Oracle8*i*

Data Warehousing Guide

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Send Us Your Comments xv

Preface xvii

Audience xvii
Knowledge Assumed of the Reader xvii
Installation and Migration Information xvii
Application Design Information xvii
How Oracle8*i* Data Warehousing Guide Is Organized xviii
Conventions Used in This Manual xx

Part I Concepts

1 Data Warehousing Concepts

What is a Data Warehouse? 1-2
Subject Oriented 1-2
Integrated 1-2
Nonvolatile 1-2
Time Variant 1-3
Contrasting a Data Warehouse with an OLTP System 1-3
Typical Data Warehouse Architectures 1-5

Part II Logical Design

2 Overview of Logical Design

Logical vs. Physical 2-2
Create a Logical Design 2-2
Data Warehousing Schemas 2-3
Star Schemas 2-3
Other Schemas 2-4
Data Warehousing Objects 2-4
Fact Tables 2-5
Dimensions 2-5

Part III Physical Design

3 Overview of Physical Design

Moving from Logical to Physical Design 3-2
Physical Design 3-3
Physical Design Structures 3-3
Tablespaces 3-3
Partitions 3-3
Indexes 3-4
Constraints 3-4

4 Hardware and I/O

Striping 4-2
Input/Output Considerations 4-9
Staging File Systems 4-9

5 Parallelism and Partitioning

Overview of Parallel Execution Tuning 5-2
When to Implement Parallel Execution 5-2
Tuning Physical Database Layouts 5-3
Types of Parallelism 5-3
Partitioning Data 5-4
Partition Pruning 5-10
Partition-wise Joins 5-12

6 Indexes

Bitmap Indexes 6-2
B-tree Indexes 6-6
Local Versus Global 6-6

7 Constraints

Why Constraints are Useful in a Data Warehouse 7-2
Overview of Constraint States 7-2
Typical Data Warehouse Constraints 7-3
Unique Constraints in a Data Warehouse 7-3

Foreign Key Constraints in a Data Warehouse 7-5
RELY Constraints 7-5
Constraints and Parallelism 7-6
Constraints and Partitioning 7-6

8 Materialized Views

Overview of Data Warehousing with Materialized Views 8-2
Materialized Views for Data Warehouses 8-3
Materialized Views for Distributed Computing 8-3
Materialized Views for Mobile Computing 8-3
The Need for Materialized Views 8-3
Components of Summary Management 8-5
Terminology 8-7
Schema Design Guidelines for Materialized Views 8-8
Types of Materialized Views 8-10
Materialized Views with Joins and Aggregates 8-11
Single-Table Aggregate Materialized Views 8-12
Materialized Views Containing Only Joins 8-13
Creating a Materialized View 8-16
Naming 8-17
Storage Characteristics 8-17
Build Methods 8-18
Used for Query Rewrite 8-18
Query Rewrite Restrictions 8-18
Refresh Options 8-19
ORDER BY 8-22
Using Oracle Enterprise Manager 8-23
Nested Materialized Views 8-23
Why Use Nested Materialized Views? 8-23
Rules for Using Nested Materialized Views 8-24
Restrictions when Using Nested Materialized Views 8-24
Limitations of Nested Materialized Views 8-25
Example of a Nested Materialized View 8-26
Nesting Materialized Views with Joins and Aggregates 8-28
Nested Materialized View Usage Guidelines 8-28

Registration of an Existing Materialized View 8-29
Partitioning a Materialized View 8-31
Partitioning the Materialized View 8-32
Partitioning a Prebuilt Table 8-33
Indexing Selection for Materialized Views 8-34
Invalidating a Materialized View 8-34
Security Issues 8-35
Guidelines for Using Materialized Views in a Data Warehouse 8-35
Altering a Materialized View 8-36
Dropping a Materialized View 8-36
Overview of Materialized View Management Tasks 8-37

9 Dimensions

What is a Dimension? 9-2
Drilling Across 9-5
Creating a Dimension 9-6
Multiple Hierarchies 9-8
Using Normalized Dimension Tables 9-10
Dimension Wizard 9-11
Viewing Dimensions 9-11
Using The DEMO_DIM Package 9-12
Using Oracle Enterprise Manager 9-13
Dimensions and Constraints 9-13
Validating a Dimension 9-14
Altering a Dimension 9-14
Deleting a Dimension 9-15

Part IV Managing the Warehouse Environment

10 ETT Overview

ETT Overview 10-2
ETT Tools 10-2
ETT Sample Schema 10-3

11 Extraction

Overview of Extraction 11-2
Extracting Via Data Files 11-2
- Extracting into Flat Files Using SQL*Plus 11-3
- Extracting into Flat Files Using OCI or Pro*C Programs 11-4
- Exporting into Oracle Export Files Using Oracle's EXP Utility 11-4
- Copying to Another Oracle Database Using Transportable Tablespaces 11-5

Extracting Via Distributed Operations 11-5
Change Capture 11-6
- Timestamps 11-7
- Partitioning 11-7
- Triggers 11-7

12 Transportation

Transportation Overview 12-2
- Transportation of Flat Files 12-2
- Transportation Via Distributed Operations 12-2
- Transportable Tablespaces 12-3

13 Transformation

Techniques for Data Transformation Inside the Database 13-2
- Transformation Flow 13-2
- Transformations Provided by SQL*Loader 13-3
- Transformations Using SQL and PL/SQL 13-4
- Data Substitution 13-5
- Key Lookups 13-5
- Pivoting 13-7
- Emphasis on Transformation Techniques 13-9

14 Loading and Refreshing

Refreshing a Data Warehouse 14-2
- Using Partitioning to Improve Data Warehouse Refresh 14-2
- Populating Databases Using Parallel Load 14-10

Refreshing Materialized Views 14-16

Complete Refresh 14-18
Fast Refresh 14-18
Tips for Refreshing Using Refresh 14-22
Complex Materialized Views 14-27
Recommended Initialization Parameters for Parallelism 14-27
Monitoring a Refresh 14-28
Tips after Refreshing Materialized Views 14-28

15 Summary Advisor

Summary Advisor 15-2
Collecting Structural Statistics 15-3
Collection of Dynamic Workload Statistics 15-3
Recommending Materialized Views 15-5
Estimating Materialized View Size 15-7
Summary Advisor Wizard 15-8
Is a Materialized View Being Used? 15-8

Part V Warehouse Performance

16 Schemas

Schemas 16-2
Star Schemas 16-2
Optimizing Star Queries 16-4
Tuning Star Queries 16-4
Star Transformation 16-5

17 SQL for Analysis

Overview 17-2
Analyzing Across Multiple Dimensions 17-2
Optimized Performance 17-4
A Scenario 17-5
ROLLUP 17-6
Syntax 17-6
Details 17-6

Example 17-6
Interpreting NULLs in Results 17-8
Partial Rollup 17-8
Calculating Subtotals without ROLLUP 17-9
When to Use ROLLUP 17-10
CUBE 17-10
Syntax 17-11
Details 17-11
Example 17-11
Partial Cube 17-13
Calculating Subtotals without CUBE 17-14
When to Use CUBE 17-14
Using Other Aggregate Functions with ROLLUP and CUBE 17-15
GROUPING Function 17-15
Syntax 17-15
Examples 17-16
When to Use GROUPING 17-18
Other Considerations when Using ROLLUP and CUBE 17-19
Hierarchy Handling in ROLLUP and CUBE 17-19
Column Capacity in ROLLUP and CUBE 17-20
HAVING Clause Used with ROLLUP and CUBE 17-20
ORDER BY Clause Used with ROLLUP and CUBE 17-21
Analytic Functions 17-21
Ranking Functions 17-24
Windowing Functions 17-35
Reporting Functions 17-43
Lag/Lead Functions 17-46
Statistics Functions 17-46
Case Expressions 17-52
CASE Example 17-52
Creating Histograms with User-defined Buckets 17-53

18 Tuning Parallel Execution

Introduction to Parallel Execution Tuning 18-2
When to Implement Parallel Execution 18-2

Initializing and Tuning Parameters for Parallel Execution 18-3
Selecting Automated or Manual Tuning of Parallel Execution 18-3
Automatically Derived Parameter Settings under Fully Automated Parallel Execution 18-4
Setting the Degree of Parallelism and Enabling Adaptive Multi-User 18-5
Degree of Parallelism and Adaptive Multi-User and How They Interact 18-5
Enabling Parallelism for Tables and Queries........ 18-6
Forcing Parallel Execution for a Session........ 18-7
Controlling Performance with PARALLEL_THREADS_PER_CPU 18-7
Tuning General Parameters........ 18-8
Parameters Establishing Resource Limits for Parallel Operations 18-8
Parameters Affecting Resource Consumption 18-17
Parameters Related to I/O........ 18-25
Example Parameter Setting Scenarios for Parallel Execution 18-27
Example One: Small Datamart........ 18-28
Example Two: Medium-sized Data Warehouse........ 18-29
Example Three: Large Data Warehouse 18-30
Example Four: Very Large Data Warehouse 18-31
Miscellaneous Tuning Tips 18-33
Formula for Memory, Users, and Parallel Execution Server Processes........ 18-33
Setting Buffer Pool Size for Parallel Operations........ 18-36
Balancing the Formula 18-37
Examples: Balancing Memory, Users, and Parallel Execution Servers........ 18-40
Parallel Execution Space Management Issues 18-43
Tuning Parallel Execution on Oracle Parallel Server........ 18-44
Overriding the Default Degree of Parallelism........ 18-48
Rewriting SQL Statements........ 18-49
Creating and Populating Tables in Parallel 18-50
Creating Temporary Tablespaces for Parallel Sort and Hash Join 18-51
Executing Parallel SQL Statements 18-53
Using EXPLAIN PLAN to Show Parallel Operations Plans........ 18-54
Additional Considerations for Parallel DML 18-54
Creating Indexes in Parallel 18-57
Parallel DML Tips........ 18-59
Incremental Data Loading in Parallel........ 18-62
Using Hints with Cost-Based Optimization 18-64

Monitoring and Diagnosing Parallel Execution Performance 18-64
Is There Regression? 18-66
Is There a Plan Change? 18-67
Is There a Parallel Plan? 18-67
Is There a Serial Plan? 18-67
Is There Parallel Execution? 18-68
Is The Workload Evenly Distributed? 18-68
Monitoring Parallel Execution Performance with Dynamic Performance Views 18-69
Monitoring Session Statistics 18-72
Monitoring Operating System Statistics 18-75

19 Query Rewrite

Overview of Query Rewrite 19-2
Cost-Based Rewrite 19-3
Enabling Query Rewrite 19-4
Initialization Parameters for Query Rewrite 19-5
Privileges for Enabling Query Rewrite 19-6
When Does Oracle Rewrite a Query? 19-6
Query Rewrite Methods 19-8
SQL Text Match Rewrite Methods 19-8
General Query Rewrite Methods 19-9
Query Rewrite with CUBE/ROLLUP Operator 19-20
When are Constraints and Dimensions Needed? 19-21
Complex Materialized Views 19-21
View-based Materialized View 19-22
Rewrite with Nested Materialized Views 19-22
Expression Matching 19-23
Date Folding 19-24
Accuracy of Query Rewrite 19-26
Did Query Rewrite Occur? 19-27
Explain Plan 19-27
Controlling Query Rewrite 19-28
Guidelines for Using Query Rewrite 19-29
Constraints 19-29
Dimensions 19-29

Outer Joins 19-29
SQL Text Match 19-30
Aggregates 19-30
Grouping Conditions 19-30
Expression Matching 19-31
Date Folding 19-31
Statistics 19-31

Part VI Miscellaneous

20 Data Marts

What Is a Data Mart? 20-2
How Is It Different from a Data Warehouse? 20-2
Dependent, Independent, and Hybrid Data Marts 20-2
Extraction, Transformation, and Transportation 20-5

A Glossary

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Oracle8*i* Data Warehousing Guide, Release 2 (8.1.6)

Part No. A76994-01

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- Did you find any errors?
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Preface

This manual provides reference information about Oracle8*i*’s data warehousing capabilities.

Audience

This manual is written for database administrators, system administrators, and database application developers who need to deal with data warehouses.

Knowledge Assumed of the Reader

It is assumed that readers of this manual are familiar with relational database concepts, basic Oracle server concepts, and the operating system environment under which they are running Oracle.

Installation and Migration Information

This manual is not an installation or migration guide. If your primary interest is installation, refer to your operating-system-specific Oracle documentation. If your primary interest is database and application migration, refer to *Oracle8i Migration*.

Application Design Information

In addition to administrators, experienced users of Oracle and advanced database application designers will find information in this manual useful. However, database application developers should also refer to the *Oracle8i Application Developer’s Guide - Fundamentals* and to the documentation for the tool or language product they are using to develop Oracle database applications.

How Oracle8*i* Data Warehousing Guide Is Organized

This manual is organized as follows:

Chapter 1, "Data Warehousing Concepts"

This chapter contains an overview of data warehousing concepts.

Chapter 2, "Overview of Logical Design"

This chapter contains an explanation of how to do logical design.

Chapter 3, "Overview of Physical Design"

This chapter contains an explanation of how to do physical design.

Chapter 4, "Hardware and I/O"

This chapter describes some hardware and input/output issues.

Chapter 5, "Parallelism and Partitioning"

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, "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, "ETT Overview"

This chapter describes an overview of the ETT process.

Chapter 11, "Extraction"

This chapter describes issues involved with extraction.

Chapter 12, "Transportation"

This chapter describes issues involved with transporting data in data warehouses.

Chapter 13, "Transformation"

This chapter describes issues involved with transforming data in data warehouses.

Chapter 14, "Loading and Refreshing"

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

Chapter 15, "Summary Advisor"

This chapter describes how to use the Summary Advisor utility.

Chapter 16, "Schemas"

This chapter describes the schemas useful in data warehousing environments.

Chapter 17, "SQL for Analysis"

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

Chapter 18, "Tuning Parallel Execution"

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

Chapter 19, "Query Rewrite"

This chapter describes using Query Rewrite.

Chapter 20, "Data Marts"

This chapter contains an introduction to Data Marts, and how they differ from warehouses.

Appendix A, "Glossary"

This chapter defines commonly used data warehousing terms.

Conventions Used in This Manual

The following sections describe the conventions used in this manual.

Text of the Manual

The text of this manual uses the following conventions.

UPPERCASE Characters

Uppercase text is used to call attention to command keywords, database object names, parameters, filenames, and so on.

For example, "After inserting the default value, Oracle checks the FOREIGN KEY integrity constraint defined on the DEPTNO column," or "If you create a private rollback segment, the name must be included in the ROLLBACK_SEGMENTS initialization parameter."

Italicized Characters

Italicized words within text are book titles or emphasized words.

Code Examples

Commands or statements of SQL, Oracle Enterprise Manager line mode (Server Manager), and SQL*Plus appear in a monospaced font.

For example:

```
INSERT INTO emp (empno, ename) VALUES (1000, 'SMITH');
ALTER TABLESPACE users ADD DATAFILE 'users2.ora' SIZE 50K;
```

Example statements may include punctuation, such as commas or quotation marks. All punctuation in example statements is required. All example statements terminate with a semicolon (;). Depending on the application, a semicolon or other terminator may or may not be required to end a statement.

`UPPERCASE` in Code Examples

Uppercase words in example statements indicate the keywords within Oracle SQL. When you issue statements, however, keywords are not case sensitive.

`lowercase` in Code Examples

Lowercase words in example statements indicate words supplied only for the context of the example. For example, lowercase words may indicate the name of a table, column, or file.

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Part I
Concepts

This section introduces basic data warehousing concepts.

It contains the following chapter:

- Data Warehousing Concepts

1 Data Warehousing Concepts

This chapter provides an overview of the Oracle implementation of data warehousing. Its sections include:

- What is a Data Warehouse?
- Typical Data Warehouse Architectures

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

- *The Data Warehouse Toolkit* by Ralph Kimball
- *Building the Data Warehouse* by William Inmon

What is a Data Warehouse?

A data warehouse is a relational database that is designed for query and analysis rather than transaction processing. It 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 an organization to consolidate data from several sources.

In addition to a relational database, a data warehouse environment often consists of an Extraction, Transportation, and Transformation (ETT) 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 Chapter 10, "ETT Overview", for further information regarding the ETT process.

A common way of introducing data warehousing is to refer to Inmon's characteristics of a data warehouse, who says that they are:

- Subject Oriented
- Integrated
- Nonvolatile
- Time Variant

Subject Oriented

Data warehouses are designed to help you analyze your data. For example, you might want to learn more about your company's sales data. To do this, you could build a warehouse concentrating on sales. In this warehouse, you could answer questions like "Who was our best customer for this item last year?" This kind of focus on a topic, sales in this case, is what is meant by *subject oriented*.

Integrated

Integration is closely related to subject orientation. Data warehouses need to have the data from disparate sources put into a consistent format. This means that naming conflicts have to be resolved and problems like data being in different units of measure must be resolved.

Nonvolatile

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

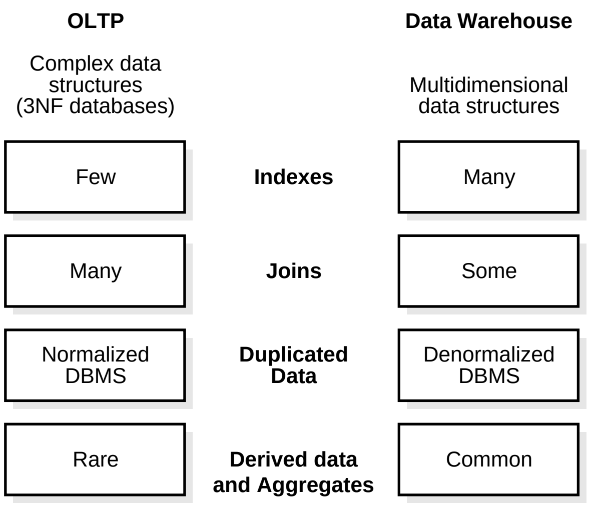
Time Variant

Most business analysis requires analyzing trends. Because of this, analysts tend to need large amounts of data. This is very much in contrast to OLTP systems, where performance requirements demand that historical data be moved to an archive.

Contrasting a Data Warehouse with an OLTP System

Figure 1–1 illustrates some of the key differences between a data warehouse's model and an OLTP system's.

Figure 1–1 Contrasting OLTP and Data Warehousing Environments



One major difference between the types of system is that data warehouses are not usually in third-normal form.

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

- Workload

  Data warehouses are designed to accommodate ad hoc queries. The workload of a data warehouse may not be completely understood in advance, and the data warehouse is optimized to perform well for a wide variety of possible query operations.

OLTP systems support only predefined operations. The application may be specifically tuned or designed to support only these operations.

- Data Modifications

  The data in a data warehouse is updated on a regular basis by the ETT process (often, every night or every week) using bulk data-modification techniques. The end users of a data warehouse do not directly update the data warehouse.

  In an OLTP system, end users routinely issue individual data-modification statements in 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 guarantee data consistency.

- Typical Operations

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

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

- Historical Data

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

  OLTP systems usually store only a few weeks' or months' worth of data. The OLTP system only stores as much historical data as is necessary to successfully meet the current transactional requirements.

Typical Data Warehouse Architectures

As you might expect, data warehouses and their architectures can vary depending upon the specifics of each organization's situation. Figure 1–2 shows the most basic architecture for a data warehouse. In it, a data warehouse is fed from one or more source systems, and end users directly access the data warehouse.

Figure 1–2 Typical Architecture for a Data Warehouse

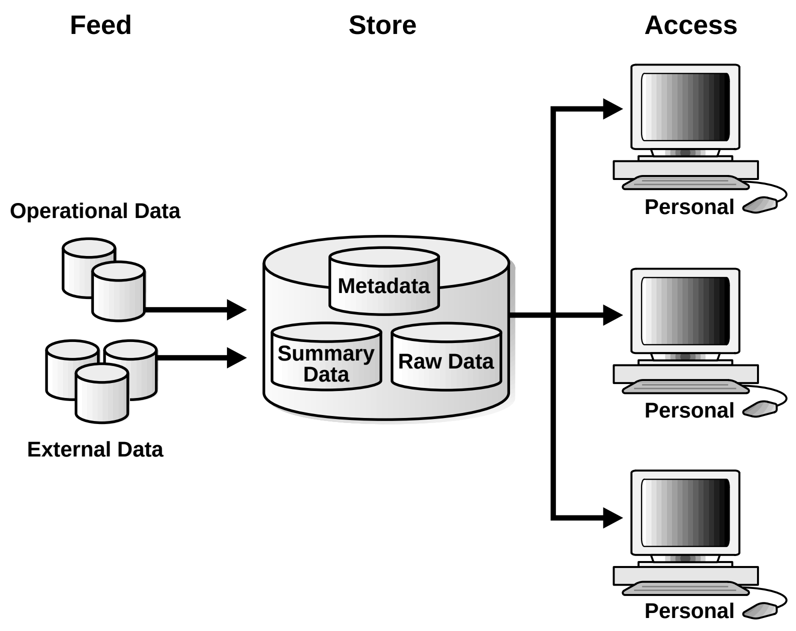
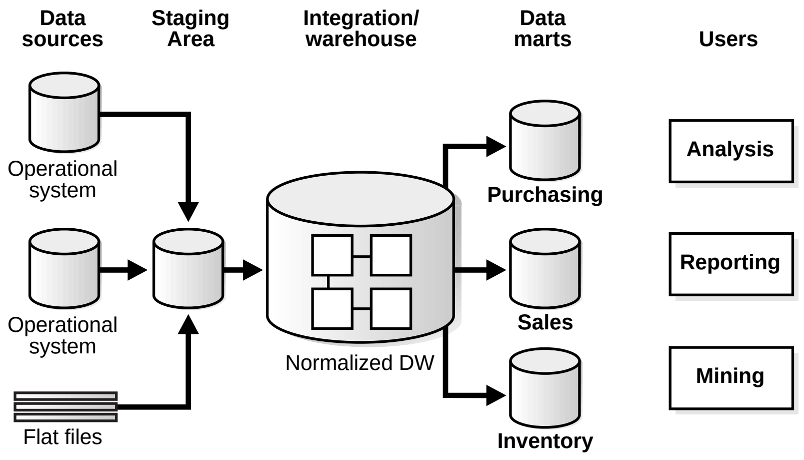


Figure 1–3 illustrates a more complex data warehouse environment. In addition to a central database, there is a staging system used to cleanse and integrate data, as well as multiple data marts, which are systems designed for a particular line of business.

Figure 1–3 Typical Architecture for a Complex Data Warehouse



Part II

Logical Design

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

It contains the following chapter:

- Overview of Logical Design

2
Overview of Logical Design

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

- Logical vs. Physical
- Create a Logical Design
- Data Warehousing Schemas

Logical vs. Physical

If you are reading this guide, it is likely that your organization has already decided to build a data warehouse. Moreover, it is likely that the business requirements are already defined, the scope of your application has been agreed upon, and you have a conceptual design. So now you need to translate your requirements into a system deliverable. In this step, you create the logical and physical design for the data warehouse and, in the process, define the specific data content, relationships within and between groups of data, the system environment supporting your data warehouse, the data transformations required, and 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.

Your design should be oriented toward the needs of the end users. End users typically want to perform analysis and look at aggregated data, rather than at individual transactions. Your design is driven primarily by end-user utility, but the end users may not know what they need until they see it. 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 without getting bogged down immediately with implementation detail.

Create a Logical Design

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

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 and helps define the uniqueness of the entity. In relational databases, an attribute maps to a column.

You can create the logical design using a pen and paper, or you can use a design tool such as Oracle Warehouse Builder or Oracle Designer.

While entity-relationship diagramming has traditionally been associated with highly normalized models such as online transaction processing (OLTP) applications, the technique is still useful in dimensional modeling. You just approach it differently. In dimensional modeling, instead of seeking to discover atomic units of information and all of the relationships between them, you try to identify which information belongs to a central fact table(s) and which information belongs to its associated dimension tables.

One output of the logical design is a set of entities and attributes corresponding to fact tables and dimension tables. Another output of mapping is operational data from your source into subject-oriented information in your target data warehouse schema. You identify business subjects or fields of data, define relationships between business subjects, and name the attributes for each subject.

The elements that help you to determine the data warehouse schema are the model of your source data and your user requirements. Sometimes, you can 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 due to your system parameters—size of machine, number of users, storage capacity, type of network, and software.

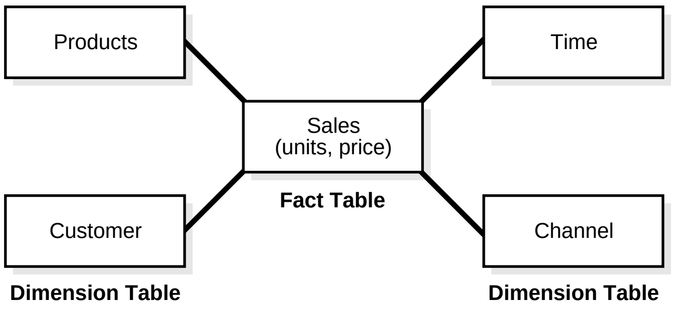
Data Warehousing Schemas

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

Star Schemas

The star schema is the simplest data warehouse schema. It is called a star schema because the diagram of a star schema 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 shown in Figure 2–1:

Figure 2–1 Star Schema



Unlike other database structures, in a star schema, the dimensions are denormalized. That is, the dimension tables have redundancy which eliminates the need for multiple joins on dimension tables. In a star schema, only one join is needed to establish the relationship between the fact table and any one of the dimension tables.

The main advantage to a star schema is optimized performance. A star schema keeps queries simple and provides fast response time because all the information about each level is stored in one row. See Chapter 16, "Schemas", for further information regarding schemas.

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

Other Schemas

Some schemas use third normal form rather than star schemas or the dimensional model.

Data Warehousing Objects

The following types of objects are commonly used in data warehouses:

- Fact tables are the central tables in your warehouse schema. 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. Examples are stores or products.

Fact Tables

A fact table is 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. A fact table might contain 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.

Values for facts or measures are usually not known in advance; they are observed and stored.

Fact tables are the basis for the data queried by OLAP tools.

Creating a New Fact Table

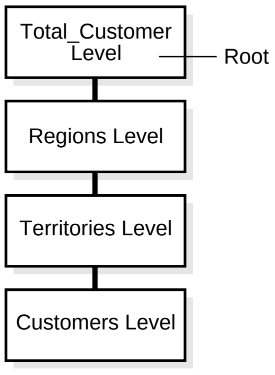
You must define a fact table for each star schema. A fact table typically has two types of columns: those that contain facts, and those that are foreign keys to dimension tables. From a modeling standpoint, the primary key of the fact table is usually a composite key that is made up of all of its foreign keys; in the physical data warehouse, the data warehouse administrator may or may not choose to create this primary key explicitly.

Facts support mathematical calculations used to report on and analyze the business. Some numeric data are dimensions in disguise, even if they seem to be facts. If you are not interested in a summarization of a particular item, the item may actually be a dimension. Database size and overall performance improve if you categorize borderline fields as dimensions.

Dimensions

A dimension is a structure, often composed of one or more hierarchies, that categorizes data. Several distinct dimensions, combined with measures, enable you to answer business questions. Commonly used dimensions are Customer, Product, and Time. Figure 2–2 shows some a typical dimension hierarchy.

Figure 2–2 Typical Levels in a Dimension Hierarchy



Dimension data is typically collected at the lowest level of detail and then aggregated into higher level totals, which is more useful for analysis. For example, in the Total_Customer dimension, there are four levels: Total_Customer, Regions, Territories, and Customers. Data collected at the Customers level is aggregated to the Territories level. For the Regions dimension, data collected for several regions such as Western Europe or Eastern Europe might be aggregated as a fact in the fact table into totals for a larger area such as Europe.

See Chapter 9, "Dimensions", for further information regarding dimensions.

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 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 and 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. For example, in the Product dimension, there might be two hierarchies—one for product identification and one for product responsibility.

Dimension hierarchies also group levels from very general to very granular. Hierarchies are utilized by query tools, allowing you to drill down into your data to view different levels of granularity—one of the key benefits of a data warehouse.

When designing your hierarchies, you must consider the relationships defined in your source data. For example, a hierarchy design must honor the foreign key relationships between the source tables in order to properly aggregate data.

Hierarchies imposes 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 allow analysts to access data quickly.

See Chapter 9, "Dimensions", for further information regarding hierarchies.

Levels Levels represent 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 very 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 and define the parent-child relationship between the levels in a hierarchy.

You can define hierarchies where each level rolls up to the previous level in the dimension or you can define hierarchies that skip one or multiple levels.

Part III

Physical Design

This section deals with physical design in a data warehouse.

It contains the following chapters:

- Overview of Physical Design
- Hardware and I/O
- Parallelism and Partitioning
- Indexes
- Constraints
- Materialized Views
- Dimensions

3

Overview of Physical Design

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

- Moving from Logical to Physical Design
- Physical Design

Moving from Logical to Physical Design

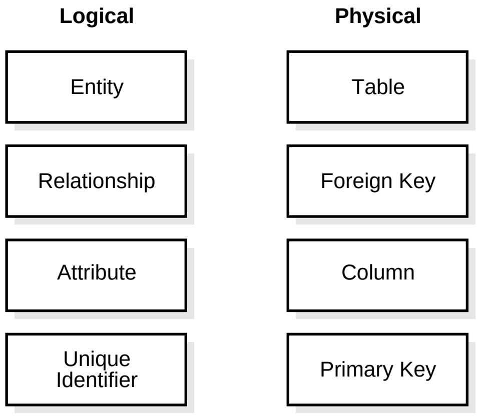
In a sense, logical design is what you draw with a pencil before building your warehouse and physical design is when you create the database with SQL statements.

During the physical design process, you convert the data gathered during the logical design phase into a description of the physical database, including tables and constraints. Physical design decisions, such as the type of index or partitioning have a large impact on query performance. See Chapter 6, "Indexes" for further information regarding indexes. See Chapter 5, "Parallelism and Partitioning" for further information regarding partitioning.

Logical models use fully normalized entities. The entities are linked together using relationships. Attributes are used to describe the entities. The UID distinguishes between one instance of an entity and another.

A graphical way of looking at the differences between logical and physical designs is in Figure 3–1:

Figure 3–1 Logical Design Compared with Physical Design



Physical Design

Physical design is where you translate the expected schemas into actual database structures. At this time, you have to map:

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

You will have to decide whether to use a one-to-one mapping as well.

Physical Design Structures

Translating your schemas into actual database structures requires creating the following:

- Tablespaces
- Partitions
- Indexes
- Constraints

Tablespaces

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. See Chapter 4, "Hardware and I/O", for further information regarding tablespaces.

Partitions

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. This month’s worth of data can be assigned its own partition. See Chapter 5, "Parallelism and Partitioning", for further details.

Indexes

Data warehouses' indexes resemble OLTP indexes. An important point is that bitmap indexes are quite common. See Chapter 6, "Indexes", for further information.

Constraints

Constraints are somewhat different in data warehouses than in OLTP environments because data integrity is reasonably ensured due to the limited sources of data and because you can check the data integrity of large files for batch loads. Not null constraints are particularly common in data warehouses. See Chapter 7, "Constraints", for further details.

4 Hardware and I/O

This chapter explains some of the hardware and input/output issues in a data warehousing environment, and includes the following topics:

- Striping
- Input/Output Considerations

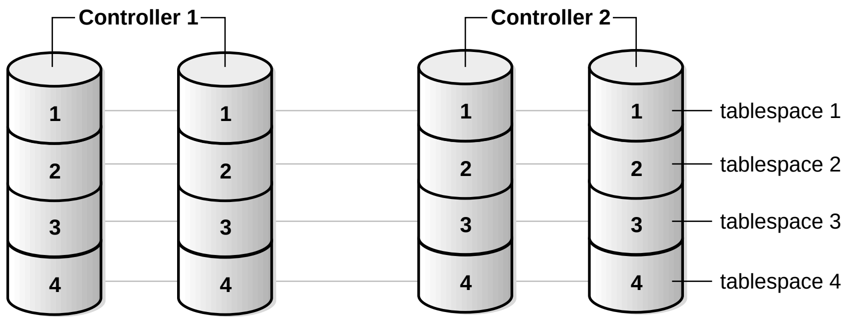
Striping

Striping Data

To avoid I/O bottlenecks during parallel processing or concurrent query access, all tablespaces accessed by parallel operations should be striped. 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.

Stripe tablespaces for tables, indexes, rollback segments, and temporary tablespaces. You must also spread the devices over controllers, I/O channels, and/or internal buses.

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



It is also important to ensure that data is evenly distributed across these files. One way to stripe data during loads, use the FILE= clause of parallel loader to load data from multiple load sessions into different files in the tablespace. To make striping effective, ensure 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.

Your operating system or volume manager may perform striping (operating system striping), or you can perform striping manually through careful data file allocation to tablespaces.

We recommend using a large stripe size of at least 64KB with OS striping when possible. This approach always performs better than manual striping, especially in multi-user environments.

Operating System Striping Operating system striping is usually flexible and easy to manage. It supports multiple users running sequentially as well as single users running in parallel. Two main advantages make OS 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 compensated by the large I/O size (DB_BLOCK_SIZE * MULTIBLOCK_READ_COUNT) that 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: I/O is more evenly distributed across the disks.

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 2 or 4, then certain trade-offs may arise. The large stripe size can be beneficial because it allows the system to perform more sequential operations on each disk; it decreases the number of seeks on disk. The disadvantage is that it reduces the I/O parallelism so fewer disks are simultaneously active. If you encounter problems, increase the I/O size of scan operations (going, for example, from 64KB to 128KB), instead of changing the stripe size. The maximum I/O size is platform-specific (in a range, for example, of 64KB to 1MB).

With OS striping, from a performance standpoint, the best layout is to stripe data, indexes, and temporary tablespaces across all the disks of your platform. For availability reasons, it may be more practical to strip over fewer disks to prevent a single disk value from affecting the entire data warehouse. However, for performance, it is crucial to strip all objects over multiple disks. In this way, maximum I/O performance (both in terms of throughput and 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 multi-user 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, each on a separate disk. If you use manual striping correctly, your system will experience significant performance gains. However, you should be aware of several drawbacks that may adversely affect performance if you do not stripe correctly.

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

> **See Also:** *Oracle8i Concepts* for information on disk striping and partitioning. For MPP systems, see your platform-specific Oracle documentation regarding the advisability of disabling disk affinity when using operating system striping.

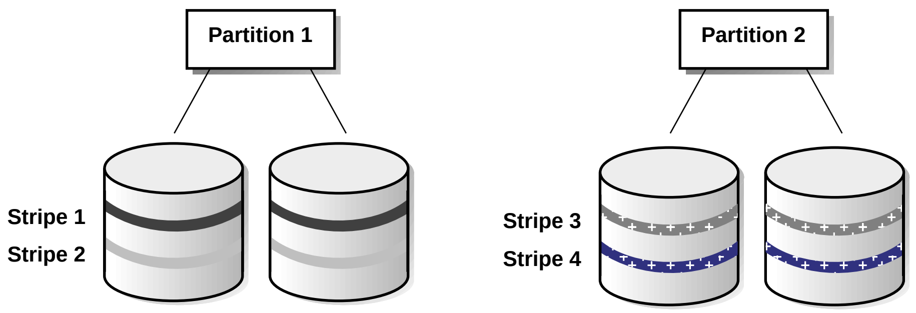
Local and Global Striping

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. There is no overlapping disk access, and no overlapping of 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.

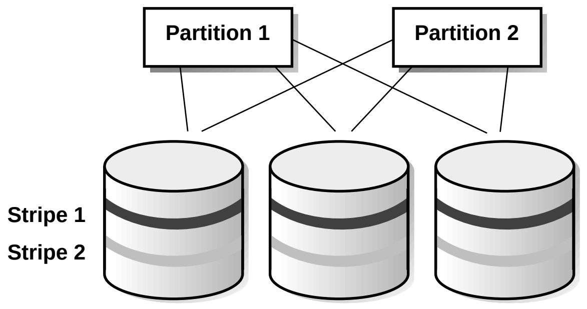
A disadvantage of local striping is that you need many more disks to implement it—each partition requires multiple disks of its own. Another major disadvantage is that after partition pruning to only a single or a few partitions, the system will have limited I/O bandwidth. As a result, local striping is not optimal for parallel operations. For this reason, consider local striping only if your main concern is availability, and not 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 only in 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.

Analyzing Striping

There are two considerations 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. These two topics are discussed under the following headings.

Cardinality of Storage Object Relationships To analyze striping, consider the following relationships:

Figure 4–4 Cardinality of Relationships

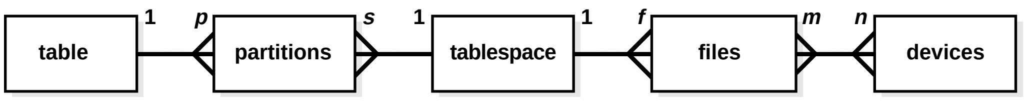


Figure 4–4 shows the cardinality of the relationships among objects in a typical Oracle storage system. For every table there may be:

- *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. This means placing a table on many devices.
- Goal 2: To optimize availability. This means restricting the tablespace to a few devices.
- Goal 3: To optimize partition scans. This means achieving intra-partition parallelism by placing each partition on many devices.

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

For highest availability but the least 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 benefits of both goals.

Goal 1: To optimize full table scans. Having a table on many devices is beneficial because full table scans are scalable.

Calculate the number of partitions multiplied by the number of files in the tablespace multiplied by the number of devices per file. Divide this product by the number of partitions that share the same tablespace, multiplied by the number of files that share the same device. The formula is as follows:

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

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 x 1 / p x 1 x 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 x 1 x 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 x f x 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.

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

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 beneficial because partition scans are scalable. To do this, place each partition on many devices.

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

Partitions can reside in a tablespace that can have many files. There could be either

- Many files per tablespace or
- Striped file

Striping 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 objects are striped over all disks, then loss of any disk stops the entire database. Furthermore, you may need to restore all 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 OS subsystem that provides striping also provides mirroring. With the declining price of disks, mirroring can provide an effective supplement to backups and log archival, *but not a substitute for them*. Mirroring can help your system recover from device failures more quickly than with a backup, but is not as robust. Mirroring does not protect against software faults and other problems that an independent backup would protect your system against.

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 could involve lengthy downtime, whereas restoring it from a mirrored disk would enable your system to get back online quickly.

RAID-5 technology is even less expensive than mirroring. RAID-5 avoids full duplication in favor of more expensive write operations. For "read-mostly" applications, this may suffice.

Note: RAID-5 technology is particularly slow on write operations. Performance of write operations, such as loading, should be considered when evaluating RAID-5.

For more information about automatic file striping and tools you can use to determine I/O distribution among your devices, refer to your operating system, server, and storage documentation.

Input/Output Considerations

Be careful when configuring the I/O subsystem that the throughput capacity of the disks that you will be accessing at any given time does not exceed the throughput capacity of the I/O controllers. You must balance the number of disks with the total number of I/O controllers to prevent bottlenecks at the controller level.

Staging File Systems

It is important for data warehouses that the staging file systems perform well. Staging file systems are used to store flat files while these files are loaded into the data warehouse. Most operating systems that support OS striping support creating file systems on striped devices.

If you intend to have more than one process reading from or writing to a file system simultaneously, you should create the file system on a device that is striped over the same number of devices as the number of processes that you intend to use. For example, if you will be using five Parallel SQL*Loader processes to load five flat files into the database, the file system where the flat files reside should be striped over five devices. Alternatively, place each flat file in a separate unstriped file system.

5 Parallelism and Partitioning

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

Parallel execution dramatically reduces response time for data-intensive operations on large databases typically associated with decision support systems (DSS). You can also implement parallel execution on certain types of online transaction processing (OLTP) and hybrid systems.

Note: Parallel execution is available only with the Oracle8*i* Enterprise Edition.

This chapter explains how to implement parallel execution and tune your system to optimize parallel execution performance. The following topics are discussed:

- Overview of Parallel Execution Tuning
- Tuning Physical Database Layouts

Overview of Parallel Execution Tuning

Parallel execution is useful for many types of operations accessing 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, you can use parallel execution to access LOBs (large binary objects).

Parallel execution benefits systems if they 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 *may not* significantly improve performance. In fact, parallel execution can reduce system performance on overutilized systems or systems with small I/O bandwidth.

Note: The term *parallel execution server* designates server processes, or *threads* on NT systems, that perform parallel operations. This is not the same as the Oracle Parallel Server option, which refers to multiple Oracle instances accessing the same database.

When to Implement Parallel Execution

Parallel execution provides the greatest performance improvements in decision support systems (DSS). Online transaction processing (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.

The more common example of using parallel execution is for DSS. Complex queries, such as those involving joins of several tables or searches of very large tables, are often best executed in parallel.

See Chapter 18, "Tuning Parallel Execution", for further information regarding parallel execution.

Tuning Physical Database Layouts

This section describes how to tune the physical database layout for optimal performance of parallel execution. The following topics are discussed:

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

Types of Parallelism

Different parallel operations use different types of parallelism. The optimal physical database layout depends on what parallel operations are most prevalent in your application.

The basic unit of parallelism is a called a *granule*. The operation being parallelized (a table scan, table update, or index creation, for example) is divided by Oracle into granules. Parallel execution processes execute the operation one granule at a time. The number of granules and their size affect the degree of parallelism (DOP) you can use. It also affects how well the work is balanced across query server processes.

Block Range Granules

Block range granules are the basic unit of most parallel operations. This is true even on partitioned tables; it is the reason why, on Oracle, the parallel degree is not related to the number of partitions.

Block range granules are ranges of physical blocks from a table. Because they are based on physical data addresses, Oracle can size block range granules to allow better load balancing. Block range granules permit dynamic parallelism that does not depend on static preallocation of tables or indexes. On SMP (symmetric multi-processors) systems, granules are located on different devices to drive as many disks as possible. On many MPP (massively parallel processing) systems, block range granules are preferentially assigned to query server processes that have physical proximity to the disks storing the granules. Block range granules are also used with global striping.

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) may influence partition layout more than performance considerations. The number of disks that you stripe partitions over should be at least equal to the value of the DOP so that parallel execution efficiency is not reduced when or if partition pruning occurs.

Partition Granules

When partition granules are used, a query server process works on an entire partition or subpartition of a table or index. Because partition granules are statically determined when a table or index is created, partition granules do not allow as much flexibility in parallelizing an operation. This means that the allowable DOP might be limited, and that load might not be well balanced across query server processes.

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

When partition granules are used for parallel access to a table or index, it is important that there be a relatively large number of partitions (ideally, three times the DOP), so Oracle can effectively balance work across the query server processes.

See Also: *Oracle8i Concepts* for information on disk striping and partitioning.

Partitioning Data

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

Partitioned tables and indexes facilitate administrative operations by allowing these operations to work on subsets of data. For example, you can add a new partition, organize an existing partition, or drop a partition with 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 amount 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.

Types of Partitioning

Oracle offers three partitioning methods:

- Range
- Hash
- Composite

Each partitioning method has a different set of advantages and disadvantages. Thus, each method is appropriate for a particular situation.

Range Partitioning Range partitioning maps data to partitions based on boundaries identified by ranges of column values that you establish for each partition. This method is often useful for applications that manage historical data, especially data warehouses.

Hash Partitioning Hash partitioning maps data to partitions based on a hashing algorithm that Oracle applies to a partitioning key identified by the user. The hashing algorithm evenly distributes rows among partitions. Therefore, the resulting set of partitions should be approximately of the same size. This makes hash partitioning ideal for distributing data evenly across devices. Hash partitioning is also a good and easy-to-use alternative to range partitioning when data is not historical in content.

Note: You cannot define alternate hashing algorithms for partitions.

Composite Partitioning Composite partitioning combines the features of range and hash partitioning. With composite partitioning, Oracle first distributes data into partitions according to boundaries established by the partition ranges. Then Oracle further divides the data into subpartitions within each range partition. Oracle uses a hashing algorithm to distribute data into the subpartitions.

Index Partitioning

You can create both local and global indexes on a table partitioned by range, hash, or composite. 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 indexes. You cannot partition global indexes using the hash or composite partitioning methods.

Performance Issues for Range, Hash, and Composite Partitioning

The following section describes performance issues for range, hash, and composite partitioning.

Performance Considerations for 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.

The most common use of range partitioning leverages the partitioning of data into time intervals on a column of type DATE. Because of this, SQL statements accessing range partitions tend to focus on time frames. 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 one month's worth of data, 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. This optimization method is called 'partition pruning'.

Range partitioning is also ideal when you periodically load new data and purge old data. This adding or dropping of partitions is a major manageability enhancement.

It is common to keep a rolling window of data, for example keeping the past 36 months of data online. Range partitioning simplifies this process. To add a new month's data you load it into a separate table, clean the data, index it, and then add it to the range-partitioned table using the EXCHANGE PARTITION command, all while the table remains online. Once you add the new partition, you can drop the trailing month with the DROP PARTITION command.

In conclusion, consider using range partitioning when:

- Very large tables are frequently scanned by a range predicate on a column that is a good partitioning column, such as ORDER_DATE or PURCHASE_DATE. Partitioning the table on that column would enable partitioning pruning.
- You want to maintain a rolling window of data
- You cannot complete administrative operations on large tables, such as backup and restore, in an allotted time frame
- You need to implement parallel DML (PDML) operations

The following SQL example creates the table Sales for a period of two years, 1994 and 1995, and partitions it by range according to the column *s_saledate* to separate the data into eight quarters, each corresponding to a partition:

```
CREATE TABLE sales
  (s_productid NUMBER,
   s_saledate DATE,
   s_custid NUMBER,
   s_totalprice NUMBER)
PARTITION BY RANGE(s_saledate)
 (PARTITION sal94q1 VALUES LESS THAN TO_DATE (01-APR-1994, DD-MON-YYYY),
  PARTITION sal94q2 VALUES LESS THAN TO_DATE (01-JUL-1994, DD-MON-YYYY),
  PARTITION sal94q3 VALUES LESS THAN TO_DATE (01-OCT-1994, DD-MON-YYYY),
  PARTITION sal94q4 VALUES LESS THAN TO_DATE (01-JAN-1995, DD-MON-YYYY),
  PARTITION sal95q1 VALUES LESS THAN TO_DATE (01-APR-1995, DD-MON-YYYY),
  PARTITION sal95q2 VALUES LESS THAN TO_DATE (01-JUL-1995, DD-MON-YYYY),
  PARTITION sal95q3 VALUES LESS THAN TO_DATE (01-OCT-1995, DD-MON-YYYY),
  PARTITION sal95q4 VALUES LESS THAN TO_DATE (01-JAN-1996, DD-MON-YYYY));
```

Performance Considerations for Hash Partitioning Unlike range partitioning, the way in which Oracle distributes data in hash partitions does not correspond to a business, or logical, view of the data. Therefore, hash partitioning is not an effective way to manage historical data. However, hash partitions share some performance characteristics of range partitions, such as using partition pruning is limited to equality predicates. You can also use partition-wise joins, parallel index access and PDML.

> **See Also:** Partition-wise joins are described later in this chapter under the heading "Partition-wise Joins" on page 5-12.

As a general rule, use hash partitioning:

- To improve the availability and manageability of large tables or to enable PDML, in tables that do not store historical data (where range partitioning is not appropriate).
- 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 as many devices as required to maximize I/O throughput. Similarly, you can use hash partitioning to evenly distribute data among the nodes of an MPP platform that uses the Oracle Parallel Server.
- If it is important to use partition pruning and partition-wise joins according to a partitioning key.

