Oracle® Database

Performance Tuning Guide

10*g* Release 1 (10.1)

Part No. B10752-01

December 2003

ORACLE®

Oracle Database Performance Tuning Guide, 10*g* Release 1 (10.1)

Part No. B10752-01

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Preface

This preface contains these topics:

Audience

Oracle Database Performance Tuning Guide is an aid for people responsible for the operation, maintenance, and performance of Oracle. This book describes detailed ways to enhance Oracle performance by writing and tuning SQL properly, using performance tools, and optimizing instance performance. It also explains how to create an initial database for good performance and includes performance-related reference information. This book could be useful for database administrators, application designers, and programmers.

For information on quick and easy monitoring and tuning of the Oracle database, read the *Oracle 2 Day DBA* manual.

Organization

This document contains:

"What's New in Oracle Performance?"

A summary of recent enhancements to Oracle Performance and updates to this book.

Part I, "Performance Tuning"

This part of the book provides an introduction and overview of performance tuning.

Chapter 1, "Performance Tuning Overview"

An introduction to performance tuning.

Part II, "Performance Planning"

This part of the book describes ways to improve Oracle performance by starting with good application design and using statistics to monitor application performance. It explains the Oracle Performance Improvement Method, as well as emergency performance techniques for dealing with performance problems.

Chapter 2, "Designing and Developing for Performance"

This chapter describes performance issues to consider when designing Oracle applications.

Chapter 3, "Performance Improvement Methods"

This chapter describes Oracle Performance Improvement Methods.

Part III, "Optimizing Instance Performance"

This part of the book describes how to create and configure a database for good performance. This section provides information about Oracle system-related performance tools and describes how to tune various elements of a database system to optimize performance of an Oracle instance.

Chapter 4, "Configuring a Database for Performance"

This chapter describes some of the performance considerations when designing a database, including considerations for shared servers, undo segments, and temporary tablespaces.

Chapter 5, "Automatic Performance Statistics"

Oracle provides a number of tools that allow a performance engineer to gather information regarding instance and database performance. This chapter discusses the importance of performance data gathering and describes the available Oracle features.

Chapter 6, "Automatic Performance Diagnostics"

Oracle provides a number of tools that allow a performance engineer to monitor and diagnose database performance. This chapter describes the available Oracle features and tools.

Chapter 7, "Memory Configuration and Use"

This chapter explains how to allocate memory to database structures.

Chapter 8, "I/O Configuration and Design"

This chapter introduces fundamental I/O concepts, discusses the I/O requirements of different parts of the database, and provides sample configurations for I/O subsystem design.

Chapter 9, "Understanding Operating System Resources"

This chapter explains how to tune the operating system for optimal performance of Oracle.

Chapter 10, "Instance Tuning Using Performance Views"

This chapter discusses the method used for performing tuning. It also describes Oracle statistics and wait events.

Chapter 11, "Tuning Networks"

This chapter describes different connection models and networking issues that affect tuning.

Part IV, "Optimizing SQL Statements"

This part of the book provides information to help understand and manage SQL statements and information about Oracle SQL-related performance tools.

Chapter 12, "SQL Tuning Overview"

This chapter provides an overview of SQL tuning.

Chapter 13, "Automatic SQL Tuning"

This chapter describes Oracle automatic SQL tuning features.

Chapter 14, "The Query Optimizer"

This chapter discusses SQL processing, Oracle optimization, and how the Oracle optimizer chooses how to execute SQL statements.

Chapter 15, "Managing Optimizer Statistics"

This chapter explains why statistics are important for the query optimizer and describes how to gather and use statistics.

Chapter 16, "Using Indexes and Clusters"

This chapter describes how to create indexes and clusters, and when to use them.

Chapter 17, "Optimizer Hints"

This chapter offers recommendations on how to use query optimizer hints to enhance Oracle performance.

Chapter 18, "Using Plan Stability"

This chapter describes how to use plan stability (stored outlines) to preserve performance characteristics.

Chapter 19, "Using EXPLAIN PLAN"

This chapter shows how to use the SQL statement `EXPLAIN PLAN` and format its output.

Chapter 20, "Using Application Tracing Tools"

This chapter describes the use of the SQL trace facility and `TKPROF`, two basic performance diagnostic tools that can help you monitor and tune applications that run against the Oracle Server.

Related Documentation

Before reading this manual, you should have already read *Oracle Database Concepts*, *Oracle 2 Day DBA*, *Oracle Database Application Developer's Guide - Fundamentals*, and the *Oracle Database Administrator's Guide.*

For more information about Oracle Enterprise Manager and its optional applications, see *Oracle Enterprise Manager Concepts*.

For more information about tuning data warehouse environments, see the *Oracle Data Warehousing Guide.*

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

For information about Oracle error messages, see *Oracle Database Error Messages*. Oracle error message documentation is only available in HTML. If you are accessing the error message documentation on the Oracle Documentation CD, you can browse the error messages by range. After you find the specific range, use your browser's find feature to locate the specific message. When connected to the Internet, you can search for a specific error message using the error message search feature of the Oracle online documentation.

Printed documentation is available for sale in the Oracle Store at

`http://oraclestore.oracle.com/`

To download free release notes, installation documentation, white papers, or other collateral, please visit the Oracle Technology Network (OTN). You must register online before using OTN; registration is free and can be done at

`http://otn.oracle.com/membership/`

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

`http://otn.oracle.com/documentation/`

Conventions

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

- Conventions in Text
- Conventions in Code Examples

Conventions in Text

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

Convention	Meaning	Example
Bold	Bold typeface indicates terms that are defined in the text or terms that appear in a glossary, or both.	When you specify this clause, you create an **index-organized table**.
Italics	Italic typeface indicates book titles, emphasis, syntax clauses, or placeholders.	*Oracle Database Concepts* You can specify the *parallel_clause*. Run `U`*`old_release`*`.SQL` where *old_release* refers to the release you installed prior to upgrading.
UPPERCASE monospace (fixed-width font)	Uppercase monospace typeface indicates elements supplied by the system. Such elements include parameters, privileges, datatypes, RMAN keywords, SQL keywords, SQL*Plus or utility commands, packages and methods, as well as system-supplied column names, database objects and structures, user names, and roles.	You can specify this clause only for a `NUMBER` column. You can back up the database using the `BACKUP` command. Query the `TABLE_NAME` column in the `USER_TABLES` data dictionary view. Specify the `ROLLBACK_SEGMENTS` parameter. Use the `DBMS_STATS.GENERATE_STATS` procedure.

Convention	Meaning	Example
lowercase monospace (fixed-width font)	Lowercase monospace typeface indicates executables and sample user-supplied elements. Such elements include computer and database names, net service names, and connect identifiers, as well as user-supplied database objects and structures, column names, packages and classes, user names and roles, program units, and parameter values.	Enter `sqlplus` to open SQL*Plus. The `department_id`, `department_name`, and `location_id` columns are in the `hr.departments` table. Set the `QUERY_REWRITE_ENABLED` initialization parameter to `true`. Connect as `oe` user.

Conventions in Code Examples

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

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

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

Convention	Meaning	Example
[ ]	Brackets enclose one or more optional items. Do not enter the brackets.	`DECIMAL (digits [ , precision ])`
{ }	Braces enclose two or more items, one of which is required. Do not enter the braces.	`{ENABLE | DISABLE}`
|	A vertical bar represents a choice of two or more options within brackets or braces. Enter one of the options. Do not enter the vertical bar.	`{ENABLE | DISABLE}` `[COMPRESS | NOCOMPRESS]`
...	Horizontal ellipsis points indicate either: ■ That we have omitted parts of the code that are not directly related to the example ■ That you can repeat a portion of the code	`CREATE TABLE ... AS subquery;` `SELECT col1, col2, ... , coln FROM employees;`

Convention	Meaning	Example
. . .	Vertical ellipsis points indicate that we have omitted several lines of code not directly related to the example.	SQL> SELECT NAME FROM V$DATAFILE; NAME ---------- /fsl/dbs/tbs_01.dbf /fs1/dbs/tbs_02.dbf . . . /fsl/dbs/tbs_09.dbf 9 rows selected.
Other notation	You must enter symbols other than brackets, braces, vertical bars, and ellipsis points as shown.	acctbal NUMBER(11,2); acct CONSTANT NUMBER(4) := 3;
Italics	Italicized text indicates placeholders or variables for which you must supply particular values.	CONNECT SYSTEM/*system_password* DB_NAME = *database_name*
UPPERCASE	Uppercase typeface indicates elements supplied by the system. We show these terms in uppercase in order to distinguish them from terms you define. Unless terms appear in brackets, enter them in the order with the spelling shown. However, because these terms are not case sensitive, you can enter them in lowercase.	SELECT last_name, employee_id FROM employees; SELECT * FROM USER_TABLES; DROP TABLE hr.employees;
lowercase	Lowercase typeface indicates programmatic elements that you supply. For example, lowercase indicates names of tables, columns, or files. **Note:** Some programmatic elements use a mixture of UPPERCASE and lowercase. Enter these elements as shown.	SELECT last_name, employee_id FROM employees; sqlplus hr/my_hr_password CREATE USER mjones IDENTIFIED BY ty3MU9;

Documentation Accessibility

Our goal is to make Oracle products, services, and supporting documentation accessible, with good usability, to the disabled community. To that end, our documentation includes features that make information available to users of assistive technology. This documentation is available in HTML format, and contains markup to facilitate access by the disabled community. Standards will continue to evolve over time, and Oracle is actively engaged with other market-leading

technology vendors to address technical obstacles so that our documentation can be accessible to all of our customers. For additional information, visit the Oracle Accessibility Program Web site at

`http://www.oracle.com/accessibility/`

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

Accessibility of Links to External Web Sites in Documentation This documentation may contain links to Web sites of other companies or organizations that Oracle does not own or control. Oracle neither evaluates nor makes any representations regarding the accessibility of these Web sites.

What's New in Oracle Performance?

This section describes new performance features of Oracle Database 10*g* Release 1 (10.1) and provides pointers to additional information. The features and enhancements described in this section comprise the overall effort to optimize server performance.

For a summary of all new features for Oracle Database 10*g* Release 1 (10.1), see *Oracle Database New Features*.

Oracle Database 10*g* Release 1 (10.1) New and Updated Features for Performance Tuning

The new and updated performance features in 10*g* Release 1 (10.1) include the following:

- Automatic Performance Diagnostic and Tuning Features

  These features include Automatic Statistics Collection, Automatic Database Diagnostic Monitoring, and Automatic SQL Tuning. The Automatic Workload Repository collects, processes, and maintains performance statistics for problem detection and self-tuning purposes.The Automatic Database Diagnostic Monitor (ADDM) reduces the amount of effort that is required to diagnose and tune Oracle systems. The SQL Tuning Advisor feature allows a quick and efficient technique for optimizing SQL statements. See "Introduction to Performance Tuning Features and Tools" on page 1-6 for a brief summary of the new performance features and tools.

- Application End to End Tracing

  Application End to End Tracing identifies the source of an excessive workload, such as a high load SQL statement, by client identifier, service, module, or action. This feature simplifies the debugging of performance problems in multitier environments. See "End to End Application Tracing" on page 20-2.

- `trcsess` Utility

  The `trcsess` command-line utility consolidates trace information from selected trace files based on specified criteria. See "Using the trcsess Utility" on page 20-7.

- Automatic Optimizer Statistics Collection

  This feature automates the collection of optimizer statistics for objects. Objects with stale or no statistics are automatically analyzed, so administrators no longer need to keep track of what does and what does not need to be analyzed, nor to perform analysis by hand. See "Automatic Statistics Gathering" on page 15-3.

- Automatic Shared Memory Management

  Automatic Shared Memory Management simplifies the configuration of System Global Area (SGA) memory-related parameters through self-tuning algorithms. It simplifies database configuration, ensures most efficient utilization of available memory and improves performance. See "Automatic Shared Memory Management" on page 7-3.

- Rule-based Optimization (RBO) Obsolescence

  RBO as a functionality is no longer supported. RBO still exists in Oracle 10*g* Release 1, but is an unsupported feature. No code changes have been made to RBO and no bug fixes are provided. Oracle supports only the query optimizer, and all applications running on Oracle Database 10*g* Release 1 (10.1) should use that optimizer. Please review the following Oracle Metalink desupport notice (189702.1) for RBO:

  ```
  http://metalink.oracle.com/metalink/plsql/ml2_documents.showDocument?p_
  database_id=NOT&p_id=189702.1
  ```

  You can also access desupport notice 189702.1 and related notices by searching for "desupport of RBO" at:

  ```
  http://metalink.oracle.com
  ```

  Notice 189702.1 provides details about the desupport of RBO and the migration of applications based on RBO to query optimization.

  Some consequences of the desupport of RBO are:

  – `CHOOSE` and `RULE` are no longer supported as `OPTIMIZER_MODE` initialization parameter values and a warning is displayed in the alert log if the value is set to `RULE` or `CHOOSE`. The functionalities of those parameter values still exist but will be removed in a future release. See "OPTIMIZER_MODE Initialization Parameter" on page 14-4 for information optimizer mode parameters.

  – `ALL_ROWS` is the default value for the `OPTIMIZER_MODE` initialization parameter.

  – The `CHOOSE` and `RULE` optimizer hints are no longer supported. The functionalities of those hints still exist but will be removed in a future release.

  – Existing applications that previously relied on rule-based optimization (RBO) need to be moved to query optimization.

    See Also:

    - *Oracle Database Upgrade Guide*
    - Oracle Metalink desupport notice for RBO
    - "Moving from RBO to the Query Optimizer" on page 18-12

- Dynamic Sampling

  The default setting for the `OPTIMIZER_DYNAMIC_SAMPLING` initialization parameter is now 2. See "Estimating Statistics with Dynamic Sampling" on page 15-16 for information about when and how to use dynamic sampling.

- CPU Costing
  - The default cost model for the optimizer is now CPU+I/O and the cost unit is time. See "Understanding the Query Optimizer" on page 14-9.
- New Optimizer Hints
  - "SPREAD_MIN_ANALYSIS" on page 17-48 specifies analysis options for spreadsheets.
  - "USE_NL_WITH_INDEX" on page 17-34 specifies a nested loops join.
  - "QB_NAME" on page 17-46 specifies a name for a query block.
  - "NO_QUERY_TRANSFORMATION" on page 17-24 causes the optimizer to skip all query transformations.
  - The "NO_USE_NL" on page 17-33, "NO_USE_MERGE" on page 17-35, "NO_USE_HASH" on page 17-36, "NO_INDEX_FFS" on page 17-21, "NO_INDEX_SS" on page 17-23, and "NO_STAR_TRANSFORMATION" on page 17-29 hints cause the optimizer to exclude various operations from the execution plan.
  - The "INDEX_SS" on page 17-22, "INDEX_SS_ASC" on page 17-22, and "INDEX_SS_DESC" on page 17-23 hints cause the optimizer to use index skip scan operations in the execution plan.
- Updated Optimizer Hints
  - Hints that use a table or index argument in their syntax have been updated to use an expanded table or index specification. See "Specifying Global Table Hints" on page 17-7 and "Specifying Complex Index Hints" on page 17-9.
  - Some hints can use an optional query block argument. See "Specifying a Query Block in a Hint" on page 17-6
- Renamed Optimizer Hints

  The "NO_PARALLEL" on page 17-37, "NO_PARALLEL_INDEX" on page 17-40, and "NO_REWRITE" on page 17-26 hints have been renamed. The `NOPARALLEL`, `NOPARALLEL_INDEX`, and `NOREWRITE` hints have been deprecated and should not be used.

- Additional Deprecated Optimizer Hints

  The AND_EQUAL, HASH_AJ, MERGE_AJ, NL_AJ, HASH_SJ, MERGE_SJ, NL_SJ, EXPAND_GSET_TO_UNION, ORDERED_PREDICATES, ROWID, and STAR hints have been deprecated and should not be used.

- Wait Model Improvements

  New and updated dynamic performance views are available. Existing V$EVENT_NAME, V$SESSION, and V$SESSION_WAIT views were modified. New V$ACTIVE_SESSION_HISTORY, V$SESS_TIME_MODEL, V$SYS_TIME_MODEL, V$SYSTEM_WAIT_CLASS, V$SESSION_WAIT_CLASS, V$EVENT_HISTOGRAM, V$FILE_HISTOGRAM, and V$TEMP_HISTOGRAM were added.

  See Also:

  - *Oracle Database Reference* for information about dynamic performance views
  - "Active Session History (ASH)" on page 5-4
  - "Dynamic Performance Views Containing Wait Event Statistics" on page 10-9

- SAMPLE Clause Enhancements

  The sample clause can now be present in complex select statements. See "Sample Table Scans" on page 14-28.

- Hash Partitioned Global Indexes

  New hash method can improve performance of indexes where a small number leaf blocks in the index have high contention in multiuser OLTP environment. See "Using Partitioned Indexes for Performance" on page 16-11.

- Oracle Trace Obsolescence

  Oracle Trace as a functionality is no longer available. For the tracing of database activity, use SQL Trace or TKPROF instead. The chapter on Oracle Trace has been removed from this book. See Chapter 20, "Using Application Tracing Tools".

Part I

Performance Tuning

Part I provides an introduction and overview of performance tuning.

The chapter in this part is:

- Chapter 1, "Performance Tuning Overview"

1

Performance Tuning Overview

This chapter provides an introduction to performance tuning.

This chapter contains the following:

Introduction to Performance Tuning

This guide provides information on tuning an Oracle Database system for performance. Topics discussed in this guide include:

- Performance Planning
- Instance Tuning
- SQL Tuning

Performance Planning

Before you start on the instance or SQL tuning sections of this guide, make sure you have read Part II, "Performance Planning". Based on years of designing and performance experience, Oracle has designed a performance methodology. This brief section explains clear and simple activities that can dramatically improve system performance. It discusses the following topics:

- Investment Options
- Scalability
- System Architecture
- Application Design Principles
- Workload Testing, Modeling, and Implementation
- Deploying New Applications

Instance Tuning

Part III, "Optimizing Instance Performance" of this guide discusses the factors involved with the tuning and optimizing of an Oracle database instance.

When considering instance tuning, care must be taken in the initial design of the database system to avoid bottlenecks that could lead to performance problems. In addition, you need to consider:

- Allocating memory to database structures
- Determining I/O requirements of different parts of the database
- Tuning the operating system for optimal performance of the database

After the database instance has been installed and configured, you need to monitor the database as it is running to check for performance-related problems.

Performance Principles

Performance tuning requires a different, although related, method to the initial configuration of a system. Configuring a system involves allocating resources in an ordered manner so that the initial system configuration is functional.

Tuning is driven by identifying the most significant bottleneck and making the appropriate changes to reduce or eliminate the effect of that bottleneck. Usually, tuning is performed reactively, either while the system is preproduction or after it is live.

Baselines

The most effective way to tune is to have an established performance baseline that can be used for comparison if a performance issue arises. Most database administrators (DBAs) know their system well and can easily identify peak usage periods. For example, the peak periods could be between 10.00am and 12.00pm and also between 1.30pm and 3.00pm. This could include a batch window of 12.00am midnight to 6am.

It is important to identify these high-load times at the site and install a monitoring tool that gathers performance data for those times. Optimally, data gathering should be configured from when the application is in its initial trial phase during the QA cycle. Otherwise, this should be configured when the system is first in production.

Ideally, baseline data gathered should include the following:

- Application statistics (transaction volumes, response time)
- Database statistics
- Operating system statistics
- Disk I/O statistics
- Network statistics

In the Automatic Workload Repository, baselines are identified by a range of snapshots that are preserved for future comparisons. See "Automatic Workload Repository" on page 5-10.

The Symptoms and the Problems

A common pitfall in performance tuning is to mistake the symptoms of a problem for the actual problem itself. It is important to recognize that many performance

statistics indicate the symptoms, and that identifying the symptom is not sufficient data to implement a remedy. For example:

- Slow physical I/O

  Generally, this is caused by poorly-configured disks. However, it could also be caused by a significant amount of unnecessary physical I/O on those disks issued by poorly-tuned SQL.

- Latch contention

  Rarely is latch contention tunable by reconfiguring the instance. Rather, latch contention usually is resolved through application changes.

- Excessive CPU usage

  Excessive CPU usage usually means that there is little idle CPU on the system. This could be caused by an inadequately-sized system, by untuned SQL statements, or by inefficient application programs.

When to Tune

There are two distinct types of tuning:

- Proactive Monitoring
- Bottleneck Elimination

Proactive Monitoring Proactive monitoring usually occurs on a regularly scheduled interval, where a number of performance statistics are examined to identify whether the system behavior and resource usage has changed. Proactive monitoring also can be called proactive tuning.

Usually, monitoring does not result in configuration changes to the system, unless the monitoring exposes a serious problem that is developing. In some situations, experienced performance engineers can identify potential problems through statistics alone, although accompanying performance degradation is usual.

Experimenting with or tweaking a system when there is no apparent performance degradation as a proactive action can be a dangerous activity, resulting in unnecessary performance drops. Tweaking a system should be considered reactive tuning, and the steps for reactive tuning should be followed.

Monitoring is usually part of a larger capacity planning exercise, where resource consumption is examined to see the changes in the way the application is being used and the way the application is using the database and host resources.

Bottleneck Elimination Tuning usually implies fixing a performance problem. However, tuning should be part of the life cycle of an application, through the analysis, design, coding, production, and maintenance stages. Many times, the tuning phase is left until the system is in production. At this time, tuning becomes a reactive fire-fighting exercise, where the most important bottleneck is identified and fixed.

Usually, the purpose for tuning is to reduce resource consumption or to reduce the elapsed time for an operation to complete. Either way, the goal is to improve the effective use of a particular resource. In general, performance problems are caused by the over-use of a particular resource. That resource is the bottleneck in the system. There are a number of distinct phases in identifying the bottleneck and the potential fixes. These are discussed in the sections that follow.

Remember that the different forms of contention are symptoms that can be fixed by making changes in the following places:

- Changes in the application, or the way the application is used
- Changes in Oracle
- Changes in the host hardware configuration

Often, the most effective way of resolving a bottleneck is to change the application.

SQL Tuning

Part IV, "Optimizing SQL Statements" of this guide discusses the process of tuning and optimizing SQL statements.

Many client/server application programmers consider SQL a messaging language, because queries are issued and data is returned. However, client tools often generate inefficient SQL statements. Therefore, a good understanding of the database SQL processing engine is necessary for writing optimal SQL. This is especially true for high transaction processing systems.

Typically, SQL statements issued by OLTP applications operate on relatively few rows at a time. If an index can point to the exact rows that you want, then Oracle can construct an accurate plan to access those rows efficiently through the shortest possible path. In decision support system (DSS) environments, selectivity is less important, because they often access most of a table's rows. In such situations, full table scans are common, and indexes are not even used. This book is primarily focussed on OLTP-type applications. For detailed information on DSS and mixed environments, see the *Oracle Data Warehousing Guide*.

Query Optimizer and Execution Plans

When a SQL statement is executed on an Oracle database, the Oracle query optimizer determines the most efficient execution plan after considering many factors related to the objects referenced and the conditions specified in the query. This determination is an important step in the processing of any SQL statement and can greatly affect execution time.

During the evaluation process, the query optimizer reviews statistics gathered on the system to determine the best data access path and other considerations. You can override the execution plan of the query optimizer with hints inserted in SQL statement.

Introduction to Performance Tuning Features and Tools

Effective data collection and analysis is essential for identifying and correcting performance problems. Oracle provides a number of tools that allow a performance engineer to gather information regarding database performance. In addition to gathering data, Oracle provides tools to monitor performance, diagnose problems, and tune applications.

The Oracle gathering and monitoring features are mainly automatic, managed by an Oracle background processes. To enable automatic statistics collection and automatic performance features, the `STATISTICS_LEVEL` initialization parameter must be set to `TYPICAL` or `ALL`. You can administer and display the output of the gathering and tuning tools with Oracle Enterprise Manager or with APIs and views. Oracle Enterprise Manager Database Control is recommended for ease of use.

See Also:

- *Oracle 2 Day DBA* for information on monitoring, diagnosing, and tuning the database
- *Oracle Enterprise Manager Concepts* for information about monitoring and diagnostic tools available with Oracle Enterprise Manager
- *PL/SQL Packages and Types Reference* for detailed information on the `DBMS_ADVISOR`, `DBMS_SQLTUNE`, and `DBMS_WORKLOAD_REPOSITORY` packages
- *Oracle Database Reference* for information on the `STATISTICS_LEVEL` initialization parameter

Automatic Performance Tuning Features

The Oracle automatic performance tuning features include:

- Automatic Workload Repository (AWR) collects, processes, and maintains performance statistics for problem detection and self-tuning purposes. See "Automatic Workload Repository" on page 5-10.
- Automatic Database Diagnostic Monitor (ADDM) analyzes the information collected by the AWR for possible performance problems with the Oracle database. See "Automatic Database Diagnostic Monitor" on page 6-3.
- SQL Tuning Advisor allows a quick and efficient technique for optimizing SQL statements without modifying any statements. See "SQL Tuning Advisor" on page 13-6.
- SQLAccess Advisor provides advice on materialized views, indexes, and materialized view logs. See "SQLAccess Advisor" on page 12-7 and *Oracle Data Warehousing Guide* for information on SQLAccess Advisor.
- End to End Application tracing identifies excessive workloads on the system by specific user, service, or application component. See "End to End Application Tracing" on page 20-2.
- Server-generated alerts automatically provide notifications when impending problems are detected. See *Oracle Database Administrator's Guide* for information about monitoring the operation of the database with server-generated alerts.
- Additional advisors that can be launched from Oracle Enterprise Manager, such as memory advisors to optimize memory for an instance. The memory advisors are commonly used when automatic memory management is not set up for the database. Other advisors are used to optimize mean time to recovery (MTTR), shrinking of segments, and undo tablespace settings. See *Oracle Enterprise Manager Concepts* for information on advisors that are available with Oracle Enterprise Manager.

  To access the advisors through Oracle Enterprise Manager Database Control:

  - Click the **Advisor Central** link under **Related Links** at the bottom of the **Database** pages.
  - On the **Advisor Central** page, you can click one of the advisor links.
- Oracle Enterprise Manager Performance page displays host, instance service time, and throughput information for real time monitoring and diagnosis. The page can be set to refresh automatically in selected intervals or manually. See

Oracle Enterprise Manager Concepts for information on the Performance page available with Oracle Enterprise Manager.

Additional Oracle Tools

This section describes additional Oracle tools that can be used for determining performance problems.

V$ Performance Views

The V$ views are the performance information sources used by all Oracle performance tuning tools. The V$ views are based on memory structures initialized at instance startup. The memory structures, and the views that represent them, are automatically maintained by Oracle throughout the life of the instance. See Chapter 10, "Instance Tuning Using Performance Views" for information diagnosing tuning problems using the V$ performance views.

See Also: *Oracle Database Reference* for information about dynamic performance views

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Note: Oracle recommends using the Automatic Workload Repository to gather performance data. These tools have been designed to capture all of the data needed for performance analysis.

Part II

Performance Planning

Part II describes ways to improve Oracle performance by starting with good application design and using statistics to monitor application performance. It explains the Oracle Performance Improvement Method, as well as emergency performance techniques for dealing with performance problems.

The chapters in this part are:

- Chapter 2, "Designing and Developing for Performance"
- Chapter 3, "Performance Improvement Methods"

2

Designing and Developing for Performance

Good system performance begins with design and continues throughout the life of your system. Carefully consider performance issues during the initial design phase, and it will be easier to tune your system during production.

This chapter contains the following sections:

Oracle Methodology

System performance has become increasingly important as computer systems get larger and more complex and as the Internet plays a bigger role in business applications. In order to accommodate this, Oracle has produced a performance methodology based on years of designing and performance experience. This methodology explains clear and simple activities that can dramatically improve system performance.

Performance strategies vary in their effectiveness, and systems with different purposes, such as operational systems and decision support systems, require different performance skills. This book examines the considerations that any database designer, administrator, or performance expert should focus their efforts on.

System performance is designed and built into a system. It does not just happen. Performance problems are usually the result of contention for, or exhaustion of, some system resource. When a system resource is exhausted, the system is unable to scale to higher levels of performance. This new performance methodology is based on careful planning and design of the database, to prevent system resources from becoming exhausted and causing down-time. By eliminating resource conflicts, systems can be made scalable to the levels required by the business.

Understanding Investment Options

With the availability of relatively inexpensive, high-powered processors, memory, and disk drives, there is a temptation to buy more system resources to improve performance. In many situations, new CPUs, memory, or more disk drives can indeed provide an immediate performance improvement. However, any performance increases achieved by adding hardware should be considered a short-term relief to an immediate problem. If the demand and load rates on the application continue to grow, then the chance that you will face the same problem in the near future is very likely.

In other situations, additional hardware does not improve the system's performance at all. Poorly designed systems perform poorly no matter how much extra hardware is allocated. Before purchasing additional hardware, make sure that there is no serialization or single threading going on within the application. Long-term, it is generally more valuable to increase the efficiency of your application in terms of the number of physical resources used for each business transaction.

Understanding Scalability

The word *scalability* is used in many contexts in development environments. The following section provides an explanation of scalability that is aimed at application designers and performance specialists.

What is Scalability?

Scalability is a system's ability to process more workload, with a proportional increase in system resource usage. In other words, in a scalable system, if you double the workload, then the system would use twice as many system resources. This sounds obvious, but due to conflicts within the system, the resource usage might exceed twice the original workload.

Examples of bad scalability due to resource conflicts include the following:

- Applications requiring significant concurrency management as user populations increase
- Increased locking activities
- Increased data consistency workload
- Increased operating system workload
- Transactions requiring increases in data access as data volumes increase
- Poor SQL and index design resulting in a higher number of logical I/Os for the same number of rows returned
- Reduced availability, because database objects take longer to maintain

An application is said to be unscalable if it exhausts a system resource to the point where no more throughput is possible when it's workload is increased. Such applications result in fixed throughputs and poor response times.

Examples of resource exhaustion include the following:

- Hardware exhaustion
- Table scans in high-volume transactions causing inevitable disk I/O shortages
- Excessive network requests, resulting in network and scheduling bottlenecks
- Memory allocation causing paging and swapping
- Excessive process and thread allocation causing operating system thrashing

This means that application designers must create a design that uses the same resources, regardless of user populations and data volumes, and does not put loads on the system resources beyond their limits.

System Scalability

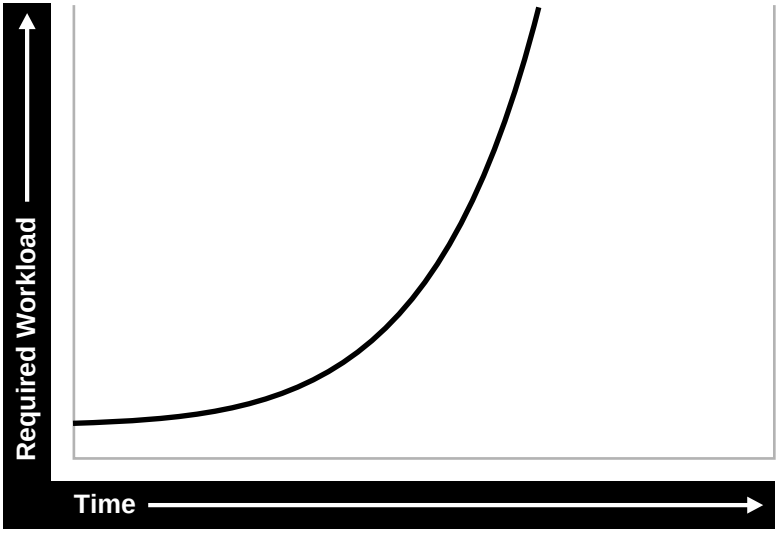
Applications that are accessible through the Internet have more complex performance and availability requirements. Some applications are designed and written only for Internet use, but even typical back-office applications, such as a general ledger application, might require some or all data to be available online.

Characteristics of Internet age applications include the following:

- Availability 24 hours a day, 365 days a year
- Unpredictable and imprecise number of concurrent users
- Difficulty in capacity planning
- Availability for any type of query
- Multitier architectures
- Stateless middleware
- Rapid development timescale
- Minimal time for testing

Figure 2–1 illustrates the classic workload growth curve, with demand growing at an increasing rate. Applications must scale with the increase of workload and also when additional hardware is added to support increasing demand. Design errors can cause the implementation to reach its maximum, regardless of additional hardware resources or re-design efforts.

Figure 2–1 Workload Growth Curve



Applications are challenged by very short development timeframes with limited time for testing and evaluation. However, bad design generally means that at some point in the future, the system will need to be re-architected or re-implemented. If an application with known architectural and implementation limitations is deployed on the Internet, and if the workload exceeds the anticipated demand, then there is real chance of failure in the future. From a business perspective, poor performance can mean a loss of customers. If Web users do not get a response in seven seconds, then the user's attention could be lost forever.

In many cases, the cost of re-designing a system with the associated downtime costs in migrating to new implementations exceeds the costs of properly building the original system. The moral of the story is simple: design and implement with scalability in mind from the start.

Factors Preventing Scalability

When building applications, designers and architects should aim for as close to perfect scalability as possible. This is sometimes called *linear* scalability, where system throughput is directly proportional to the number of CPUs.

In real life, linear scalability is impossible for reasons beyond a designer's control. However, making the application design and implementation as scalable as possible

should ensure that current and future performance objectives can be achieved through expansion of hardware components and the evolution of CPU technology.

Factors Preventing Linear Scalability

1. Poor Application Design, Implementation, and Configuration

   The application has the biggest impact on scalability. For example:

   - Poor schema design can cause expensive SQL that does not scale.
   - Poor transaction design can cause locking and serialization problems.
   - Poor connection management can cause poor response times and unreliable systems.

   However, the design is not the only problem. The physical implementation of the application can be the weak link. For example:

   - Systems can move to production environments with bad I/O strategies.
   - The production environment could use different execution plans than those generated in testing.
   - Memory-intensive applications that allocate a large amount of memory without much thought for freeing the memory at runtime can cause excessive memory usage.
   - Inefficient memory usage and memory leaks put a high stress on the operating virtual memory subsystem. This impacts performance and availability.

2. Incorrect Sizing of Hardware Components

   Bad capacity planning of all hardware components is becoming less of a problem as relative hardware prices decrease. However, too much capacity can mask scalability problems as the workload is increased on a system.

3. Limitations of Software Components

   All software components have scalability and resource usage limitations. This applies to application servers, database servers, and operating systems. Application design should not place demands on the software beyond what it can handle.

4. Limitations of Hardware Components

   Hardware is not perfectly scalable. Most multiprocessor machines can get close to linear scaling with a finite number of CPUs, but after a certain point each

additional CPU can increase performance overall, but not proportionately. There might come a time when an additional CPU offers no increase in performance, or even degrades performance. This behavior is very closely linked to the workload and the operating system setup.

Note: These factors are based on Oracle Server Performance group's experience of tuning unscalable systems.

System Architecture

There are two main parts to a system's architecture:

- Hardware and Software Components
- Configuring the Right System Architecture for Your Requirements

Hardware and Software Components

This section discusses hardware and software components.

Hardware Components

Today's designers and architects are responsible for sizing and capacity planning of hardware at each tier in a multitier environment. It is the architect's responsibility to achieve a balanced design. This is analogous to a bridge designer who must consider all the various payload and structural requirements for the bridge. A bridge is only as strong as its weakest component. As a result, a bridge is designed in balance, such that all components reach their design limits simultaneously.

The main hardware components are the following:

- CPU
- Memory
- I/O Subsystem
- Network

CPU There can be one or more CPUs, and they can vary in processing power from simple CPUs found in hand-held devices to high-powered server CPUs. Sizing of other hardware components is usually a multiple of the CPUs on the system. See Chapter 9, "Understanding Operating System Resources".

Memory Database and application servers require considerable amounts of memory to cache data and avoid time-consuming disk access. See Chapter 7, "Memory Configuration and Use".

I/O Subsystem The I/O subsystem can vary between the hard disk on a client PC and high performance disk arrays. Disk arrays can perform thousands of I/Os each second and provide availability through redundancy in terms of multiple I/O paths and hot pluggable mirrored disks. See Chapter 8, "I/O Configuration and Design".

Network All computers in a system are connected to a network, from a modem line to a high speed internal LAN. The primary concerns with network specifications are bandwidth (volume) and latency (speed). See Chapter 11, "Tuning Networks".

Software Components

The same way computers have common hardware components, applications have common functional components. By dividing software development into functional components, it is possible to comprehend the application design and architecture better. Some components of the system are performed by existing software bought to accelerate application implementation or to avoid re-development of common components.

The difference between software components and hardware components is that while hardware components only perform one task, a piece of software can perform the roles of various software components. For example, a disk drive only stores and retrieves data, but a client program can manage the user interface and perform business logic.

Most applications involve the following components:

- Managing the User Interface
- Implementing Business Logic
- Managing User Requests and Resource Allocation
- Managing Data and Transactions

Managing the User Interface This component is the most visible to application users. This includes the following functions:

- Painting the screen in front of the user
- Collecting user data and transferring it to business logic
- Validating data entry

- Navigating through levels or states of the application

Implementing Business Logic This component implements core business rules that are central to the application function. Errors made in this component could be very costly to repair. This component is implemented by a mixture of declarative and procedural approaches. An example of a declarative activity is defining unique and foreign keys. An example of procedure-based logic is implementing a discounting strategy.

Common functions of this component include the following:

- Moving a data model to a relational table structure
- Defining constraints in the relational table structure
- Coding procedural logic to implement business rules

Managing User Requests and Resource Allocation This component is implemented in all pieces of software. However, there are some requests and resources that can be influenced by the application design and some that cannot.

In a multiuser application, most resource allocation by user requests are handled by the database server or the operating system. However, in a large application where the number of users and their usage pattern is unknown or growing rapidly, the system architect must be proactive to ensure that no single software component becomes overloaded and unstable.

Common functions of this component include the following:

- Connection management with the database
- Executing SQL efficiently (cursors and SQL sharing)
- Managing client state information
- Balancing the load of user requests across hardware resources
- Setting operational targets for hardware/software components
- Persistent queuing for asynchronous execution of tasks

Managing Data and Transactions This component is largely the responsibility of the database server and the operating system.

Common functions of this component include the following:

- Providing concurrent access to data using locks and transactional semantics
- Providing optimized access to the data using indexes and memory cache

- Ensuring that data changes are logged in the event of a hardware failure
- Enforcing any rules defined for the data

Configuring the Right System Architecture for Your Requirements

Configuring the initial system architecture is a largely iterative process. Architects must satisfy the system requirements within budget and schedule constraints. If the system requires interactive users transacting business or making decisions based on the contents of a database, then user requirements drive the architecture. If there are few interactive users on the system, then the architecture is process-driven.

Examples of interactive user applications:

- Accounting and bookkeeping applications
- Order entry systems
- Email servers
- Web-based retail applications
- Trading systems

Examples of process-driven applications:

- Utility billing systems
- Fraud detection systems
- Direct mail

In many ways, process-driven applications are easier to design than multiuser applications because the user interface element is eliminated. However, because the objectives are process-oriented, architects not accustomed to dealing with large data volumes and different success factors can become confused. Process-driven applications draw from the skills sets used in both user-based applications and data warehousing. Therefore, this book focuses on evolving system architectures for interactive users.

Note: Generating a system architecture is not a deterministic process. It requires careful consideration of business requirements, technology choices, existing infrastructure and systems, and actual physical resources, such as budget and manpower.

The following questions should stimulate thought on architecture, though they are not a definitive guide to system architecture. These questions demonstrate how business requirements can influence the architecture, ease of implementation, and overall performance and availability of a system. For example:

- How many users will the system support?

  Most applications fall into one of the following categories:

  - Very few users on a lightly-used or exclusive machine

    For this type of application, there is usually one user. The focus of the application design is to make the single user as productive as possible by providing good response time, yet make the application require minimal administration. Users of these applications rarely interfere with each other and have minimal resource conflicts.

