_cat_desc         VARCHAR2(2000)
      CONSTRAINT            products_prod_catd_nn     NOT NULL,
  prod_weight_class     NUMBER(2),
  prod_unit_of_measure VARCHAR2(20),
  prod_pack_size        VARCHAR2(30),
  supplier_id           NUMBER(6),
  prod_status           VARCHAR2(20)
     CONSTRAINT            products_prod_stat_nn NOT NULL,
  prod_list_price       NUMBER(8,2)
     CONSTRAINT            products_prod_list_price_nn NOT NULL,
  prod_min_price        NUMBER(8,2)
     CONSTRAINT            products_prod_min_price_nn NOT NULL
);

REM creation of fact table SALES ...
CREATE TABLE sales
(
  prod_id                NUMBER(6)
      CONSTRAINT            sales_product_nn      NOT NULL,
  cust_id                NUMBER
      CONSTRAINT            sales_customer_nn     NOT NULL,
  time_id               DATE
      CONSTRAINT             sales_time_nn        NOT NULL,
  channel_id            CHAR(1)
      CONSTRAINT             sales_channel_nn     NOT NULL,
  promo_id               NUMBER(6),
  quantity_sold          NUMBER(3)
      CONSTRAINT             sales_quantity_nn    NOT NULL,
  amount                 NUMBER(10,2)
      CONSTRAINT             sales_amount_nn      NOT NULL,
  cost                   NUMBER(10,2)
      CONSTRAINT             sales_cost_nn        NOT NULL
)

PARTITION BY RANGE (time_id)
(PARTITION Q1_1998 VALUES LESS THAN (TO_DATE('01-APR-1998','DD-MON-YYYY')),
 PARTITION Q2_1998 VALUES LESS THAN (TO_DATE('01-JUL-1998','DD-MON-YYYY')),
 PARTITION Q3_1998 VALUES LESS THAN (TO_DATE('01-OCT-1998','DD-MON-YYYY')),
 PARTITION Q4_1998 VALUES LESS THAN (TO_DATE('01-JAN-1999','DD-MON-YYYY')),
 PARTITION Q1_1999 VALUES LESS THAN (TO_DATE('01-APR-1999','DD-MON-YYYY')),
 PARTITION Q2_1999 VALUES LESS THAN (TO_DATE('01-JUL-1999','DD-MON-YYYY')),
 PARTITION Q3_1999 VALUES LESS THAN (TO_DATE('01-OCT-1999','DD-MON-YYYY')),
 PARTITION Q4_1999 VALUES LESS THAN (TO_DATE('01-JAN-2000','DD-MON-YYYY')),
 PARTITION Q1_2000 VALUES LESS THAN (TO_DATE('01-APR-2000','DD-MON-YYYY')),
 PARTITION Q2_2000 VALUES LESS THAN (TO_DATE('01-JUL-2000','DD-MON-YYYY')),
 PARTITION Q3_2000 VALUES LESS THAN (TO_DATE('01-OCT-2000','DD-MON-YYYY')),
 PARTITION Q4_2000 VALUES LESS THAN (MAXVALUE))
 ;
```

```
REM A foreign-key relationship between SALES and PROMOTIONS is
REM intentionally omitted to demonstrate more sophisticated query
REM rewrite mechanisms

ALTER TABLE sales
ADD ( CONSTRAINT sales_product_fk
      FOREIGN KEY (prod_id)
      REFERENCES products,
      CONSTRAINT sales_customer_fk
      FOREIGN KEY (cust_id)
      REFERENCES customers,
      CONSTRAINT sales_time_fk
      FOREIGN KEY (time_id)
      REFERENCES times,
      CONSTRAINT sales_channel_fk
      FOREIGN KEY (channel_id)
      REFERENCES channels
    );
COMMIT;
```

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