Note: In hash partitioning, partition pruning is limited to using 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 this 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 2. If you do not quantify the number of partitions by a power of 2, in the worst case the largest partition can be twice the size of the smallest. So for optimal performance, create partitions, or subpartitions per partition, using a power of two. For example, 2, 4, 8, 16, 32, 64, 128, and so on.

The following example creates four hashed partitions for the table Sales using the column *s_productid* as the partition key:

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

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

Performance Considerations for Composite Partitioning Composite partitioning offers the benefits of both range and hash partitioning. With composite partitioning, Oracle first partitions by range, and then within each range Oracle creates subpartitions and distributes data within them using a hashing algorithm. Oracle uses the same hashing algorithm to distribute data among the hash subpartitions of composite partitioned tables as it does for hash partitioned tables.

Data placed in composite partitions is logically ordered only in terms of the partition boundaries you use to 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, for example, 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 may be spread across multiple tablespaces, devices, or nodes (of an MPP system)
- You need to use both partition pruning and partition-wise joins even when the pruning and join predicates use different columns of the partitioned table
- You want to use 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 above. When using the composite method, Oracle stores each subpartition on a different segment. Thus, the subpartitions may have properties that are different from the properties of the table or the partition to which the subpartitions belong.

The following SQL example partitions the table Sales by range on the column *s_saledate* to create four partitions. This takes advantage of ordering data by a time frame. Then within each range partition, the data is further subdivided into four subpartitions by hash on the column *s_productid*.

```
CREATE TABLE sales(
  s_productid NUMBER,
  s_saledate DATE,
  s_custid NUMBER,
  s_totalprice)
   PARTITION BY RANGE (s_saledate)
   SUBPARTITION BY HASH (s_productid) SUBPARTITIONS 4
  (PARTITION sal94q1 VALUES LESS THAN TO_DATE (01-APR-1994, DD-MON-YYYY),
   PARTITION sal94q2 VALUES LESS THAN TO_DATE (01-JUL-1994, DD-MON-YYYY),
   PARTITION sal94q3 VALUES LESS THAN TO_DATE (01-OCT-1994, DD-MON-YYYY),
   PARTITION sal94q4 VALUES LESS THAN TO_DATE (01-JAN-1995, DD-MON-YYYY));
```

Each hashed subpartition contains sales of a single quarter ordered by product code. The total number of subpartitions is 16.

Partition Pruning

Partition pruning is a very important 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 allows Oracle to perform operations only on partitions relevant to the SQL statement. Oracle does this when you use range, equality, and IN-list predicates on the range partitioning columns, and equality and IN-list predicates on the hash partitioning columns.

Partition pruning can also dramatically reduce the amount of data retrieved from disk and reduce processing time. This results in substantial improvements in 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 underlying table's partitions cannot be eliminated.

On composite partitioned objects, Oracle can prune at both the range partition level and hash subpartition level using the relevant predicates. For example, referring to the table Sales from the previous example, partitioned by range on the column *s_saledate* and subpartitioned by hash on column *s_productid*, consider the following SQL statement:

```
SELECT * FROM sales
WHERE s_saledate BETWEEN TO_DATE(01-JUL-1994, DD-MON-YYYY) AND
TO_DATE(01-OCT-1994, 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 sal94q2 and sal94q3
- When using hash partitioning, Oracle accesses only the third partition, h3, where rows with *s_productid* equal to 1200 are mapped

Pruning Using DATE Columns

In the previous example, the date value was fully specified, 4 digits for year, using the TO_DATE function. While this is the recommended format for specifying date values, the optimizer can prune partitions using the predicates on *s_saledate* when you use other formats, as in the following examples:

```
SELECT * FROM sales
WHERE s_saledate BETWEEN TO_DATE(01-JUL-1994, DD-MON-YY) AND
TO_DATE(01-OCT-1994, DD-MON-YY) AND s_productid = 1200;

SELECT * FROM sales
WHERE s_saledate BETWEEN '01-JUL-1994' AND
'01-OCT-1994' AND s_productid = 1200;
```

However, you will not be able to see which partitions Oracle is accessing as is usually shown on the *partition_start* and *partition_stop* columns of the EXPLAIN PLAN command output on the SQL statement. Instead, you will see the keyword 'KEY' for both columns.

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 query servers when joins execute in parallel. This significantly reduces response time and resource utilization, both in terms of CPU and memory. In Oracle Parallel Server (OPS) environments, it also avoids or at least limits the data traffic over the interconnect, which is the key to achieving good scalability for massive join operations.

There are two variations of partition-wise join, full and partial, as discussed under the following headings.

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 equi-partition 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 1994" 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-1994, DD-MON-YYYY) AND
  TO_DATE(01-oct-1994, DD-MON-YYYY)
GROUP BY c_customer_name HAVING
COUNT(*) > 100;
```

This is a very large join typical in data warehousing environments. The entire customer table is joined with one quarter of the sales data. In large data warehouse applications, it might mean joining millions of rows. The join method to use in that case is obviously a hash join. But you can reduce the processing time for this hash join even more if both tables are equi-partitioned 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 "Types 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 should have at least 16 partitions to set the degree of parallelism of the query to 16.

You can use various partitioning methods to equi-partition both tables on the column *customerid* with 16 partitions. These methods are described in the following subsections.

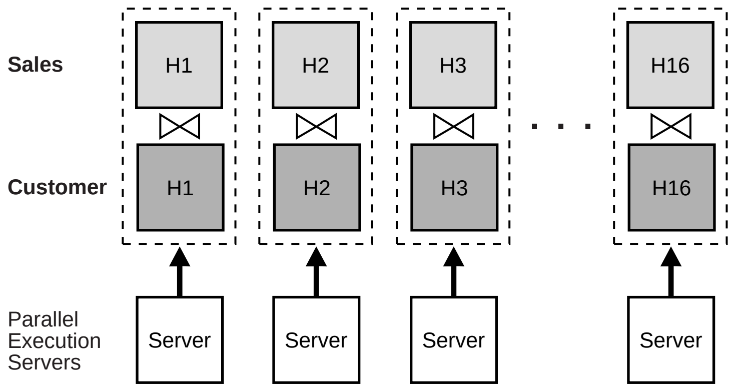
Hash - Hash This is the simplest method: the Customer and Sales tables are both partitioned by hash into 16 partitions, on *s_customerid* and *c_customerid* respectively. This partitioning method should enable full partition-wise join when the tables are joined on the customerid column.

In serial, this join is performed between a pair of matching hash partitions 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 from each table with the same partition number. 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, we assume that the degree of parallelism and the number of partitions are the same, in other words, 16 for both. It is possible to have more partitions than the degree of parallelism to improve load balancing and limit possible skew in the execution. If you have more partitions than query servers, when one query server is done with 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 allows dynamic load balancing 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: Always use a number of partitions that is a multiple of the degree of parallelism.

In Oracle Parallel Server environments running on shared-nothing platforms or MPPs, partition placements 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.

You can, however, have node host multiple pairs when there are more pairs than nodes. For example, with an 8-node system and 16 partition pairs, each node should receive two pairs.

See Also: For more information on data affinity, please refer to *Oracle8i Parallel Server Concepts.*

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 "Performance Considerations for Range Partitioning" on page 5-6, a more logical partitioning method for sales is probably the range method, not the hash method.

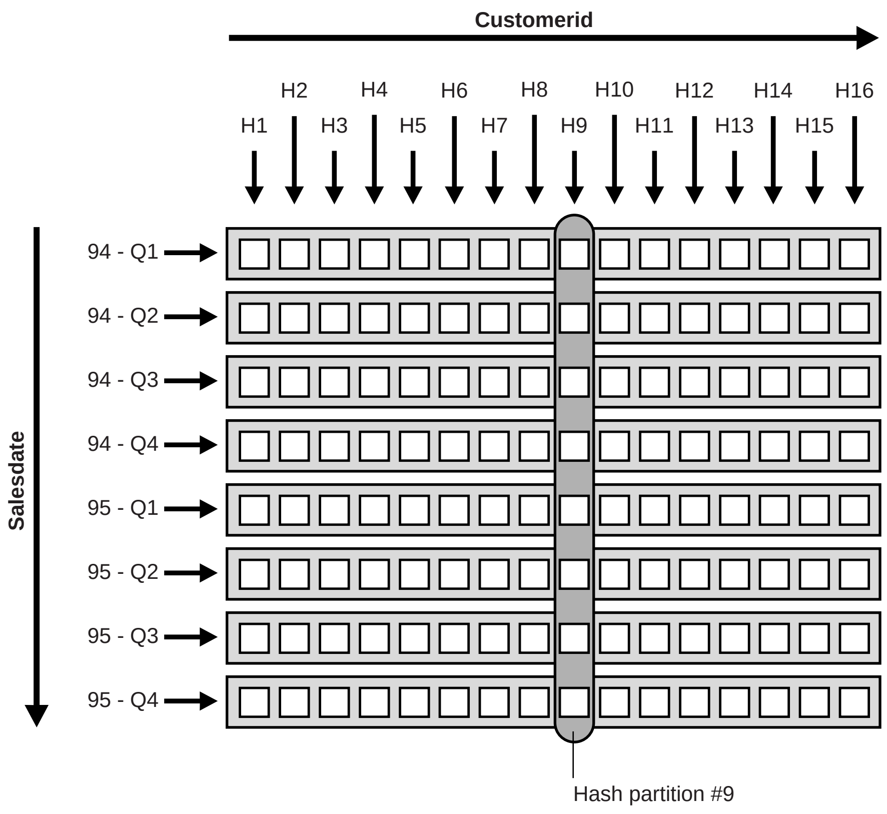
For example, assume you want to partition the Sales table by range on the column *s_saledate* into 8 partitions. Also assume you have two years' of data and each partition represents a quarter. Instead of range partitioning you can use composite to enable a full partition-wise join while preserving the partitioning on *s_saledate*. Do this by partitioning the Sales table by range on *s_saledate* and then by subpartitioning 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.

With that new partitioning method, a full partition-wise join works similarly to 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. In it, 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. Symmetrically, each column on the figure 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 in a composite table are implicit. 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



This partitioning method is effective because it allows you to combine pruning (on *s_salesdate*) with a full partition-wise join (on *customerid*). In the previous example query, pruning is achieved by only scanning the subpartitions corresponding to Q3 of 1994, in other words, row number 3 on Figure 5–2. Oracle them joins these subpartitions with the customer table using a full partition-wise join.

All characteristics of the hash-hash method also apply to the composite-hash method. 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. This is because even though the Sales table has 128 subpartitions, it has only 16 hash partitions.

- The same 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 with the matching hash partition from the other table. For example, in Figure 5–2, you should 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 composite. For example, you can partition it by range on a zip code column to enable pruning based on zip code. You should then subpartition it by hash on *customerid* to enable a partition-wise join on the hash dimension.

Range - Range You can also use partition-wise joins for range partitioning. However, this is more complex to implement because you must know your data's distribution before performing the join. Furthermore, this can lead to data skew during the execution if you do not correctly identify the partition bounds so that you have partitions of equal size.

The basic principle for using range-range is the same as for hash-hash: you must equi-partition 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 the values for *customerid* vary from 1 to 10000000. In other words, you have possibly 10 million different values. To create 16 partitions, you can range partition both tables, Sales on *s_customerid* and Customer on *c_customerid*. You should define partition bounds for both tables to generate partitions of the same size. In this example, partition bounds should be defined as 625001, 1250001, 1875001, ..., 10000001, so 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 only perform partial partition-wise joins in parallel. Unlike full partition-wise joins, partial partition-wise joins require you to partition only one table on the join key, not both. 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, because they require that you partition only one of the joined tables on the join key.

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 conventional parallel joins is that the reference table is not moved during the join operation. Conventional parallel joins require both input tables to be redistributed on the join key. This redistribution operation involves exchanging rows between query servers. This is a very CPU-intensive operation and can lead to excessive interconnect traffic in OPS environments. Partitioning large tables on a join key, either a foreign or primary key, prevents this re-distribution 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.

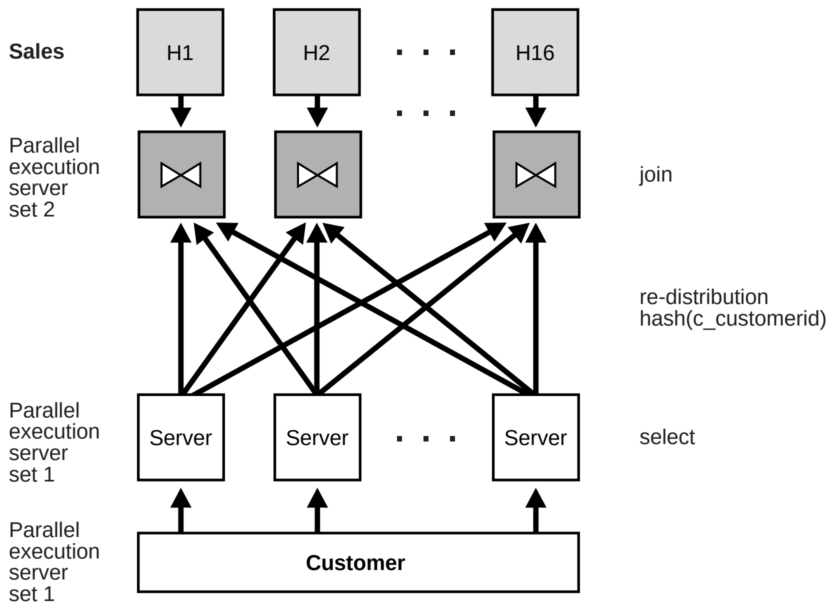
To illustrate partial partition-wise joins, consider the previous Sales/Customer example. Assume that Customer is not partitioned or partitioned on a column other than *c_customerid*. Because Sales is often joined with Customer on *customerid*, and because this join dominates our application workload, 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, "Partial Partition-wise Join", 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
re-distribution hash(c_customerid)
Parallel execution server set 1
Server
Server
Server
select
Parallel execution server set 1
Customer

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 8 query server sets. In this case, Oracle assigns 2 partitions 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 Parallel Server environments on shared-nothing platforms (MPPs), each hash partition of sales should preferably have affinity to only one node to avoid remote I/Os. Also, spread partitions over all nodes to avoid bottlenecks and use all CPU resources available on the system. It is adequate for a node to host multiple partitions when there are more partitions than nodes.

  See Also: For more information on data affinity, please refer to *Oracle8i Parallel Server Concepts*.

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, you can 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 the definition 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 8 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, although it is not recommended. 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 which is also a join key.

Benefits of Partition-wise Joins

Partition-wise joins offer benefits as described in this section:

- Reduction of Communications Overhead
- Reduction of Memory Requirements

Reduction of Communications Overhead Partition-wise joins reduce communications overhead when they are executed in parallel. 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 allows each parallel execution server to join a pair of matching partitions.

This performance enhancement is even more noticeable in OPS configurations with internode parallel execution. This is because partition-wise joins can dramatically reduce interconnect traffic. Using this feature is an almost mandatory optimization measure for large DSS configurations that use OPS.

Currently, most OPS platforms, such as MPP and SMP clusters, provide limited interconnect bandwidths compared to 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 OPS experience high interconnect latencies without this optimization.

Reduction of Memory Requirements Partition-wise joins require less memory. In the case of serial joins, the join is performed on a pair of matching partitions at the same time. Thus, if data is evenly distributed across partitions, the memory requirement is divided by the number of partitions. In this case, there is no skew.

In the parallel case, it depends 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 does not need to write blocks to disk during the build phase of a hash join.

Performance Considerations for Parallel Partition-wise Joins

The performance improvements from parallel partition-wise joins also come with disadvantages. The cost-based optimizer weighs the advantages and disadvantages when deciding whether to use partition-wise joins.

- In the case of range partitioning, data skew may increase response time if the partitions are of different sizes. This is because 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 limits the risk of skew, assuming that the number of partitions is a power of 2.
- 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, it is acceptable to have 16, 32, or even 64 partitions (or subpartitions). But Oracle will serially execute the last phase of the join if the degree of parallelism is, for example, 17. 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 query server joins this remaining pair while all other query servers are idle.
- Sometimes, parallel joins can cause remote I/Os. For example, on Oracle Parallel Server environments running on MPP configurations, if a pair of matching partitions is not collocated on the same node, a partition-wise join requires extra inter-node communication due to remote I/Os. 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 tells how to use indexes in a data warehousing environment, and discusses the following types of index:

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

Bitmap Indexes

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

- Reduced response time for large classes of ad hoc queries
- A substantial reduction of space usage compared to other indexing techniques
- Dramatic performance gains even on hardware with a relatively small number of CPUs or small amount of memory
- Very 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.

Attention: Bitmap indexes are available only if you have purchased the Oracle8*i* Enterprise Edition. See *Getting to Know Oracle8i* for more information about the features available in Oracle8*i* and the Oracle8*i* Enterprise Edition.

The purpose of an index is to provide pointers to the rows in a table that contain a given key value. In a regular index, this is achieved by storing 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 is used instead of 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 the bitmap index provides the same functionality as a regular index even though it uses a different representation internally. If the number of different key values is small, bitmap indexes are very space efficient.

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 not suitable for OLTP applications with large numbers of concurrent transactions modifying the data. These indexes are primarily intended for decision support (DSS) in data warehousing applications where users typically query the data rather than update it.

Parallel query and parallel DML work with bitmap indexes as with traditional indexes. (Bitmap indexes on partitioned tables must be local indexes; see "Index Partitioning" on page 5-6 for more information.) Parallel create index and concatenated indexes are also supported.

Cardinality

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

B-tree indexes are most effective for high-cardinality data: that is, data with many possible values, such as CUSTOMER_NAME or PHONE_NUMBER. In a data warehouse, B-tree indexes should only be used 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 quickly resolved 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 very quickly without resorting to a full table scan of the table.

Bitmap Index Example

Table 6–1 shows a portion of a company's customer data.

Table 6–1 Bitmap Index Example

CUSTOMER #	MARITAL_ STATUS	REGION	GENDER	INCOME_ LEVEL
101	single	east	male	bracket_1
102	married	central	female	bracket_4
103	married	west	female	bracket_2
104	divorced	west	male	bracket_4
105	single	central	female	bracket_2
106	married	central	female	bracket_3

Because MARITAL_STATUS, REGION, GENDER, and INCOME_LEVEL are all low-cardinality columns (there are only three possible values for marital status and region, two possible values for gender, and four for income level), bitmap indexes are ideal for these columns. A bitmap index should not be created on CUSTOMER# because this is a unique column. Instead, a unique B-tree index on this column in order would provide the most efficient representation and retrieval.

Table 6–2 illustrates the bitmap index for the REGION column in this example. It consists of three separate bitmaps, one for each region.

Table 6–2 Sample Bitmap

REGION='east'	REGION='central'	REGION='west'
1	0	0
0	1	0
0	0	1
0	0	1
0	1	0
0	1	0

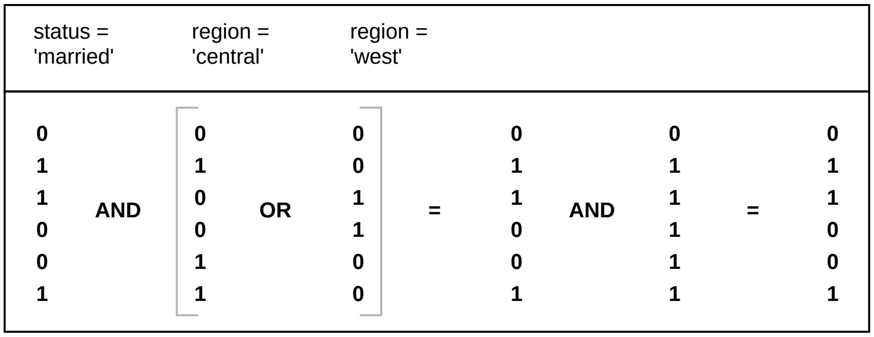
Each entry (or *bit*) in the bitmap corresponds to a single row of the CUSTOMER table. The value of each bit depends upon the values of the corresponding row in the table. For instance, the bitmap REGION='east' contains a one as its first bit: this is because the region is "east" in the first row of the CUSTOMER table. The bitmap REGION='east' has a zero for its other bits because none of the other rows of the table contain "east" as their value for REGION.

An analyst investigating demographic trends of the company's customers might ask, "How many of our married customers live in the central or west regions?" This corresponds to the following SQL query:

```
SELECT COUNT(*) FROM customer
    WHERE MARITAL_STATUS = 'married' AND REGION IN ('central','west');
```

Bitmap indexes can process this query with great efficiency by merely counting the number of ones in the resulting bitmap, as illustrated in Figure 6–1. To identify the specific customers who satisfy the criteria, the resulting bitmap would be used to access the table.

Figure 6–1 Executing a Query Using Bitmap Indexes



Bitmap Indexes and Nulls

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

Example

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

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

Bitmap Indexes on Partitioned Tables

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

B-tree Indexes

A B-tree index is organized like an upside-down tree. The bottommost level of the index holds the actual data values and pointers to the corresponding rows, much like the index in a book has a page number associated with each index entry. See *Oracle8i 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, there is a tricky issue here—return to the analogy of a book index to understand it. 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 keys which are unique or near-unique. 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 since typical data warehouse queries may not yield better performance with such indexes. Bitmap indexes should be more common that B-tree indexes in most data warehouse environments.

Local Versus Global

A B-tree index on a partitioned table can be local or global. Global indexes must be fully rebuilt after a direct load, which can be very costly when loading a relatively small number of rows into a large table. For this reason, it is strongly recommended that indexes on partitioned tables should be defined as local indexes unless there is a well-justified performance requirement for a global index. Bitmap indexes on partitioned tables are always local. See "Partitioning Data" on page 5-4 for further details.

7 Constraints

This chapter describes constraints, and discusses:

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

Why Constraints are Useful in a Data Warehouse

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 (ensuring that a given column is unique), not-null constraints, and foreign-key constraints (which ensure that two keys share a primary key-foreign key relationship).

Constraints can be used for the following basic purposes in a data warehouse:

- Data cleanliness: Constraints can be used to verify that the data in the data warehouse conforms to basic level of data consistency and correctness. Thus, constraints are often used in a data warehouse to prevent the introduction of dirty data.
- Supporting query optimization: The Oracle database will utilize 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 many relational-database environments, data in a data warehouse is typically added and/or modified under very controlled circumstances during the ETT process. Multiple users typically do not update the data warehouse directly; this is considerably different from the usage of a typical operational system.

Thus, the specific usage of constraints in a data warehouse may vary considerably from the usage of constraints in operational systems. Oracle8*i* provides a wide breadth of constraint functionality to address both the needs of data warehouses as well as the needs to operational systems.

Many significant constraint features for data warehousing were introduced in Oracle8*i*, so that readers familiar with Oracle's constraint functionality in Oracle7 and Oracle8 should take special note of the new functionality described in this chapter. In fact, many Oracle7 and Oracle8-based data warehouses lacked constraints because of concerns about constraint performance. The new Oracle8*i* functionality for constraints is designed to address these concerns for data warehouses.

Overview of Constraint States

In order to understand how to best utilize constraints in a data warehouse, it is important to 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 can be used to ensure that all data-modifications upon a given table (or tables) will satisfy the conditions of the constraints. Data-modification operations, which would result in data that violated the constraint, will fail with a constraint-violation error.

- Validation: In order to use a constraint for validation, the constraint must be in the VALIDATE state. If the constraint is validated, then all of the 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 enforced or vice versa (enforced but not validated). These latter two cases can be very useful for data warehouses, and are discussed in the examples below.

- Belief: In order to use a constraint for belief, the constraint must be in the RELY state. In some cases, the data-warehouse administrator may know that a given constraint is true. The RELY state provides the data-warehouse administrator with a mechanism for telling Oracle8*i* that a given constraint is believed to be true.

  Note that the RELY state is only meaningful for constraints that have not been validated.

Typical Data Warehouse Constraints

This section assumes that most readers are familiar with the typical usage of constraints; that is, constraints that are both enabled and validated. For data warehousing, many users have discovered the such constraints may not be effective, because it may be prohibitively costly to build and maintain such constraints.

Unique Constraints in a Data Warehouse

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

Suppose that a data warehouse contained a table SALES, with includes a column SALES_ID. SALES_ID uniquely identifies a single sales transaction, and the data-warehouse wants to 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(sales_id);
```

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

- The unique index can be very large, since the SALES table could easily have millions or even billions of rows.
- The unique index is rarely used for query execution; most typical data warehousing queries will not have predicates on unique keys, so this index will probably not improve performance.
- If SALES is partitioned along a column other than SALES_ID, the unique index must be a global index. This can detrimentally affect all maintenance operations on the SALES table.

Why is an index required for unique constraints? The index is used for enforcement. That is, the unique index is necessary to ensure that each individual row that is modified in the SALES table will satisfy the unique constraint.

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

```
ALTER TABLE sales ADD CONSTRAINT sales_unique UNIQUE (sales_id)
  DISABLE VALIDATE;
```

This statement will create a unique constraint, but since the constraint is disabled, there is no need for a unique index. This approach can be advantageous for many data warehousing environments, because the constraint now ensures uniqueness without the shortcomings of a unique index.

However, there are trade-offs for the data warehouse administrator to consider with DISABLE VALIDATE constraints. Since this constraint is disabled, no DML statements which may modify the unique column are permitted against the SALES table. Thus, there are 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, "Loading and Refreshing".
- Prior to the modifying this table, drop the constraint. Then, make all of the necessary data modifications. Finally, recreate the disabled constraint. Note that recreating the constraint will be much more efficient that re-creating an enabled constraint. This approach will not guarantee that the data in the SALES table is unique while the constraint has been dropped.

Foreign Key Constraints in a Data Warehouse

In a star schema data warehouse, foreign-key constraints are typically created in order to validate the relationship between the fact table and the dimension tables. An example constraint might be:

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

However, there are several different requirements in which a data warehouse administrator may choose to use different states for the foreign-key constraints. In particular, the ENABLE NOVALIDATE state can be useful for data warehousing. A data warehouse administrator may choose to use an ENABLE NOVALIDATE constraint when either:

- There is data in the tables that currently disobeys the constraint, but the data warehouse administrator wishes to create a constraint for enforcement.
- There is a requirement to quickly create an enforced constraint.

Suppose that the data warehouse loaded new data into the fact table(s) every day, but only refreshed the dimension tables on the weekend. Then, during the week, it is possible that the dimension tables and fact tables may in fact disobey the foreign-key constraints. Nevertheless, the data warehouse administrator may wish to maintain the enforcement of this constraint to prevent any changes that might affect the foreign key constraint outside of the ETT process. Thus, the foreign key constraints could be created every night, following the ETT process, as:

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

Another usage of ENABLE NOVALIDATE is for quickly creating an enforced constraint, even when the constraint is believed to be true. Suppose that the ETT 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

It is not uncommon for the ETT process to verify that certain constraints are true. For example, the ETT process may validate all of the foreign keys in the incoming data for the fact table. In these environments, the data warehouse administrator may choose to trust the ETT process to provide clean data, instead of implementing constraints in the data warehouse.

For example, during the ETT process, the data warehouse administrator may have verified 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 with the RELY state:

```
ALTER TABLE sales add CONSTRAINT fk_sales_time
FOREIGN KEY (sales_time_id) REFERENCES time (time_id)
DISABLE NOVALIDATE rely;
```

The existence of RELY constraints, even though they are not used for data-validation, may be important for several purposes, including:

- constraints may be used to enable more sophisticated query-rewrites for materialized views. See Chapter 19, "Query Rewrite", for further details.
- other data-warehousing tools may retrieve information regarding constraints directly from the Oracle data dictionary.

Creating a RELY constraint is very inexpensive. Because the constraint is not being validated, there is no data processing necessary to create such a constraint.

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.

Constraints and Partitioning

Many aspects of creating and maintaining constraints can be executed on a per-partition basis. Later chapters will discuss the significance of partitioning for data warehousing, and partitioning can provide benefits to constraint management (just as partitioning provide benefits to managing of many other operations). For example, Chapter 14, "Loading and Refreshing", provides a scenario example of creating unique and foreign-key constraints on a separate staging table, and these constraints are maintained during the EXCHANGE PARTITION statement.

8 Materialized Views

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

- Overview of Data Warehousing with Materialized Views
- The Need for Materialized Views
- Types of Materialized Views
- Creating a Materialized View
- Nested Materialized Views
- Registration of an Existing Materialized View
- Partitioning a Materialized View
- Indexing Selection for Materialized Views
- Invalidating a Materialized View
- Guidelines for Using Materialized Views in a Data Warehouse
- Altering a Materialized View
- Dropping a Materialized View
- Overview of Materialized View Management Tasks

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 usually processed in a *staging file* before being added to the data warehouse. Data warehouses typically range in size from tens of gigabytes to a few terabytes, usually with the vast majority of the data stored in a few very large fact tables.

One technique employed in data warehouses to improve performance is the creation of summaries, or aggregates. They are a special kind of aggregate view that improves 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, a table could be created to contain the sum of sales by region and by product.

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

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, as described below.

Although materialized views are usually accessed via 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, once the summaries are directly referenced in queries, the DBA will not be free to drop and create summaries without affecting applications.

Materialized Views for Data Warehouses

In data warehouses, materialized views can be used to precompute and store aggregated data such as the sum of sales. Materialized views in these environments are typically 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 or aggregations for a large or important class of queries.

Materialized Views for Distributed Computing

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

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 from the central servers and propagation of updates by clients back to the central servers.

This chapter focuses on the use of materialized views in data warehouses. See also *Oracle8i Replication* and *Oracle8i Distributed Database Systems* for details on distributed and mobile computing.

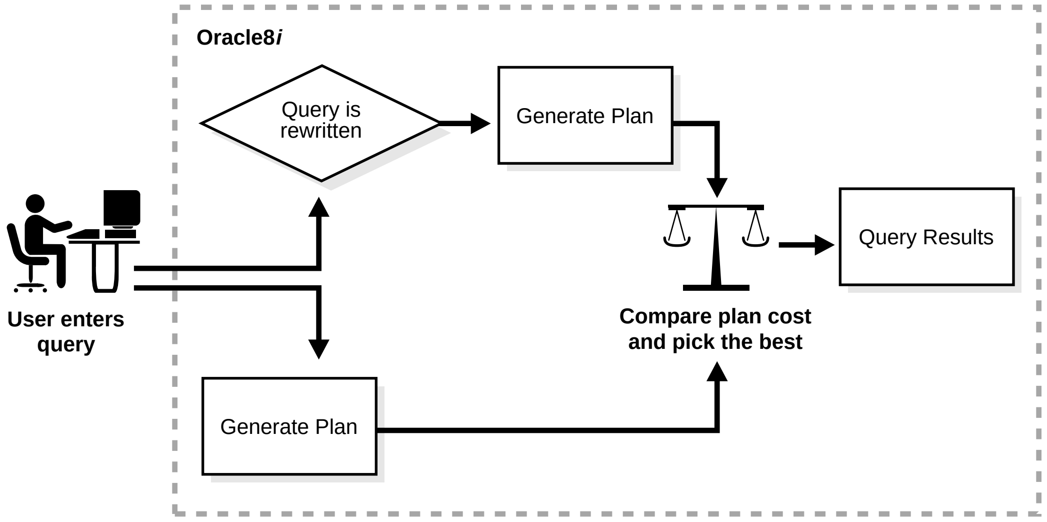
The Need for Materialized Views

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

Materialized views can be used in a number of ways and almost identical syntax can be used to perform a number of roles. For example, a materialized view can be used to replicate data, which was 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 time and storing the results in the database. The query optimizer can use materialized views by automatically recognizing 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 are then directed to the materialized view and not to the underlying detail tables. In general, rewriting queries to use materialized views rather than detail tables results in a significant performance gain.

Figure 8–1 Transparent Query Rewrite



When using query rewrite, you want to 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) and/or include any number of joins. If you are unsure of which materialized views to create, Oracle provides a set of advisory functions in the DBMS_OLAP package to help in designing and evaluating materialized views for query rewrite.

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

Materialized views are similar to indexes in several ways: they consume storage space, they must be refreshed when the data in their master tables changes, and, when used for query rewrite, they improve the performance of SQL execution and their existence is transparent to SQL applications and users. Unlike indexes, materialized views can be accessed directly using a SELECT statement. Depending on the type of refresh that is required, they can also be accessed directly in an INSERT, UPDATE, or DELETE statement.

Note: Materialized views can also be used by Oracle Replication. The techniques shown in this chapter illustrate how to use materialized views in data warehouses. See *Oracle8i Replication* for further information.

Components of Summary Management

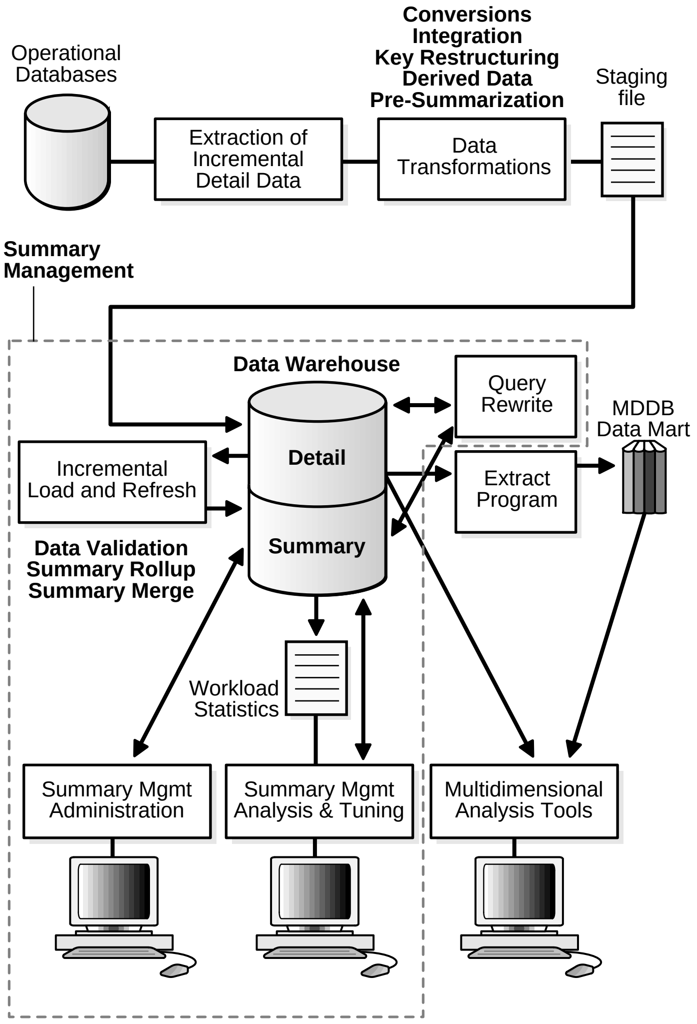
Summary management consists of:

- 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
- An advisor utility to recommend which materialized views to create, retain, and drop

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 may enable some existing DSS database applications to achieve large gains in performance without requiring a redesign of the database or application. This functionality is thus available to all database users.

Figure 8–2 illustrates where summary management is used in the warehousing cycle. After the data has been transformed, staged, and loaded into the detail data in the warehouse, the summary management process can be invoked. This means that summaries can be created, queries can be rewritten, and the advisor can be used to plan summary usage and creation.

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.

The summary management process begins with the creation of dimensions and hierarchies that 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 then be used to create materialized views. Materialized views improve query execution performance by precalculating expensive join or aggregation operations prior to execution time. Query rewrite then automatically recognizes when an existing materialized view can and should be used to satisfy a request, and can transparently rewrite a request to use a materialized view, thus improving performance.

Terminology

Some basic data warehousing terms are defined as follows:

- *Dimension tables* describe the business entities of an enterprise, which usually represent 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 typically not large, but they affect the performance of long-running decision support queries that consist of joins of fact tables with dimension tables, followed by aggregation to specific levels of the dimension hierarchies. Dimensions and dimension tables are discussed in 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. They 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 only simple measures of one table, for example, FACT.REVENUES - FACT.EXPENSES.
  - A multi-table measure is a computed measure defined on multiple tables, for example, FACT_A.REVENUES - FACT_B.EXPENSES.

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

- *A materialized view* is a pre-computed table comprising aggregated and/or joined data from fact and possibly dimension tables. Builders of data warehouses will know a materialized view as a *summary* or *aggregation*.

Schema Design Guidelines for Materialized Views

A materialized view definition can include 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 request execution performance.
- The existence of a materialized view is transparent to SQL applications, so 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.

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

Guideline 1: Your 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 a Dimension" on page 9-6.

If desired, this condition can be enforced by adding FOREIGN KEY and NOT NULL constraints on the child-side join key(s) and PRIMARY KEY constraints on the parent-side join key(s). If your materialized view contains only a single detail table, or if it performs no aggregation, a preferred alternative would be to use queries containing outer joins in place of inner joins. In this case, the Oracle optimizer can guarantee the integrity of the result without enforced referential integrity constraints.

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 tables 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 options to avoid constraint enforcement performance overhead.

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 (including INSERT AS SELECT with the APPEND or PARALLEL hints). Fast refresh after conventional DML is not supported with views with aggregates and joins, but it is for single-table aggregate views. See *Oracle8i SQL Reference* for further details.

Guideline 5: Range-partition your tables by a monotonically increasing time column if possible (preferably of type DATE). Different materialized views have different requirements for speeding up refresh.

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

Guideline 7: Horizontally partition and index the materialized view 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 may be violated, use the ENABLE NOVALIDATE 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, the designer must determine how clean the data is and whether the risk of wrong results is too great.

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.

Types of Materialized Views

The SELECT clause in the materialized view creation statement defines the data that the materialized view is to contain. There are only a few restrictions on what may 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 or the warehouse refresh facility (part of the DBMS_OLAP package). Besides tables, views, inline views, subqueries, and materialized views may all be joined or referenced in the SELECT clause.

The types of materialized views are:

- Materialized Views with Joins and Aggregates
- Single-Table Aggregate Materialized Views
- Materialized Views Containing Only Joins

Materialized Views with Joins and Aggregates

In data warehouses, materialized views would normally contain one of the aggregates shown in Example 2 below. For fast refresh to be possible, the SELECT list must contain all of the GROUP BY columns (if present), and may contain one or more aggregate functions. The aggregate function must be one of: SUM, COUNT(x), COUNT(*),COUNT(DISTINCT x), AVG, VARIANCE, STDDEV, MIN, and MAX, and the expression to be aggregated can be any SQL value expression.

If a materialized view contains joins and aggregates, then it cannot be fast refreshed using a materialized view log. Therefore, for a fast refresh to be possible, only new data can be added to the detail tables and it must be loaded using the direct path method.

Here are some examples of the type of materialized view that can be created.

Create Materialized View: Example 1

```
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 1 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, a complete refresh is performed and, once populated, this materialized view can be used by query rewrite.

Create Materialized View: Example 2

```
CREATE MATERIALIZED VIEW store_stdcnt_mv
  PCTFREE 0 TABLESPACE mviews
  STORAGE (INITIAL 16k NEXT 16k PCTINCREASE 0)
  BUILD IMMEDIATE
  REFRESH FAST
```

```
ENABLE QUERY REWRITE
AS
SELECT store_name, t.time_key,
   STDDEV(unit_sales) AS stdcnt_unit_sales
   AVG(unit_sales) AS avgcnt_unit_sales
   COUNT(unit_sales) AS count_days
   SUM(unit_sales) AS sum_unit_sales
 FROM store s, fact f, time t
    WHERE s.store_key = f.store_key AND
          f.time_key = t.time_key
    GROUP BY store_name, t.time_key;
```

The statement above creates a materialized view *store_stdcnt_mv* that computes the standard deviation for the number of units sold by a *store* on a given date. It is derived by joining the tables *store, time*, and *fact* on the columns store_key and time_key. 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 COUNT and SUM aggregates have been included to support fast refresh of the STDDEV aggregate.

Single-Table Aggregate Materialized Views

A materialized view that contains one or more aggregates (SUM, AVG, VARIANCE, STDDEV, COUNT) and a GROUP BY clause may be based on a single table. The aggregate function can involve an expression on the columns such as SUM(a*b). If this materialized view is to be incrementally refreshed, then a materialized view log must be created on the detail table with the INCLUDING NEW VALUES option, and the log must contain all columns referenced in the materialized view query definition.

```
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;
```

In this example, a materialized view has been created which 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, when the commit is issued, the changes will be reflected in the materialized view.

Table 8–1 illustrates the aggregate requirements for a single-table aggregate materialized view.

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

Note that COUNT(*) must always be present.

Incremental refresh for a single-table aggregate materialized view is possible after any type of DML to the base tables (direct load or conventional INSERT, UPDATE, or DELETE).

A single-table aggregate materialized view 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 one of the materialized view's detail tables.

After a refresh ON COMMIT, you are urged to check the alert log and trace files to see if any error occurred during the refresh.

Materialized Views Containing Only Joins

Materialized views may contain only joins and no aggregates, such as in the next example where a materialized view is created which joins the *fact* table to the *store* table. The advantage of creating this type of materialized view is that expensive joins will be precalculated.

Incremental refresh for a materialized view containing only joins is possible after any type of DML to the base tables (direct load 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.

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 include:

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 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, then the materialized view should be created as REFRESH FORCE to take advantage of incremental 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 incrementally refreshable with respect to the other tables for which all the criteria are met.

In a data warehouse star schema, if space is at a premium, you can include the rowid of the fact table only because this is the table that will be most frequently updated, and the user can specify the FORCE option when the materialized view is created.

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

To speed up refresh, it is recommended that the user create indexes on the columns of the materialized view that stores the rowids of the fact table.

```
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 REFRESH FAST, unique constraints should exist on *s.store_key* and *t.time_key*. It is also recommended that indexes be created on the columns *fact_rid*, *time_rid*, and *store_rid*, as illustrated below, which will improve the performance of refresh.

```
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(+);
```

Creating a Materialized View

A materialized view can be created with the CREATE MATERIALIZED VIEW statement or using Oracle Enterprise Manager. The following command creates the materialized view *store_sales_mv*.

```
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;
```

See Also: For a complete description of CREATE MATERIALIZED VIEW, see the *Oracle8i SQL Reference*.

It is not uncommon in a data warehouse to have already created summary or aggregation tables, and the DBA may not wish to repeat this work by building a new materialized view. In this instance, the table that already exists in the database can be registered as a *prebuilt* materialized view. This technique is described in "Registration of an Existing Materialized View" on page 8-29.

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

1. Do the physical design of 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 generally benefits from a large number of partitions because it can take advantage of the parallel DML capabilities in Oracle.

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 PREBUILT 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 at a more convenient time. The 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: See *Oracle8i SQL Reference* for descriptions of the SQL statements CREATE MATERIALIZED VIEW, ALTER MATERIALIZED VIEW, ORDER BY, 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 may 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, for instance.

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 15, "Summary Advisor", can provide an estimate on 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: For a complete description of the STORAGE semantics, see the *Oracle8i SQL Reference*.

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, "Loading and Refreshing".

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

Used for Query Rewrite

Even though a materialized view is defined, it will not automatically be used by the query rewrite facility. The clause ENABLE QUERY REWRITE must be specified 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 initially 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 also 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. There cannot be non-repeatable expressions (ROWNUM, SYSDATE, non-repeatable PL/SQL functions, and so on) anywhere in the defining query.
2. There cannot be references to RAW or LONG RAW datatypes or object REFs.
3. The query must be a single-block query, that is, it cannot contain set functions (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 WITH REDUCED PRECISION.

Query Rewrite Restrictions

1. If a query has both local and remote tables, only local tables will be considered for potential rewrite.
2. None of the detail tables can be owned by SYS, and the materialized view cannot be owned by SYS.

Non-SQL Text Rewrite Restrictions

1. SELECT and GROUP BY lists, if present, must be the same in the query and the materialized view and must contain straight columns, that is, no expressions are allowed in the columns.
2. Aggregate operators 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.
3. The WHERE clause must contain only inner or outer equijoins, and they can be connected only by ANDs. No ORs and no selections on single tables are allowed in the WHERE clause.
4. HAVING or CONNECT BY clauses are not allowed.

Refresh Options

When you define a materialized view, you can specify its 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. The method you select will affect the type of materialized view that can be defined.

Refresh Mode	Description
ON COMMIT	Refresh occurs automatically when a transaction that modified one of the materialized view’s fact tables commits. Can be used with materialized views on single table aggregates and materialized views containing joins only.
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).

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, the user has to 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: FORCE, COMPLETE, FAST, and NEVER.

Refresh Option	Description
COMPLETE	Refreshes by recalculating the materialized view's defining query.
FAST	Refreshes by incrementally adding the new data that has been inserted into the tables. The new data is obtained from the direct path log or from the materialized view logs.
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 will depend upon the type of materialized view. Fast refresh is available for three general classes of materialized views: materialized views with joins only, materialized views with joins and aggregates, and materialized views with aggregates on a single table.

General Restrictions on Fast Refresh

The materialized view’s defining query is restricted as follows:

- The FROM list must contain base tables only (that is, no views).

- It cannot contain references to non-repeating expressions like SYSDATE and ROWNUM.
- It cannot contain references to RAW or LONG RAW data types.
- It cannot contain HAVING or CONNECT BY clauses.
- The WHERE clause can contain only joins and they must be equi-joins (inner or outer) and all join predicates must be connected with ANDs. No selection predicates on individual tables are allowed.
- It cannot have subqueries, inline views, or set functions like UNION or MINUS.

Restrictions on Fast Refresh on Materialized Views with Joins Only

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 8-20.
- 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.
- 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.
- Materialized views from this category are FAST refreshable after DML or Direct Load to the base tables.

Restrictions on Fast Refresh on Materialized Views with Single-Table Aggregates

Defining queries for materialized views with single-table aggregates have these restrictions on fast refresh:

- All restrictions from "General Restrictions on Fast Refresh" on page 8-20.
- They can only have a single table.
- The SELECT list must contain all GROUP BY columns.
- Expressions are allowed in the GROUP BY and SELECT clauses provided they are the same.
- They cannot have a WHERE clause.

- COUNT(*) must be present.
- They cannot have a MIN or MAX function.
- For a materialized view with an aggregate with a single table, a materialized view log must exist on the table and must contain all columns referenced in the materialized view. The log must have been created with the INCLUDING NEW VALUES clause.
- If AVG(expr) or SUM(expr) is specified, you must have COUNT(expr).
- If VARIANCE(expr) or STDDEV(expr) is specified, you must have COUNT(expr) and SUM(expr).

Restrictions on Fast Refresh on Materialized Views with Joins and 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 8-20.
- The WHERE clause can contain inner equi-joins only (that is, no outer joins)
- Materialized views from this category are FAST refreshable after Direct Load to the base tables; they are not FAST refreshable after conventional DML to the base tables.
- Materialized views from this category can have only the ON DEMAND option (that is, no ON COMMIT refresh option is allowed).

ORDER BY

An ORDER BY clause is allowed in the CREATE MATERIALIZED VIEW statement. It is only used during the initial creation of the materialized view. It is not used during a full refresh or an incremental 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 will significantly reduce 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. For example:

```
CREATE MATERIALIZED VIEW sum_sales
  REFRESH FAST ON DEMAND AS
  SELECT cityid, COUNT(*) count_all,
  SUM(sales) sum_sales, COUNT(sales) cnt_sales
  FROM city_sales
  ORDER BY cityid;
```

In the above example, we would use the "ORDER BY cityid" clause only during the creation of the materialized view. The materialized view definition is not affected by the ORDER BY clause. The definition is:

```
SELECT cityid, COUNT(*) count_all,
SUM(sales) sum_sales, COUNT(sales) cnt_sales
FROM city_sales
```

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, there are three property sheets which must be completed and you need to ensure that the option "Enable Query Rewrite" on the General sheet is selected.

Nested Materialized Views

A nested materialized view is a materialized view whose definition is based on another materialized view. A nested materialized view may reference other relations in the database in addition to 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) and incremental maintenance of single-table aggregate materialized views is very fast due to the self-maintenance refresh operations on this class of views. Using nested materialized views also overcomes the limitation posed by materialized aggregate views, where incremental maintenance can only be done with direct-load insert.

Rules for Using Nested Materialized Views

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

1. If you do not need the FAST REFRESH 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.

Restrictions when Using Nested Materialized Views

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

Materialized join views and single-table aggregate materialized views can be incrementally refreshed in the presence of arbitrary DML. In addition, the ON COMMIT refresh mode can be used with these types of materialized views. To maximize performance with materialized join views and single-table aggregate materialized views, you should first combine the two together. That is, define a single-table aggregate materialized view on top of a materialized join view. Such a composition yields a *materialized aggregate view* with respect to the base tables. Thus, logically:

```
single-table aggregate materialized view (materialized join view (<tables>))
```

is equivalent to:

```
materialized view with joins and aggregates(<tables>)
```

Figure 8–3 Nested Materialized View Equivalents

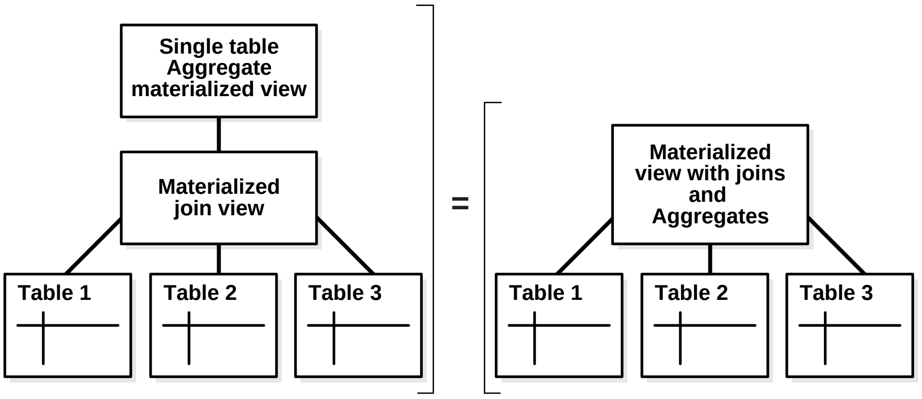
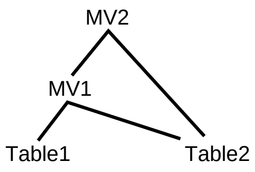

Single table Aggregate materialized view
Materialized join view
Table 1
Table 2
Table 3
=
Materialized view with joins and Aggregates
Table 1
Table 2
Table 3

Figure 8–3 is just one of many possible ways to nest materialized views, but it is likely to be the most frequent and practical. Cyclic dependencies (a materialized view that indirectly references itself) are caught at creation time and an error is generated. Some restrictions are placed 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 amongst 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 it is both a parent and grandparent of the same object.

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. This is in contrast to materialized aggregate views where the space requirements of the materialized join view and its log are not demanding, but have relatively long refresh times due to multiple computations of the same join.

Nested materialized views are incrementally refreshable under any type of DML while materialized aggregate views are incrementally refreshable under direct-load insert only.

Example of a Nested Materialized View

You can create a materialized join view or a single-table aggregate materialized view on a single-table on top of another materialized join view, single-table aggregate materialized view, complex materialized view (a materialized view Oracle cannot perform incremental refresh on) or base table. All the underlying objects (be they materialized views or tables) on which the materialized view is defined on **must** have a materialized view log. All the underlying objects are treated as if they were tables. All the existing options for materialized join views and single-table aggregate materialized views can be used. Thus, ON COMMIT refresh is supported for these types of nested materialized views.

The following presents a retail database with an example schema and some materialized views to illustrate how nested materialized views can be created.