  - A medium to large number of users in a corporation using shared applications

    For this type of application, the users are limited by the number of employees in the corporation actually transacting business through the system. Therefore, the number of users is predictable. However, delivering a reliable service is crucial to the business. The users will be using a shared resource, so design efforts must address response time under heavy system load, escalation of resource for each session usage, and room for future growth.

  - An infinite user population distributed on the Internet

    For this type of application, extra engineering effort is required to ensure that no system component exceeds its design limits. This would create a bottleneck that brings the system to a halt and becomes unstable. These applications require complex load balancing, stateless application servers, and efficient database connection management. In addition, statistics and governors should be used to ensure that the user gets some feedback if their requests cannot be satisfied due to system overload.

- What will be the user interaction method?

  The choices of user interface range from a simple Web browser to a custom client program.

- Where are the users located?

The distance between users influences how the application is engineered to cope with network latencies. The location also affects which times of the day are busy, when it is impossible to perform batch or system maintenance functions.

- What is the network speed?

  Network speed affects the amount of data and the conversational nature of the user interface with the application and database servers. A highly conversational user interface can communicate with back-end servers on every key stroke or field level validation. A less conversational interface works on a screen-sent and a screen-received model. On a slow network, it is impossible to get good data entry speeds with a highly conversational user interface.

- How much data will the user access, and how much of that data is largely read only?

  The amount of data queried online influences all aspects of the design, from table and index design to the presentation layers. Design efforts must ensure that user response time is not a function of the size of the database. If the application is largely read only, then replication and data distribution to local caches in the application servers become a viable option. This also reduces workload on the core transactional server.

- What is the user response time requirement?

  Consideration of the user type is important. If the user is an executive who requires accurate information to make split second decisions, then user response time cannot be compromised. Other types of users, such as users performing data entry activities, might not need such a high level of performance.

- Do users expect 24 hour service?

  This is mandatory for today's Internet applications where trade is conducted 24 hours a day. However, corporate systems that run in a single time zone might be able to tolerate after-hours downtime. This after-hours downtime can be used to run batch processes or to perform system administration. In this case, it might be more economic not to run a fully-available system.

- Must all changes be made in real time?

  It is important to determine if transactions need to be executed within the user response time, or if they can they be queued for asynchronous execution.

The following are secondary questions, which can also influence the design, but really have more impact on budget and ease of implementation. For example:

- How big will the database be?

  This influences the sizing of the database server machine. On systems with a very large database, it might be necessary to have a bigger machine than dictated by the workload. This is because the administration overhead with large databases is largely a function of the database size. As tables and indexes grow, it takes proportionately more CPUs to allow table reorganizations and index builds to complete in an acceptable time limit.
- What is the required throughput of business transactions?
- What are the availability requirements?
- Do skills exist to build and administer this application?
- What compromises will be forced by budget constraints?

Application Design Principles

This section describes design decisions that are involved in building applications.

Simplicity In Application Design

Applications are no different than any other designed and engineered product. Well-designed structures, machines, and tools are usually reliable, easy to use and maintain, and simple in concept. In the most general terms, if the design looks right, then it probably is right. This principle should always be kept in mind when building applications.

Consider some of the following design issues:

- If the table design is so complicated that nobody can fully understand it, then the table is probably designed badly.
- If SQL statements are so long and involved that it would be impossible for any optimizer to effectively optimize it in real time, then there is probably a bad statement, underlying transaction, or table design.
- If there are indexes on a table and the same columns are repeatedly indexed, then there is probably a bad index design.
- If queries are submitted without suitable qualification for rapid response for online users, then there is probably a bad user interface or transaction design.

- If the calls to the database are abstracted away from the application logic by many layers of software, then there is probably a bad software development method.

Data Modeling

Data modeling is important to successful relational application design. This should be done in a way that quickly represents the business practices. Chances are, there will be heated debates about the correct data model. The important thing is to apply greatest modeling efforts to those entities affected by the most frequent business transactions. In the modeling phase, there is a great temptation to spend too much time modeling the non-core data elements, which results in increased development lead times. Use of modeling tools can then rapidly generate schema definitions and can be useful when a fast prototype is required.

Table and Index Design

Table design is largely a compromise between flexibility and performance of core transactions. To keep the database flexible and able to accommodate unforeseen workloads, the table design should be very similar to the data model, and it should be normalized to at least 3rd normal form. However, certain core transactions required by users can require selective denormalization for performance purposes.

Examples of this technique include storing tables pre-joined, the addition of derived columns, and aggregate values. Oracle provides numerous options for storage of aggregates and pre-joined data by clustering and materialized view functions. These features allow a simpler table design to be adopted initially.

Again, focus and resources should be spent on the business critical tables, so that good performance can be achieved. For non-critical tables, shortcuts in design can be adopted to enable a more rapid application development. If, however, in prototyping and testing a non-core table becomes a performance problem, then remedial design effort should be applied immediately.

Index design is also a largely iterative process, based on the SQL generated by application designers. However, it is possible to make a sensible start by building indexes that enforce primary key constraints and indexes on known access patterns, such as a person's name. As the application evolves and testing is performed on realistic sizes of data, certain queries will need performance improvements for which building a better index is a good solution. The following list of indexing design ideas should be considered when building a new index:

- Appending Columns to an Index or Using Index-Organized Tables

Appending Columns to an Index or Using Index-Organized Tables

One of the easiest ways to speed up a query is to reduce the number of logical I/Os by eliminating a table access from the execution plan. This can be done by appending to the index all columns referenced by the query. These columns are the select list columns and any required join or sort columns. This technique is particularly useful in speeding up online applications response times when time-consuming I/Os are reduced. This is best applied when testing the application with properly sized data for the first time.

The most aggressive form of this technique is to build an index-organized table (IOT). However, you must be careful that the increased leaf size of an IOT does not undermine the efforts to reduce I/O.

Using a Different Index Type

There are several index types available, and each index has benefits for certain situations. The following list gives performance ideas associated with each index type.

B-Tree Indexes These are the standard index type, and they are excellent for primary key and highly-selective indexes. Used as concatenated indexes, B-tree indexes can be used to retrieve data sorted by the index columns.

Bitmap Indexes These are suitable for low cardinality data. Through compression techniques, they can generate a large number of rowids with minimal I/O. Combining bitmap indexes on non-selective columns allows efficient `AND` and `OR` operations with a great number of rowids with minimal I/O. Bitmap indexes are particularly efficient in queries with `COUNT()`, because the query can be satisfied within the index.

Function-based Indexes These indexes allow access through a B-tree on a value derived from a function on the base data. Function-based indexes have some limitations with regards to the use of nulls, and they require that you have the query optimizer enabled.

Function-based indexes are particularly useful when querying on composite columns to produce a derived result or to overcome limitations in the way data is stored in the database. An example of this is querying for line items in an order exceeding a certain value derived from (sales price - discount) x quantity, where these were columns in the table. Another example is to apply the UPPER function to the data to allow case-insensitive searches.

Partitioned Indexes Partitioning a global index allows partition pruning to take place within an index access, which results in reduced I/Os. By definition of good range or list partitioning, fast index scans of the correct index partitions can result in very fast query times.

Reverse Key Indexes These are designed to eliminate index hot spots on insert applications. These indexes are excellent for insert performance, but they are limited in that they cannot be used for index range scans.

Finding the Cost of an Index

Building and maintaining an index structure can be expensive, and it can consume resources such as disk space, CPU, and I/O capacity. Designers must ensure that the benefits of any index outweigh the negatives of index maintenance.

Use this simple estimation guide for the cost of index maintenance: Each index maintained by an `INSERT`, `DELETE`, or `UPDATE` of the indexed keys requires about three times as much resource as the actual DML operation on the table. What this means is that if you `INSERT` into a table with three indexes, then it will be approximately 10 times slower than an `INSERT` into a table with no indexes. For DML, and particularly for `INSERT`-heavy applications, the index design should be seriously reviewed, which might require a compromise between the query and `INSERT` performance.

> **See Also:** *Oracle Database Administrator's Guide* for information on monitoring index usage

Serializing within Indexes

Use of sequences, or timestamps, to generate key values that are indexed themselves can lead to database hotspot problems, which affect response time and throughput. This is usually the result of a monotonically growing key that results in a right-growing index. To avoid this problem, try to generate keys that insert over the full range of the index. This results in a well-balanced index that is more scalable and space efficient. You can achieve this by using a reverse key index or using a cycling sequence to prefix and sequence values.

Ordering Columns in an Index

Designers should be flexible in defining any rules for index building. Depending on your circumstances, use one of the following two ways to order the keys in an index:

1. Order columns with most selectivity first. This method is the most commonly used, because it provides the fastest access with minimal I/O to the actual rowids required. This technique is used mainly for primary keys and for very selective range scans.
2. Order columns to reduce I/O by clustering or sorting data. In large range scans, I/Os can usually be reduced by ordering the columns in the least selective order, or in a manner that sorts the data in the way it should be retrieved. See Chapter 16, "Using Indexes and Clusters".

Using Views

Views can speed up and simplify application design. A simple view definition can mask data model complexity from the programmers whose priorities are to retrieve, display, collect, and store data.

However, while views provide clean programming interfaces, they can cause sub-optimal, resource-intensive queries. The worst type of view use is when a view references other views, and when they are joined in queries. In many cases, developers can satisfy the query directly from the table without using a view. Usually, because of their inherent properties, views make it difficult for the optimizer to generate the optimal execution plan.

SQL Execution Efficiency

In the design and architecture phase of any system development, care should be taken to ensure that the application developers understand SQL execution efficiency. To do this, the development environment must support the following characteristics:

- Good Database Connection Management

  Connecting to the database is an expensive operation that is highly unscalable. Therefore, the number of concurrent connections to the database should be minimized as much as possible. A simple system, where a user connects at application initialization, is ideal. However, in a Web-based or multitiered application, where application servers are used to multiplex database connections to users, this can be difficult. With these types of applications,

design efforts should ensure that database connections are pooled and are not reestablished for each user request.

- Good Cursor Usage and Management

  Maintaining user connections is equally important to minimizing the parsing activity on the system. Parsing is the process of interpreting a SQL statement and creating an execution plan for it. This process has many phases, including syntax checking, security checking, execution plan generation, and loading shared structures into the shared pool. There are two types of parse operations:

  - Hard Parsing: A SQL statement is submitted for the first time, and no match is found in the shared pool. Hard parses are the most resource-intensive and unscalable, because they perform all the operations involved in a parse.
  - Soft Parsing: A SQL statement is submitted for the first time, and a match *is* found in the shared pool. The match can be the result of previous execution by another user. The SQL statement is shared, which is good for performance. However, soft parses are not ideal, because they still require syntax and security checking, which consume system resources.

  Because parsing should be minimized as much as possible, application developers should design their applications to parse SQL statements once and execute them many times. This is done through cursors. Experienced SQL programmers should be familiar with the concept of opening and re-executing cursors.

  Application developers must also ensure that SQL statements are shared within the shared pool. To do this, bind variables to represent the parts of the query that change from execution to execution. If this is not done, then the SQL statement is likely to be parsed once and never re-used by other users. To ensure that SQL is shared, use bind variables and do not use string literals with SQL statements. For example:

  Statement with string literals:

```
SELECT * FROM employees
  WHERE last_name LIKE 'KING';
```

  Statement with bind variables:

```
SELECT * FROM employees
  WHERE last_name LIKE :1;
```

The following example shows the results of some tests on a simple OLTP application:

```
Test                          #Users Supported
No Parsing all statements             270
Soft Parsing all statements           150
Hard Parsing all statements            60
Re-Connecting for each Transaction     30
```

These tests were performed on a four-CPU machine. The differences increase as the number of CPUs on the system increase. See Chapter 12, "SQL Tuning Overview" for information on optimizing SQL statements.

Implementing the Application

The choice of development environment and programming language is largely a function of the skills available in the development team and architectural decisions made when specifying the application. There are, however, some simple performance management rules that can lead to scalable, high-performance applications.

1. Choose a development environment suitable for software components, and do not let it limit your design for performance decisions. If it does, then you probably chose the wrong language or environment.

   - User Interface

     The programming model can vary between HTML generation and calling the windowing system directly. The development method should focus on response time of the user interface code. If HTML or Java is being sent over a network, then try to minimize network volume and interactions.

   - Business Logic

     Interpreted languages, such as Java and PL/SQL, are ideal to encode business logic. They are fully portable, which makes upgrading logic relatively easy. Both languages are syntactically rich to allow code that is easy to read and interpret. If business logic requires complex mathematical functions, then a compiled binary language might be needed. The business logic code can be on the client machine, the application server, and the database server. However, the application server is the most common location for business logic.

   - User Requests and Resource Allocation

Most of this is not affected by the programming language, but tools and 4th generation languages that mask database connection and cursor management might use inefficient mechanisms. When evaluating these tools and environments, check their database connection model and their use of cursors and bind variables.

- Data Management and Transactions

  Most of this is not affected by the programming language.

2. When implementing a software component, implement its function and not the functionality associated with other components. Implementing another component's functionality results in sub-optimal designs and implementations. This applies to all components.
3. Do not leave gaps in functionality or have software components under-researched in design, implementation, or testing. In many cases, gaps are not discovered until the application is rolled out or tested at realistic volumes. This is usually a sign of poor architecture or initial system specification. Data archival/purge modules are most frequently neglected during initial system design, build, and implementation.
4. When implementing procedural logic, implement in a procedural language, such as C, Java, PL/SQL. When implementing data access (queries) or data changes (DML), use SQL. This rule is specific to the business logic modules of code where procedural code is mixed with data access (non-procedural SQL) code. There is great temptation to put procedural logic into the SQL access. This tends to result in poor SQL that is resource-intensive. SQL statements with `DECODE` case statements are very often candidates for optimization, as are statements with a large amount of `OR` predicates or set operators, such as `UNION` and `MINUS`.
5. Cache frequently accessed, rarely changing data that is expensive to retrieve on a repeated basis. However, make this cache mechanism easy to use, and ensure that it is really cheaper than accessing the data in the original method. This is applicable to all modules where frequently used data values should be cached or stored locally, rather than be repeatedly retrieved from a remote or expensive data store.

   The most common examples of candidates for local caching include the following:

   - Today's date. `SELECT SYSDATE FROM DUAL` can account for over 60% of the workload on a database.
   - The current user name.

- Repeated application variables and constants, such as tax rates, discounting rates, or location information.
- Caching data locally can be further extended into building a local data cache into the application server middle tiers. This helps take load off the central database servers. However, care should be taken when constructing local caches so that they do not become so complex that they cease to give a performance gain.
- Local sequence generation.

The design implications of using a cache should be considered. For example, if a user is connected at midnight and the date is cached, then the date value he has becomes invalid.

6. Optimize the interfaces between components, and ensure that all components are used in the most scalable configuration. This rule requires minimal explanation and applies to all modules and their interfaces.
7. Use foreign key references. Enforcing referential integrity through an application is expensive. You can maintain a foreign key reference by selecting the column value of the child from the parent and ensuring that it exists. The foreign key constraint enforcement supplied by Oracle, which does not use SQL, is fast, easy to declare, and does not create network traffic.
8. Consider setting up action and module names in the application to use with End to End Application Tracing. This allows greater flexibility in tracing workload problems. See "End to End Application Tracing" on page 20-2.

Trends in Application Development

The two biggest challenges in application development today are the increased use of Java to replace compiled C or C++ applications, and increased use of object-oriented techniques, influencing the schema design.

Java provides better portability of code and availability to programmers. However, there are a number of performance implications associated with Java. Because Java is an interpreted language, it is slower at executing similar logic than compiled languages such as C. As a result, resource usage of client machines increases. This requires more powerful CPUs to be applied in the client or middle-tier machines and greater care from programmers to produce efficient code.

Because Java is an object-oriented language, it encourages insulation of data access into classes not performing the business logic. As a result, programmers might invoke methods without knowledge of the efficiency of the data access method

being used. This tends to result in database access that is very minimal and uses the simplest and crudest interfaces to the database.

With this type of software design, queries do not always include all the WHERE predicates to be efficient, and row filtering is performed in the Java program. This is very inefficient. In addition, for DML operations, and especially for INSERTs, single INSERTs are performed, making use of the array interface impossible. In some cases, this is made more inefficient by procedure calls. More resources are used moving the data to and from the database than in the actual database calls.

In general, it is best to place data access calls next to the business logic to achieve the best overall transaction design.

The acceptance of object-orientation at a programming level has led to the creation of object-oriented databases within the Oracle Server. This has manifested itself in many ways, from storing object structures within BLOBs and only using the database effectively as an indexed card file to the use of the Oracle object relational features.

If you adopt an object-oriented approach to schema design, then make sure that you do not lose the flexibility of the relational storage model. In many cases, the object-oriented approach to schema design ends up in a heavily denormalized data structure that requires considerable maintenance and REF pointers associated with objects. Often, these designs represent a step backward to the hierarchical and network database designs that were replaced with the relational storage method.

In summary, if you are storing your data in your database for the long-term and you anticipate a degree of ad hoc queries or application development on the same schema, then you will probably find that the relational storage method gives the best performance and flexibility.

Workload Testing, Modeling, and Implementation

This section describes workload estimation, modeling, implementation, and testing.

Sizing Data

You could experience errors in your sizing estimates when dealing with variable length data if you work with a poor sample set. Also, as data volumes grow, your key lengths could grow considerably, altering your assumptions for column sizes.

When the system becomes operational it becomes harder to predict database growth, especially that of indexes. Tables grow over time, and indexes are subject to the individual behavior of the application in terms of key generation, insertion

pattern, and deletion of rows. The worst case is where you insert using an ascending key and then delete most rows from the left-hand side but not all the rows. This leaves gaps and wasted space. If you have index use like this make sure that you know how to use the online index rebuild facility.

Most good DBAs monitor space allocation for each object and look for objects that could grow out of control. A good understanding of the application can highlight objects that could grow rapidly or unpredictably. This is a crucial part of both performance and availability planning for any system. When implementing the production database, the design should attempt to ensure that minimal space management takes place when interactive users are using the application. This applies for all data, temp, and rollback segments.

Estimating Workloads

Estimation of workloads for capacity planning and testing purposes is often described as a black art. When considering the number of variables involved it is easy to see why this process is largely impossible to get precisely correct. However, designers need to specify machines with CPUs, memory, and disk drives, and eventually roll out an application. There are a number of techniques used for sizing, and each technique has merit. When sizing, it is best to use at least two methods to validate your decision-making process and provide supporting documentation.

Extrapolating From a Similar System

This is an entirely empirical approach where an existing system of similar characteristics and known performance is used as a basis system. The specification of this system is then modified by the sizing specialist according to the known differences. This approach has merit in that it correlates with an existing system, but it provides little assistance when dealing with the differences.

This approach is used in nearly all large engineering disciplines when preparing the cost of an engineering project be it a large building, a ship, a bridge, or an oil rig. If the reference system is an order of magnitude different in size from the anticipated system, then some of the components could have exceeded their design limits.

Benchmarking

The benchmarking process is both resource and time consuming, and it might not get the correct results. By simulating in a benchmark an application in early development or prototype form, there is a danger of measuring something that has no resemblance to the actual production system. This sounds strange, but over the many years of benchmarking customer applications with the database development

organization, we have yet to see good correlation between the benchmark application and the actual production system. This is mainly due to the number of application inefficiencies introduced in the development process.

However, benchmarks have been used successfully to size systems to an acceptable level of accuracy. In particular, benchmarks are very good at determining the actual I/O requirements and testing recovery processes when a system is fully loaded.

Benchmarks by their nature stress all system components to their limits. As all components are being stressed be prepared to see all errors in application design and implementation manifest themselves while benchmarking. Benchmarks also test database, operating system, and hardware components. Because most benchmarks are performed in a rush, expect setbacks and problems when a system component fails. Benchmarking is a stressful activity, and it takes considerable experience to get the most out of a benchmarking exercise.

Application Modeling

Modeling the application can range from complex mathematical modeling exercises to the classic simple calculations performed on the back of an envelope. Both methods have merit, with one attempting to be very precise and the other making gross estimates. The down side of both methods is that they do not allow for implementation errors and inefficiencies.

The estimation and sizing process is an imprecise science. However, by investigating the process, some intelligent estimates can be made. The whole estimation process makes no allowances for application inefficiencies introduced by writing bad SQL, poor index design, or poor cursor management. A good sizing engineer builds in margin for application inefficiencies. A good performance engineer discovers the inefficiencies and makes the estimates look realistic. The process of discovering the application inefficiencies is described in the Oracle performance method.

Testing, Debugging, and Validating a Design

The testing process mainly consists of functional and stability testing. At some point in the process, performance testing is performed.

The following list describes some simple rules for performance testing an application. If correctly documented, this provides important information for the production application and the capacity planning process after the application has gone live.

- Use the Automatic Database Diagnostic Monitor (ADDM) and the SQL Tuning Advisor for design validation.
- Test with realistic data volumes and distributions.

  All testing must be done with fully populated tables. The test database should contain data representative of the production system in terms of data volume and cardinality between tables. All the production indexes should be built and the schema statistics should be populated correctly.
- Use the correct optimizer mode.

  All testing should be performed with the optimizer mode that will be used in production. All Oracle research and development effort is focused upon the query optimizer, and therefore Oracle Corporation recommends the use of the query optimizer.
- Test a single user performance.

  A single user on an idle or lightly used system should be tested for acceptable performance. If a single user cannot get acceptable performance under ideal conditions, it is impossible there will be good performance under multiple users where resources are shared.
- Obtain and document plans for all SQL statements.

  Obtain an execution plan for each SQL statement, and some metrics should be obtained for at least one execution of the statement. This process should be used to validate that a good execution plan is being obtained by the optimizer and the relative cost of the SQL statement is understood in terms of CPU time and physical I/Os. This process assists in identifying the heavy use transactions that will require the most tuning and performance work in the future. See Chapter 18, "Using Plan Stability" for information on plan stability.
- Attempt multiuser testing.

  This process is difficult to perform accurately, because user workload and profiles might not be fully quantified. However, transactions performing DML statements should be tested to ensure that there are no locking conflicts or serialization problems.
- Test with the correct hardware configuration.

  It is important to test with a configuration as close to the production system as possible. This is particularly important with respect to network latencies, I/O sub-system bandwidth and processor type and speed. A failure to do this could result in an incorrect analysis of potential performance problems.

- Measure steady state performance.

  When benchmarking, it is important to measure the performance under steady state conditions. Each benchmark run should have a ramp-up phase, where users are connected to the application and gradually start performing work on the application. This process allows for frequently cached data to be initialized into the cache and single execution operations, such as parsing, to be completed prior to the steady state condition. Likewise, at the end of a benchmark run, there should be a ramp-down period, where resources are freed from the system and users cease work and disconnect.

Deploying New Applications

This section describes the design decisions involved in deploying applications.

Rollout Strategies

When new applications are rolled out, two strategies are commonly adopted:

- Big Bang Approach - All users migrate to the new system at once.
- Trickle Approach - Users slowly migrate from existing systems to the new one.

Both approaches have merits and disadvantages. The Big Bang approach relies on good testing of the application at the required scale, but has the advantage of minimal data conversion and synchronization with the old system, because it is simply switched off. The Trickle approach allows debugging of scalability issues as the workload increases, but might mean that data needs to be migrated to and from legacy systems as the transition takes place.

It is hard to recommend one approach over the other, because each method has associated risks that could lead to system outages as the transition takes place. Certainly, the Trickle approach allows profiling of real users as they are introduced to the new application and allows the system to be reconfigured only affecting the migrated users. This approach affects the work of the early adopters, but limits the load on support services. This means that unscheduled outages only affect a small percentage of the user population.

The decision on how to roll out a new application is specific to each business. The approach adopted will have its own unique pressures and stresses. The more testing and knowledge derived from the testing process, the more you will realize what is best for the rollout.

Performance Checklist

To assist in the rollout process, build a list of tasks that, if performed correctly, increase the chance of good performance in production and, if there is a problem, enable rapid debugging of the application. For example:

1. When you create the control file for the production database, allow for growth by setting MAXINSTANCES, MAXDATAFILES, MAXLOGFILES, MAXLOGMEMBERS, and MAXLOGHISTORY to values higher than what you anticipate for the rollout. This results in more disk space usage and bigger control files, but saves time later should these need extension in an emergency.
2. Set block size to that used to develop the application. Export the schema statistics from the development/test environment to the production database if the testing was done on representative data volumes and the current SQL execution plans are correct.
3. Set the minimal number of initialization parameters. Ideally, most other parameters should be left at default. If there is more tuning to perform, this shows up when the system is under load. See Chapter 4, "Configuring a Database for Performance" for information on parameter settings in an initial instance configuration.
4. Be prepared to manage block contention by setting storage options of database objects. Tables and indexes that experience high INSERT/UPDATE/DELETE rates should be created with automatic segment space management. To avoid contention of rollback segments, automatic undo management should be used. See Chapter 4, "Configuring a Database for Performance" for information on undo and temporary segments.
5. All SQL statements should be verified to be optimal and their resource usage understood.
6. Validate that middleware and programs that connect to the database are efficient in their connection management and do not logon/logoff repeatedly.
7. Validate that the SQL statements use cursors efficiently. Each SQL statement should be parsed once and then executed multiple times. The most common reason this does not happen is because bind variables are not used properly and WHERE clause predicates are sent as string literals. If the precompilers are used to develop the application, then make sure that the parameters MAXOPENCURSORS, HOLD_CURSOR, and RELEASE_CURSOR have been reset from the default values prior to precompiling the application.

8. Validate that all schema objects have been correctly migrated from the development environment to the production database. This includes tables, indexes, sequences, triggers, packages, procedures, functions, java objects, synonyms, grants, and views. Ensure that any modifications made in testing are made to the production system.
9. As soon as the system is rolled out, establish a baseline set of statistics from the database and operating system. This first set of statistics validates or corrects any assumptions made in the design and rollout process.

Start anticipating the first bottleneck (there will always be one) and follow the Oracle performance method to make performance improvement.

3

Performance Improvement Methods

This chapter discusses Oracle improvement methods.

This chapter contains the following sections:

The Oracle Performance Improvement Method

Oracle performance methodology helps you to pinpoint performance problems in your Oracle system. This involves identifying bottlenecks and fixing them. It is recommended that changes be made to a system only after you have confirmed that there is a bottleneck.

Performance improvement, by its nature, is iterative. For this reason, removing the first bottleneck might not lead to performance improvement immediately, because another bottleneck might be revealed. Also, in some cases, if serialization points move to a more inefficient sharing mechanism, then performance could degrade. With experience, and by following a rigorous method of bottleneck elimination, applications can be debugged and made scalable.

Performance problems generally result from either a lack of throughput, unacceptable user/job response time, or both. The problem might be localized between application modules, or it might be for the entire system.

Before looking at any database or operating system statistics, it is crucial to get feedback from the most important components of the system: the users of the system and the people ultimately paying for the application. Typical user feedback includes statements like the following:

- "The online performance is so bad that it prevents my staff from doing their jobs."
- "The billing run takes too long."
- "When I experience high amounts of Web traffic, the response time becomes unacceptable, and I am losing customers."
- "I am currently performing 5000 trades a day, and the system is maxed out. Next month, we roll out to all our users, and the number of trades is expected to quadruple."

From candid feedback, it is easy to set critical success factors for any performance work. Determining the performance targets and the performance engineer's exit criteria make managing the performance process much simpler and more successful at all levels. These critical success factors are better defined in terms of real business goals rather than system statistics.

Some real business goals for these typical user statements might be:

- "The billing run must process 1,000,000 accounts in a three-hour window."
- "At a peak period on a Web site, the response time will not exceed five seconds for a page refresh."

- "The system must be able to process 25,000 trades in an eight-hour window."

The ultimate measure of success is the user's perception of system performance. The performance engineer's role is to eliminate any bottlenecks that degrade performance. These bottlenecks could be caused by inefficient use of limited shared resources or by abuse of shared resources, causing serialization. Because all shared resources are limited, the goal of a performance engineer is to maximize the number of business operations with efficient use of shared resources. At a very high level, the entire database server can be seen as a shared resource. Conversely, at a low level, a single CPU or disk can be seen as shared resources.

The Oracle performance improvement method can be applied until performance goals are met or deemed impossible. This process is highly iterative, and it is inevitable that some investigations will be made that have little impact on the performance of the system. It takes time and experience to develop the necessary skills to accurately pinpoint critical bottlenecks in a timely manner. However, prior experience can sometimes work against the experienced engineer who neglects to use the data and statistics available to him. It is this type of behavior that encourages database tuning by myth and folklore. This is a very risky, expensive, and unlikely to succeed method of database tuning.

The Automatic Database Diagnostic Monitor (ADDM) implements parts of the performance improvement method and analyzes statistics to provide automatic diagnosis of major performance issues. Using ADDM can significantly shorten the time required to improve the performance of a system. See Chapter 6, "Automatic Performance Diagnostics" for a description of ADDM.

Today's systems are so different and complex that hard and fast rules for performance analysis cannot be made. In essence, the Oracle performance improvement method defines a way of working, but not a definitive set of rules. With bottleneck detection, the only rule is that there are no rules! The best performance engineers use the data provided and think laterally to determine performance problems.

Steps in The Oracle Performance Improvement Method

1. Perform the following initial standard checks:

   a. Get candid feedback from users. Determine the performance project's scope and subsequent performance goals, as well as performance goals for the future. This process is key in future capacity planning.

   b. Get a full set of operating system, database, and application statistics from the system when the performance is both good and bad. If these are not

available, then get whatever is available. Missing statistics are analogous to missing evidence at a crime scene: They make detectives work harder and it is more time-consuming.

c. Sanity-check the operating systems of all machines involved with user performance. By sanity-checking the operating system, you look for hardware or operating system resources that are fully utilized. List any over-used resources as symptoms for analysis later. In addition, check that all hardware shows no errors or diagnostics.

2. Check for the top ten most common mistakes with Oracle, and determine if any of these are likely to be the problem. List these as symptoms for later analysis. These are included because they represent the most likely problems. ADDM automatically detects and reports nine of these top ten issues. See Chapter 6, "Automatic Performance Diagnostics" and "Top Ten Mistakes Found in Oracle Systems" on page 3-6.

3. Build a conceptual model of what is happening on the system using the symptoms as clues to understand what caused the performance problems. See "A Sample Decision Process for Performance Conceptual Modeling" on page 3-5.

4. Propose a series of remedy actions and the anticipated behavior to the system, then apply them in the order that can benefit the application the most. ADDM produces recommendations each with an expected benefit. A golden rule in performance work is that you only change one thing at a time and then measure the differences. Unfortunately, system downtime requirements might prohibit such a rigorous investigation method. If multiple changes are applied at the same time, then try to ensure that they are isolated so that the effects of each change can be independently validated.

5. Validate that the changes made have had the desired effect, and see if the user's perception of performance has improved. Otherwise, look for more bottlenecks, and continue refining the conceptual model until your understanding of the application becomes more accurate.

6. Repeat the last three steps until performance goals are met or become impossible due to other constraints.

This method identifies the biggest bottleneck and uses an objective approach to performance improvement. The focus is on making large performance improvements by increasing application efficiency and eliminating resource shortages and bottlenecks. In this process, it is anticipated that minimal (less than 10%) performance gains are made from instance tuning, and large gains (100% +) are made from isolating application inefficiencies.

A Sample Decision Process for Performance Conceptual Modeling

Conceptual modeling is almost deterministic. However, as your performance tuning experience increases, you will appreciate that there are no real rules to follow. A flexible heads-up approach is required to interpret the various statistics and make good decisions.

For a quick and easy approach to performance tuning, use the Automatic Database Diagnostic Monitor (ADDM). ADDM automatically monitors your Oracle system and provides recommendations for solving performance problems should problems occur. For example, suppose a DBA receives a call from a user complaining that the system is slow. The DBA simply examines the latest ADDM report to see which of the recommendations should be implemented to solve the problem. See Chapter 6, "Automatic Performance Diagnostics" for information on the features that help monitor and diagnose Oracle systems.

The following steps illustrate how a performance engineer might look for bottlenecks without using automatic diagnostic features. These steps are only intended as a guideline for the manual process. With experience, performance engineers add to the steps involved. This analysis assumes that statistics for both the operating system and the database have been gathered.

1. Is the response time / batch run time acceptable for a single user on an empty or lightly loaded machine?

   If it is not acceptable, then the application is probably not coded or designed optimally, and it will never be acceptable in a multiple user situation when system resources are shared. In this case, get application internal statistics, and get SQL Trace and SQL plan information. Work with developers to investigate problems in data, index, transaction SQL design, and potential deferral of work to batch / background processing.

2. Is all the CPU being utilized?

   If the kernel utilization is over 40%, then investigate the operating system for network transfers, paging, swapping, or process thrashing. Otherwise, move onto CPU utilization in user space. Check to see if there are any non-database jobs consuming CPU on the machine limiting the amount of shared CPU resources, such as backups, file transforms, print queues, and so on. After determining that the database is using most of the CPU, investigate the top SQL by CPU utilization. These statements form the basis of all future analysis. Check the SQL and the transactions submitting the SQL for optimal execution. Oracle provides CPU statistics in V$SQL.

> **See Also:** *Oracle Database Reference* for more information on V$SQL

If the application is optimal and there are no inefficiencies in the SQL execution, consider rescheduling some work to off-peak hours or using a bigger machine.

3. At this point, the system performance is unsatisfactory, yet the CPU resources are not fully utilized.

   In this case, you have serialization and unscalable behavior within the server. Get the `WAIT_EVENTS` statistics from the server, and determine the biggest serialization point. If there are no serialization points, then the problem is most likely outside the database, and this should be the focus of investigation. Elimination of `WAIT_EVENTS` involves modifying application SQL and tuning database parameters. This process is very iterative and requires the ability to drill down on the `WAIT_EVENTS` systematically to eliminate serialization points.

Top Ten Mistakes Found in Oracle Systems

This section lists the most common mistakes found in Oracle systems. By following the Oracle performance improvement methodology, you should be able to avoid these mistakes altogether. If you find these mistakes in your system, then re-engineer the application where the performance effort is worthwhile. See "Automatic Performance Tuning Features" on page 1-7 for information on the features that help diagnose and tune Oracle systems. See Chapter 10, "Instance Tuning Using Performance Views" for a discussion on how wait event data reveals symptoms of problems that can be impacting performance.

1. Bad Connection Management

   The application connects and disconnects for each database interaction. This problem is common with stateless middleware in application servers. It has over two orders of magnitude impact on performance, and is totally unscalable.

2. Bad Use of Cursors and the Shared Pool

   Not using cursors results in repeated parses. If bind variables are not used, then there is hard parsing of all SQL statements. This has an order of magnitude impact in performance, and it is totally unscalable. Use cursors with bind variables that open the cursor and execute it many times. Be suspicious of applications generating dynamic SQL.

3. Bad SQL

Bad SQL is SQL that uses more resources than appropriate for the application requirement. This can be a decision support systems (DSS) query that runs for more than 24 hours or a query from an online application that takes more than a minute. SQL that consumes significant system resources should be investigated for potential improvement. ADDM identifies high load SQL and the SQL tuning advisor can be used to provide recommendations for improvement. See Chapter 6, "Automatic Performance Diagnostics" and Chapter 13, "Automatic SQL Tuning".

4. Use of Nonstandard Initialization Parameters

   These might have been implemented based on poor advice or incorrect assumptions. Most systems will give acceptable performance using only the set of basic parameters. In particular, parameters associated with `SPIN_COUNT` on latches and undocumented optimizer features can cause a great deal of problems that can require considerable investigation.

   Likewise, optimizer parameters set in the initialization parameter file can override proven optimal execution plans. For these reasons, schemas, schema statistics, and optimizer settings should be managed together as a group to ensure consistency of performance.

   See Also:

   - *Oracle Database Administrator's Guide* for information on initialization parameters and database creation
   - *Oracle Database Reference* for details on initialization parameters
   - "Performance Considerations for Initial Instance Configuration" on page 4-2 for information on parameters and settings in an initial instance configuration

5. Getting Database I/O Wrong

   Many sites lay out their databases poorly over the available disks. Other sites specify the number of disks incorrectly, because they configure disks by disk space and not I/O bandwidth. See Chapter 8, "I/O Configuration and Design".

6. Redo Log Setup Problems

   Many sites run with too few redo logs that are too small. Small redo logs cause system checkpoints to continuously put a high load on the buffer cache and I/O system. If there are too few redo logs, then the archive cannot keep up, and the database will wait for the archive process to catch up. See Chapter 4,

"Configuring a Database for Performance" for information on sizing redo logs for performance.

7. Serialization of data blocks in the buffer cache due to lack of free lists, free list groups, transaction slots (`INITRANS`), or shortage of rollback segments.

   This is particularly common on `INSERT`-heavy applications, in applications that have raised the block size above 8K, or in applications with large numbers of active users and few rollback segments. Use automatic segment-space management (ASSM) to and automatic undo management solve this problem.

8. Long Full Table Scans

   Long full table scans for high-volume or interactive online operations could indicate poor transaction design, missing indexes, or poor SQL optimization. Long table scans, by nature, are I/O intensive and unscalable.

9. High Amounts of Recursive (`SYS`) SQL

   Large amounts of recursive SQL executed by `SYS` could indicate space management activities, such as extent allocations, taking place. This is unscalable and impacts user response time. Use locally managed tablespaces to reduce recursive SQL due to extent allocation. Recursive SQL executed under another user Id is probably SQL and PL/SQL, and this is not a problem.

10. Deployment and Migration Errors

    In many cases, an application uses too many resources because the schema owning the tables has not been successfully migrated from the development environment or from an older implementation. Examples of this are missing indexes or incorrect statistics. These errors can lead to sub-optimal execution plans and poor interactive user performance. When migrating applications of known performance, export the schema statistics to maintain plan stability using the `DBMS_STATS` package.

    Although these errors are not directly detected by ADDM, ADDM highlights the resulting high load SQL.

Emergency Performance Methods

This section provides techniques for dealing with performance emergencies. You have already had the opportunity to read about a detailed methodology for establishing and improving application performance. However, in an emergency situation, a component of the system has changed to transform it from a reliable, predictable system to one that is unpredictable and not satisfying user requests.

In this case, the role of the performance engineer is to rapidly determine what has changed and take appropriate actions to resume normal service as quickly as possible. In many cases, it is necessary to take immediate action, and a rigorous performance improvement project is unrealistic.

After addressing the immediate performance problem, the performance engineer must collect sufficient debugging information either to get better clarity on the performance problem or to at least ensure that it does not happen again.

The method for debugging emergency performance problems is the same as the method described in the performance improvement method earlier in this book. However, shortcuts are taken in various stages because of the timely nature of the problem. Keeping detailed notes and records of facts found as the debugging process progresses is essential for later analysis and justification of any remedial actions. This is analogous to a doctor keeping good patient notes for future reference.

Steps in the Emergency Performance Method

The Emergency Performance Method is as follows:

1. Survey the performance problem and collect the symptoms of the performance problem. This process should include the following:
   - User feedback on how the system is underperforming. Is the problem throughput or response time?
   - Ask the question, "What has changed since we last had good performance?" This answer can give clues to the problem. However, getting unbiased answers in an escalated situation can be difficult. Try to locate some reference points, such as collected statistics or log files, that were taken before and after the problem.
   - Use automatic tuning features to diagnose and monitor the problem. See "Automatic Performance Tuning Features" on page 1-7 for information on the features that help diagnose and tune Oracle systems. In addition, you can use Oracle Enterprise Manager performance features to identify top SQL and sessions.
2. Sanity-check the hardware utilization of all components of the application system. Check where the highest CPU utilization is, and check the disk, memory usage, and network performance on all the system components. This quick process identifies which tier is causing the problem. If the problem is in the application, then shift analysis to application debugging. Otherwise, move on to database server analysis.

3. Determine if the database server is constrained on CPU or if it is spending time waiting on wait events. If the database server is CPU-constrained, then investigate the following:

   - Sessions that are consuming large amounts of CPU at the operating system level and database; check V$SESS_TIME_MODEL for database CPU usage
   - Sessions or statements that perform many buffer gets at the database level; check V$SESSTAT and V$SQL
   - Execution plan changes causing sub-optimal SQL execution; these can be difficult to locate
   - Incorrect setting of initialization parameters
   - Algorithmic issues as a result of code changes or upgrades of all components

   If the database sessions are waiting on events, then follow the wait events listed in V$SESSION_WAIT to determine what is causing serialization. The V$ACTIVE_SESSION_HISTORY view contains a sampled history of session activity which can be used to perform diagnosis even after an incident has ended and the system has returned to normal operation. In cases of massive contention for the library cache, it might not be possible to logon or submit SQL to the database. In this case, use historical data to determine why there is suddenly contention on this latch. If most waits are for I/O, then examine V$ACTIVE_SESSION_HISTORY to determine the SQL being run by the sessions that are performing all of the inputs and outputs. See Chapter 10, "Instance Tuning Using Performance Views" for a discussion on wait events.

4. Apply emergency action to stabilize the system. This could involve actions that take parts of the application off-line or restrict the workload that can be applied to the system. It could also involve a system restart or the termination of job in process. These naturally have service level implications.

5. Validate that the system is stable. Having made changes and restrictions to the system, validate that the system is now stable, and collect a reference set of statistics for the database. Now follow the rigorous performance method described earlier in this book to bring back all functionality and users to the system. This process may require significant application re-engineering before it is complete.

Part III

Optimizing Instance Performance

Part III describes how to tune various elements of your database system to optimize performance of an Oracle instance.

The chapters in this part are:

- Chapter 4, "Configuring a Database for Performance"
- Chapter 5, "Automatic Performance Statistics"
- Chapter 6, "Automatic Performance Diagnostics"
- Chapter 7, "Memory Configuration and Use"
- Chapter 8, "I/O Configuration and Design"
- Chapter 9, "Understanding Operating System Resources"
- Chapter 10, "Instance Tuning Using Performance Views"
- Chapter 11, "Tuning Networks"

4

Configuring a Database for Performance

This chapter is an overview of the Oracle methodology for configuring a database for performance. Although performance modifications can be made to the Oracle database instance at a later time, much can be gained by proper initial configuration of the database for the intended needs.

This chapter contains the following sections:

Performance Considerations for Initial Instance Configuration

This section discusses some initial database instance configuration options that have important performance impacts.

If you use the Database Configuration Assistant (DBCA) to create a database, the the supplied seed database includes the necessary basic initialization parameters and meets the performance recommendations that are discussed in this chapter.

See Also:

- *Oracle 2 Day DBA* for information creating a database with the Database Configuration Assistant
- *Oracle Database Administrator's Guide* for information about the process of creating a database

Initialization Parameters

A running Oracle instance is configured using initialization parameters, which are set in the initialization parameter file. These parameters influence the behavior of the running instance, including influencing performance. In general, a very simple initialization file with few relevant settings covers most situations, and the initialization file should not be the first place you expect to do performance tuning, except for the few parameters shown in Table 4–2.

Table 4–1 describes the parameters necessary in a minimal initialization file. Although these parameters are necessary they have no performance impact.

Table 4–1 Necessary Initialization Parameters Without Performance Impact

Parameter	Description
`DB_NAME`	Name of the database. This should match the `ORACLE_SID` environment variable.
`DB_DOMAIN`	Location of the database in Internet dot notation.
`OPEN_CURSORS`	Limit on the maximum number of cursors (active SQL statements) for each session. The setting is application-dependent; 500 is recommended.
`CONTROL_FILES`	Set to contain at least two files on different disk drives to prevent failures from control file loss.
`DB_FILES`	Set to the maximum number of files that can assigned to the database.

See Also: *Oracle Database Administrator's Guide* for information about managing the initialization parameters

Table 4–2 includes the most important parameters to set with performance implications:

Table 4–2 Important Initialization Parameters With Performance Impact

Parameter	Description
COMPATIBLE	Specifies the release with which the Oracle server must maintain compatibility. It lets you take advantage of the maintenance improvements of a new release immediately in your production systems without testing the new functionality in your environment. If your application was designed for a specific release of Oracle, and you are actually installing a later release, then you might want to set this parameter to the version of the previous release.
DB_BLOCK_SIZE	Sets the size of the Oracle database blocks stored in the database files and cached in the SGA. The range of values depends on the operating system, but it is typically powers of two in the range 2048 to 16384. Common values are 4096 or 8192 for transaction processing systems and higher values for database warehouse systems.
SGA_TARGET	Specifies the total size of all SGA components. If SGA_TARGET is specified, then the buffer cache (DB_CACHE_SIZE), Java pool (JAVA_POOL_SIZE), large pool (LARGE_POOL_SIZE), and shared pool (SHARED_POOL_SIZE) memory pools are automatically sized. See "Automatic Shared Memory Management" on page 7-3.
PGA_AGGREGATE_TARGET	Specifies the target aggregate PGA memory available to all server processes attached to the instance. See "PGA Memory Management" on page 7-50 for information on PGA memory management.
PROCESSES	Sets the maximum number of processes that can be started by that instance. This is the most important primary parameter to set, because many other parameter values are deduced from this.
SESSIONS	This is set by default from the value of processes. However, if you are using the shared server, then the deduced value is likely to be insufficient.
UNDO_MANAGEMENT	Specifies which undo space management mode the system should use. AUTO mode is recommended.

Table 4–2 (Cont.) Important Initialization Parameters With Performance Impact

Parameter	Description
UNDO_TABLESPACE	Specifies the undo tablespace to be used when an instance starts up.

See Also:

- Chapter 7, "Memory Configuration and Use"
- *Oracle Database Reference* for information on initialization parameters
- *Oracle Streams Concepts and Administration* for information about the STREAMS_POOL_SIZE initialization parameter

Configuring Undo Space

Oracle needs undo space to keep information for read consistency, for recovery, and for actual rollback statements. This information is kept in one or more undo tablespaces.

Oracle provides automatic undo management, which completely automates the management of undo data. A database running in automatic undo management mode transparently creates and manages undo segments. Oracle Corporation strongly recommends using automatic undo management, because it significantly simplifies database management and removes the need for any manual tuning of undo (rollback) segments. Manual undo management using rollback segments is supported for backward compatibility reasons.

Adding the UNDO TABLESPACE clause in the CREATE DATABASE statement sets up the undo tablespace. Set the UNDO_MANAGEMENT initialization parameter to AUTO to operate your database in automatic undo management mode.

The V$UNDOSTAT view contains statistics for monitoring and tuning undo space. Using this view, you can better estimate the amount of undo space required for the current workload. Oracle also uses this information to help tune undo usage in the system. The V$ROLLSTAT view contains information about the behavior of the undo segments in the undo tablespace.

See Also:

- *Oracle 2 Day DBA* and Oracle Enterprise Manager online help for information about the Undo Management Advisor
- *Oracle Database Administrator's Guide* for information on managing undo space using automatic undo management
- *Oracle Database Reference* for information about the dynamic performance V$ROLLSTAT and V$UNDOSTAT views

Sizing Redo Log Files

The size of the redo log files can influence performance, because the behavior of the database writer and archiver processes depend on the redo log sizes. Generally, larger redo log files provide better performance. Undersized log files increase checkpoint activity and reduce performance.

Although the size of the redo log files does not affect LGWR performance, it can affect DBWR and checkpoint behavior. Checkpoint frequency is affected by several factors, including log file size and the setting of the FAST_START_MTTR_TARGET initialization parameter. If the FAST_START_MTTR_TARGET parameter is set to limit the instance recovery time, Oracle automatically tries to checkpoint as frequently as necessary. Under this condition, the size of the log files should be large enough to avoid additional checkpointing due to under sized log files. The optimal size can be obtained by querying the OPTIMAL_LOGFILE_SIZE column from the V$INSTANCE_RECOVERY view. You can also obtain sizing advice on the **Redo Log Groups** page of Oracle Enterprise Manager Database Control.

It may not always be possible to provide a specific size recommendation for redo log files, but redo log files in the range of a hundred megabytes to a few gigabytes are considered reasonable. Size your online redo log files according to the amount of redo your system generates. A rough guide is to switch logs at most once every twenty minutes.

See Also: *Oracle Database Administrator's Guide* for information on managing the redo log

Creating Subsequent Tablespaces

If you use the Database Configuration Assistant (DBCA) to create a database, the the supplied seed database automatically includes all the necessary tablespaces. If you choose not to use DBCA, you need to create extra tablespaces after creating the initial database.

All databases should have several tablespaces in addition to the SYSTEM and SYSAUX tablespaces. These additional tablespaces include:

- A temporary tablespace, which is used for things like sorting
- An undo tablespace to contain information for read consistency, recovery, and rollback statements
- At least one tablespace for actual application use

In most cases, applications require several tablespaces. For extremely large tablespaces with many datafiles, multiple `ALTER TABLESPACE` *x* `ADD DATAFILE` *Y* statements can also be run in parallel.

During tablespace creation, the datafiles that make up the tablespace are initialized with special empty block images. Temporary files are not initialized.

Oracle does this to ensure that all datafiles can be written in their entirety, but this can obviously be a lengthy process if done serially. Therefore, run multiple `CREATE TABLESPACE` statements concurrently to speed up the tablespace creation process. For permanent tables, the choice between local and global extent management on tablespace creation can have a large effect on performance. For any permanent tablespace that has moderate to large insert, modify, or delete operations compared to reads, local extent management should be chosen.

Creating Permanent Tablespaces - Automatic Segment-Space Management

For permanent tablespaces, Oracle recommends using automatic segment-space management. Such tablespaces, often referred to as bitmap tablespaces, are locally managed tablespaces with bitmap segment space management.

See Also:

- *Oracle Database Concepts* for a discussion of free space management
- *Oracle Database Administrator's Guide* for more information on creating and using automatic segment-space management for tablespaces

Creating Temporary Tablespaces

Properly configuring the temporary tablespace helps optimize disk sort performance. Temporary tablespaces can be dictionary-managed or locally managed. Oracle Corporation recommends the use of locally managed temporary tablespaces with a `UNIFORM` extent size of 1 `MB`.

You should monitor temporary tablespace activity to check how many extents are being allocated for the temporary segment. If an application extensively uses temporary tables, as in a situation when many users are concurrently using temporary tables, the extent size could be set smaller, such as 256K, because every usage requires at least one extent. The `EXTENT MANAGEMENT LOCAL` clause is optional for temporary tablespaces because all temporary tablespaces are created with locally managed extents of a uniform size. The default for `SIZE` is `1M`.

See Also:

- *Oracle Database Administrator's Guide* for more information on managing temporary tablespaces
- *Oracle Database Concepts* for more information on temporary tablespaces
- *Oracle Database SQL Reference* for more information on using the `CREATE` and `ALTER TABLESPACE` statements with the `TEMPORARY` clause

Creating and Maintaining Tables for Good Performance

When installing applications, an initial step is to create all necessary tables and indexes. When you create a segment, such as a table, Oracle allocates space in the database for the data. If subsequent database operations cause the data volume to increase and exceed the space allocated, then Oracle extends the segment.

When creating tables and indexes, note the following:

- Specify automatic segment-space management for tablespaces

  This allows Oracle to automatically manage segment space for best performance.

- Set storage options carefully

  Applications should carefully set storage options for the intended use of the table or index. This includes setting the value for `PCTFREE`. Note that using automatic segment-space management eliminates the need to specify `PCTUSED`.

Note: Use of free lists is no longer encouraged. To use automatic segment-space management, create locally managed tablespaces, with the segment space management clause set to `AUTO`.

Table Compression

Heap-organized tables can be stored in a compressed format that is transparent for any kind of application. Table compression was designed primarily for read-only environments and can cause processing overhead for DML operations in some cases. However, it increases performance for many read operations, especially when your system is I/O bound.

Compressed data in a database block is self-contained which means that all the information needed to re-create the uncompressed data in a block is available within that block. A block will also be kept compressed in the buffer cache. Table compression not only reduces the disk storage but also the memory usage, specifically the buffer cache requirements. Performance improvements are accomplished by reducing the amount of necessary I/O operations for accessing a table and by increasing the probability of buffer cache hits.

Estimating the Compression factor

Table compression works by eliminating column value repetitions within individual blocks. Duplicate values in all the rows and columns in a block are stored once at the beginning of the block, in what is called a symbol table for that block. All occurrences of such values are replaced with a short reference to the symbol table. The compression is higher in blocks that have more repeated values.

Before compressing large tables you should estimate the expected compression factor. The compression factor is defined as the number of blocks necessary to store the information in an uncompressed form divided by the number of blocks necessary for a compressed storage. The compression factor can be estimated by sampling a small number of representative data blocks of the table to be compressed and comparing the average number of records for each block for the uncompressed and compressed case. Experience shows that approximately 1000 data blocks provides a very accurate estimation of the compression factor. Note that the more blocks you are sampling, the more accurate the result become.

> **See Also:** *Oracle Database SQL Reference* for block group sampling syntax `SAMPLE BLOCK(x,y)`

Tuning to Achieve a Better Compression Ratio

Oracle achieves a good compression factor in many cases with no special tuning. As a database administrator or application developer, you can try to tune the compression factor by reorganizing the records when the compression actually takes place. Tuning can improve the compression factor slightly in some cases and very substantially in other cases.

To improve the compression factor you have to increase the likelihood of value repetitions within a database block. The compression factor that can be achieved depends on the cardinality of a specific column or column pairs (representing the likelihood of column value repetitions) and on the average row length of those columns. Oracle table compression not only compresses duplicate values of a single column but tries to use multi-column value pairs whenever possible. Without a very detailed understanding of the data distribution it is very difficult to predict the most optimal order.

> **See Also:** *Oracle Data Warehousing Guide* for information on table compression and partitions

Reclaiming Unused Space

Over time, it is common for segment space to become fragmented or for a segment to acquire a lot of free space as the result of update and delete operations. The resulting sparsely populated objects can suffer performance degradation during queries and DML operations.

Oracle Database provides a Segment Advisor that provides advice on whether an object has space available for reclamation based on the level of space fragmentation within an object.

> **See Also:** *Oracle Database Administrator's Guide* and *Oracle 2 Day DBA* for information about the Segment Advisor

If an object does have space available for reclamation, you can compact and shrink database segments or you can deallocate unused space at the end of a database segment.

> **See Also:**
>
> - *Oracle Database Administrator's Guide* for a discussion of reclaiming unused space
> - *Oracle Database SQL Reference* for details about the SQL statements used to shrink database segments or deallocate unused space

Indexing Data

The most efficient way to create indexes is to create them after data has been loaded. By doing this, space management becomes much simpler, and no index

maintenance takes place for each row inserted. SQL*Loader automatically does this, but if you are using other methods to do initial data load, you might need to do this manually. Additionally, index creation can be done in parallel using the PARALLEL clause of the CREATE INDEX statement. However, SQL*Loader is not able to do this, so you must manually create indexes in parallel after loading data.

See Also: *Oracle Database Utilities* for information on SQL*Loader

Specifying Memory for Sorting Data

During index creation on tables that contain data, the data must be sorted. This sorting is done in the fastest possible way, if all available memory is used for sorting. Oracle recommends that you enable automatic sizing of SQL working areas by setting the PGA_AGGREGATE_TARGET initialization parameter.

See Also:

- "PGA Memory Management" on page 7-50 for information on PGA memory management
- *Oracle Database Reference* for information on the PGA_AGGREGATE_TARGET initialization parameter

Performance Considerations for Shared Servers

Using shared servers reduces the number of processes and the amount of memory consumed on the server machine. Shared servers are beneficial for systems where there are many OLTP users performing intermittent transactions.

Using shared servers rather than dedicated servers is also generally better for systems that have a high connection rate to the database. With shared servers, when a connect request is received, a dispatcher is already available to handle concurrent connection requests. With dedicated servers, on the other hand, a connection-specific dedicated server is sequentially initialized for each connection request.

Performance of certain database features can improve when a shared server architecture is used, and performance of certain database features can degrade slightly when a shared server architecture is used. For example, a session can be prevented from migrating to another shared server while parallel execution is active.

A session can remain nonmigratable even after a request from the client has been processed, because not all the user information has been stored in the UGA. If a

server were to process the request from the client, then the part of the user state that was not stored in the UGA would be inaccessible. To avoid this, individual shared servers often need to remain bound to a user session.

See Also:

- *Oracle Database Administrator's Guide* for information on managing shared servers
- *Oracle Net Services Administrator's Guide* for information on configuring dispatchers for shared servers

When using some features, you may need to configure more shared servers, because some servers might be bound to sessions for an excessive amount of time.

This section discusses how to reduce contention for processes used by Oracle architecture:

- Identifying Contention Using the Dispatcher-Specific Views
- Identifying Contention for Shared Servers

Identifying Contention Using the Dispatcher-Specific Views

The following views provide dispatcher performance statistics:

- V$DISPATCHER - general information about dispatcher processes
- V$DISPATCHER_RATE - dispatcher processing statistics

The V$DISPATCHER_RATE view contains current, average, and maximum dispatcher statistics for several categories. Statistics with the prefix CUR_ are statistics for the current sample. Statistics with the prefix AVG_ are the average values for the statistics since the collection period began. Statistics with the prefix MAX_ are the maximum values for these categories since statistics collection began.

To assess dispatcher performance, query the V$DISPATCHER_RATE view and compare the current values with the maximums. If your present system throughput provides adequate response time and current values from this view are near the average and less than the maximum, then you likely have an optimally tuned shared server environment.

If the current and average rates are significantly less than the maximums, then consider reducing the number of dispatchers. Conversely, if current and average rates are close to the maximums, then you might need to add more dispatchers. A general rule is to examine V$DISPATCHER_RATE statistics during both light and

heavy system use periods. After identifying your shared server load patterns, adjust your parameters accordingly.

If needed, you can also mimic processing loads by running system stress tests and periodically polling the V$DISPATCHER_RATE statistics. Proper interpretation of these statistics varies from platform to platform. Different types of applications also can cause significant variations on the statistical values recorded in V$DISPATCHER_RATE.

See Also:

- *Oracle Database Reference* for detailed information about the V$DISPATCHER and V$DISPATCHER_RATE views
- *Oracle Enterprise Manager Concepts* for information about Oracle Tuning Pack applications that monitor statistics

Reducing Contention for Dispatcher Processes

To reduce contention, consider the following:

- Adding dispatcher processes

  The total number of dispatcher processes is limited by the value of the initialization parameter MAX_DISPATCHERS. You might need to increase this value before adding dispatcher processes.

- Enabling connection pooling

  When system load increases and dispatcher throughput is maximized, it is not necessarily a good idea to immediately add more dispatchers. Instead, consider configuring the dispatcher to support more users with connection pooling.

- Enabling Session Multiplexing

  Multiplexing is used by a connection manager process to establish and maintain network sessions from multiple users to individual dispatchers. For example, several user processes can connect to one dispatcher by way of a single connection from a connection manager process. Session multiplexing is beneficial because it maximizes use of the dispatcher process connections. Multiplexing is also useful for multiplexing database link sessions between dispatchers.

See Also:

- *Oracle Database Administrator's Guide* for information on configuring dispatcher processes
- *Oracle Net Services Administrator's Guide* for information on configuring connection pooling
- *Oracle Database Reference* for information about the DISPATCHERS and MAX_DISPATCHERS parameters

Identifying Contention for Shared Servers

This section discusses how to identify contention for shared servers.

Steadily increasing wait times in the requests queue indicate contention for shared servers. To examine wait time data, use the dynamic performance view V$QUEUE. This view contains statistics showing request queue activity for shared servers. By default, this view is available only to the user SYS and to other users with SELECT ANY TABLE system privilege, such as SYSTEM. Table 4–3 lists the columns showing the wait times for requests and the number of requests in the queue.

Table 4–3 Wait Time and Request Columns in V$QUEUE

Column	Description
WAIT	Displays the total waiting time, in hundredths of a second, for all requests that have ever been in the queue
TOTALQ	Displays the total number of requests that have ever been in the queue

Monitor these statistics occasionally while your application is running by issuing the following SQL statement:

```
SELECT DECODE(TOTALQ, 0, 'No Requests',
   WAIT/TOTALQ || ' HUNDREDTHS OF SECONDS') "AVERAGE WAIT TIME PER REQUESTS"
  FROM V$QUEUE
 WHERE TYPE = 'COMMON';
```

This query returns the results of a calculation that show the following:

```
AVERAGE WAIT TIME PER REQUEST
----------------------------
.090909 HUNDREDTHS OF SECONDS
```

From the result, you can tell that a request waits an average of 0.09 hundredths of a second in the queue before processing.

You can also determine how many shared servers are currently running by issuing the following query:

```
SELECT COUNT(*) "Shared Server Processes"
  FROM V$SHARED_SERVER
 WHERE STATUS != 'QUIT';
```

The result of this query could look like the following:

```
Shared Server Processes
----------------------
10
```

If you detect resource contention with shared servers, then first make sure that this is not a memory contention issue by examining the shared pool and the large pool. If performance remains poor, then you might want to create more resources to reduce shared server process contention. You can do this by modifying the optional server process initialization parameters:

- MAX_DISPATCHERS
- MAX_SHARED_SERVERS
- DISPATCHERS
- SHARED_SERVERS

> **See Also:** *Oracle Database Administrator's Guide* for information on setting the shared server process initialization parameters

5

Automatic Performance Statistics

This chapter discusses the gathering of performance statistics. This chapter contains the following topics:

- Overview of Data Gathering
- Automatic Workload Repository

> **See Also:** *Oracle 2 Day DBA* for information on monitoring and tuning the database

Overview of Data Gathering

To effectively diagnose performance problems, statistics must be available. Oracle generates many types of cumulative statistics for the system, sessions, and individual SQL statements. Oracle also tracks cumulative statistics on segments and services. When analyzing a performance problem in any of these scopes, you typically look at the change in statistics (delta value) over the period of time you are interested in. Specifically, you look at the difference between the cumulative value of a statistic at the start of the period and the cumulative value at the end.

Cumulative values for statistics are generally available through dynamic performance views, such as the V$SESSTAT and V$SYSSTAT views. Note that the cumulative values in dynamic views are reset when the database instance is shutdown. The Automatic Workload Repository (AWR) automatically persists the cumulative and delta values for most of the statistics at all levels except the session level. This process is repeated on a regular time period and the result is called an AWR snapshot. The delta values captured by the snapshot represent the changes for each statistic over the time period. See "Automatic Workload Repository" on page 5-10.

Another type of statistic collected by Oracle is called a metric. A metric is defined as the rate of change in some cumulative statistic. That rate can be measured against a variety of units, including time, transactions, or database calls. For example, the number database calls per second is a metric. Metric values are exposed in some V$ views, where the values are the average over a fairly small time interval, typically 60 seconds. A history of recent metric values is available through V$ views, and some of the data is also persisted by AWR snapshots.

A third type of statistical data collected by Oracle is sampled data. This sampling is performed by the active session history (ASH) sampler. ASH samples the current state of all active sessions. This data is collected into memory and can be accessed by a V$ view. It is also written out to persistent store by the AWR snapshot processing. See "Active Session History (ASH)" on page 5-4.

A powerful tool for diagnosing performance problems is the use of statistical baselines. A statistical baseline is collection of statistic rates usually taken over time period where the system is performing well at peak load. Comparing statistics captured during a period of bad performance to a baseline helps discover specific statistics that have increased significantly and could be the cause of the problem.

AWR supports the capture of baseline data by enabling you to specify and preserve a pair or range of AWR snapshots as a baseline. Carefully consider the time period you choose as a baseline; the baseline should be a good representation of the peak

load on the system. In the future, you can compare these baselines with snapshots captured during periods of poor performance.

Oracle Enterprise Manager is the recommended tool for viewing both real time data in the dynamic performance views and historical data from the AWR history tables. Enterprise manager also is able to capture operating system and network statistical data that can be correlated with AWR data.

Database Statistics

Database statistics provide information on the type of load on the database, as well as the internal and external resources used by the database. This section describes some of the more important statistics.

Wait Events

Wait events are statistics that are incremented by a server process/thread to indicate that it had to wait for an event to complete before being able to continue processing. Wait event data reveals various symptoms of problems that might be impacting performance, such as latch contention, buffer contention, and I/O contention.

To enable easier high-level analysis of the wait events, the events are grouped into classes. The wait event classes include: Administrative, Application, Cluster, Commit, Concurrency, Configuration, Idle, Network, Other, Scheduler, System I/O, and User I/O.

The wait classes are based on a common solution that usually applies to fixing a problem with the wait event. For example, exclusive TX locks are generally an application level issue and HW locks are generally a configuration issue.

The following list includes common examples of the waits in some of the classes:

- Application: locks waits caused by row level locking or explicit lock commands
- Commit: waits for redo log write confirmation after a commit
- Idle: wait events that signify the session is inactive, such as `SQL*Net message from client`
- Network: waits for data to be sent over the network
- User I/O: wait for blocks to be read off a disk

> **See Also:** *Oracle Database Reference* for more information about Oracle wait events

Time Model Statistics

When tuning an Oracle system, each component has its own set of statistics. To look at the system as a whole, it is necessary to have a common scale for comparisons. Because of this, most Oracle advisories and reports describe statistics in terms of time. In addition, the V$SESS_TIME_MODEL and V$SYS_TIME_MODEL views provide time model statistics. Using the common time instrumentation helps to identify quantitative effects on the database operations.

The most important of the time model statistics is DB time. This statistics represents the total time spent in database calls and is a indicator of the total instance workload. It is calculated by aggregating the CPU and wait times of all sessions not waiting on idle wait events (non-idle user sessions).

DB time is measured cumulatively from the time that the instance was started. Because DB time it is calculated by combining the times from all non-idle user sessions, it is possible that the DB time can exceed the actual time elapsed since the instance started up. For example, a instance that has been running for 30 minutes could have four active user sessions whose cumulative DB time is approximately 120 minutes.

The objective for tuning an Oracle system could be stated as reducing the time that users spend in performing some action on the database, or simply reducing DB time. Other time model statistics provide quantitative effects (in time) on specific actions, such as logon operations and hard and soft parses.

> **See Also:** *Oracle Database Reference* for information about the V$SESS_TIME_MODEL and V$SYS_TIME_MODEL views

Active Session History (ASH)

The V$ACTIVE_SESSION_HISTORY view provides sampled session activity in the instance. Active sessions are sampled every second and are stored in a circular buffer in SGA. Any session that is connected to the database and is waiting for an event that does not belong to the Idle wait class is considered as an active session. This includes any session that was on the CPU at the time of sampling.

Each session sample is a set of rows and the V$ACTIVE_SESSION_HISTORY view returns one row for each active session per sample, returning the latest session sample rows first. Because the active session samples are stored in a circular buffer in SGA, the greater the system activity, the smaller the number of seconds of session activity that can be stored in the circular buffer. This means that the duration for which a session sample appears in the V$ view, or the number of seconds of session activity that is displayed in the V$ view, is completely dependent on the database activity.

As part of the Automatic Workload Repository (AWR) snapshots, the content of V$ACTIVE_SESSION_HISTORY is also flushed to disk. Because the content of this V$ view can get quite large during heavy system activity, only a portion of the session samples is written to disk.

By capturing only active sessions, a manageable set of data is represented with the size being directly related to the work being performed rather than the number of sessions allowed on the system. Using the Active Session History enables you to examine and perform detailed analysis on both current data in the V$ACTIVE_SESSION_HISTORY view and historical data in the DBA_HIST_ACTIVE_SESS_HISTORY view, often avoiding the need to replay the workload to gather additional performance tracing information. The data present in ASH can be rolled up on various dimensions that it captures, including the following:

- SQL identifier of SQL statement
- Object number, file number, and block number
- Wait event identifier and parameters
- Session identifier and session serial number
- Module and action name
- Client identifier of the session
- Service hash identifier

> **See Also:** *Oracle Database Reference* for more information about the V$ACTIVE_SESSION_HISTORY view

System and Session Statistics

A large number of cumulative database statistics are available on a system and session level through the V$SYSSTAT and V$SESSTAT views.

> **See Also:** *Oracle Database Reference* for information about the V$SYSSTAT and V$SESSTAT views

Operating System Statistics

Operating system statistics provide information on the usage and performance of the main hardware components of the system, as well as the performance of the operating system itself. This information is crucial for detecting potential resource exhaustion, such as CPU cycles and physical memory, and for detecting bad performance of peripherals, such as disk drives.

Operating system statistics are only an indication of how the hardware and operating system are working. Many system performance analysts react to a hardware resource shortage by installing more hardware. This is a reactionary response to a series of symptoms shown in the operating system statistics. It is always best to consider operating system statistics as a diagnostic tool, similar to the way many doctors use body temperature, pulse rate, and patient pain when making a diagnosis. To help identify bottlenecks, gather operating system statistics for all servers in the system under performance analysis.

Operating system statistics include the following:

- CPU Statistics
- Virtual Memory Statistics
- Disk Statistics
- Network Statistics

For information on tools for gathering operating statistics, see "Operating System Data Gathering Tools" on page 5-7.

CPU Statistics

CPU utilization is the most important operating system statistic in the tuning process. Get CPU utilization for the entire system and for each individual CPU on multi-processor environments. Utilization for each CPU can detect single-threading and scalability issues.

Most operating systems report CPU usage as time spent in user space or mode and time spent in kernel space or mode. These additional statistics allow better analysis of what is actually being executed on the CPU.

On an Oracle data server system, where there is generally only one application running, the server runs database activity in user space. Activities required to service database requests (such as scheduling, synchronization, I/O, memory management, and process/thread creation and tear down) run in kernel mode. In a system where all CPU is fully utilized, a healthy Oracle system runs between 65% and 95% in user space.

The `V$OSSTAT` view captures machine level information in the database making it easier for you to determine if there are hardware level resource issues. The `V$SYS_TIME_MODEL` supplies statistics on the CPU usage by the Oracle database. Using both sets of statistics enable you to determine whether the Oracle database or other system activity is the cause of the CPU problems.

Virtual Memory Statistics

Virtual memory statistics should mainly be used as a check to validate that there is very little paging or swapping activity on the system. System performance degrades rapidly and unpredictably when paging or swapping occurs.

Individual process memory statistics can detect memory leaks due to a programming failure to deallocate memory taken from the process heap. These statistics should be used to validate that memory usage does not increase after the system has reached a steady state after startup. This problem is particularly acute on shared server applications on middle tier machines where session state may persist across user interactions, and on completion state information that is not fully deallocated.

Disk Statistics

Because the database resides on a set of disks, the performance of the I/O subsystem is very important to the performance of the database. Most operating systems provide extensive statistics on disk performance. The most important disk statistics are the current response time and the length of the disk queues. These statistics show if the disk is performing optimally or if the disk is being overworked.

Measure the normal performance of the I/O system; typical values for a single block read range from 5 to 20 milliseconds, depending on the hardware used. If the hardware shows response times much higher than the normal performance value, then it is performing badly or is overworked. This is your bottleneck. If disk queues start to exceed two, then the disk is a potential bottleneck of the system.

Network Statistics

Network statistics can be used in much the same way as disk statistics to determine if a network or network interface is overloaded or not performing optimally. In today's networked applications, network latency can be a large portion of the actual user response time. For this reason, these statistics are a crucial debugging tool. See "Using Dynamic Performance Views for Network Performance" on page 11-6.

Operating System Data Gathering Tools

Table 5–1 shows the various tools for gathering operating statistics on UNIX. For Windows NT/2000, use the Performance Monitor tool.

Table 5–1 UNIX Tools for Operating Statistics

Component	UNIX Tool
CPU	sar, vmstat, mpstat, iostat
Memory	sar, vmstat
Disk	sar, iostat
Network	netstat

Interpreting Statistics

When initially examining performance data, you can formulate potential theories by examining your statistics. One way to ensure that your interpretation of the statistics is correct is to perform cross-checks with other data. This establishes whether a statistic or event is really of interest.

Some pitfalls are discussed in the following sections:

- Hit ratios

  When tuning, it is common to compute a ratio that helps determine whether there is a problem. Such ratios include the buffer cache hit ratio, the soft-parse ratio, and the latch hit ratio. These ratios should not be used as 'hard and fast' identifiers of whether there is or is not a performance bottleneck. Rather, they should be used as indicators. In order to identify whether there is a bottleneck, other related evidence should be examined. See "Calculating the Buffer Cache Hit Ratio" on page 7-11.

- Wait events with timed statistics

  Setting `TIMED_STATISTICS` to true at the instance level directs the Oracle server to gather wait time for events, in addition to wait counts already available. This data is useful for comparing the total wait time for an event to the total elapsed time between the performance data collections. For example, if the wait event accounts for only 30 seconds out of a two hour period, then there is probably little to be gained by investigating this event, even though it may be the highest ranked wait event when ordered by time waited. However, if the event accounts for 30 minutes of a 45 minute period, then the event is worth investigating. See "Wait Events Statistics" on page 10-21.

> **Note:** Timed statistics are automatically collected for the database if the initialization parameter STATISTICS_LEVEL is set to TYPICAL or ALL. If STATISTICS_LEVEL is set to BASIC, then you must set TIMED_STATISTICS to TRUE to enable collection of timed statistics. Note that setting STATISTICS_LEVEL to BASIC disables many automatic features and is not recommended.
>
> If you explicitly set DB_CACHE_ADVICE, TIMED_STATISTICS, or TIMED_OS_STATISTICS, either in the initialization parameter file or by using ALTER_SYSTEM or ALTER SESSION, the explicitly set value overrides the value derived from STATISTICS_LEVEL.

- Comparing Oracle statistics with other factors

  When looking at statistics, it is important to consider other factors that influence whether the statistic is of value. Such factors include the user load and the hardware capability. Even an event that had a wait of 30 minutes in a 45 minute snapshot might not be indicative of a problem if you discover that there were 2000 users on the system, and the host hardware was a 64 node machine.

- Wait events without timed statistics

  If TIMED_STATISTICS is false, then the amount of time waited for an event is not available. Therefore, it is only possible to order wait events by the number of times each event was waited for. Although the events with the largest number of waits might indicate the potential bottleneck, they might not be the main bottleneck. This can happen when an event is waited for a large number of times, but the total time waited for that event is small. The converse is also true: an event with fewer waits might be a problem if the wait time is a significant proportion of the total wait time. Without having the wait times to use for comparison, it is difficult to determine whether a wait event is really of interest.

- Idle wait events

  Oracle uses some wait events to indicate if the Oracle server process is idle. Typically, these events are of no value when investigating performance problems, and they should be ignored when examining the wait events. See "Idle Wait Events" on page 10-48.

- Computed statistics

When interpreting computed statistics (such as rates, statistics normalized over transactions, or ratios), it is important to cross-verify the computed statistic with the actual statistic counts. This confirms whether the derived rates are really of interest: small statistic counts usually can discount an unusual ratio. For example, on initial examination, a soft-parse ratio of 50% generally indicates a potential tuning area. If, however, there was only one hard parse and one soft parse during the data collection interval, then the soft-parse ratio would be 50%, even though the statistic counts show this is not an area of concern. In this case, the ratio is not of interest due to the low raw statistic counts.

See Also:

- "Setting the Level of Statistics Collection" on page 10-7 for information about `STATISTICS_LEVEL` settings
- *Oracle Database Reference* for information on the `STATISTICS_LEVEL` initialization parameter

Automatic Workload Repository

The Automatic Workload Repository (AWR) collects, processes, and maintains performance statistics for problem detection and self-tuning purposes. This data is both in memory and stored in the database. The gathered data can be displayed in both reports and views. See "Workload Repository Views" on page 5-16 and "Workload Repository Reports" on page 5-17.

The statistics collected and processed by AWR include:

- Object statistics that determine both access and usage statistics of database segments
- Time model statistics based on time usage for activities, displayed in the `V$SYS_TIME_MODEL` and `V$SESS_TIME_MODEL` views
- Some of the system and session statistics collected in the `V$SYSSTAT` and `V$SESSTAT` views
- SQL statements that are producing the highest load on the system, based on criteria such as elapsed time and CPU time
- Active Session History (ASH) statistics, representing the history of recent sessions activity

AWR automatically generates snapshots of the performance data once every hour and collects the statistics in the workload repository. You can also manually create

snapshots, but this is usually not necessary. The data in the snapshot interval is then analyzed by the Automatic Database Diagnostic Monitor (ADDM). See "Automatic Database Diagnostic Monitor" on page 6-3.

AWR compares the difference between snapshots to determine which SQL statements to capture based on the effect on the system load. This reduces the number of SQL statements that need to be captured over time.

The space consumed by the Automatic Workload Repository is determined by several factors:

- Number of active sessions in the system at any given time
- Snapshot interval

  The snapshot interval determines the frequency at which snapshots are captured. A smaller snapshot interval increases the frequency, which increases the volume of data collected by the Automatic Workload Repository.
- Historical data retention period

  The retention period determines how long this data is retained before being purged. A longer retention period increases the space consumed by the Automatic Workload Repository.

By default, the snapshots are captured once every hour and are retained in the database for 7 days. With these default settings, a typical system with an average of 10 concurrent active sessions can require approximately 200 to 300 MB of space for its AWR data. It is possible to change the default values for both snapshot interval and retention period. See "Accessing the Automatic Workload Repository with Oracle Enterprise Manager" on page 5-12 and "Modifying Snapshot Settings" on page 5-14 for information on modifying AWR settings.

The Automatic Workload Repository space consumption can be reduced by the increasing the snapshot interval and reducing the retention period. When reducing the retention period, note that several Oracle self-managing features depend on AWR data for proper functioning. Not having enough data can affect the validity and accuracy of these components and features, including the following:

- Automatic Database Diagnostic Monitor
- SQL Tuning Advisor
- Undo Advisor
- Segment Advisor

If possible, Oracle Corporation recommends that you set the AWR retention period large enough to capture at least one complete workload cycle. If your system experiences weekly workload cycles, such as OLTP workload during weekdays and batch jobs during the weekend, you do not need to change the default AWR retention period of 7 days. However if your system is subjected to a monthly peak load during month end book closing, you may have to set the retention period to one month.

Under exceptional circumstances, the automatic snapshot collection can be completely turned off by setting the snapshot interval to 0. Under this condition, the automatic collection of the workload and statistical data is stopped and much of the Oracle self-management functionality is not operational. In addition, you will not be able to manually create snapshots. For this reason, Oracle Corporation strongly recommends that you do not turn off the automatic snapshot collection.

It is important that you create baselines from the Automatic Workload Repository to capture typical performance periods. The baselines, which are specified by a range of snapshots, are preserved for comparisons with other similar workload periods when performance problems occur.

The `STATISTICS_LEVEL` initialization parameter must be set to the `TYPICAL` or `ALL` to enable the Automatic Workload Repository. If the value is set to `BASIC`, you can manually capture AWR statistics using procedures in the `DBMS_WORKLOAD_REPOSITORY` package. However, because setting the `STATISTICS_LEVEL` parameter to `BASIC` turns off in-memory collection of many system statistics, such as segments statistics and memory advisor information, manually captured snapshots will not contain these statistics and will be incomplete.

> **See Also:** *Oracle Database Reference* for information on the `STATISTICS_LEVEL` initialization parameter

In addition to the data collection by the AWR, Automatic Optimizer Statistics Collection is performed by the `DBMS_STATS.GATHER_DATABASE_STATS_JOB_PROC` procedure as a scheduled job of the Maintenance Window. See "Automatic Statistics Gathering" on page 15-3.

Accessing the Automatic Workload Repository with Oracle Enterprise Manager

To access Automatic Workload Repository through Oracle Enterprise Manager Database Control:

- On the **Administration** page, select the **Workload Repository** link under **Workload**. From the **Automatic Workload Repository** page, you can manage snapshots or modify AWR settings.
  - To manage snapshots, click the link next to **Snapshots** or **Preserved Snapshot Sets**. On the **Snapshots** or **Preserved Snapshot Sets** pages, you can:
    * View information about snapshots or preserved snapshot sets (baselines).
    * Perform a variety of tasks through the pull-down **Actions** menu, including creating additional snapshots, preserved snapshot sets from an existing range of snapshots, or an ADDM task to perform analysis on a range of snapshots or a set of preserved snapshots.
  - To modify AWR settings, click the **Edit** button. On the **Edit Settings** page, you can set the **Snapshot Retention** period and **Snapshot Collection** interval.