```
STORE   (store_key, store_name, store_city, store_state, store_country)
PRODUCT (prod_key, prod_name, prod_brand)
TIME    (time_key, time_day, time_week, time_month)
FACT    (store_key, prod_key, time_key, dollar_sales)

/* 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 VIEW LOG ON product
  WITH ROWID;

/*create materialized join view join_fact_store_time as incrementally
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 incrementally 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;
```

Note that the above single-table aggregate materialized view *sum_sales_store_time* is logically equivalent to a multi-table aggregate on the tables fact, time, and store whose definition is

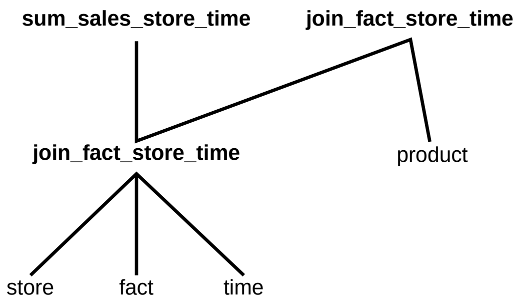
```
SELECT COUNT(*) cnt_all, SUM(f.dollar_sales) sum_sales,
       COUNT(f.dollar_sales) cnt_sales, s.store_name, t.time_day
FROM fact f, time t , store s
WHERE f.time_key = t.time_key AND
      f.store_key = s.store_key
GROUP BY store_name, time_day;
```

You can now define a materialized join view *join_fact_store_time_prod* as a join between *join_fact_store_time* and table *product*.

```
CREATE MATERIALIZED VIEW join_fact_store_time_prod
  REFRESH FAST ON COMMIT
  AS
  SELECT j.rowid jrid, p.rowid prid, j.store_name, j.prod_key, j.prod_name,
         j.dollar_sales
  FROM join_fact_store_time j, product p
  WHERE j.prod_key = p.prod_key;
```

The above schema can be diagrammatically represented as in Figure 8–5.

Figure 8–5 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, a user can arbitrarily nest materialized views having joins and aggregates. No incremental maintenance is possible for these materialized views.

Note that the ON COMMIT refresh option 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

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

1. If incremental refresh is desired when a materialized view contains joins and aggregates and standard fast refresh cannot be used because DML is occurring on the tables, consider creating a single-table aggregate materialized view nested on a materialized join view.
2. If incremental refresh is desired, you should incrementally refresh all the materialized views along any chain. It makes little sense to define an

incrementally refreshable materialized view on top of a materialized view that must be refreshed with a complete refresh.

3. When using materialized join views and single-table aggregate 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 one expects 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.

Registration of an Existing Materialized View

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 incremental materialized view refresh

Because of these problems, and because existing materialized views may 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.

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 may 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 incrementally refreshed each update cycle.
- A view should be created that selects the complete time period of interest.

For example, if a materialized view was formerly refreshed monthly at the end of each month, then the view would contain the selection WHERE *time.month* < CURRENT_MONTH().

- 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:

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

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 TRUSTED. See Chapter 19, "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.

```
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;
```

This 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.

Partitioning a Materialized View

Because of the large volume of data held in a data warehouse, partitioning is an extremely useful option that can be used by the database designer.

Partitioning the fact tables improves scalability, simplifies system administration, and makes it possible to define local indexes that can be efficiently rebuilt. See Chapter 5, "Parallelism and Partitioning", for further details about partitioning.

Partitioning a materialized view also has benefits for refresh, since the refresh procedure can use parallel DML to maintain the materialized view. To realize these benefits, the materialized view has to be defined as PARALLEL and parallel DML must be enabled in the session.

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, 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 that 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, then 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.

With the introduction of new partitioning options in Oracle8*i*, you are not restricted to using range partitions. For example, a composite partition using both a time value and, say, a key value could result in an ideal partition solution for your data.

An ideal case for using partitions is when a materialized view contains a subset of the data. For example, this can be achieved by defining an expression of the form WHERE time_key < '1-OCT-1998' in the SELECT expression for the materialized view. However, if a WHERE clause of this type is included, then query rewrite will be restricted to the *exact match* case, which severely restricts when the materialized view is used. To overcome this problem, use a partitioned materialized view with no WHERE clause and then query rewrite will be able to use the materialized view and it will only search the appropriate partition, thus improving query performance.

There are two approaches to partitioning a materialized view:

- Partitioning the Materialized View
- Partitioning a Prebuilt Table

Partitioning the 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, is, by default, fast refreshed, and is eligible for query rewrite.

```
CREATE MATERIALIZED VIEW part_sales_mv
  PARALLEL
  PARTITION by RANGE (time_key)
  (
    PARTITION time_key
      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('31-01-1998', '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('31-01-1998', 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.

Indexing Selection for Materialized Views

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

In the case of materialized views containing only joins using the fast refresh option, it is highly recommended 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 and cannot be disabled.

See Chapter 18, "Tuning Parallel Execution", for further details.

Invalidating a Materialized View

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 DDL operation, such as a DROP or ALTER, on any dependency in the materialized view will cause it to become invalid.

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 has now been granted to the owner, the command:

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

should be used to revalidate the materialized view. If there are any problems, an error will be returned.

The state of a materialized view can be checked by querying the tables 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.

Security Issues

To create a materialized view, the privilege CREATE MATERIALIZED VIEW is required, and to create a materialized view that references a table in another schema, you must have SELECT privileges on that table. Moreover, if you enable query rewrite, you must have the QUERY REWRITE or GLOBAL QUERY REWRITE privilege to reference tables in your own schema. To enable query rewrite on a materialized view that references tables outside your schema, you must have the GLOBAL QUERY REWRITE privilege.

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 they are in a different schema.

Guidelines for Using Materialized Views in a Data Warehouse

Determining what materialized views would be most beneficial for performance gains is aided by the analysis tools of the DBMS_OLAP package. Specifically, you can call the DBMS_OLAP.RECOMMEND_MV procedure to see a list of materialized views that Oracle recommends based on the statistics and the usage of the target database. See Chapter 15, "Summary Advisor", for further details.

If you are going to write your own materialized views without the aid of Oracle analysis tools, then use these guidelines to achieve maximum performance:

1. Instead of defining multiple materialized views on the same tables with the same GROUP BY columns but with different measures, define a single materialized view including all of the different measures.
2. If your materialized view includes the aggregated measure AVG(x), also include COUNT(x) to support incremental refresh. Similarly, if VARIANCE(x) or STDDEV(x) is present, then always include COUNT(x) and SUM(x) to support incremental refresh.

Altering a Materialized View

There are five amendments that can be made to a materialized view:

- change its refresh option (FAST/FORCE/COMPLETE/NEVER)
- change its refresh mode (ON COMMIT/ ON DEMAND)
- recompile
- enable/disable its use for query rewrite
- consider fresh

All other changes are achieved by dropping and then recreating the materialized view.

The COMPILE clause of the ALTER MATERIALIZED VIEW statement can be used when the materialized view has been invalidated as described in "Invalidating a Materialized View" on page 8-34. This compile process is quick, and allows the materialized view to be used by query rewrite again.

For further information about ALTER MATERIALIZED VIEW, see *Oracle8i SQL Reference*.

Dropping a Materialized View

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

```
DROP MATERIALIZED VIEW sales_sum_mv;
```

This command 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. Alternatively, you can drop a materialized view using Oracle Enterprise Manager.

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 the periodic extraction of incremental changes from the operational systems; transforming the data; verification that the incremental changes are correct, consistent, and complete; bulk-loading the data into the warehouse; and 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.

The update window usually displays the time 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:** See *Oracle8i 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-phase*. 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 may be adversely affected, but temporary space requirements and load time are minimized. The DML that may be required after one-phase loading causes multi-table 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. Query rewrite can be disabled by default (with ALTER SYSTEM SET QUERY_REWRITE_ENABLED = FALSE) until all the materialized views are refreshed, but enabled at the session level for any users who do not require the materialized views to reflect the data from the latest load (with ALTER SESSION SET QUERY_REWRITE_ENABLED = TRUE). However, as long as QUERY_REWRITE_INTEGRITY = ENFORCED or TRUSTED, this is not necessary because the system ensures 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 is a Dimension?
- Creating a Dimension
- Viewing Dimensions
- Dimensions and Constraints
- Validating a Dimension
- Altering a Dimension
- Deleting a Dimension

What is a Dimension?

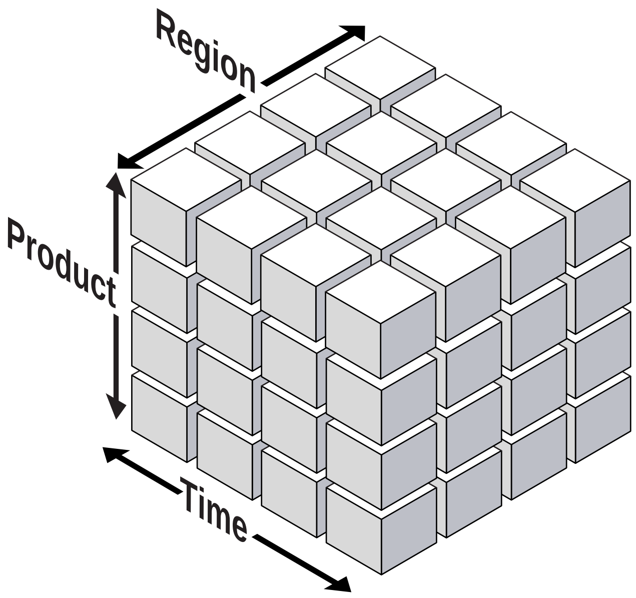
A dimension is a structure that categorizes data in order to enable end users to answer business questions. Commonly used dimensions are Customer, Product, and Time. For example, each store of a video chain might gather and store data regarding sales and rentals of video tapes at the check-out counter. The video 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 product sales before and after the promotion?

The data in the video chain's data warehouse system has two important components: dimensions and facts. The dimensions are products, locations (stores), promotions, 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 store table containing all information about a store. The facts are sales (units sold or rented) and profits. A data warehouse contains facts about the sales of each product at each store on a daily basis.

A typical dimensional cube is shown in Figure 9–1:

Figure 9–1 Sample Dimensional Cube

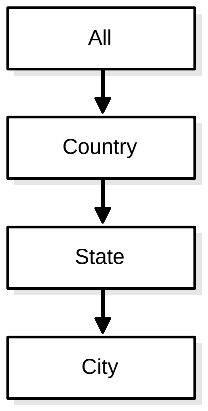


Dimensions do not have to be defined, but spending time creating them can yield significant benefits because they help query rewrite perform more complex types of rewrite. They are mandatory if you use the Summary Advisor to recommend which materialized views to create, drop, or retain. See Chapter 19, "Query Rewrite", for further details regarding query rewrite. See Chapter 15, "Summary Advisor", for further details regarding the Summary Advisor.

Dimension values are usually organized into hierarchies. 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 video chain 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 categories, categories roll up to departments, and departments roll up to all departments.
- Within the location dimension, stores roll up to cities, cities roll up to states, states roll up to regions, regions roll up to countries, and countries roll up to all countries, as shown in Figure 9–2.

Figure 9–2 Geography Dimension



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

You can visualize the dimensions of a business process as an n-dimensional data cube. In the video chain example, the business dimensions product, location, and time can be represented along the three axes of the cube. Each unit along the product axis represents a different product, each unit along the location axis represents a store, and each unit along the time axis represents a month. At the intersection of these values is a cell that contains factual information, such as units sold and profits made. Higher-level analysis consists of selecting and aggregating the factual information within a subcube, such as rentals of comedy videos in California stores during the second quarter of 1998.

Therefore, the first step towards creating a dimension is to identify the dimensions within your data warehouse and then draw the hierarchies as shown in Figure 9–2. For example, *city* is a child of *state* (because you can aggregate city-level data up to state), and *state*. Using this approach, you should find it easier to translate this into an actual dimension.

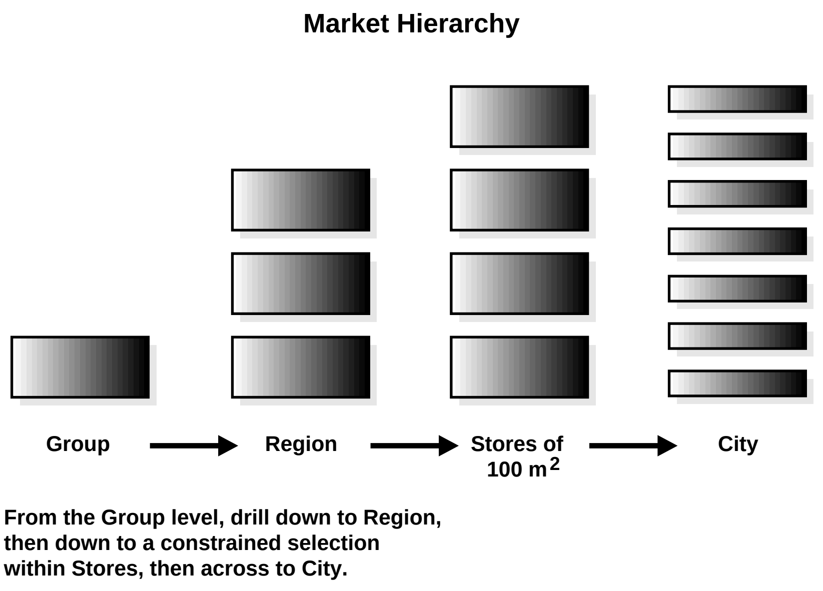
In the case of normalized or partially normalized dimensions (a dimension that is stored in more than one table), identify how these tables are joined. Note whether the joins between the dimension tables can guarantee that each child-side row joins with one and only one parent-side row. In the case of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

Drilling Across

Drilling across is when you change what you are viewing to another hierarchy at the same level. An example of drilling across is in Figure 9–3:

Figure 9–3 Drilling Across


Market Hierarchy
Group
Region
Stores of 100 m^2
City
From the Group level, drill down to Region, then down to a constrained selection within Stores, then across to City.

Going from Group to Region is drilling down, but Region to Stores is drilling across. Stores of > 100 is a non-hierarchical attribute.

The caveat with drilling across is that you will not necessarily enter another hierarchy at the same level, which means the totals may be different.

Creating a Dimension

Before you can create a dimension, tables must exist in the database which contain this dimension data. For example, if you create a dimension called LOCATION, one or more tables must exist which contains 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.

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...IS clause to identify the names of the dimension levels.

The location dimension contains a single hierarchy, with arrows drawn from the *child level* to the *parent level*. At the top of this dimension graph is the special level ALL, that represents aggregation over all rows. 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 LOCATION which contains levels CITY, STATE, and COUNTRY:

```
CREATE DIMENSION location_dim
    LEVEL city      IS location.city
    LEVEL state     IS location.state
    LEVEL country   IS location.country
```

Each level in the dimension must correspond to one or more columns in a table in the database. Thus, level *city* is identified by the column *city* in the table called *location* and level *country* is identified by a column called *country* 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 9-10 shows how to create a dimension 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. Again, using the entities in Figure 9–4 on page 9-9, the following statements declare a hierarchy LOC_ROLLUP and define the relationship between CITY, STATE, and COUNTRY.

```
HIERARCHY loc_rollup    (
       city     CHILD OF
       state    CHILD OF
       country     )
```

In addition to the 1:n hierarchical relationships, dimensions also include 1:1 attribute relationships between the hierarchy levels and their dependent dimension attributes. For example, if there are columns *governor* and *mayor*, then the ATTRIBUTE...DETERMINES statement would be state to governor and city to mayor.

In our example, suppose a query were issued that queried by *mayor* instead of *city*. Since this 1:1 relationship exists between the attribute and the level, city can be used to identify the data.

```
ATTRIBUTE     city      DETERMINES   mayor
```

The complete dimension definition, including the creation of the location table, follows:

```
CREATE TABLE location  (
       city     VARCHAR2(30),
       state    VARCHAR2(30),
       country  VARCHAR2(30),
       mayor    VARCHAR2(30),
       governor  VARCHAR2(30)  );

CREATE DIMENSION location_dim
       LEVEL city      IS location.city
       LEVEL state     IS location.state
       LEVEL country   IS location.country
HIERARCHY loc_rollup    (
       city     CHILD OF
       state    CHILD OF
       country )
ATTRIBUTE     city      DETERMINES   location.mayor
ATTRIBUTE     state     DETERMINES   location.governor;
```

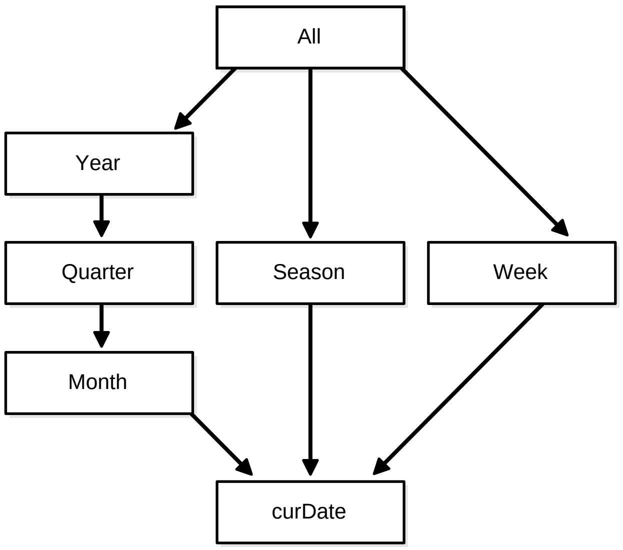
The design, creation, and maintenance of dimensions is part of the design, creation, and maintenance of your data warehouse schema. Once the dimension has been created, check that it meets these requirements:

- **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 *corporation*, then a possible attribute relationship would be *corporation* to *president*.
- **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 may 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.

Multiple Hierarchies

A single dimension definition can contain multiple hierarchies as illustrated below. Suppose a department store 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 9–4 on page 9-9 illustrates a dimension "Time_dim" with three time hierarchies.

Figure 9–4 Time_dim Dimension with Three Time Hierarchies



From the illustration, you can construct the following denormalized Time dimension statement. The associated CREATE TABLE statement is also shown.

```
CREATE TABLE time (
        curDate     DATE,
        month       INTEGER,
        quarter     INTEGER,
        year        INTEGER,
        season      INTEGER,
        week_num    INTEGER,
        dayofweek   VARCHAR2(30),
        month_name  VARCHAR2(30)  );

CREATE DIMENSION Time_dim
    LEVEL curDate    IS time.curDate
    LEVEL month      IS time.month
    LEVEL quarter    IS time.quarter
    LEVEL year       IS time.year
    LEVEL season     IS time.season
    LEVEL week_num   IS time.week_num
```

```
HIERARCHY calendar_rollup  (
    curDate       CHILD OF
    month         CHILD OF
    quarter       CHILD OF
    year                    )
HIERARCHY weekly_rollup    (
         curDate         CHILD OF
         week_num          )
HIERARCHY seasonal_rollup  (
         curDate         CHILD OF
         season            )
ATTRIBUTE curDate     DETERMINES  time.dayofweek
ATTRIBUTE month       DETERMINES  time.month_name;
```

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, CALENDAR_ROLLUP in the Time 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 products is done by product, brand, and department. This data is stored in the tables PRODUCT, BRAND, and DEPARTMENT. The product dimension is *normalized* because the data entities ITEM_NAME, BRAND_ID, and DEPT_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 and the associated CREATE TABLE statements for the PRODUCT, BRAND, and DEPARTMENT tables are shown below.

```
CREATE TABLE product  (
        item_name    VARCHAR2(30),
        brand_id     INTEGER  );

CREATE TABLE brand  (
        brand_id     INTEGER,
        brand_name   VARCHAR2(30),
        dept_id      INTEGER);

CREATE TABLE department  (
        dept_id       INTEGER,
        dept_name     VARCHAR2(30),
        dept_type     INTEGER);

CREATE DIMENSION product_dim
    LEVEL item      IS product.item_name
    LEVEL brand_id  IS brand.brand_id
    LEVEL dept_id   IS department.dept_id

HIERARCHY merchandise_rollup
(
    item                   CHILD OF
    brand_id               CHILD OF
    dept_id

    JOIN KEY  product.brand_id REFERENCES brand_id
    JOIN KEY  brand.dept_id    REFERENCES dept_id
)
ATTRIBUTE brand_id DETERMINES product.brand_name
ATTRIBUTE dept_id  DETERMINES (product.dept_name, product.dept_type);
```

Dimension Wizard

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

A dimension created via the wizard may contain any of the attributes described in "Creating a Dimension" on page 9-6, such as join keys, multiple hierarchies and attributes. Some users may prefer to use the wizard because it will graphically display the hierarchical relationships as they are being constructed. When it is time to describe the hierarchy, the dimension wizard will automatically display a default hierarchy based on the column values, which the user can subsequently amend. See the Oracle Enterprise Manager documentation set for further details.

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 are available which allow you to display the dimensions that have been defined. First, the file smdim.sql 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 TIME_PD.

```
DEMO_DIM.PRINT_DIM  ('TIME_PD');
```

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

```
DEMO_DIM.PRINT_ALLDIMS ();
```

Irrespective of which procedure is called, the output format is identical. A sample display is shown below.

```
DIMENSION GROCERY.TIME_PD
LEVEL FISCAL_QTR IS GROCERY.WEEK.FISCAL_QTR
LEVEL MONTH IS GROCERY.MONTH.MONTH
LEVEL QUARTER IS GROCERY.QUARTER.QUARTER
LEVEL TIME_KEY IS GROCERY.TIME.TIME_KEY
LEVEL WEEK IS GROCERY.WEEK.WEEK
LEVEL YEAR IS GROCERY.YEAR.YEAR
HIERARCHY WEEKLY_ROLLUP (
      TIME_KEY
       CHILD OF WEEK
   JOIN KEY GROCERY.TIME.WEEK REFERENCES WEEK
  )
    HIERARCHY FISCAL_ROLLUP (
             TIME_KEY
             CHILD OF WEEK
             CHILD OF FISCAL_QTR
    JOIN KEY GROCERY.TIME.WEEK REFERENCES WEEK
    )
   HIERARCHY CALENDAR_ROLLUP (
             TIME_KEY
             CHILD OF MONTH
             CHILD OF QUARTER
             CHILD OF YEAR
      JOIN KEY GROCERY.TIME.MONTH REFERENCES MONTH
      JOIN KEY GROCERY.MONTH.QUARTER REFERENCES QUARTER
      JOIN KEY GROCERY.QUARTER.YEAR REFERENCES YEAR
    )

    ATTRIBUTE TIME_KEY DETERMINES GROCERY.TIME.DAY_NUMBER_IN_MONTH
    ATTRIBUTE TIME_KEY DETERMINES GROCERY.TIME.DAY_NUMBER_IN_YEAR
    ATTRIBUTE WEEK DETERMINES GROCERY.WEEK.WEEK_NUMBER_OF_YEAR
    ATTRIBUTE MONTH DETERMINES GROCERY.MONTH.FULL_MONTH_NAME
```

Using Oracle Enterprise Manager

All of the dimensions which exist in the data warehouse can be easily viewed using Oracle Enterprise Manager. Selecting the Dimension object from within the Schema icon, will display all of the dimensions. Selecting a specific dimension will graphically display its hierarchy, levels and any attributes which may have been defined. See the Oracle Enterprise Manager documentation set for further details.

Dimensions and Constraints

Constraints play an important role with dimensions. In most cases, full referential integrity is enforced on the operational databases, and operational procedures can be used to ensure that data flowing into the data warehouse (after data cleansing) never violates referential integrity; so, in practice, referential integrity constraints may or may not be enabled in the data warehouse.

It is recommended 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 as described. 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, the RELY clause should be used to advise query rewrite that it can rely upon the constraints being correct as follows:

```
ALTER TABLE time MODIFY CONSTRAINT pk_time RELY;
```

Validating a Dimension

If the relationships described by the dimensions are incorrect, wrong 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 only has four 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

The following example validates the dimension time_fn in the Grocery schema

```
DBMS_OLAP.VALIDATE_DIMENSION ('TIME_FN', 'GROCERY', FALSE, TRUE);
```

All exceptions encountered by the VALIDATE_DIMENSION procedure are placed in the table MVIEW$_EXCEPTIONS, which is created in the user's schema. Querying this table will identify the exceptions that were found. For example:

```
OWNER    TABLE_NAME  DIMENSION_NAME RELATIONSHIP BAD_ROWID
-------- ----------- -------------- ------------ ------------------
GROCERY  MONTH       TIME_FN        FOREIGN KEY  AAAAuwAAJAAAARwAAA
```

However, rather than query this table, it may be better to query as follows where the rowid of the invalid row is used to retrieve the actual row that has violated the constraint. In this example, the dimension TIME_FD is checking a table called month. It has found a row that violates the constraints and using the rowid, we can see exactly which row in the month table is causing the problem.

```
SELECT * FROM month
WHERE rowid IN (SELECT bad_rowid FROM mview$_exceptions);

MONTH      QUARTER    FISCAL_QTR YEAR       FULL_MONTH_NAME      MONTH_NUMB
---------- ---------- ---------- ---------- -------------------- ----------
199903     19981      19981      1998       March                3
```

Altering a Dimension

Some modification can be made to 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 9–4, you could remove the attribute month, drop the hierarchy weekly_rollup, and remove the level week. In addition, you could add a new level called qtr1.

```
ALTER DIMENSION time_dim DROP ATTRIBUTE month;
ALTER DIMENSION time_dim DROP HIERARCHY weekly_rollup;
ALTER DIMENSION time_dim DROP LEVEL week;
ALTER DIMENSION time_dim ADD LEVEL qtr1 IS time.fiscal_qtr;
```

A dimension becomes invalid if you change any schema object which 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 table ALL_DIMENSIONS.

To revalidate the dimension, use the COMPILE option as follows:

```
ALTER DIMENSION time_dim COMPILE;
```

Dimensions can also be modified using Oracle Enterprise Manager.

Deleting a Dimension

A dimension is removed using the DROP DIMENSION command. For example:

```
DROP DIMENSION time_dim;
```

Dimensions can also be deleted using Oracle Enterprise Manager.

Part IV
Managing the Warehouse Environment

This section deals with the tasks for managing a data warehouse.

It contains the following chapters:

- ETT Overview
- Extraction
- Transportation
- Transformation
- Loading and Refreshing
- Summary Advisor

10 ETT Overview

This chapter discusses extracting, transporting, and transforming in a data warehousing environment:

- ETT Overview
- ETT Tools
- ETT Sample Schema

ETT Overview

You need to load your data warehouse regularly so that it can serve its purpose of allowing business analysis. To do this, however, data from one or more operational systems needs to be extracted and copied into the warehouse. This process of reading and preparing the data is relatively difficult, and needs to be performed on a regular basis.

The process of extracting data from source systems and bringing it into the data warehouse is commonly called *ETT*, which stands for Extraction, Transformation, and Transportation. Indeed, the acronym ETT is perhaps too simplistic, since it omits one important phase, the loading of the data warehouse, and implies that each of other phases of the process is distinct. Rather than introduce new terminology, we will instead refer to the entire process as ETT. You should understand that ETT refers to a broad process, and not three well-defined steps.

The emphasis in many of the examples in this section is scalability. While many longtime users of Oracle are experts in programming complex data-transformation logic using PL/SQL, these chapters seek to suggest alternatives for many such data-manipulation operations, with a particular emphasis on implementations that leverage Oracle's existing parallel-query infrastructure.

ETT Tools

Building and maintaining the ETT process is often considered one of the most difficult and resource-intensive portions of a data-warehouse project. Many data-warehousing projects use ETT tools to manage this process. Oracle Warehouse Builder, for example, provides ETT capabilities. Other data warehouse builders choose to create their own ETT tools and processes.

Oracle8*i* is not an ETT tool, and does not provide a complete solution for ETT. However, Oracle8*i* does provide a rich set of capabilities which can be leveraged by both ETT tools and home-grown ETT solutions. Oracle8*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.

ETT Sample Schema

Many examples in the ETT section of this guide (Chapter 10 through Chapter 15) use the same, simple star schema. This schema consists of a single fact table (called *sales*) partitioned by month and four dimension tables. The definitions of these tables follow:

```
CREATE TABLE product
(
  product_id         VARCHAR2(6) NOT NULL,
  product_oe_id      VARCHAR2(6),
  product_name       VARCHAR2(60),
  product_language   VARCHAR2(30),
  product_media      VARCHAR2(8),
  product_category   VARCHAR2(30)
)

CREATE TABLE time
(
  time_id          DATE NOT NULL,
  time_month       VARCHAR2(5) NOT NULL,
  time_quarter     VARCHAR2(4) NOT NULL,
  time_year        NUMBER NOT NULL,
  time_dayno       NUMBER NOT NULL,
  time_weekno      NUMBER NOT NULL,
  time_day_of_week VARCHAR2(9) NOT NULL
)

CREATE TABLE customer
(
  customer_id          VARCHAR2(6) NOT NULL,
  customer_name        VARCHAR2(25),
  customer_address     VARCHAR2(40),
  customer_city        VARCHAR2(30),
  customer_subregion   VARCHAR2(30),
  customer_region      VARCHAR2(15),
  customer_postalcode  NUMBER(9),
  customer_age         NUMBER(2),
  customer_gender      VARCHAR2(1)
)
CREATE TABLE channel
(
  channel_id           VARCHAR2(2) NOT NULL,
  channel_description  VARCHAR2(10)
)
```

```
CREATE TABLE sales
(
  sales_transaction_id    VARCHAR2(8) NOT NULL,
  sales_product_id        VARCHAR2(4) NOT NULL,
  sales_customer_id       VARCHAR2(6) NOT NULL,
  sales_time_id           DATE NOT NULL,
  sales_channel_id        VARCHAR2(4) NOT NULL,
  sales_quantity_sold     NUMBER NOT NULL,
  sales_dollar_amount     NUMBER NOT NULL)
)
```

11 Extraction

This chapter discusses extraction, which is when you take data from an operational system and move it to your warehouse. The chapter discusses:

- Overview of Extraction
- Extracting Via Data Files
- Extracting Via Distributed Operations
- Change Capture

Overview of Extraction

Extraction is the operation of copying data from a database into a file or onto a network connection. This is the first step of the ETT process: data must be extracted from the source system(s) so that this data may be subsequently transformed and loaded into the data warehouse.

The *source systems* for a data warehouse are typically transaction-processing database applications. For example, one of the source systems for a sales-analysis data warehouse may be the order-entry system which records all of the current order activities.

Designing and creating the extraction process is often one of the most time-consuming tasks in the ETT process and, indeed, in the entire data warehousing process. The source systems may be very complex, and thus determining which data needs to be extracted can be difficult. Moreover, the source system typically cannot be modified, nor can its performance or availability be impacted, to accommodate the needs of the data warehouse extraction process. These are very important considerations for extraction, and ETT in general.

This chapter, however, focuses on the technical considerations for extracting data. 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. The techniques for extraction fall into two broad categories:

- Techniques which extract data from an operational system and place the data into a file. Examples are data-unloads and exports.
- Techniques which extract data from an operational system and directly transport data into the target database (a data warehouse or a staging database). Examples are gateways and distributed queries.

Extracting Via Data Files

Most database systems provide mechanisms for exporting and/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 and/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, or unload the results of joining multiple tables together.

Different extraction techniques may vary in their capabilities to support these two scenarios.

When the source system is an Oracle database, there are several alternatives 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 EXP Utility
- Copying to Another Oracle Database Using Transportable Tablespaces

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, empdept.log, containing a list of employee names and department names from the EMP and DEPT tables, the following SQL script could be run:

```
SET echo off
SET pagesize 0
SPOOL empdept.dat
SELECT ename, dname FROM emp, dept
WHERE emp.deptno = dept.deptno;
SPOOL off
```

The exact format of the output file can be specified using SQL*Plus's system variables.

Note that 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. Parallelization can be achieved 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, ORDER_FEB1998, and so on. Then, in order 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. These files may need to be concatenated (using OS utilities) following the extraction.

Even if the ORDERS table is not partitioned, it is still possible to parallelize the extraction. 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>;
```

Parallelization of the extraction of complex SQL queries may also be possible, although the process of breaking a single complex query into multiple components can be challenging.

Note that 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 program 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 be used to 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.

Exporting into Oracle Export Files Using Oracle's EXP 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, EXP provides a mechanism for extracting database objects. Thus, EXP 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 recreate the table, potentially including any indexes, constraints, grants, and other attributes associated with that table.
- A single export file may contain many database objects, and even an entire schema.

- Export cannot be directly used to export portions of a database object, or to export the results of a complex SQL query. Export can only be used to extract entire database objects.
- The output of the export utility can only be processed using the Oracle import utility.

Oracle provides a direct-path export, which is quite efficient for extracting data. Note that in Oracle8*i*, there is no direct-path import, which should be considered when evaluating the overall performance of an export-based extraction strategy.

Although the SQL*Plus and OCI extraction techniques are more common, EXP may be useful for certain ETT environments that require extraction of metadata as well as data.

See *Oracle8i Utilities* for more information on using export.

Copying to Another Oracle Database Using Transportable Tablespaces

One of the most powerful features for extracting and moving large volumes of data between Oracle database is transportable tablespaces. A more detailed example of using this feature to extract and transport data is provided in Chapter 12, "Transportation". When possible, transportable tablespaces are very highly recommended for data extraction, because they often provide considerable advantages in performance and manageability over other extraction techniques.

Extracting Via Distributed Operations

Using distributed-query technology, one Oracle database can directly query tables located in another Oracle database. Specifically, a data warehouse or staging database could directly access tables and data located in an Oracle-based source system. This is perhaps the simplest method for moving data between two Oracle databases because it combines the extraction and transformation into a single step, and, moreover, requires minimal programming.

Continuing our example from above, suppose that we wanted to extract a list of employee names with department names from a source database, and store it into our data warehouse. Using a Net8 connection, and distributed-query technology, this can be achieved using a single SQL statement:

```
CREATE TABLE empdept
AS
SELECT ename, dname FROM emp@source_db, dept@source_db
WHERE emp.deptno = dept.deptno;
```

This statement creates a local table in the data warehouse, EMPDEPT, and populates it with data from the EMP and DEPT 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 via a single Net8 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.

Gateways are another form of distributed-query technology, except that gateways allow an Oracle database (such as a data warehouse) to access database tables stored in remote, non-Oracle databases. Like distributed queries, gateways are very easy to set up and use, but also lack scalability for very large data volumes.

For more information on distributed queries, see *Oracle8i Distributed Database Systems* and *Oracle8i Concepts.*

Change 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 only data which that data warehouse requires is the data that has changed since the last extraction (that is, the data that has been modified in the last 24 hours).

If it was possible to efficiently identify and extract only the most recently-changed data, the extraction process (as well as all downstream operations in the ETT process) could be much more efficient since it would only need to 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.

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. While this approach may not have significant impact on the source systems, it clearly can place a considerable burden on the data-warehouse processes particularly if the data volumes are large.

Thus, change data capture as part of the extraction process is often desirable. This section describes several techniques for implementing change-data-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 change-capture techniques will 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 via distributed query.

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 TIMESTAMP = TO_DATE(sysdate, 'mm-dd-yyyy');
```

If timestamps are not available in an operational system, the system may be able to be modified to include timestamps. This would require, first, modifying the operational system's tables to include a new timestamp column, and second, creating a trigger (see "Triggers" on page 11-7) to update the timestamp column following every operation which modifies a given row.

Partitioning

Some source systems may utilize Oracle's 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 allow you 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 trigger-based technique is to use Oracle's 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 will be inserted into the materialized-view log indicating which row(s) were modified. The materialized view log can then be subsequently queried by the extraction process to identify the changed data.

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.

Both of these trigger-based techniques will impact performance on the source systems, and this impact should be carefully consider prior to implementing on a production source system.

12

Transportation

The following topics provide information about transporting data into a data warehouse:

- Transportation Overview

Transportation Overview

Transportation is, literally, the act 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; from a staging database to a data warehouse; or from a data warehouse to a data mart.

Transportation is often one of the simplest portions of the ETT process, and is commonly integrated with other portions of the process. For example, as shown in Chapter 11, "Extraction", distributed query technology provides a mechanism for both extracting and transporting data.

There are various techniques for transporting data, each with its own distinct advantages. This chapter introduces some of these techniques, and includes:

- Transportation of Flat Files
- Transportation Via Distributed Operations
- Transportable Tablespaces

Transportation of 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", 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, flat files are often the simplest mechanism 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 Via Distributed Operations

Distributed queries and gateways can be an effective mechanism for extracting data. These mechanisms also transport the data directly to the target systems, thus providing both extracting and transformation in a single step. For relatively small volumes of data, these mechanisms are very well-suited for both extraction and transformation. See Chapter 11, "Extraction", for further details.

Transportable Tablespaces

Oracle8*i* introduced an important mechanism for transporting data: transportable tablespaces. This feature is the fastest mechanism 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, and, after transportation, that these files be 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 OS, must use the same character set, and must have the same block size. Nevertheless, 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 *Oracle8i Concepts* for more information on transportable tablespaces.

Transportable Tablespaces Example

Suppose that you have a data warehouse containing sales data, and several data marts which 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 needs to be placed into a separate tablespace in order to be transported. In this example, you have a tablespace TS_SALES_TEMP, 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
UNRECOVERABLE
TABLESPACE ts_temp_sales
AS
```

```
SELECT * FROM sales
WHERE sales_date BETWEEN '31-DEC-1999' AND '01-FEB-2000';
```

Following this create-table 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 deleted, and 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 an 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.

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, two conditions must be satisfied in order to transport the tablespace TS_SALES_JAN2000. First, this tablespace must be set to read only. Second, since 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), in order to transport the January data. The EXCHANGE operation is very quick; however, 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. The January data can be exchanged back into the SALES table following 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 only contains 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 which 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

The data files that make up TS_TEMP_SALES, as well as the export file jan_sales.dmp, should be copied 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
```

Like the export operation in step 2, the import operation in this step should be very fast.

At this point, the tablespace TS_TEMP_SALES and the table TEMP_SALES_JAN are accessible in the data mart.

There are two potential scenarios for incorporating this new data into the data mart's tables.

First, the data from the TEMP_SALES_JAN table could be inserted into the data mart's sales table:

```
INSERT /*+ APPEND */ INTO sales SELECT * FROM temp_sales_jan;
```

Following this operation, the temp_sales_jan table (and even the entire ts_temp_ sales tablespace) could be deleted.

Second, if the data mart's sales table is partitioned by month, then the new transported tablespace and the TEMP_SALES_JAN table could become a permanent part of the data mart. The TEMP_SALES_JAN table could 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 illustrated 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 Transformation

This chapter helps you create and manage a data warehouse, and discusses:

- Techniques for Data Transformation Inside the Database

Techniques for Data Transformation Inside the Database

Data transformations are often the most complex and, in terms of processing time, the most costly part of the ETT process. They can run the gamut from simple data conversions to extremely complex data-scrubbing techniques. Many, if not all, data transformations can occur within an Oracle8*i* database, although transformations are also often implemented outside of the database (for example, on flat files) as well.

This chapter discusses the techniques used to implement data transformation within Oracle8*i* and special considerations for choosing among these techniques, and includes:

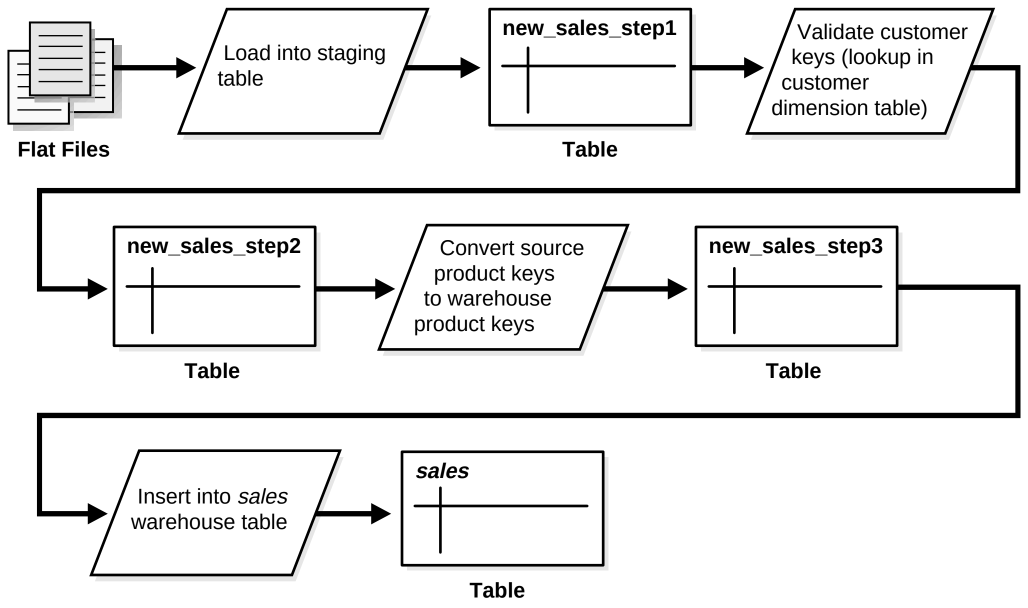
- Transformation Flow
- Transformations Provided by SQL*Loader
- Transformations Using SQL and PL/SQL
- Data Substitution
- Key Lookups
- Pivoting
- Emphasis on Transformation Techniques

Transformation Flow

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 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 Oracle8*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 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 strategy also provides a natural *checkpointing* scheme to the entire transformation process, which enables to the process to be more easily monitored and restarted.

It may also be possible to combine many simple logical transformations into a single SQL statement or single PL/SQL procedure. While this may provide better performance than performing each step independently, it may also introduce difficulties in modifying, adding or dropping individual transformations, and, moreover, prevents any effective checkpointing.

Transformations Provided by SQL*Loader

Before any data-transformations can occur within the database, the raw data must first be loaded into the database. Chapter 12, "Transportation", discussed several techniques for transporting data to an Oracle data warehouse. Perhaps the most common technique for transporting data is via 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, datatype conversion and simple NULL handling can be automatically resolved during the data load. Most data warehouses choose to use *direct-path* loading for performance reasons.

Oracle's conventional-path loader provides broader capabilities for data transformation than 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 less efficient than direct-path loader and is not parallelizable. For these reasons, the conventional-path loader should be considered primarily for loading and transforming smaller amounts of data.

For more information on SQL*Loader, see *Oracle8i Utilities*.

Transformations Using SQL and PL/SQL

Once data is loaded into an Oracle8*i* database, data transformations can be executed using SQL and PL/SQL operations. There are two basic techniques for implementing data-transformations within Oracle8*i*.

Technique 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 we shall see in the examples below, many data transformations can be expressed in standard SQL, and Oracle's implementation of CTAS provides a mechanism for efficiently executing a SQL query, and storing the results of that query in a database table.

In a data warehouse environment, CTAS is typically run in parallel and using NOLOGGING mode for best performance.

Technique 2: PL/SQL Procedures

In a data warehouse environment, PL/SQL can be used to implement complex transformations in the Oracle8*i* database.

While 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 tables; it may be difficult or impossible to express the same sequence of operations using standard SQL commands.

The following examples demonstrate transformations using SQL and PL/SQL.

Data Substitution

A simple and common type of data transformation is a 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 sales_channel_id column. This column is used to specify whether a given sales transaction was made by our company's own sales force (a *direct* sale) or via a distributor (an *indirect* sale).

We may receive data from multiple source systems for our data warehouse. Let us 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 of sales records have a null value for the sales_channel_id field. These null values must be modified, and set to the proper key value.