    See Also: *Oracle Enterprise Manager Concepts* and Oracle Enterprise Manager online help for information about monitoring and diagnostic tools available with Oracle Enterprise Manager

Managing Snapshot and Baseline Data with APIs

While the primary interface for managing the Automatic Workload Repository is the Oracle Enterprise Manager Database Control, monitoring functions can be managed with procedures in the `DBMS_WORKLOAD_REPOSITORY` package.

Snapshots are automatically generated for an Oracle database; however, you can use `DBMS_WORKLOAD_REPOSITORY` procedures to manually create, drop, and modify the snapshots and baselines that are used by automatic database diagnostic monitoring. Snapshots and baselines are sets of historical data for specific time periods that are used for performance comparisons.

To invoke these procedures, a user must be granted the DBA role.

See Also: *PL/SQL Packages and Types Reference* for detailed information on the `DBMS_WORKLOAD_REPOSITORY` package

Creating Snapshots

You can manually create snapshots with the CREATE_SNAPSHOT procedure if you want to capture statistics at times different than those of the automatically generated snapshots. For example:

```
BEGIN
  DBMS_WORKLOAD_REPOSITORY.CREATE_SNAPSHOT ();
END;
/
```

In this example, a snapshot for the instance is created immediately with the flush level specified to the default flush level of TYPICAL. You can view this snapshot in the DBA_HIST_SNAPSHOT view.

Dropping Snapshots

You can drop a range of snapshots using the DROP_SNAPSHOT_RANGE procedure. To view a list of the snapshot Ids along with database Ids, check the DBA_HIST_SNAPSHOT view. For example, you can drop the following range of snapshots:

```
BEGIN
  DBMS_WORKLOAD_REPOSITORY.DROP_SNAPSHOT_RANGE (low_snap_id => 22,
                           high_snap_id => 32, dbid => 3310949047);
END;
/
```

In the example, the range of snapshot Ids to drop is specified from 22 to 32. The optional database identifier is 3310949047. If you do not specify a value for dbid, the local database identifier is used as the default value.

Active Session History data (ASH) that belongs to the time period specified by the snapshot range is also purged when the DROP_SNAPSHOT_RANGE procedure is called.

Modifying Snapshot Settings

You can adjust the interval and retention of snapshot generation for a specified database Id, but note that this can affect the precision of the Oracle diagnostic tools.

The INTERVAL setting affects how often in minutes that snapshots are automatically generated. The RETENTION setting affects how long in minutes that snapshots are stored in the workload repository. To adjust the settings, use the MODIFY_SNAPSHOT_SETTINGS procedure. For example:

```
BEGIN
```

```
  DBMS_WORKLOAD_REPOSITORY.MODIFY_SNAPSHOT_SETTINGS( retention => 43200,
                interval => 30, dbid => 3310949047);
END;
/
```

In this example, the retention period is specified as 43200 minutes (30 days) and the interval between each snapshot is specified as 30 minutes. If NULL is specified, the existing value is preserved. The optional database identifier is 3310949047. If you do not specify a value for dbid, the local database identifier is used as the default value. You can check the current settings for your database instance with the DBA_HIST_WR_CONTROL view.

Creating and Dropping Baselines

A baseline is created with the CREATE_BASELINE procedure. A baseline is simply performance data for a set of snapshots that is preserved and used for comparisons with other similar workload periods when performance problems occur. You can review the existing snapshots in the DBA_HIST_SNAPSHOT view to determine the range of snapshots that you want to use. For example:

```
BEGIN
    DBMS_WORKLOAD_REPOSITORY.CREATE_BASELINE (start_snap_id => 270,
                  end_snap_id => 280, baseline_name => 'peak baseline',
                  dbid => 3310949047);
END;
/
```

In this example, 270 is the start snapshot sequence number and 280 is the end snapshot sequence. peak baseline is the name of baseline and 3310949047 is an optional database identifier. If you do not specify a value for dbid, the local database identifier is used as the default value.

The system automatically assign a unique baseline Id to the new baseline when the baseline is created. The baseline Id and database identifier are displayed in the DBA_HIST_BASELINE view.

The pair of snapshots associated with the baseline are retained until you explicitly drop the baseline. You can drop a baseline with the DROP_BASELINE procedure. For example:

```
BEGIN
  DBMS_WORKLOAD_REPOSITORY.DROP_BASELINE (baseline_name => 'peak baseline',
                 cascade => FALSE, dbid => 3310949047);
END;
/
```

In the example, peak baseline is the name of baseline and FALSE specifies that only the baseline is dropped. TRUE specifies that drop operation should remove the pair of snapshots associated with baseline along with the baseline. 3310949047 is an optional database identifier.

Workload Repository Views

Typically, you would view the AWR data through Oracle Enterprise Manager screens or AWR reports. However, you can view the statistics with the following views:

- V$ACTIVE_SESSION_HISTORY

  This view displays active database session activity, sampled once every second. See "Active Session History (ASH)" on page 5-4.

- V$ metric views provide metric data to track the performance of the system

  The metric views are organized into various groups, such as event, event class, system, session, service, file, and tablespace metrics. These groups are identified in the V$METRICGROUP view.

- DBA_HIST views

  The DBA_HIST views contain historical data stored in the database. This group of views includes:

  - DBA_HIST_ACTIVE_SESS_HISTORY displays the history of the contents of the in-memory active session history for recent system activity.
  - DBA_HIST_BASELINE displays information about the baselines captured on the system
  - DBA_HIST_DATABASE_INSTANCE displays information about the database environment
  - DBA_HIST_SNAPSHOT displays information on snapshots in the system
  - DBA_HIST_SQL_PLAN displays the SQL execution plans
  - DBA_HIST_WR_CONTROL displays the settings for controlling AWR

    See Also: *Oracle Database Reference* for information on dynamic and static data dictionary views

Workload Repository Reports

You can view the AWR reports with Oracle Enterprise Manager or by running the following SQL scripts:

- The `awrrpt.sql` SQL script generates an HTML or text report that displays statistics for a range of snapshot Ids.
- The `awrrpti.sql` SQL script generates an HTML or text report that displays statistics for a range of snapshot Ids for a specified database and instance.

To run an AWR report, a user must be granted the DBA role.

The reports are divided into multiple sections. The HTML report includes links that can be used to navigate quickly between sections. The content of the report contains the workload profile of the system for the selected range of snapshots.

> **Note:** If you run a report on a database that does not have any workload activity during the specified range of snapshots, calculated percentages for some report statistics can be less than 0 or greater than 100. This result simply means that there is no meaningful value for the statistic.

Running the awrrpt.sql Report

To generate a text report for a range of snapshot Ids, run the `awrrpt.sql` script at the SQL prompt:

```
@$ORACLE_HOME/rdbms/admin/awrrpt.sql
```

First, you need to specify whether you want an HTML or a text report.

```
Enter value for report_type: text
```

Specify the number days for which you want to list snapshot Ids.

```
Enter value for num_days: 2
```

After the list displays, you are prompted for the beginning and ending snapshot Id for the workload repository report.

```
Enter value for begin_snap: 150
Enter value for end_snap: 160
```

Next, accept the default report name or enter a report name. The default name is accepted in the following example:

```
Enter value for report_name:
Using the report name awrrpt_1_150_160
```

The workload repository report is generated.

Running the awrrpti.sql Report

If you want to specify a database and instance before entering a range of snapshot Ids, run the `awrrpti.sql` script at the SQL prompt to generate a text report:

```
@$ORACLE_HOME/rdbms/admin/awrrpti.sql
```

First, specify whether you want an HTML or a text report. After that, a list of the database Ids and instance numbers displays, similar to the following:

```
Instances in this Workload Repository schema
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
   DB Id    Inst Num DB Name      Instance     Host
------------ -------- ------------ ------------ ------------
 3309173529        1 MAIN         main         dlsun1690
 3309173529        1 TINT251      tint251      stint251
```

Enter the values for the database identifier (`dbid`) and instance number (`inst_num`) at the prompts.

```
Enter value for dbid: 3309173529
Using 3309173529 for database Id
Enter value for inst_num: 1
```

Next you are prompted for the number of days and snapshot Ids, similar to the `awrrpt.sql` script, before the text report is generated. See "Running the awrrpt.sql Report" on page 5-17.

6

Automatic Performance Diagnostics

This chapter describes Oracle automatic features for performance diagnosing and tuning.

This chapter contains the following topics:

- Introduction to Database Diagnostic Monitoring
- Automatic Database Diagnostic Monitor

> **See Also:** *Oracle 2 Day DBA* for information on monitoring, diagnosing, and tuning the database, including Oracle Enterprise Manager Interfaces for using the Automatic Database Diagnostic Monitor

Introduction to Database Diagnostic Monitoring

When problems occur with a system, it is important to perform accurate and timely diagnosis of the problem before making any changes to a system. Often a database administrator (DBA) simply looks at the symptoms and immediately starts changing the system to fix those symptoms. However, long-time experience has shown that an initial accurate diagnosis of the actual problem significantly increases the probability of success in resolving the problem.

For Oracle systems, the statistical data needed for accurate diagnosis of a problem is saved in the Automatic Workload Repository (AWR). The Automatic Database Diagnostic Monitor (ADDM) analyzes the AWR data on a regular basis, then locates the root causes of performance problems, provides recommendations for correcting any problems, and identifies non-problem areas of the system. Because AWR is a repository of historical performance data, ADDM can be used to analyze performance issues after the event, often saving time and resources reproducing a problem. See "Automatic Workload Repository" on page 5-10.

An ADDM analysis is performed every time an AWR snapshot is taken and the results are saved in the database. You can view the results of the analysis using Oracle Enterprise Manager or by viewing a report in a SQL*Plus session.

In most cases, ADDM output should be the first place that a DBA looks when notified of a performance problem. ADDM provides the following benefits:

- Automatic performance diagnostic report every hour by default
- Problem diagnosis based on decades of tuning expertise
- Time-based quantification of problem impacts and recommendation benefits
- Identification of root cause, not symptoms
- Recommendations for treating the root causes of problems
- Identification of non-problem areas of the system
- Minimal overhead to the system during the diagnostic process

It is important to realize that tuning is an iterative process and fixing one problem can cause the bottleneck to shift to another part of the system. Even with the benefit of ADDM analysis, it can take multiple tuning cycles to reach acceptable system performance. ADDM benefits apply beyond production systems; on development and test systems ADDM can provide an early warning of performance issues.

Automatic Database Diagnostic Monitor

The Automatic Database Diagnostic Monitor (ADDM) provides a holistic tuning solution. ADDM analysis can be performed over any time period defined by a pair of AWR snapshots taken on a particular instance. Analysis is performed top down, first identifying symptoms and then refining them to reach the root causes of performance problems.

The goal of the analysis is to reduce a single throughput metric called DB time. DB time is the cumulative time spent by the database server in processing user requests. It includes wait time and CPU time of all non-idle user sessions. DB time is displayed in the V$SESS_TIME_MODEL and V$SYS_TIME_MODEL views.

See Also:

- *Oracle Database Reference* for information about the V$SESS_TIME_MODEL and V$SYS_TIME_MODEL views
- "Time Model Statistics" on page 5-4 for a discussion of time model statistics and DB time
- *Oracle Database Concepts* for information on server processes

Note that ADDM does not target the tuning of individual user response times. Use tracing techniques to tune for individual user response times. See "End to End Application Tracing" on page 20-2.

By reducing DB time, the database server is able to support more user requests using the same resources, which increases throughput. The problems reported by the ADDM are sorted by the amount of DB time they are responsible for. System areas that are not responsible for a significant portion of DB time are reported as non-problem areas.

The types of problems that ADDM considers include the following:

- CPU bottlenecks - Is the system CPU bound by Oracle or some other application?
- Undersized Memory Structures - Are the Oracle memory structures, such as the SGA, PGA, and buffer cache, adequately sized?
- I/O capacity issues - Is the I/O subsystem performing as expected?
- High load SQL statements - Are there any SQL statements which are consuming excessive system resources?
- High load PL/SQL execution and compilation, as well as high load Java usage

- RAC specific issues - What are the global cache hot blocks and objects; are there any interconnect latency issues?
- Sub-optimal use of Oracle by the application - Are there problems with poor connection management, excessive parsing, or application level lock contention?
- Database configuration issues - Is there evidence of incorrect sizing of log files, archiving issues, excessive checkpoints, or sub-optimal parameter settings?
- Concurrency issues - Are there buffer busy problems?
- Hot objects and top SQL for various problem areas

ADDM also documents the non-problem areas of the system. For example, wait event classes that are not significantly impacting the performance of the system are identified and removed from the tuning consideration at an early stage, saving time and effort that would be spent on items that do not impact overall system performance.

In addition to problem diagnostics, ADDM recommends possible solutions. When appropriate, ADDM recommends multiple solutions for the DBA to choose from. ADDM considers a variety of changes to a system while generating its recommendations. Recommendations include:

- Hardware changes - Adding CPUs or changing the I/O subsystem configuration
- Database configuration - Changing initialization parameter settings
- Schema changes - Hash partitioning a table or index, or using automatic segment-space management (ASSM)
- Application changes - Using the cache option for sequences or using bind variables
- Using other advisors - Running the SQL Tuning Advisor on high load SQL or running the Segment Advisor on hot objects

ADDM Analysis Results

ADDM analysis results are represented as a set of FINDINGs. See Example 6–1 on page 6-5 for an example of ADDM analysis results. Each ADDM finding can belong to one of three types:

- Problem: Findings that describe the root cause of a database performance issue.

- Symptom: Findings that contain information that often lead to one or more problem findings.
- Information: Findings that are used for reporting non-problem areas of the system.

Each problem finding is quantified by an impact that is an estimate of the portion of DB time caused by the finding's performance issue. A problem finding can be associated with a list of RECOMMENDATIONs for reducing the impact of the performance problem. Each recommendation has a benefit which is an estimate of the portion of DB time that can be saved if the recommendation is implemented. A list of recommendations can contain various alternatives for solving the same problem; you not have to apply all the recommendations to solve a specific problem.

Recommendations are composed of ACTIONs and RATIONALEs. You need to apply all the actions of a recommendation in order to gain the estimated benefit. The rationales are used for explaining why the set of actions were recommended and to provide additional information to implement the suggested recommendation.

An ADDM Example

Consider the following section of an ADDM report in Example 6–1.

Example 6–1 Example ADDM Report

```
FINDING 1: 31% impact (7798 seconds)
-----------------------------------
SQL statements were not shared due to the usage of literals. This resulted in
additional hard parses which were consuming significant database time.

RECOMMENDATION 1: Application Analysis, 31% benefit (7798 seconds)
  ACTION: Investigate application logic for possible use of bind variables
    instead of literals. Alternatively, you may set the parameter
    "cursor_sharing" to "force".
  RATIONALE: SQL statements with PLAN_HASH_VALUE 3106087033 were found to be
    using literals. Look in V$SQL for examples of such SQL statements.
```

In this example, the finding points to a particular root cause, the usage of literals in SQL statements, which is estimated to have an impact of about 31% of total DB time in the analysis period.

The finding has a recommendation associated with it, composed of one action and one rationale. The action specifies a solution to the problem found and is estimated to have a maximum benefit of up to 31% DB time in the analysis period. Note that the benefit is given as a portion of the total DB time and not as a portion of the finding's impact. The rationale provides additional information on tracking potential SQL statements that were using literals and causing this performance issue. Using the specified plan hash value of SQL statements that could be a problem, a DBA could quickly examine a few sample statements.

When a specific problem has multiple causes, the ADDM may report multiple problem and symptom findings. In this case, the impacts of these multiple findings can contain the same portion of DB time. Because the performance issues of findings can overlap, summing all the impacts of the reported findings can yield a number higher than 100% of DB time. For example, if a system performs many read I/Os the ADDM might report a SQL statement responsible for 50% of DB time due to I/O activity as one finding, and an undersized buffer cache responsible for 75% of DB time as another finding.

When multiple recommendations are associated with a problem finding, the recommendations may contain alternatives for solving the problem. In this case, the sum of the recommendations' benefits may be higher than the finding's impact.

When appropriate, an ADDM action many haves multiple solutions for the DBA to choose from. In the example, the most effective solution is to use bind variables. However, it is often difficult to modify the application. Changing the value of the CURSOR_SHARING initialization parameter is much easier to implement and can provide significant improvement.

Setting Up ADDM

Automatic database diagnostic monitoring is enabled by default and is controlled by the STATISTICS_LEVEL initialization parameter. The STATISTICS_LEVEL parameter should be set to the TYPICAL or ALL to enable the automatic database diagnostic monitoring. The default setting is TYPICAL. Setting STATISTICS_LEVEL to BASIC disables many Oracle features, including ADDM, and is strongly discouraged.

> **See Also:** *Oracle Database Reference* for information on the STATISTICS_LEVEL initialization parameter

ADDM analysis of I/O performance partially depends on a single argument, DBIO_EXPECTED, that describes the expected performance of the I/O subsystem. The value of DBIO_EXPECTED is the average time it takes to read a single database

block in microseconds. Oracle uses the default value of 10 milliseconds, which is an appropriate value for most modern hard drives. If your hardware is significantly different, such as very old hardware or very fast RAM disks, consider using a different value.

To determine the correct setting for `DBIO_EXPECTED` parameter, perform the following steps:

1. Measure the average read time of a single database block read for your hardware. Note that this measurement is for random I/O, which includes seek time if you use standard hard drives. Typical values for hard drives are between 5000 and 20000 microseconds.
2. Set the value one time for all subsequent ADDM executions. For example, if the measured value if 8000 microseconds, you should execute the following command as SYS user:

```
EXECUTE DBMS_ADVISOR.SET_DEFAULT_TASK_PARAMETER(
                     'ADDM', 'DBIO_EXPECTED', 8000);
```

Accessing ADDM with Oracle Enterprise Manager

The primary interface for diagnostic monitoring is the Oracle Enterprise Manager Database Control. To access Automatic Database Diagnostic Monitor through Oracle Enterprise Manager Database Control:

- On the **Database Home** page, ADDM findings for the last analysis period are displayed under **Performance Analysis**. You can click the link associated with each finding to display a more detailed page containing recommendations for the findings.
- You can click the **Advisor Central** link under **Related Links** at the bottom of the Oracle Enterprise Manager **Database** pages. On the **Advisor Central** page, you can search for previous ADDM tasks or click the **ADDM** link to create a new task.
- On the **Database Performance** page, click a clipboard icon just below the **Sessions: Waiting and Working** graph to display ADDM analysis.
- You can run ADDM tasks on selected snapshots or a set of preserved snapshots (baseline) from the **Workload Repository Snapshots** page.
    - On the **Administration** page, click the **Automatic Workload Repository** link under **Workload**.

- On **Automatic Workload Repository** page, click the link next to **Snapshots** or **Preserved Snapshot Sets**.
  - On the **Snapshots** page, you can select **Create ADDM Task** from the pull-down **Actions** menu. Next select the beginning and ending snapshots corresponding to the time period that you want to analyze.
  - On the **Preserved Snapshot Sets** page, you can select **Create ADDM Task** from the pull-down **Actions** menu. Next select the preserved snapshot set corresponding to the time period that you want to analyze.

See Also: *Oracle Enterprise Manager Concepts* and Oracle Enterprise Manager online help for information about monitoring and diagnostic tools available with Oracle Enterprise Manager

Diagnosing Database Performance Issues with ADDM

To diagnose database performance issues, ADDM analysis can be performed across any two AWR snapshots as long as the following requirements are met:

- Both the snapshots did not encounter any errors during creation and both have not yet been purged.
- There were no shutdown and startup actions between the two snapshots.

Consider a scenario in which users complain that the database was performing poorly between 7 P.M. and 9 P.M. of the previous night. The first step in diagnosing the database performance during that time period is invoking an ADDM analysis over that specific time frame.

While the simplest way to run an ADDM analysis over a specific time period is with the Oracle Enterprise Manager GUI, ADDM can also be run manually using the `$ORACLE_HOME/rdbms/admin/addmrpt.sql` script and `DBMS_ADVISOR` package APIs. The SQL script and APIs can be run by any user who has been granted the `ADVISOR` privilege.

See Also: *PL/SQL Packages and Types Reference* for detailed information on the `DBMS_ADVISOR` package

Running ADDM Using addmrpt.sql

To invoke ADDM analysis for the scenario previously described, you can simply run the `addmrpt.sql` script at the SQL prompt:

```
@$ORACLE_HOME/rdbms/admin/addmrpt.sql
```

When running the `addmrpt.sql` report to analyze the specific time period in the example scenario, you need to:

1. Identify the last snapshot that was taken before or at 7 P.M. and the first snapshot that was taken after or at 9 P.M. of the previous night from the list of recent snapshots that the report initially displays. The output is similar to the following:

```
Listing the last 3 days of Completed Snapshots
...
                                                           Snap
Instance     DB Name        Snap Id    Snap Started    Level
------------ ------------ --------- ------------------ -----
main         MAIN              136 20 Oct 2003 18:30      1
                               137 20 Oct 2003 19:00      1
                               138 20 Oct 2003 19:30      1
                               139 20 Oct 2003 20:00      1
                               140 20 Oct 2003 20:30      1
                               141 20 Oct 2003 21:00      1
                               142 20 Oct 2003 21:30      1
```

2. Provide the snapshot Id closest to 7 P.M. when prompted for the beginning snapshot and the 9 P.M. snapshot Id when prompted for the ending snapshot.

```
Enter value for begin_snap: 137
Begin Snapshot Id specified: 137

Enter value for end_snap: 141
End   Snapshot Id specified: 141
```

3. Enter a report name or accept the default name when prompted to specify the report name.

```
Enter value for report_name:
Using the report name addmrpt_1_137_145.txt
Running the ADDM analysis on the specified pair of snapshots ...
Generating the ADDM report for this analysis ...
```

After the report name is specified, ADDM analysis over the specific time frame is performed. At the end of the analysis, the SQL script displays the textual ADDM report of the analysis. You can review the report to find the top performance issues affecting the database and possible ways to solve those issues.

Instructions for running the report `addmrpt.sql` in a non-interactive mode can be found at the beginning of the `$ORACLE_HOME/rdbms/admin/addmrpt.sql` file.

Running ADDM using DBMS_ADVISOR APIs

To perform specific ADDM analysis, you can use the DBMS_ADVISOR APIs to write your own PL/SQL program. Using the DBMS_ADVISOR procedures, you can create and execute any of the advisor tasks, such as an ADDM task. An advisor task is an executable data area in the workload repository that manages all users tuning efforts.

A typical usage of the DBMS_ADVISOR package involves:

- Creating an advisor task of a particular type, such as ADDM, using DBMS_ADVISOR.CREATE_TASK
- Setting the required parameters to run a specific type of task, such as START_SNAPSHOT and END_SNAPSHOT parameters, using DBMS_ADVISOR.SET_TASK_PARAMETER
- Executing the task using DBMS_ADVISOR.EXECUTE_TASK
- Viewing the results using DBMS_ADVISOR.GET_TASK_REPORT

In terms of the scenario previously discussed, you can write a PL/SQL function that can automatically identify the snapshots that were taken closest to a given time period and then run ADDM. The PL/SQL function is similar to the following:

Example 6–2 Function for ADDM Analysis on a Pair of Snapshots

```
CREATE OR REPLACE FUNCTION run_addm(start_time IN DATE, end_time IN DATE )
  RETURN VARCHAR2
IS
  begin_snap          NUMBER;
  end_snap            NUMBER;
  tid                 NUMBER;          -- Task ID
  tname               VARCHAR2(30);    -- Task Name
  tdesc               VARCHAR2(256);   -- Task Description
BEGIN
  -- Find the snapshot IDs corresponding to the given input parameters.
  SELECT max(snap_id)INTO begin_snap
    FROM DBA_HIST_SNAPSHOT
   WHERE trunc(end_interval_time, 'MI') <= start_time;
  SELECT min(snap_id) INTO end_snap
    FROM DBA_HIST_SNAPSHOT
   WHERE  end_interval_time >= end_time;
  --
  -- set Task Name (tname) to NULL and let create_task return a
  -- unique name for the task.
  tname := '';
```

```
  tdesc := 'run_addm( ' || begin_snap || ', ' || end_snap || ' )';
  --
  -- Create a task, set task parameters and execute it
  DBMS_ADVISOR.CREATE_TASK( 'ADDM', tid, tname, tdesc );
  DBMS_ADVISOR.SET_TASK_PARAMETER( tname, 'START_SNAPSHOT', begin_snap );
  DBMS_ADVISOR.SET_TASK_PARAMETER( tname, 'END_SNAPSHOT' , end_snap );
  DBMS_ADVISOR.EXECUTE_TASK( tname );
  RETURN tname;
END;
/
```

The PL/SQL function `run_addm` in Example 6–2 finds the snapshots that were taken closest to a specified time frame and executes an ADDM analysis over that time period. The function also returns the name of the ADDM task that performed the analysis.

To run ADDM between 7 P.M. and 9 P.M. using the PL/SQL function `run_addm` and produce the text report of the analysis, you can execute SQL statements similar to the following:

Example 6–3 Reporting ADDM Analysis on a Pair of Specific Snapshots

```
-- set SQL*Plus variables and column formats for the report
SET PAGESIZE 0 LONG 1000000 LONGCHUNKSIZE 1000;
COLUMN get_clob FORMAT a80;
-- execute run_addm() with 7pm and 9pm as input
VARIABLE task_name VARCHAR2(30);
BEGIN
  :task_name := run_addm( TO_DATE('19:00:00 (10/20)', 'HH24:MI:SS (MM/DD)'),
                          TO_DATE('21:00:00 (10/20)', 'HH24:MI:SS (MM/DD)') );
END;
/
-- execute GET_TASK_REPORT to get the textual ADDM report.
SELECT DBMS_ADVISOR.GET_TASK_REPORT(:task_name)
  FROM DBA_ADVISOR_TASKS t
 WHERE t.task_name = :task_name
  AND t.owner = SYS_CONTEXT( 'userenv', 'session_user' );
```

Note that the SQL*Plus system variable `LONG` has to be set to a value that is large enough to show the entire ADDM report because the `DBMS_ADVISOR.GET_TASK_REPORT` function returns a `CLOB`.

Views with ADDM Information

Typically, you would view output and information from the automatic database diagnostic monitor through Oracle Enterprise Manager or ADDM reports. However, you can display ADDM information through the DBA_ADVISOR views. This group of views includes:

- DBA_ADVISOR_TASKS

  This view provides basic information about existing tasks, such as the task Id, task name, and when created.

- DBA_ADVISOR_LOG

  This view contains the current task information, such as status, progress, error messages, and execution times.

- DBA_ADVISOR_RECOMMENDATIONS

  This view displays the results of completed diagnostic tasks with recommendations for the problems identified in each run. The recommendations should be looked at in the order of the RANK column, as this relays the magnitude of the problem for the recommendation. The BENEFIT column gives the benefit to the system you can expect after the recommendation is carried out.

- DBA_ADVISOR_FINDINGS

  This view displays all the findings and symptoms that the diagnostic monitor encountered along with the specific recommendation.

  See Also: *Oracle Database Reference* for information on static data dictionary views

7

Memory Configuration and Use

This chapter explains how to allocate memory to Oracle memory caches, and how to use those caches. Proper sizing and effective use of the Oracle memory caches greatly improves database performance.

Oracle recommends automatic memory configuration for your system using the SGA_TARGET and PGA_AGGREGATE_TARGET initialization parameters. However, you can manually adjust the memory pools on your system and that process is provided in this chapter.

This chapter contains the following sections:

> **See Also:** *Oracle Database Concepts* for information on the memory architecture of an Oracle database

Understanding Memory Allocation Issues

Oracle stores information in memory caches and on disk. Memory access is much faster than disk access. Disk access (physical I/O) take a significant amount of time, compared with memory access, typically in the order of 10 milliseconds. Physical I/O also increases the CPU resources required, because of the path length in device drivers and operating system event schedulers. For this reason, it is more efficient for data requests for frequently accessed objects to be satisfied solely by memory, rather than also requiring disk access.

A performance goal is to reduce the physical I/O overhead as much as possible, either by making it more likely that the required data is in memory or by making the process of retrieving the required data more efficient.

Oracle strongly recommends the use of automatic memory management. Before setting any memory pool sizes, review the following:

- "Automatic Shared Memory Management" on page 7-3
- "PGA Memory Management" on page 7-50

If you need to configure memory allocations, Oracle Enterprise Manager provides the Memory Advisor for updates. To access the Memory Advisor through Oracle Enterprise Manager Database Control:

- Click the **Advisor Central** link under **Related Links** at the bottom of the **Database** pages.
- On the **Advisor Central** page, you can click the **Memory Advisor** link to access the **Memory Parameters SGA** and **PGA** pages.

Oracle Memory Caches

The main Oracle memory caches that affect performance are:

- Shared pool
- Large pool
- Java pool
- Buffer cache
- Streams pool size
- Log buffer
- Process-private memory, such as memory used for sorting and hash joins

Automatic Shared Memory Management

Automatic Shared Memory Management simplifies the configuration of the SGA and is the recommended memory configuration. To use Automatic Shared Memory Management, set the SGA_TARGET initialization parameter to a nonzero value and set the STATISTICS_LEVEL initialization parameter to TYPICAL or ALL. The value of the SGA_TARGET parameter should be set to the amount of memory that you want to dedicate for the SGA. In response to the workload on the system, the automatic SGA management distributes the memory appropriately for the following memory pools:

- Database buffer cache (default pool)
- Shared pool
- Large pool
- Java pool

If these automatically tuned memory pools had been set to nonzero values, those values are used as a minimum levels by Automatic Shared Memory Management. You would set minimum values if an application components needs a minimum amount of memory to function properly.

SGA_TARGET is a dynamic parameter and can be changed through Oracle Enterprise Manager or with the ALTER SYSTEM command. SGA_TARGET can be set less than or equal to the value of SGA_MAX_SIZE initialization parameter. Changes in the value of SGA_TARGET automatically resize the automatically tuned memory pools.

See Also:

- *Oracle Database Concepts* for information automatic SGA management
- *Oracle Database Administrator's Guide* for information on managing the System Global Area (SGA)

If you set SGA_TARGET to 0, Automatic Shared Memory Management is disabled and you can manually size the memory pools with the DB_CACHE_SIZE, SHARED_POOL_SIZE, LARGE_POOL_SIZE, and JAVA_POOL_SIZE initialization parameters. See "Dynamically Changing Cache Sizes" on page 7-4.

The following pools are manually sized components and are not affected by Automatic Shared Memory Management:

- Log buffer

- Other buffer caches, such as KEEP, RECYCLE, and other block sizes
- Streams pool
- Fixed SGA and other internal allocations

To manually size these memory pools, you need to set the DB_KEEP_CACHE_SIZE, DB_RECYCLE_CACHE_SIZE, DB_nK_CACHE_SIZE, STREAMS_POOL_SIZE, and LOG_BUFFER initialization parameters. The memory allocated to these pools is deducted from the total available for SGA_TARGET when Automatic Shared Memory Management computes the values of the automatically tuned memory pools.

See Also:

- *Oracle Database Administrator's Guide* for information on managing initialization parameters
- *Oracle Streams Concepts and Administration* for information about configuring the STREAMS_POOL_SIZE initialization parameter
- *Oracle Database Java Developer's Guide* for information on Java memory usage

Dynamically Changing Cache Sizes

If the system is not using Automatic Shared Memory Management, you can choose to dynamically reconfigure the sizes of the shared pool, the large pool, the buffer cache, and the process-private memory. The following sections contain details on sizing of caches:

- Configuring and Using the Buffer Cache
- Configuring and Using the Shared Pool and Large Pool
- Configuring and Using the Redo Log Buffer

The size of these memory caches is configurable using initialization configuration parameters, such as DB_CACHE_ADVICE, JAVA_POOL_SIZE, LARGE_POOL_SIZE, LOG_BUFFER, and SHARED_POOL_SIZE. The values for these parameters are also dynamically configurable using the ALTER SYSTEM statement except for the log buffer pool and process-private memory, which are static after startup.

Memory for the shared pool, large pool, java pool, and buffer cache is allocated in units of granules. The granule size is 4MB if the SGA size is less than 1GB. If the SGA size is greater than 1GB, the granule size changes to 16MB. The granule size is

calculated and fixed when the instance starts up. The size does not change during the lifetime of the instance.

The granule size that is currently being used for SGA can be viewed in the view V$SGA_DYNAMIC_COMPONENTS. The same granule size is used for all dynamic components in the SGA.

You can expand the total SGA size to a value equal to the SGA_MAX_SIZE parameter. If the SGA_MAX_SIZE is not set, you can decrease the size of one cache and reallocate that memory to another cache if necessary. SGA_MAX_SIZE defaults to the aggregate setting of all the components.

Note: SGA_MAX_SIZE cannot be dynamically resized.

The maximum amount of memory usable by the instance is determined at instance startup by the initialization parameter SGA_MAX_SIZE. You can specify SGA_MAX_SIZE to be larger than the sum of all of the memory components, such as buffer cache and shared pool. Otherwise, SGA_MAX_SIZE defaults to the actual size used by those components. Setting SGA_MAX_SIZE larger than the sum of memory used by all of the components lets you dynamically increase a cache size without needing to decrease the size of another cache.

> **See Also:** Your operating system's documentation for information on managing dynamic SGA.

Viewing Information About Dynamic Resize Operations

The following views provide information about dynamic SGA resize operations:

- V$SGA_CURRENT_RESIZE_OPS: Information about SGA resize operations that are currently in progress. An operation can be a grow or a shrink of a dynamic SGA component.
- V$SGA_RESIZE_OPS: Information about the last 400 completed SGA resize operations. This does not include any operations currently in progress.
- V$SGA_DYNAMIC_COMPONENTS: Information about the dynamic components in SGA. This view summarizes information based on all completed SGA resize operations since startup.
- V$SGA_DYNAMIC_FREE_MEMORY: Information about the amount of SGA memory available for future dynamic SGA resize operations.

See Also:

- *Oracle Database Concepts* for more information about dynamic SGA
- *Oracle Database Reference* for detailed column information for these views

Application Considerations

With memory configuration, it is important to size the cache appropriately for the application's needs. Conversely, tuning the application's use of the caches can greatly reduce resource requirements. Efficient use of the Oracle memory caches also reduces the load on related resources, such as the latches that protect the caches, the CPU, and the I/O system.

For best performance, you should consider the following:

- The cache should be optimally designed to use the operating system and database resources most efficiently.
- Memory allocations to Oracle memory structures should best reflect the needs of the application.

Making changes or additions to an existing application might require resizing Oracle memory structures to meet the needs of your modified application.

If your application uses Java, you should investigate whether you need to modify the default configuration for the Java pool. See the *Oracle Database Java Developer's Guide* for information on Java memory usage.

Operating System Memory Use

For most operating systems, it is important to consider the following:

Reduce paging

Paging occurs when an operating system transfers memory-resident pages to disk solely to allow new pages to be loaded into memory. Many operating systems page to accommodate large amounts of information that do not fit into real memory. On most operating systems, paging reduces performance.

Use the operating system utilities to examine the operating system, to identify whether there is a lot of paging on your system. If there is, then the total memory on the system might not be large enough to hold everything for which you have

allocated memory. Either increase the total memory on your system, or decrease the amount of memory allocated.

Fit the SGA into main memory

Because the purpose of the SGA is to store data in memory for fast access, the SGA should be within main memory. If pages of the SGA are swapped to disk, then the data is no longer quickly accessible. On most operating systems, the disadvantage of paging significantly outweighs the advantage of a large SGA.

> **Note:** The LOCK_SGA parameter can be used to lock the SGA into physical memory and prevent it from being paged out.

To see how much memory is allocated to the SGA and each of its internal structures, enter the following SQL*Plus statement:

```
SHOW SGA
```

The output of this statement will look similar to the following:

```
Total System Global Area  840205000 bytes
Fixed Size                   279240 bytes
Variable Size             520093696 bytes
Database Buffers          318767104 bytes
Redo Buffers                1064960 bytes
```

Allow adequate memory to individual users

When sizing the SGA, ensure that you allow enough memory for the individual server processes and any other programs running on the system.

> **See Also:** Your operating system hardware and software documentation, as well as the Oracle documentation specific to your operating system, for more information on tuning operating system memory usage

Iteration During Configuration

Configuring memory allocation involves distributing available memory to Oracle memory structures, depending on the needs of the application. The distribution of memory to Oracle structures can affect the amount of physical I/O necessary for Oracle to operate. Having a good first initial memory configuration also provides an indication of whether the I/O system is effectively configured.

It might be necessary to repeat the steps of memory allocation after the initial pass through the process. Subsequent passes let you make adjustments in earlier steps, based on changes in later steps. For example, decreasing the size of the buffer cache lets you increase the size of another memory structure, such as the shared pool.

Configuring and Using the Buffer Cache

For many types of operations, Oracle uses the buffer cache to store blocks read from disk. Oracle bypasses the buffer cache for particular operations, such as sorting and parallel reads. For operations that use the buffer cache, this section explains the following:

- Using the Buffer Cache Effectively
- Sizing the Buffer Cache
- Interpreting and Using the Buffer Cache Advisory Statistics
- Considering Multiple Buffer Pools

Using the Buffer Cache Effectively

To use the buffer cache effectively, SQL statements for the application should be tuned to avoid unnecessary resource consumption. To ensure this, verify that frequently executed SQL statements and SQL statements that perform many buffer gets have been tuned.

> **See Also:** Chapter 12, "SQL Tuning Overview" for information on how to do this

Sizing the Buffer Cache

When configuring a new instance, it is impossible to know the correct size for the buffer cache. Typically, a database administrator makes a first estimate for the cache size, then runs a representative workload on the instance and examines the relevant statistics to see whether the cache is under or over configured.

Buffer Cache Advisory Statistics

A number of statistics can be used to examine buffer cache activity. These include the following:

- `V$DB_CACHE_ADVICE`
- Buffer cache hit ratio

Using V$DB_CACHE_ADVICE

This view is populated when the DB_CACHE_ADVICE initialization parameter is set to ON. This view shows the simulated miss rates for a range of potential buffer cache sizes.

Each cache size simulated has its own row in this view, with the predicted physical I/O activity that would take place for that size. The DB_CACHE_ADVICE parameter is dynamic, so the advisory can be enabled and disabled dynamically to allow you to collect advisory data for a specific workload.

There is some overhead associated with this advisory. When the advisory is enabled, there is a small increase in CPU usage, because additional bookkeeping is required.

Oracle uses DBA-based sampling to gather cache advisory statistics. Sampling substantially reduces both CPU and memory overhead associated with bookkeeping. Sampling is not used for a buffer pool if the number of buffers in that buffer pool is small to begin with.

To use V$DB_CACHE_ADVICE, the parameter DB_CACHE_ADVICE should be set to ON, and a representative workload should be running on the instance. Allow the workload to stabilize before querying the V$DB_CACHE_ADVICE view.

The following SQL statement returns the predicted I/O requirement for the default buffer pool for various cache sizes:

```
COLUMN size_for_estimate          FORMAT 999,999,999,999 heading 'Cache Size (MB)'
COLUMN buffers_for_estimate       FORMAT 999,999,999 heading 'Buffers'
COLUMN estd_physical_read_factor  FORMAT 999.90 heading 'Estd Phys|Read Factor'
COLUMN estd_physical_reads        FORMAT 999,999,999 heading 'Estd Phys| Reads'

SELECT size_for_estimate, buffers_for_estimate, estd_physical_read_factor, estd_physical_reads
   FROM V$DB_CACHE_ADVICE
   WHERE name          = 'DEFAULT'
     AND block_size    = (SELECT value FROM V$PARAMETER WHERE name = 'db_block_size')
     AND advice_status = 'ON';
```

The following output shows that if the cache was 212 MB, rather than the current size of 304 MB, the estimated number of physical reads would increase by a factor of 1.74 or 74%. This means it would not be advisable to decrease the cache size to 212MB.

However, increasing the cache size to 334MB would potentially decrease reads by a factor of .93 or 7%. If an additional 30MB memory is available on the host machine

and the SGA_MAX_SIZE setting allows the increment, it would be advisable to increase the default buffer cache pool size to 334MB.

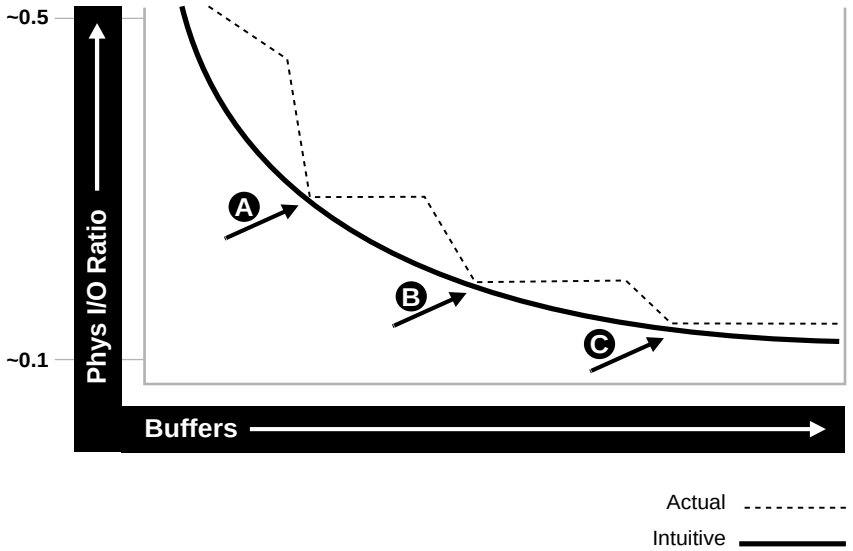
Cache Size (MB)	Buffers	Estd Phys Read Factor	Estd Phys Reads	
30	3,802	18.70	192,317,943	10% of Current Size
60	7,604	12.83	131,949,536	
91	11,406	7.38	75,865,861	
121	15,208	4.97	51,111,658	
152	19,010	3.64	37,460,786	
182	22,812	2.50	25,668,196	
212	26,614	1.74	17,850,847	
243	30,416	1.33	13,720,149	
273	34,218	1.13	11,583,180	
304	38,020	1.00	10,282,475	Current Size
334	41,822	.93	9,515,878	
364	45,624	.87	8,909,026	
395	49,426	.83	8,495,039	
424	53,228	.79	8,116,496	
456	57,030	.76	7,824,764	
486	60,832	.74	7,563,180	
517	64,634	.71	7,311,729	
547	68,436	.69	7,104,280	
577	72,238	.67	6,895,122	
608	76,040	.66	6,739,731	200% of Current Size

This view assists in cache sizing by providing information that predicts the number of physical reads for each potential cache size. The data also includes a physical read factor, which is a factor by which the current number of physical reads is estimated to change if the buffer cache is resized to a given value.

Note: With Oracle, physical reads do not necessarily indicate disk reads; physical reads may well be satisfied from the file system cache.

The relationship between successfully finding a block in the cache and the size of the cache is not always a smooth distribution. When sizing the buffer pool, avoid the use of additional buffers that contribute little or nothing to the cache hit ratio. In the example illustrated in Figure 7–1 on page 7-11, only narrow bands of increments to the cache size may be worthy of consideration.

Figure 7–1 Physical I/O and Buffer Cache Size



Examining Figure 7–1 leads to the following observations:

- The benefit from increasing buffers from point A to point B is considerably higher than from point B to point C.
- The decrease in the physical I/O between points A and B and points B and C is not smooth, as indicated by the dotted line in the graph.

Calculating the Buffer Cache Hit Ratio

The buffer cache hit ratio calculates how often a requested block has been found in the buffer cache without requiring disk access. This ratio is computed using data selected from the dynamic performance view V$SYSSTAT. The buffer cache hit ratio can be used to verify the physical I/O as predicted by V$DB_CACHE_ADVICE.

The statistics in Table 7–1 are used to calculate the hit ratio.

Table 7–1 Statistics for Calculating the Hit Ratio

Statistic	Description
consistent gets from cache	Number of times a consistent read was requested for a block from the buffer cache.

Table 7–1 (Cont.) Statistics for Calculating the Hit Ratio

Statistic	Description
db block gets from cache	Number of times a CURRENT block was requested from the buffer cache.
physical reads cache	The total number of requests to access a data block that resulted in access to the buffer cache.

Example 7–1 has been simplified by using values selected directly from the V$SYSSTAT table, rather than over an interval. It is best to calculate the delta of these statistics over an interval while your application is running, then use them to determine the hit ratio.

> **See Also:** Chapter 6, "Automatic Performance Diagnostics" for more information on collecting statistics over an interval

Example 7–1 Calculating the Buffer Cache Hit Ratio

```
SELECT NAME, VALUE
  FROM V$SYSSTAT
WHERE NAME IN ('db block gets from cache', 'consistent gets from cache',
'physical reads cache');
```

Using the values in the output of the query, calculate the hit ratio for the buffer cache with the following formula:

```
1 - (('physical reads cache') / ('consistent gets from cache' + 'db block gets from cache')
```

> **See Also:** *Oracle Database Reference* for information on the V$SYSSTAT view

Interpreting and Using the Buffer Cache Advisory Statistics

There are many factors to examine before considering whether to increase or decrease the buffer cache size. For example, you should examine V$DB_CACHE_ADVICE data and the buffer cache hit ratio.

A low cache hit ratio does not imply that increasing the size of the cache would be beneficial for performance. A good cache hit ratio could wrongly indicate that the cache is adequately sized for the workload.

To interpret the buffer cache hit ratio, you should consider the following:

- Repeated scanning of the same large table or index can artificially inflate a poor cache hit ratio. Examine frequently executed SQL statements with a large number of buffer gets, to ensure that the execution plan for such SQL statements is optimal. If possible, avoid repeated scanning of frequently accessed data by performing all of the processing in a single pass or by optimizing the SQL statement.
- If possible, avoid requerying the same data, by caching frequently accessed data in the client program or middle tier.
- Oracle Blocks accessed during a long full table scan are put on the tail end of the least recently used (LRU) list and not on the head of the list. Therefore, the blocks are aged out faster than blocks read when performing indexed lookups or small table scans. When interpreting the buffer cache data, poor hit ratios when valid large full table scans are occurring should also be considered.

> **Note:** Short table scans are scans performed on tables under a certain size threshold. The definition of a small table is the maximum of 2% of the buffer cache and 20, whichever is bigger.

- In any large database running OLTP applications in any given unit of time, most rows are accessed either one or zero times. On this basis, there might be little purpose in keeping the block in memory for very long following its use.
- A common mistake is to continue increasing the buffer cache size. Such increases have no effect if you are doing full table scans or operations that do not use the buffer cache.

Increasing Memory Allocated to the Buffer Cache

As a general rule, investigate increasing the size of the cache if the cache hit ratio is low and your application has been tuned to avoid performing full table scans.

To increase cache size, first set the `DB_CACHE_ADVICE` initialization parameter to `ON`, and let the cache statistics stabilize. Examine the advisory data in the `V$DB_CACHE_ADVICE` view to determine the next increment required to significantly decrease the amount of physical I/O performed. If it is possible to allocate the required extra memory to the buffer cache without causing the host operating system to page, then allocate this memory. To increase the amount of memory allocated to the buffer cache, increase the value of the `DB_CACHE_SIZE` initialization parameter.

If required, resize the buffer pools dynamically, rather than shutting down the instance to perform this change.

Note: When the cache is resized significantly (greater than 20 percent), the old cache advisory value is discarded and the cache advisory is set to the new size. Otherwise, the old cache advisory value is adjusted to the new size by the interpolation of existing values.

The DB_CACHE_SIZE parameter specifies the size of the default cache for the database's standard block size. To create and use tablespaces with block sizes different than the database's standard block sizes (such as to support transportable tablespaces), you must configure a separate cache for each block size used. The DB_*n*K_CACHE_SIZE parameter can be used to configure the nonstandard block size needed (where *n* is 2, 4, 8, 16 or 32 and *n* is not the standard block size).

Note: The process of choosing a cache size is the same, regardless of whether the cache is the default standard block size cache, the KEEP or RECYCLE cache, or a nonstandard block size cache.

See Also: *Oracle Database Reference* and *Oracle Database Administrator's Guide* for more information on using the DB_*n*K_CACHE_SIZE parameters

Reducing Memory Allocated to the Buffer Cache

If the cache hit ratio is high, then the cache is probably large enough to hold the most frequently accessed data. Check V$DB_CACHE_ADVICE data to see whether decreasing the cache size significantly causes the number of physical I/Os to increase. If not, and if you require memory for another memory structure, then you might be able to reduce the cache size and still maintain good performance. To make the buffer cache smaller, reduce the size of the cache by changing the value for the parameter DB_CACHE_SIZE.

Considering Multiple Buffer Pools

A single default buffer pool is generally adequate for most systems. However, users with detailed knowledge of an application's buffer pool might benefit from configuring multiple buffer pools.

With segments that have atypical access patterns, store blocks from those segments in two different buffer pools: the KEEP pool and the RECYCLE pool. A segment's access pattern may be atypical if it is constantly accessed (that is, hot) or infrequently accessed (for example, a large segment accessed by a batch job only once a day).

Multiple buffer pools let you address these differences. You can use a KEEP buffer pool to maintain frequently accessed segments in the buffer cache, and a RECYCLE buffer pool to prevent objects from consuming unnecessary space in the cache. When an object is associated with a cache, all blocks from that object are placed in that cache. Oracle maintains a DEFAULT buffer pool for objects that have not been assigned to a specific buffer pool. The default buffer pool is of size DB_CACHE_SIZE. Each buffer pool uses the same LRU replacement policy (for example, if the KEEP pool is not large enough to store all of the segments allocated to it, then the oldest blocks age out of the cache).

By allocating objects to appropriate buffer pools, you can:

- Reduce or eliminate I/Os
- Isolate or limit an object to a separate cache

Random Access to Large Segments

A problem can occur with an LRU aging method when a very large segment is accessed with a large or unbounded index range scan. Here, very large means large compared to the size of the cache. Any single segment that accounts for a substantial portion (more than 10%) of nonsequential physical reads can be considered very large. Random reads to a large segment can cause buffers that contain data for other segments to be aged out of the cache. The large segment ends up consuming a large percentage of the cache, but it does not benefit from the cache.

Very frequently accessed segments are not affected by large segment reads because their buffers are warmed frequently enough that they do not age out of the cache. However, the problem affects warm segments that are not accessed frequently enough to survive the buffer aging caused by the large segment reads. There are three options for solving this problem:

1. If the object accessed is an index, find out whether the index is selective. If not, tune the SQL statement to use a more selective index.
2. If the SQL statement is tuned, you can move the large segment into a separate RECYCLE cache so that it does not affect the other segments. The RECYCLE

cache should be smaller than the DEFAULT buffer pool, and it should reuse buffers more quickly than the DEFAULT buffer pool.

3. Alternatively, you can move the small warm segments into a separate KEEP cache that is not used at all for large segments. The KEEP cache can be sized to minimize misses in the cache. You can make the response times for specific queries more predictable by putting the segments accessed by the queries in the KEEP cache to ensure that they do not age out.

Oracle Real Application Cluster Instances

You can create multiple buffer pools for each database instance. The same set of buffer pools need not be defined for each instance of the database. Among instances, the buffer pools can be different sizes or not defined at all. Tune each instance according to the application requirements for that instance.

Using Multiple Buffer Pools

To define a default buffer pool for an object, use the BUFFER_POOL keyword of the STORAGE clause. This clause is valid for CREATE and ALTER TABLE, CLUSTER, and INDEX SQL statements. After a buffer pool has been specified, all subsequent blocks read for the object are placed in that pool.

If a buffer pool is defined for a partitioned table or index, then each partition of the object inherits the buffer pool from the table or index definition, unless you override it with a specific buffer pool.

When the buffer pool of an object is changed using the ALTER statement, all buffers currently containing blocks of the altered segment remain in the buffer pool they were in before the ALTER statement. Newly loaded blocks and any blocks that have aged out and are reloaded go into the new buffer pool.

> **See Also:** *Oracle Database SQL Reference* for information on specifying BUFFER_POOL in the STORAGE clause

Buffer Pool Data in V$DB_CACHE_ADVICE

V$DB_CACHE_ADVICE can be used to size all pools configured on an instance. Make the initial cache size estimate, run the representative workload, then simply query the V$DB_CACHE_ADVICE view for the pool you want to use.

For example, to query data from the KEEP pool:

```
SELECT SIZE_FOR_ESTIMATE, BUFFERS_FOR_ESTIMATE, ESTD_PHYSICAL_READ_FACTOR, ESTD_PHYSICAL_READS
  FROM V$DB_CACHE_ADVICE
```

```
WHERE NAME          = 'KEEP'
 AND BLOCK_SIZE    = (SELECT VALUE FROM V$PARAMETER WHERE NAME = 'db_block_size')
 AND ADVICE_STATUS = 'ON';
```

Buffer Pool Hit Ratios

The data in V$SYSSTAT reflects the logical and physical reads for all buffer pools within one set of statistics. To determine the hit ratio for the buffer pools individually, query the V$BUFFER_POOL_STATISTICS view. This view maintains statistics for each pool on the number of logical reads and writes.

The buffer pool hit ratio can be determined using the following formula:

```
1 - (physical_reads/(db_block_gets + consistent_gets))
```

The ratio can be calculated with the following query:

```
SELECT NAME, PHYSICAL_READS, DB_BLOCK_GETS, CONSISTENT_GETS,
      1 - (PHYSICAL_READS / (DB_BLOCK_GETS + CONSISTENT_GETS)) "Hit Ratio"
  FROM V$BUFFER_POOL_STATISTICS;
```

See Also: *Oracle Database Reference* for information on the V$BUFFER_POOL_STATISTICS view

Determining Which Segments Have Many Buffers in the Pool

The V$BH view shows the data object ID of all blocks that currently reside in the SGA. To determine which segments have many buffers in the pool, you can use one of the two methods described in this section. You can either look at the buffer cache usage pattern for all segments (Method 1) or examine the usage pattern of a specific segment, (Method 2).

Method 1

The following query counts the number of blocks for all segments that reside in the buffer cache at that point in time. Depending on buffer cache size, this might require a lot of sort space.

```
COLUMN OBJECT_NAME FORMAT A40
COLUMN NUMBER_OF_BLOCKS FORMAT 999,999,999,999

SELECT o.OBJECT_NAME, COUNT(*) NUMBER_OF_BLOCKS
     FROM DBA_OBJECTS o, V$BH bh
    WHERE o.DATA_OBJECT_ID = bh.OBJD
```

```
      AND o.OWNER         != 'SYS'
    GROUP BY o.OBJECT_NAME
    ORDER BY COUNT(*);

OBJECT_NAME                              NUMBER_OF_BLOCKS
---------------------------------------- ----------------
OA_PREF_UNIQ_KEY                                       1
SYS_C002651                                            1
..
DS_PERSON                                             78
OM_EXT_HEADER                                        701
OM_SHELL                                           1,765
OM_HEADER                                          5,826
OM_INSTANCE                                       12,644
```

Method 2

Use the following steps to determine the percentage of the cache used by an individual object at a given point in time:

1. Find the Oracle internal object number of the segment by entering the following query:

   ```
   SELECT DATA_OBJECT_ID, OBJECT_TYPE
     FROM DBA_OBJECTS
    WHERE OBJECT_NAME = UPPER('segment_name');
   ```

   Because two objects can have the same name (if they are different types of objects), use the OBJECT_TYPE column to identify the object of interest.

2. Find the number of buffers in the buffer cache for SEGMENT_NAME:

   ```
   SELECT COUNT(*) BUFFERS
     FROM V$BH
    WHERE OBJD = data_object_id_value;
   ```

   where *data_object_id_value* is from step 1.

3. Find the number of buffers in the instance:

   ```
   SELECT NAME, BLOCK_SIZE, SUM(BUFFERS)
     FROM V$BUFFER_POOL
    GROUP BY NAME, BLOCK_SIZE
    HAVING SUM(BUFFERS) > 0;
   ```

4. Calculate the ratio of buffers to total buffers to obtain the percentage of the cache currently used by SEGMENT_NAME:

```
% cache used by segment_name = [buffers(Step2)/total buffers(Step3)]
```

Note: This technique works only for a single segment. You must run the query for each partition for a partitioned object.

KEEP Pool

If there are certain segments in your application that are referenced frequently, then store the blocks from those segments in a separate cache called the KEEP buffer pool. Memory is allocated to the KEEP buffer pool by setting the parameter DB_KEEP_CACHE_SIZE to the required size. The memory for the KEEP pool is not a subset of the default pool. Typical segments that can be kept are small reference tables that are used frequently. Application developers and DBAs can determine which tables are candidates.

You can check the number of blocks from candidate tables by querying V$BH, as described in "Determining Which Segments Have Many Buffers in the Pool" on page 7-17.

Note: The NOCACHE clause has no effect on a table in the KEEP cache.

The goal of the KEEP buffer pool is to retain objects in memory, thus avoiding I/O operations. The size of the KEEP buffer pool, therefore, depends on the objects that you want to keep in the buffer cache. You can compute an approximate size for the KEEP buffer pool by adding together the blocks used by all objects assigned to this pool. If you gather statistics on the segments, you can query DBA_TABLES.BLOCKS and DBA_TABLES.EMPTY_BLOCKS to determine the number of blocks used.

Calculate the hit ratio by taking two snapshots of system performance at different times, using the previous query. Subtract the more recent values for `physical reads`, `block gets`, and `consistent gets` from the older values, and use the results to compute the hit ratio.

A buffer pool hit ratio of 100% might not be optimal. Often, you can decrease the size of your KEEP buffer pool and still maintain a sufficiently high hit ratio. Allocate blocks removed from the KEEP buffer pool to other buffer pools.

Note: If an object grows in size, then it might no longer fit in the KEEP buffer pool. You will begin to lose blocks out of the cache.

Each object kept in memory results in a trade-off. It is beneficial to keep frequently-accessed blocks in the cache, but retaining infrequently-used blocks results in less space for other, more active blocks.

RECYCLE Pool

It is possible to configure a RECYCLE buffer pool for blocks belonging to those segments that you do not want to remain in memory. The RECYCLE pool is good for segments that are scanned rarely or are not referenced frequently. If an application accesses the blocks of a very large object in a random fashion, then there is little chance of reusing a block stored in the buffer pool before it is aged out. This is true regardless of the size of the buffer pool (given the constraint of the amount of available physical memory). Consequently, the object's blocks need not be cached; those cache buffers can be allocated to other objects.

Memory is allocated to the RECYCLE buffer pool by setting the parameter DB_RECYCLE_CACHE_SIZE to the required size. This memory for the RECYCLE buffer pool is not a subset of the default pool.

Do not discard blocks from memory too quickly. If the buffer pool is too small, then blocks can age out of the cache before the transaction or SQL statement has completed execution. For example, an application might select a value from a table, use the value to process some data, and then update the record. If the block is removed from the cache after the SELECT statement, then it must be read from disk again to perform the update. The block should be retained for the duration of the user transaction.

Configuring and Using the Shared Pool and Large Pool

Oracle uses the shared pool to cache many different types of data. Cached data includes the textual and executable forms of PL/SQL blocks and SQL statements, dictionary cache data, and other data.

Proper use and sizing of the shared pool can reduce resource consumption in at least four ways:

1. Parse overhead is avoided if the SQL statement is already in the shared pool. This saves CPU resources on the host and elapsed time for the end user.
2. Latching resource usage is significantly reduced, which results in greater scalability.
3. Shared pool memory requirements are reduced, because all applications use the same pool of SQL statements and dictionary resources.

4. I/O resources are saved, because dictionary elements that are in the shared pool do not require disk access.

This section covers the following:

- Shared Pool Concepts
- Using the Shared Pool Effectively
- Sizing the Shared Pool
- Interpreting Shared Pool Statistics
- Using the Large Pool
- Using CURSOR_SPACE_FOR_TIME
- Caching Session Cursors
- Configuring the Reserved Pool
- Keeping Large Objects to Prevent Aging
- CURSOR_SHARING for Existing Applications
- Maintaining Connections

Shared Pool Concepts

The main components of the shared pool are the library cache and the dictionary cache. The library cache stores the executable (parsed or compiled) form of recently referenced SQL and PL/SQL code. The dictionary cache stores data referenced from the data dictionary. Many of the caches in the shared pool automatically increase or decrease in size, as needed, including the library cache and the dictionary cache. Old entries are aged out of these caches to accommodate new entries when the shared pool does not have free space.

A cache miss on the data dictionary cache or library cache is more expensive than a miss on the buffer cache. For this reason, the shared pool should be sized to ensure that frequently used data is cached.

A number of features make large memory allocations in the shared pool: for example, the shared server, parallel query, or Recovery Manager. Oracle recommends segregating the SGA memory used by these features by configuring a distinct memory area, called the large pool.

> **See Also:** "Using the Large Pool" on page 7-36 for more information on configuring the large pool

Allocation of memory from the shared pool is performed in chunks. This allows large objects (over 5k) to be loaded into the cache without requiring a single contiguous area, hence reducing the possibility of running out of enough contiguous memory due to fragmentation.

Infrequently, Java, PL/SQL, or SQL cursors may make allocations out of the shared pool that are larger than 5k. To allow these allocations to occur most efficiently, Oracle segregates a small amount of the shared pool. This memory is used if the shared pool does not have enough space. The segregated area of the shared pool is called the reserved pool**.**

> **See Also:** "Configuring the Reserved Pool" on page 7-42 for more information on the reserved area of the shared pool

Dictionary Cache Concepts

Information stored in the data dictionary cache includes usernames, segment information, profile data, tablespace information, and sequence numbers. The dictionary cache also stores descriptive information, or metadata, about schema objects. Oracle uses this metadata when parsing SQL cursors or during the compilation of PL/SQL programs.

Library Cache Concepts

The library cache holds executable forms of SQL cursors, PL/SQL programs, and Java classes. This section focuses on tuning as it relates to cursors, PL/SQL programs, and Java classes. These are collectively referred to as application code.

When application code is run, Oracle attempts to reuse existing code if it has been executed previously and can be shared. If the parsed representation of the statement does exist in the library cache and it can be shared, then Oracle reuses the existing code. This is known as a soft parse, or a library cache hit. If Oracle is unable to use existing code, then a new executable version of the application code must be built. This is known as a hard parse, or a library cache miss. See "SQL Sharing Criteria" on page 7-23 for details on when a SQL and PL/SQL statements can be shared.

Library cache misses can occur on either the parse step or the execute step when processing a SQL statement. When an application makes a parse call for a SQL statement, if the parsed representation of the statement does not already exist in the library cache, then Oracle parses the statement and stores the parsed form in the shared pool. This is a hard parse. You might be able to reduce library cache misses on parse calls by ensuring that all shareable SQL statements are in the shared pool whenever possible.

If an application makes an execute call for a SQL statement, and if the executable portion of the previously built SQL statement has been aged out (that is, deallocated) from the library cache to make room for another statement, then Oracle implicitly reparses the statement, creating a new shared SQL area for it, and executes it. This also results in a hard parse. Usually, you can reduce library cache misses on execution calls by allocating more memory to the library cache.

In order to perform a hard parse, Oracle uses more resources than during a soft parse. Resources used for a soft parse include CPU and library cache latch gets. Resources required for a hard parse include additional CPU, library cache latch gets, and shared pool latch gets. See "SQL Execution Efficiency" on page 2-17 for a discussion of hard and soft parsing.

SQL Sharing Criteria

Oracle automatically determines whether a SQL statement or PL/SQL block being issued is identical to another statement currently in the shared pool.

Oracle performs the following steps for the comparison:

1. The text of the statement issued is compared to existing statements in the shared pool.
2. The text of the statement is hashed. If there is no matching hash value, then the SQL statement does not currently exist in the shared pool, and a hard parse is performed.
3. If there is a matching hash value for an existing SQL statement in the shared pool, then Oracle compares the text of the matched statement to the text of the statement hashed to see if they are identical. The text of the SQL statements or PL/SQL blocks must be identical, character for character, including spaces, case, and comments. For example, the following statements cannot use the same shared SQL area:

   ```
   SELECT * FROM employees;
   SELECT * FROM Employees;
   SELECT *  FROM employees;
   ```

   Usually, SQL statements that differ only in literals cannot use the same shared SQL area. For example, the following SQL statements do not resolve to the same SQL area:

   ```
   SELECT count(1) FROM employees WHERE manager_id = 121;
   SELECT count(1) FROM employees WHERE manager_id = 247;
   ```

The only exception to this rule is when the parameter CURSOR_SHARING has been set to SIMILAR or FORCE. Similar statements can share SQL areas when the CURSOR_SHARING parameter is set to SIMILAR or FORCE. The costs and benefits involved in using CURSOR_SHARING are explained later in this section.

> **See Also:** *Oracle Database Reference* for more information on the CURSOR_SHARING parameter

4. The objects referenced in the issued statement are compared to the referenced objects of all existing statements in the shared pool to ensure that they are identical.

   References to schema objects in the SQL statements or PL/SQL blocks must resolve to the same object in the same schema. For example, if two users each issue the following SQL statement:

   ```
   SELECT * FROM employees;
   ```

   and they each have their own employees table, then this statement is not considered identical, because the statement references different tables for each user.

5. Bind variables in the SQL statements must match in name, datatype, and length.

   For example, the following statements cannot use the same shared SQL area, because the bind variable names differ:

   ```
   SELECT * FROM employees WHERE department_id = :department_id;
   SELECT * FROM employees WHERE department_id = :dept_id;
   ```

   Many Oracle products, such as Oracle Forms and the precompilers, convert the SQL before passing statements to the database. Characters are uniformly changed to uppercase, white space is compressed, and bind variables are renamed so that a consistent set of SQL statements is produced.

6. The session's environment must be identical. For example, SQL statements must be optimized using the same optimization goal.

Using the Shared Pool Effectively

An important purpose of the shared pool is to cache the executable versions of SQL and PL/SQL statements. This allows multiple executions of the same SQL or PL/SQL code to be performed without the resources required for a hard parse, which results in significant reductions in CPU, memory, and latch usage.

The shared pool is also able to support unshared SQL in data warehousing applications, which execute low-concurrency, high-resource SQL statements. In this situation, using unshared SQL with literal values is recommended. Using literal values rather than bind variables allows the optimizer to make good column selectivity estimates, thus providing an optimal data access plan.

See Also: *Oracle Data Warehousing Guide*

In an OLTP system, there are a number of ways to ensure efficient use of the shared pool and related resources. Discuss the following items with application developers and agree on strategies to ensure that the shared pool is used effectively:

- Shared Cursors
- Single-User Logon and Qualified Table Reference
- Use of PL/SQL
- Avoid Performing DDL
- Cache Sequence Numbers
- Cursor Access and Management

Efficient use of the shared pool in high-concurrency OLTP systems significantly reduces the probability of parse-related application scalability issues.

Shared Cursors

Reuse of shared SQL for multiple users running the same application, avoids hard parsing. Soft parses provide a significant reduction in the use of resources such as the shared pool and library cache latches. To share cursors, do the following:

- Use bind variables rather than literals in SQL statements whenever possible. For example, the following two statements cannot use the same shared area because they do not match character for character:

  ```
  SELECT employee_id FROM employees WHERE department_id = 10;
  SELECT employee_id FROM employees WHERE department_id = 20;
  ```

  By replacing the literals with a bind variable, only one SQL statement would result, which could be executed twice:

  ```
  SELECT employee_id FROM employees WHERE department_id = :dept_id;
  ```

> **Note:** For existing applications where rewriting the code to use bind variables is impractical, it is possible to use the CURSOR_SHARING initialization parameter to avoid some of the hard parse overhead. For more information see section "CURSOR_SHARING for Existing Applications" on page 7-45.

- Avoid application designs that result in large numbers of users issuing dynamic, unshared SQL statements. Typically, the majority of data required by most users can be satisfied using preset queries. Use dynamic SQL where such functionality is required.
- Be sure that users of the application do not change the optimization approach and goal for their individual sessions.
- Establish the following policies for application developers:
  - Standardize naming conventions for bind variables and spacing conventions for SQL statements and PL/SQL blocks.
  - Consider using stored procedures whenever possible. Multiple users issuing the same stored procedure use the same shared PL/SQL area automatically. Because stored procedures are stored in a parsed form, their use reduces runtime parsing.
- For SQL statements which are identical but are not being shared, you can query V$SQL_SHARED_CURSOR to determine why the cursors are not shared. This would include optimizer settings and bind variable mismatches.

Single-User Logon and Qualified Table Reference

Large OLTP systems where users log in to the database as their own user ID can benefit from explicitly qualifying the segment owner, rather than using public synonyms. This significantly reduces the number of entries in the dictionary cache. For example:

```
SELECT employee_id FROM hr.employees WHERE department_id = :dept_id;
```

An alternative to qualifying table names is to connect to the database through a single user ID, rather than individual user IDs. User-level validation can take place locally on the middle tier. Reducing the number of distinct userIDs also reduces the load on the dictionary cache.

Use of PL/SQL

Using stored PL/SQL packages can overcome many of the scalability issues for systems with thousands of users, each with individual user sign-on and public synonyms. This is because a package is executed as the owner, rather than the caller, which reduces the dictionary cache load considerably.

Note: Oracle Corporation encourages the use of definer-rights packages to overcome scalability issues. The benefits of reduced dictionary cache load are not as obvious with invoker-rights packages.

Avoid Performing DDL

Avoid performing DDL operations on high-usage segments during peak hours. Performing DDL on such segments often results in the dependent SQL being invalidated and hence reparsed on a later execution.

Cache Sequence Numbers

Allocating sufficient cache space for frequently updated sequence numbers significantly reduces the frequency of dictionary cache locks, which improves scalability. The CACHE keyword on the CREATE SEQUENCE or ALTER SEQUENCE statement lets you configure the number of cached entries for each sequence.

> **See Also:** *Oracle Database SQL Reference* for details on the CREATE SEQUENCE and ALTER SEQUENCE statements

Cursor Access and Management

Depending on the Oracle application tool you are using, it is possible to control how frequently your application performs parse calls.

The frequency with which your application either closes cursors or reuses existing cursors for new SQL statements affects the amount of memory used by a session and often the amount of parsing performed by that session.

An application that closes cursors or reuses cursors (for a different SQL statement), does not need as much session memory as an application that keeps cursors open. Conversely, that same application may need to perform more parse calls, using extra CPU and Oracle resources.

Cursors associated with SQL statements that are not executed frequently can be closed or reused for other statements, because the likelihood of reexecuting (and reparsing) that statement is low.

Extra parse calls are required when a cursor containing a SQL statement that will be reexecuted is closed or reused for another statement. Had the cursor remained open, it could have been reused without the overhead of issuing a parse call.

The ways in which you control cursor management depends on your application development tool. The following sections introduce the methods used for some Oracle tools.

> **See Also:**
>
> - The tool-specific documentation for more information about each tool
> - *Oracle Database Concepts* for more information on cursors shared SQL

Reducing Parse Calls with OCI When using Oracle Call Interface (OCI), do not close and reopen cursors that you will be reexecuting. Instead, leave the cursors open, and change the literal values in the bind variables before execution.

Avoid reusing statement handles for new SQL statements when the existing SQL statement will be reexecuted in the future.

Reducing Parse Calls with the Oracle Precompilers When using the Oracle precompilers, you can control when cursors are closed by setting precompiler clauses. In Oracle mode, the clauses are as follows:

- `HOLD_CURSOR = YES`
- `RELEASE_CURSOR = NO`
- `MAXOPENCURSORS = desired_value`

Oracle Corporation recommends that you not use ANSI mode, in which the values of `HOLD_CURSOR` and `RELEASE_CURSOR` are switched.

The precompiler clauses can be specified on the precompiler command line or within the precompiler program. With these clauses, you can employ different strategies for managing cursors during execution of the program.

> **See Also:** Your language's precompiler manual for more information on these clauses

Reducing Parse Calls with SQLJ Prepare the statement, then reexecute the statement with the new values for the bind variables. The cursor stays open for the duration of the session.

Reducing Parse Calls with JDBC Avoid closing cursors if they will be reexecuted, because the new literal values can be bound to the cursor for reexecution. Alternatively, JDBC provides a SQL statement cache within the JDBC client using the `setStmtCacheSize()` method. Using this method, JDBC creates a SQL statement cache that is local to the JDBC program.

> **See Also:** *Oracle Database JDBC Developer's Guide and Reference* for more information on using the JDBC SQL statement cache

Reducing Parse Calls with Oracle Forms With Oracle Forms, it is possible to control some aspects of cursor management. You can exercise this control either at the trigger level, at the form level, or at run time.

Sizing the Shared Pool

When configuring a brand new instance, it is impossible to know the correct size to make the shared pool cache. Typically, a DBA makes a first estimate for the cache size, then runs a representative workload on the instance, and examines the relevant statistics to see whether the cache is under-configured or over-configured.

For most OLTP applications, shared pool size is an important factor in application performance. Shared pool size is less important for applications that issue a very limited number of discrete SQL statements, such as decision support systems (DSS).

If the shared pool is too small, then extra resources are used to manage the limited amount of available space. This consumes CPU and latching resources, and causes contention. Optimally, the shared pool should be just large enough to cache frequently accessed objects. Having a significant amount of free memory in the shared pool is a waste of memory. When examining the statistics after the database has been running, a DBA should check that none of these mistakes are in the workload.

Shared Pool: Library Cache Statistics

When sizing the shared pool, the goal is to ensure that SQL statements that will be executed multiple times are cached in the library cache, without allocating too much memory.

The statistic that shows the amount of reloading (that is, reparsing) of a previously cached SQL statement that was aged out of the cache is the RELOADS column in the V$LIBRARYCACHE view. In an application that reuses SQL effectively, on a system with an optimal shared pool size, the RELOADS statistic will have a value near zero.

The INVALIDATIONS column in V$LIBRARYCACHE view shows the number of times library cache data was invalidated and had to be reparsed. INVALIDATIONS should be near zero. This means SQL statements that could have been shared were invalidated by some operation (for example, a DDL). This statistic should be near zero on OLTP systems during peak loads.

Another key statistic is the amount of free memory in the shared pool at peak times. The amount of free memory can be queried from V$SGASTAT, looking at the free memory for the shared pool. Optimally, free memory should be as low as possible, without causing any reloads on the system.

Lastly, a broad indicator of library cache health is the library cache hit ratio. This value should be considered along with the other statistics discussed in this section and other data, such as the rate of hard parsing and whether there is any shared pool or library cache latch contention.

These statistics are discussed in more detail in the following section.

V$LIBRARYCACHE

You can monitor statistics reflecting library cache activity by examining the dynamic performance view V$LIBRARYCACHE. These statistics reflect all library cache activity since the most recent instance startup.

Each row in this view contains statistics for one type of item kept in the library cache. The item described by each row is identified by the value of the NAMESPACE column. Rows with the following NAMESPACE values reflect library cache activity for SQL statements and PL/SQL blocks:

- SQL AREA
- TABLE/PROCEDURE
- BODY
- TRIGGER

Rows with other NAMESPACE values reflect library cache activity for object definitions that Oracle uses for dependency maintenance.

> **See Also:** *Oracle Database Reference* for information about the dynamic performance V$LIBRARYCACHE view

To examine each namespace individually, use the following query:

```
SELECT NAMESPACE, PINS, PINHITS, RELOADS, INVALIDATIONS
  FROM V$LIBRARYCACHE
 ORDER BY NAMESPACE;
```

The output of this query could look like the following:

```
NAMESPACE             PINS    PINHITS    RELOADS INVALIDATIONS
--------------- ---------- ---------- ---------- -------------
BODY                  8870       8819          0             0
CLUSTER                393        380          0             0
INDEX                   29          0          0             0
OBJECT                   0          0          0             0
PIPE                 55265      55263          0             0
SQL AREA          21536413   21520516      11204             2
TABLE/PROCEDURE   10775684   10774401          0             0
TRIGGER               1852       1844          0             0
```

To calculate the library cache hit ratio, use the following formula:

```
Library Cache Hit Ratio = sum(pinhits) / sum(pins)
```

Using the library cache hit ratio formula, the cache hit ratio is the following:

```
SUM(PINHITS)/SUM(PINS)
----------------------
            .999466248
```

Note: These queries return data from instance startup, rather than statistics gathered during an interval; interval statistics can better pinpoint the problem.

See Also: Chapter 6, "Automatic Performance Diagnostics" for information on how gather information over an interval

Examining the returned data leads to the following observations:

- For the SQL AREA namespace, there were 21,536,413 executions.
- 11,204 of the executions resulted in a library cache miss, requiring Oracle to implicitly reparse a statement or block or reload an object definition because it aged out of the library cache (that is, a RELOAD).

- SQL statements were invalidated two times, again causing library cache misses.
- The hit percentage is about 99.94%. This means that only .06% of executions resulted in reparsing.

The amount of free memory in the shared pool is reported in V$SGASTAT. Report the current value from this view using the following query:

```
SELECT * FROM V$SGASTAT
 WHERE NAME = 'free memory'
   AND POOL = 'shared pool';

The output will be similar to the following:

POOL        NAME                            BYTES
----------- ------------------------- ----------
shared pool free memory                   4928280
```

If free memory is always available in the shared pool, then increasing the size of the pool offers little or no benefit. However, just because the shared pool is full does not necessarily mean there is a problem. It may be indicative of a well-configured system.

Shared Pool Advisory Statistics

The amount of memory available for the library cache can drastically affect the parse rate of an Oracle instance. The shared pool advisory statistics provide a database administrator with information about library cache memory, allowing a DBA to predict how changes in the size of the shared pool can affect aging out of objects in the shared pool.

The shared pool advisory statistics track the library cache's use of shared pool memory and predict how the library cache will behave in shared pools of different sizes. Two fixed views provide the information to determine how much memory the library cache is using, how much is currently pinned, how much is on the shared pool's LRU list, as well as how much time might be lost or gained by changing the size of the shared pool.

The following views of the shared pool advisory statistics are available. These views display any data when shared pool advisory is on. These statistics reset when the advisory is turned off.

V$SHARED_POOL_ADVICE This view displays information about estimated parse time in the shared pool for different pool sizes. The sizes range from 10% of the current shared pool size or the amount of pinned library cache memory, whichever

is higher, to 200% of the current shared pool size, in equal intervals. The value of the interval depends on the current size of the shared pool.

V$LIBRARY_CACHE_MEMORY This view displays information about memory allocated to library cache memory objects in different namespaces. A memory object is an internal grouping of memory for efficient management. A library cache object may consist of one or more memory objects.

V$JAVA_POOL_ADVICE and V$JAVA_LIBRARY_CACHE_MEMORY These views contain Java pool advisory statistics that track information about library cache memory used for Java and predict how changes in the size of the Java pool can affect the parse rate.

V$JAVA_POOL_ADVICE displays information about estimated parse time in the Java pool for different pool sizes. The sizes range from 10% of the current Java pool size or the amount of pinned Java library cache memory, whichever is higher, to 200% of the current Java pool size, in equal intervals. The value of the interval depends on the current size of the Java pool.

> **See Also:** *Oracle Database Reference* for information about the dynamic performance V$SHARED_POOL_ADVICE, V$LIBRARY_CACHE_MEMORY, V$JAVA_POOL_ADVICE, and V$JAVA_LIBRARY_CACHE_MEMORY view

Shared Pool: Dictionary Cache Statistics

Typically, if the shared pool is adequately sized for the library cache, it will also be adequate for the dictionary cache data.

Misses on the data dictionary cache are to be expected in some cases. On instance startup, the data dictionary cache contains no data. Therefore, any SQL statement issued is likely to result in cache misses. As more data is read into the cache, the likelihood of cache misses decreases. Eventually, the database reaches a steady state, in which the most frequently used dictionary data is in the cache. At this point, very few cache misses occur.

Each row in the V$ROWCACHE view contains statistics for a single type of data dictionary item. These statistics reflect all data dictionary activity since the most recent instance startup. The columns in the V$ROWCACHE view that reflect the use and effectiveness of the data dictionary cache are listed in Table 7–2.