This can be efficiently done using a CTAS statement:

```
CREATE TABLE temp_sales_step2
NOLOGGING PARALLEL AS
SELECT sales_product_id, NVL(sales_channel_id, 1) sales_channel_id,
       sales_customer_id, sales_time_id, sales_quantity_sold,
       sales_dollar_amount
FROM   temp_sales_step1;
```

Another possible 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, many data-substitution transformations require that a very large percentage of the rows (often all of the rows) be modified. In these cases, it may be more efficient to use a CTAS statement than an UPDATE.

Key Lookups

Another simple transformation is a key lookup For example, suppose that, in a retail data warehouse, sales transaction data has been loaded into the data warehouse. Although the data warehouse's SALES table contains a PRODUCT_ID column, the sales transaction data extracted from the source system contains UPC codes 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, there must be a lookup table which relates the PRODUCT_ID values to the UPC codes. This may be the PRODUCT dimension table, or perhaps there is 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 ETT process has guaranteed that each UPC code is valid, then this statement alone may be sufficient to implement the entire transformation.

Exception Handling: Invalid Data

However, it can be important to handle new sales data that does not have valid UPC codes.

One approach is to 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 ETT process.

A second approach 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 PRODUCT_IDs can be handled later.

There are other possible approaches to handling invalid UPC codes. Some data warehouses may choose to insert null-valued PRODUCT_IDs 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

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 non-relational database having the form:

```
product_id, store_id, week_id, sales_sun, sales_mon, sales_tue,
sales_wed, sales_thu, sales_fri, sales_sat
```

In your data warehouse, you would want to store the records in a more typical relational form:

```
product_id, store_id, time_id, sales_amount
```

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*.

The CTAS approach to pivoting would require a UNION-ALL query:

```
CREATE table temp_sales_step2
NOLOGGING PARALLEL
AS
SELECT product_id, time_id, sales_amount
FROM
(SELECT product_id, store_id, TO_DATE(week_id,'WW') time_id,
          sales_sun sales_amount FROM temp_sales_step1
 UNION ALL
 SELECT product_id, store_id, TO_DATE(week_id,'WW')+1 time_id,
        sales_mon sales_amount FROM temp_sales_step1
 UNION ALL
 SELECT product_id, store_id, TO_DATE(week_id,'WW')+2 time_id,
        sales_tue sales_amount FROM temp_sales_step1
 UNION ALL
 SELECT product_id, store_id, TO_DATE(week_id,'WW')+3 time_id,
        sales_web sales_amount FROM temp_sales_step1
 UNION ALL
 SELECT product_id, store_id, TO_DATE(week_id,'WW')+4 time_id,
        sales_thu sales_amount FROM temp_sales_step1
 UNION ALL
 SELECT product_id, store_id, TO_DATE(week_id,'WW')+5 time_id,
        sales_fri sales_amount FROM temp_sales_step1
 UNION ALL
 SELECT product_id, store_id, TO_DATE(week_id,'WW')+6 time_id,
        sales_sat sales_amount FROM temp_sales_step1);
```

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 may be time-consuming.

An alternative implementation is PL/SQL. A very basic PL/SQL function to implement the pivoting operation would be:

```
DECLARE
   CURSOR c1 is
      SELECT
       product_id, store_id, week_id, sales_sun, sales_mon, sales_tue,
       sales_wed, sales_thu, sales_fri, sales_sat
      FROM temp_sales_step1;
BEGIN
   FOR next IN c1 LOOP
      INSERT INTO temp_sales_step2 VALUES (product_id, store_id,
         TO_DATE(week_id,'WW') time_id, sales_sun );
      INSERT INTO temp_sales_step2 VALUES (product_id, store_id,
         TO_DATE(week_id,'WW')+1 time_id, sales_mon );
      INSERT INTO temp_sales_step2 VALUES (product_id, store_id,
         TO_DATE(week_id,'WW')+2 time_id, sales_tue );
      INSERT INTO temp_sales_step2 VALUES (product_id, store_id,
         TO_DATE(week_id,'WW')+3 time_id, sales_wed );
      INSERT INTO temp_sales_step2 VALUES (product_id, store_id,
         TO_DATE(week_id,'WW')+4 time_id, sales_thu );
      INSERT INTO temp_sales_step2 VALUES (product_id, store_id,
         TO_DATE(week_id,'WW')+5 time_id, sales_fri );
      INSERT INTO temp_sales_step2 VALUES (product_id, store_id,
         TO_DATE(week_id,'WW')+6 time_id, sales_sat );
   END LOOP;
   COMMIT;
END;
```

This PL/SQL procedure could be modified to provide even better performance. Array inserts could accelerate the insertion phase of the procedure. Further performance could 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".

The primary advantage of this PL/SQL procedure over a CTAS approach is that it only requires a single scan of the data. Pivoting is an example of a complex transformation that may be more amenable to PL/SQL.

Emphasis on Transformation Techniques

This chapter is designed to introduce techniques for implementing scalable and efficient data transformations within Oracle8*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 techniques that can be applied to implement these transformations and to provide guidance in how to choose the best techniques.

14 Loading and Refreshing

This chapter discusses how to load and refresh a data warehouse, and discusses:

- Refreshing a Data Warehouse
- Refreshing Materialized Views

Refreshing a Data Warehouse

Following extraction and transformation, the final step of the ETT process is to 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.

Using Partitioning to Improve Data Warehouse Refresh

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 on a regular schedule: every night, every week or every 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 week. In this very common scenario, the data warehouse is being loaded by time. This suggests that the data-warehouse tables should be partitioned by a date key. 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, 2000) to SALES table:

Step 1: Place the new data into a separate table, SALES_00JAN. This data may be directly loaded into SALES_00JAN from outside the data warehouse, or this data may be the result of previous data-transformation operations that have already occurred in the data warehouse. SALES_00JAN has the exact same columns, datatypes, etc. as the SALES table. Gather statistics on the SALES_00JAN table.

Step 2: Create indexes and add constraints on SALES_00JAN. Again, the indexes and constraints on SALES_00JAN 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_00jan_customer_id_bix
     tablespace (sales_index) NOLOGGING parallel (degree 8) COMPUTE STATISTICS;
```

All constraints should be applied to the SALES_00JAN table that are present on the SALES table. This includes referential integrity constraints. Some typical constraints would be:

```
ALTER TABLE sales_00jan add CONSTRAINT sales_pk
      unique(sales_transaction_id) disable validate;
ALTER TABLE sales_00jan add constraint sales_customer_ri
      sales_customer_id REFERENCES customer(customer_id);
```

Step 3: Add the SALES_00JAN 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_00jan
VALUES LESS THAN (TO_DATE('01-FEB-2000', '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_00jan WITH TABLE sales_00jan
INCLUDING INDEXES WITHOUT VALIDATION;
```

The exchange operator will preserve the indexes and constraints that were already present on the SALES_00JAN table. For unique constraints (such as the unique constraint on SALES_TRANSACTION_ID), the exchange operator might need to do additional processing to ensure consistency. 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 only applied to the new partition. If the SALES table was 50GB 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 46GB 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. Since all of the operations associated with data loading are occurring on a separate

SALES_00JAN table, none of the existing data or indexes of the SALES table is impacted during this data-refresh process. The SALES table, and its indexes, remain entirely untouched throughout this refresh process.

The EXCHANGE operator can be viewed as a *publishing* mechanism. Until the data-warehouse administrator exchanges the SALES_00JAN table into the SALES table, end-user cannot see the new data. Once the EXCHANGE has occurred, than any end-user query accessing the SALES table will immediately be able to see the SALES_00JAN data.

Note that partitioning is not only useful for adding new data, but also for removing data. Many data warehouses maintain a *rolling window* of data; that is, the data warehouse stores the most recent 12-months of SALES data for example. 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. Since INSERT is only affecting a single partition, the benefits described above remain intact. The INSERT could occur while the partition remains a part of the table. INSERT into a single partition can be parallelized:

   ```
   INSERT INTO SALES PARTITION (SALES_00JAN) SELECT * FROM NEW_SALES;
   ```

   The indexes of this SALES partition will be maintained in parallel as well. Alternatively, the SALES_00JAN partition could be EXCHANGEd out of the SALES table, and the INSERT could occur there (this approach could be used, for example, if it was determined that based on data volumes it would be more efficient to drop and rebuild the indexes on this partition rather than maintain them)

2. New data feeds, although consisting primarily of data for the most recent day / week / month, also contain some data from previous time periods.

SOLUTION: 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. This can occur when a data warehouse receives data from multiple operational systems. 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: Oracle supports concatenated partitioning keys. The SALES table could be partitioned by (month, 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 only feasible 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.

The *rolling window* approach is the most basic technique for refreshing a data warehouse.

Example: Implementing an Efficient Upsert

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, however, some records may reflect modifications of previous transactions, such as returned merchandise or transactions that may have been incomplete or incorrect when initially loaded into the data warehouse. The records require updates to the SALES table.

As a typical scenario, suppose that there is a table, called NEW_SALES, which contains both inserts and updates that will be applied to the data warehouse's 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*. Upsert can be executed using two SQL statements. The first SQL statement updates the appropriate rows in the SALES tables, while the second SQL statement inserts the rows:

```
UPDATE sales SET
       sales.sales_dollar_amount = sales.sales_dollar_amount
        + new_sales.sales_dollar_amount,
       sales.sales_quantity_sold = sales.sales_quantity_sold
        + new_sales.sales_quantity_sold
WHERE new_sales.sales_transaction_id = sales.transaction_id;

INSERT INTO sales
SELECT * FROM new_sales
WHERE new_sales.sales_transaction_id NOT IN
 (SELECT sales_transaction_id FROM sales);
```

Both of these SQL statements can be parallelized, and this provides a very scalable mechanism for handling large amounts of changes.

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 will certainly be effective if the NEW_SALES table is small, although the above approach will often be more efficient for larger data volumes.

Example: Maintaining Referential Integrity

In some data warehousing environments, the data warehouse administrator may wish 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. The 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, since 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, the data warehouse administrator may choose to insert the sales transactions into the SALES table.

However, the administrator may 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));
```

Example: Purging Data

Occasionally, it is necessary to remove large amounts of data from a data warehouse.

A very common scenario was discussed above with the *rolling window*, in which older data is rolled out of the data warehouse to make room for new data.

However, sometimes other data may need to removed from a data warehouse. Let's 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 via 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. The advantage to this approach is that this will be much more efficient than a serial DELETE statement, and that none of the data in the SALES table will need to 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 will not be reclaimed. Moreover, even though the DELETE statement is parallelized, there may be more efficient methods. An alternative method is to recreate 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, etc.
DROP TABLE SALES;
RENAME SALES2 TO SALES;
```

This approach may be more efficient than a parallel delete. However, this approach is also costly in terms of the amount of disk space, since the SALES table must effectively be instantiated twice.

An alternative method to utilize less space is to recreate 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.

Example: Re-synchronizing a Materialized View

Another major component of loading and refreshing a data warehouse is the refreshing of materialized views. Because many of the previous examples in this chapter relied on partition-maintenance operations, this section will initially discuss how to maintain materialized views following these operations. The following example demonstrates how you can manually re-synchronize a materialized view with its detail tables after performing partition maintenance operations on one of its detail tables. The method shown requires the materialized view to be partitioned on the same key column(s) as that of detail table and that the materialized view partitions have a one to one correspondence with the detail table partitions.

Drop an old partition from table FACT

```
ALTER TABLE fact DROP PARTITION month1;
```

Drop the corresponding old partition from materialized view DAILY_SUM using ALTER MATERIALIZED VIEW is currently not allowed, but ALTER TABLE works.)

```
ALTER TABLE daily_sum DROP PARTITION daily_sum_month1;
```

The materialized view is now stale and requires a complete refresh because of the partition operations. However, the materialized view is in fact fresh since we have manually re-synchronized it with its detail tables by dropping the corresponding materialized view partition. Therefore, we can alter the materialized view to tell Oracle to consider it fresh.

```
ALTER MATERIALIZED VIEW daily_sum CONSIDER FRESH;
```

DAILY_SUM's status is now neither known fresh nor known stale. Instead, it is UNKNOWN, enabling it to be used in QUERY_REWRITE_INTEGRITY = TRUSTED mode (if the materialized view is enabled for query rewrite). Moreover, the materialized view is again eligible for fast refresh after any subsequent updates.

In addition to re-synchronizing materialized views, this technique is also useful when the materialized view is intended to accumulate historical, aggregated data after it has been removed from the detail table. For example, you might wish to store 12 months of detail sales data in your warehouse, but also store 36 months of aggregate data in your materialized views. Oracle does not recommend you enable such a materialized view for query rewrite since the contents of the materialized view are deliberately not synchronized with its detail tables. This scenario can be implemented as shown above, except you omit the following statement:

```
ALTER TABLE daily_sum DROP PARTITION daily_sum_month1;
```

In order to deliberately not synchronize the materialized view with its detail tables. So long as the materialized view is not enabled for query rewrite, it is safe to use the following statement:

```
ALTER MATERIALIZED VIEW daily_sum CONSIDER FRESH;
```

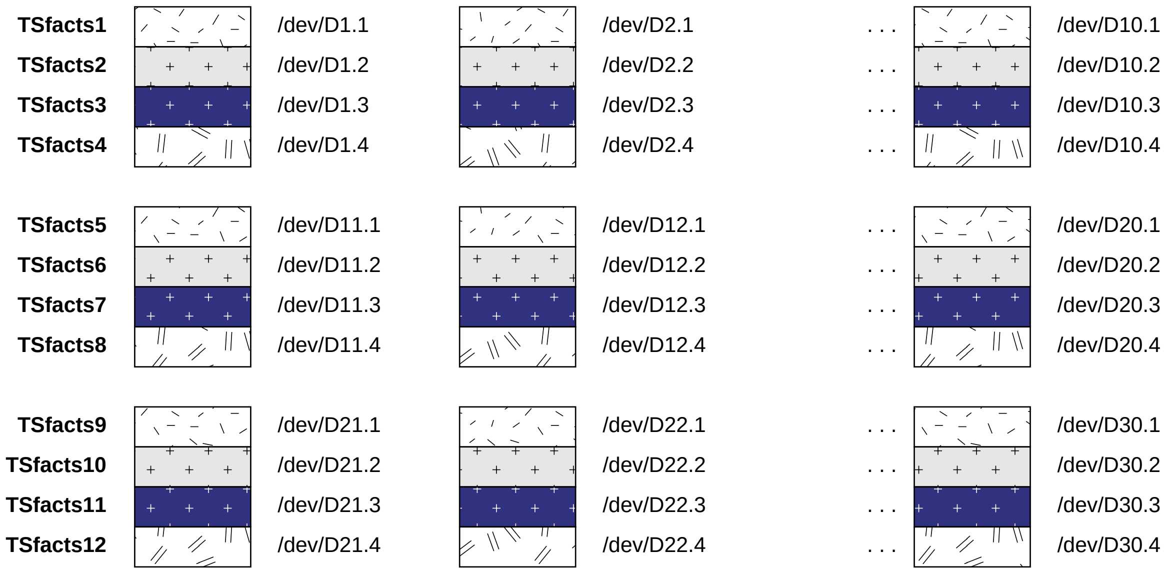
This statement informs Oracle that DAILY_SUM is fresh for your purposes, and thereby re-enable fast refresh after subsequent updates.

Populating Databases Using Parallel Load

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) will be used for base table data, 10 disks for index, 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 logical 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 OS utility into 4 OS 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 14–1.

Figure 14–1 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 commands 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 system parameter to match the current release number, and use the MAXEXTENTS keyword on the CREATE or ALTER command 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: It is not desirable to 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 50MB for a large object. Too small an extent size incurs significant overhead and this affects performance and scalability of parallel operations. The largest possible extent size for a 4GB disk evenly divided into 4 partitions is 1GB. 100MB 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 fact (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 restrictions such as the following:

- Indexes cannot be defined.
- You need to 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.

Case 1

In this approach, assume 12 input files are partitioned in the same way as your table. The DBA has 1 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 fact partition(jan95)
```

The advantages of this approach are 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.

Case 2

In another common approach, assume an arbitrary number of input files that are not partitioned in the same way as the table. The DBA can adopt a strategy of performing parallel load for each input file individually. Thus if there are 7 input files, the DBA can start 7 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 7 loader sessions can write into every partition. In case 1, every loader session would write into only 1 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.

Case 3

In Case 3 (illustrated in the example), the DBA wants precise control over the load. To achieve this, the DBA 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, the DBA 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. The DBA runs 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 Parallel Server, 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.

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.

Refreshing Materialized Views

When creating a materialized view, you have the option of specifying whether the refresh occurs ON DEMAND or ON COMMIT. When ON_DEMAND refresh is used, then the materialized view can be refreshed by calling one of the procedures in DBMS_MVIEW.

The DBMS_MVIEW package 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 "Manual Refresh Using the DBMS_MVIEW Package" on page 14-18 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 may prefer to not refresh all of their materialized views at the same time. Therefore, if you defer refreshing your materialized views, you can temporarily disable query rewrite with ALTER SYSTEM SET QUERY_REWRITE_ENABLED = FALSE. Users who still want access to the stale materialized views can override this default with ALTER SESSION SET QUERY_REWRITE_ENABLED = TRUE. After refreshing the materialized views, you can re-enable query rewrite as the default for all sessions in the current database instance by setting ALTER SYSTEM SET QUERY_REWRITE_ENABLED = TRUE.

Refreshing a materialized view automatically updates all of its indexes; in the case of full refresh, this requires temporary sort space. 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.

When a materialized view is refreshed, one of four refresh methods may be specified as shown in the table below.

Refresh Option		**Description**
COMPLETE	C	Refreshes by recalculating the materialized view's defining query.
FAST	F	Refreshes by incrementally applying changes to the detail tables.
FORCE	?	Tries to do a fast refresh. If that is not possible, it does a complete refresh.
ALWAYS	A	Unconditionally does a complete refresh.

Complete Refresh

A complete refresh occurs when the materialized view is initially defined, unless the materialized view references a prebuilt table, and complete refresh may be requested at any time during the life of the materialized view. Because the refresh involves reading the detail table 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, one should always consider the time required to process a complete refresh before requesting it. See *Oracle8i Designing and Tuning for Performance* for further details.

However, there are cases when the only refresh method available 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 require 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 direct path option, or any bulk load utility that uses Oracle's direct path interface, to perform incremental loads of detail data. Use of Oracle's direct path interface makes fast refresh of your materialized views efficient because, instead of having to recompute the entire materialized view, the changes are added to the existing data. Thus, applying only the changes can result in a very fast refresh time.

The time required to perform incremental refresh is sensitive to several factors:

- Whether the data in the materialized view container table is partitioned
- The number of inner joins in the materialized view that have not been declared as part of a referential integrity constraint or JOIN KEY declaration in a CREATE or ALTER DIMENSION statement

The first factors can be addressed by partitioning the materialized view container by time, like the fact tables, and by creating a local concatenated index on the materialized view keys. The third factor can be addressed by creating dimensions and hierarchies for your schema, and by ensuring that all materialized view inner joins are strict 1:n relationships whenever possible, as described below.

Manual Refresh Using the DBMS_MVIEW Package

Three different refresh procedures are available in the DBMS_MVIEW package for performing ON DEMAND refresh and they each have their own unique set of parameters. To use this package, Oracle8 queues must be available, which means that the following parameters must be set in the initialization parameter file. If queues are unavailable, refresh will fail with an appropriate message.

> **See Also:** See *Oracle8i Supplied PL/SQL Packages Reference* for detailed information about the DBMS_MVIEW package. *Oracle8i Replication* explains how to use it in a replication environment.

Required Initialization Parameters for Refresh

- JOB_QUEUE_PROCESSES

  The number of background processes. Determines how many materialized views can be refreshed concurrently.

- JOB_QUEUE_INTERVAL

  In seconds, the interval between which the job queue scheduler checks to see if a new job has been submitted to the job queue.

- UTL_FILE_DIR

  Determines the directory where the refresh log is written. If unspecified, no refresh log will be created.

These packages also create a log which, by default, is called refresh.log and is useful in helping to diagnose problems during the refresh process. This log file can be renamed by calling the procedure DBMS_OLAP.SET_LOGFILE_NAME ('log filename').

Refresh Specific Materialized Views

The DBMS_MVIEW.REFRESH procedure is used to refresh one or more materialized views that are explicitly defined in the FROM list. This refresh procedure can also be used to refresh materialized views used by replication, so not all of the parameters are required. The required parameters to use this procedure are:

- The list of materialized views to refresh, delimited by a comma
- The refresh method: A-Always, F-Fast, ?-Force, C-Complete
- The rollback segment to use
- Continue after errors

  When refreshing multiple materialized views, if one of them has an error while being refreshed, the job will continue if set to TRUE.

- The following four parameters should be set to FALSE, 0,0,0

  These are the values required by warehouse refresh, since these parameters are used by the replication process.

- Atomic refresh

  If set to TRUE, all refreshes are done in one transaction. If set to FALSE, then each refresh is done in a separate transaction.

Therefore, to perform a fast refresh on the materialized view *store_mv*, the package would be called as follows:

```
DBMS_MVIEW.REFRESH('STORE_MV', 'A', '', TRUE, FALSE, 0,0,0, FALSE);
```

Multiple materialized views can be refreshed at the same time and they don't 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 *store_mv* will be completely refreshed and *product_mv* will receive a fast refresh.

```
DBMS_MVIEW.REFRESH('STORE_MV,PRODUCT_MV', 'AF', '', TRUE, FALSE, 0,0,0, FALSE);
```

Refresh All Materialized Views

An alternative to specifying the materialized views to refresh is to use the procedure DBMS_MVIEW.REFRESH_ALL_MVIEWS. This will result in all materialized views being refreshed. 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
- The datatype number
- The refresh method: A-Always, F-Fast, ?-Force, C-Complete
- The rollback segment to use
- Continue after errors

An example of refreshing all materialized views is:

```
DBMS_MVIEW.REFRESH_ALL_MVIEWS ( failures,'A','',FALSE,FALSE);
```

Refresh Dependent

The third option is the ability to refresh only those materialized views that depend on a specific table using the procedure DBMS_MVIEW. REFRESH_DEPENDENT. For example, suppose the changes have been received for the orders table but not customer payments. The refresh dependent procedure can be called to refresh only those materialized views that reference the ORDER table.

The parameters for this procedure are:

- The number of failures
- The dependent table
- The refresh method: A-Always, F-Fast, ?-Force, C-Complete
- The rollback segment to use
- Continue after errors

  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 refresh log will give details of each of the errors, as will the alert log for the instance. 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

  A Boolean parameter.

In order to perform a full refresh on all materialized views that reference the ORDERS table, use:

```
DBMS_mview.refresh_dependent  (failures, 'ORDERS', 'A', '', FALSE, FALSE );
```

To provide the list of materialized views that are directly dependent on a given object (table/MV), use:

```
DBMS_mview.get_mv_dependencies ( mvlist  IN   VARCHAR2, deplist OUT  VARCHAR2)
```

The input to the above functions is the name(s) of the materialized view and 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)
```

would populate deplist with the list of materialized views defined on the input arguments

```
deplist <= "JOHN.SUM_SALES_WEST, JOHN.SUM_SALES_EAST, SCOTT.SUM_PROD_MONTH".
```

Tips for Refreshing Using Refresh

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.

Materialized Views with Joins and Aggregates

1-Enable Parallel DML.

2-Use atomic=FALSE, which will use TRUNCATE instead of DELETE to delete existing rows.

Here are some guidelines for using the refresh mechanism for materialized views with joins and aggregates.

1. Always load new data using the direct-path option if possible. Avoid deletes and updates because a complete refresh will be necessary (for aggregates only). However, you can drop a partition on a materialized view and do a fast refresh.
2. Place fixed key constraints on the fact table, and primary key constraints from the fact table to the dimension table. Doing this enables refresh to identify the fact table, which helps fast refresh.
3. During loading, disable all constraints and re-enable when finished loading.
4. Index the materialized view on the foreign key columns using a concatenated index.
5. To speed up fast refresh, make the number of job queue processes greater than the number of processors.
6. If there are many materialized views to refresh, it is faster to refresh all in a single command than to call them individually.
7. Make use of the "?" refresh method to ensure getting a refreshed materialized view that can be used to query rewrite. If a fast refresh cannot be done, a complete refresh will be performed. Whereas, if a fast refresh had been requested and there was no need for a refresh, the materialized view would not be refreshed at all.
8. Try to create materialized views that are fast refreshable because it refreshes more quickly.

9. If a materialized view contains data that is based on data which is no longer in the fact table, maintain the materialized view using fast refresh. If no job queues are started, two job queue processes will be started by the refresh. This can be modified by:

   ```
   ALTER SYSTEM SET JOB_QUEUE_PROCESSES = value
   ```

10. In general, the more processors there are, the more job queue processes should be created. Also, if you are doing mostly complete refreshes, reduce the number of job queue processes, since each refresh consumes more system resources than a fast refresh. The number of job queue processes limits the number of materialized views that can be refreshed concurrently. In contrast, if you perform mostly fast refreshes, increase the number of job queue processes.

Refresh of Materialized Views Containing a Single Table with Aggregates

A materialized view which contains aggregates and is based on a single table may be fast refreshable, provided it adheres to the rules in Requirements for Fast Refresh when data changes are made using either direct path or SQL DML statements. At refresh time, Oracle detects the type of DML that has been done (direct-load or SQL DML) and uses either the materialized view log or information available from the direct-path to determine the new data. If changes will be made to your data using both methods, then refresh should be performed after each type of data change rather than issuing one refresh at the end. This is because Oracle can perform significant optimizations if it detects that only one type of DML is done. It is therefore recommended that scenario 2 be followed rather than scenario 1.

To improve fast refresh performance, it is highly recommended that indexes be created on the columns which contain the rowids.

Scenario 1

- Direct-load data to detail table
- SQL DML such as INSERT or DELETE to detail table
- Refresh materialized view

Scenario 2

- Direct-load data to detail table
- Refresh materialized view
- SQL DML such as INSERT or DELETE to detail table

- Refresh materialized view

Furthermore, for refresh ON COMMIT, Oracle keeps track of the type of DML done in the committed transaction. It is thus recommended that the user does not do direct-path load and SQL DML to other tables in the same transaction as Oracle may not be able to optimize the refresh phase.

If the user has done a lot of updates to the table, it is better to bunch them in one transaction, so that refresh of the materialized view will be performed just once at commit time rather than after each update. In the warehouse, after a bulk load, the user should enable parallel DML in the session and perform the refresh. Oracle will use parallel DML to do the refresh, which will enhance performance tremendously. There is more to gain if the materialized view is partitioned.

As an example, assume that a materialized view is partitioned and has a parallel clause. The following sequence would be recommended in a data warehouse

1. Bulk load into detail table
2. ALTER SESSION ENABLE PARALLEL DML;
3. Refresh materialized view

Refresh of Materialized Views Containing only Joins

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, referring to the following materialized view:

```
CREATE MATERIALIZED VIEW  detail_fact_mv
BUILD IMMEDIATE
REFRESH FAST ON COMMIT
 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(+);
```

Indexes should be created on columns FACT_RID, TIME_RID and STORE_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 therefore 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 load 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, it is recommended that the refresh be invoked after each table is loaded, rather than load all the tables and then perform the refresh. Therefore, try to use scenario 2 below for your refresh procedures.

Scenario 1

```
apply changes to fact
apply changes to store
refresh detail_fact_mv
```

Scenario 2

```
apply changes to fact
refresh detail_fact_mv
apply changes to store
refresh detail_fact_mv
```

For refresh ON COMMIT, Oracle keeps track of the type of DML done in the committed transaction. It is therefore recommended 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:

```
direct path new data into fact
Conventional dml into store
commit
```

One should 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:

```
insert into fact ..
delete from fact ..
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.

Scenario 1

```
update fact
commit
update fact
commit
update fact
commit
```

Scenario 2

```
update fact
update fact
update fact
commit
```

Note that if, when you use the DBMS_MVIEW package to refresh a number of materialized views containing only joins with the "atomic" parameter set to TRUE, parallel DML is disabled, which could lead to poorer refresh performance.

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 fact
2. ALTER SESSION ENABLE PARALLEL DML;
3. Refresh materialized view

Refreshing Nested Materialized Views

Refreshing materialized join views 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.

Example: Consider the schema in Figure 8–5. Assume all the materialized views are defined for ON COMMIT refresh. If table *fact* changes, at commit time, you could refresh *join_fact_store_time* first and then *sum_sales_store_time* and *join_fact_store_time_prod* (with 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, ALL)_MVIEWS view.

If any of the materialized views is 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) since the nested materialized view will be refreshed with respect to the current state of the other materialized views (whether fresh or not). You can find out dependent materialized views for a particular object using the PL/SQL function GET_MVIEW_DEPENDENCIES() in the DBMS_MVIEWS package.

If a refresh fails during commit time, the list of materialized views that have not been refreshed will be written to the alert log and the user will have to manually refresh them along with all their dependent materialized views.

APIs As is the case with all materialized views, the functions in the DBMS_MVIEW package have to be used to refresh a nested materialized view on demand. These functions have the following behavior when used with nested materialized views:

- If REFRESH() is used to refresh a materialized view M that is built on other materialized views, then M will be refreshed with respect to the current state of the other materialized views (that is, they won't be made fresh first).
- If REFRESH_DEPENDENT() is used to refresh with respect to the materialized view M, then only materialized views that directly depend on M will be refreshed (that is, a materialized view that depends on a materialized view that depends on M 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() is a new function provided to list the immediate (or direct) materialized view dependencies for an object.

Complex Materialized Views

A complex materialized view is one which cannot be fast refreshed. If you will be using only COMPLETE REFRESH, you can create a materialized view with any definition.

Recommended Initialization Parameters for Parallelism

The following parameters

- PARALLEL_MAX_SERVERS should be set high enough to take care of parallelism.

- SORT_AREA_SIZE should be less than HASH_AREA_SIZE.
- OPTIMIZER_MODE should equal ALL_ROWS (cost based optimization).
- OPTIMIZER_PERCENT_PARALLEL should equal 100.

  Analyze all tables and indexes for better costing.

Monitoring a Refresh

While a job is running, a SELECT * FROM V$SESSION_LONGOPS statement will tell you the progress of each materialized view being refreshed.

To look at the progress of which jobs are on which queue, use a SELECT * FROM DBA_JOBS_RUNNING statement.

The table ALL_MVIEWS contains the values, as a moving average, for the time most recently refreshed and the average time to refresh using both full and incremental methods.

Refresh will schedule the long running jobs first. Use the refresh log to check what each refresh did.

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 may 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 REFRESH.

If the materialized view is being refreshed using the ON COMMIT method, then, following refresh operations, the alert log (alert_ <SID>.log) and the trace file (ora_ <SID>_number.trc) should be consulted to check that no errors have occurred.

15

Summary Advisor

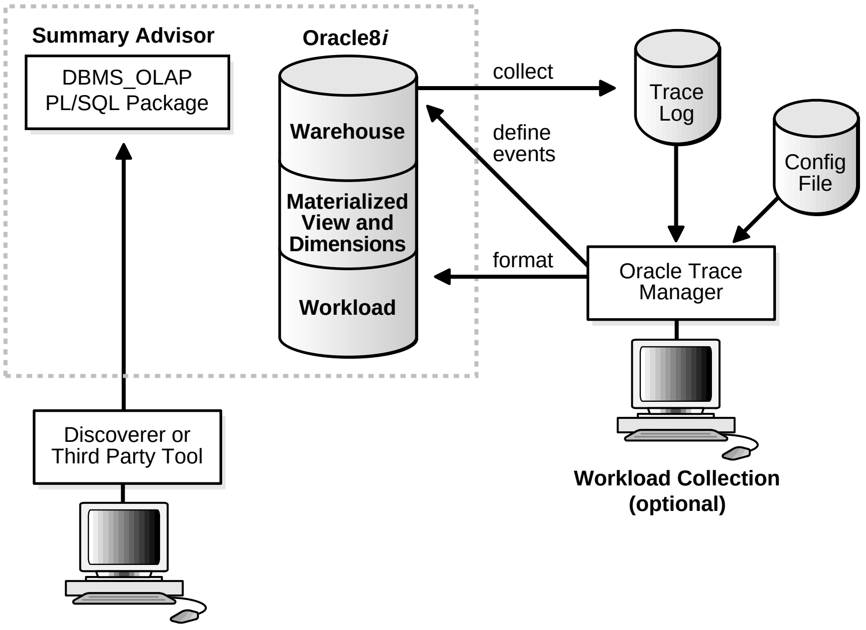
This chapter can help you create and manage a data warehouse, and includes:

- Summary Advisor
- Is a Materialized View Being Used?

Summary Advisor

To help you select from among the many materialized views that are possible in your schema, Oracle provides a collection of materialized view analysis and advisory functions in the DBMS_OLAP package. These functions are callable from any PL/SQL program.

Figure 15–1 Materialized Views and the Summary Advisor



From within the DBMS_OLAP package, several facilities are available to:

- 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

Whenever the summary advisor is run, with the exception of reporting the size of a materialized view, the results are placed in a table in the database which means that they can be queried, thereby saving the need to keep running the advisor process.

Collecting Structural Statistics

The advisory functions of the DBMS_OLAP package require you to gather structural statistics about fact table cardinalities, dimension table cardinalities, and the distinct cardinalities of every dimension LEVEL column, JOIN KEY column, and fact table key column. This can be accomplished 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. The advisor cannot be used if no dimensions have been defined, which is a good reason for ensuring that some time is spent creating them.

Collection of Dynamic Workload Statistics

Optionally, if you have purchased the *Oracle Enterprise Manager Performance Pack*, then you may also run Oracle Trace to gather dynamic information about your query work load, which can then be used by an advisory function. If Oracle Trace is available, serious consideration should be given to collecting materialized view usage. Not only does it enable the DBA to see which materialized views are in use, but it also means that the advisor may detect some unusual query requests from the users which would result in recommending some different materialized views.

Oracle Trace gathers the following work load statistics for the analysis of materialized views:

- The name of each materialized view selected by query rewrite
- The estimated benefit obtained by using the materialized view, which is roughly the ratio of the fact table cardinality to the materialized view cardinality, adjusted for the need to further aggregate over the materialized view or join it back to other relations
- The *ideal* materialized view that could have been used by the request

Oracle Trace includes two new *point events* for collecting runtime statistics about materialized views: one event that records the selected materialized view names at request execution time, and another event that records the estimated benefit and ideal materialized view at compile time. You can log just these two events for materialized view analysis if desired, or you can join this information with other information collected by Oracle Trace, such as the SQL text or the execution time of the request, if other Trace events are also collected. A collection option in the Oracle Trace Manager GUI provides a way to collect materialized view management statistics.

To collect and analyze the summary event set, you must do the following:

1. Set six initialization parameters to collect data via Oracle Trace. Enabling these parameters incurs some additional overhead at database connection, but is otherwise transparent.

   - ORACLE_TRACE_COLLECTION_NAME = oraclesm
   - ORACLE_TRACE_COLLECTION_PATH = location of collection files
   - ORACLE_TRACE_COLLECTION_SIZE = 0
   - ORACLE_TRACE_ENABLE = TRUE turns on Trace collecting
   - ORACLE_TRACE_FACILITY_NAME = oraclesm
   - ORACLE_TRACE_FACILITY_PATH = location of trace facility files

   For further information on these parameters, refer to the *Oracle Trace Users Guide*.

2. Run the Oracle Trace Manager GUI, 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 V_ 192216243_F_5_E_14_8_1 and V_192216243_F_5_E_15_8_1. The workload tables should be located in the same schema that the subsequent workload analysis will be performed in. Alternatively, the collection file, which usually has an extension of .CDF, can be formatted manually using **otrcfmt**. A manual collection command is illustrated below:

   ```
   otrcfmt   collection_name.cdf   user/password@database
   ```

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 KEY clause of a CREATE DIMENSION statement).

Once these four steps have been completed, you will be ready to make recommendations about your materialized views.

Recommending Materialized Views

The analysis and advisory functions for materialized views are RECOMMEND_MV and RECOMMEND_MV_W in the DBMS_OLAP package. These functions automatically recommend which materialized views to create, retain, or drop.

- RECOMMEND_MV uses structural statistics, but not workload statistics, to generate recommendations.
- RECOMMEND_MV_W uses both workload statistics and structural statistics.

You can call these functions 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.

The summary advisor will not be able to recommend summaries if the following conditions are not met:

1. All tables including existing materialized views must have been analyzed as described in step 4 above.
2. Dimensions must exist.
3. The advisor should be able to identify the fact table because it will contain foreign key references to other tables.

See Also: See *Oracle8i Supplied PL/SQL Packages Reference* for detailed information about the DBMS_OLAP package.

Four parameters are required to use these functions:

- Fact table names or null to analyze all fact tables
- The maximum storage that can be used for storing materialized views
- A list or materialized views that you want to retain
- A number between 0 to 100 that specifies the percentage of materialized views that must be retained

A typical call to the package, where the main fact table is called FACT, would be:

```
DBMS_OLAP.RECOMMEND_MV('fact', 100000, '', 10);
```

No workload statistics are used in this example.

The results from calling this package are put in the table MVIEWS$_RECOMMENDATIONS. The contents of this table can be queried or they can be displayed using the SQL file sadvdemo.sql. The output from calling this procedure is the same irrespective of whether the workload statistics are used.

The recommendations can be viewed by calling the procedure DEMO_SUMADV.PRETTYPRINT_RECOMMENDATIONS, but first you need to run sadvdemo.sql. It is suggested that SET SERVEROUTPUT ON SIZE 900000 be used to ensure that all the information can be displayed. A sample recommendation that resulted from calling this package is shown below.

Recommendation Number 1

```
Recommended Action is DROP existing summary GROCERY.QTR_STORE_PROMO_SUM
Storage in bytes is 196020
Percent performance gain is null
Benefit-to-cost ratio is null
```

Recommendation Number 2

```
Recommended Action is RETAIN existing summary GROCERY.STORE_SUM
Storage in bytes is 21
Percent performance gain is null
Benefit-to-cost ratio is null
```

To call the package and use the workload statistics, the only difference is the procedure name that is called. For example, instead of *recommend_mv*, it's *recommend_mv_w*.

```
DBMS_OLAP.RECOMMEND_MV_W('fact', 100000, '', 10);
```

Recommendation Number 3

```
Recommendation Number = 3
Recommended Action is CREATE new summary:
SELECT PROMOTION.PROMOTION_KEY, STORE.STORE_KEY, STORE.STORE_NAME,
     STORE.DISTRICT, STORE.REGION , COUNT(*), SUM(FACT.CUSTOMER_COUNT),
     COUNT(FACT.CUSTOMER_COUNT), SUM(FACT.DOLLAR_COST),
COUNT(FACT.DOLLAR_COST),
     SUM(FACT.DOLLAR_SALES), COUNT(FACT.DOLLAR_SALES), MIN(FACT.DOLLAR_SALES),
     MAX(FACT.DOLLAR_SALES), SUM(FACT.RANDOM1), COUNT(FACT.RANDOM1),
     SUM(FACT.RANDOM2), COUNT(FACT.RANDOM2), SUM(FACT.RANDOM3),
     COUNT(FACT.RANDOM3), SUM(FACT.UNIT_SALES), COUNT(FACT.UNIT_SALES)
FROM GROCERY.FACT, GROCERY.PROMOTION, GROCERY.STORE
WHERE FACT.PROMOTION_KEY = PROMOTION.PROMOTION_KEY AND FACT.STORE_KEY =
     STORE.STORE_KEY
GROUP BY PROMOTION.PROMOTION_KEY, STORE.STORE_KEY, STORE.STORE_NAME,
     STORE.DISTRICT, STORE.REGION
```

```
Storage in bytes is 257999.999999976
Percent performance gain is .533948057298649
Benefit-to-cost ratio is .0000206956611356085
```

Recommendation Number 4

```
Recommended Action is CREATE new summary:
SELECT STORE.REGION, TIME.QUARTER, TIME.YEAR , COUNT(*),
     SUM(FACT.CUSTOMER_COUNT), COUNT(FACT.CUSTOMER_COUNT),
SUM(FACT.DOLLAR_COST),
     COUNT(FACT.DOLLAR_COST), SUM(FACT.DOLLAR_SALES),
COUNT(FACT.DOLLAR_SALES),
     MIN(FACT.DOLLAR_SALES), MAX(FACT.DOLLAR_SALES), SUM(FACT.RANDOM1),
     COUNT(FACT.RANDOM1), SUM(FACT.RANDOM2), COUNT(FACT.RANDOM2),
     SUM(FACT.RANDOM3), COUNT(FACT.RANDOM3), SUM(FACT.UNIT_SALES),
     COUNT(FACT.UNIT_SALES)
FROM GROCERY.FACT, GROCERY.STORE, GROCERY.TIME
WHERE FACT.STORE_KEY = STORE.STORE_KEY AND FACT.TIME_KEY = TIME.TIME_KEY
GROUP BY STORE.REGION, TIME.QUARTER, TIME.YEAR

Storage in bytes is 86
Percent performance gain is .523360688578368
Benefit-to-cost ratio is .00608558940207405
```

Estimating Materialized View Size

Since a materialized view occupies storage space in the database, 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 discoverer that insufficient space is available in the tablespace, use the package DBMS_ESTIMATE_SIZE. Calling this procedure instantly returns an estimate of the size in bytes that the materialized view is likely to occupy.

The parameters to this procedure are:

- the name for sizing
- the SELECT statement

and the package 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 that will be specified in the materialized view is passed into the ESTIMATE_SUMMARY_SIZE package. Note that the SQL statement is passed in without a ";".

```
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
```

Summary Advisor Wizard

The Summary Advisor Wizard, which can be found in Oracle Enterprise Manager, provides an interactive environment to recommend and build materialized views. Using this approach, 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 will be automatically selected, otherwise, it will display the recommendations that are generated from the advisor functions RECOMMEND_MV or RECOMMEND_MV_W.

By using the wizard, all of the steps required to maintain your materialized views can be completed by answering the wizard's questions and no subsequent DML operations are required. See the Oracle Enterprise Manager documentation set for further details.

Is a Materialized View Being Used?

One of the major administrative problems with materialized views is knowing whether they are being used. Materialized views could be in regular use or they could have been created for a one-time problem that has now been resolved. However, the usergroup who requested this level of analysis might never have told the DBA that it was no longer required, so the materialized view remains in the database occupying storage space and possibly being regularly refreshed.

If the Oracle Trace option is available, then it can advise the DBA which materialized views are in use, using exactly the same procedure as for collecting workload statistics. Trace collection is enabled and in this case the collection period is likely to be longer that for query collection because Trace will only report 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.

Once you are satisfied that you have collected sufficient data, the data is formatted by Oracle Trace, just as if it were workload information, and then the package EVALUATE_UTILIZATION_W is called. It analyzes the data and then the results are placed in the table MVIEWS$_EVALUATIONS.

In the example below, the utilization of materialized views is analyzed and the results are displayed.

```
DBMS_OLAP.EVALUATE_UTILIZATION_W();
```

Note that no parameters are passed into the package.

Shown below is a sample output obtained by querying the table MVIEW$EVALUATIONS which is providing 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 is calculated each time the materialized view is used as
- The benefit-to-cost ratio is 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:

- Schemas
- SQL for Analysis
- Tuning Parallel Execution
- Query Rewrite

16 Schemas

The following topics provide information about schemas in a data warehouse:

- Schemas
- Optimizing Star Queries

Schemas

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, most of the examples in this book utilize a star schema. However, a significant but smaller number of data warehouses use third-normal-form (3NF) schemas, or other schemas which are more highly normalized than star schemas. These 3NF data warehouses are typically very large data warehouses, which are used primarily for loading data and for feeding data marts. These data warehouses are not typically used for heavy end-user query workloads.

Some features of the Oracle8*i* database, such as the *star transformation* feature described in this chapter, are specific to star schemas, however, the vast majority of Oracle8*i*'s data warehousing features are equally applicable to both star schemas and 3NF schemas.

Star Schemas

The star schema is the simplest data warehouse schema. It is called a star schema because the diagram of a star schema 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.

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 lookup tables. Each lookup table is joined to the fact table using a primary-key to foreign-key join, but the lookup tables are not joined to each other.

Cost-based optimization recognizes star queries and generates efficient execution plans for them. (Star queries are not recognized by rule-based optimization.)

A typical fact table contains *keys* and *measures*. For example, a simple fact table might contain the measure Sales, and keys Time, Product, and Market. In this case, there would be corresponding dimension tables for Time, Product, and Market. The Product dimension table, for example, would typically contain information about each product number that appears in the fact table. A measure is typically a numeric or character column, and can be taken from one column in one table or derived from two columns in one table or two columns in more than one table.

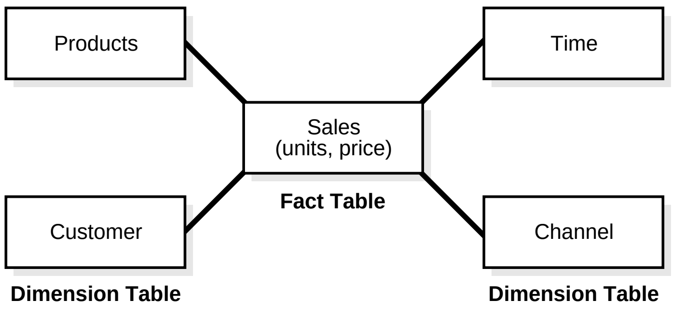
A *star join* is a primary-key to foreign-key join of the dimension tables to a fact table. The fact table normally has a concatenated index on the key columns to facilitate this type of join.

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.
- Provides highly optimized performance for typical data warehouse queries.

Figure 16–1 presents a graphical representation of a star schema.

Figure 16–1 Star Schema

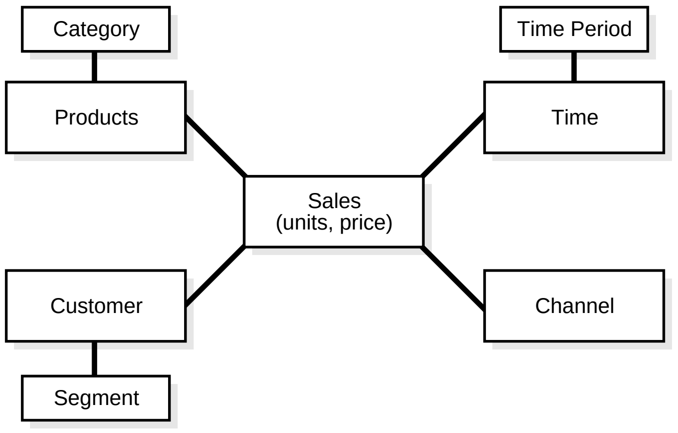


Snowflake Schemas

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 Product 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 16–2 presents a graphical representation of a snowflake schema.

Figure 16–2 Snowflake Schema



Note: Oracle recommends you choose a star schema over a snowflake schema unless you have a clear reason not to.

Optimizing Star Queries

Tuning Star Queries

In order 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(s).
- 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.

Star Transformation

The star transformation is a cost-based query transformation aimed at executing star queries efficiently. Whereas the star optimization works well for schemas with a small number of dimensions and dense fact tables, the star transformation may be considered as an alternative if any of the following holds true:

- The number of dimensions is large
- The fact table is sparse
- There are queries where not all dimension tables have constraining predicates

The star transformation does not rely on computing a Cartesian product of the dimension tables, which makes it better suited for cases where fact table sparsity and/or a large number of dimensions would lead to a large Cartesian product with few rows having actual matches in the fact table. In addition, rather than relying on concatenated indexes, the star transformation is based on combining bitmap indexes on individual fact table columns.

The transformation can thus combine indexes corresponding precisely to the constrained dimensions. There is no need to create many concatenated indexes where the different column orders match different patterns of constrained dimensions in different queries.

Attention: Bitmap indexes are available only if you have purchased the Oracle8*i* Enterprise Edition. In Oracle8*i*, bitmap indexes and star transformation are not available.

Star Transformation Example

This section provides an example of the star transformation. The star transformation is a powerful, and interesting, optimization technique which 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 will automatically choose the star transformation where appropriate.

However, the DBA may be interested to learn the details of the star transformation. This section will enable the DBA to understand how the star transformation algorithm works, and moreover, the DBA will be able to recognize the execution plans of star queries which are using the star transformation.

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. Below is an example of how an end-user may query this data warehouse: "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. The SQL generated by an end-user tool could look like:

```
SELECT
    store.sales_district,
    time.fiscal_period,
    SUM(sales.dollar_sales) revenue,
    SUM(dollar_sales) - SUM(dollar_cost) income
FROM
    sales, store, time, product
WHERE
    sales.store_key = store.store_key AND
    sales.time_key  = time.time_key AND
    sales.product_key = product.product_key AND
    time.fiscal_period IN ('3Q95', '4Q95', '1Q96') and
    product.department = 'Grocery' AND
    store.sales_district IN ('San Francisco', 'Los Angeles')
GROUP BY
    store.sales_district, time.fiscal_period;
```

Oracle will process this query in two phases. In the first phase, Oracle will use the bitmap indexes on the foreign-key columns of the fact table to identify and retrieve the 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
    store_key IN (SELECT store_key FROM store WHERE
                  sales_district IN ('WEST', 'SOUTHWEST')) AND
    time_key  IN (SELECT time_key FROM time WHERE
                  quarter IN ('3Q96', '4Q96', '1Q97')) AND
    product_key IN (SELECT product_key FROM product WHERE
                    department = 'GROCERY');
```

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 store_key is used to identify the set of all rows in the fact table corresponding to sales in the West sales district. 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 in the Southwest sales district. The bitmap OR operation is used to combine this set of Southwest sales with the set of West sales.

Additional set operations will be done for the time 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' patented, 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.

The second phase of this query is to join these rows from the fact table 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 may be used to quickly identify all of those products in the grocery department. Oracle8's cost-based optimizer will automatically determine 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 tables 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

The following execution plan might result from "Star Transformation Example" on page 16-5:

```
SELECT STATEMENT
  HASH JOIN
   HASH JOIN
    HASH JOIN
     TABLE ACCESS                SALES              BY INDEX ROWID
      BITMAP CONVERSION                             TO ROWIDS
       BITMAP AND
        BITMAP MERGE
         BITMAP KEY ITERATION
          TABLE ACCESS           STORE              FULL
          BITMAP INDEX           SALES_STORE_KEY    RANGE SCAN
        BITMAP MERGE
         BITMAP KEY ITERATION
          TABLE ACCESS           TIME               FULL
          BITMAP INDEX           SALES_TIME_KEY     RANGE SCAN
        BITMAP MERGE
         BITMAP KEY ITERATION
          TABLE ACCESS           PRODUCTS           FULL
          BITMAP INDEX           SALES_PRODUCT_KEY  RANGE SCAN
     TABLE ACCESS                TIME               FULL
    TABLE ACCESS                 PRODUCTS           FULL
   TABLE ACCESS                  STORE              FULL
```

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 just 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.

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 may well 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 will generate 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.

Restrictions on Star Transformation

Star transformation is not supported for tables with any of the following characteristics:

- Tables with a table hint that is incompatible with a bitmap access path
- 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 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
- 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

17

SQL for Analysis

The following topics provide information about how to improve analytical SQL queries in a data warehouse:

- Overview
- ROLLUP
- CUBE
- Using Other Aggregate Functions with ROLLUP and CUBE
- GROUPING Function
- Other Considerations when Using ROLLUP and CUBE
- Analytic Functions
- Case Expressions

Overview

Oracle has enhanced SQL's analytical processing power along several paths:

- The CUBE and ROLLUP extensions to the GROUP BY clause of the SELECT statement
- A new family of analytic SQL functions
- Linear regression functions
- CASE expressions

The CUBE and ROLLUP extensions to SQL make querying and reporting easier in data warehousing environments. ROLLUP creates subtotals 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 subtotals. CUBE can generate the information needed in cross-tabulation reports with a single query.

Analytic functions enable rankings, moving window calculations, and lead/lag analysis. 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. Lead/lag analysis enables direct inter-row references so you can calculate period-to-period changes.

Other enhancements to SQL include a family of regression functions and the CASE expression. Regression functions offer a full set of linear regression calculations. CASE expressions provide if-then logic useful in many situations.

These CUBE and ROLLUP extensions and analytic functions are part of the core SQL processing. To enhance performance, CUBE, ROLLUP, and 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:** For information on parallel execution, see Chapter 18, "Tuning Parallel Execution".

Analyzing Across Multiple Dimensions

One of the key concepts in decision support systems is multi-dimensional 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 may be sales in units or local currency, profits, customer counts, production volumes, or anything else worth tracking.

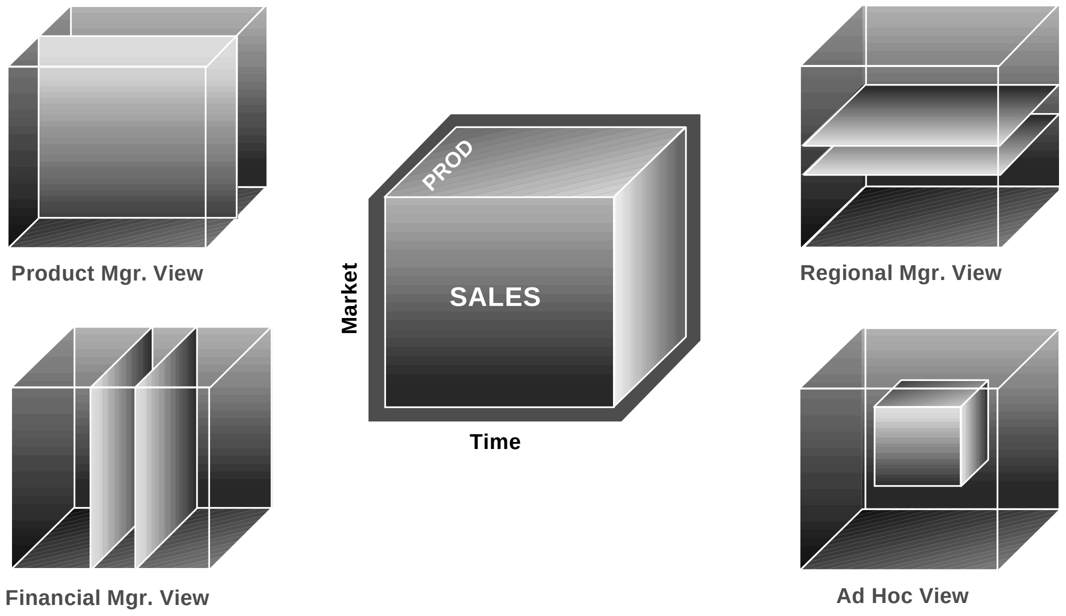
Here are some examples of multidimensional requests:

- Show total sales across all products at increasing aggregation levels for a geography dimension: from state to country to region for 1998 and 1999.
- Create a cross-tabular analysis of our operations showing expenses by territory in South America for 1998 and 1999. Include all possible subtotals.
- List the top 10 sales representatives in Asia according to 1999 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 17–1 shows a data cube and how it could be used differently by various groups. The cube stores sales data organized by the dimensions of Product, Market, and Time.

Figure 17–1 Cubes and Views by Different Users



We can retrieve *slices* of data from the cube. These correspond to cross-tabular reports such as the one shown in Table 17–1. 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 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. Subtotals 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 needs optimized performance.

Oracle8*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

Oracle8*i* provides all these benefits with the new CUBE and ROLLUP extensions to the GROUP BY clause. These extensions adhere to the ANSI and ISO proposals for SQL3, a draft standard for enhancements to SQL.

A Scenario

To illustrate CUBE and ROLLUP queries, this chapter uses a hypothetical videotape sales and rental company. All the examples given refer to data from this scenario. The hypothetical company has stores in several regions and tracks sales and profit information. The data is categorized by three dimensions: Time, Department, and Region. The time dimension members are 1996 and 1997, the departments are Video Sales and Video Rentals, and the regions are East, West, and Central.

Table 17–1 is a sample cross-tabular report showing the total profit by region and department in 1999:

Table 17–1 Simple Cross-Tabular Report, with Subtotals Shaded

		1999	
Region		**Department**	
	Video Rental Profit	**Video Sales Profit**	**Total Profit**
Central	82,000	85,000	167,000
East	101,000	137,000	238,000
West	96,000	97,000	193,000
Total	279,000	319,000	598,000

Consider that even a simple report like Table 17–1, with just twelve values in its grid, generates five 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 used standard SUM() and GROUP BY operations. Database commands that offer improved calculation of subtotals bring major benefits to querying, reporting, and analytical operations.

ROLLUP

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.

Syntax

ROLLUP appears in the GROUP BY clause in a SELECT statement. Its form is:

```
SELECT … GROUP BY ROLLUP(grouping_column_reference_list)
```

Details

ROLLUP's action is straightforward: it creates subtotals which *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.

Example

This example of ROLLUP uses the data in the video store database, the same database as was used in Table 17–1, "Simple Cross-Tabular Report, with Subtotals Shaded".

```
SELECT Time, Region, Department,
   SUM(Profit) AS Profit FROM sales
   GROUP BY ROLLUP(Time, Region, Dept);
```

As you can see in Output 15-1, 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 Department for each combination of Time and Region
- Second-level subtotals aggregating across Region and Department for each Time value
- A grand total row

Output 15-1

ROLLUP Aggregation across Three Dimensions

```
Time      Region      Department        Profit
----      ------      ----------        ------
1996      Central     VideoRental       75,000
1996      Central     VideoSales        74,000
1996      Central     NULL             149,000
1996      East        VideoRental       89,000
1996      East        VideoSales       115,000
1996      East        NULL             204,000
1996      West        VideoRental       87,000
1996      West        VideoSales        86,000
1996      West        NULL             173,000
1996      NULL        NULL             526,000
1997      Central     VideoRental       82,000
1997      Central     VideoSales        85,000
1997      Central     NULL             167,000
1997      East        VideoRental      101,000
1997      East        VideoSales       137,000
1997      East        NULL             238,000
1997      West        VideoRental       96,000
1997      West        VideoSales        97,000
1997      West        NULL             193,000
1997      NULL        NULL             598,000
NULL      NULL        NULL           1,124,000
```

Note: The NULLs shown in the figures of this chapter are displayed only for clarity: in standard Oracle output, these cells would be blank.

Interpreting NULLs in Results

NULLs returned by ROLLUP and CUBE 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 Output 15-1 is in the Department column. This NULL means that the row is a subtotal for "All Departments" for the Central region in 1996. To avoid introducing another non-value in the database system, these subtotal values are not given a special tag.

See the section "GROUPING Function" on page 17-15 for details on how the NULLs representing subtotals are distinguished from NULLs stored in the data.

Partial Rollup

You can also ROLLUP 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, ROLLUP creates subtotals at (2+1=3) aggregation levels. That is, at level (expr1, expr2, expr3), (expr1, expr2), and (expr1). It does not produce a grand total.

Example:

This example of partial ROLLUP uses the data in the video store database.

```
SELECT Time, Region, Department,
   SUM(Profit) AS Profit FROM sales
   GROUP BY Time, ROLLUP(Region, Dept);
```

As you can see in Output 15-2, 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 Department for each combination of Time and Region
- Second-level subtotals aggregating across Region and Department for each Time value
- It does *not* produce a grand total row

Output 15-2

Partial ROLLUP

```
Time       Region      Department        Profit
----       ------      ----------        ------
1996       Central     VideoRental       75,000
1996       Central     VideoSales        74,000
1996       Central     NULL             149,000
1996       East        VideoRental       89,000
1996       East        VideoSales       115,000
1996       East        NULL             204,000
1996       West        VideoRental       87,000
1996       West        VideoSales        86,000
1996       West        NULL             173,000
1996       NULL        NULL             526,000
1997       Central     VideoRental       82,000
1997       Central     VideoSales        85,000
1997       Central     NULL             167,000
1997       East        VideoRental      101,000
1997       East        VideoSales       137,000
1997       East        NULL             238,000
1997       West        VideoRental       96,000
1997       West        VideoSales        97,000
1997       West        NULL             193,000
1997       NULL        NULL             598,000
```

Calculating Subtotals without ROLLUP

The result set in Table 17–1 could be generated by the UNION of four SELECT statements, as shown below. This is a subtotal across three dimensions. Notice that a complete set of ROLLUP-style subtotals in n dimensions would require n+1 SELECT statements linked with UNION ALL.

```
SELECT Time, Region, Department, SUM(Profit)
 FROM Sales
 GROUP BY Time, Region, Department
UNION  ALL
 SELECT Time, Region, '' , SUM(Profit)
 FROM Sales
 GROUP BY Time, Region
UNION ALL
 SELECT Time, '', '', SUM(Profits)
 FROM Sales
 GROUP BY Time
UNION ALL
```

```
SELECT '', '', '', SUM(Profits)
FROM Sales;
```

The approach shown in the SQL above has two shortcomings compared with the ROLLUP operator. First, the syntax is complex, requiring more effort to generate and understand. Second, and more importantly, query execution is inefficient because the optimizer receives no guidance about the user's overall goal. Each of the four SELECT statements above causes table access even though all the needed subtotals could be gathered with a single pass. **The ROLLUP extension makes the desired result explicit and gathers its results with just one table access.**

The more columns used in a ROLLUP clause, the greater the savings compared to the UNION ALL approach. For instance, if a four-column ROLLUP replaces a UNION of five SELECT statements, the reduction in table access is four-fifths or 80%.

Some data access tools calculate subtotals on the client side and thereby avoid the multiple SELECT statements described above. While this approach can work, it places significant loads on the computing environment. For large reports, the client must have substantial memory and processing power to handle the subtotaling tasks. Even if the client has the necessary resources, a heavy processing burden for subtotal calculations may slow down the client in its performance of other activities.

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, but not yet utilizing materialized views, ROLLUP may simplify and speed up the maintenance of summary tables.

See Also: For information on parallel execution, see Chapter 18, "Tuning Parallel Execution".

CUBE

The subtotals created by ROLLUP represent only a fraction of possible subtotal combinations. For instance, in the cross-tabulation shown in Table 17–1, the departmental totals across regions (279,000 and 319,000) would not be calculated by a ROLLUP(Time, Region, Department) clause. To generate those numbers would require a ROLLUP clause with the grouping columns specified in a different order: ROLLUP(Time, Department, Region). The easiest way to generate the full set of subtotals needed for cross-tabular reports such as those needed for Table 17–1 is to use the CUBE extension.

CUBE enables a SELECT statement to calculate subtotals for all possible combinations of a group of dimensions. It also calculates a grand total. This is the set of information typically needed for all cross-tabular reports, so CUBE can calculate a cross-tabular report with a single SELECT statement. Like ROLLUP, CUBE is a simple extension to the GROUP BY clause, and its syntax is also easy to learn.

Syntax

CUBE appears in the GROUP BY clause in a SELECT statement. Its form is:

```
SELECT …  GROUP BY
  CUBE (grouping_column_reference_list)
```

Details

CUBE takes a specified set of grouping columns and creates subtotals for all possible combinations of them. In terms of multi-dimensional 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 Table 17–1, 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 2n combinations of subtotals returned. Output 15-3 gives an example of a three-dimension CUBE.

Example

This example of CUBE uses the data in the video store database.

```
SELECT Time, Region, Department,
   SUM(Profit) AS Profit FROM sales
   GROUP BY CUBE  (Time, Region, Dept);
```

Output 15-3 shows the results of this query.

Output 15-3

CUBE Aggregation across Three Dimensions

```
Time      Region      Department       Profit
----      ------      ----------       ------
1996      Central     VideoRental      75,000
1996      Central     VideoSales       74,000
1996      Central     NULL            149,000
1996      East        VideoRental      89,000
1996      East        VideoSales      115,000
1996      East        NULL            204,000
1996      West        VideoRental      87,000
1996      West        VideoSales       86,000
1996      West        NULL            173,000
1996      NULL        VideoRental     251,000
1996      NULL        VideoSales      275,000
1996      NULL        NULL            526,000
1997      Central     VideoRental      82,000
1997      Central     VideoSales       85,000
1997      Central     NULL            167,000
1997      East        VideoRental     101,000
1997      East        VideoSales      137,000
1997      East        NULL            238,000
1997      West        VideoRental      96,000
1997      West        VideoSales       97,000
1997      West        NULL            193,000
1997      NULL        VideoRental     279,000
1997      NULL        VideoSales      319,000
1997      NULL        NULL            598,000
NULL      Central     VideoRental     157,000
NULL      Central     VideoSales      159,000
NULL      Central     NULL            316,000
NULL      East        VideoRental     190,000
NULL      East        VideoSales      252,000
NULL      East        NULL            442,000
NULL      West        VideoRental     183,000
NULL      West        VideoSales      183,000
NULL      West        NULL            366,000
NULL      NULL        VideoRental     530,000
NULL      NULL        VideoSales      594,000
NULL      NULL        NULL          1,124,000
```

Partial Cube

Partial cube resembles partial rollup in that you can limit it to certain dimensions. In this case, subtotals of all possible combinations are limited to the dimensions within the cube list (in parentheses).

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)

Using the video store database, we can issue the following statement:

```
SELECT Time, Region, Department,
   SUM(Profit) AS Profit FROM sales
   GROUP BY Time CUBE(Region, Dept);
```

Output 15-4 shows the results of this query.

Output 15-4

Partial CUBE

```
Time       Region       Department       Profit
----       ------       ----------       ------
1996       Central      VideoRental      75,000
1996       Central      VideoSales       74,000
1996       Central      NULL            149,000
1996       East         VideoRental      89,000
1996       East         VideoSales      115,000
1996       East         NULL            204,000
1996       West         VideoRental      87,000
1996       West         VideoSales       86,000
1996       West         NULL            173,000
1996       NULL         VideoRental     251,000
1996       NULL         VideoSales      275,000
1996       NULL         NULL            526,000
1997       Central      VideoRental      82,000
1997       Central      VideoSales       85,000
```

```
1997      Central     NULL           167,000
1997      East        VideoRental    101,000
1997      East        VideoSales     137,000
1997      East        NULL           238,000
1997      West        VideoRental     96,000
1997      West        VideoSales      97,000
1997      West        NULL           193,000
1997      NULL        VideoRental    279,000
1997      NULL        VideoSales     319,000
1997      NULL        NULL           598,000
```

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, 2n SELECT statements are needed. In our three-dimension example, this would mean issuing eight SELECTS linked with UNION ALL.

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. For instance, if a four-column CUBE replaces UNION ALL of 16 SELECT statements, the reduction in table access is fifteen-sixteenths or 93.75%.

When to Use CUBE

- Use 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: For information on parallel execution, see Chapter 18, "Tuning Parallel Execution".

- CUBE is especially valuable 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, since 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.

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 helpful function.

Note: The DISTINCT qualifier has ambiguous semantics when combined with ROLLUP and CUBE. To minimize confusion and opportunities for error, DISTINCT is not permitted together with the extensions.

GROUPING Function

Two challenges arise with the use of ROLLUP and CUBE. First, how can we programmatically determine which result set rows are subtotals, and how do we find the exact level of aggregation of a given subtotal? We will often need to use subtotals in calculations such as percent-of-totals, so we need an easy way to determine which rows are the subtotals we seek. Second, what happens if query results contain both stored NULL values and "NULL" values created by a ROLLUP or CUBE? How does an application or developer differentiate between the two?

To handle these issues, Oracle 8*i* provides a function called GROUPING. 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.

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)
```

Examples

This example uses GROUPING to create a set of mask columns for the result set shown in Output 15-3. The mask columns are easy to analyze programmatically.

```
SELECT Time, Region, Department, SUM(Profit) AS Profit,
  GROUPING (Time) as T,
  GROUPING (Region) as R,
  GROUPING (Department) as D
  FROM Sales
GROUP BY ROLLUP (Time, Region, Department);
```

Output 15-5 shows the results of this query.

Output 15-5

Use of GROUPING Function:

```
Time       Region        Department         Profit    T   R   D
----       ------        ----------         ------    -   -   -
1996       Central       VideoRental        75,000    0   0   0
1996       Central       VideoSales         74,000    0   0   0
1996       Central       NULL              149,000    0   0   1
1996       East          VideoRental        89,000    0   0   0
1996       East          VideoSales        115,000    0   0   0
1996       East          NULL              204,000    0   0   1
1996       West          VideoRental        87,000    0   0   0
1996       West          VideoSales         86,000    0   0   0
1996       West          NULL              173,000    0   0   1
1996       NULL          NULL              526,000    0   1   1
1997       Central       VideoRental        82,000    0   0   0
1997       Central       VideoSales         85,000    0   0   0
1997       Central       NULL              167,000    0   0   1
1997       East          VideoRental       101,000    0   0   0
1997       East          VideoSales        137,000    0   0   0
1997       East          NULL              238,000    0   0   1
1997       West          VideoRental        96,000    0   0   0
1997       West          VideoSales         97,000    0   0   0
1997       West          NULL              193,000    0   0   1
1997       NULL          VideoRental       598,000    0   1   1
NULL       NULL          NULL            1,124,000    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".

Output 15-6 shows an ambiguous result set created using the CUBE extension.

Output 15-6

Distinguishing Aggregate NULL from Stored NULL Value:

```
Time   Region    Profit
----   ------    ------
1996   East     200,000
1996   NULL     200,000
NULL   East     200,000
NULL   NULL     190,000
NULL   NULL     190,000
NULL   NULL     190,000
NULL   NULL     390,000
```

In this case, four different rows show NULL for both Time and Region. Some of those NULLs must represent aggregates due to the CUBE extension, and others must be NULLs stored in the database. How can we tell which is which? GROUPING functions, combined with the NVL and DECODE functions, resolve the ambiguity so that human readers can easily interpret the values.

Note: The numbers in this example differ from the set used in the other figures.

We can resolve the ambiguity by using the GROUPING and other functions in the code below.

```
SELECT
  DECODE(GROUPING(Time), 1, 'All Times', Time) AS Time,
  DECODE(GROUPING(region), 1, 'All Regions', 0, null)) AS
  Region, SUM(Profit) AS Profit FROM Sales
  GROUP BY CUBE(Time, Region);
```

This code generates the result set in Output 15-7. These results include text values clarifying which rows have aggregations.

Output 15-7

Grouping Function used to Differentiate Aggregate-based "NULL" from Stored NULL Values.

```
Time        Region        Profit
----        ------        ------
1996        East         200,000
1996        All Regions  200,000
All Times   East         200,000
NULL        NULL         190,000
NULL        All Regions  190,000
All Times   NULL         190,000
All Times   All Regions  390,000
```

To explain the SQL statement above, we will examine its first column specification, which handles the Time column. Look at the first line of the SQL code above, namely,

```
DECODE(GROUPING(Time), 1, 'All Times', Time) as Time,
```

The Time 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 Times" if it receives a 1 and the time value from the database if it receives a 0. Values from the database will be either a real value such as 1996 or a stored NULL. The second column specification, displaying Region, works the same way.

When to Use GROUPING

The GROUPING function is not only useful for identifying NULLs, it also enables sorting subtotal rows and filtering results. In the next example (Output 15-8), we retrieve a subset of the subtotals created by a CUBE and none of the base-level aggregations. The HAVING clause constrains columns which use GROUPING functions.

```
SELECT Time, Region, Department, SUM(Profit) AS Profit,
  GROUPING (Time) AS T,
  GROUPING (Region) AS R,
  GROUPING (Department) AS D
  FROM Sales
  GROUP BY CUBE (Time, Region, Department)
  HAVING (GROUPING(Department)=1 AND GROUPING(Region)=1 AND GROUPING(Time)=1)
  OR (GROUPING(Region)=1 AND (GROUPING(Department)=1)
  OR (GROUPING(Time)=1 AND GROUPING(department)=1);
```

Output 15-8 shows the results of this query.

Output 15-8

Example of GROUPING Function Used to Filter Results to Subtotals and Grand Total:

```
Time       Region       Department       Profit
----       ------       ----------       ------
1996       NULL         NULL            526,000
1997       NULL         NULL            598,000
NULL       Central      NULL            316,000
NULL       East         NULL            442,000
NULL       West         NULL            366,000
NULL       NULL         NULL          1,124,000
```

Compare the result set of Output 15-8 with that in Output 15-3 to see how Output 15-8 is a precisely specified group: it contains only the yearly totals, regional totals aggregated over time and department, and the grand total.

Other Considerations when Using ROLLUP and CUBE

This section discusses the following topics.

- Hierarchy Handling in ROLLUP and CUBE
- Column Capacity in ROLLUP and CUBE
- HAVING Clause Used 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.

```
SELECT Year, Quarter, Month,
   SUM(Profit) AS Profit FROM sales
   GROUP BY ROLLUP(Year, Quarter, Month)
```

This query returns the rows in Output 15-9.

Output 15-9

Example of ROLLUP across Time Levels:

```
Year       Quarter       Month              Profit
----       -------       -----              ------
1997       Winter        January            55,000
1997       Winter        February           64,000
1997       Winter        March              71,000
1997       Winter        NULL              190,000
1997       Spring        April              75,000
1997       Spring        May                86,000
1997       Spring        June               88,000
1997       Spring        NULL              249,000
1997       Summer        July               91,000
1997       Summer        August             87,000
1997       Summer        September         101,000
1997       Summer        NULL              279,000
1997       Fall          October           109,000
1997       Fall          November          114,000
1997       Fall          December          133,000
1997       Fall          NULL              356,000
1997       NULL          NULL            1,074,000
```

Note: The numbers in this example differ from the set used in the other figures.

Column Capacity in ROLLUP and CUBE

CUBE and ROLLUP 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 220 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 ROLLUP and CUBE

The HAVING clause of SELECT statements is unaffected by the use of ROLLUP and CUBE. 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 the GROUPING function together with the HAVING clause. See Output 15-8 on page 17-19 and its associated SQL for an example.

ORDER BY Clause Used with ROLLUP and CUBE

The ORDER BY clause of a SELECT statement is unaffected by the use of ROLLUP and CUBE. Note that the conditions specified in the ORDER BY clause apply to both subtotal and non-subtotal rows of the result set. In some cases, a query may need to order the rows in a certain way. This can be achieved by using a grouping function in the ORDER BY clause.

Analytic Functions

The SQL language, while extremely capable in many areas, has never provided strong support for analytic tasks. Basic business intelligence calculations such as moving averages, rankings, and lead/lag comparisons have required extensive programming outside of standard SQL, often with performance problems. Oracle8*i* now provides a new set of functions which address this longstanding need. These functions are referred to as analytic functions because they are useful in all types of analyses. The analytic functions improve performance. In addition, the functions are now under review by ANSI for addition to the SQL standard during 2000.

Analytic functions are classified in the following categories:

- Ranking Functions
- Windowing Functions
- Reporting Functions
- Lag/Lead Functions
- Statistics Functions

They are used as follows:

Table 17–2 Analytic Functions and Their Uses

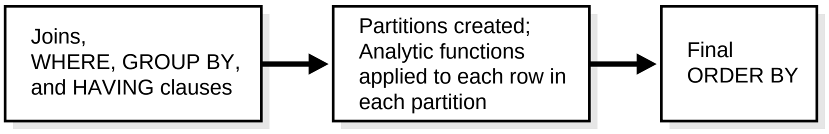
Type	Used for
Ranking	Calculating ranks, percentiles, and n-tiles of the values in a result set.

Table 17–2 Analytic Functions and Their Uses

Type	Used for
Windowing	Calculating cumulative and moving averages. Works with these functions: SUM, AVG, MIN, MAX, COUNT, VARIANCE, STDDEV, FIRST_VALUE, LAST_VALUE, and new statistical functions
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.
Statistics	Calculating linear regression and other statistics (slope, intercept, etc.).

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. The processing flow is represented in Figure 17–2.

Figure 17–2 Processing Order


Joins, WHERE, GROUP BY, and HAVING clauses
Partitions created; Analytic functions applied to each row in each partition
Final ORDER BY

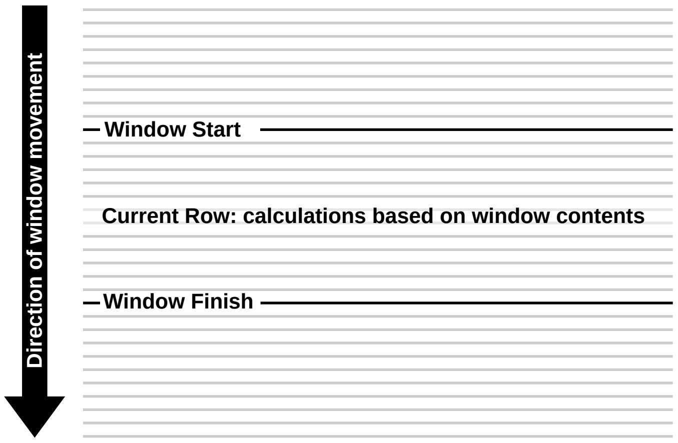
Here are the essential concepts used in the analytic functions:

- 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 17–2.

- 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, we use partitions only in the meaning related to analytic functions. Partitions are created after the groups defined with GROUP BY clauses, so any aggregate results such as SUMs and AVGs are available to them. 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* (defined in the next bullet). 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. On the other hand, it could be just a sliding window of 1 row within a partition.
- 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 5 preceding rows, and the 6 rows following. This would create a sliding window of 12 rows, as shown in Figure 17–3.

Figure 17–3 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 with respect 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 3 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 we were ranking a competition using DENSE_RANK and had three people tie for second place, we 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.

Some relevant points about RANK:

- Ascending is the default sort order, which you may want to change to descending.
- The 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 expression*>s 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 17-29.

- 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.

```
SELECT s_productkey, s_amount,
  RANK() OVER (ORDER BY s_amount) AS default_rank,
  RANK() OVER (ORDER BY s_amount DESC NULLS LAST) AS custom_rank
FROM sales;
```

This statement gives:

```
S_PRODUCTKEY    S_AMOUNT    DEFAULT_RANK    CUSTOM_RANK
------------    --------    ------------    -----------
SHOES                130               6              1
JACKETS               95               5              2
SWEATERS              80               4              3
SHIRTS                75               3              4
PANTS                 60               2              5
TIES                  45               1              6
```

Note: While the data in this result is ordered on the measure `s_amount`, 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 `s_amount` 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, to rank products based on their dollar sales within each region, breaking ties with the profits, we would say:

```
SELECT r_regionkey, p_productkey, s_amount, s_profit,
  RANK() OVER
    (ORDER BY s_amount DESC, s_profit DESC) AS rank_in_east
FROM region, product, sales
WHERE r_regionkey = s_regionkey AND p_productkey = s_productkey AND r_regionkey
= 'east';
```

The result would be:

```
R_REGIONKEY  S_PRODUCTKEY   S_AMOUNT   S_PROFIT  RANK_IN_EAST
-----------  ------------   --------   --------  ------------
EAST         SHOES               130         30             1
EAST         JACKETS             100         28             2
EAST         PANTS               100         24             3
EAST         SWEATERS             75         24             4
EAST         SHIRTS               75         24             4
EAST         TIES                 60         12             6
EAST         T-SHIRTS             20         10             7
```

For jackets and pants, the *s_profit* column resolves the tie in the *s_amount* column. But for sweaters and shirts, *s_profit* cannot resolve the tie in *s_amount* column. Hence, they are given the same rank.

RANK and DENSE_RANK Difference The difference between RANK() and DENSE_RANK() functions is illustrated below:

```
SELECT s_productkey, SUM(s_amount) as sum_s_amount,
  RANK() OVER (ORDER BY SUM(s_amount) DESC) AS rank_all,
  DENSE_RANK() OVER (ORDER BY SUM(s_amount) DESC) AS rank_dense
FROM sales
GROUP BY s_productkey;
```

This statement produces this result:

```
S_PRODUCTKEY    SUM_S_AMOUNT    RANK_ALL   RANK_DENSE
------------    ------------    --------   ----------
SHOES                    100           1            1
JACKETS                  100           1            1
SHIRTS                    89           3            2
SWEATERS                  75           4            3
SHIRTS                    75           4            3
TIES                      66           6            4
PANTS                     66           6            4
```

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 option. The group expressions in the PARTITION BY subclause divide the dataset into groups within which RANK operates. For example, to rank products within each region by their dollar sales, we say:

```
SELECT r_regionkey, p_productkey, SUM(s_amount),
  RANK() OVER (PARTITION BY r_regionkey
    ORDER BY SUM(s_amount) DESC)
      AS rank_of_product_per_region
FROM product, region, sales
WHERE r_regionkey = s_regionkey AND p_productkey = s_productkey
GROUP BY r_regionkey, p_productkey;
```

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 region (`rank_of_product_per_region`) and over all regions (`rank_of_product_total`).

```
SELECT r_regionkey, p_productkey, SUM(s_amount) AS SUM_S_AMOUNT,
  RANK() OVER (PARTITION BY r_regionkey
              ORDER BY SUM(s_amount) DESC)
AS rank_of_product_per_region,
  RANK() OVER (ORDER BY SUM(s_amount) DESC)
               AS rank_of_product_total
FROM product, region, sales
WHERE r_regionkey = s_regionkey AND p_productkey = s_productkey
GROUP BY r_regionkey, p_productkey
ORDER BY r_regionkey;
```

The query produces this result:

```
R_REGIONKEY  P_PRODUCTKEY  SUM_S_AMOUNT  RANK_OF_PRODUCT_PER_REGION  RANK_OF_PRODUCT_TOTAL
-----------  ------------  ------------  --------------------------  --------------------
EAST         SHOES                  130                           1                     1
EAST         JACKETS                 95                           2                     4
EAST         SHIRTS                  80                           3                     6
EAST         SWEATERS                75                           4                     7
EAST         T-SHIRTS                60                           5                    11
EAST         TIES                    50                           6                    12
EAST         PANTS                   20                           7                    14
WEST         SHOES                  100                           1                     2
WEST         JACKETS                 99                           2                     3
WEST         T-SHIRTS                89                           3                     5
WEST         SWEATERS                75                           4                     7
WEST         SHIRTS                  75                           4                     7
WEST         TIES                    66                           6                    10
WEST         PANTS                   45                           7                    13
```

Per Cube- and Rollup-group Ranking Analytic functions, RANK for example, can be reset based on the groupings provided by a CUBE or ROLLUP operator.

It is useful to assign ranks to the groups created by CUBE and ROLLUP queries. See the CUBE/ROLLUP section, which includes information about the GROUPING function for further details. A sample query is:

```
SELECT r_regionkey, p_productkey, SUM(s_amount) AS SUM_S_AMOUNT,
  RANK() OVER (PARTITION BY GROUPING(r_regionkey),
                             GROUPING(p_productkey)
               ORDER BY SUM(s_amount) DESC) AS rank_per_cube
FROM product, region, sales
WHERE r_regionkey = s_regionkey AND p_productkey = s_productkey
GROUP BY CUBE(r_regionkey, p_productkey)
ORDER BY GROUPING(r_regionkey), GROUPING(p_productkey), r_regionkey;
```

It produces this result:

```
R_REGIONKEY  P_PRODUCTKEY   SUM_S_AMOUNT    RANK_PER_CUBE
-----------  ------------   ------------    -------------
EAST         SHOES                   130                1
EAST         JACKETS                  50               12
EAST         SHIRTS                   80                6
EAST         SWEATERS                 75                7
EAST         T-SHIRTS                 60               11
EAST         TIES                     95                4
EAST         PANTS                    20               14
WEST         SHOES                   100                2
WEST         JACKETS                  99                3
WEST         SHIRTS                   89                5
WEST         SWEATERS                 75                7
WEST         T-SHIRTS                 75                7
WEST         TIES                     66               10
WEST         PANTS                    45               13
EAST         NULL                    510                2
WEST         NULL                    549                1
NULL         SHOES                   230                1
NULL         JACKETS                 149                5
NULL         SHIRTS                  169                2
NULL         SWEATERS                150                4
NULL         T-SHIRTS                135                6
NULL         TIES                    161                3
NULL         PANTS                    65                7
NULL         NULL                   1059                1
```

Treatment of NULLs NULLs are treated like normal values. Also, for the purpose of 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 option, NULLs will either sort low or high and hence, are given ranks appropriately. The following example shows how NULLs are ranked in different cases:

```
SELECT s_productkey, s_amount,
    RANK() OVER (ORDER BY s_amount ASC NULLS FIRST) AS rank1,
    RANK() OVER (ORDER BY s_amount ASC NULLS LAST) AS rank2,
    RANK() OVER (ORDER BY s_amount DESC NULLS FIRST) AS rank3,
    RANK() OVER (ORDER BY s_amount DESC NULLS LAST) AS rank4
FROM sales;
```

The query gives the result:

```
S_PRODUCTKEY   S_AMOUNT   RANK1    RANK2    RANK3    RANK4
------------   --------   -----    -----     ----    -----
SHOES               100       6        4        3        1
JACKETS             100       6        4        3        1
SHIRTS               89       5        3        5        3
SWEATERS             75       3        1        6        4
T-SHIRTS             75       3        1        6        4
TIES               NULL       1        6        1        6
PANTS              NULL       1        6        1        6
```

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:

```
SELECT s_productkey, s_amount, s_quantity, s_profit,
    RANK() OVER
    (ORDER BY s_amount NULLS LAST,
              s_quantity NULLS LAST,
              s_profit NULLS LAST) AS rank_of_product
FROM sales;
```

would give the result:

```
S_PRODUCTKEY   S_AMOUNT     S_QUANTITY    S_PROFIT     RANK_OF_PRODUCT
------------   --------     ----------    --------     ---------------
SHOES                75              6           4                   1
JACKETS              75           NULL           4                   2
SWEAT-SHIRTS         96           NULL           6                   3
SHIRTS               96           NULL           6                   3
SWEATERS            100           NULL           1                   5
T-SHIRTS            100           NULL           3                   6
TIES               NULL              1           2                   7
PANTS              NULL              1        NULL                   8
```

```
HATS                 NULL              6           2                    9
SOCKS                NULL              6           2                    9
SUITS                NULL              6        NULL                   10
JEANS                NULL           NULL        NULL                   11
BELTS                NULL           NULL        NULL                   11
```

TOP_N

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 four sales items per region, you can issue:

```
SELECT region, product, sum_s_amount FROM (SELECT r_regionkey AS region, p_
product_key AS product, SUM(s_amount) AS sum_s_amount, RANK() OVER(PARTITION BY
r_region_key ORDER BY SUM(s_amount) DESC AS rank1,
FROM product, region, sales
WHERE r_region_key = s_region_key AND p_product_key = s_product_key
GROUP BY r_region_key ORDER BY r_region_key)
WHERE rank1 <= 4;
```

The query produces this result:

```
R_REGIONKEY    P_PRODUCTKEY    SUM_S_AMOUNT
-----------    ------------    ------------
EAST           SHOES                    130
EAST           JACKETS                   95
EAST           SHIRTS                    80
EAST           SWEATERS                  75
WEST           SHOES                    100
WEST           JACKETS                   99
WEST           T-SHIRTS                  89
WEST           SWEATERS                  75
WEST           SHIRTS                    75
```

BOTTOM_N

BOTTOM_N is similar to TOP_N except for the ordering sequence within the rank expression. In the previous example, you can order SUM(s_amount) ASC instead of DESC.

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, we use the formula:

```
CUME_DIST(x) =
 number of values (different from, or equal to, x) in S coming before 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. To assign cume_dists to products per region based on their sales and profits, we would say:

```
SELECT r_regionkey, p_productkey, SUM(s_amount) AS  SUM_S_AMOUNT,
   CUME_DIST() OVER
    (PARTITION BY r_regionkey
        ORDER BY SUM(s_amount))
     AS cume_dist_per_region
FROM region, product, sales
WHERE r_regionkey = s_regionkey AND p_productkey = s_productkey
GROUP BY r_regionkey, p_productkey
ORDER BY r_regionkey, s_amount DESC;
```

It will produce this result:

```
R_REGIONKEY  P_PRODUCTKEY   SUM_S_AMOUNT     CUME_DIST_PER_REGION
-----------  ------------   ------------     --------------------
EAST         SHOES                   130                     1.00
EAST         JACKETS                  95                      .84
EAST         SHIRTS                   80                      .70
EAST         SWEATERS                 75                      .56
EAST         T-SHIRTS                 60                      .42
EAST         TIES                     50                      .28
EAST         PANTS                    20                      .14
WEST         SHOES                   100                     1.00
WEST         JACKETS                  99                      .84
WEST         T-SHIRTS                 89                      .70
WEST         SWEATERS                  75                       .56
WEST         SHIRTS                    75                       .28
WEST         TIES                      66                       .28
WEST         PANTS                     45                       .14
```

PERCENT_RANK

PERCENT_RANK is very 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 first row 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 since 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 we 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.

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 (e.g., 5) or an expression. The expression can include expressions in the PARTITION BY clause. For example, (5*2) or (5*c1) OVER (PARTITION BT c1)).

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,

```
SELECT p_productkey, s_amount,
   NTILE(4) (ORDER BY s_amount DESC NULLS FIRST) AS 4_tile
FROM product, sales
WHERE p_productkey = s_productkey;
```

This query would give:

```
P_PRODUCTKEY   S_AMOUNT    4_TILE
------------   --------    ------
SUITS              NULL         1
SHOES               100         1
JACKETS              90         1
SHIRTS               89         2
T-SHIRTS             84         2
SWEATERS             75         2
JEANS                75         3
TIES                 75         3
PANTS                69         3
BELTS                56         4
SOCKS                45         4
```

NTILE is a nondeterministic function. Equal values can get distributed across adjacent buckets (75 is assigned to buckets 2 and 3) and buckets '1', '2' and '3' 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] [, ...])
```

As an example, consider this query:

```
SELECT p_productkey, s_amount,
     ROW_NUMBER() (ORDER BY s_amount DESC NULLS LAST) AS srnum
FROM product, sales
WHERE p_productkey = s_productkey;
```

It would give:

```
P_PRODUCTKEY      S_AMOUNT     SRNUM
------------      --------     -----
SHOES                  100         1
JACKETS                 90         2
SHIRTS                  89         3
T-SHIRTS                84         4
SWEATERS                75         5
JEANS                   75         6
TIES                    75         7
PANTS                   69         8
BELTS                   56         9
SOCKS                   45        10
SUITS                 NULL        11
```

Sweaters, jeans and ties each with s_amount of 75 are assigned different row number (5, 6, 7). Like NTILE, ROW_NUMBER is a non-deterministic function, so "SWEATERS" could as well be assigned a rownumber of 7 (instead of 5) and "TIES" a rownumber of 5 (instead of 7). To ensure deterministic results, you must order on a unique key.

Windowing 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}}
```

where:

`OVER`	indicates that the function operates on a query result set. That is, it is computed after the `FROM`, `WHERE`, `GROUP BY`, and `HAVING` clauses. OVER is used to define the window of the rows to be included while computing the function.

`query_partition_clause`

`PARTITION BY`	partitions the query result set into groups based on one or more *value_expr*. If you omit this clause, the function treats all rows of the query result set as a single group. You can specify multiple analytic functions in the same query, each with the same or different `PARTITION BY` keys. **Note:** If the objects being queried have the parallel attribute, and if you specify an analytic function with the *query_partition_clause*, then the function computations are parallelized as well.
`value_expr`	Valid value expressions are constants, columns, nonanalytic functions, function expressions, or expressions involving any of these.

`ORDER_BY_clause`

`ORDER BY`

specifies how data is ordered within a partition. You can order the values in a partition on multiple keys, each defined by a *value_expr* and each qualified by an ordering sequence.

Within each function, you can specify multiple ordering expressions. Doing so is especially useful when using functions that rank values, because the second expression can resolve ties between identical values for the first expression.

Note: Analytic functions always operate on rows in the order specified in the *ORDER_BY_clause* of the function. However, the *ORDER_BY_clause* of the function does not guarantee the order of the result. Use the *ORDER_BY_clause* of the query to guarantee the final result ordering.

Restriction: When used in an analytic function, the *ORDER_BY_clause* must take an expression (*expr*). Position (*position*) and column aliases (*c_alias*) are invalid. Otherwise this *ORDER_BY_clause* is the same as that used to order the overall query or subquery.

`ASC | DESC`

specifies the ordering sequence (ascending or descending). `ASC` is the default.

`NULLS FIRST | NULLS LAST`

specifies whether returned rows containing null values should appear first or last in the ordering sequence.

`NULLS LAST` is the default for ascending order, and `NULLS FIRST` is the default for descending order.

windowing_clause

`ROWS | RANGE`

These keywords define for each row a "window" (a physical or logical set of rows) used for calculating the function result. The function is then applied to all the rows in the window. The window "slides" through the query result set or partition from top to bottom.

- `ROWS` specifies the window in physical units (rows)
- `RANGE` specifies the window as a logical offset.

You cannot specify this clause unless you have specified the *ORDER_BY_clause*.

Note: The value returned by an analytic function with a logical offset is always deterministic. However, the value returned by an analytic function with a physical offset may produce nondeterministic results unless the ordering expression(s) results in a unique ordering. You may have to specify multiple columns in the *ORDER_BY_clause* to achieve this unique ordering.

`BETWEEN ... AND`

lets you specify a start point and end point for the window. The first expression (before `AND`) defines the start point and the second expression (after `AND`) defines the end point.

	If you omit `BETWEEN` and specify only one end point, Oracle considers it the start point, and the end point defaults to the current row.
`UNBOUNDED PRECEDING`	specifies that the window starts at the first row of the partition. This is the start point specification and cannot be used as an end point specification. UNBOUNDED PRECEDING - specifies that the window starts at the first row of the partition. If the PARTITION BY clause is absent, then it refers to the first row in the dataset.
`UNBOUNDED FOLLOWING`	specifies that the window ends at the last row of the partition. This is the end point specification and cannot be used as a start point specification.
`CURRENT ROW`	As a start point, `CURRENT ROW` specifies that the window begins at the current row or value (depending on whether you have specified `ROW` or `RANGE`, respectively). In this case the end point cannot be *value_expr* `PRECEDING`. As an end point, `CURRENT ROW` specifies that the window ends at the current row or value (depending on whether you have specified `ROW` or `RANGE`, respectively). In this case the start point cannot be *value_expr* `FOLLOWING`.

`value_expr` `PRECEDING`
 	
`value_expr` `FOLLOWING`
	For `RANGE` or `ROW`:
	
	■ If *value_expr* `FOLLOWING` is the start point, then the end point must be *value_expr* `FOLLOWING` or `UNBOUNDED FOLLOWING`.
	
	■ If *value_expr* `PRECEDING` is the end point, then the start point must be *value_expr* `PRECEDING` or `UNBOUNDED FOLLOWING`.
	
	If you are defining a logical window defined by an interval of time in numeric format, you may need to use conversion functions, like NUMTODS or NUMTOYM.
	
	If you specify `ROWS`:
	
	■ *value_expr* is a physical offset. It must be a constant or expression and must evaluate to a positive numeric value.
	
	If you specify `RANGE`:
	
	■ *value_expr* is a logical offset. It must be a constant or expression that evaluates to a positive numeric value or an interval literal.
	
	■ You can specify only one expression in the *ORDER_BY_clause* if the start or end point is specified using <*value_expr*> PRECEDING *or* FOLLOWING.
	
	■ If *value_expr* evaluates to a numeric value, the `ORDER BY` *expr* must be a `NUMBER` or `DATE` datatype.
	
	■ If *value_expr* evaluates to an interval value, the `ORDER BY` *expr* must be a `DATE` datatype.

If you omit the *windowing_clause* entirely, the default is RANGE BETWEEN UNBOUNDED PRECEDING AND CURRENT ROW.

Treatment of NULLs on 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 DAYS/MONTHS/YEARS 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.

Some examples of windowing functions follow:

Example of Cumulative Aggregate Function The following is an example of a cumulative balance per account ordered by deposit date.