Table 7–2 V$ROWCACHE Columns

Column	Description
PARAMETER	Identifies a particular data dictionary item. For each row, the value in this column is the item prefixed by dc_. For example, in the row that contains statistics for file descriptions, this column has the value dc_files.
GETS	Shows the total number of requests for information on the corresponding item. For example, in the row that contains statistics for file descriptions, this column has the total number of requests for file description data.
GETMISSES	Shows the number of data requests which were not satisfied by the cache, requiring an I/O.
MODIFICATIONS	Shows the number of times data in the dictionary cache was updated.

Use the following query to monitor the statistics in the V$ROWCACHE view over a period of time while your application is running. The derived column PCT_SUCC_GETS can be considered the item-specific hit ratio:

```
column parameter format a21
column pct_succ_gets format 999.9
column updates format 999,999,999

SELECT parameter
     , sum(gets)
     , sum(getmisses)
     , 100*sum(gets - getmisses) / sum(gets)  pct_succ_gets
     , sum(modifications)                     updates
  FROM V$ROWCACHE
 WHERE gets > 0
 GROUP BY parameter;
```

The output of this query will be similar to the following:

```
PARAMETER             SUM(GETS) SUM(GETMISSES) PCT_SUCC_GETS      UPDATES
--------------------- ---------- -------------- ------------ ------------
dc_database_links             81              1         98.8            0
dc_free_extents            44876          20301         54.8       40,453
dc_global_oids                42              9         78.6            0
dc_histogram_defs           9419            651         93.1            0
dc_object_ids              29854            239         99.2           52
dc_objects                 33600            590         98.2           53
dc_profiles                19001              1        100.0            0
```

```
dc_rollback_segments       47244            16         100.0          19
dc_segments               100467         19042          81.0      40,272
dc_sequence_grants           119            16          86.6           0
dc_sequences               26973            16          99.9      26,811
dc_synonyms                 6617           168          97.5           0
dc_tablespace_quotas         120             7          94.2          51
dc_tablespaces            581248            10         100.0           0
dc_used_extents            51418         20249          60.6      42,811
dc_user_grants             76082            18         100.0           0
dc_usernames              216860            12         100.0           0
dc_users                  376895            22         100.0           0
```

Examining the data returned by the sample query leads to these observations:

- There are large numbers of misses and updates for used extents, free extents, and segments. This implies that the instance had a significant amount of dynamic space extension.
- Based on the percentage of successful gets, and comparing that statistic with the actual number of gets, the shared pool is large enough to store dictionary cache data adequately.

It is also possible to calculate an overall dictionary cache hit ratio using the following formula; however, summing up the data over all the caches will lose the finer granularity of data:

```
SELECT (SUM(GETS - GETMISSES - FIXED)) / SUM(GETS) "ROW CACHE" FROM V$ROWCACHE;
```

Interpreting Shared Pool Statistics

Shared pool statistics indicate adjustments that can be made. The following sections describe some of your choices.

Increasing Memory Allocation

Increasing the amount of memory for the shared pool increases the amount of memory available to both the library cache and the dictionary cache.

Allocating Additional Memory for the Library Cache To ensure that shared SQL areas remain in the cache after their SQL statements are parsed, increase the amount of memory available to the library cache until the V$LIBRARYCACHE.RELOADS value is near zero. To increase the amount of memory available to the library cache, increase the value of the initialization parameter SHARED_POOL_SIZE. The maximum value for this parameter depends on your operating system. This

measure reduces implicit reparsing of SQL statements and PL/SQL blocks on execution.

To take advantage of additional memory available for shared SQL areas, you might also need to increase the number of cursors permitted for a session. You can do this by increasing the value of the initialization parameter OPEN_CURSORS.

Allocating Additional Memory to the Data Dictionary Cache Examine cache activity by monitoring the GETS and GETMISSES columns. For frequently accessed dictionary caches, the ratio of total GETMISSES to total GETS should be less than 10% or 15%, depending on the application.

Consider increasing the amount of memory available to the cache if all of the following are true:

- Your application is using the shared pool effectively. See "Using the Shared Pool Effectively" on page 7-24.
- Your system has reached a steady state, any of the item-specific hit ratios are low, and there are a large numbers of gets for the caches with low hit ratios.

Increase the amount of memory available to the data dictionary cache by increasing the value of the initialization parameter SHARED_POOL_SIZE.

Reducing Memory Allocation

If your RELOADS are near zero, and if you have a small amount of free memory in the shared pool, then the shared pool is probably large enough to hold the most frequently accessed data.

If you always have significant amounts of memory free in the shared pool, and if you would like to allocate this memory elsewhere, then you might be able to reduce the shared pool size and still maintain good performance.

To make the shared pool smaller, reduce the size of the cache by changing the value for the parameter SHARED_POOL_SIZE.

Using the Large Pool

Unlike the shared pool, the large pool does not have an LRU list. Oracle does not attempt to age objects out of the large pool.

You should consider configuring a large pool if your instance uses any of the following:

- Parallel query

Parallel query uses shared pool memory to cache parallel execution message buffers.

> **See Also:** *Oracle Data Warehousing Guide* for more information on sizing the large pool with parallel query

- Recovery Manager

  Recovery Manager uses the shared pool to cache I/O buffers during backup and restore operations. For I/O server processes and backup and restore operations, Oracle allocates buffers that are a few hundred kilobytes in size.

  > **See Also:** *Oracle Database Recovery Manager Reference* for more information on sizing the large pool when using Recovery Manager

- Shared server

  In a shared server architecture, the session memory for each client process is included in the shared pool.

Tuning the Large Pool and Shared Pool for the Shared Server Architecture

As Oracle allocates shared pool memory for shared server session memory, the amount of shared pool memory available for the library cache and dictionary cache decreases. If you allocate this session memory from a different pool, then Oracle can use the shared pool primarily for caching shared SQL and not incur the performance overhead from shrinking the shared SQL cache.

Oracle recommends using the large pool to allocate the shared server-related User Global Area (UGA), rather that using the shared pool. This is because Oracle uses the shared pool to allocate System Global Area (SGA) memory for other purposes, such as shared SQL and PL/SQL procedures. Using the large pool instead of the shared pool decreases fragmentation of the shared pool.

To store shared server-related UGA in the large pool, specify a value for the initialization parameter `LARGE_POOL_SIZE`. To see which pool (shared pool or large pool) the memory for an object resides in, check the column `POOL` in `V$SGASTAT`. The large pool is not configured by default; its minimum value is 300K. If you do not configure the large pool, then Oracle uses the shared pool for shared server user session memory.

Configure the size of the large pool based on the number of simultaneously active sessions. Each application requires a different amount of memory for session information, and your configuration of the large pool or SGA should reflect the

memory requirement. For example, assuming that the shared server requires 200K to 300K to store session information for each active session. If you anticipate 100 active sessions simultaneously, then configure the large pool to be 30M, or increase the shared pool accordingly if the large pool is not configured.

Note: If a shared server architecture is used, then Oracle allocates some fixed amount of memory (about 10K) for each configured session from the shared pool, even if you have configured the large pool. The `CIRCUITS` initialization parameter specifies the maximum number of concurrent shared server connections that the database allows.

See Also:

- *Oracle Database Concepts* for more information about the large pool
- *Oracle Database Reference* for complete information about initialization parameters

Determining an Effective Setting for Shared Server UGA Storage The exact amount of UGA Oracle uses depends on each application. To determine an effective setting for the large or shared pools, observe UGA use for a typical user and multiply this amount by the estimated number of user sessions.

Even though use of shared memory increases with shared servers, the total amount of memory use decreases. This is because there are fewer processes; therefore, Oracle uses less PGA memory with shared servers when compared to dedicated server environments.

Note: For best performance with sorts using shared servers, set `SORT_AREA_SIZE` and `SORT_AREA_RETAINED_SIZE` to the same value. This keeps the sort result in the large pool instead of having it written to disk.

Checking System Statistics in the V$SESSTAT View Oracle collects statistics on total memory used by a session and stores them in the dynamic performance view V$SESSTAT. Table 7–3 lists these statistics.

Table 7–3 V$SESSTAT Statistics Reflecting Memory

Statistic	Description
session UGA memory	The value of this statistic is the amount of memory in bytes allocated to the session.
Session UGA memory max	The value of this statistic is the maximum amount of memory in bytes ever allocated to the session.

To find the value, query V$STATNAME. If you are using a shared server, you can use the following query to decide how much larger to make the shared pool. Issue the following queries while your application is running:

```
SELECT SUM(VALUE) || ' BYTES' "TOTAL MEMORY FOR ALL SESSIONS"
    FROM V$SESSTAT, V$STATNAME
    WHERE NAME = 'session uga memory'
    AND V$SESSTAT.STATISTIC# = V$STATNAME.STATISTIC#;

SELECT SUM(VALUE) || ' BYTES' "TOTAL MAX MEM FOR ALL SESSIONS"
    FROM V$SESSTAT, V$STATNAME
    WHERE NAME = 'session uga memory max'
    AND V$SESSTAT.STATISTIC# = V$STATNAME.STATISTIC#;
```

These queries also select from the dynamic performance view V$STATNAME to obtain internal identifiers for session memory and max session memory. The results of these queries could look like the following:

```
TOTAL MEMORY FOR ALL SESSIONS
-----------------------------
157125 BYTES

TOTAL MAX MEM FOR ALL SESSIONS
------------------------------
417381 BYTES
```

The result of the first query indicates that the memory currently allocated to all sessions is 157,125 bytes. This value is the total memory with a location that depends on how the sessions are connected to Oracle. If the sessions are connected to dedicated server processes, then this memory is part of the memories of the user processes. If the sessions are connected to shared server processes, then this memory is part of the shared pool.

The result of the second query indicates that the sum of the maximum size of the memory for all sessions is 417,381 bytes. The second result is greater than the first

because some sessions have deallocated memory since allocating their maximum amounts.

If you use a shared server architecture, you can use the result of either of these queries to determine how much larger to make the shared pool. The first value is likely to be a better estimate than the second unless nearly all sessions are likely to reach their maximum allocations at the same time.

Limiting Memory Use for Each User Session by Setting PRIVATE_SGA You can set the PRIVATE_SGA resource limit to restrict the memory used by each client session from the SGA. PRIVATE_SGA defines the number of bytes of memory used from the SGA by a session. However, this parameter is used rarely, because most DBAs do not limit SGA consumption on a user-by-user basis.

> **See Also:** *Oracle Database SQL Reference*, ALTER RESOURCE COST statement, for more information about setting the PRIVATE_SGA resource limit

Reducing Memory Use with Three-Tier Connections If you have a high number of connected users, then you can reduce memory usage by implementing three-tier connections. This by-product of using a transaction process (TP) monitor is feasible only with pure transactional models, because locks and uncommitted DMLs cannot be held between calls. A shared server environment offers the following advantages:

- It is much less restrictive of the application design than a TP monitor.
- It dramatically reduces operating system process count and context switches by enabling users to share a pool of servers.
- It substantially reduces overall memory usage, even though more SGA is used in shared server mode.

Using CURSOR_SPACE_FOR_TIME

If you have no library cache misses, then you might be able to accelerate execution calls by setting the value of the initialization parameter CURSOR_SPACE_FOR_TIME to `true`. This parameter specifies whether a cursor can be deallocated from the library cache to make room for a new SQL statement. CURSOR_SPACE_FOR_TIME has the following values meanings:

- If CURSOR_SPACE_FOR_TIME is set to `false` (the default), then a cursor can be deallocated from the library cache regardless of whether application cursors

associated with its SQL statement are open. In this case, Oracle must verify that the cursor containing the SQL statement is in the library cache.

- If CURSOR_SPACE_FOR_TIME is set to true, then a cursor can be deallocated only when all application cursors associated with its statement are closed. In this case, Oracle need not verify that a cursor is in the cache, because it cannot be deallocated while an application cursor associated with it is open.

Setting the value of the parameter to true saves Oracle a small amount of time and can slightly improve the performance of execution calls. This value also prevents the deallocation of cursors until associated application cursors are closed.

Do not set the value of CURSOR_SPACE_FOR_TIME to true if you have found library cache misses on execution calls. Such library cache misses indicate that the shared pool is not large enough to hold the shared SQL areas of all concurrently open cursors. If the value is true, and if the shared pool has no space for a new SQL statement, then the statement cannot be parsed, and Oracle returns an error saying that there is no more shared memory. If the value is false, and if there is no space for a new statement, then Oracle deallocates an existing cursor. Although deallocating a cursor could result in a library cache miss later (only if the cursor is reexecuted), it is preferable to an error halting your application because a SQL statement cannot be parsed.

Do not set the value of CURSOR_SPACE_FOR_TIME to true if the amount of memory available to each user for private SQL areas is scarce. This value also prevents the deallocation of private SQL areas associated with open cursors. If the private SQL areas for all concurrently open cursors fills your available memory so that there is no space for a new SQL statement, then the statement cannot be parsed. Oracle returns an error indicating that there is not enough memory.

Caching Session Cursors

If an application repeatedly issues parse calls on the same set of SQL statements, then the reopening of the session cursors can affect system performance. To minimize the impact on performance, session cursors can be stored in a session cursor cache. These cursors are those that have been closed by the application and can be reused. This feature can be particularly useful for applications that use Oracle Forms, because switching from one form to another closes all session cursors associated with the first form.

Oracle checks the library cache to determine whether more than three parse requests have been issued on a given statement. If so, then Oracle assumes that the session cursor associated with the statement should be cached and moves the cursor

into the session cursor cache. Subsequent requests to parse that SQL statement by the same session then find the cursor in the session cursor cache.

To enable caching of session cursors, you must set the initialization parameter SESSION_CACHED_CURSORS. The value of this parameter is a positive integer specifying the maximum number of session cursors kept in the cache. An LRU algorithm removes entries in the session cursor cache to make room for new entries when needed.

You can also enable the session cursor cache dynamically with the statement:

```
ALTER SESSION SET SESSION_CACHED_CURSORS = value;
```

To determine whether the session cursor cache is sufficiently large for your instance, you can examine the session statistic `session cursor cache hits` in the V$SYSSTAT view. This statistic counts the number of times a parse call found a cursor in the session cursor cache. If this statistic is a relatively low percentage of the total parse call count for the session, then consider setting SESSION_CACHED_CURSORS to a larger value.

Configuring the Reserved Pool

Although Oracle breaks down very large requests for memory into smaller chunks, on some systems there might still be a requirement to find a contiguous chunk (for example, over 5 KB) of memory. (The default minimum reserved pool allocation is 4,400 bytes.)

If there is not enough free space in the shared pool, then Oracle must search for and free enough memory to satisfy this request. This operation could conceivably hold the latch resource for detectable periods of time, causing minor disruption to other concurrent attempts at memory allocation.

Hence, Oracle internally reserves a small memory area in the shared pool that can be used if the shared pool does not have enough space. This reserved pool makes allocation of large chunks more efficient.

By default, Oracle configures a small reserved pool. This memory can be used for operations such as PL/SQL and trigger compilation or for temporary space while loading Java objects. After the memory allocated from the reserved pool is freed, it returns to the reserved pool.

You probably will not need to change the default amount of space Oracle reserves. However, if necessary, the reserved pool size can be changed by setting the SHARED_POOL_RESERVED_SIZE initialization parameter. This parameter sets aside space in the shared pool for unusually large allocations.

For large allocations, Oracle attempts to allocate space in the shared pool in the following order:

1. From the unreserved part of the shared pool.
2. From the reserved pool. If there is not enough space in the unreserved part of the shared pool, then Oracle checks whether the reserved pool has enough space.
3. From memory. If there is not enough space in the unreserved and reserved parts of the shared pool, then Oracle attempts to free enough memory for the allocation. It then retries the unreserved and reserved parts of the shared pool.

Using SHARED_POOL_RESERVED_SIZE

The default value for SHARED_POOL_RESERVED_SIZE is 5% of the SHARED_POOL_SIZE. This means that, by default, the reserved list is configured.

If you set SHARED_POOL_RESERVED_SIZE to more than half of SHARED_POOL_SIZE, then Oracle signals an error. Oracle does not let you reserve too much memory for the reserved pool. The amount of operating system memory, however, might constrain the size of the shared pool. In general, set SHARED_POOL_RESERVED_SIZE to 10% of SHARED_POOL_SIZE. For most systems, this value is sufficient if you have already tuned the shared pool. If you increase this value, then the database takes memory from the shared pool. (This reduces the amount of unreserved shared pool memory available for smaller allocations.)

Statistics from the V$SHARED_POOL_RESERVED view help you tune these parameters. On a system with ample free memory to increase the size of the SGA, the goal is to have the value of REQUEST_MISSES equal zero. If the system is constrained for operating system memory, then the goal is to not have REQUEST_FAILURES or at least prevent this value from increasing.

If you cannot achieve these target values, then increase the value for SHARED_POOL_RESERVED_SIZE. Also, increase the value for SHARED_POOL_SIZE by the same amount, because the reserved list is taken from the shared pool.

> **See Also:** *Oracle Database Reference* for details on setting the LARGE_POOL_SIZE parameter

When SHARED_POOL_RESERVED_SIZE Is Too Small

The reserved pool is too small when the value for REQUEST_FAILURES is more than zero and increasing. To resolve this, increase the value for the SHARED_POOL_

RESERVED_SIZE and SHARED_POOL_SIZE accordingly. The settings you select for these parameters depend on your system's SGA size constraints.

Increasing the value of SHARED_POOL_RESERVED_SIZE increases the amount of memory available on the reserved list without having an effect on users who do not allocate memory from the reserved list.

When SHARED_POOL_RESERVED_SIZE Is Too Large

Too much memory might have been allocated to the reserved list if:

- REQUEST_MISSES is zero or not increasing
- FREE_MEMORY is greater than or equal to 50% of SHARED_POOL_RESERVED_SIZE minimum

If either of these conditions is true, then decrease the value for SHARED_POOL_RESERVED_SIZE.

When SHARED_POOL_SIZE is Too Small

The V$SHARED_POOL_RESERVED fixed view can also indicate when the value for SHARED_POOL_SIZE is too small. This can be the case if REQUEST_FAILURES is greater than zero and increasing.

If you have enabled the reserved list, then decrease the value for SHARED_POOL_RESERVED_SIZE. If you have not enabled the reserved list, then you could increase SHARED_POOL_SIZE.

Keeping Large Objects to Prevent Aging

After an entry has been loaded into the shared pool, it cannot be moved. Sometimes, as entries are loaded and aged, the free memory can become fragmented.

Use the PL/SQL package DBMS_SHARED_POOL to manage the shared pool. Shared SQL and PL/SQL areas age out of the shared pool according to a least recently used (LRU) algorithm, similar to database buffers. To improve performance and prevent reparsing, you might want to prevent large SQL or PL/SQL areas from aging out of the shared pool.

The DBMS_SHARED_POOL package lets you keep objects in shared memory, so that they do not age out with the normal LRU mechanism. By using the DBMS_SHARED_POOL package and by loading the SQL and PL/SQL areas before memory fragmentation occurs, the objects can be kept in memory. This ensures that memory

is available, and it prevents the sudden, inexplicable slowdowns in user response time that occur when SQL and PL/SQL areas are accessed after aging out.

The DBMS_SHARED_POOL package is useful for the following:

- When loading large PL/SQL objects, such as the STANDARD and DIUTIL packages. When large PL/SQL objects are loaded, user response time may be affected if smaller objects that need to age out of the shared pool to make room. In some cases, there might be insufficient memory to load the large objects.
- Frequently executed triggers. You might want to keep compiled triggers on frequently used tables in the shared pool.
- DBMS_SHARED_POOL supports sequences. Sequence numbers are lost when a sequence ages out of the shared pool. DBMS_SHARED_POOL keeps sequences in the shared pool, thus preventing the loss of sequence numbers.

To use the DBMS_SHARED_POOL package to pin a SQL or PL/SQL area, complete the following steps:

1. Decide which packages or cursors to pin in memory.
2. Start up the database.
3. Make the call to DBMS_SHARED_POOL.KEEP to pin your objects.

   This procedure ensures that your system does not run out of shared memory before the kept objects are loaded. By pinning the objects early in the life of the instance, you prevent memory fragmentation that could result from pinning a large portion of memory in the middle of the shared pool.

   See Also: *PL/SQL Packages and Types Reference* for specific information on using DBMS_SHARED_POOL procedures

CURSOR_SHARING for Existing Applications

One of the first stages of parsing is to compare the text of the statement with existing statements in the shared pool to see if the statement can be shared. If the statement differs textually in any way, then Oracle does not share the statement.

Exceptions to this are possible when the parameter CURSOR_SHARING has been set to SIMILAR or FORCE. When this parameter is used, Oracle first checks the shared pool to see if there is an identical statement in the shared pool. If an identical statement is not found, then Oracle searches for a similar statement in the shared pool. If the similar statement is there, then the parse checks continue to verify the

executable form of the cursor can be used. If the statement is not there, then a hard parse is necessary to generate the executable form of the statement.

Similar SQL Statements

Statements that are identical, except for the values of some literals, are called similar statements. Similar statements pass the textual check in the parse phase when the CURSOR_SHARING parameter is set to SIMILAR or FORCE. Textual similarity does not guarantee sharing. The new form of the SQL statement still needs to go through the remaining steps of the parse phase to ensure that the execution plan of the preexisting statement is equally applicable to the new statement.

> **See Also:** "SQL Sharing Criteria" on page 7-23 for more details on the various checks performed

CURSOR_SHARING

Setting CURSOR_SHARING to EXACT allows SQL statements to share the SQL area only when their texts match exactly. This is the default behavior. Using this setting, similar statements cannot shared; only textually exact statements can be shared.

Setting CURSOR_SHARING to either SIMILAR or FORCE allows similar statements to share SQL. The difference between SIMILAR and FORCE is that SIMILAR forces similar statements to share the SQL area without deteriorating execution plans. Setting CURSOR_SHARING to FORCE forces similar statements to share the executable SQL area, potentially deteriorating execution plans. Hence, FORCE should be used as a last resort, when the risk of suboptimal plans is outweighed by the improvements in cursor sharing.

When to use CURSOR_SHARING

The CURSOR_SHARING initialization parameter can solve some performance problems. It has the following values: FORCE, SIMILAR, and EXACT (default). Using this parameter provides benefit to existing applications that have many similar SQL statements.

Note: Oracle does not recommend setting CURSOR_SHARING to FORCE in a DSS environment or if you are using complex queries. Also, star transformation is not supported with CURSOR_SHARING set to either SIMILAR or FORCE. For more information, see the "OPTIMIZER_FEATURES_ENABLE Parameter" on page 14-6.

The optimal solution is to write sharable SQL, rather than rely on the CURSOR_SHARING parameter. This is because although CURSOR_SHARING does significantly reduce the amount of resources used by eliminating hard parses, it requires some extra work as a part of the soft parse to find a similar statement in the shared pool.

Note: Setting CURSOR_SHARING to SIMILAR or FORCE causes an increase in the maximum lengths (as returned by DESCRIBE) of any selected expressions that contain literals (in a SELECT statement). However, the actual length of the data returned does not change.

Consider setting CURSOR_SHARING to SIMILAR or FORCE if both of the following questions are true:

1. Are there statements in the shared pool that differ only in the values of literals?
2. Is the response time low due to a very high number of library cache misses?

Caution: Setting CURSOR_SHARING to FORCE or SIMILAR prevents any outlines generated with literals from being used if they were generated with CURSOR_SHARING set to EXACT.

To use stored outlines with CURSOR_SHARING=FORCE or SIMILAR, the outlines must be generated with CURSOR_SHARING set to FORCE or SIMILAR and with the CREATE_STORED_OUTLINES parameter.

Using CURSOR_SHARING = SIMILAR (or FORCE) can significantly improve cursor sharing on some applications that have many similar statements, resulting in reduced memory usage, faster parses, and reduced latch contention.

Maintaining Connections

Large OLTP applications with middle tiers should maintain connections, rather than connecting and disconnecting for each database request. Maintaining persistent connections saves CPU resources and database resources, such as latches.

See Also: "Operating System Statistics" on page 5-5 for a description of important operating system statistics

Configuring and Using the Redo Log Buffer

Server processes making changes to data blocks in the buffer cache generate redo data into the log buffer. LGWR begins writing to copy entries from the redo log buffer to the online redo log if any of the following are true:

- The log buffer becomes one third full.
- LGWR is posted by a server process performing a `COMMIT` or `ROLLBACK`.
- DBWR posts LGWR to do so.

When LGWR writes redo entries from the redo log buffer to a redo log file or disk, user processes can then copy new entries over the entries in memory that have been written to disk. LGWR usually writes fast enough to ensure that space is available in the buffer for new entries, even when access to the redo log is heavy.

A larger buffer makes it more likely that there is space for new entries, and also gives LGWR the opportunity to efficiently write out redo records (too small a log buffer on a system with large updates means that LGWR is continuously flushing redo to disk so that the log buffer remains 2/3 empty).

On machines with fast processors and relatively slow disks, the processors might be filling the rest of the buffer in the time it takes the redo log writer to move a portion of the buffer to disk. A larger log buffer can temporarily mask the effect of slower disks in this situation. Alternatively, you can do one of the following:

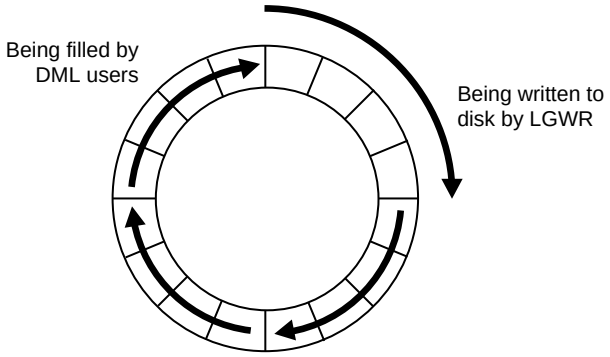
- Improve the checkpointing or archiving process
- Improve the performance of log writer (perhaps by moving all online logs to fast raw devices)

Good usage of the redo log buffer is a simple matter of:

- Batching commit operations for batch jobs, so that log writer is able to write redo log entries efficiently
- Using `NOLOGGING` operations when you are loading large quantities of data

The size of the redo log buffer is determined by the initialization parameter `LOG_BUFFER`. The log buffer size cannot be modified after instance startup.

Figure 7–2 Redo Log Buffer



Sizing the Log Buffer

Applications that insert, modify, or delete large volumes of data usually need to change the default log buffer size. The log buffer is small compared with the total SGA size, and a modestly sized log buffer can significantly enhance throughput on systems that perform many updates.

A reasonable first estimate for such systems is to the default value, which is:

```
MAX(0.5M, (128K * number of cpus))
```

On most systems, sizing the log buffer larger than 1M does not provide any performance benefit. Increasing the log buffer size does not have any negative implications on performance or recoverability. It merely uses extra memory.

Log Buffer Statistics

The statistic REDO BUFFER ALLOCATION RETRIES reflects the number of times a user process waits for space in the redo log buffer. This statistic can be queried through the dynamic performance view V$SYSSTAT.

Use the following query to monitor these statistics over a period of time while your application is running:

```
SELECT NAME, VALUE
  FROM V$SYSSTAT
 WHERE NAME = 'redo buffer allocation retries';
```

The value of `redo buffer allocation retries` should be near zero over an interval. If this value increments consistently, then processes have had to wait for space in the redo log buffer. The wait can be caused by the log buffer being too small or by checkpointing. Increase the size of the redo log buffer, if necessary, by changing the value of the initialization parameter `LOG_BUFFER`. The value of this parameter is expressed in bytes. Alternatively, improve the checkpointing or archiving process.

Another data source is to check whether the `log buffer space` wait event is not a significant factor in the wait time for the instance; if not, the log buffer size is most likely adequate.

PGA Memory Management

The Program Global Area (PGA) is a private memory region containing data and control information for a server process. Access to it is exclusive to that server process and is read and written only by the Oracle code acting on behalf of it. An example of such information is the runtime area of a cursor. Each time a cursor is executed, a new runtime area is created for that cursor in the PGA memory region of the server process executing that cursor.

> **Note:** Part of the runtime area can be located in the SGA when using shared servers.

For complex queries (for example, decision support queries), a big portion of the runtime area is dedicated to work areas allocated by memory intensive operators, such as the following:

- Sort-based operators, such as `ORDER BY`, `GROUP BY`, `ROLLUP`, and window functions
- Hash-join
- Bitmap merge
- Bitmap create
- Write buffers used by bulk load operations

A sort operator uses a work area (the sort area) to perform the in-memory sort of a set of rows. Similarly, a hash-join operator uses a work area (the hash area) to build a hash table from its left input.

The size of a work area can be controlled and tuned. Generally, bigger work areas can significantly improve the performance of a particular operator at the cost of higher memory consumption. Ideally, the size of a work area is big enough that it can accommodate the input data and auxiliary memory structures allocated by its associated SQL operator. This is known as the optimal size of a work area. When the size of the work area is smaller than optimal, the response time increases, because an extra pass is performed over part of the input data. This is known as the one-pass size of the work area. Under the one-pass threshold, when the size of a work area is far too small compared to the input data size, multiple passes over the input data are needed. This could dramatically increase the response time of the operator. This is known as the multi-pass size of the work area. For example, a serial sort operation that needs to sort 10GB of data needs a little more than 10GB to run optimal and at least 40MB to run one-pass. If this sort gets less that 40MB, then it must perform several passes over the input data.

The goal is to have most work areas running with an optimal size (for example, more than 90% or even 100% for pure OLTP systems), while a smaller fraction of them are running with a one-pass size (for example, less than 10%). Multi-pass execution should be avoided. Even for DSS systems running large sorts and hash-joins, the memory requirement for the one-pass executions is relatively small. A system configured with a reasonable amount of PGA memory should not need to perform multiple passes over the input data.

Automatic PGA memory management simplifies and improves the way PGA memory is allocated. By default, PGA memory management is enabled. In this mode, Oracle dynamically adjusts the size of the portion of the PGA memory dedicated to work areas, based on 20% of the SGA memory size. The minimum value is 10MB.

Note: For backward compatibility, automatic PGA memory management can be disabled by setting the value of the PGA_AGGREGATE_TARGET initialization parameter to 0. When automatic PGA memory management is disabled, the maximum size of a work area can be sized with the associated _AREA_SIZE parameter, such as the SORT_AREA_SIZE initialization parameter.

See *Oracle Database Reference* for information on the PGA_AGGREGATE_TARGET, SORT_AREA_SIZE, HASH_AREA_SIZE, BITMAP_MERGE_AREA_SIZE and CREATE_BITMAP_AREA_SIZE initialization parameters.

Configuring Automatic PGA Memory

When running under the automatic PGA memory management mode, sizing of work areas for all sessions becomes automatic and the *_AREA_SIZE parameters are ignored by all sessions running in that mode. At any given time, the total amount of PGA memory available to active work areas in the instance is automatically derived from the PGA_AGGREGATE_TARGET initialization parameter. This amount is set to the value of PGA_AGGREGATE_TARGET minus the amount of PGA memory allocated by other components of the system (for example, PGA memory allocated by sessions). The resulting PGA memory is then assigned to individual active work areas, based on their specific memory requirements.

Under automatic PGA memory management mode, the main goal of Oracle is to honor the PGA_AGGREGATE_TARGET limit set by the DBA, by controlling dynamically the amount of PGA memory allotted to SQL work areas. At the same time, Oracle tries to maximize the performance of all the memory-intensive SQL operations, by maximizing the number of work areas that are using an optimal amount of PGA memory (cache memory). The rest of the work areas are executed in one-pass mode, unless the PGA memory limit set by the DBA with the parameter PGA_AGGREGATE_TARGET is so low that multi-pass execution is required to reduce even more the consumption of PGA memory and honor the PGA target limit.

When configuring a brand new instance, it is hard to know precisely the appropriate setting for PGA_AGGREGATE_TARGET. You can determine this setting in three stages:

1. Make a first estimate for PGA_AGGREGATE_TARGET, based on a rule of thumb. By default, Oracle uses 20% of the SGA size. However, this initial setting may be too low for a large DSS system.
2. Run a representative workload on the instance and monitor performance, using PGA statistics collected by Oracle, to see whether the maximum PGA size is under-configured or over-configured.
3. Tune PGA_AGGREGATE_TARGET, using Oracle PGA advice statistics.

> **See Also:** *Oracle Database Reference* for information on the PGA_AGGREGATE_TARGET initialization parameter

The following sections explain this in detail:

- Setting PGA_AGGREGATE_TARGET Initially
- Monitoring the Performance of the Automatic PGA Memory Management
- Tuning PGA_AGGREGATE_TARGET

Setting PGA_AGGREGATE_TARGET Initially

The value of the PGA_AGGREGATE_TARGET initialization parameter (for example 100000 KB, 2500 MB, or 50 GB) should be set based on the total amount of memory available for the Oracle instance. This value can then be tuned and dynamically modified at the instance level. Example 7–2 illustrates a typical situation.

Example 7–2 Initial Setting of PGA_AGGREGATE_TARGET

Assume that an Oracle instance is configured to run on a system with 4 GB of physical memory. Part of that memory should be left for the operating system and other non-Oracle applications running on the same hardware system. You might decide to dedicate only 80% (3.2 GB) of the available memory to the Oracle instance.

You must then divide the resulting memory between the SGA and the PGA.

- For OLTP systems, the PGA memory typically accounts for a small fraction of the total memory available (for example, 20%), leaving 80% for the SGA.
- For DSS systems running large, memory-intensive queries, PGA memory can typically use up to 70% of that total (up to 2.2 GB in this example).

Good initial values for the parameter PGA_AGGREGATE_TARGET might be:

- For OLTP: PGA_AGGREGATE_TARGET = (*total_mem* * 80%) * 20%
- For DSS: PGA_AGGREGATE_TARGET = (*total_mem* * 80%) * 50%

  where *total_mem* is the total amount of physical memory available on the system.

In this example, with a value of *total_mem* equal to 4 GB, you can initially set PGA_AGGREGATE_TARGET to 1600 MB for a DSS system and to 655 MB for an OLTP system.

Monitoring the Performance of the Automatic PGA Memory Management

Before starting the tuning process, you need to know how to monitor and interpret the key statistics collected by Oracle to help in assessing the performance of the automatic PGA memory management component. Several dynamic performance views are available for this purpose:

- V$PGASTAT
- V$PROCESS
- V$SQL_WORKAREA_HISTOGRAM
- V$SQL_WORKAREA_ACTIVE

- V$SQL_WORKAREA

V$PGASTAT This view gives instance-level statistics on the PGA memory usage and the automatic PGA memory manager. For example:

```
SELECT * FROM V$PGASTAT;
```

The output of this query might look like the following:

```
NAME                                                       VALUE UNIT
---------------------------------------------------------- ---------- ------------
aggregate PGA target parameter                           41156608 bytes
aggregate PGA auto target                                21823488 bytes
global memory bound                                       2057216 bytes
total PGA inuse                                          16899072 bytes
total PGA allocated                                      35014656 bytes
maximum PGA allocated                                   136795136 bytes
total freeable PGA memory                                  524288 bytes
PGA memory freed back to OS                             1713242112 bytes
total PGA used for auto workareas                             0 bytes
maximum PGA used for auto workareas                     2383872 bytes
total PGA used for manual workareas                           0 bytes
maximum PGA used for manual workareas                    8470528 bytes
over allocation count                                        291
bytes processed                                         2124600320 bytes
extra bytes read/written                                  39949312 bytes
cache hit percentage                                         98.15 percent
```

The main statistics displayed in V$PGASTAT are as follows:

- `aggregate PGA target parameter`: This is the current value of the initialization parameter PGA_AGGREGATE_TARGET. The default value is 20% of the SGA size. If you set this parameter to 0, automatic management of the PGA memory is disabled.
- `aggregate PGA auto target`: This gives the amount of PGA memory Oracle can use for work areas running in automatic mode. This amount is dynamically derived from the value of the parameter PGA_AGGREGATE_TARGET and the current work area workload. Hence, it is continuously adjusted by Oracle. If this value is small compared to the value of PGA_AGGREGATE_TARGET, then a lot of PGA memory is used by other components of the system (for example, PL/SQL or Java memory) and little is left for sort work areas. You must ensure that enough PGA memory is left for work areas running in automatic mode.

- global memory bound: This gives the maximum size of a work area executed in AUTO mode. This value is continuously adjusted by Oracle to reflect the current state of the work area workload. The global memory bound generally decreases when the number of active work areas is increasing in the system. As a rule of thumb, the value of the global bound should not decrease to less than one megabyte. If it does, then the value of PGA_AGGREGATE_TARGET should probably be increased.
- total PGA allocated: This gives the current amount of PGA memory allocated by the instance. Oracle tries to keep this number less than the value of PGA_AGGREGATE_TARGET. However, it is possible for the PGA allocated to exceed that value by a small percentage and for a short period of time, when the work area workload is increasing very rapidly or when the initialization parameter PGA_AGGREGATE_TARGET is set to a too small value.
- total freeable PGA memory: This indicates how much allocated PGA memory which can be freed.
- total PGA used for auto workareas: This indicates how much PGA memory is currently consumed by work areas running under automatic memory management mode. This number can be used to determine how much memory is consumed by other consumers of the PGA memory (for example, PL/SQL or Java):

  ```
  PGA other = total PGA allocated - total PGA used for auto workareas
  ```

- over allocation count: This statistic is cumulative from instance start-up. Over-allocating PGA memory can happen if the value of PGA_AGGREGATE_TARGET is too small to accommodate the PGA other component in the previous equation plus the minimum memory required to execute the work area workload. When this happens, Oracle cannot honor the initialization parameter PGA_AGGREGATE_TARGET, and extra PGA memory needs to be allocated. If over-allocation occurs, you should increase the value of PGA_AGGREGATE_TARGET using the information provided by the advice view V$PGA_TARGET_ADVICE.
- total bytes processed: This is the number of bytes processed by memory-intensive SQL operators since instance start-up. For example, the number of byte processed is the input size for a sort operation. This number is used to compute the cache hit percentage metric.
- extra bytes read/written: When a work area cannot run optimally, one or more extra passes is performed over the input data. extra bytes read/written represents the number of bytes processed during these extra

passes since instance start-up. This number is also used to compute the cache hit percentage. Ideally, it should be small compared to total bytes processed.

- cache hit percentage: This metric is computed by Oracle to reflect the performance of the PGA memory component. It is cumulative from instance start-up. A value of 100% means that all work areas executed by the system since instance start-up have used an optimal amount of PGA memory. This is, of course, ideal but rarely happens except maybe for pure OLTP systems. In reality, some work areas run one-pass or even multi-pass, depending on the overall size of the PGA memory. When a work area cannot run optimally, one or more extra passes is performed over the input data. This reduces the cache hit percentage in proportion to the size of the input data and the number of extra passes performed. Example 7–3 shows how cache hit percentage is affected by extra passes.

Example 7–3 Calculating Cache Hit Percentage

Consider a simple example: Four sort operations have been executed, three were small (1 MB of input data) and one was bigger (100 MB of input data). The total number of bytes processed (BP) by the four operations is 103 MB. If one of the small sorts runs one-pass, an extra pass over 1 MB of input data is performed. This 1 MB value is the number of extra bytes read/written, or EBP. The cache hit percentage is calculated by the following formula:

```
BP x 100 / (BP + EBP)
```

The cache hit percentage in this case is 99.03%, almost 100%. This value reflects the fact that only one of the small sorts had to perform an extra pass while all other sorts were able to run optimally. Hence, the cache hit percentage is almost 100%, because this extra pass over 1 MB represents a tiny overhead. On the other hand, if the big sort is the one to run one-pass, then EBP is 100 MB instead of 1 MB, and the cache hit percentage falls to 50.73%, because the extra pass has a much bigger impact.