```
SELECT Acct_number, Trans_date, Trans_amount,
       SUM(Trans_amount) OVER (PARTITION BY Acct_number
       ORDER BY Trans_date ROWS UNBOUNDED PRECEDING) AS Balance
FROM Ledger
ORDER BY Acct_number, Trans_date;

Acct_number    Trans_date    Trans_amount        Balance
-----------    ----------    ------------        -------
      73829    1998-11-01          113.45         113.45
      73829    1998-11-05          -52.01          61.44
      73829    1998-11-13           36.25          97.69
      82930    1998-11-01           10.56          10.56
      82930    1998-11-21           32.55          43.11
      82930    1998-11-29           -5.02          38.09
```

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.

Example of Moving Aggregate function
Here is an example of a time-based window that shows, for each transaction, the moving average of transaction amount for the preceding 7 days of transactions:

```
SELECT Account_number, Trans_date, Trans_amount,
  AVG (Trans_amount) OVER
       (PARTITION BY Account_number ORDER BY Trans_date
            RANGE INTERVAL '7' DAY PRECEDING) AS mavg_7day
FROM Ledger;

Acct_number    Trans_date    Trans_amount    mavg_7day
-----------    ----------    ------------    ---------
      73829    1998-11-03          113.45       113.45
      73829    1998-11-09          -52.01        30.72
      73829    1998-11-13           36.25        -7.88
      73829    1998-11-14           10.56        -1.73
      73829    1998-11-20           32.55        26.45
      82930    1998-11-01          100.25       100.25
      82930    1998-11-10           10.01        10.01
      82930    1998-11-25           11.02        11.02
      82930    1998-11-26          100.56        55.79
      82930    1998-11-30           -5.02        35.52
```

Example of Centered Aggregate function Calculating windowing aggregate functions centered around the current row is straightforward. This example computes for each account a centered moving average of the transaction amount for the 1 month preceding the current row and 1 month following the current row including the current row as well.

```
SELECT Account_number, Trans_date, Trans_amount,
  AVG (Trans_amount) OVER
       (PARTITION BY Account_number ORDER BY Trans_date
            RANGE BETWEEN INTERVAL '1' MONTH PRECEDING
                      AND INTERVAL '1' MONTH FOLLOWING) as c_avg
FROM Ledger;
```

Windowing Aggregate Functions with Logical Offsets The following example illustrates how window aggregate functions compute values in the presence of duplicates.

```
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.

Example of Variable Sized Window Assume that you want to calculate the moving average of stock price over 3 working days. If the data is dense (that is, you have data for all working days) then you can use a physical window function. However, if there are holidays and no data is available for those days, here is how you can calculate moving average under those circumstances.

```
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;
```

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 implicitly the number of days. We 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.

Windowing Aggregate Functions with Physical Offsets For windows expressed in physical units (ROWS), the ordering expressions should be unique to produce deterministic results. For example, the query below is not deterministic since *t_timekey* is not unique.

```
SELECT t_timekey, s_amount,
       FIRST_VALUE(s_amount) OVER
              (ORDER BY t_timekey ROWS 1 PRECEDING) AS LAG_physical,
       SUM(s_amount) OVER
          (ORDER BY t_timekey ROWS 1 PRECEDING) AS MOVINGSUM,
FROM sales, time
WHERE sales.s_timekey = time.t_timekey
ORDER BY t_timekey;
```

It can yield either of the following:

```
T_TIMEKEY   S_AMOUNT    LAG_PHYSICAL     MOVINGSUM
---------   --------    -----------      ---------
92-10-11           1              1              1
92-10-12           4              1              5
92-10-12           3              4              7
92-10-12           2              3              5
92-10-15           5              2              7

T_TIMEKEY   S_AMOUNT    LAG_PHYSICAL     MOVINGSUM
---------   --------    -----------      ---------
92-10-11           1             1               1
92-10-12           3             1               4
92-10-12           4             3               7
92-10-12           2             4               6
92-10-15           5             2               7
```

FIRST_VALUE AND LAST_VALUE FUNCTIONS The FIRST_VALUE and LAST_VALUE functions help users derive full power and flexibility from the window aggregate functions. They allow queries to select the first and last rows from a window. These rows are specially valuable since they are often used as the baselines in calculations. For instance, with a partition holding sales data ordered by day, we might ask "How much was each day's sales compared to the first sales day (FIRST_VALUE) of the period?" Or we 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 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. Here is the syntax:

```
{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. 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, find the region in which it had maximum sales". The equivalent SQL query using the MAX reporting function would look like this:

```
SELECT s_productkey, s_regionkey, sum_s_amount
FROM
  (SELECT s_productkey, s_regionkey, SUM(s_amount) AS sum_s_amount,
        MAX(SUM(s_amount)) OVER
           (PARTITION BY s_productkey) AS max_sum_s_amount
   FROM sales
   GROUP BY s_productkey, s_regionkey)
WHERE sum_s_amount = max_sum_s_amount;
```

Given this aggregated (sales grouped by s_productkey and s_regionkey) data for the first three columns below, the reporting aggregate function MAX(SUM(s_amount)) returns:

```
S_PRODUCTKEY    S_REGIONKEY    SUM_S_AMOUNT      MAX_SUM_S_AMOUNT
------------    -----------    ------------      ----------------
JACKETS         WEST                     99                    99
JACKETS         EAST                     50                    99
PANTS           EAST                     20                    45
PANTS           WEST                     45                    45
SHIRTS          EAST                     60                    80
SHIRTS          WEST                     80                    80
SHOES           WEST                    100                   130
SHOES           EAST                    130                   130
SWEATERS        WEST                     75                    75
SWEATERS        EAST                     75                    75
TIES            EAST                     95                    95
TIES            WEST                     66                    95
```

The outer query would return:

```
S_PRODUCTKEY    S_REGIONKEY    SUM_S_AMOUNT
------------    -----------    ------------
JACKETS         WEST                     99
PANTS           WEST                     45
SHIRTS          WEST                     80
SWEATERS        WEST                     75
SWEATERS        EAST                     75
SHOES           EAST                    130
TIES            EAST                     95
```

Complex example Here is an example of computing the top 10 items in sales within those product lines which contribute more than 10% within their product category. The first column is the key in each of the tables.

```
SELECT *
FROM (
       SELECT item_name, prod_line_name, prod_cat_name,
          SUM(sales) OVER (PARTITION BY prod_cat_table.cat_id) cat_sales,
          SUM(sales) OVER (PARTITION BY prod_line_table.line_id)
          line_sales,
            RANK(sales) OVER (PARTITION BY prod_line_table.line_id
                         ORDER BY sales DESC NULLS LAST) rnk
       FROM item_table, prod_line_table, prod_cat_table
       WHERE item_table.line_id = prod_line_table.line_id AND
       prod_line_table.cat_id = prod_cat_table.cat_id
```

```
     )
WHERE line_sales > 0.1 * cat_sales AND rnk <= 10;
```

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.

To calculate RATIO_TO_REPORT of sales per product, we might use the following syntax:

```
SELECT s_productkey, SUM(s_amount) AS sum_s_amount,
       SUM(SUM(s_amount)) OVER () AS sum_total,
       RATIO_TO_REPORT(SUM(s_amount)) OVER () AS ratio_to_report
FROM sales
GROUP BY s_productkey;
```

with this result:

```
S_PRODUCTKEY    SUM_S_AMOUNT      SUM_TOTAL      RATIO_TO_REPORT
------------    ------------      ---------      ---------------
SHOES                    100            520                 0.19
JACKETS                   90            520                 0.17
SHIRTS                    80            520                 0.15
SWEATERS                  75            520                 0.14
SHIRTS                    75            520                 0.14
TIES                      10            520                 0.01
PANTS                     45            520                 0.08
SOCKS                     45            520                 0.08
```

Lag/Lead Functions

The LAG and LEAD functions are useful for comparing values in different time periods—for example, March 98 to March 99.

These functions provide access to more than one row of a table at the same time without a self-join. The LAG function provides access to a row at a given offset prior to the position and the LEAD function provides access to a row at a given offset after the current position.

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.

If column sales.s_amount contains values 1,2,3,..., then:

```
SELECT t_timekey, s_amount,
       LAG(s_amount,1) OVER (ORDER BY t_timekey) AS LAG_amount,
       LEAD(s_amount,1) OVER (ORDER BY t_timekey) AS LEAD_amount
FROM sales, time
WHERE sales.s_timekey = time.t_timekey
ORDER BY t_timekey;
```

gives:

```
T_TIMEKEY   S_AMOUNT      LAG_AMOUNT     LEAD_AMOUNT
---------   --------      ----------     -----------
99-10-11           1            NULL               2
99-10-12           2               1               3
99-10-13           3               2               4
99-10-14           4               4               5
99-10-15           5               2            NULL
```

Statistics Functions

Oracle has statistics functions you can use to compute covariance, correlation, and linear regression statistics. Each of these functions operates on an unordered set.

They also can be used as windowing and reporting functions. They differ from the aggregate functions (such as AVG(x)) in that most of them take two arguments.

VAR_POP

VAR_POP returns the population variance of a set of numbers after discarding the nulls in this set.

The argument is a number expression. The result is of type number and can be null.

For a given expression e, population variance of e is defined as:

```
(SUM(e*e) - SUM(e)*SUM(e)/COUNT(e))/COUNT(e)
```

If the function is applied to an empty set, the result is a null value.

VAR_SAMP

VAR_SAMP returns the sample variance of a set of numbers after discarding the NULLs in this set.

The argument is a number expression. The result is of type NUMBER and can be null.

For a given expression e, the sample variance of e is defined as:

```
(SUM(e*e) - SUM(e)*SUM(e)/COUNT(e))/(COUNT(e)-1)
```

If the function is applied to an empty set or a set with a single element, the result is a null value.

The VAR_SAMP function is similar to the existing VARIANCE function. The only difference is when the function takes a single argument. In this case, VARIANCE returns 0 and VAR_SAMP returns NULL.

STDDEV_POP/STDDEV_SAMP

The STDDEV_POP and STDDEV_SAMP functions compute the population standard deviation and the sample standard deviation, respectively.

For both functions, the argument is a number expression. Population standard deviation is simply defined as the square root of population variance. Similarly, sample standard deviation is defined as the square root of sample variance.

COVAR_POP

COVAR_POP returns the population covariance of a set of number pairs.

Argument values e1 and e2 are number expressions. Oracle applies the function to the set of (e1, e2) pairs after eliminating all pairs for which either e1 or e2 is null. Then Oracle makes the following computation:

```
(SUM(e1 * e2) - SUM(e2) * SUM(e1) / n) / n
```

where n is the number of (e1, e2) pairs where neither e1 nor e2 is null.

The function returns a value of type NUMBER. If the function is applied to an empty set, it returns null.

COVAR_SAMP

COVAR_SAMP returns the sample variance of a set of number pairs.

Argument values e1 and e2 are number expressions. Oracle applies the function to the set of (e1, e2) pairs after eliminating all pairs for which either e1 or e2 is null. Then Oracle makes the following computation:

```
(SUM(e1*e2)-SUM(e1)*SUM(e2)/n)/(n-1)
```

where n is the number of (e1, e2) pairs where neither e1 nor e2 is null.

The function returns a value of type NUMBER.

CORR

The CORR function returns the coefficient of correlation of a set of number pairs. The argument values e1 and e2 are number expressions.

The datatype of the result is NUMBER and can be null. When not null, the result is between -1 and 1.

The function is applied to the set of (e1, e2) pairs after eliminating all the pairs for which either e1 or e2 is null. Then Oracle makes the following computation:

```
COVAR_POP(e1, e2)/(STDDEV_POP(e1)*STDDEV_POP(e2))
```

If the function is applied to an empty set, or if either STDDEV_POP(e1) or STDDEV_POP(e2) is equal to zero after null elimination, the result is a null value.

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.

For further information regarding syntax and semantics, see *Oracle8i SQL Reference*.

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, 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, REGR_INTERCEPT

The REGR_SLOPE function computes the slope of the regression line fitted to non-null (e1, e2) pairs. For this, it makes the following computation after eliminating (e1, e2) pairs where either of e1 or e2 is null:

```
COVAR_POP(e1, e2) / VAR_POP(e2)
```

If VAR_POP(e2) is 0 (a vertical regression line), REGR_SLOPE returns NULL.

The REGR_INTERCEPT function computes the y-intercept of the regression line. For this, it makes the following computation:

```
REGR_AVGY(e1, e2) - REGR_SLOPE(e1, e2) * REGR_AVGX(e1, e2)
```

REGR_INTERCEPT returns NULL whenever slope or the regression averages are NULL.

REGR_R2

The REGR_R2 function computes the coefficient of determination (also called "R-squared" or "goodness of fit") for the regression line. It computes and returns one of the following values after eliminating (e1, e2) pairs where either e1 or e2 is null:

- POWER(CORR(e1, e2), 2)

  when VAR_POP(e1) > 0 and VAR_POP(e2) > 0
- 1

  when VAR_POP(e1) = 0 and VAR_POP(e2) > 0
- NULL

  otherwise

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.

REGR_SXX, REGR_SYY, 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)
```

Examples of Linear Regression Statistics Some common diagnostic statistics that accompany linear regression analysis are given in Table 17–3, "Common Diagnostic Statistics and Their Expressions".

Table 17–3 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	(Total sum of squares) - (Regression sum of squares)
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, you can compute an ordinary-least-squares regression line that expresses the bonus of an employee as a linear function of the employee's salary. The values SLOPE, ICPT, RSQR are slope, intercept, and coefficient of determination of the regression line, respectively. The values AVGSAL and AVGBONUS are the average salary and average bonus, respectively, of the employees, and the (integer) value CNT is the number of employees in the department for whom both salary and bonus data are available. The remaining regression statistics are named SXX, SYY, and SXY.

Consider the following Employee table with 8 employees:

```
SELECT * FROM employee;
EMPNO        NAME       DEPT       SALARY   BONUS      HIREDATE
---------- ---------- ---------- ---------- ---------- ---------
        45 SAM        SALES            4500        500 20-SEP-97
        52 MILES      SALES            4300        450 01-FEB-98
        41 CLAIRE     SALES            5600        800 14-JUN-96
        65 MOLLY      SALES            3200            07-AUG-99
        36 FRANK      HARDWARE         6700       1150 01-MAY-95
        58 DEREK      HARDWARE         3000        350 20-JUL-98
        25 DIANA      HARDWARE         8200       1860 12-APR-94
        54 BILL       HARDWARE         6000        900 05-MAR-98
8 rows selected.
```

We can then calculate:

```
SELECT  REGR_SLOPE(BONUS, SALARY) SLOPE,
        REGR_INTERCEPT(BONUS, SALARY) ICPT,
        REGR_R2(BONUS, SALARY) RSQR,
        REGR_COUNT(BONUS, SALARY) COUNT,
        REGR_AVGX(BONUS, SALARY) AVGSAL,
        REGR_AVGY(BONUS, SALARY) AVGBONUS,
        REGR_SXX(BONUS, SALARY) SXX,
        REGR_SXY(BONUS, SALARY) SXY,
        REGR_SYY(BONUS, SALARY) SXY
FROM employee
GROUP BY dept;

SLOPE    ICPT     RSQR     COUNT AVGSAL AVGBONUS  SXX      SXY     SXY
-------- -------- -------- ----- ------ --------- -------- ------- ----------
.2759379 -583.729 .9263144     4   5975      1065 14327500 3953500    1177700
.2704082 -714.626 .9998813     3   4800 583.33333   980000  265000 71666.6667
```

Case Expressions

Oracle now supports *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, etc.). The syntax is:

CASE WHEN <cond1> THEN <v1> WHEN <cond2> THEN <v2> ... [ELSE <v_{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 *Oracle8i SQL Reference*.

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, then use $2000 instead. Currently, 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 PL/SQL function for each row.

Using CASE expressions natively in the RDBMS, the above query can be rewritten as:

```
SELECT AVG(CASE when e.sal > 2000 THEN e.sal ELSE 2000 end) FROM emps e;
```

Because this query does not require a PL/SQL function invocation, it is much 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.

Given the following dataset, we wish to create a histogram which includes the following four buckets: 70-79, 80-89 and 90-99, 100+.

Ages
100
96
93
90
88
85
79
76
76
72

Example 1:

```
SELECT
SUM(CASE WHEN age BETWEEN 70 AND 79 THEN 1 ELSE 0 END) as "70-79",
SUM(CASE WHEN age BETWEEN 80 AND 89 THEN 1 ELSE 0 END) as "80-89",
SUM(CASE WHEN age BETWEEN 90 AND 99 THEN 1 ELSE 0 END) as "90-99",
SUM(CASE WHEN age > 99 THEN 1 ELSE 0 END) as "100+"
FROM customer;
```

The output is:

```
70-79     80-89     90-99    100+
-----     -----     -----    ----
    4         2         3       1
```

Example 2:

```
SELECT
CASE WHEN age BETWEEN 70 AND 79 THEN '70-79'
   WHEN age BETWEEN 80 and 89 THEN '80-89'
   WHEN age BETWEEN 90 and 99 THEN '90-99'
   WHEN age > 99 THEN '100+' END) as age_group,
COUNT(*) as age_count
FROM customer
GROUP BY
CASE WHEN age BETWEEN 70 AND 79 THEN '70-79'
   WHEN age BETWEEN 80 and 89 THEN '80-89'
   WHEN age BETWEEN 90 and 99 THEN '90-99'
   WHEN age > 99 THEN '100+' END);
```

The output is:

```
age_group    age_count
---------    ---------
70-79                4
80-89                2
90-99                3
100+                 1
```

18

Tuning Parallel Execution

This chapter covers tuning in a parallel execution environment, and discusses:

- Introduction to Parallel Execution Tuning
- Initializing and Tuning Parameters for Parallel Execution
- Selecting Automated or Manual Tuning of Parallel Execution
- Setting the Degree of Parallelism and Enabling Adaptive Multi-User
- Tuning General Parameters
- Example Parameter Setting Scenarios for Parallel Execution
- Miscellaneous Tuning Tips
- Monitoring and Diagnosing Parallel Execution Performance

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). You can also implement parallel execution on certain types of OLTP (Online Transaction Processing) and hybrid systems. Parallel execution improves processing for:

- Queries requiring large table scans, joins, and/or partitioned index scans
- Creation of large indexes
- Creation of large tables (including materialized views)
- Bulk inserts, updates, 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 LOBs (Large Binary Objects).

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

- Symmetric Multi-processors (SMP), clusters, or massively parallel systems
- Sufficient I/O bandwidth
- Under utilized 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 over-utilized systems or systems with small I/O bandwidth.

When to Implement Parallel Execution

Parallel execution provides the greatest performance improvements in Decision Support Systems (DSS). Online Transaction Processing (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.

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

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 (degree of parallelism), the adaptive multi-user 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 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 three steps described under the following headings. These are:

- Selecting Automated or Manual Tuning of Parallel Execution
- Setting the Degree of Parallelism and Enabling Adaptive Multi-User
- Tuning General Parameters

Step Three is a discussion of tuning general parameters. You may find the general parameters information useful if your parallel execution performance requires further tuning after you complete the first two steps.

Several examples describing parallel execution tuning appear at the end of this section. The example scenarios describe configurations that range from completely automated to completely manual systems.

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 may not benefit from automated parallel execution.

Automatically Derived Parameter Settings under Fully Automated Parallel Execution

When PARALLEL_AUTOMATIC_TUNING is TRUE, Oracle automatically sets other parameters as shown in Table 18–1. For most systems, you do not need to make further adjustments to have an adequately tuned, fully automated parallel execution environment.

Table 18–1 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.

Table 18–1 Parameters Affected by PARALLEL_AUTOMATIC_TUNING

Parameter	Default	Default if PARALLEL_ AUTOMATIC_ TUNING = TRUE	Comments
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 may vary from system to system.
LARGE_POOL_SIZE	None	PARALLEL_EXECUTION_ POOL + MTS heap requirements + Backup buffer requests + 600KB	Oracle does not allocate parallel execution buffers from the SHARED_POOL.
PARALLEL_EXECUTION _MESSAGE_SIZE	2KB (port specific)	4KB (port specific)	Default increased since Oracle allocates memory from the LARGE_POOL.

As mentioned, you can manually adjust the parameters shown in Table 18–1, 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.

Because parallel execution improves performance for a wide range of system types, you might want to use the examples at the end of this section as starting points. After observing your system's performance using these initial settings, you can further customize your system for parallel execution.

Setting the Degree of Parallelism and Enabling Adaptive Multi-User

In this step, establish your system's degree of parallelism (DOP) and consider whether to enable adaptive multi-user.

Degree of Parallelism and Adaptive Multi-User and How They Interact

DOP specifies the number of available processes, or threads, used in parallel operations. Each parallel thread may use one or two query processes depending on the query's complexity.

The adaptive multi-user feature adjusts DOP based on user load. For example, you may have a table with a DOP of 5. This DOP may be acceptable with 10 users. But 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 multi-user 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 multi-user for single-user, batch processing systems or if your system already provides optimal performance.

How the Adaptive Multi-User Algorithm Works

The adaptive multi-user 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 INIT.ORA, as well as parallelism options used in CREATE TABLE and ALTER TABLE commands 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 8, the next 4, 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.

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-related parameters, enable parallel execution for each table you want parallelized using the PARALLEL option of the CREATE TABLE or ALTER TABLE commands. 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 set it automatically based on the value of PARALLEL_THREADS_PER_CPU.

Forcing Parallel Execution for a Session

If you are sure you want to execute in parallel and want to avoid setting the degree of 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. 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. See *Oracle8i SQL Reference* for further details.

Controlling Performance with PARALLEL_THREADS_PER_CPU

The initialization parameter PARALLEL_THREADS_PER_CPU affects algorithms controlling both the DOP and the adaptive multi-user 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 multi-user 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.

The default for PARALLEL_THREADS_PER_CPU is appropriate for most systems. However, if your I/O subsystem cannot keep pace with the processors, you may need to increase the value for PARALLEL_THREADS_PER_CPU. In this case, you need more processes to achieve better system scalability. If too many processes are running, reduce the number.

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 8.

Tuning General Parameters

This section discusses the following types of parameters:

- 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/SHARED_POOL_SIZE
- SHARED_POOL_SIZE
- PARALLEL_MIN_PERCENT
- PARALLEL_SERVER_INSTANCES

PARALLEL_MAX_SERVERS

The recommended value 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 executing parallel execution. If you manually set the parameter PARALLEL_MAX_SERVERS, set it to 10 times the number of CPUs. This is a reasonable starting value.

To support concurrent users, add more query server processes. You probably want to limit the number of CPU-bound processes to be a small multiple of the number of CPUs: perhaps 4 to 16 times the number of CPUs. This would limit the number of concurrent parallel execution statements to be in the range of 2 to 8.

If a database's users initiate too many concurrent operations, Oracle may 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 another value other than the default value of 0 (zero).

This condition can be verified through the GV$SYSSTAT view and comparing the statistics for parallel operations not downgraded and Parallel operations downgraded to serial. For example:

```
SQL> 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 your system has sufficient memory and I/O bandwidth for the resulting load. You can find by using operating system performance monitoring tools to determine how much memory, swap space and I/O bandwidth is 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 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 that 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:** For more information about resource consumer groups, refer to discussions on the Database Resource Manager in the *Oracle8i Administrator's Guide* and *Oracle8i Concepts*.

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 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 there remain 10 parallel processes that consist of two sets of query server servers. This would allow 1 session for the parallel coordinator and 10 sessions for the parallel execution processes.

> **See Also:** Refer to the *Oracle8i Administrator's Guide* for more information about managing resources with user profiles and *Oracle8i Parallel Server Concepts* for more information on querying GV$ views.

PARALLEL_MIN_SERVERS

The recommended value is 0 (zero).

The system parameter PARALLEL_MIN_SERVERS allows you to specify the number of processes to be started and reserved for parallel operations at startup in a single instance. The syntax is:

```
PARALLEL_MIN_SERVERS=n
```

Where *n* 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 5 minutes.

LARGE_POOL_SIZE/SHARED_POOL_SIZE

The following discussion of how to tune the large pool is also true for tuning the shared pool, except as noted under the heading "SHARED_POOL_SIZE" on page 18-16. You must also increase the value for this memory setting by the amount you determine.

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, if Oracle displays the following error on startup:

```
ORA-27102: out of memory
SVR4 Error: 12: Not enough space
```

Consider reducing the value for LARGE_POOL_SIZE low enough so your database starts. If, after lowering the value of LARGE_POOL_SIZE, you see the error:

```
ORA-04031: unable to allocate 16084 bytes of shared memory ("large
pool","unknown object","large pool hea","PX msg pool")
```

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);
```

Oracle should respond with output similar to:

```
NAME                       SUM(BYTES)
-------------------------- ----------
PX msg pool                   1474572
free memory                    562132
-----------------------------2036704
3 rows selected.
```

To resolve this, increase the value for LARGE_POOL_SIZE. This example shows the LARGE_POOL_SIZE to be about 2MB. Depending on the amount of memory available, you could increase the value of LARGE_POOL_SIZE to 4MB 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 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 using either the PARALLEL_MAX_SERVERS parameter or by using policies and profiles.

Calculate how much additional memory you need for message buffers according the following five steps. These steps are nearly the same steps Oracle performs when you set the PARALLEL_AUTOMATIC_TUNING parameter to TRUE. If you enable automatic tuning and check the computed value, you will get the same result.

1. Determine the maximum DOP possible on your system. When determining this value, consider how you parallelize your batch jobs: you use more memory for a single job using a large DOP than you use for multiple jobs with smaller DOPs. Thus, to ensure you have enough memory for message buffers, calculate an upper bound DOP. This DOP should also take multiple instances into account. In other words, to use a degree of 4 in 2 instances, the number you calculate should be 8, not 4. A conservative way to compute the maximum value is to take the value of PARALLEL_MAX_SERVERS multiplied by the number of instances and divide by 4. This number is the DOP in the formula appearing after step 5.
2. Determine the number of instances participating in the SQL statements. For most installations, this number will be 1. This value is INSTANCES in the formula.

3. Estimate the maximum number of concurrent queries executing at this DOP. A number of 1 is a reasonable value if either PARALLEL_ADAPTIVE_MULTI_USER is set to TRUE or if you have set DOP to be a value which is either greater than or equal to the value for PARALLEL_MAX_SERVERS divided by 4. This is because your DOP is then bound by the number of servers. This number is USERS in the formula below.
4. Calculate the maximum number of query server process groups per query. Normally, Oracle uses only one group of query server processes per query. Sometimes with subqueries, however, Oracle uses one group of query server processes for each subquery. A conservative starting value for this number is 2. This number is GROUPS in the formula appearing after step 5.
5. Determine the parallel message size using the value for the parameter PARALLEL_MESSAGE_SIZE. This is usually 2KB or 4KB. Use the SQL*Plus SHOW PARAMETERS command to see the current value for PARALLEL_MESSAGE_SIZE.

Memory Formula for SMP Systems Most SMP systems use the following formula:

$$\textit{Memory in bytes} = (3 \times \textit{SETS} \times \textit{USERS} \times \textit{SIZE} \times \textit{CONNECTIONS})$$

Where CONNECTIONS = $(\text{DOP}^2 + 2 \times \text{DOP})$.

Memory Formula for MPP Systems If you are using OPS and the value for INSTANCES is greater than 1, use the following formula. This formula calculates the number of buffers needed for local virtual connections as well as for remote physical connections. You can use the value of REMOTE as the number of remote connections among nodes to help tune your operating system. The formula is:

$$\textit{Memory in bytes} = (\textit{GROUPS} \times \textit{USERS} \times \textit{SIZE}) \times ((\textit{LOCAL} \times 3) + (\textit{REMOTE} \times 2))$$

Where:

- CONNECTIONS = $(\text{DOP}^2 + 2 \times \text{DOP})$
- LOCAL = CONNECTIONS / INSTANCES
- REMOTE = CONNECTIONS - LOCAL

Each instance uses the memory computed by the formula.

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 under the following heading.

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 both structures have enough memory to accommodate your system's processing requirements.

Note: If you used parallel execution in previous releases and now intend to manually tune it, reduce the amount of memory allocated for LARGE_POOL_SIZE to account for the decreased demand on this pool.

Adjusting Memory After Processing Begins

The formulae 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 pool 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);
```

Sample output:

```
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 query:

```
SELECT * FROM V$PX_PROCESS_SYSSTAT WHERE STATISTIC LIKE 'Buffers%';
```

Oracle responds with output similar to:

```
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 statistics "Buffers Current" and "Buffers HWM". 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 38092812 or 38MB. The "BuffersHWM" 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 15MB. In this case, the high water mark has reached approximately 40% 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 except for the following:

- Allow for other clients of the shared pool such as shared cursors and stored procedures
- Larger values improve performance in multi-user 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.

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 this 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 required minimum 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%", and the DOP is reduced by 50% or greater because of the adaptive algorithm or because of a resource limitation, then Oracle returns ORA-12827. For example:

```
SELECT /*+ PARALLEL(e, 4, 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
```

PARALLEL_SERVER_INSTANCES

The recommended value is to set this parameter equal to the number of instances in your parallel server environment.

The PARALLEL_SERVER_INSTANCES parameter specifies the number of instances configured in a parallel server 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, and in particular for parallel execution. These parameters are:

- HASH_AREA_SIZE
- SORT_AREA_SIZE
- PARALLEL_EXECUTION_MESSAGE_SIZE
- OPTIMIZER_PERCENT_PARALLEL
- PARALLEL_BROADCAST_ENABLE

A second subset of parameters discussed in this section explains parameters affecting parallel DML and DDL.

To control resource consumption, 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 may 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.

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 may 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 may want to configure fewer processes, each with a greater limit on the amount of memory it can use. Sort performance, however, degrades with increased memory use.

HASH_AREA_SIZE

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 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 there is swapping, decrease the values for these parameters. If a significant amount of free memory remains, you may 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.

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 1MB.

This relationship can be expressed as follows:

$$\mathit{HASH\_AREA\_SIZE} \;>=\; \frac{\sqrt{S}}{2}$$

For example, if *S* equals 16MB, a minimum appropriate value for HASH_AREA_SIZE might be 2MB summed over all parallel processes. Thus if you have 2 parallel processes, a minimum value for HASH_AREA_SIZE might be 1MB. A smaller hash area is not advisable.

For a large data warehouse, HASH_AREA_SIZE may range from 8MB to 32MB 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 may 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 fall in the range from 256KB to 4MB.

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 may 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, then 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 may 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-load INSERT (if an index is involved)
- ALTER INDEX ... REBUILD

See Also: "HASH_AREA_SIZE" on page 18-18.

PARALLEL_EXECUTION_MESSAGE_SIZE

The recommended value for PARALLEL_EXECUTION_MESSAGE_SIZE is 4KB. If PARALLEL_AUTOMATIC_TUNING is TRUE, the default is 4KB. If PARALLEL_AUTOMATIC_TUNING is FALSE, the default is slightly greater than 2KB.

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've enabled parallel automatic tuning.

While you may 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, then 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.

OPTIMIZER_PERCENT_PARALLEL

The recommended value is 100 / *number_of_concurrent_users*.

This parameter determines how aggressively the optimizer attempts to parallelize a given execution plan. OPTIMIZER_PERCENT_PARALLEL encourages the optimizer to use plans with low response times because of parallel execution, even if total resource used is not minimized.

The default value of OPTIMIZER_PERCENT_PARALLEL is 0 (zero), which, if possible, parallelizes the plan using the fewest resources. Here, the execution time of the operation may be long because only a small amount of resource is used.

Note: Given an appropriate index, Oracle can quickly select a single record from a table; Oracle does not require parallelism to do this. A full scan to locate the single row can be executed in parallel. Normally, however, each parallel process examines many rows. In this case, the response time of a parallel plan will be longer and total system resource use will be much greater than if it were done by a serial plan using an index. With a parallel plan, the delay is shortened because more resources are used. The parallel plan could use up to *n* times more resources where *n* is equal to the value set for the degree of parallelism. A value between 0 and 100 sets an intermediate trade-off between throughput and response time. Low values favor indexes; high values favor table scans.

A nonzero setting of OPTIMIZER_PERCENT_PARALLEL is overridden if you use a FIRST_ROWS hint or set OPTIMIZER_MODE to FIRST_ROWS.

PARALLEL_BROADCAST_ENABLE

The default value is FALSE.

Set this parameter 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 is to avoid excessive communication overhead.

You cannot dynamically set the parameter PARALLEL_BROADCAST_ENABLE as it only affects hash joins and merge joins.

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 require. Likewise, PARALLEL CREATE TABLE ... AS SELECT and PARALLEL CREATE INDEX may 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. You may thus 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; thus you should increase TRANSACTIONS by 21 (or 41), if they are running in the same instance. If you do not set this parameter, Oracle sets it 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 5 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 they 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 to be at most 4 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 to 5MB. If the number of retries is still high after increasing LOG_BUFFER size, a problem may 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 16KB. 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 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 18–2 shows the types of locks acquired by coordinator and query server processes for different types of parallel DML statements. Using this information, you can determine the value required for these parameters. A query server process can work on one or more partitions or subpartitions, but a partition or subpartition can only be worked on by one server process (this is different from parallel execution).

Table 18–2 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/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, 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 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/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. Therefore, increase the value of the ENQUEUE_RESOURCES and DML_LOCKS parameters by equal amounts.

> **See Also:** "DML_LOCKS" on page 18-23.

Parameters Related to I/O

The parameters that affect I/O are:

- DB_BLOCK_BUFFERS
- DB_BLOCK_SIZE
- DB_FILE_MULTIBLOCK_READ_COUNT
- HASH_MULTIBLOCK_IO_COUNT
- SORT_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 and deletes, the buffer cache behavior is very similar to any system running a high volume of updates.

DB_BLOCK_SIZE

The recommended value is 8KB or 16KB.

Set the database block size when you create the database. If you are creating a new database, use a large block size.

DB_FILE_MULTIBLOCK_READ_COUNT

The recommended value is 8 for 8KB block size, or 4 for 16KB block size.

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 64KB to 1MB.

HASH_MULTIBLOCK_IO_COUNT

The recommended value is 4.

This parameter specifies how many blocks a hash join reads and writes at once. Increasing the value of HASH_MULTIBLOCK_IO_COUNT decreases the number of hash buckets. If a system is I/O bound, you can increase the efficiency of I/O by having larger transfers per I/O.

Because memory for I/O buffers comes from the HASH_AREA_SIZE, larger I/O buffers mean fewer hash buckets. There is a trade-off, however. For large tables (hundreds of gigabytes in size) it is better to have more hash buckets and slightly less efficient I/Os. If you find an I/O bound condition on temporary space during hash joins, consider increasing the value of HASH_MULTIBLOCK_IO_COUNT.

SORT_MULTIBLOCK_READ_COUNT

The recommended value is to use the default value.

The SORT_MULTIBLOCK_READ_COUNT parameter specifies the number of database blocks to read each time a sort performs a read from a temporary segment. Temporary segments are used by a sort when the data does not fit in SORT_AREA_SIZE of memory.

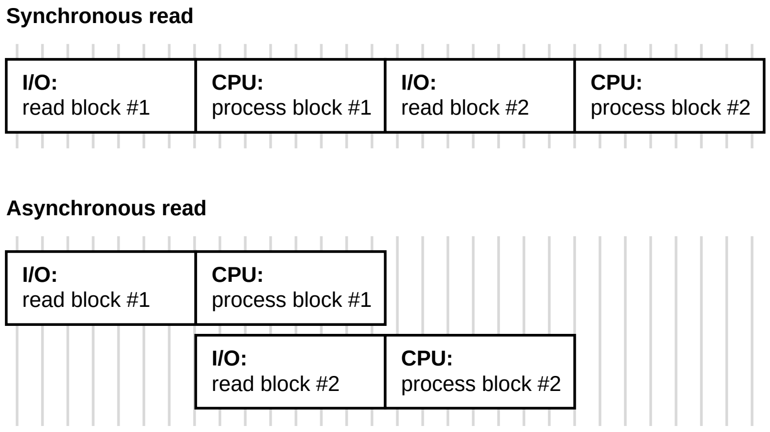
If the system is performing too many I/Os per second during sort operations and the CPUs are relatively idle during that time, consider increasing the SORT_MUTLIBLOCK_READ_COUNT parameter to force the sort operations to perform fewer, larger I/Os.

DISK_ASYNCH_IO and TAPE_ASYNCH_IO

The recommended value 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 18–1 Asynchronous Read



Asynchronous operations are currently supported for parallel table scans, hash joins, sorts, and serial table scans. However, this feature may require operating system specific configuration and may not be supported on all platforms. Check your Oracle operating system-specific documentation.

Example Parameter Setting Scenarios for Parallel Execution

The following examples describe a limited variety of parallel execution implementation possibilities. Each example begins by using either automatic or manual parallel execution tuning. Oracle automatically sets other parameters based on each sample system's characteristics and on how parallel execution tuning was initialized. The examples then describe setting the degree of parallelism and the enabling of the adaptive multi-user feature.

The effects that the parameter settings in these examples have on internally-derived settings and overall performance are only approximations. Your system's performance characteristics will vary depending on operating system dependencies and user workloads.

With additional adjustments, you can fine tune these examples to make them more closely resemble your environment. To further analyze the consequences of setting PARALLEL_AUTOMATIC_TUNING to TRUE, refer to Table 18–1 on page 18-4.

In your production environment, after you set the DOP for your tables and enable the adaptive multi-user feature, you may want to analyze system performance as explained in "Monitoring and Diagnosing Parallel Execution Performance" on page 18-64. If your system performance remains poor, refer to the explanation of "Tuning General Parameters" on page 18-8.

The following four examples describe different system types in ascending order of size and complexity.

Example One: Small Datamart

In this example, the DBA has limited parallel execution experience and does not have time to closely monitor the system.

The database is mostly a star type schema with some summary tables and a few tables in third normal form. The workload is mostly ad hoc in nature. Users expect parallel execution to improve the performance of their high-volume queries.

Other facts about the system are:

- CPUs = 4
- Main Memory = 750MB
- Disk = 40GB
- Users = 16

The DBA makes the following settings:

- PARALLEL_AUTOMATIC_TUNING = TRUE
- SHARED_POOL_SIZE = 12MB
- TRANSACTIONS = Left unset to use system default

Oracle automatically makes the following default settings:

- PARALLEL_MAX_SERVERS = 64
- PARALLEL_ADAPTIVE_MULTI_USER = TRUE
- PARALLEL_THREADS_PER_CPU = 2
- PROCESSES = 76
- SESSIONS = 88
- TRANSACTIONS = 96
- LARGE_POOL_SIZE = 29MB

Parameter Settings for DOP and the Adaptive Multi-User Feature

The DBA parallelizes every table having more than 10,000 rows using a command similar to the following:

```
ALTER TABLE employee PARALLEL;
```

In this example, because PARALLEL_THREADS_PER_CPU is 2 and the number of CPUs is 4, the DOP is 8. Because PARALLEL_ADAPTIVE_MULTI_USER is set to TRUE, Oracle may reduce this DOP in response to the system load that exists at the time of the query's initiation.

Example Two: Medium-sized Data Warehouse

In this example, the DBA is experienced but is also busy with other responsibilities. The DBA knows how to organize users into resource consumer groups and uses views and other roles to control access to parallelism. The DBA also has experimented with manually adjusting the settings that automated parallel tuning generates and has chosen to use all of the generated settings except for the PARALLEL_ADAPTIVE_MULTI_USER parameter, which the DBA sets to FALSE.

The system workload involves some ad hoc queries and a high volume of batch operations to convert a central repository into summary tables and star schemas. Most queries on this system are generated by Oracle Express and other tools.

The database has source tables in third normal form and end-user tables in a star schema and summary form only.

Other facts about the system are:

- CPUS = 8
- Main Memory = 2GB
- Disk = 80GB
- Users = 40

The DBA makes the following settings:

- PARALLEL_AUTOMATIC_TUNING = TRUE
- PARALLEL_ADAPTIVE_MULTI_USER = FALSE
- PARALLEL_THREADS_PER_CPU = 4
- SHARED_POOL_SIZE = 20MB

The DBA also sets other parameters unrelated to parallelism. As a result, Oracle responds by automatically adjusting the following parameter settings:

- PROCESSES = 307
- SESSIONS = 342
- TRANSACTIONS = 376
- PARALLEL_MAX_SERVERS = 256
- LARGE_POOL_SIZE = 78MB

Parameter Settings for DOP and the Adaptive Multi-User Feature

The DBA parallelizes some tables in the data warehouse while creating other views for special users:

```
ALTER TABLE sales PARALLEL;
CREATE VIEW invoice_parallel AS SELECT /*+ PARALLEL(P) */ * FROM invoices P;
```

The DBA allows the system to use the PARALLEL_THREADS_PER_CPU setting of 4 with 8 CPUs. The DOP for the tables is 32. This means a simple query uses 32 processes while more complex queries use 64.

Example Three: Large Data Warehouse

In this example, the DBA is experienced and is occupied primarily with managing this system. The DBA has good control over resources and understands how to tune the system. The DBA schedules large queries in batch mode.

The workload includes some ad hoc parallel queries. In addition, a large number of serial queries are processed against a star schema. There is also some batch processing that generates summary tables and indexes. The database is completely denormalized and the Oracle Parallel Server option is in use.

Other facts about the system are:

- 24 Nodes, 1 CPU per node
- Uses MPP Architecture (Massively Parallel Processing)
- Main Memory = 750MB per node
- Disk = 200GB
- Users = 256

The DBA uses manual parallel tuning by setting the following:

- PARALLEL_AUTOMATIC_TUNING = FALSE
- PARALLEL_THREADS_PER_CPU = 1
- PARALLEL_MAX_SERVERS = 10
- SHARED_POOL_SIZE = 75MB
- PARALLEL_SERVER_INSTANCES = 24
- PARALLEL_SERVER = TRUE
- PROCESSES = 40
- SESSIONS = 50
- TRANSACTIONS = 60

The DBA also sets other parameters unrelated to parallel execution. Because PARALLEL_AUTOMATIC_TUNING is set to FALSE, Oracle allocates parallel execution buffers from the SHARED_POOL.

Parameter Settings for DOP and the Adaptive Multi-User Feature

The DBA parallelizes tables in the data warehouse by explicitly setting the DOP using syntax similar to the following:

```
ALTER TABLE department1 PARALLEL 10;
ALTER TABLE department2 PARALLEL 5;
CREATE VIEW current_sales AS SELECT /*+ PARALLEL(P, 20) */ * FROM sales P;
```

In this example, Oracle does not make calculations for parallel execution because the DBA has manually set all parallel execution parameters.

Example Four: Very Large Data Warehouse

In this example, the DBA is very experienced and is dedicated to administering this system. The DBA has good control over the environment, but the variety of users requires the DBA to devote constant attention to the system.

The DBA sets PARALLEL_AUTOMATIC_TUNING to TRUE, which makes Oracle allocate parallel execution buffers from the large pool. PARALLEL_ADAPTIVE_MULTI_USER is automatically enabled. After gaining experience with the system, the DBA fine-tunes the system supplied defaults to further improve performance.

The database is a very large data warehouse with data marts residing on the same machine. The data marts are generated and refreshed from data in the warehouse.

The warehouse is mostly normalized while the marts are mostly star schemas and summary tables. The DBA has carefully customized system parameters through experimentation.

Other facts about the system are:

- CPUS = 64
- Main Memory 32GB
- Disk = 3TB
- Users = 1,000

The DBA makes the following settings:

- PARALLEL_AUTOMATIC_TUNING = TRUE
- PARALLEL_MAX_SERVERS = 600
- PARALLEL_MIN_SERVERS = 600
- LARGE_POOL_SIZE = 1,300MB
- SHARED_POOL_SIZE = 500MB
- PROCESSES = 800
- SESSIONS = 900
- TRANSACTIONS = 1,024

Parameter Settings for DOP and the Adaptive Multi-User Feature

The DBA has carefully evaluated which users and tables require parallelism and has set the values according to their requirements. The DBA has taken all steps mentioned in the earlier examples, but in addition, the DBA also uses the following command during peak user hours to enable the adaptive DOP algorithms:

```
ALTER SYSTEM SET PARALLEL_ADAPTIVE_MULTI_USER = TRUE;
```

During off hours when batch processing is about to begin, the DBA disables adaptive processing by issuing the command:

```
ALTER SYSTEM SET PARALLEL_ADAPTIVE_MULTI_USER = FALSE;
```

Miscellaneous Tuning Tips

This section contains some ideas for improving performance in a parallel execution environment, and includes:

- Formula for Memory, Users, and Parallel Execution Server Processes
- Setting Buffer Pool Size for Parallel Operations
- Balancing the Formula
- Examples: Balancing Memory, Users, and Parallel Execution Servers
- Parallel Execution Space Management Issues
- Tuning Parallel Execution on Oracle Parallel Server
- 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 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 18–3 defines high, medium, and low memory processes.

Analyze the maximum number of processes that can fit in memory as follows:

Figure 18–2 Formula for Memory/Users/Server Relationship

$$\begin{array}{l}
\quad \mathit{sga\_size} \\
+\ (\#\ \mathit{low\_memory\_processes} * \mathit{low\_memory\_required}) \\
+\ (\#\ \mathit{medium\_memory\_processes} * \mathit{medium\_memory\_required}) \\
+\ (\#\ \mathit{high\_memory\_processes} * \mathit{high\_memory\_required}) \\
\hline
\quad \mathit{total\ memory\ required}
\end{array}$$

Table 18–3 Memory Requirements for Three Classes of Process

Class	Description
Low Memory Processes: 100KB to 1MB	Low Memory Processes include table scans, index lookups, index nested loop joins; single-row aggregates (such as sum or average with no GROUP BYs, 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 could 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 by using the multi-threaded server, and support even more users.
Medium Memory Processes: 1MB to 10MB	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 *Oracle8i Designing and Tuning for Performance*.
High Memory Processes: 10MB to 100MB	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 8MB to 32MB, and you might need two of them. If you are performing 2 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 1 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 (Data Manipulation Language) and parallel DDL (Data Definition Language) operations also depend upon the query portion of the statement.

Setting Buffer Pool Size for Parallel Operations

The formula to calculate the maximum number of processes your system can support (referred to here as *max_processes*) is:

Figure 18–3 Formula for Calculating the Maximum Number of Processes

$$\begin{array}{l}
\quad \#\ \mathit{low\_memory\_processes} \\
+\ \#\ \mathit{medium\_memory\_processes} \\
+\ \#\ \mathit{high\_memory\_processes} \\
\hline
\quad \mathit{max\_processes}
\end{array}$$

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 "Balancing the Formula" on page 18-37.

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 can 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 techniques to balance the memory/users/server formula given in Figure 18–2:

- Oversubscribing with Attention to Paging
- Reducing the Number of Memory-Intensive Processes
- Decreasing Data Warehousing Memory per Process
- Decreasing Parallelism for Multiple Users

Oversubscribing with Attention to Paging

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% oversubscription. Thus, if you have 1GB of memory, you might be able to support 1.2GB of demand: the other 20% 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 may perform acceptably even if oversubscribed by 60%, if on average not all of the processes are performing hash joins concurrently. Users might then try to use 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% of the time should be spent simply waiting in the operating system on page faults. More than 5% wait time 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%, you can reduce memory requirements in one of these ways:

- Reducing the memory required for each class of process
- Reducing the number of processes in memory-intensive classes
- Adding memory

If the wait time indicates an I/O bottleneck in the paging subsystem, you could resolve this by striping.

Reducing the Number of Memory-Intensive Processes

This section describes two things you can do to reduce the number of memory-intensive processes:

- Adjusting the Degree of Parallelism
- Scheduling Parallel Jobs

Adjusting the Degree of Parallelism. You can adjust not only the number of operations that run in parallel, but also the DOP (degree of parallelism) with which operations run. To do this, issue an ALTER TABLE statement with a PARALLEL clause, or use a hint.

You can limit the parallel pool by reducing the value of PARALLEL_MAX_SERVERS. Doing so places a system-level limit on the total amount of parallelism. It also makes your system easier to administer. More processes are then forced to run in serial mode.

If you enable the parallel adaptive multi-user feature by setting the PARALLEL_ADAPTIVE_MULTI_USER parameter to TRUE, Oracle adjusts DOP based on user load.

Scheduling Parallel Jobs Queuing jobs is another way to reduce the number of processes but not reduce parallelism. Rather than reducing parallelism for all operations, you may be able to schedule large parallel batch jobs to run with full parallelism one at a time, rather than concurrently. Queries at the head of the queue would have a fast response time, those at the end of the queue would have a slow response time. However, this method entails a certain amount of administrative overhead.

Decreasing Data Warehousing Memory per Process

The following discussion focuses upon the relationship of HASH_AREA_SIZE to memory, but all the same considerations apply to SORT_AREA_SIZE. The lower bound of SORT_AREA_SIZE, however, is not as critical as the 8MB recommended minimum HASH_AREA_SIZE.

If every operation performs a hash join and a sort, the high memory requirement limits the number of processes you can have. To allow more users to run concurrently you may need to reduce the data warehouse's process memory.

Moving Processes from High to Medium Memory Requirements You can move a process from the high-memory to the medium-memory class by reducing the value for HASH_AREA_SIZE. With the same amount of memory, Oracle always processes hash joins faster than sort merge joins. Therefore, Oracle does not recommend that you make your hash area smaller than your sort area.

Moving Processes from High or Medium Memory Requirements to Low Memory Requirements If you need to support thousands of users, create access paths so operations do not access data unnecessarily. To do this, perform one or more of the following:

- Decrease the demand for index joins by creating indexes and/or summary tables.
- Decrease the demand for GROUP BY sorting by creating summary tables and encouraging users and applications to reference summaries and materialized views rather than detailed data.
- Decrease the demand for ORDER BY sorts by creating indexes on frequently sorted columns.

Decreasing Parallelism for Multiple Users

The easiest way to decrease parallelism for multiple users is to enable the parallel adaptive multi-user feature.

If you decide to control this manually, however, there is a trade-off between parallelism for fast single-user response time and efficient use of resources for multiple users. For example, a system with 2GB of memory and a HASH_AREA_SIZE of 32MB can support about 60 parallel execution servers. A 10 CPU machine can support up to 3 concurrent parallel operations (2 * 10 * 3 = 60). To support 12 concurrent parallel operations, you could override the default parallelism (reduce it), decrease HASH_AREA_SIZE, buy more memory, or you could use some combination of these three strategies. Thus you could ALTER TABLE *t* PARALLEL (DOP = 5) for all parallel tables *t*, set HASH_AREA_SIZE to 16MB, and increase PARALLEL_MAX_SERVERS to 120. By reducing the memory of each parallel server by a factor of 2, and reducing the parallelism of a single operation by a factor of 2, the system can accommodate 2 * 2 = 4 times more concurrent parallel operations.

The penalty for using such an approach is that, when a single operation happens to be running, the system uses just half the CPU resource of the 10 CPU machine. The other half is idle until another operation is started.

To determine whether your system is being fully utilized, use one of the graphical system monitors available on most operating systems. These monitors often give you a better idea of CPU utilization and system performance than monitoring the execution time of an operation. Consult your operating system documentation to determine whether your system supports graphical system monitors.

Examples: Balancing Memory, Users, and Parallel Execution Servers

The examples in this section show how to evaluate the relationship between memory, users, and parallel execution servers, and balance the formula given in Figure 18–2. They show concretely how you might adjust your system workload to accommodate the necessary number of processes and users.

Example 1

Assume your system has 1GB of memory, the DOP is 10, and that your users perform 2 hash joins with 3 or more tables. If you need 300MB for the SGA, that leaves 700MB to accommodate processes. If you allow a generous hash area size, such as 32MB, then your system can support:

Figure 18–4 Formula for Balancing Memory, Users, and Processes

$$\begin{array}{l} \textit{1 parallel operation}\ (32MB * 10 * 2 = 640MB) \\ \textit{1 serial operation}\ (32MB * 2 = 64MB) \end{array}$$

This makes a total of 704MB. In this case, the memory is not significantly oversubscribed.

Remember that every parallel, hash, or sort merge join operation takes a number of parallel execution servers equal to twice the DOP, utilizing 2 server sets, and often each individual process of a parallel operation uses a significant amount of memory. Thus you can support many more users by running their processes serially, or by using less parallelism to run their processes.

To service more users, you can reduce hash area size to 2MB. This configuration can support 17 parallel operations, or 170 serial operations, but response times may be significantly higher than if you were using hash joins.

The trade-off in this example reveals that by reducing memory per process by a factor of 16, you can increase the number of concurrent users by a factor of 16. Thus the amount of physical memory on the machine imposes another limit on the total number of parallel operations you can run involving hash joins and sorts.

Example 2

In a mixed workload example, consider a user population with diverse needs, as described in Table 18–4. In this situation, you would have to allocate resources selectively. You could not allow everyone to run hash joins—even though they outperform sort merge joins—because you do not have adequate memory to support workload level.

You might consider it safe to oversubscribe by 50%, because of the infrequent batch jobs that run during the day: 700MB * 1.5 = 1.05GB. This gives you enough virtual memory for the total workload.

Table 18–4 How to Accommodate a Mixed Workload

User Needs	How to Accommodate
DBA: runs nightly batch jobs, and occasional batch jobs during the day. These might be parallel operations that perform hash joins and thus use a lot of memory.	You might take 20 parallel execution servers, and set HASH_AREA_SIZE to a mid-range value, perhaps 20MB, for a single powerful batch job in the high memory class. This might be a large GROUP BY operation with a join to produce a summary of data. Twenty servers multiplied by 20MB equals 400MB of memory.
Analysts: interactive users who extract data for their spreadsheets.	You might plan for 10 analysts running serial operations that use complex hash joins accessing a large amount of data. You would not allow them to perform parallel operations because of memory requirements. Ten such serial processes at 40MB each equals 400MB of memory.
Users: Several hundred users performing simple lookups of individual customer accounts, and making reports on already joined, partially summarized data.	To support hundreds of users performing low memory processes at about 0.5MB each, you might reserve 200MB.

Example 3

Suppose your system has 2GB of memory and you have 200 query server processes and 100 users doing performing heavy data warehousing operations involving hash joins. You decide not to consider tasks such as index retrievals and small sorts. Instead, you concentrate on the high memory processes. You might have 300 processes, of which 200 must come from the parallel pool and 100 are single threaded. One quarter of the total 2GB of memory might be used by the SGA, leaving 1.5GB of memory to handle all the processes. You could apply the formula considering only the high memory requirements, including a factor of 20% oversubscription:

Figure 18–5 Formula for Memory/User/Server Relationship: High-Memory Processes

$$high\_memory\_req'd = \frac{total\_memory}{\#\_high\text{-}memory\_processes} * 1.2 = \frac{1.5\text{GB} * 1.2}{300} = \frac{1.8\text{GB}}{300}$$

Here, 5MB = 1.8GB / 300. Less than 5MB of hash area would be available for each process, whereas 8MB is the recommended minimum. If you must have 300 processes, you may need to reduce hash area size to change them from the highly memory-intensive class to the moderately memory-intensive class. Then they may fit within your system's constraints.

Example 4

Consider a system with 2GB of memory and 10 users who want to run intensive data warehousing parallel operations concurrently and still have good performance. If you choose a DOP of 10, then the 10 users will require 200 processes. (Processes running large joins need twice the number of parallel execution servers as the DOP, so you would set PARALLEL_MAX_SERVERS to 10 * 10 * 2.) In this example each process would get 1.8GB / 200—or about 9MB of hash area—which should be adequate.

With only 5 users doing large hash joins, each process would get over 16MB of hash area, which would be fine. But if you want 32MB available for lots of hash joins, the system could only support 2 or 3 users. By contrast, if users are just computing aggregates, the system needs adequate sort area size—and can have many more users.

Example 5

If a system with 2GB of memory needs to support 1000 users, all of them running large queries, you must evaluate the situation carefully. Here, the per-user memory budget is only 1.8MB (that is, 1.8GB divided by 1,000). Since this figure is at the low end of the medium memory process class, you must rule out parallel operations, which use even more resources. You must also rule out large hash joins. Each sequential process could require up to 2 hash areas plus the sort area, so you would have to set HASH_AREA_SIZE to the same value as SORT_AREA_SIZE, which would be 600KB(1.8MB / 3). Such a small hash area size is likely to be ineffective.

Given the organization's resources and business needs, is it reasonable for you to upgrade your system's memory? If memory upgrade is not an option, then you must change your expectations. To adjust the balance, you might:

- Accept the fact that the system will actually support a limited number of users executing large hash joins.
- Give the users access to summary tables, rather than to the whole database.
- Classify users into different groups, and give some groups more memory than others. Instead of all users doing sorts with a small sort area, you could have a few users doing high-memory hash joins, while most users use summary tables or do low-memory index joins. (You could accomplish this by forcing users in each group to use hints in their queries such that operations are performed in a particular way.)

Parallel Execution Space Management Issues

This section describes space management issues that occur when using parallel execution. These issues are:

- ST (Space Transaction) Enqueue for Sorts and Temporary Data
- External Fragmentation

These problems become particularly important for parallel operations in an OPS (Oracle Parallel Server) environment; the more nodes that are involved, the more tuning becomes critical.

If you can implement locally-managed tablespaces, you can avoid these issues altogether.

Note: For more information about locally-managed tablespaces, please refer to the *Oracle8i Administrator's Guide*.

ST (Space Transaction) 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-load inserts of non-partitioned tables) is controlled by a single ST enqueue. A high transaction rate, for example, more than 2 or 3 transactions per minute, on ST enqueues may result in poor scalability on OPS 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

Use dedicated temporary tablespaces to optimize space management for sorts. This is particularly beneficial on OPS. You can monitor this using V$SORT_SEGMENT.

Set INITIAL and NEXT extent size to a value in the range of 1MB to 10MB. Processes may use temporary space at a rate of up to 1MB per second. Do not accept the default value of 40KB for next extent size, because this will result in many requests for space per second.

External Fragmentation

External fragmentation is a concern for parallel load, direct-load insert, and PARALLEL CREATE TABLE ... AS SELECT. Memory tends to become fragmented as extents are allocated and data is inserted and deleted. This may result in a fair amount of free space that is unusable because it consists of small, non-contiguous 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 zero. 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 MAXEXTENS in excess of 10,000. For tables that are not partitioned, the initial extent should be small.

Tuning Parallel Execution on Oracle Parallel Server

This section describe several aspects of parallel execution for OPS.

Lock Allocation

This section provides parallel execution tuning guidelines for optimal lock management on OPS.

To optimize parallel execution on OPS, you need to correctly set GC_FILES_TO_LOCKS. On OPS, a certain number of parallel cache management (PCM) locks are assigned to each data file. Data block address locking in its default behavior assigns one lock to each block. During a full table scan, a PCM lock must then be acquired for each block read into the scan. To speed up full table scans, you have three possibilities:

- For data files containing truly read-only data, set the tablespace to read only. Then PCM locking does not occur.
- Alternatively, for data that is mostly read-only, assign very few hashed PCM locks (for example, 2 shared locks) to each data file. Then these are the only locks you have to acquire when you read the data.
- If you want data block address or fine-grain locking, group together the blocks controlled by each lock, using the ! option. This has advantages over default data block address locking because with the default, you would need to acquire one million locks in order to read one million blocks. When you group the blocks, you reduce the number of locks allocated by the grouping factor. Thus a grouping of !10 would mean that you would only have to acquire one tenth as many PCM locks as with the default. Performance improves due to the dramatically reduced amount of lock allocation. As a rule of thumb, performance with a grouping of !10 is comparable to the speed of hashed locking.

  To speed up parallel DML operations, consider using hashed locking or a high grouping factor rather than database address locking. A parallel execution server works on non-overlapping partitions; it is recommended that partitions not share files. You can thus reduce the number of lock operations by having only 1 hashed lock per file. Because the parallel execution server only works on non-overlapping files, there are no lock pings.

The following guidelines effect memory usage, and thus indirectly affect performance:

- Never allocate PCM locks for datafiles of temporary tablespaces.
- Never allocate PCM locks for datafiles that contain only rollback segments. These are protected by GC_ROLLBACK_LOCKS and GC_ROLLBACK_SEGMENTS.
- Allocate specific PCM locks for the SYSTEM tablespace. This practice ensures that data dictionary activity such as space management never interferes with the data tablespaces at a cache management level (error 1575).

  For example, on a read-only database with a data warehousing application's query-only workload, you might create 500 PCM locks on the SYSTEM tablespace in file 1, then create 50 more locks to be shared for all the data in the other files. Space management work will never interfere with the rest of the database.

See Also: *Oracle8i Parallel Server Concepts* for a thorough discussion of PCM locks and locking parameters.

Load Balancing for Multiple Concurrent Parallel Operations

Load balancing distributes query server processes to spread CPU and memory use evenly among nodes. It also minimizes communication and remote I/O among nodes. Oracle does this by allocating servers to the nodes that are running the fewest number of processes.

The load balancing algorithm attempts to maintain an even load across all nodes. For example, if a DOP of 8 is requested on an 8-node MPP (Massively Parallel Processing) system with 1 CPU per node, the algorithm places 2 servers on each node.

If the entire query server group fits on one node, the load balancing algorithm places all the processes on a single node to avoid communications overhead. For example, if a DOP of 8 is requested on a 2-node cluster with 16 CPUs per node, the algorithm places all 16 query server processes on one node.

Using Parallel Instance Groups

A user or the DBA can control which instances allocate query server processes by using Instance Group functionality. To use this feature, you must first assign each active instance to at least one or more instance groups. Then you can dynamically control which instances spawn parallel processes by activating a particular group of instances.

Establish instance group membership on an instance-by-instance basis by setting the initialization parameter INSTANCE_GROUPS to a name representing one or more instance groups. For example, on a 32-node MPP system owned by both a Marketing and a Sales organization, you could assign half the nodes to one organization and the other half to the other organization using instance group names. To do this, assign nodes 1-16 to the Marketing organization using the following parameter syntax in each initialization parameter file:

```
INSTANCE_GROUPS=marketing
```

Then assign nodes 17-32 to Sales using this syntax in the remaining INIT.ORA files:

```
INSTANCE_GROUPS=sales
```

Then a user or the DBA can activate the nodes owned by Sales to spawn a query server process by entering the following:

```
ALTER SESSION SET PARALLEL_INSTANCE_GROUP = 'sales';
```

In response, Oracle allocates query server processes to nodes 17-32. The default value for PARALLEL_INSTANCE_GROUP is all active instances.

Note: An instance can belong to one or more groups. You can enter multiple instance group names with the INSTANCE_GROUP parameter using a comma as a separator.

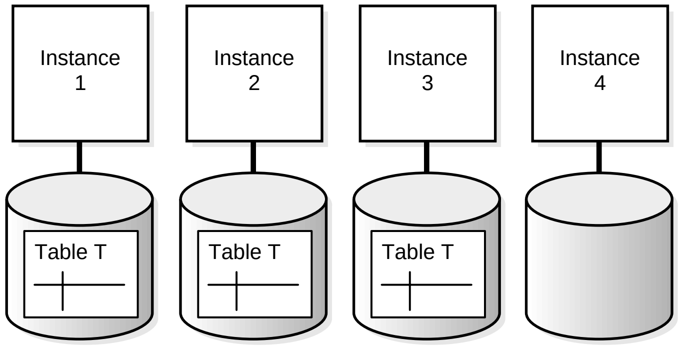
Disk Affinity

Some OPS platforms use disk affinity. Without disk affinity, Oracle tries to balance the allocation evenly across instances; with disk affinity, Oracle tries to allocate parallel execution servers for parallel table scans on the instances that are closest to the requested data. Disk affinity minimizes data shipping and internode communication on a shared nothing architecture. Disk affinity can thus significantly increase parallel operation throughput and decrease response time.

Disk affinity is used for parallel table scans, parallel temporary tablespace allocation, parallel DML, and parallel index scan. It is not used for parallel table creation or parallel index creation. Access to temporary tablespaces preferentially uses local datafiles. It guarantees optimal space management extent allocation. Disks striped by the operating system are treated by disk affinity as a single unit.

In the following example of disk affinity, table T is distributed across 3 nodes, and a full table scan on table T is being performed.

Figure 18–6 Disk Affinity Example



- If a query requires 2 instances, then two instances from the set 1, 2, and 3 are used.
- If a query requires 3 instances, then instances 1, 2, and 3 are used.
- If a query requires 4 instances, then all four instances are used.
- If there are two concurrent operations against table T, each requiring 3 instances (and enough processes are available on the instances for both operations), then both operations use instances 1, 2, and 3. Instance 4 is not used. In contrast, without disk affinity instance 4 is used.

> **See Also:** *Oracle8i Parallel Server Concepts* for more information on instance affinity.

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 an operation is I/O bound, consider increasing the default DOP. If it is memory bound, or 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 when the PARALLEL hint is specified. If a table does not have parallelism attributed to it, or has NOPARALLEL (the default) attributed to it, then that table is never scanned in parallel—regardless of the default DOP that would be indicated by the number of CPUs, instances, and devices storing that table.

Use the following guidelines when adjusting the DOP:

- You can modify the default DOP by changing the value for the PARALLEL_THREADS_PER_CPU parameter.
- You can 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.
- For I/O-bound parallel operations, first spread the data over more disks than there are CPUs. Then, increase parallelism in stages. Stop when the query becomes CPU bound.

  For example, assume a parallel indexed nested loop join is I/O bound performing the index lookups, with *#CPUs*=10 and *#disks*=36. The default DOP is 10, and this is I/O bound. You could first try a DOP of 12. If the application is still I/O bound, try a DOP of 24; if still I/O bound, try 36.

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.

By making the following changes you can increase the optimizer's ability to generate parallel plans:

- Convert subqueries, especially correlated subqueries, into joins. Oracle can parallelize joins more efficiently than subqueries. This also applies to updates.
- Use a PL/SQL function in the WHERE clause of the main query instead of a correlated subquery.
- Rewrite queries with distinct aggregates as nested queries. For example, rewrite

  ```
  SELECT COUNT(DISTINCT C) FROM T;
  ```

  To:

  ```
  SELECT COUNT(*)FROM (SELECT DISTINCT C FROM T);
  ```

See Also: "Updating the Table" on page 18-62.

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 may indeed be faster; however, the user process can only receive the rows serially. To optimize parallel execution performance with queries that retrieve large result sets, use PARALLEL CREATE TABLE ... AS SELECT or direct-load insert to store the result set in the database. At a later time, users can view the result set serially.

Note: Parallelism of the SELECT 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 may 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 / restart. For example, a complex multi-table 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 and / 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.

- Materialize a Cartesian product. This may allow queries against star schemas to execute in parallel. It may also increase scalability of parallel hash joins by increasing the number of distinct values in the join column.

  Consider a large table of retail sales data that is joined to region and to department lookup tables. There are 5 regions and 25 departments. If the huge table is joined to regions using parallel hash partitioning, the maximum speedup is 5. Similarly, if the huge table is joined to departments, the maximum speedup is 25. But if a temporary table containing the Cartesian product of regions and departments is joined with the huge table, the maximum speedup is 125.
- Efficiently implement manual parallel deletes 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 can directly delete 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 salesperson.
- 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 ANALYZE statement 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.

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 1MB to 10MB. Once you allocate an extent it is yours for the duration of your 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 spend all their time waiting 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 may 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 OS striped temporary space, you will probably have to drop and recreate the tablespace. This could take several hours for the 120GB 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 1KB, which is less than the extent size, the corrupt file is not accessed. Eventually, you may wish to recreate the tablespace.

Be sure to make your temporary tablespace available for use:

```
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 degree of parallelism used. The following operations should scale:

- Table scans
- NESTED LOOP JOIN
- SORT MERGE JOIN
- HASH JOIN
- NOT IN
- GROUP BY
- SELECT DISTINCT
- UNION and UNION ALL
- AGGREGATION
- PL/SQL functions called from SQL
- ORDER BY
- CREATE TABLE AS SELECT
- CREATE INDEX
- REBUILD INDEX
- REBUILD INDEX PARTITION
- MOVE PARTITION
- SPLIT PARTITION
- UPDATE
- DELETE
- INSERT ... SELECT
- ENABLE CONSTRAINT
- STAR TRANSFORMATION

Start with simple parallel operations. Evaluate total I/O throughput with SELECT COUNT(*) FROM facts. Evaluate total CPU power by adding a complex WHERE clause. I/O imbalance may 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. 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 command to see the execution plans for parallel queries. EXPLAIN PLAN output shows optimizer information in the COST, BYTES, and CARDINALITY columns. For more information on using EXPLAIN PLAN, refer to *Oracle8i Designing and Tuning for Performance*.

There are several ways to optimize the parallel execution of join statements. You can alter your system's configuration, adjust parameters as discussed earlier in this chapter, or use hints, such as the DISTRIBUTION hint.

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-load Restrictions
- Limitation on the Degree of Parallelism
- Using Local and Global Striping
- Increasing INITRANS and MAXTRANS
- Limitation on Available Number of Transaction Free Lists
- Using Multiple Archivers
- Database Writer Process (DBWn) Workload
- [NO]LOGGING Clause

PDML and Direct-load Restrictions

A complete listing of PDML and direct-load insert restrictions is found in *Oracle8i Concepts*. If a parallel restriction is violated, the operation is simply performed serially. If a direct-load 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 insert, update, or delete operations, the DOP is equal to or less than the number of partitions in the table.

Using Local and Global Striping

Parallel DML works mostly on partitioned tables. It does not use asynchronous I/O and may generate a high number of random I/O requests during index maintenance of parallel UPDATE and DELETE operations. 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 non-partitioned), 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 may 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

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 may find that this limits the number of transaction free lists that are available. You can abate this limitation the next time you recreate 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 may 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 4KB block has about 80 transaction free lists by default. The minimum number of transaction free lists is 25.

> **See Also:** *Oracle8i Parallel Server Concepts* for information about transaction free lists.

Using Multiple Archivers

Parallel DDL and parallel DML operations may 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. If 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';
```

Tune the DBW*n* process(es). If there are no waits for free buffers, the above query does 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-load 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 command for the table, partition, index, or tablespace.

When a table or index has NOLOGGING set, neither parallel nor serial direct-load 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 may be corrupted.

Note: Direct-load INSERT operations (except for dictionary updates) never generate undo logs. The NOLOGGING attribute does not affect undo, but only redo. To be precise, NOLOGGING allows the direct-load 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 command. This alternate keyword may 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, the Oracle Server 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 this 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 5MB and a DOP of 12 consumes at least 60MB of storage during index creation because each process starts with an extent of 5MB. When the query coordinator process combines the sorted subindexes, some of the extents may be trimmed, and the resulting index may be smaller than the requested 60MB.

When you add or enable a UNIQUE key 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 enabled 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: For more information on how extents are allocated when using the parallel execution feature, see *Oracle8i Concepts*. Also refer to the *Oracle8i SQL Reference* for the complete syntax of the CREATE INDEX statement.

Parallel DML Tips

This section provides an overview of parallel DML functionality.

- INSERT
- Direct-Load INSERT
- Parallelizing INSERT, UPDATE, and DELETE

See Also: *Oracle8i Concepts* for a detailed discussion of parallel DML and DOP. For a discussion of parallel DML affinity, please see *Oracle8i Parallel Server Concepts*.

INSERT

Oracle INSERT functionality can be summarized as follows:

Table 18–5 Summary of INSERT Features

Insert Type	Parallel	Serial	NOLOGGING
Conventional	No	Yes	No
Direct Load 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, then the insert is performed serially.

Direct-Load 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, 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:** *Oracle8i 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 INSERT 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 may also have their insert operation parallelized.

If you query multiple tables, you can specify multiple SELECT PARALLEL hints and multiple PARALLEL attributes.

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/delete operation. Alternatively, you can specify update/delete parallelism in the PARALLEL clause specified in the definition of the table to be modified.

If you have explicitly enabled PDML (Parallel Data Manipulation Language) for the session or transaction, UPDATE/DELETE statements that have their query operation parallelized may also have their UPDATE/DELETE operation parallelized. Any subqueries or updatable views in the statement may 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.

You can only use parallel UPDATE and DELETE on partitioned tables.

Example 1

Give a 10% 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 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 PROCUT_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(c_key, c_name, 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 is performed in two phases:

- Updating the table
- Inserting the new rows in parallel

Updating the Table

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 the preceding statement affect the 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);
```

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 18-49. Also see the *Oracle8i 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 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);
```

But here, the HASH_AJ hint transforms the subquery into an anti-hash join. (The hint is not required if the parameter ALWAYS_ANTI_JOIN is set to hash in the initialization file). Doing so allows you to use parallel insert to execute the preceding statement very efficiently. Parallel insert is applicable even if the table is not partitioned.

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 may need to change the hints. Otherwise, the effectiveness of your execution plans may 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 = RULE, or if there is a RULE hint in the query itself.

Monitoring and Diagnosing Parallel Execution Performance

Use the decision tree in Figure 18–7 to diagnose parallel performance problems. The questions in the decision points of Figure 18–7 are discussed in more detail after the figure.

Some key issues in diagnosing parallel execution performance problems are the following:

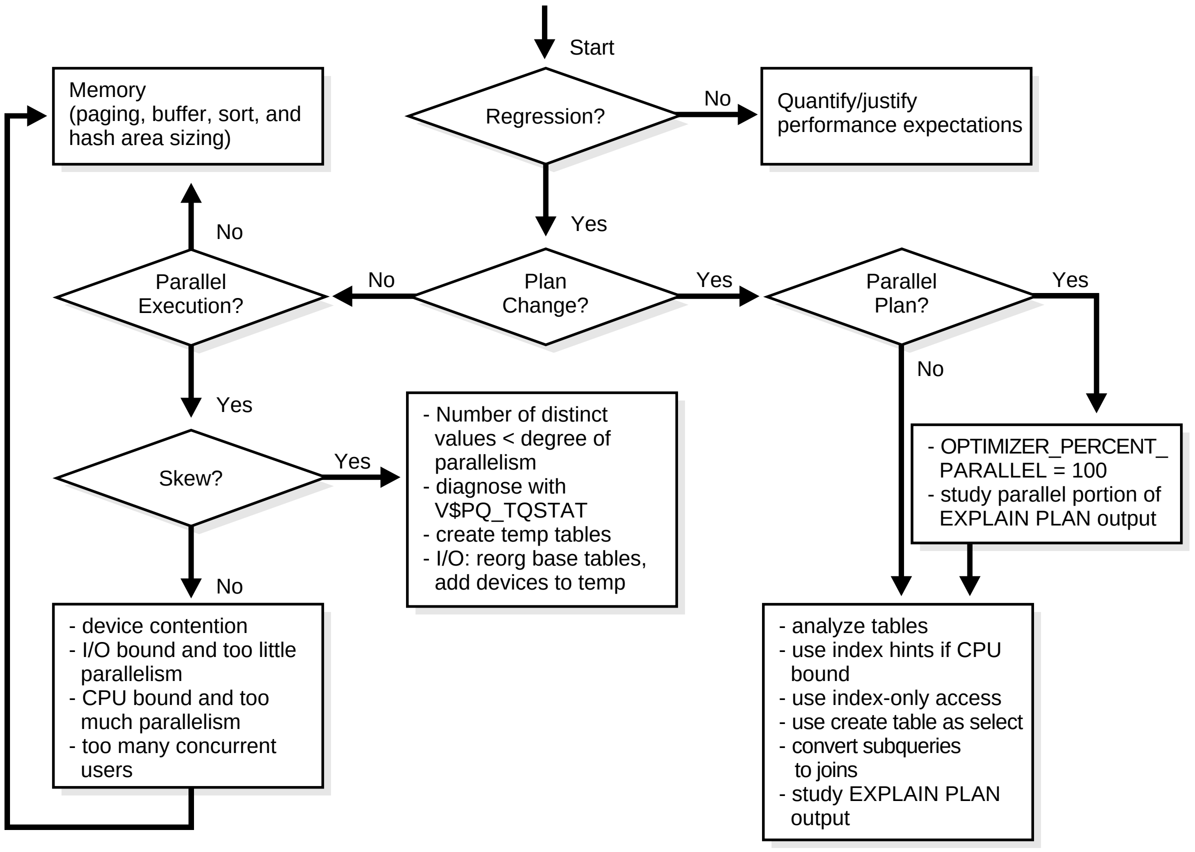
- Quantify your performance expectations to determine whether there is a problem.

- Determine whether a problem pertains to optimization, such as inefficient plans that may require re-analyzing 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.

This phase discusses the following topics for monitoring parallel execution performance:

- Monitoring Parallel Execution Performance with Dynamic Performance Views
- Monitoring Session Statistics
- Monitoring Operating System Statistics

Figure 18–7 Parallel Execution Performance Checklist


Start
Regression?
No
Quantify/justify performance expectations
Yes
Memory (paging, buffer, sort, and hash area sizing)
No
Parallel Execution?
No
Plan Change?
Yes
Parallel Plan?
Yes
No
Yes
Skew?
Yes
- Number of distinct values < degree of parallelism
- diagnose with V$PQ_TQSTAT
- create temp tables
- I/O: reorg base tables, add devices to temp
- OPTIMIZER_PERCENT_ PARALLEL = 100
- study parallel portion of EXPLAIN PLAN output
No
- device contention
- I/O bound and too little parallelism
- CPU bound and too much parallelism
- too many concurrent users
- analyze tables
- use index hints if CPU bound
- use index-only access
- use create table as select
- convert subqueries to joins
- study EXPLAIN PLAN output

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 particular execution plan in the past, but now, with a similar environment and operation, your 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 the data, reanalyze, 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 may find that plan performance improves if you use hints. You may want to understand why hints were necessary, and determine how to get the optimizer to generate the desired plan without the hints. Try increasing the statistical sample size: better statistics may give you a better plan. If you had to use a PARALLEL hint, determine whether you had OPTIMIZER_PERCENT_PARALLEL set to 100%.

> **See Also:** For information on preserving plans throughout changes to your system using Plan Stability and outlines, please refer to *Oracle8i Designing and Tuning for Performance*.

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:

- Try increasing OPTIMIZER_PERCENT_PARALLEL to 100 if you want a parallel plan, but the optimizer has not given you one.
- 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 gives better results.
- 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 non-uniform distributions.
- Check initialization parameters to be sure the values are reasonable.
- Replace bind variables with literals.
- 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.

See Also: *Oracle8i Concepts* regarding the CREATE TABLE ... AS SELECT statement.

Is There Parallel Execution?

If the cause of regression cannot be traced to problems in the plan, then the problem must be an execution issue. For data warehousing operations, both serial and parallel, consider how your 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 may 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 can be useful to run in single-user mode and check operating system monitors that show system level CPU and I/O activity.

When workload distribution is unbalanced, a common culprit is the presence of skew in the data. For a hash join, this may be the case if the number of distinct values is less than the degree of parallelism. When joining two tables on a column with only 4 distinct values, you will not get scaling on more than 4. If you have 10 CPUs, 4 of them will be saturated but 6 will be idle. To avoid this problem, change the query: use temporary tables to change the join order such that all operations have more values in the join column than the number of CPUs.

If I/O problems occur you may need to reorganize your data, 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? Are there enough disk controllers to provide adequate I/O bandwidth?
- 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 may be overcommitted, and too much parallelism may 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 phase.

View Names in Oracle Parallel Server

In Oracle Parallel Server, global versions of views described in this phase 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. Displays real-time data about the processes working on behalf of parallel execution. This table includes information about the requested DOP and 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. Includes 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$PQ_SESSTAT view shows the status of all current server groups in the system such as data about how queries allocate processes and how the multi-user and load balancing algorithms are affecting the default and hinted values. V$PQ_SESSTAT will be obsolete in a future release.

You may 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" on page 18-8. 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 commands 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 command.

V$PQ_TQSTAT

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 or 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 may 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 may 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 intra- and inter-instance messages exchanged during parallel execution during the session.

V$SYSSTAT does the same as V$SESSTAT for the entire system.

Monitoring Session Statistics

These examples use the dynamic performance views just described.

Use V$PX_SESSION to determine the configuration of the server group executing in parallel. In this example, Session ID 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;
```

Oracle responds with:

```
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, 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;
```

Oracle responds with output similar to:

```
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 be similar to 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: For more details about these views, please refer to the *Oracle8i Reference.*

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, 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 multi-user algorithm or due to 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%' ;
```

Oracle responds with output similar to:

```
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 OS 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 move up a level and 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.

19 Query Rewrite

This chapter contains:

- Overview of Query Rewrite
- Cost-Based Rewrite
- Enabling Query Rewrite
- When Does Oracle Rewrite a Query?
- Query Rewrite Methods
- When are Constraints and Dimensions Needed?
- Expression Matching
- Accuracy of Query Rewrite
- Did Query Rewrite Occur?
- Guidelines for Using Query Rewrite

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 join conditions, 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 / 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

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.

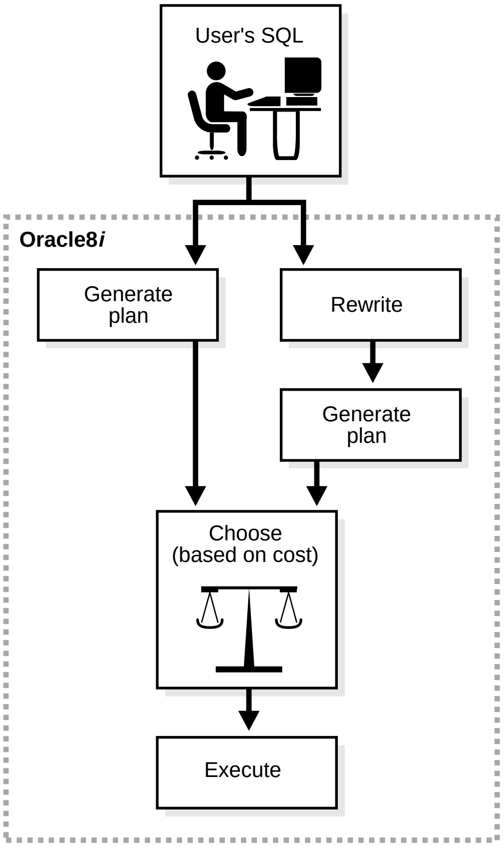
After a materialized view has been picked for a rewrite, the optimizer performs the rewrite, and then tests whether the rewritten query can be rewritten further with another materialized view. This process continues until no further rewrites are possible. Then the rewritten query is optimized and the 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 with the ANALYZE statement or by using the DBMS_STATISTICS 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. That is, the set of named views in a materialized view definition should match exactly with the set of views in the query. When a query contains an inline view, the inline view may be merged into the query before matching between a materialized view and the query occurs.

The following presents a graphical view of the cost-based approach.

Figure 19–1 The Query Rewrite Process



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".

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 via the ALTER MATERIALIZED VIEW statement.

```
CREATE MATERIALIZED VIEW store_sales_mv
 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;
```

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 (*mview_name*, ...) hint 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 19-26). It will default 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 may not work. So you should set your integrity level to a lower level of granularity such as TRUSTED or STALE_TOLERATED.

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.

Privileges for Enabling Query Rewrite

A materialized view is used based not on privileges the user has on that materialized view, but based on privileges the user has on detail tables or views in the query.

The system privilege GRANT REWRITE allows you to 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 *Oracle8i Concepts* for further information.

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 via constraints and dimensions. Such data relationships include hierarchies, referential integrity, and uniqueness of key data, and so on.

The following sections use an example schema and a few materialized views to illustrate how the data relationships are used by the optimizer to rewrite queries. A retail database consists of these tables:

```
STORE   (store_key, store_name, store_city, store_state, store_country)
PRODUCT (prod_key, prod_name, prod_brand)
TIME    (time_key, time_day, time_week, time_month)
```

```
FACT    (store_key, prod_key, time_key, dollar_sales)
```

Two materialized views created on these tables contain only joins:

```
CREATE MATERIALIZED VIEW join_fact_store_time
  ENABLE QUERY REWRITE
  AS
  SELECT s.store_key, s.store_name, f.dollar_sales, t.time_key, t.time_day,
         f.prod_key, f.rowid, t.rowid
  FROM   fact f, store s, time t
  WHERE  f.time_key = t.time_key AND f.store_key = s.store_key;

CREATE MATERIALIZED VIEW join_fact_store_time_oj
  ENABLE QUERY REWRITE
  AS
  SELECT s.store_key, s.store_name, f.dollar_sales, t.time_key,
         f.rowid, t.rowid
  FROM   fact f, store s, time t
  WHERE  f.time_key = t.time_key(+) AND f.store_key = s.store_key(+);
```

and two materialized views contain joins and aggregates:

```
CREATE MATERIALIZED VIEW sum_fact_store_time_prod
  ENABLE QUERY REWRITE
  AS
  SELECT  s.store_name, time_week, p.prod_key,
          SUM(f.dollar_sales) AS sum_sales,
          COUNT(f.dollar_sales) AS count_sales
  FROM   fact f, store s, time t, product p
  WHERE  f.time_key = t.time_key  AND  f.store_key = s.store_key AND
         f.prod_key = p.prod_key
  GROUP BY s.store_name, time_week, p.prod_key;

CREATE MATERIALIZED VIEW sum_fact_store_prod
  ENABLE QUERY REWRITE
  AS
  SELECT  s.store_city, p.prod_name
          SUM(f.dollar_sales) AS sum_sales,
          COUNT(f.dollar_sales) AS count_sales
  FROM     fact f, store s, product p
  WHERE    f.store_key = s.store_key  AND f.prod_key = p.prod_key
  GROUP BY store_city, p.prod_name;
```

You must collect statistics on the materialized views so that the optimizer can determine based on cost whether to rewrite the queries.

```
ANALYZE TABLE join_fact_store_time COMPUTE STATISTICS;
ANALYZE TABLE join_fact_store_time_oj COMPUTE STATISTICS;
ANALYZE TABLE sum_fact_store_time_prod COMPUTE STATISTICS;
ANALYZE TABLE sum_fact_store_prod COMPUTE STATISTICS;
```

Query Rewrite Methods

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 SQL text of the query with the SQL text of the materialized view definition. This method is most straightforward and also very limiting.

When the SQL text comparison test fails, the Oracle optimizer performs a series of generalized checks based on the joins, grouping, aggregates, and column data fetched. This is accomplished by individually comparing various clauses (SELECT, FROM, WHERE, GROUP BY) of a query with those of a materialized view.

SQL Text Match Rewrite Methods

Two methods are used by the optimizer:

1. Full SQL text match
2. Partial SQL text match

In full SQL text match, the entire SQL text of a query is compared against the entire SQL text of a materialized view definition (that is, the entire SELECT expression), ignoring the white space during SQL text comparison. The following query

```
SELECT s.store_name, time_week, p.prod_key,
       SUM(f.dollar_sales) AS sum_sales,
       COUNT(f.dollar_sales) AS count_sales
FROM   fact f, store s, time t, product p
WHERE  f.time_key = t.time_key  AND
       f.store_key = s.store_key AND
       f.prod_key = p.prod_key
GROUP BY s.store_name, time_week, p.prod_key;
```

which matches *sum_fact_store_time_prod* (white space excluded) will be rewritten as:

```
SELECT store_name, time_week, product_key, sum_sales, count_sales
```

```
FROM   sum_fact_store_time_prod;
```

When full SQL text match fails, the optimizer then attempts a partial SQL text match. In this method, the SQL text starting from the FROM clause of a query is compared against the SQL text starting from the FROM clause of a materialized view definition. Therefore, this query:

```
SELECT s.store_name, time_week, p.prod_key,
       AVG(f.dollar_sales) AS avg_sales
FROM   fact f, store s, time t, product p
WHERE  f.time_key = t.time_key  AND
       f.store_key = s.store_key AND
       f.prod_key = p.prod_key
GROUP BY s.store_name, time_week, p.prod_key;
```

will be rewritten as:

```
SELECT store_name, time_week, prod_key, sum_sales/count_sales AS avg_sales
FROM   sum_fact_store_time_prod;
```

Note that, under the partial SQL text match rewrite method, the average of sales aggregate required by the query is computed using sum of sales and count of sales aggregates stored in the materialized view.

When neither SQL text match succeeds, the optimizer uses a general query rewrite method.

General Query Rewrite Methods

The general query rewrite methods are much more powerful than SQL text match methods because they can enable the use of a materialized view even if it contains only part of the data requested by a query, or it contains more data than what is requested by a query, or it contains data in a different form which can be converted into a form required by a query. To achieve this, the optimizer compares the SQL clauses (SELECT, FROM, WHERE, GROUP BY) individually between a query and a materialized view.

The Oracle optimizer employs four different checks called:

- Join Compatibility
- Data Sufficiency
- Grouping Compatibility
- Aggregate Computability

Depending on the type of a materialized view, some or all four checks are made to determine if the materialized view can be used to rewrite a query as illustrated in Table 19–1.

Table 19–1 Materialized View Types and General Query Rewrite Methods

	MV with Joins Only	**MV with Joins and Aggregates**	**MV with Aggregates on a Single Table**
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 joins with 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.

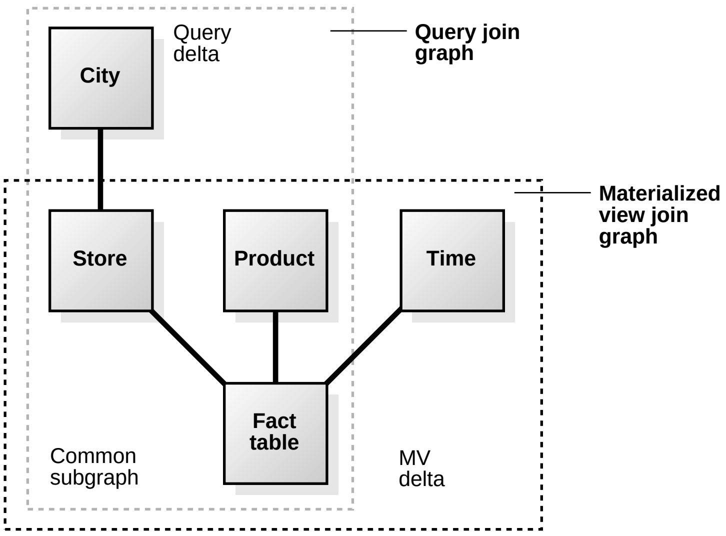
Join Compatibility Check

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 follows:

Figure 19–2 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 s.store_name, t.time_day, SUM(f.dollar_sales)
FROM   fact f, store s, time t
WHERE  f.time_key = t.time_key AND
       f.store_key = s.store_key AND
       t.time_day BETWEEN '01-DEC-1997' AND '31-DEC-1997'
GROUP BY s.store_name, t.time_day;
```

The common joins between this query and the materialized view *join_fact_store_time* are:

```
f.time_key = t.time_key AND f.store_key = s.store_key
```

They match exactly and the query can be rewritten as:

```
SELECT store_name, time_day, SUM(dollar_sales)
FROM   join_fact_store_time
```

```
WHERE  time_day BETWEEN '01-DEC-1997' AND '31-DEC-1997'
GROUP BY store_name, time_day;
```

The query could also be answered using the *join_fact_store_time_oj* 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 store_name, time_day, SUM(f.dollar_sales)
FROM   join_fact_store_time_oj
WHERE  time_key IS NOT NULL AND store_key IS NOT NULL AND
       time_day BETWEEN '01-DEC-1997' AND '31-DEC-1997'
GROUP BY store_name, time_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_fact_store_time_oj* there is a primary key on both store and time.

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 stores that had sales greater than $10,000 during the 1997 Christmas season.

```
SELECT DISTINCT store_name
FROM store s
WHERE EXISTS (SELECT *
              FROM fact f
              WHERE f.store_key = s.store_key
                AND f.dollar_sales > 10000
                AND f.time_key BETWEEN '01-DEC-1997' AND '31-DEC-1997');
```

This query could also be seen as:

```
SELECT DISTINCT store_name
FROM store s
WHERE s.store_key IN (SELECT f.store_key
                     FROM fact f
                     WHERE f.dollar_sales > 10000);
```

This query contains a semi-join 'f.store_key = s.store_key' between the store and the fact table. This query can be rewritten to use either the *join_fact_store_time* materialized view, if foreign key constraints are active or *join_fact_store_time_oj* materialized view, if primary keys are active. Observe that both materialized views contain 'f.store_key = s.store_key' which can be used to derive the semi-join in the query.

The query is rewritten with *join_fact_store_time* as follows:

```
SELECT store_name
FROM (SELECT DISTINCT store_name, store_key
      FROM join_fact_store_time
      WHERE dollar_sales > 10000
      AND f.time_key BETWEEN '01-DEC-1997' AND '31-DEC-1997');
```

If the materialized view *join_fact_store_time* is partitioned by *time_key*, then this query is likely to be more efficient than the original query because the original join between *store* and *fact* has been avoided.