V$PROCESS This view has one row for each Oracle process connected to the instance. The columns PGA_USED_MEM, PGA_ALLOC_MEM, PGA_FREEABLE_MEM and PGA_MAX_MEM can be used to monitor the PGA memory usage of these processes. For example:

```
SELECT PROGRAM, PGA_USED_MEM, PGA_ALLOC_MEM, PGA_FREEABLE_MEM, PGA_MAX_MEM
  FROM V$PROCESS;
```

The output of this query might look like the following:

```
PROGRAM                                  PGA_USED_MEM PGA_ALLOC_MEM PGA_FREEABLE_MEM PGA_MAX_MEM
---------------------------------------- ------------ ------------- ---------------- -----------
PSEUDO                                              0             0                0           0
oracle@dlsun1690 (PMON)                        314540        685860                0      685860
oracle@dlsun1690 (MMAN)                        313992        685860                0      685860
oracle@dlsun1690 (DBW0)                        696720       1063112                0     1063112
oracle@dlsun1690 (LGWR)                      10835108      22967940                0    22967940
oracle@dlsun1690 (CKPT)                        352716        710376                0      710376
oracle@dlsun1690 (SMON)                        541508        948004                0     1603364
oracle@dlsun1690 (RECO)                        323688        685860                0      816932
oracle@dlsun1690 (q001)                        233508        585128                0      585128
oracle@dlsun1690 (QMNC)                        314332        685860                0      685860
oracle@dlsun1690 (MMON)                        885756       1996548           393216     1996548
oracle@dlsun1690 (MMNL)                        315068        685860                0      685860
oracle@dlsun1690 (q000)                        330872        716200            65536      716200
oracle@dlsun1690 (TNS V1-V3)                   635768        928024                0     1255704
oracle@dlsun1690 (CJQ0)                        533476       1013540                0     1144612
oracle@dlsun1690 (TNS V1-V3)                   430648        812108                0      812108
```

V$SQL_WORKAREA_HISTOGRAM This view shows the number of work areas executed with optimal memory size, one-pass memory size, and multi-pass memory size since instance start-up. Statistics in this view are subdivided into buckets that are defined by the optimal memory requirement of the work area. Each bucket is identified by a range of optimal memory requirements specified by the values of the columns LOW_OPTIMAL_SIZE and HIGH_OPTIMAL_SIZE.

Example 7–4 and Example 7–5 show two ways of using V$SQL_WORKAREA_HISTOGRAM.

Example 7–4 Querying V$SQL_WORKAREA_HISTOGRAM: Non-empty Buckets

Consider a sort operation that requires 3 MB of memory to run optimally (cached). Statistics about the work area used by this sort are placed in the bucket defined by LOW_OPTIMAL_SIZE = 2097152 (2 MB) and HIGH_OPTIMAL_SIZE = 4194303 (4 MB minus 1 byte), because 3 MB falls within that range of optimal sizes. Statistics are segmented by work area size, because the performance impact of running a work area in optimal, one-pass or multi-pass mode depends mainly on the size of that work area.

The following query shows statistics for all non-empty buckets. Empty buckets are removed with the predicate where total_execution != 0.

```
SELECT LOW_OPTIMAL_SIZE/1024 low_kb,
       (HIGH_OPTIMAL_SIZE+1)/1024 high_kb,
```

```
       OPTIMAL_EXECUTIONS, ONEPASS_EXECUTIONS, MULTIPASSES_EXECUTIONS
  FROM V$SQL_WORKAREA_HISTOGRAM
 WHERE TOTAL_EXECUTIONS != 0;
```

The result of the query might look like the following:

```
LOW_KB HIGH_KB OPTIMAL_EXECUTIONS ONEPASS_EXECUTIONS MULTIPASSES_EXECUTIONS
------ ------- ------------------ ------------------ ---------------------
     8      16             156255                  0                     0
    16      32                150                  0                     0
    32      64                 89                  0                     0
    64     128                 13                  0                     0
   128     256                 60                  0                     0
   256     512                  8                  0                     0
   512    1024                657                  0                     0
  1024    2048                551                 16                     0
  2048    4096                538                 26                     0
  4096    8192                243                 28                     0
  8192   16384                137                 35                     0
 16384   32768                 45                107                     0
 32768   65536                  0                153                     0
 65536  131072                  0                 73                     0
131072  262144                  0                 44                     0
262144  524288                  0                 22                     0
```

The query result shows that, in the 1024 KB to 2048 KB bucket, 551 work areas used an optimal amount of memory, while 16 ran in one-pass mode and none ran in multi-pass mode. It also shows that all work areas under 1 MB were able to run in optimal mode.

Example 7–5 Querying V$SQL_WORKAREA_HISTOGRAM: Percent Optimal

You can also use V$SQL_WORKAREA_HISTOGRAM to find the percentage of times work areas were executed in optimal, one-pass, or multi-pass mode since start-up. This query only considers work areas of a certain size, with an optimal memory requirement of at least 64 KB.

```
SELECT optimal_count, round(optimal_count*100/total, 2) optimal_perc,
       onepass_count, round(onepass_count*100/total, 2) onepass_perc,
       multipass_count, round(multipass_count*100/total, 2) multipass_perc
FROM
 (SELECT decode(sum(total_executions), 0, 1, sum(total_executions)) total,
         sum(OPTIMAL_EXECUTIONS) optimal_count,
         sum(ONEPASS_EXECUTIONS) onepass_count,
         sum(MULTIPASSES_EXECUTIONS) multipass_count
```

```
    FROM v$sql_workarea_histogram
   WHERE low_optimal_size > 64*1024);
```

The output of this query might look like the following:

```
OPTIMAL_COUNT OPTIMAL_PERC ONEPASS_COUNT ONEPASS_PERC MULTIPASS_COUNT MULTIPASS_PERC
------------- ------------ ------------- ------------ --------------- --------------
         2239        81.63           504        18.37               0              0
```

This result shows that 81.63% of these work areas have been able to run using an optimal amount of memory. The rest (18.37%) ran one-pass. None of them ran multi-pass. Such behavior is preferable, for the following reasons:

- Multi-pass mode can severely degrade performance. A high number of multi-pass work areas has an exponentially adverse effect on the response time of its associated SQL operator.
- Running one-pass does not require a large amount of memory; only 22 MB is required to sort 1 GB of data in one-pass mode.

V$SQL_WORKAREA_ACTIVE This view can be used to display the work areas that are active (or executing) in the instance. Small active sorts (under 64 KB) are excluded from the view. Use this view to precisely monitor the size of all active work areas and to determine if these active work areas spill to a temporary segment. Example 7–6 shows a typical query of this view:

Example 7–6 Querying V$SQL_WORKAREA_ACTIVE

```
SELECT to_number(decode(SID, 65535, NULL, SID)) sid,
       operation_type OPERATION,
       trunc(EXPECTED_SIZE/1024) ESIZE,
       trunc(ACTUAL_MEM_USED/1024) MEM,
       trunc(MAX_MEM_USED/1024) "MAX MEM",
       NUMBER_PASSES PASS,
       trunc(TEMPSEG_SIZE/1024) TSIZE
  FROM V$SQL_WORKAREA_ACTIVE
 ORDER BY 1,2;

The output of this query might look like the following:
SID         OPERATION     ESIZE       MEM   MAX MEM  PASS   TSIZE
--- ---------------- --------- --------- --------- ----- -------
  8   GROUP BY (SORT)       315       280       904     0
  8         HASH-JOIN      2995      2377      2430     1   20000
  9   GROUP BY (SORT)     34300     22688     22688     0
 11         HASH-JOIN     18044     54482     54482     0
```

```
 12         HASH-JOIN     18044     11406     21406     1  120000
```

This output shows that session 12 (column SID) is running a hash-join having its work area running in one-pass mode (PASS column). This work area is currently using 11406 KB of memory (MEM column) and has used, in the past, up to 21406 KB of PGA memory (MAX MEM column). It has also spilled to a temporary segment of size 120000 KB. Finally, the column ESIZE indicates the maximum amount of memory that the PGA memory manager expects this hash-join to use. This maximum is dynamically computed by the PGA memory manager according to workload.

When a work area is deallocated—that is, when the execution of its associated SQL operator is complete—the work area is automatically removed from the V$SQL_WORKAREA_ACTIVE view.

V$SQL_WORKAREA Oracle maintains cumulative work area statistics for each loaded cursor whose execution plan uses one or more work areas. Every time a work area is deallocated, the V$SQL_WORKAREA table is updated with execution statistics for that work area.

V$SQL_WORKAREA can be joined with V$SQL to relate a work area to a cursor. It can even be joined to V$SQL_PLAN to precisely determine which operator in the plan uses a work area.

Example 7–7 shows three typical queries on the V$SQL_WORKAREA dynamic view:

Example 7–7 Querying V$SQL_WORKAREA

The following query finds the top 10 work areas requiring most cache memory:

```
SELECT *
  FROM
     ( SELECT workarea_address, operation_type, policy, estimated_optimal_size
         FROM V$SQL_WORKAREA
        ORDER BY estimated_optimal_size )
 WHERE ROWNUM <= 10;
```

The following query finds the cursors with one or more work areas that have been executed in one or even multiple passes:

```
col sql_text format A80 wrap
SELECT sql_text, sum(ONEPASS_EXECUTIONS) onepass_cnt,
       sum(MULTIPASSES_EXECUTIONS) mpass_cnt
FROM V$SQL s, V$SQL_WORKAREA wa
WHERE s.address = wa.address
```

```
GROUP BY sql_text
HAVING sum(ONEPASS_EXECUTIONS+MULTIPASSES_EXECUTIONS)>0;
```

Using the hash value and address of a particular cursor, the following query displays the cursor execution plan, including information about the associated work areas.

```
col "O/1/M" format a10
col name format a20
SELECT operation, options, object_name name,
       trunc(bytes/1024/1024) "input(MB)",
       trunc(last_memory_used/1024) last_mem,
       trunc(estimated_optimal_size/1024) optimal_mem,
       trunc(estimated_onepass_size/1024) onepass_mem,
       decode(optimal_executions, null, null,
              optimal_executions||'/'||onepass_executions||'/'||
              multipasses_executions) "O/1/M"
  FROM V$SQL_PLAN p, V$SQL_WORKAREA w
 WHERE p.address=w.address(+)
   AND p.hash_value=w.hash_value(+)
   AND p.id=w.operation_id(+)
   AND p.address='88BB460C'
   AND p.hash_value=3738161960;

OPERATION    OPTIONS  NAME     input(MB) LAST_MEM OPTIMAL_ME ONEPASS_ME O/1/M
------------ -------- -------- --------- -------- ---------- ---------- ------
SELECT STATE
SORT         GROUP BY              4582        8         16         16 16/0/0
HASH JOIN    SEMI                  4582     5976       5194       2187 16/0/0
TABLE ACCESS FULL     ORDERS          51
TABLE ACCESS FUL      LINEITEM      1000
```

You can get the address and hash value from the V$SQL view by specifying a pattern in the query. For example:

```
SELECT address, hash_value
  FROM V$SQL
WHERE sql_text LIKE '%my_pattern%';
```

Tuning PGA_AGGREGATE_TARGET

To help you tune the initialization parameter PGA_AGGREGATE_TARGET, Oracle provides two PGA advice performance views:

- V$PGA_TARGET_ADVICE

- V$PGA_TARGET_ADVICE_HISTOGRAM

By examining these two views, you no longer need to use an empirical approach to tune the value of PGA_AGGREGATE_TARGET. Instead, you can use the content of these views to determine how key PGA statistics will be impacted if you change the value of PGA_AGGREGATE_TARGET.

In both views, values of PGA_AGGREGATE_TARGET used for the prediction are derived from fractions and multiples of the current value of that parameter, to assess possible higher and lower values. Values used for the prediction range from 10 MB to a maximum of 256 GB.

Oracle generates PGA advice performance views by recording the workload history and then simulating this history for different values of PGA_AGGREGATE_TARGET. The simulation process happens in the background and continuously updates the workload history to produce the simulation result. You can view the result at any time by querying V$PGA_TARGET_ADVICE or V$PGA_TARGET_ADVICE_HISTOGRAM.

To enable automatic generation of PGA advice performance views, make sure the following parameters are set:

- PGA_AGGREGATE_TARGET, to enable automatic PGA memory management. Set the initial value as described in "Setting PGA_AGGREGATE_TARGET Initially" on page 7-53.
- STATISTICS_LEVEL. Set this to TYPICAL (the default) or ALL; setting this parameter to BASIC turns off generation of PGA performance advice views.

The content of these PGA advice performance views is reset at instance start-up or when PGA_AGGREGATE_TARGET is altered.

Note: Simulation cannot include all factors of real execution, so derived statistics might not exactly match up with real performance statistics. You should always monitor the system after changing PGA_AGGREGATE_TARGET, to verify that the new performance is what you expect.

V$PGA_TARGET_ADVICE This view predicts how the statistics cache hit percentage and over allocation count in V$PGASTAT will be impacted if you change the value of the initialization parameter PGA_AGGREGATE_TARGET. Example 7–8 shows a typical query of this view:

Example 7–8 Querying V$PGA_TARGET_ADVICE

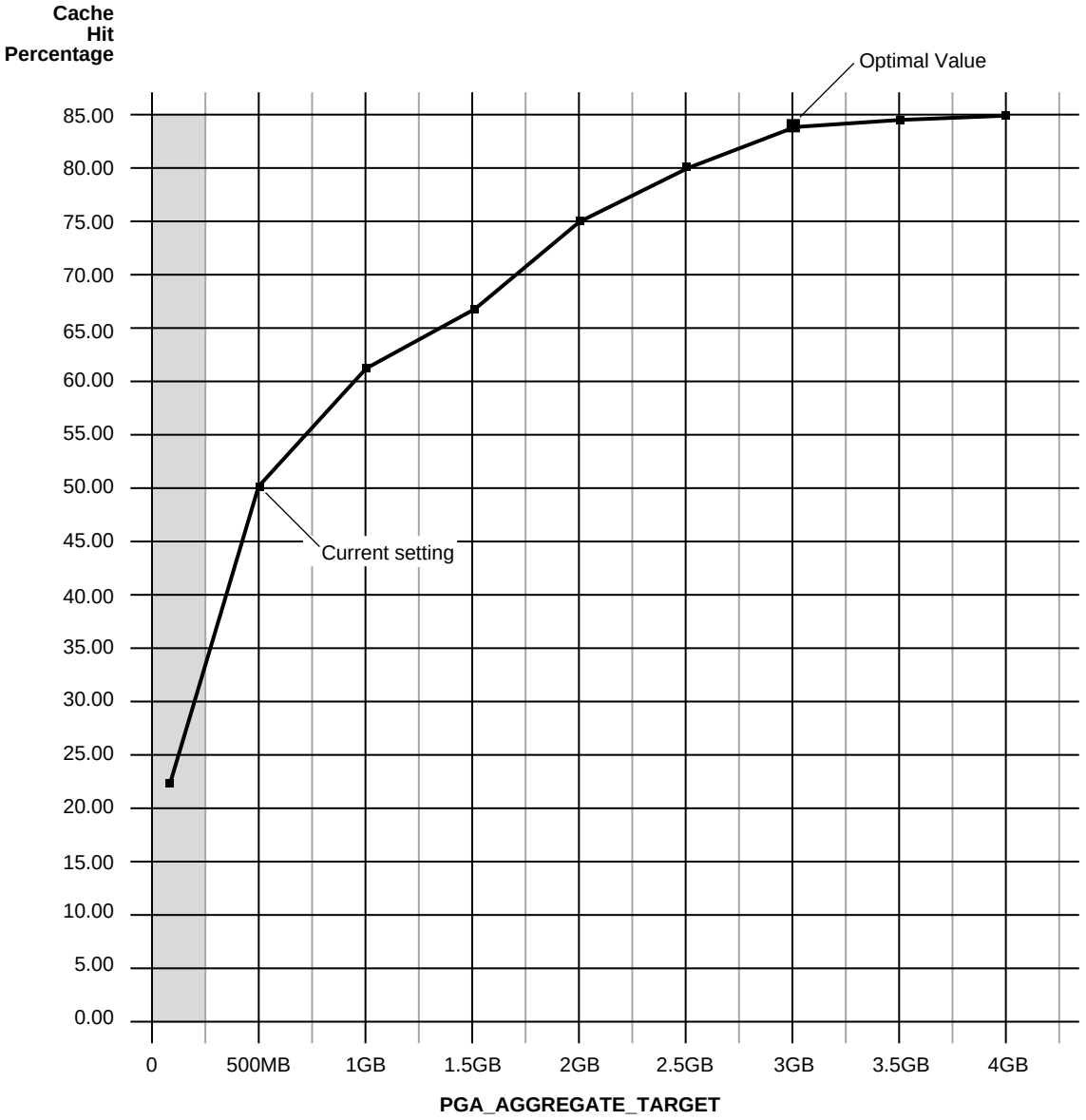
```
SELECT round(PGA_TARGET_FOR_ESTIMATE/1024/1024) target_mb,
       ESTD_PGA_CACHE_HIT_PERCENTAGE cache_hit_perc,
       ESTD_OVERALLOC_COUNT
  FROM V$PGA_TARGET_ADVICE;
```

The output of this query might look like the following:

```
 TARGET_MB  CACHE_HIT_PERC  ESTD_OVERALLOC_COUNT
----------  --------------  --------------------
        63              23                   367
       125              24                    30
       250              30                     3
       375              39                     0
       500              58                     0
       600              59                     0
       700              59                     0
       800              60                     0
       900              60                     0
      1000              61                     0
      1500              67                     0
      2000              76                     0
      3000              83                     0
      4000              85                     0
```

The result of the this query can be plotted as shown in Example 7–3:

Figure 7–3 Graphical Representation of V$PGA_TARGET_ADVICE



The curve shows how the PGA cache hit percentage improves as the value of PGA_AGGREGATE_TARGET increases. The shaded zone in the graph is the over allocation zone, where the value of the column ESTD_OVERALLOCATION_COUNT is nonzero. It indicates that PGA_AGGREGATE_TARGET is too small to even meet the minimum PGA memory needs. If PGA_AGGREGATE_TARGET is set within the over allocation zone, the memory manager will over-allocate memory and actual PGA memory consumed will be more than the limit you set. It is therefore meaningless to set a value of PGA_AGGREGATE_TARGET in that zone. In this particular example PGA_AGGREGATE_TARGET should be set to at least 375 MB.

Note: Even though the theoretical maximum for the PGA cache hit percentage is 100%, there is a practical limit on the maximum size of a work area, which may prevent this theoretical maximum from being reached, even if you further increase PGA_AGGREGATE_TARGET. This should happen only in large DSS systems where the optimal memory requirement is large and might cause the value of the cache hit percentage to taper off at a lower percentage, like 90%.

Beyond the over allocation zone, the value of the PGA cache hit percentage increases rapidly. This is due to an increase in the number of work areas which run optimally or one-pass and a decrease in the number of multi-pass executions. At some point, somewhere around 500 MB in this example, there is an inflection in the curve that corresponds to the point where most (probably all) work areas can run optimally or at least one-pass. After this inflection, the cache hit percentage keeps increasing, though at a lower pace, up to the point where it starts to taper off and shows only slight improvement with increase in PGA_AGGREGATE_TARGET. In Figure 7–3, this happens when PGA_AGGREGATE_TARGET reaches 3 GB. At that point, the cache hit percentage is 83% and only improves marginally (by 2%) with one extra gigabyte of PGA memory. In this particular example, 3 GB is probably the optimal value for PGA_AGGREGATE_TARGET.

Ideally, PGA_AGGREGATE_TARGET should be set at the optimal value, or at least to the maximum value possible in the region beyond the over allocation zone. As a rule of thumb, the PGA cache hit percentage should be higher than 60%, because at 60% the system is almost processing double the number of bytes it actually needs to process in an ideal situation. Using this particular example, it makes sense to set PGA_AGGREGATE_TARGET to at least 500 MB and as close as possible to 3 GB. But the right setting for the parameter PGA_AGGREGATE_TARGET really depends on how much memory can be dedicated to the PGA component.

Generally, adding PGA memory requires reducing memory for some of the SGA components, like the shared pool or the buffer cache. This is because the overall memory dedicated to the Oracle instance is often bound by the amount of physical memory available on the system. As a result, any decisions to increase PGA memory must be taken in the larger context of the available memory in the system and the performance of the various SGA components (which you monitor with shared pool advisory and buffer cache advisory statistics). If memory cannot be taken away from the SGA, you might consider adding more physical memory to the system.

See Also:

- "Shared Pool Advisory Statistics" on page 7-32
- "Sizing the Buffer Cache" on page 7-8

How to Tune PGA_AGGREGATE_TARGET You can use the following steps as a tuning guideline in tuning PGA_AGGREGATE_TARGET:

1. Set PGA_AGGREGATE_TARGET so there is no memory over-allocation; avoid setting it in the over-allocation zone. In Example 7–8, PGA_AGGREGATE_TARGET should be set to at least 375 MB.
2. After eliminating over-allocations, aim at maximizing the PGA `cache hit percentage`, based on your response-time requirement and memory constraints. In Example 7–8, assume you have a limit *X* on memory you can allocate to PGA.
   - If this limit *X* is beyond the optimal value, then you would set PGA_AGGREGATE_TARGET to the optimal value. After this point, the incremental benefit with higher memory allocation to PGA_AGGREGATE_TARGET is very small. In Example 7–8, if you have 10 GB to dedicate to PGA, set PGA_AGGREGATE_TARGET to 3 GB, the optimal value. The remaining 7 GB is dedicated to the SGA.
   - If the limit *X* is less than the optimal value, then you would set PGA_AGGREGATE_TARGET to *X*. In Example 7–8, if you have only 2 GB to dedicate to PGA, set PGA_AGGREGATE_TARGET to 2 GB and accept a `cache hit percentage` of 75%.

Finally, like most statistics collected by Oracle that are cumulative since instance start-up, you can take a snapshot of the view at the beginning and at the end of a time interval. You can then derive the predicted statistics for that time interval as follows:

```
        estd_overalloc_count = (difference in estd_overalloc_count between the two snapshots)

                                   (difference in bytes_processed between the two snapshots)
estd_pga_cache_hit_percentage = ------------------------------------------------------------
                               (difference in bytes_processed + extra_bytes_rw  between the two snapshots )
```

V$PGA_TARGET_ADVICE_HISTOGRAM This view predicts how the statistics displayed by the performance view V$SQL_WORKAREA_HISTOGRAM will be impacted if you change the value of the initialization parameter PGA_AGGREGATE_TARGET. You can use the dynamic view V$PGA_TARGET_ADVICE_HISTOGRAM to view detailed information on the predicted number of optimal, one-pass and multi-pass work area executions for the set of PGA_AGGREGATE_TARGET values you use for the prediction.

The V$PGA_TARGET_ADVICE_HISTOGRAM view is identical to the V$SQL_WORKAREA_HISTOGRAM view, with two additional columns to represent the PGA_AGGREGATE_TARGET values used for the prediction. Therefore, any query executed against the V$SQL_WORKAREA_HISTOGRAM view can be used on this view, with an additional predicate to select the desired value of PGA_AGGREGATE_TARGET.

Example 7–9 Querying V$PGA_TARGET_ADVICE_HISTOGRAM

The following query displays the predicted content of V$SQL_WORKAREA_HISTOGRAM for a value of the initialization parameter PGA_AGGREGATE_TARGET set to twice its current value.

```
SELECT LOW_OPTIMAL_SIZE/1024 low_kb, (HIGH_OPTIMAL_SIZE+1)/1024 high_kb,
       estd_optimal_executions estd_opt_cnt,
       estd_onepass_executions estd_onepass_cnt,
       estd_multipasses_executions estd_mpass_cnt
  FROM v$pga_target_advice_histogram
 WHERE pga_target_factor = 2
   AND estd_total_executions != 0
 ORDER BY 1;
```

The output of this query might look like the following.

```
LOW_KB   HIGH_KB   ESTD_OPTIMAL_CNT   ESTD_ONEPASS_CNT   ESTD_MPASS_CNT
------   -------   ----------------   ----------------   --------------
     8        16             156107                  0                0
    16        32                148                  0                0
    32        64                 89                  0                0
    64       128                 13                  0                0
   128       256                 58                  0                0
```

```
   256       512                10                0                0
   512      1024               653                0                0
  1024      2048               530                0                0
  2048      4096               509                0                0
  4096      8192               227                0                0
  8192     16384               176                0                0
 16384     32768               133               16                0
 32768     65536                66              103                0
 65536    131072                15               47                0
131072    262144                 0               48                0
262144    524288                 0               23                0
```

The output shows that increasing PGA_AGGREGATE_TARGET by a factor of 2 will allow all work areas under 16 MB to execute in optimal mode.

See Also: *Oracle Database Reference*

V$SYSSTAT and V$SESSTAT

Statistics in the V$SYSSTAT and V$SESSTAT views show the total number of work areas executed with optimal memory size, one-pass memory size, and multi-pass memory size. These statistics are cumulative since the instance or the session was started.

The following query gives the total number and the percentage of times work areas were executed in these three modes since the instance was started:

```
SELECT name profile, cnt, decode(total, 0, 0, round(cnt*100/total)) percentage
    FROM (SELECT name, value cnt, (sum(value) over ()) total
    FROM V$SYSSTAT
    WHERE name like 'workarea exec%');
```

The output of this query might look like the following:

```
PROFILE                                       CNT PERCENTAGE
---------------------------------- ---------- ----------
workarea executions - optimal             5395         95
workarea executions - onepass              284          5
workarea executions - multipass              0          0
```

Configuring OLAP_PAGE_POOL_SIZE

The OLAP_PAGE_POOL_SIZE initialization parameter specifies (in bytes) the maximum size of the paging cache to be allocated to an OLAP session.

For performance reasons, it is usually preferable to configure a small OLAP paging cache and set a larger default buffer pool with DB_CACHE_SIZE. An OLAP paging cache of 4 MB is fairly typical, with 2 MB used for systems with limited memory resources.

See Also: *Oracle OLAP Application Developer's Guide*

8

I/O Configuration and Design

The I/O subsystem is a vital component of an Oracle database. This chapter introduces fundamental I/O concepts, discusses the I/O requirements of different parts of the database, and provides sample configurations for I/O subsystem design.

This chapter includes the following topics:

Understanding I/O

The performance of many software applications is inherently limited by disk I/O. Applications that spend the majority of CPU time waiting for I/O activity to complete are said to be I/O-bound.

Oracle is designed so that if an application is well written, its performance should not be limited by I/O. Tuning I/O can enhance the performance of the application if the I/O system is operating at or near capacity and is not able to service the I/O requests within an acceptable time. However, tuning I/O cannot help performance if the application is not I/O-bound (for example, when CPU is the limiting factor).

Consider the following database requirements when designing an I/O system:

- Storage, such as minimum disk capacity
- Availability, such as continuous (24 x 7) or business hours only
- Performance, such as I/O throughput and application response times

Many I/O designs plan for storage and availability requirements with the assumption that performance will not be an issue. This is not always the case. Optimally, the number of disks and controllers to be configured should be determined by I/O throughput and redundancy requirements. Then, the size of disks can be determined by the storage requirements.

Basic I/O Configuration

This section describes the basic information to be gathered and decisions to be made when defining a system's I/O configuration. You want to keep the configuration as simple as possible, while maintaining the required availability, recoverability, and performance. The more complex a configuration becomes, the more difficult it is to administer, maintain, and tune.

Lay Out the Files Using Operating System or Hardware Striping

If your operating system has LVM software or hardware-based striping, then it is possible to distribute I/O using these tools. Decisions to be made when using an LVM or hardware striping include **stripe depth** and **stripe width**.

- Stripe depth is the size of the stripe, sometimes called stripe unit.
- Stripe width is the product of the stripe depth and the number of drives in the striped set.

Choose these values wisely so that the system is capable of sustaining the required throughput. For an Oracle database, reasonable stripe depths range from 256 KB to 1 MB. Different types of applications benefit from different stripe depths. The optimal stripe depth and stripe width depend on the following:

- Requested I/O Size
- Concurrency of I/O Requests
- Alignment of Physical Stripe Boundaries with Block Size Boundaries
- Manageability of the Proposed System

Requested I/O Size

Table 8–1 lists the Oracle and operating system parameters that you can use to set I/O size:

Table 8–1 Oracle and Operating System Operational Parameters

Parameter	Description
DB_BLOCK_SIZE	The size of single-block I/O requests. This parameter is also used in combination with multiblock parameters to determine multiblock I/O request size.
OS block size	Determines I/O size for redo log and archive log operations.
Maximum OS I/O size	Places an upper bound on the size of a single I/O request.
DB_FILE_MULTIBLOCK_READ_COUNT	The maximum I/O size for full table scans is computed by multiplying this parameter with DB_BLOCK_SIZE. (the upper value is subject to operating system limits).
SORT_AREA_SIZE	Determines I/O sizes and concurrency for sort operations.
HASH_AREA_SIZE	Determines the I/O size for hash operations.

In addition to I/O size, the degree of concurrency also helps in determining the ideal stripe depth. Consider the following when choosing stripe width and stripe depth:

- On low-concurrency (sequential) systems, ensure that no single I/O visits the same disk twice. For example, assume that the stripe width is four disks, and the stripe depth is 32k. If a single 1MB I/O request (for example, for a full table scan) is issued by an Oracle server process, then each disk in the stripe must perform eight I/Os to return the requested data. To avoid this situation, the size of the average I/O should be smaller than the stripe width multiplied by the

stripe depth. If this is not the case, then a single I/O request made by Oracle to the operating system results in multiple physical I/O requests to the same disk.

- On high-concurrency (random) systems, ensure that no single I/O request is broken up into more than one physical I/O call. Failing to do this multiplies the number of physical I/O requests performed in your system, which in turn can severely degrade the I/O response times.

Concurrency of I/O Requests

In a system with a high degree of concurrent small I/O requests, such as in a traditional OLTP environment, it is beneficial to keep the stripe depth large. Using stripe depths larger than the I/O size is called coarse grain striping. In high-concurrency systems, the stripe depth can be

n * DB_BLOCK_SIZE

where *n* is greater than 1.

Coarse grain striping allows a disk in the array to service several I/O requests. In this way, a large number of concurrent I/O requests can be serviced by a set of striped disks with minimal I/O setup costs. Coarse grain striping strives to maximize overall I/O throughput. Multiblock reads, as in full table scans, will benefit when stripe depths are large and can be serviced from one drive. Parallel query in a DSS environment is also a candidate for coarse grain striping. This is because there are many individual processes, each issuing separate I/Os. If coarse grain striping is used in systems that do not have high concurrent requests, then hot spots could result.

In a system with a few large I/O requests, such as in a traditional DSS environment or a low-concurrency OLTP system, then it is beneficial to keep the stripe depth small. This is called fine grain striping. In such systems, the stripe depth is

n * DB_BLOCK_SIZE

where *n* is smaller than the multiblock read parameters, such as `DB_FILE_MULTIBLOCK_READ_COUNT`.

Fine grain striping allows a single I/O request to be serviced by multiple disks. Fine grain striping strives to maximize performance for individual I/O requests or response time.

Alignment of Physical Stripe Boundaries with Block Size Boundaries

On some Oracle ports, an Oracle block boundary may not align with the stripe. If your stripe depth is the same size as the Oracle block, then a single I/O issued by Oracle might result in two physical I/O operations.

This is not optimal in an OLTP environment. To ensure a higher probability of one logical I/O resulting in no more than one physical I/O, the minimum stripe depth should be at least twice the Oracle block size. Table 8–2 shows recommended minimum stripe depth for random access and for sequential reads.

Table 8–2 Minimum Stripe Depth

Disk Access	Minimum Stripe Depth
Random reads and writes	The minimum stripe depth is twice the Oracle block size.
Sequential reads	The minimum stripe depth is twice the value of `DB_FILE_MULTIBLOCK_READ_COUNT`, multiplied by the Oracle block size.

See Also: The specific documentation for your platform

Manageability of the Proposed System

With an LVM, the simplest configuration to manage is one with a single striped volume over all available disks. In this case, the stripe width encompasses all available disks. All database files reside within that volume, effectively distributing the load evenly. This single-volume layout provides adequate performance in most situations.

A single-volume configuration is viable only when used in conjunction with RAID technology that allows easy recoverability, such as RAID 1. Otherwise, losing a single disk means losing all files concurrently and, hence, performing a full database restore and recovery.

In addition to performance, there is a manageability concern: the design of the system must allow disks to be added simply, to allow for database growth. The challenge is to do so while keeping the load balanced evenly.

For example, an initial configuration can involve the creation of a single striped volume over 64 disks, each disk being 16 GB. This is total disk space of 1 terabyte (TB) for the primary data. Sometime after the system is operational, an additional 80 GB (that is, five disks) must be added to account for future database growth.

The options for making this space available to the database include creating a second volume that includes the five new disks. However, an I/O bottleneck might develop, if these new disks are unable to sustain the I/O throughput required for the files placed on them.

Another option is to increase the size of the original volume. LVMs are becoming sophisticated enough to allow dynamic reconfiguration of the stripe width, which allows disks to be added while the system is online. This begins to make the placement of all files on a single striped volume feasible in a production environment.

If your LVM is unable to support dynamically adding disks to the stripe, then it is likely that you need to choose a smaller, more manageable stripe width. Then, when new disks are added, the system can grow by a stripe width.

In the preceding example, eight disks might be a more manageable stripe width. This is only feasible if eight disks are capable of sustaining the required number of I/Os each second. Thus, when extra disk space is required, another eight-disk stripe can be added, keeping the I/O balanced across the volumes.

Note: The smaller the stripe width becomes, the more likely it is that you will need to spend time distributing the files on the volumes, and the closer the procedure becomes to manually distributing I/O.

Manually Distributing I/O

If your system does not have an LVM or hardware striping, then I/O must be manually balanced across the available disks by distributing the files according to each file's I/O requirements. In order to make decisions on file placement, you should be familiar with the I/O requirements of the database files and the capabilities of the I/O system. If you are not familiar with this data and do not have a representative workload to analyze, you can make a first guess and then tune the layout as the usage becomes known.

To stripe disks manually, you need to relate a file's storage requirements to its I/O requirements.

1. Evaluate database disk-storage requirements by checking the size of the files and the disks.

2. Identify the expected I/O throughput for each file. Determine which files have the highest I/O rate and which do not have many I/Os. Lay out the files on all the available disks so as to even out the I/O rate.

One popular approach to manual I/O distribution suggests separating a frequently used table from its index. This is not correct. During the course of a transaction, the index is read first, and then the table is read. Because these I/Os occur sequentially, the table and index can be stored on the same disk without contention. It is not sufficient to separate a datafile simply because the datafile contains indexes or table data. The decision to segregate a file should be made only when the I/O rate for that file affects database performance.

When to Separate Files

Regardless of whether you use operating system striping or manual I/O distribution, if the I/O system or I/O layout is not able to support the I/O rate required, then you need to separate files with high I/O rates from the remaining files. You can identify such files either at the planning stage or after the system is live.

The decision to segregate files should only be driven by I/O rates, recoverability concerns, or manageability issues. (For example, if your LVM does not support dynamic reconfiguration of stripe width, then you might need to create smaller stripe widths to be able to add *n* disks at a time to create a new stripe of identical configuration.)

Before segregating files, verify that the bottleneck is truly an I/O issue. The data produced from investigating the bottleneck identifies which files have the highest I/O rates.

See Also: "Identifying High-Load SQL" on page 12-3

Tables, Indexes, and TEMP Tablespaces

If the files with high I/O are datafiles belonging to tablespaces that contain tables and indexes, then identify whether the I/O for those files can be reduced by tuning SQL or application code.

If the files with high-I/O are datafiles that belong to the `TEMP` tablespace, then investigate whether to tune the SQL statements performing disk sorts to avoid this activity, or to tune the sorting.

After the application has been tuned to avoid unnecessary I/O, if the I/O layout is still not able to sustain the required throughput, then consider segregating the high-I/O files.

See Also: "Identifying High-Load SQL" on page 12-3

Redo Log Files

If the high-I/O files are redo log files, then consider splitting the redo log files from the other files. Possible configurations can include the following:

- Placing all redo logs on one disk without any other files. Also consider availability; members of the same group should be on different physical disks and controllers for recoverability purposes.
- Placing each redo log group on a separate disk that does not store any other files.
- Striping the redo log files across several disks, using an operating system striping tool. (Manual striping is not possible in this situation.)
- Avoiding the use of RAID 5 for redo logs.

Redo log files are written sequentially by the Log Writer (LGWR) process. This operation can be made faster if there is no concurrent activity on the same disk. Dedicating a separate disk to redo log files usually ensures that LGWR runs smoothly with no further tuning necessary. If your system supports asynchronous I/O but this feature is not currently configured, then test to see if using this feature is beneficial. Performance bottlenecks related to LGWR are rare.

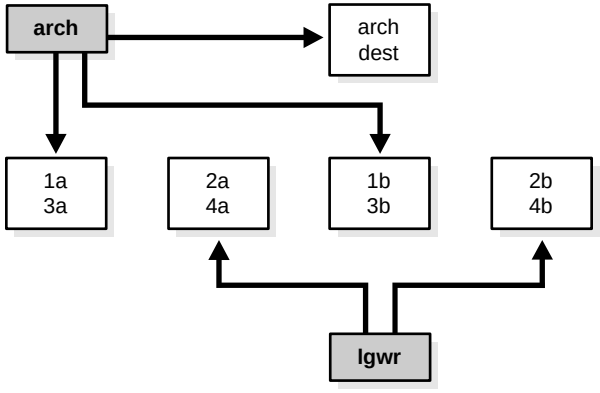
Archived Redo Logs

If the archiver is slow, then it might be prudent to prevent I/O contention between the archiver process and LGWR by ensuring that archiver reads and LGWR writes are separated. This is achieved by placing logs on alternating drives.

For example, suppose a system has four redo log groups, each group with two members. To create separate-disk access, the eight log files should be labeled 1a, 1b, 2a, 2b, 3a, 3b, 4a, and 4b. This requires at least four disks, plus one disk for archived files.

Figure 8–1 illustrates how redo members should be distributed across disks to minimize contention.

Figure 8–1 Distributing Redo Members Across Disks



In this example, LGWR switches out of log group 1 (member 1a and 1b) and writes to log group 2 (2a and 2b). Concurrently, the archiver process reads from group 1 and writes to its archive destination. Note how the redo log files are isolated from contention.

Note: Mirroring redo log files, or maintaining multiple copies of each redo log file on separate disks, does not slow LGWR considerably. LGWR writes to each disk in parallel and waits until each part of the parallel write is complete. Hence, a parallel write does not take longer than the longest possible single-disk write.

Because redo logs are written serially, drives dedicated to redo log activity generally require limited head movement. This significantly accelerates log writing.

Three Sample Configurations

This section contains three high-level examples of configuring I/O systems. These examples include sample calculations that define the disk topology, stripe depths, and so on.

Stripe Everything Across Every Disk

The simplest approach to I/O configuration is to build one giant volume, striped across all available disks. To account for recoverability, the volume is mirrored

(RAID 1). The striping unit for each disk should be larger than the maximum I/O size for the frequent I/O operations. This provides adequate performance for most cases.

Move Archive Logs to Different Disks

If archive logs are striped on the same set of disks as other files, then any I/O requests on those disks could suffer when redo logs are being archived. Moving archive logs to separate disks provides the following benefits:

- The archive can be performed at very high rate (using sequential I/O).
- Nothing else is affected by the degraded response time on the archive destination disks.

The number of disks for archive logs is determined by the rate of archive log generation and the amount of archive storage required.

Move Redo Logs to Separate Disks

In high-update OLTP systems, the redo logs are write-intensive. Moving the redo log files to disks that are separate from other disks and from archived redo log files has the following benefits:

- Writing redo logs is performed at the highest possible rate. Hence, transaction processing performance is at its best.
- Writing of the redo logs is not impaired with any other I/O.

The number of disks for redo logs is mostly determined by the redo log size, which is generally small compared to current technology disk sizes. Typically, a configuration with two disks (possibly mirrored to four disks for fault tolerance) is adequate. In particular, by having the redo log files alternating on two disks, writing redo log information to one file does not interfere with reading a completed redo log for archiving.

Oracle-Managed Files

For systems where a file system can be used to contain all Oracle data, database administration is simplified by using Oracle-managed files. Oracle internally uses standard file system interfaces to create and delete files as needed for tablespaces, temp files, online logs, and control files. Administrators only specify the file system directory to be used for a particular type of file. You can specify one default location for datafiles and up to five multiplexed locations for the control and online redo log files.