The query could be rewritten using *join_fact_store_time_oj* as follows.

```
SELECT store_name
FROM (SELECT DISTINCT store_name, store_key
      FROM join_fact_store_time_oj
      WHERE dollar_sales > 10000
        AND store_key IS NOT NULL
        AND time_key BETWEEN '01-DEC-1997' AND '31-DEC-1997');
```

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 store_name, prod_name, SUM(f.dollar_sales)
FROM   fact f, store s, time t, product p
WHERE  f.time_key = t.time_key AND
       f.store_key = s.store_key AND
       f.prod_key = p.prod_key AND
       t.time_day BETWEEN '01-DEC-1997' AND '31-DEC-1997'
GROUP BY  store_name, prod_name;
```

Using the materialized view *join_fact_store_time*, common joins are: f.time_key = t.time_key AND f.store_key = s.store_key. The delta join in the query is f.prod_key = p.prod_key.

The rewritten form will then join the *join_fact_store_time* materialized view with the *product* table:

```
SELECT store_name, prod_name, SUM(f.dollar_sales)
FROM   join_fact_store_time mv,  product p
WHERE  mv.prod_key = p.prod_key AND
       mv.time_day BETWEEN '01-DEC-1997' AND '31-DEC-1997'
GROUP BY store_name, prod_name;
```

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 which joins FACT and TIME:

```
SELECT t.time_day, SUM(f.dollar_sales)
FROM   fact f, time t
WHERE  f.time_key = t.time_key AND
       t.time_day BETWEEN '01-DEC-1997' AND '31-DEC-1997'
GROUP  t.time_day;
```

The materialized view *join_fact_store_time* has an additional join between FACT and STORE: 'f.store_key = s.store_key'. This is the delta join in *join_fact_store_time*.

We can rewrite the query if this join is lossless and non-duplicating. This is the case if f.store_key is a foreign key to s.store_key and is not null. The query is therefore rewritten as:

```
SELECT time_day, SUM(f.dollar_sales)
FROM   join_fact_store_time
WHERE  time_day BETWEEN '01-DEC-1997' AND '31-DEC-1997'
GROUP BY time_day;
```

The query could also be rewritten with the materialized view *join_fact_store_time_oj* where foreign key constraints are not needed. This view contains an outer join between fact and store: 'f.store_key = s.store_key(+)' which makes the join lossless. If s.store_key is a primary key, then the non-duplicating condition is satisfied as well and optimizer will rewrite the query as:

```
SELECT time_day, SUM(f.dollar_sales)
FROM   join_fact_store_time_oj
WHERE  time_key IS NOT NULL AND
       time_day BETWEEN '01-DEC-1997' AND '31-DEC-1997'
GROUP BY time_day;
```

The current limitations restrict most rewrites with outer joins to materialized views with joins only. There is very limited support for rewrites with materialized aggregate views with outer joins. 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 s.store_name, f.time_key, SUM(f.dollar_sales)
FROM   fact f, store s, time t
WHERE  f.time_key = t.time_key AND
       f.store_key = s.store_key
GROUP BY s.store_name, f.time_key;
```

This query can be answered with *join_fact_store_time* even though the materialized view doesn't have f.time_key. Instead, it has t.time_key which, through a join condition 'f.time_key = t.time_key', is equivalent to f.time_key.

Thus, the optimizer may select this rewrite:

```
SELECT store_name, time_key, SUM(dollar_sales)
FROM   join_fact_store_time
GROUP BY store_name, time_key;
```

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_key* and another column called *prod_name*, then, given a *prod_key* 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_key*.

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  s.store_name, t.time_week, p.prod_name,
        SUM(f.dollar_sales) AS sum_sales,
FROM   fact f, store s, time t, product p
WHERE  f.time_key = t.time_key  AND  f.store_key = s.store_key AND
       f.prod_key = p.prod_key  AND p.prod_brand = 'KELLOGG'
GROUP BY s.store_name, t.time_week, p.prod_name;
```

The materialized view *sum_fact_store_time_prod* contains *p.prod_key*, but not *p.prod_brand*. However, we can join *sum_fact_store_time_prod* back to PRODUCT to retrieve *prod_brand* because *prod_key* functionally determines *prod_brand*. The optimizer rewrites this query using *sum_fact_store_time_prod* as:

```
SELECT  mv.store_name, mv.time_week, p.product_key, mv.sum_sales,
FROM    sum_fact_store_time_prod mv, product p
WHERE   mv.prod_key = p.prod_key  AND p.prod_brand = 'KELLOGG'
GROUP BY mv.store_name, mv.time_week, p.prod_key;
```

Here the PRODUCT 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
- Using the DETERMINES clause of a dimension

The DETERMINES clause of a dimension definition may be the only way you could declare functional dependency when the column that determines another column cannot be a primary key. For example, the STORE table is a denormalized dimension table which has columns *store_key*, *store_name*, *store_city*, *city_name*, and *store_state*. *Store_key* functionally determines *store_name* and *store_city* functionally determines *city_name*.

The first functional dependency can be established by declaring store_key as the primary key, but not the second functional dependency because the store_city 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 store_dim
LEVEL store_key      IS store.store_key
LEVEL city           IS store.store_city
LEVEL state          IS store.store_state
LEVEL country        IS store.store_country
  HIERARCHY geographical_rollup          (
             store_key     CHILD OF
             city          CHILD OF
             state         CHILD OF
             country                    )
ATTRIBUTE store_key DETERMINES store.store_name;
ATTRIBUTE store_city DETERMINES store.city_name;
```

The hierarchy *geographical_rollup* declares hierarchical relationships which are also 1:n functional dependencies. The 1:1 functional dependencies are declared using the DETERMINES clause, such as store_city functionally determines city_name.

The following query:

```
SELECT  s.store_city, p.prod_name
          SUM(f.dollar_sales) AS sum_sales,
FROM    fact f, store s, product p
WHERE   f.store_key = s.store_key AND f.prod_key = p.prod_key
          AND s.city_name = 'BELMONT'
GROUP BY s.store_city, p.prod_name;
```

can be rewritten by joining *sum_fact_store_prod* to the STORE table so that *city_name* is available to evaluate the predicate. But the join will be based on the *store_city* column, which is not a primary key in the STORE table; therefore, it allows duplicates. This is accomplished by using an inline view which selects distinct values and this view is joined to the materialized view as shown in the rewritten query below.

```
SELECT  iv.store_city, mv.prod_name, mv.sum_sales
FROM    sum_fact_store_prod mv, (SELECT DISTINCT store_city, city_name
                                   FROM store) iv
WHERE   mv.store_city = iv.store_city AND
          iv.city_name = 'BELMONT'
GROUP BY iv.store_city, mv.prod_name;
```

This type of rewrite is possible because of the fact that *store_city* functionally determines *city_name* 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 *store_city* and a materialized view stores data grouped by *store_city* and *store_state*. The grouping is the same in both provided *store_city* functionally determines *store_state*, 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_fact_store_time_prod* groups by *store_name*, *time_week*, and *prod_key*. This query groups by *store_name*, a coarser grouping granularity:

```
SELECT s.store_name, SUM(f.dollar_sales) AS sum_sales,
FROM   fact f, store s
WHERE  f.store_key = s.store_key
GROUP BY s.store_name;
```

Therefore, the optimizer will rewrite this query as:

```
SELECT store_name, SUM(sum_dollar_sales) AS sum_sales,
FROM   sum_fact_store_time_prod
GROUP BY s.store_name;
```

In another example, a query requests data grouped by *store_state* whereas a materialized view stores data grouped by *store_city*. If *store_city* is a CHILD OF *store_state* (see the dimension example above), the grouped data stored in the materialized view can be further grouped by *store_state* when the query is rewritten.

In other words, aggregates at *store_city* level (finer granularity) stored in a materialized view can be rolled up into aggregates at *store_state* level (coarser granularity).

For example, consider the following query:

```
SELECT  store_state, prod_name, SUM(f.dollar_sales) AS sum_sales
FROM    fact f, store s, product p
WHERE   f.store_key = s.store_key  AND  f.prod_key = p.prod_key
GROUP BY store_state, prod_name;
```

Because store_city functionally determines *store_state*, *sum_fact_store_prod* can be used with a joinback to store table to retrieve *store_state* column data, and then aggregates can be rolled up to *store_state* level, as shown below:

```
SELECT  store_state, prod_name, sum(mv.sum_sales) AS sum_sales
FROM    sum_fact_store_prod mv, (SELECT DISTINCT store_city, store_state
                                  FROM store) iv
WHERE   mv.store_city = iv.store_city
GROUP BY store_state, prod_name;
```

Note that for this rewrite, the data sufficiency check determines that a joinback to the STORE 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_name, AVG(f.dollar_sales) AS avg_sales
FROM    fact f, product p
WHERE   f.prod_key = p.prod_key
GROUP BY p.prod_name;
```

The materialized view *sum_fact_store_prod* can be used to rewrite it provided the join between FACT and STORE is lossless and non-duplicating. Further, the query groups by *prod_name* whereas the materialized view groups by *store_city*, *prod_name*, 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_name, SUM(mv.sum_sales)/SUM(mv.count_sales) AS avg_sales
FROM    sum_fact_store_prod mv
GROUP BY mv.prod_name;
```

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 CUBE/ROLLUP Operator

A query that contains GROUP BY CUBE or GROUP BY ROLLUP clauses can be rewritten in terms of a materialized view as long as the grouping of the query is compatible with the grouping in a materialized view. For example, consider the following query:

```
SELECT store_city, prod_name, AVG(f.dollar_sales) AS avg_sales
FROM fact f, store s, product p
WHERE f.store_key = s.store_key AND f.prod_key = p.prod_key
GROUP BY CUBE(store_city, prod_name);
```

This query can be rewritten in terms of the materialized view sum_fact_store_prod as follows:

```
SELECT store_city, prod_name, SUM(sum_sales)/SUM(count_sales) AS avg_sales
FROM sum_fact_store_prod
GROUP BY CUBE (store_city, prod_name);
```

Note that the grouping in sum_fact_store_prod matches with the grouping in the query. However, the query requires a cube result which means super aggregates should be computed from the base aggregates available from the materialized view. This is accomplished by retaining the GROUP BY CUBE clause in the rewritten query.

A cube or rollup query can be also rewritten in terms of a materialized view which groups data at a finer granularity level. In this type of rewrite, the rewritten query will compute both the base aggregates (from finer to coarser granularity level) and the super aggregates.

When are Constraints and Dimensions Needed?

To clarify when dimensions and constraints are required for the different types of query rewrite, refer to Table 19–2.

Table 19–2 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

Complex Materialized Views

Rewrite capability with complex materialized views is limited to SQL text match-based rewrite (partial or full). A materialized view can be defined 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: selection predicates in the WHERE clause, a HAVING clause, inline views, multiple instances of same table or view, set operators (UNION, UNION ALL, INTERSECT, MINUS), START WITH clause, CONNECT BY clause, etc. Therefore, a complex materialized view limits rewritability but can be used to rewrite specific queries that are highly complex and execute very slowly.

View-based Materialized View

A view-based materialized view contains one or more named views in the FROM clause of its SQL expression. Such a materialized view is subject to some important query rewrite restrictions. In order for the view-based materialized view to be eligible to rewrite a query, all views referenced in it must also be referenced in the query. However, the query can have additional views and this will not make a view-based materialized view ineligible.

Another important restriction with view-based materialized views is related to the determination of the lossless joins. Any join based on view columns in a view-based materialized view is considered a lossy join by the join compatibility check. This means that if there are some delta joins in a view-based materialized view and if at least one of the delta joins is based on view columns, the join compatibility check will fail.

View-based materialized views are useful when you want to materialize only a subset of table data. For example, if you want to summarize the data only for the year 1996 and store it in a materialized view, it can be done in two ways.

- Define a materialized view with a selection predicate year=1996 in the WHERE clause. This makes the materialized view complex so only SQL text match rewrite is possible.
- Define a regular view with a selection predicate year=1996 and then define a materialized view on this view. This produces a view-based materialized view for which both SQL text match and general query rewrite methods can be used.

Rewrite with Nested Materialized Views

Query rewrite is attempted recursively to take advantage of nested materialized views. Oracle first tries to rewrite a query Q 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 materialized views *join_fact_store_time* and *sum_sales_store_time* as in "Example of a Nested Materialized View" on page 8-26.

Consider this query:

```
SELECT store_name, time_day, SUM(dollar_sales)
FROM fact f, store s, time t
WHERE f.time_key = t.time_key AND
      f.store_key = s.store_key
GROUP BY store_name, time_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* cannot yet be used), and then tries a rewrite with a materialized join view and finds that *join_fact_store_time* is eligible for rewrite. The rewritten query has this form:

```
SELECT store_name, time_day, SUM(dollar_sales)
FROM join_fact_store_time
GROUP BY store_name, time_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 store_name, time_day, sum_sales
FROM sum_sales_store_time;
```

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. Because a materialized view stores pre-computed results of an expression, any query that is rewritten to use such a materialized view will benefit through performance improvement achieved by obviating the need for 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,...).

```
SELECT (age+9)/10 AS age_bracket, SUM(sales) AS sum_sales
FROM fact, customer
WHERE fact.cust_id = customer.cust_id
GROUP BY (age+9)/10;
```

Assume that there is a materialized view MV1 that summarizes sales by same age brackets as shown below:

```
CREATE MATERIALIZED VIEW sum_sales_mv
```

```
ENABLE QUERY REWRITE
AS
SELECT (9+age)/10 AS age_bracket, SUM(sales) AS sum_sales
FROM fact, customer
WHERE fact.cust_id = customer.cust_id
GROUP BY (9+age)/10;
```

The above query is rewritten in terms of sum_sales_mv based on the matching of the canonical forms of the age bracket expressions (i.e. (9+age)/10 and (age+9)/10) as follows.

```
SELECT age_bracket, sum_sales
FROM sum_sales_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, 1993.

```
SELECT prod_type, sum(sales) AS sum_sales
FROM fact, product
WHERE fact.prod_id = product.prod_id AND
      sale_date BETWEEN '1-jan-1991' AND '31-dec-1993'
GROUP BY prod_type;
```

The date 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('1-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('1-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.

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 the ALTER SYSTEM or ALTER SESSION command. The three values it can take are:

- ENFORCED

  This is the default mode. The optimizer will only use materialized views which it knows contain fresh data and only use those relationships that are based on enforced constraints.

- TRUSTED

  In TRUSTED mode, the optimizer trusts that the data in the materialized views based on prebuilt tables is correct, and the relationships declared in dimensions and RELY constraints are correct. In this mode, the optimizer uses prebuilt materialized views, and uses relationships that are not enforced as well as those that are enforced. In this mode, the optimizer also 'trusts' declared but not enforced 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 wrong 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, then there are several situations where the output with rewrite may 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 may be incorrect.
4. Partition operations such as DROP and MOVE PARTITION on the detail table could affect the results of the materialized view.

Did Query Rewrite Occur?

Since 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.

Explain Plan

The EXPLAIN PLAN facility is used as described in *Oracle8i 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 *store_mv* has been created.

```
CREATE MATERIALIZED VIEW store_mv
 ENABLE QUERY REWRITE
 AS
 SELECT
   s.region, SUM(grocery_sq_ft) AS sum_floor_plan
 FROM store s
 GROUP BY s.region;
```

If EXPLAIN PLAN is used on this SQL statement, the results are placed in the default table PLAN_TABLE.

```
EXPLAIN PLAN
FOR
SELECT  s.region, SUM(grocery_sq_ft)
FROM store s
GROUP BY s.region;
```

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 STORE_MV in the output as illustrated below.

```
SELECT  object_name FROM plan_table;

OBJECT_NAME
------------------------------
STORE_MV

2 rows selected.
```

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 via an ALTER MATERIALIZED VIEW command.

The initialization parameters described above can be set using the ALTER SYSTEM SET command. 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;
```

The correctness of query rewrite can be set for a session, thus allowing different users to work at different integrity levels.

```
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 may 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 argument(s) forces rewrite to select the most suitable materialized view from the list of names specified.

For example, to prevent a rewrite, you can use:

```
SELECT  /*+ NOREWRITE */ s.city, SUM(s.grocery_sq_ft)
FROM store s
GROUP BY s.city;
```

To force a rewrite using *mv1*, you can use:

```
SELECT /*+ REWRITE (mv1) */ s.city, SUM(s.grocery_sq_ft)
FROM store s
GROUP BY s.city;
```

Note that the scope of a rewrite hint is a query block. If a SQL statement consists of several query blocks (SELECT clauses), you may need to specify rewrite hint on each query block to control the rewrite for the entire statement.

Guidelines for Using Query Rewrite

The following guidelines 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 NONVALIDATE 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_fact_store_time_oj* stores the primary keys *store_key* and *time_key* of the inner tables of outer joins.

SQL 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.

Aggregates

In order 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. Refer to Requirements for Fast Refresh in "General Restrictions on Fast Refresh" on page 8-20.

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 *city_name*, group on *city_id* (as long as there is a dimension which indicates that the attribute *city_id* determines *city_name*, you will enable the rewrite of a query involving *city_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 either the ANALYZE TABLE statement or the DBMS_STATISTICS package.

Part VI
Miscellaneous

This section deals with other topics of interest in a data warehousing environment.

It contains the following chapters:

- Data Marts

20

Data Marts

This chapter contains information useful for building and using data marts, including:

- What Is a Data Mart?

This chapter is not meant to be a substitute for other Oracle or non-Oracle documentation regarding data marts. It is simply an overview. See the *Data Mart Suites* documentation for further details.

What Is a Data Mart?

A *data mart* is a simple form of a data warehouse that is focused on a single subject (or functional area), such as Sales or Finance or Marketing. Data marts are often built and controlled by a single department within an organization. Given their single-subject focus, data marts usually draw data from only a few sources. The sources could be internal operational systems, a central data warehouse, or external data.

How Is It Different from a Data Warehouse?

A *data warehouse*, in contrast, deals with multiple subject areas and is typically implemented and controlled by a central organizational unit such as the Corporate Information Technology (IT) group. Often, it is called a central or enterprise data warehouse. Typically, a data warehouse assembles data from multiple source systems.

Nothing in these basic definitions limits the size of a data mart or the complexity of the decision-support data that it contains. Nevertheless, data marts are typically smaller and less complex than data warehouses; hence, they are typically easier to build and maintain. The following table summarizes the basic differences between a data warehouse and a data mart:

	Data Warehouse	**Data Mart**
Scope	Corporate	Line-of-Business (LoB)
Subjects	Multiple	Single Subject
Data Sources	Many	Few
Size (typical)	100 GB-TB+	< 100GB
Implementation Time	Months to years	Months

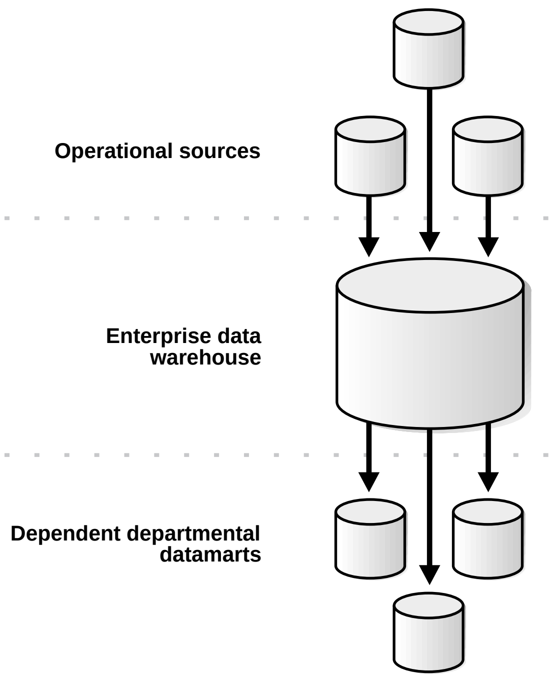
Dependent, Independent, and Hybrid Data Marts

Three basic types of data marts are dependent, independent, and hybrid. The categorization is based primarily on the data source that feeds the data mart. *Dependent data marts* draw data from a central data warehouse that has already been created. *Independent data marts*, in contrast, are standalone systems built by drawing data directly from operational or external sources of data or both. *Hybrid data marts* can draw data from operational systems or data warehouses.

Dependent Data Marts

A dependent data mart allows you to unite your organization's data in one data warehouse. This gives you the usual advantages of centralization. Figure 20–1 illustrates a dependent data mart.

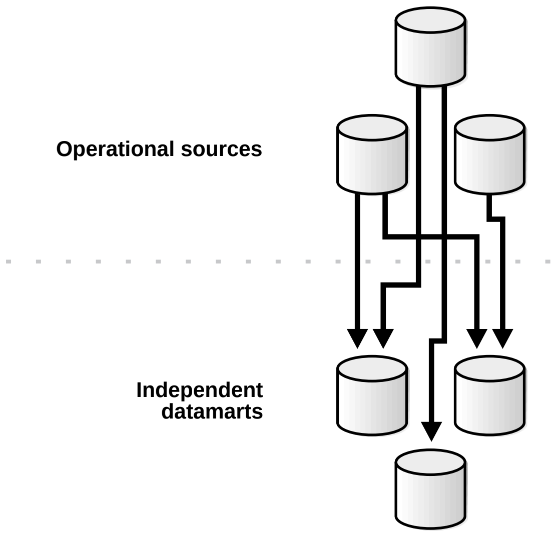
Figure 20–1 Dependent Data Mart



Independent Data Marts

An independent data mart is created without the use of a central data warehouse. This could be desirable for smaller groups within an organization. It is not, however, the focus of this Guide. See the *Data Mart Suites* documentation for further details regarding this architecture. Figure 20–2 illustrates an independent data mart.

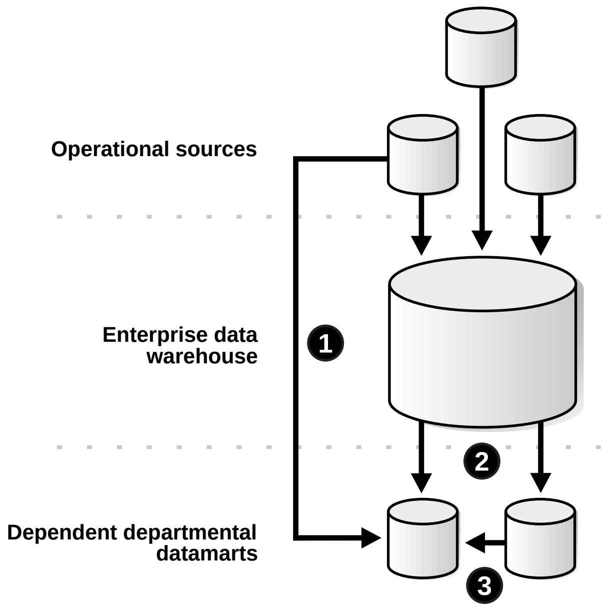
Figure 20–2 Independent Data Marts



Hybrid Data Marts

A hybrid data mart allows you to combine input from sources other than a data warehouse. This could be useful for many situations, especially when you need ad hoc integration, such as after a new group or product is added to the organization. Figure 20–3 illustrates a hybrid data mart.

Figure 20–3 Hybrid Data Mart



Extraction, Transformation, and Transportation

The main difference between independent and dependent data marts is how you populate the data mart; that is, how you get data out of the sources and into the data mart. This step, called the *Extraction-Transformation-Transportation* (ETT) process, involves moving data from operational systems, filtering it, and loading it into the data mart.

With dependent data marts, this process is somewhat simplified because formatted and summarized (clean) data has already been loaded into the central data warehouse. The ETT process for dependent data marts is mostly a process of identifying the right subset of data relevant to the chosen data mart subject and moving a copy of it, perhaps in a summarized form.

With independent data marts, however, you must deal with all aspects of the ETT process, much as you do with a central data warehouse. The number of sources are likely to be fewer and the amount of data associated with the data mart is less than the warehouse, given your focus on a single subject.

The motivations behind the creation of these two types of data marts are also typically different. Dependent data marts are usually built to achieve improved performance and availability, better control, and lower telecommunication costs resulting from local access of data relevant to a specific department. The creation of independent data marts is often driven by the need to have a solution within a shorter time.

Hybrid data marts simply combine the issues of independent and independent data marts.

See Chapter 10, "ETT Overview", for further details regarding the ETT process.

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.

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 Oracle 8*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 Oracle 8*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 ETT process. (See also *ETT.*)

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 stand-alone product that other products can share—each product owns only the objects within the CWM repository that it creates.

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 ETT 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 *ETT, 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 8*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.

ETT

Extraction, transformation, and transportation. ETT 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 ETL (extraction, transformation, load) and ETM (extraction, transformation, move) are sometimes used instead of ETT. (See also *data warehouse, extraction, transformation, transportation*.)

extraction

The process of taking data out of a source as part of an initial phase of ETT. (See also *ETT*.)

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 aggregation.

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. (Kimball)

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.*)

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 ETT process. The target of the entire ETT process is the data warehouse. (See also *data warehouse, ETT.*)

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.

Index

A

adaptive multi-user
  algorithm for, 18-6
  definition, 18-6
aggregate computability check, 19-19
aggregates, 8-8, 8-11, 18-49, 19-30
ALTER MATERIALIZED VIEW statement, 8-17
  enabling query rewrite, 19-5
ALTER TABLE statement
  NOLOGGING clause, 18-60
altering dimensions, 9-14
analytic functions, 17-21
ANALYZE statement, 18-51
ANALYZE TABLE statement, 15-3
analyzing data
  for parallel processing, 18-69
APPEND hint, 18-60
applications
  data warehouses
    star queries, 16-2
  decision support, 18-2
  decision support systems, 6-3
ARCH processes
  multiple, 18-56
asynchronous I/O, 18-26
attributes, 9-7

B

backups
  disk mirroring, 4-8
bandwidth, 5-2, 18-2
bitmap indexes, 6-2
  nulls and, 6-5
  on partitioned tables, 6-6
  parallel query and DML, 6-3
block range granules, 5-3
BOTTOM_N function, 17-31
B-tree indexes, 6-6
  bitmap indexes versus, 6-3
buffer pools
  setting for parallel operations, 18-36
build methods, 8-18

C

cardinality, 6-3
CASE expressions, 17-52
change
  capture, 11-6
  data capture, 11-6
columns
  cardinality, 6-3
common joins, 19-11
COMPATIBLE parameter, 14-13, 19-5
COMPLETE clause, 8-20
complete refresh, 14-18
complex materialized views, 14-27
complex queries
  snowflake schemas, 16-3
composite partitioning, 5-6
  performance considerations, 5-9
concurrent users
  increasing the number of, 18-9
constraints, 7-2, 9-13
  foreign key, 7-5
  RELY, 7-5

unique, 7-3
with partitioning, 7-6
with query rewrite, 19-29
CORR function, 17-48
cost-based optimizations, 18-64
parallel execution, 18-64
star queries, 16-2
cost-based rewrite, 19-3
COVAR_POP function, 17-47
COVAR_SAMP function, 17-48
CPU
utilization, 5-2, 18-2
CREATE DIMENSION statement, 9-6
CREATE INDEX statement, 18-58
CREATE MATERIALIZED VIEW statement, 8-17
enabling query rewrite, 19-5
CREATE SNAPSHOT statement, 8-3
CREATE TABLE AS SELECT statement, 18-50, 18-68
CUBE, 17-10
partial, 17-13
when to use, 17-14
CUBE/ROLLUP
with query rewrite, 19-20
CUME_DIST function, 17-31

D

data
partitioning, 5-4
purging, 14-7
substitutions, 13-5
sufficiency check, 19-15
data marts
definition of, 20-2
dependent, 20-2
differences from data warehouse, 20-2
independent, 20-2
data warehouses, 8-2
definition of, 20-2
differences from data marts, 20-2
dimension tables
(lookup tables), 8-7
dimensions, 16-2
fact tables (detail tables), 8-7
partitioned tables, 5-6
refresh tips, 14-22
refreshing, 14-2
star queries, 16-2
database writer process (DBWn)
tuning, 18-56
databases
layout, 5-3
staging, 8-2
date folding
with query rewrite, 19-24
DB_BLOCK_SIZE parameter, 18-25
and parallel query, 18-25
DB_FILE_MULTIBLOCK_READ_COUNT parameter, 18-26
DBA_DATA_FILES view, 18-71
DBA_EXTENTS view, 18-71
DBMS_MVIEW package, 14-18
DBMS_MVIEW.REFRESH procedure, 14-17, 14-19
DBMS_MVIEW.REFRESH_ALL_MVIEWS procedure, 14-17
DBMS_MVIEW.REFRESH_DEPENDENT procedure, 14-17
DBMS_OLAP package, 8-35, 15-2, 15-3, 15-5
DBMS_OLAP.RECOMMEND_MV procedure, 8-35
DBMS_STATISTICS package, 19-3
DBMS_STATS package, 15-3
decision support
processes, 18-35
decision support systems
bitmap indexes, 6-3
degree of parallelism
and adaptive multi-user, 18-5
setting, 18-5
DEMO_DIM package, 9-12
denormalized
star schemas, 2-4
DENSE_RANK function, 17-24
dependent data marts, 20-2
detail tables, 8-7
dimension tables, 8-8, 16-2
normalized, 9-10
dimension wizard, 9-11
dimensions, 2-5, 9-2, 9-13
altering, 9-14

creating, 9-6
definition, 9-2
dimension tables (lookup tables), 8-7
dropping, 9-15
hierarchies, 2-6
hierarchies overview, 2-6
multiple, 17-2
star joins, 16-3
star queries, 16-2
validating, 9-14
with query rewrite, 19-29
direct-load inserts
external fragmentation, 18-44
disk affinities
and parallel query, 18-47
disabling with MPP, 4-4
with MPP, 18-52
DISK_ASYNCH_IO parameter, 18-26
DML_LOCKS parameter, 18-23, 18-25
drilling across, 9-5
drilling down, 9-3
hierarchies, 9-3
DROP MATERIALIZED VIEW statement, 8-17
prebuilt tables, 8-30
dropping
dimensions, 9-15
materialized views, 8-36

E

ENFORCED mode, 19-26
ENQUEUE_RESOURCES parameter, 18-23, 18-25
estimating materialized view size, 15-7
ETT
overview, 10-2
process, 7-2, 20-5
tools, 10-2
EVALUATE_UTILIZATION_W package, 15-9
EXCHANGE PARTITION statement, 7-6
execution plans
parallel operations, 18-67
star transformations, 16-8
EXPLAIN PLAN statement, 18-67, 19-27
query parallelization, 18-54
star transformations, 16-8
exporting
EXP utility, 11-4
expression matching
with query rewrite, 19-23
extents
size, 14-13
temporary, 18-52
extractions
data files, 11-2
distributed operations, 11-5
OCI, 11-4
overview, 11-2
Pro*C, 11-4
SQL*Plus, 11-3

F

fact tables, 2-4, 2-5
star joins, 16-3
star queries, 16-2
facts, 9-2
FAST clause, 8-20
fast refresh, 14-18
FAST REFRESH restrictions, 8-20
FAST_START_PARALLEL_ROLLBACK parameter, 18-23
FIRST_ROWS hint, 18-21
FIRST_VALUE function, 17-42
FORCE clause, 8-20
foreign key constraints, 7-5
foreign key joins
snowflake schemas, 16-3
fragmentation
external, 18-44
FREELISTS parameter, 18-56
full partition-wise joins, 5-12
functions
LAG/LEAD, 17-46
linear regression, 17-48
ranking, 17-24
reporting, 17-43
statistics, 17-46
windowing, 17-35

G

GC_FILES_TO_LOCKS parameter, 18-44
GC_ROLLBACK_LOCKS parameter, 18-45
GC_ROLLBACK_SEGMENTS parameter, 18-45
global
  indexes, 6-6, 18-55
  striping, 4-5
granules, 5-3
  block range, 5-3
  partition, 5-4
GROUP BY clause
  decreasing demand for, 18-39
grouping
  compatibility check, 19-18
  conditions, 19-30
GROUPING function, 17-15
  when to use, 17-18
GV$FILESTAT view, 18-70

H

hash areas, 18-35
hash joins, 18-19, 18-35
hash partitioning, 5-5
HASH_AREA_SIZE parameter, 18-39
  and parallel execution, 18-18, 18-19
  relationship to memory, 18-38
HASH_MULTIBLOCK_IO_COUNT
    parameter, 18-26
hierarchies, 9-3
  drilling across, 9-5
  how used, 2-6
  multiple, 9-8
  overview, 2-6
  rolling up and drilling down, 9-3
hints
  query rewrite, 19-5, 19-28
histograms
  creating with user-defined buckets, 17-53

I

I/O
  asynchronous, 18-26
  parallel execution, 5-2, 18-2
  striping to avoid bottleneck, 4-2
independent data marts, 20-2
index joins, 18-39
indexes
  bitmap indexes, 6-6
  B-tree, 6-6
  cardinality, 6-3
  creating in parallel, 18-57
  global, 18-55
  local, 18-55
  nulls and, 6-5
  parallel creation, 18-57, 18-58
  parallel local, 18-58
  partitioned tables, 6-6
  partitioning, 5-6
  STORAGE clause, 18-58
INITIAL extent size, 14-13, 18-44
INSERT
  functionality, 18-59
invalidating
  materialized views, 8-34

J

JOB_QUEUE_INTERVALS parameter, 14-19
JOB_QUEUE_PROCESSES parameter, 14-19
join compatibility, 19-10
joins, 8-11
  full partition-wise, 5-12
  partial partition-wise, 5-17
  partition-wise, 5-12
  star joins, 16-3
  star queries, 16-2

K

key lookups, 13-5
keys, 8-8, 16-2

L

LAG/LEAD functions, 17-46
LARGE_POOL_SIZE parameter, 18-10
LAST_VALUE function, 17-42
level relationships, 2-7

purpose, 2-7
levels, 2-6, 2-7
linear regression functions, 17-48
load
  parallel, 14-15
local indexes, 6-3, 6-6, 18-55
local striping, 4-4
LOG_BUFFER parameter
  and parallel execution, 18-23
LOGGING clause, 18-56
lookup tables, 8-7, 16-2
  star queries, 16-2

M

manual
  refresh, 14-18
  striping, 4-3
massively parallel systems, 5-2, 18-2
materialized views
  altering, 8-36
  build methods, 8-18
  complex, 14-27
  containing only joins, 8-13
  creating, 8-16
  delta joins, 19-14
  dropping, 8-30, 8-36
  estimating size, 15-7
  guidelines, 8-35
  invalidating, 8-34
  joins and aggregates, 8-11
  logs, 11-8
  naming, 8-17
  nested, 8-23
  partitioning, 8-31
  prebuilt, 8-16
  query rewrite
    hints, 19-5, 19-28
    matching join graphs, 8-18
    parameters, 19-5
    privileges, 19-6
  recommending, 15-5
  refresh dependent, 14-21
  refreshing, 8-20, 14-16
  refreshing all, 14-20
  registration, 8-29
  restrictions, 8-19
  rewrites
    enabling, 19-5
  schema design guidelines, 8-8
  security, 8-35
  single table aggregate, 8-12
  storage characteristics, 8-17
  types of, 8-10
  uses for, 8-2
MAXEXTENTS keyword, 14-13, 18-44
measures, 8-7, 16-2
media recoveries, 18-52
memory
  configure at 2 levels, 18-17
  process classification, 18-35
  virtual, 18-18
mirroring
  disks, 4-8
monitoring
  parallel processing, 18-70
  refresh, 14-28
MPP
  disk affinity, 4-4
MULTIBLOCK_READ_COUNT parameter, 14-13
multiple archiver processes, 18-56
multiple hierarchies, 9-8
multi-threaded server, 18-35

N

nested loop joins, 18-35
nested materialized views, 8-23
  refreshing, 14-26
  restrictions, 8-24
nested queries, 18-49
NEVER clause, 8-20
NEXT extent, 18-44
NOAPPEND hint, 18-60
NOARCHIVELOG mode, 18-57
NOLOGGING clause, 18-50, 18-56, 18-58
  with APPEND hint, 18-60
NOPARALLEL attribute, 18-48
NOREWRITE hint, 19-5, 19-28
NTILE function, 17-33

nulls
  indexes and, 6-5

O

OLAP tools, 2-5
ON COMMIT clause, 8-20
ON DEMAND clause, 8-20
online transaction processing (OLTP)
  processes, 18-35
operating systems
  striping, 4-3
optimizations
  cost-based
    star queries, 16-2
  query rewrite
    enabling, 19-5
    hints, 19-5, 19-28
    matching join graphs, 8-18
  query rewrites
    privileges, 19-6
OPTIMIZER_MODE parameter, 14-28, 18-64, 19-5
OPTIMIZER_PERCENT_PARALLEL
    parameter, 14-28, 18-21, 18-67
optimizers
  with rewrite, 19-2
Oracle Parallel Server
  disk affinities, 18-47
  parallel execution, 18-44
  parallel load, 14-16
Oracle Trace, 15-3
ORDER BY clause, 8-22
  decreasing demand for, 18-39
outer joins
  with query rewrite, 19-29
oversubscribing resources, 18-37, 18-41

P

paging, 18-37
  rate, 18-18
  subsystem, 18-37
PARALLEL clause, 18-59, 18-60
PARALLEL CREATE INDEX statement, 18-22
PARALLEL CREATE TABLE AS SELECT statement
  external fragmentation, 18-44
  resources required, 18-22
parallel DML
  bitmap indexes, 6-3
parallel execution
  adjusting workloads, 18-40
  cost-based optimization, 18-64
  I/O parameters, 18-25
  index creation, 18-57
  introduction, 5-2
  maximum processes, 18-34
  method of, 18-3
  parallel server, 18-44
  plans, 18-67
  process classification, 4-4
  resource parameters, 18-17
  rewriting SQL, 18-49
  solving problems, 18-48
  space management, 18-43
  tuning, 5-1, 18-2
  understanding performance issues, 18-33
PARALLEL hint, 18-48, 18-59, 18-67
parallel load
  example, 14-15
  Oracle Parallel Server, 14-16
  using, 14-10
parallel partition-wise joins
  performance considerations, 5-21
parallel query
  bitmap indexes, 6-3
parallel scan operations, 4-3
parallel server
  disk affinities, 18-47
  parallel execution tuning, 18-44
PARALLEL_ADAPTIVE_MULTI_USER
    parameter, 18-6, 18-29
PARALLEL_AUTOMATIC_TUNING
    parameter, 18-3
PARALLEL_BROADCAST_ENABLE
    parameter, 18-21
PARALLEL_EXECUTION_MESSAGE_SIZE
    parameter, 18-20
PARALLEL_MAX_SERVERS parameter, 14-27,
    18-8, 18-9, 18-38
  and parallel execution, 18-8

PARALLEL_MIN_PERCENT parameter, 18-9, 18-16
PARALLEL_MIN_SERVERS parameter, 18-10
PARALLEL_SERVER_INSTANCES parameter
  and parallel execution, 18-17
PARALLEL_THREADS_PER_CPU parameter, 18-3, 18-7
parallelism
  degree, overriding, 18-48
  enabing for tables and queries, 18-6
parameters
  COMPATIBLE, 14-13, 19-5
  DB_BLOCK_SIZE, 18-25
  DB_FILE_MULTIBLOCK_READ_COUNT, 18-26
  DISK_ASYNCH_IO, 18-26
  DML_LOCKS, 18-23, 18-25
  ENQUEUE_RESOURCES, 18-23, 18-25
  FAST_START_PARALLEL_ROLLBACK, 18-23
  FREELISTS, 18-56
  GC_FILES_TO_LOCKS, 18-44
  GC_ROLLBACK_LOCKS, 18-45
  GC_ROLLBACK_SEGMENTS, 18-45
  HASH_AREA_SIZE, 18-18, 18-38, 18-39
  HASH_MULTIBLOCK_IO_COUNT, 18-26
  JOB_QUEUE_INTERVAL, 14-19
  JOB_QUEUE_PROCESSES, 14-19
  LARGE_POOL_SIZE, 18-10
  LOG_BUFFER, 18-23
  MULTIBLOCK_READ_COUNT, 14-13
  OPTIMIZED_PERCENT_PARALLEL, 18-67
  OPTIMIZER_MODE, 14-28, 18-64, 19-5
  OPTIMIZER_PERCENT_PARALLEL, 14-28, 18-21
  PARALLEL_ADAPTIVE_MULTI_USER, 18-29
  PARALLEL_AUTOMATIC_TUNING, 18-3
  PARALLEL_BROADCAST_ENABLE, 18-21
  PARALLEL_EXECUTION_MESSAGE_SIZE, 18-20
  PARALLEL_MAX_SERVERS, 14-27, 18-8, 18-9, 18-38
  PARALLEL_MIN_PERCENT, 18-9, 18-16
  PARALLEL_MIN_SERVERS, 18-10
  PARALLEL_SERVER_INSTANCES, 18-17
  PARALLEL_THREADS_PER_CPU, 18-3
  QUERY_REWRITE_ENABLED, 19-5
  ROLLBACK_SEGMENTS, 18-22
  SHARED_POOL_SIZE, 18-10, 18-16
  SORT_AREA_SIZE, 14-28, 18-19
  SORT_MULTIBLOCK_READ_COUNT, 18-26
  STAR_TRANSFORMATION_ENABLED, 16-4
  TAPE_ASYNCH_IO, 18-26
  TRANSACTIONS, 18-22
  UTL_FILE_DIR, 14-19
partial partition-wise joins, 5-17
partition granules, 5-4
partitioned tables
  data warehouses, 5-6
  example, 14-13
partitioning, 11-7
  composite, 5-6
  data, 5-4
  hash, 5-5
  indexes, 5-6
  materialized views, 8-31
  prebuilt tables, 8-33
  range, 5-5
partitions
  bitmap indexes, 6-6
  pruning, 5-10
partition-wise joins, 5-12
  benefits of, 5-20
PCM lock, 18-44
PERCENT_RANK function, 17-33
physical database layouts, 5-3
pivoting, 13-7
plans
  star transformations, 16-8
prebuilt materialized views, 8-16
PRIMARY KEY constraints, 18-58
processes
  and memory contention in parallel processing, 18-9
  classes of parallel execution, 4-4
  DSS, 18-35
  maximum number, 18-34
  maximum number for parallel query, 18-34
  OLTP, 18-35
pruning
  partitions, 5-10

using DATE columns, 5-11
purging data, 14-7

Q

queries
    enabling parallelism for, 18-6
    star queries, 16-2
query delta joins, 19-13
query rewrite
    controlling, 19-28
    correctness, 19-26
    enabling, 19-4, 19-5
    hints, 19-5, 19-28
    matching join graphs, 8-18
    methods, 19-8
    parameters, 19-5
    privileges, 19-6
    restrictions, 8-19
    when it occurs, 19-6
QUERY_REWRITE_ENABLED parameter, 19-5

R

RAID, 4-9, 18-52
range partitioning, 5-5
    performance considerations, 5-6
RANK function, 17-24
ranking functions, 17-24
RATIO_TO_REPORT function, 17-45
RECOMMEND_MV function, 15-5
RECOMMEND_MV_W function, 15-5
recovery
    media, with striping, 4-8
redo buffer allocation retries, 18-23
redundancy
    star schemas, 2-4
reference tables, 8-7
refresh
    monitoring, 14-28
    options, 8-19
refreshing
    materialized views, 14-16
    nested materialized views, 14-26
    partitioning, 14-2
REGR_AVGX function, 17-49
REGR_AVGY function, 17-49
REGR_COUNT function, 17-49
REGR_INTERCEPT function, 17-49
REGR_R2 function, 17-50
REGR_SLOPE function, 17-49
REGR_SXX function, 17-50
REGR_SXY function, 17-50
REGR_SYY function, 17-50
regression
    detecting, 18-66
RELY constraints, 7-5
reporting functions, 17-43
resources
    consumption, parameters affecting, 18-17
    consumption, parameters affecting parallel DML/DDL, 18-22
    limiting for users, 18-9
    limits, 18-8
    oversubscribing, 18-37
    oversubscription, 18-41
    parallel query usage, 18-17
restrictions
    FAST REFRESH, 8-20
    nested materialized views, 8-24
    query rewrite, 8-19
REWRITE hint, 19-5, 19-28
rewrites
    hints, 19-28
    parameters, 19-5
    privileges, 19-6
    query optimizations
        hints, 19-5, 19-28
        matching join graphs, 8-18
rollback segments, 18-22
ROLLBACK_SEGMENTS parameter, 18-22
rolling up hierarchies, 9-3
ROLLUP, 17-6
    partial, 17-8
    when to use, 17-10
root level, 2-7
ROW_NUMBER function, 17-35
RULE hint, 18-64

S

sar UNIX command, 18-75
scalable operations, 18-53
schemas, 16-2
  design guidelines for materialized views, 8-8
  snowflake, 2-3
  star, 2-3
  star schemas, 16-2
  third-normal form, 16-2
SGA size, 18-18
SHARED_POOL_SIZE parameter, 18-10, 18-16
single table aggregate requirements, 8-13
snowflake schemas, 16-3
  complex queries, 16-3
SORT_AREA_SIZE parameter, 14-28, 18-19
  and parallel execution, 18-19
SORT_MULTIBLOCK_READ_COUNT parameter, 18-26
source systems, 11-2
space management, 18-51
  parallel execution, 18-43
  reducing transactions, 18-44
SQL functions
  COUNT, 6-5
SQL Loader, 14-10
SQL text match, 19-8
  with query rewrite, 19-30
staging
  databases, 8-2
  file systems, 4-9
  files, 8-2
staging databases, 8-2
STALE_TOLERATED mode, 19-26
star joins, 16-3
star queries, 16-2
  star transformation, 16-5
star schemas
  advantages, 2-4
  defining fact tables, 2-5
  dimensional model, 2-3, 16-2
  redundancy, 2-4
star transformation, 16-2
star transformations, 16-5
  restrictions, 16-9
STAR_TRANSFORMATION_ENABLED parameter, 16-4
statistics, 19-31
  estimating, 18-67
  functions, 17-46
  operating system, 18-75
STDDEV_POP function, 17-47
STDDEV_SAMP function, 17-47
STORAGE clause
  parallel query, 18-58
striping
  analyzing, 4-5
  and disk affinity, 18-47
  example, 14-10
  local, 4-4
  manual, 4-3
  media recovery, 4-8
  operating systems, 4-3
  temporary tablespace, 18-52
subqueries
  correlated, 18-49
summary advisor, 15-2
  wizard, 15-8
summary management, 8-5
symmetric multiprocessors, 5-2, 18-2

T

table queues, 18-71
tables
  detail tables, 8-7
  dimension tables (lookup tables), 8-7
  dimensions
    star queries, 16-2
  enabling parallelism for, 18-6
  fact tables, 8-7
    star queries, 16-2
  lookup tables (dimension tables), 16-2
tablespaces
  creating, example, 14-11
  dedicated temporary, 18-51
  transportable, 11-5, 12-3
TAPE_ASYNCH_IO parameter, 18-26
temporary extents, 18-52
temporary tablespaces

striping, 18-52
third-normal-form schemas, 16-2
TIMED_STATISTICS parameter, 18-71
timestamps, 11-7
TOP_N function, 17-31
transactions
  rate, 18-43
TRANSACTIONS parameter, 18-22
transformations, 13-2
  SQL and PL/SQL, 13-4
  SQL*Loader, 13-3
  star, 16-2
transportable tablespaces, 11-5, 12-3
transportation
  definition, 12-2
  distributed operations, 12-2
  flat files, 12-2
triggers, 11-7
TRUSTED mode, 19-26
tuning
  parallel execution, 5-3
two-phase commit, 18-22

U

unique constraints, 7-3, 18-58
unusable indexes, 14-17
update frequencies, 8-37
update windows, 8-37
UPSERT statement, 14-5
user resources
  limiting, 18-9
UTL_FILE_DIR parameter, 14-19

V

V$FILESTAT view
  and parallel query, 18-71
V$PARAMETER view, 18-71
V$PQ_SESSTAT view, 18-68, 18-70
V$PQ_SYSSTAT view, 18-68
V$PQ_TQSTAT view, 18-69, 18-71
V$PX_PROCESS view, 18-70
V$PX_SESSION view, 18-70
V$PX_SESSTAT view, 18-70
V$SESSTAT view, 18-72, 18-75
V$SORT_SEGMENT view, 18-44
V$SYSSTAT view, 18-23, 18-56, 18-72
validating dimensions, 9-14
VAR_POP function, 17-47
VAR_SAMP function, 17-47
virtual memory, 18-18
vmstat UNIX command, 18-75

W

wait times, 18-37
windowing functions, 17-35
workloads
  adjusting, 18-40
  distribution, 18-68
  exceeding, 18-37