Oracle ensures that a unique file is created and then deleted when it is no longer needed. This reduces corruption caused by administrators specifying the wrong file, reduces wasted disk space consumed by obsolete files, and simplifies creation of test and development databases. It also makes development of portable third-party tools easier, because it eliminates the need to put operating-system specific file names in SQL scripts.

New files can be created as managed files, while old ones are administered in the old way. Thus, a database can have a mixture of Oracle-managed and manually managed files.

Note: Oracle-managed files cannot be used with raw devices.

Tuning Oracle-Managed Files

Several points should be considered when tuning Oracle-managed files.

- Because Oracle-managed files require the use of a file system, DBAs give up control over how the data is laid out. Therefore, it is important to correctly configure the file system.
- The Oracle-managed file system should be built on top of an LVM that supports striping. For load balancing and improved throughput, the disks in the Oracle-managed file system should be striped.
- Oracle-managed files work best if used on an LVM that supports dynamically extensible logical volumes. Otherwise, the logical volumes should be configured as large as possible.
- Oracle-managed files work best if the file system provides large extensible files.

See Also: *Oracle Database Administrator's Guide* for detailed information on using Oracle-managed files

Choosing Data Block Size

A block size of 8K is optimal for most systems. However, OLTP systems occasionally use smaller block sizes and DSS systems occasionally use larger block sizes. This section discusses considerations when choosing database block size for optimal performance.

Note: The use of multiple block sizes in a single database instance is not encouraged because of manageability issues.

Reads

Regardless of the size of the data, the goal is to minimize the number of reads required to retrieve the desired data.

- If the rows are small and access is predominantly random, then choose a smaller block size.
- If the rows are small and access is predominantly sequential, then choose a larger block size.
- If the rows are small and access is both random and sequential, then it might be effective to choose a larger block size.
- If the rows are large, such as rows containing large object (LOB) data, then choose a larger block size.

Writes

For high-concurrency OLTP systems, consider appropriate values for `INITRANS`, `MAXTRANS`, and `FREELISTS` when using a larger block size. These parameters affect the degree of update concurrency allowed within a block. However, you do not need to specify the value for `FREELISTS` when using automatic segment-space management.

If you are uncertain about which block size to choose, then try a database block size of 8 KB for most systems that process a large number of transactions. This represents a good compromise and is usually effective. Only systems processing LOB data need more than 8 KB.

See Also: The Oracle documentation specific to your operating system for information on the minimum and maximum block size on your platform

Block Size Advantages and Disadvantages

Table 8–3 lists the advantages and disadvantages of different block sizes.

Table 8–3 Block Size Advantages and Disadvantages

Block Size	Advantages	Disadvantages
Smaller	Good for small rows with lots of random access.	Has relatively large space overhead due to metadata (that is, block header).
	Reduces block contention.	Not recommended for large rows. There might only be a few rows stored for each block, or worse, row chaining if a single row does not fit into a block,
Larger	Has lower overhead, so there is more room to store data.	Wastes space in the buffer cache, if you are doing random access to small rows and have a large block size. For example, with an 8 KB block size and 50 byte row size, you waste 7,950 bytes in the buffer cache when doing random access.
	Permits reading a number of rows into the buffer cache with a single I/O (depending on row size and block size).	
	Good for sequential access or very large rows (such as LOB data).	Not good for index blocks used in an OLTP environment, because they increase block contention on the index leaf blocks.

9

Understanding Operating System Resources

This chapter explains how to tune the operating system for optimal performance of the Oracle database server.

This chapter contains the following sections:

- Understanding Operating System Performance Issues
- Solving Operating System Problems
- Understanding CPU
- Finding System CPU Utilization

See Also:

- Your Oracle platform-specific documentation and your operating system vendor' s documentation
- "Operating System Statistics" on page 5-5 for a discussion of the importance of operating system statistics

Understanding Operating System Performance Issues

Operating system performance issues commonly involve process management, memory management, and scheduling. If you have tuned the Oracle instance and you still need better performance, then verify your work or try to reduce system time. Make sure that there is enough I/O bandwidth, CPU power, and swap space. Do not expect, however, that further tuning of the operating system will have a significant effect on application performance. Changes in the Oracle configuration or in the application are likely to make a more significant difference in operating system efficiency than simply tuning the operating system.

For example, if an application experiences excessive buffer busy waits, then the number of system calls increases. If you reduce the buffer busy waits by tuning the application, then the number of system calls decreases.

> **See Also:** Your Oracle platform-specific documentation and your operating system vendor's documentation

Using Operating System Caches

Operating systems and device controllers provide data caches that do not directly conflict with Oracle cache management. Nonetheless, these structures can consume resources while offering little or no benefit to performance. This is most noticeable on a UNIX system that has the database files in the UNIX file store; by default all database I/O goes through the file system cache. On some UNIX systems, direct I/O is available to the filestore. This arrangement allows the database files to be accessed within the UNIX file system, bypassing the file system cache. It saves CPU resources and allows the file system cache to be dedicated to non-database activity, such as program texts and spool files.

This problem does not occur on Windows. All file requests by the database bypass the caches in the file system.

Although the operating system cache is often redundant because the Oracle buffer cache buffers blocks, there are a number of cases where Oracle does not use the Oracle buffer cache. In these cases, using direct I/O which bypasses the Unix or operating system cache or using raw devices which do not use the operating system cache may yield worse performance than using operating system buffering. Some examples of this include the following:

- Reads or writes to the `TEMPORARY` tablespace
- Data stored in `NOCACHE` LOBs
- Parallel Query slaves reading data

You may want a mix with some files cached at the operating system level and others not.

Asynchronous I/O

With synchronous I/O, when an I/O request is submitted to the operating system, the writing process blocks until the write is confirmed as complete. It can then continue processing. With asynchronous I/O, processing continues while the I/O request is submitted and processed. Use asynchronous I/O when possible to avoid bottlenecks.

Some platforms support asynchronous I/O by default, others need special configuration, and some only support asynchronous I/O for certain underlying file system types.

FILESYSTEMIO_OPTIONS Initialization Parameter

You can use the `FILESYSTEMIO_OPTIONS` initialization parameter to enable or disable asynchronous I/O or direct I/O on file system files. This parameter is platform-specific and has a default value that is best for a particular platform. It can be dynamically changed to update the default setting.

`FILESYTEMIO_OPTIONS` can be set to one of the following values:

- `ASYNCH:` enable asynchronous I/O on file system files, which has no timing requirement for transmission
- `DIRECTIO:` enable direct I/O on file system files, which bypasses the buffer cache
- `SETALL:` enable both asynchronous and direct I/O on file system files
- `NONE:` disable both asynchronous and direct I/O on file system files

See Also: Your platform-specific documentation for more details

Memory Usage

Memory usage is affected by both buffer cache limits and initialization parameters.

Buffer Cache Limits

The UNIX buffer cache consumes operating system memory resources. Although in some versions of UNIX the UNIX buffer cache may be allocated a set amount of memory, it is common today for more sophisticated memory management mechanisms to be used. Typically these will allow free memory pages to be used to

cache I/O. In such systems it is common for operating system reporting tools to show that there is no free memory which is not generally a problem. If processes require more memory, the memory caching I/O data is usually released to allow the process memory to be allocated.

Parameters Affecting Memory Usage

The memory required by any one Oracle session depends on many factors. Typically the major contributing factors are:

- Number of open cursors
- Memory used by PL/SQL, such as PL/SQL tables
- SORT_AREA_SIZE initialization parameter

In Oracle, the PGA_AGGREGATE_TARGET initialization parameter gives greater control over a session's memory usage.

Using Operating System Resource Managers

Some platforms provide operating system resource managers. These are designed to reduce the impact of peak load use patterns by prioritizing access to system resources. They usually implement administrative policies that govern which resources users can access and how much of those resources each user is permitted to consume.

Operating system resource managers are different from domains or other similar facilities. Domains provide one or more completely separated environments within one system. Disk, CPU, memory, and all other resources are dedicated to each domain and cannot be accessed from any other domain. Other similar facilities completely separate just a portion of system resources into different areas, usually separate CPU or memory areas. Like domains, the separate resource areas are dedicated only to the processing assigned to that area; processes cannot migrate across boundaries. Unlike domains, all other resources (usually disk) are accessed by all partitions on a system.

Oracle runs within domains, as well as within these other less complete partitioning constructs, as long as the allocation of partitioned memory (RAM) resources is fixed, not dynamic.

Note: Oracle is not supported in any resource partitioned environment in which memory resources are assigned dynamically.

Operating system resource managers prioritize resource allocation within a global pool of resources, usually a domain or an entire system. Processes are assigned to groups, which are in turn assigned resources anywhere within the resource pool.

Note: Oracle is not supported for use with any operating system resource manager's memory management and allocation facility. Oracle Database Resource Manager, which provides resource allocation capabilities within an Oracle instance, cannot be used with any operating system resource manager.

Caution: When running under operating system resource managers, Oracle is supported only when each instance is assigned to a dedicated operating system resource manager group or managed entity. Also, the dedicated entity running all the instance's processes must run at one priority (or resource consumption) level. Management of individual Oracle processes at different priority levels is *not* supported. Severe consequences, including instance crashes, can result.

See Also:

- For a complete list of operating system resource management and resource allocation and deallocation features that work with Oracle and Oracle Database Resource Manager, see your systems vendor and your Oracle representative. Oracle does not certify these system features for compatibility with specific release levels.
- *Oracle Database Administrator's Guide* for more information about Oracle Database Resource Manager

Solving Operating System Problems

This section provides hints for tuning various systems by explaining the following topics:

- Performance Hints on UNIX-Based Systems
- Performance Hints on Windows Systems

- Performance Hints on Midrange and Mainframe Computers

Familiarize yourself with platform-specific issues so that you know what performance options the operating system provides.

> **See Also:** Your Oracle platform-specific documentation and your operating system vendor's documentation

Performance Hints on UNIX-Based Systems

On UNIX systems, try to establish a good ratio between the amount of time the operating system spends fulfilling system calls and doing process scheduling and the amount of time the application runs. The goal should be to run most of the time in application mode, also called user mode, rather than system mode.

The ratio of time spent in each mode is only a symptom of the underlying problem, which might involve the following:

- Paging or swapping
- Executing too many operating system calls
- Running too many processes

If such conditions exist, then there is less time available for the application to run. The more time you can release from the operating system side, the more transactions an application can perform.

Performance Hints on Windows Systems

On Windows systems, as with UNIX-based systems, establish an appropriate ratio between time in application mode and time in system mode. You can easily monitor many factors with the Windows administrative performance tool: CPU, network, I/O, and memory are all displayed on the same graph to assist you in avoiding bottlenecks in any of these areas.

Performance Hints on Midrange and Mainframe Computers

Consider the paging parameters on a mainframe, and remember that Oracle can exploit a very large working set.

Free memory in VAX or VMS environments is actually memory that is not mapped to any operating system process. On a busy system, free memory likely contains a page belonging to one or more currently active process. When that access occurs, a `soft page fault` takes place, and the page is included in the working set for the

process. If the process cannot expand its working set, then one of the pages currently mapped by the process must be moved to the free set.

Any number of processes might have pages of shared memory within their working sets. The sum of the sizes of the working sets can thus markedly exceed the available memory. When the Oracle server is running, the SGA, the Oracle kernel code, and the Oracle Forms runtime executable are normally all sharable and account for perhaps 80% or 90% of the pages accessed.

Understanding CPU

To address CPU problems, first establish appropriate expectations for the amount of CPU resources your system should be using. Then, determine whether sufficient CPU resources are available and recognize when your system is consuming too many resources. Begin by determining the amount of CPU resources the Oracle instance utilizes with your system in the following three cases:

- System is idle, when little Oracle and non-Oracle activity exists
- System at average workloads
- System at peak workloads

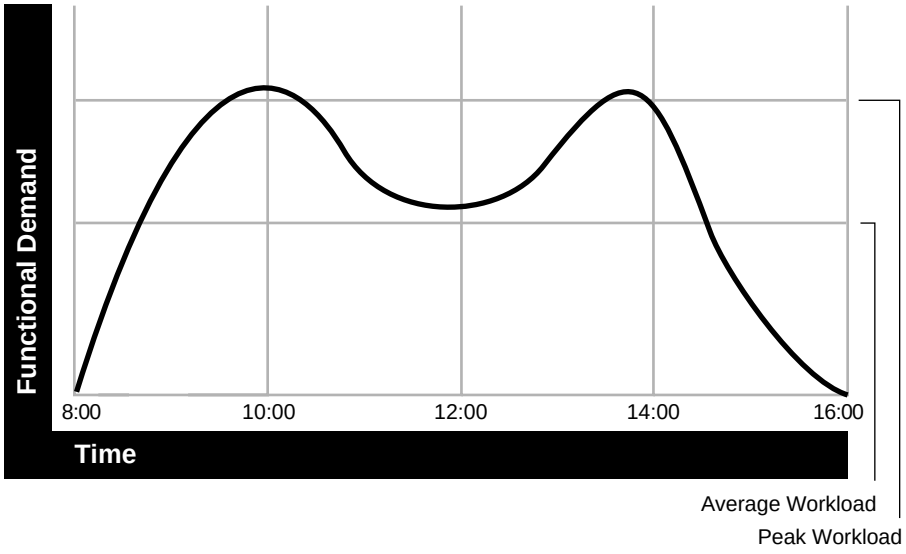
You can capture various workload snapshots using the Automatic Workload Repository, Statspack, or the UTLBSTAT/UTLESTAT utility. Operating system utilities, such as `vmstat`, `sar`, and `iostat` on UNIX and the administrative performance monitoring tool on Windows, should be run during the same time interval as Automatic Workload Repository, Statspack, or UTLBSTAT/UTLESTAT to provide a complimentary view of the overall statistics.

See Also:

- "Automatic Workload Repository" on page 5-10
- Chapter 6, "Automatic Performance Diagnostics" for more information on Oracle tools

Workload is an important factor when evaluating your system's level of CPU utilization. During peak workload hours, 90% CPU utilization with 10% idle and waiting time can be acceptable. Even 30% utilization at a time of low workload can be understandable. However, if your system shows high utilization at normal workload, then there is no room for a peak workload. For example, Figure 9–1 illustrates workload over time for an application having peak periods at 10:00 AM and 2:00 PM.

Figure 9–1 Average Workload and Peak Workload



This example application has 100 users working 8 hours a day. Each user entering one transaction every 5 minutes translates into 9,600 transactions daily. Over an 8-hour period, the system must support 1,200 transactions an hour, which is an average of 20 transactions a minute. If the demand rate were constant, then you could build a system to meet this average workload.

However, usage patterns are not constant and in this context, 20 transactions a minute can be understood as merely a minimum requirement. If the peak rate you need to achieve is 120 transactions a minute, then you must configure a system that can support this peak workload.

For this example, assume that at peak workload, Oracle uses 90% of the CPU resource. For a period of average workload, then, Oracle uses no more than about 15% of the available CPU resource, as illustrated in the following equation:

```
20 tpm / 120 tpm * 90% = 15% of available CPU resource
```

where `tpm` is transactions a minute.

If the system requires 50% of the CPU resource to achieve 20 tpm, then a problem exists: the system cannot achieve 120 transactions a minute using 90% of the CPU. However, if you tuned this system so that it achieves 20 tpm using only 15% of the CPU, then, assuming linear scalability, the system might achieve 120 transactions a minute using 90% of the CPU resources.

As users are added to an application, the workload can rise to what had previously been peak levels. No further CPU capacity is then available for the new peak rate, which is actually higher than the previous.

CPU capacity issues can be addressed with the following:

- Tuning, or the process of detecting and solving CPU problems from excessive consumption. See "Finding System CPU Utilization" on page 9-10.
- Increasing hardware capacity, including changing the system architecture

  See Also: "System Architecture" on page 2-7 for information about improving your system architecture

- Reducing the impact of peak load use patterns by prioritizing CPU resource allocation. Oracle Database Resource Manager does this by allocating and managing CPU resources among database users and applications.

  See Also: *Oracle Database Administrator's Guide* for more information about Oracle Database Resource Manager

Context Switching

Oracle has the several features for context switching, described in this section.

Post-wait Driver

An Oracle process needs to be able to post another Oracle process (give it a message) and also needs to be able to wait to be posted.

For example, a foreground process may need to post LGWR to tell it to write out all blocks up to a given point so that it can acknowledge a commit.

Often this post-wait mechanism is implemented through UNIX Semaphores, but these can be resource intensive. Therefore, some platforms supply a post-wait driver, typically a kernel device driver that is a lightweight method of implementing a post-wait interface.

Memory-mapped System Timer

Oracle often needs to query the system time for timing information. This can involve an operating system call that incurs a relatively costly context switch. Some platforms implement a memory-mapped timer that uses an address within the processes virtual address space to contain the current time information. Reading the

time from this memory-mapped timer is less expensive than the overhead of a context switch for a system call.

List I/O Interfaces to Submit Multiple Asynchronous I/Os in One Call

List I/O is an application programming interface that allows several asynchronous I/O requests to be submitted in a single system call, rather than submitting several I/O requests through separate system calls. The main benefit of this feature is to reduce the number of context switches required.

Finding System CPU Utilization

Oracle statistics report CPU use by Oracle sessions only, whereas every process running on your system affects the available CPU resources. Therefore, tuning non-Oracle factors can also improve Oracle performance.

Use operating system monitoring tools to determine what processes are running on the system as a whole. If the system is too heavily loaded, check the memory, I/O, and process management areas described later in this section.

Tools such as `sar -u` on many UNIX-based systems let you examine the level of CPU utilization on your entire system. CPU utilization in UNIX is described in statistics that show user time, system time, idle time, and time waiting for I/O. A CPU problem exists if idle time and time waiting for I/O are both close to zero (less than 5%) at a normal or low workload.

On Windows, use the administrative performance tool to monitor CPU utilization. This utility provides statistics on processor time, user time, privileged time, interrupt time, and DPC time.

Note: This section describes how to check system CPU utilization on most UNIX-based and Windows systems. For other platforms, see your operating system documentation.

Checking Memory Management

Check the following memory management areas:

Paging and Swapping

Use utilities such as `sar` or `vmstat` on UNIX or the administrative performance tool on Windows to investigate the cause of paging and swapping.

Oversize Page Tables

On UNIX, if the processing space becomes too large, then it can result in the page tables becoming too large. This is not an issue on Windows systems.

Checking I/O Management

Thrashing is an I/O management issue. Ensure that your workload fits into memory, so the machine is not thrashing (swapping and paging processes in and out of memory). The operating system allocates fixed portions of time during which CPU resources are available to your process. If the process wastes a large portion of each time period checking to be sure that it can run and ensuring that all necessary components are in the machine, then the process might be using only 50% of the time allotted to actually perform work.

See Also: Chapter 8, "I/O Configuration and Design"

Checking Network Management

Check client/server round trips. There is an overhead in processing messages. When an application generates many messages that need to be sent through the network, the latency of sending a message can result in CPU overload. To alleviate this problem, bundle multiple messages together rather than perform lots of round trips. For example, you can use array inserts, array fetches, and so on.

Checking Process Management

Several process management issues discussed in this section should be checked.

Scheduling and Switching

The operating system can spend excessive time scheduling and switching processes. Examine the way in which you are using the operating system, because you could be using too many processes. On Windows systems, do not overload your server with too many non-Oracle processes.

Context Switching

Due to operating system specific characteristics, your system could be spending a lot of time in context switches. Context switching can be expensive, especially with a large SGA. Context switching is not an issue on Windows, which has only one process for each instance. All threads share the same page table.

Starting New Operating System Processes

There is a high cost in starting new operating system processes. Programmers often create single-purpose processes, exit the process, and create a new one. Doing this re-creates and destroys the process each time. Such logic uses excessive amounts of CPU, especially with applications that have large SGAs. This is because you need to build the page tables each time. The problem is aggravated when you pin or lock shared memory, because you have to access every page.

For example, if you have a 1 gigabyte SGA, then you might have page table entries for every 4 KB, and a page table entry might be 8 bytes. You could end up with (1G / 4 KB) * 8 byte entries. This becomes expensive, because you need to continually make sure that the page table is loaded.

10

Instance Tuning Using Performance Views

After the initial configuration of a database, tuning an instance is important to eliminate any performance bottlenecks. This chapter discusses the tuning process based on the Oracle performance views.

This chapter contains the following sections:

Instance Tuning Steps

These are the main steps in the Oracle performance method for instance tuning:

1. Define the Problem

   Get candid feedback from users about the scope of the performance problem.

2. Examine the Host System and Examine the Oracle Statistics

   - After obtaining a full set of operating system, database, and application statistics, examine the data for any evidence of performance problems.
   - Consider the list of common performance errors to see whether the data gathered suggests that they are contributing to the problem.
   - Build a conceptual model of what is happening on the system using the performance data gathered.

3. Implement and Measure Change

   Propose changes to be made and the expected result of implementing the changes. Then, implement the changes and measure application performance.

4. Determine whether the performance objective defined in step 1 has been met. If not, then repeat steps 2 and 3 until the performance goals are met.

> **See Also:** "The Oracle Performance Improvement Method" on page 3-2 for a theoretical description of this performance method and a list of common errors

The remainder of this chapter discusses instance tuning using the Oracle dynamic performance views. However, Oracle recommends using the Automatic Workload Repository and Automatic Database Diagnostic Monitor for statistics gathering, monitoring, and tuning due to the extended feature list. See "Automatic Workload Repository" on page 5-10 and "Automatic Database Diagnostic Monitor" on page 6-3.

Note: If your site does not have the Automatic Workload Repository and Automatic Database Diagnostic Monitor features, then Statspack can be used to gather Oracle instance statistics.

Define the Problem

It is vital to develop a good understanding of the purpose of the tuning exercise and the nature of the problem before attempting to implement a solution. Without this understanding, it is virtually impossible to implement effective changes. The data gathered during this stage helps determine the next step to take and what evidence to examine.

Gather the following data:

1. Identify the performance objective.

   What is the measure of acceptable performance? How many transactions an hour, or seconds, response time will meet the required performance level?

2. Identify the scope of the problem.

   What is affected by the slowdown? For example, is the whole instance slow? Is it a particular application, program, specific operation, or a single user?

3. Identify the time frame when the problem occurs.

   Is the problem only evident during peak hours? Does performance deteriorate over the course of the day? Was the slowdown gradual (over the space of months or weeks) or sudden?

4. Quantify the slowdown.

   This helps identify the extent of the problem and also acts as a measure for comparison when deciding whether changes implemented to fix the problem have actually made an improvement. Find a consistently reproducible measure of the response time or job run time. How much worse are the timings than when the program was running well?

5. Identify any changes.

   Identify what has changed since performance was acceptable. This may narrow the potential cause quickly. For example, has the operating system software, hardware, application software, or Oracle release been upgraded? Has more data been loaded into the system, or has the data volume or user population grown?

At the end of this phase, you should have a good understanding of the symptoms. If the symptoms can be identified as local to a program or set of programs, then the problem is handled in a different manner than instance-wide performance issues.

> **See Also:** Chapter 12, "SQL Tuning Overview" for information on solving performance problems specific to an application or user

Examine the Host System

Look at the load on the database server, as well as the database instance. Consider the operating system, the I/O subsystem, and network statistics, because examining these areas helps determine what might be worth further investigation. In multitier systems, also examine the application server middle-tier hosts.

Examining the host hardware often gives a strong indication of the bottleneck in the system. This determines which Oracle performance data could be useful for cross-reference and further diagnosis.

Data to examine includes the following:

CPU Usage

If there is a significant amount of idle CPU, then there could be an I/O, application, or database bottleneck. Note that wait I/O should be considered as idle CPU.

If there is high CPU usage, then determine whether the CPU is being used effectively. Is the majority of CPU usage attributable to a small number of high-CPU using programs, or is the CPU consumed by an evenly distributed workload?

If the CPU is used by a small number of high-usage programs, then look at the programs to determine the cause. Check whether some processes alone consume the full power of one CPU. Depending on the process, this could be an indication of a CPU or process bound workload which can be tackled by dividing or parallelizing the process activity.

Non-Oracle Processes If the programs are not Oracle programs, then identify whether they are legitimately requiring that amount of CPU. If so, determine whether their execution be delayed to off-peak hours. Identifying these CPU intensive processes can also help narrowing what specific activity, such as I/O, network, and paging, is consuming resources and how can it be related to the Oracle workload.

Oracle Processes If a small number of Oracle processes consumes most of the CPU resources, then use SQL_TRACE and TKPROF to identify the SQL or PL/SQL statements to see if a particular query or PL/SQL program unit can be tuned. For example, a SELECT statement could be CPU-intensive if its execution involves many reads of data in cache (logical reads) that could be avoided with better SQL optimization.

Oracle CPU Statistics Oracle CPU statistics are available in several V$ views:

- V$SYSSTAT shows Oracle CPU usage for all sessions. The CPU used by this session statistic shows the aggregate CPU used by all sessions. The parse time cpu statistic shows the total CPU time used for parsing.
- V$SESSTAT shows Oracle CPU usage for each session. Use this view to determine which particular session is using the most CPU.
- V$RSRC_CONSUMER_GROUP shows CPU utilization statistics for each consumer group when the Oracle Database Resource Manager is running.

Interpreting CPU Statistics It is important to recognize that CPU time and real time are distinct. With eight CPUs, for any given minute in real time, there are eight minutes of CPU time available. On Windows and UNIX, this can be either user time or system time (privileged mode on Windows). Thus, average CPU time utilized by all processes (threads) on the system could be greater than one minute for every one minute real time interval.

At any given moment, you know how much time Oracle has used on the system. So, if eight minutes are available and Oracle uses four minutes of that time, then you know that 50% of all CPU time is used by Oracle. If your process is not consuming that time, then some other process is. Identify the processes that are using CPU time, figure out why, and then attempt to tune them. See Chapter 20, "Using Application Tracing Tools".

If the CPU usage is evenly distributed over many Oracle server processes, examine the V$SYS_TIME_MODEL view to help get a precise understanding of where most time is spent. See Table 10–1, " Wait Events and Potential Causes" on page 10-17.

Detecting I/O Problems

An overly active I/O system can be evidenced by disk queue lengths greater than two, or disk service times that are over 20-30ms. If the I/O system is overly active, then check for potential hot spots that could benefit from distributing the I/O across more disks. Also identify whether the load can be reduced by lowering the resource requirements of the programs using those resources.

Use operating system monitoring tools to determine what processes are running on the system as a whole and to monitor disk access to all files. Remember that disks holding datafiles and redo log files can also hold files that are not related to Oracle. Reduce any heavy access to disks that contain database files. Access to non-Oracle files can be monitored only through operating system facilities, rather than through the V$ views.

Utilities, such as `sar -d` (or `iostat`) on many UNIX systems and the administrative performance monitoring tool on Windows systems, examine I/O statistics for the entire system.

> **See Also:** Your operating system documentation for the tools available on your platform

Check the Oracle wait event data in V$SYSTEM_EVENT to see whether the top wait events are I/O related. I/O related events include `db file sequential read`, `db file scattered read`, `db file single write`, and `db file parallel write`, and `log file parallel write`. These are all events corresponding to I/Os performed against datafiles and log files. If any of these wait events correspond to high average time, then investigate the I/O contention.

Cross reference the host I/O system data with the I/O sections in the Automatic Repository report to identify hot datafiles and tablespaces. Also compare the I/O times reported by the operating system with the times reported by Oracle to see if they are consistent.

An I/O problem can also manifest itself with non-I/O related wait events. For example, the difficulty in finding a free buffer in the buffer cache or high wait times for log to be flushed to disk can also be symptoms of an I/O problem. Before investigating whether the I/O system should be reconfigured, determine if the load on the I/O system can be reduced. To reduce Oracle I/O load, look at SQL statements that perform many physical reads by querying the V$SQLAREA view or by reviewing the 'SQL ordered by Reads' section of the Automatic Workload Repository report. Examine these statements to see how they can be tuned to reduce the number of I/Os.

If there are Oracle-related I/O problems caused by SQL statements, then tune them. If the Oracle server is not consuming the available I/O resources, then identify the process that is using up the I/O. Determine why the process is using up the I/O, and then tune this process.

See Also:

- Chapter 12, "SQL Tuning Overview"
- *Oracle Database Reference* for information about the dynamic performance V$SQLAREA view
- Chapter 8, "I/O Configuration and Design"
- "db file scattered read" on page 10-27 and "db file sequential read" on page 10-29 for the difference between a scattered read and a sequential read, and how this affects I/O

Network

Using operating system utilities, look at the network round-trip ping time and the number of collisions. If the network is causing large delays in response time, then investigate possible causes.

Network load can be reduced by scheduling large data transfers to off-peak times, or by coding applications to batch requests to remote hosts, rather than accessing remote hosts once (or more) for one request.

Examine the Oracle Statistics

Oracle statistics should be examined and cross-referenced with operating system statistics to ensure a consistent diagnosis of the problem. operating-system statistics can indicate a good place to begin tuning. However, if the goal is to tune the Oracle instance, then look at the Oracle statistics to identify the resource bottleneck from an Oracle perspective before implementing corrective action. See "Interpreting Oracle Statistics" on page 10-13.

The following sections discuss the common Oracle data sources used while tuning.

Setting the Level of Statistics Collection

Oracle provides the initialization parameter STATISTICS_LEVEL, which controls all major statistics collections or advisories in the database. This parameter sets the statistics collection level for the database.

Depending on the setting of STATISTICS_LEVEL, certain advisories or statistics are collected, as follows:

- BASIC: No advisories or statistics are collected. Monitoring and many automatic features are disabled. Oracle does not recommend this setting because it disables important Oracle features.

- TYPICAL: This is the default value and ensures collection for all major statistics while providing best overall database performance. This setting should be adequate for most environments.
- ALL: All of the advisories or statistics that are collected with the TYPICAL setting are included, plus timed operating system statistics and row source execution statistics.

See Also:

- *Oracle Database Reference* for more information on the STATISTICS_LEVEL initialization parameter
- "Interpreting Statistics" on page 5-8 for considerations when setting the STATISTICS_LEVEL, DB_CACHE_ADVICE, TIMED_STATISTICS, or TIMED_OS_STATISTICS initialization parameters

V$STATISTICS_LEVEL This view lists the status of the statistics or advisories controlled by STATISTICS_LEVEL.

See Also: *Oracle Database Reference* for information about the dynamic performance V$STATISTICS_LEVEL view

Wait Events

Wait events are statistics that are incremented by a server process or thread to indicate that it had to wait for an event to complete before being able to continue processing. Wait event data reveals various symptoms of problems that might be impacting performance, such as latch contention, buffer contention, and I/O contention. Remember that these are only symptoms of problems, not the actual causes.

Wait events are grouped into classes. The wait event classes include: Administrative, Application, Cluster, Commit, Concurrency, Configuration, Idle, Network, Other, Scheduler, System I/O, and User I/O.

A server process can wait for the following:

- A resource to become available, such as a buffer or a latch
- An action to complete, such as an I/O
- More work to do, such as waiting for the client to provide the next SQL statement to execute. Events that identify that a server process is waiting for more work are known as idle events.

> **See Also:** *Oracle Database Reference* for more information about Oracle wait events

Wait event statistics include the number of times an event was waited for and the time waited for the event to complete. If the initialization parameter TIMED_STATISTICS is set to true, then you can also see how long each resource was waited for.

To minimize user response time, reduce the time spent by server processes waiting for event completion. Not all wait events have the same wait time. Therefore, it is more important to examine events with the most total time waited rather than wait events with a high number of occurrences. Usually, it is best to set the dynamic parameter TIMED_STATISTICS to true at least while monitoring performance. See "Setting the Level of Statistics Collection" on page 10-7 for information about STATISTICS_LEVEL settings.

Dynamic Performance Views Containing Wait Event Statistics

These dynamic performance views can be queried for wait event statistics:

- V$ACTIVE_SESSION_HISTORY

  The V$ACTIVE_SESSION_HISTORY view displays active database session activity, sampled once every second. See "Active Session History (ASH)" on page 5-4.

- V$SESS_TIME_MODEL and V$SYS_TIME_MODEL

  The V$SESS_TIME_MODEL and V$SYS_TIME_MODEL views contain time model statistics, including DB time which is the total time spent in database calls

- V$SESSION_WAIT

  The V$SESSION_WAIT view displays the resources or events for which active sessions are waiting.

- V$SESSION

  The V$SESSION view contains the same wait statistics that are contained in the V$SESSION_WAIT view. If applicable, this view also contains detailed information on the object that the session is currently waiting for (object number, block number, file number, and row number), plus the blocking session responsible for the current wait.

- V$SESSION_EVENT

The V$SESSION_EVENT view provides summary of all the events the session has waited for since it started.

- V$SESSION_WAIT_CLASS

  The V$SESSION_WAIT_CLASS view provides the number of waits and the time spent in each class of wait events for each session.

- V$SESSION_WAIT_HISTORY

  The V$SESSION_WAIT_HISTORY view provides the last ten wait events for each active session.

- V$SYSTEM_EVENT

  The V$SYSTEM_EVENT view provides a summary of all the event waits on the instance since it started.

- V$EVENT_HISTOGRAM

  The V$EVENT_HISTOGRAM view displays a histogram of the number of waits, the maximum wait, and total wait time on a per-child cursor basis.

- V$FILE_HISTOGRAM

  The V$FILE_HISTOGRAM view displays a histogram of times waited during single block reads for each file.

- V$SYSTEM_WAIT_CLASS

  The V$SYSTEM_WAIT_CLASS view provides the instance wide time totals for the number of waits and the time spent in each class of wait events. This view also shows the object number for which the session is waiting.

- V$TEMP_HISTOGRAM

  The V$TEMP_HISTOGRAM view displays a histogram of times waited during single block reads for each temporary file.

> **See Also:** *Oracle Database Reference* for information about the dynamic performance views

Investigate wait events and related timing data when performing reactive performance tuning. The events with the most time listed against them are often strong indications of the performance bottleneck. For example, by looking at V$SYSTEM_EVENT, you might notice lots of `buffer busy waits`. It might be that many processes are inserting into the same block and must wait for each other before they can insert. The solution could be to use automatic segment space

management or partitioning for the object in question. See "Wait Events Statistics" on page 10-21 for a description of the differences between the views V$SESSION_WAIT, V$SESSION_EVENT, and V$SYSTEM_EVENT.

System Statistics

System statistics are typically used in conjunction with wait event data to find further evidence of the cause of a performance problem.

For example, if V$SYSTEM_EVENT indicates that the largest wait event (in terms of wait time) is the event `buffer busy waits`, then look at the specific buffer wait statistics available in the view V$WAITSTAT to see which block type has the highest wait count and the highest wait time.

After the block type has been identified, also look at V$SESSION real-time while the problem is occurring or V$ACTIVE_SESSION_HISTORY and DBA_HIST_ACTIVE_SESS_HISTORY views after the problem has been experienced to identify the contended-for objects using the object number indicated. The combination of this data indicates the appropriate corrective action.

Statistics are available in many V$ views. Some common views include the following:

V$ACTIVE_SESSION_HISTORY This view displays active database session activity, sampled once every second. See "Active Session History (ASH)" on page 5-4.

V$SYSSTAT This contains overall statistics for many different parts of Oracle, including rollback, logical and physical I/O, and parse data. Data from V$SYSSTAT is used to compute ratios, such as the buffer cache hit ratio.

V$FILESTAT This contains detailed file I/O statistics for each file, including the number of I/Os for each file and the average read time.

V$ROLLSTAT This contains detailed rollback and undo segment statistics for each segment.

V$ENQUEUE_STAT This contains detailed enqueue statistics for each enqueue, including the number of times an enqueue was requested and the number of times an enqueue was waited for, and the wait time.

V$LATCH This contains detailed latch usage statistics for each latch, including the number of times each latch was requested and the number of times the latch was waited for.

See Also: *Oracle Database Reference* for information about dynamic performance views

Segment-Level Statistics

You can gather segment-level statistics to help you spot performance problems associated with individual segments. Collecting and viewing segment-level statistics is a good way to effectively identify hot tables or indexes in an instance.

After viewing wait events and system statistics to identify the performance problem, you can use segment-level statistics to find specific tables or indexes that are causing the problem. Consider, for example, that V$SYSTEM_EVENT indicates that buffer busy waits cause a fair amount of wait time. You can select from V$SEGMENT_STATISTICS the top segments that cause the buffer busy waits. Then you can focus your effort on eliminating the problem in those segments.

You can query segment-level statistics through the following dynamic performance views:

- V$SEGSTAT_NAME This view lists the segment statistics being collected, as well as the properties of each statistic (for instance, if it is a sampled statistic).
- V$SEGSTAT This is a highly efficient, real-time monitoring view that shows the statistic value, statistic name, and other basic information.
- V$SEGMENT_STATISTICS This is a user-friendly view of statistic values. In addition to all the columns of V$SEGSTAT, it has information about such things as the segment owner and table space name. It makes the statistics easy to understand, but it is more costly.

See Also: *Oracle Database Reference* for information about dynamic performance views

Implement and Measure Change

Often at the end of a tuning exercise, it is possible to identify two or three changes that could potentially alleviate the problem. To identify which change provides the most benefit, it is recommended that only one change be implemented at a time. The effect of the change should be measured against the baseline data measurements found in the problem definition phase.

Typically, most sites with dire performance problems implement a number of overlapping changes at once, and thus cannot identify which changes provided any benefit. Although this is not immediately an issue, this becomes a significant hindrance if similar problems subsequently appear, because it is not possible to

know which of the changes provided the most benefit and which efforts to prioritize.

If it is not possible to implement changes separately, then try to measure the effects of dissimilar changes. For example, measure the effect of making an initialization change to optimize redo generation separately from the effect of creating a new index to improve the performance of a modified query. It is impossible to measure the benefit of performing an operating system upgrade if SQL is tuned, the operating system disk layout is changed, and the initialization parameters are also changed at the same time.

Performance tuning is an iterative process. It is unlikely to find a 'silver bullet' that solves an instance-wide performance problem. In most cases, excellent performance requires iteration through the performance tuning phases, because solving one bottleneck often uncovers another (sometimes worse) problem.

Knowing when to stop tuning is also important. The best measure of performance is user perception, rather than how close the statistic is to an ideal value.

Interpreting Oracle Statistics

Gather statistics that cover the time when the instance had the performance problem. If you previously captured baseline data for comparison, then you can compare the current data to the data from the baseline that most represents the problem workload.

When comparing two reports, ensure that the two reports are from times where the system was running comparable workloads.

See Also: "Overview of Data Gathering" on page 5-2

Examine Load

Usually, wait events are the first data examined. However, if you have a baseline report, then check to see if the load has changed. Regardless of whether you have a baseline, it is useful to see whether the resource usage rates are high.

Load-related statistics to examine include `redo size`, `session logical reads`, `db block changes`, `physical reads`, `physical writes`, `parse count (total)`, `parse count (hard)`, and `user calls`. This data is queried from V$SYSSTAT. It is best to normalize this data over seconds and over transactions.

In the Automatic Workload Repository report, look at the Load Profile section. The data has been normalized over transactions and over seconds.

Changing Load

The load profile statistics over seconds show the changes in throughput (that is, whether the instance is performing more work each second). The statistics over transactions identify changes in the application characteristics by comparing these to the corresponding statistics from the baseline report.

High Rates of Activity

Examine the statistics normalized over seconds to identify whether the rates of activity are very high. It is difficult to make blanket recommendations on high values, because the thresholds are different on each site and are contingent on the application characteristics, the number and speed of CPUs, the operating system, the I/O system, and the Oracle release.

The following are some generalized examples (acceptable values vary at each site):

- A hard parse rate of more than 100 a second indicates that there is a very high amount of hard parsing on the system. High hard parse rates cause serious performance issues and must be investigated. Usually, a high hard parse rate is accompanied by latch contention on the shared pool and library cache latches.
- Check whether the sum of the wait times for library cache and shared pool latch events (latch: library cache, latch: library cache pin, latch: library cache lock and latch: shared pool) is significant compared to statistic `DB time` found in `V$SYSSTAT`. If so, examine the `SQL ordered by Parse Calls` section of the Automatic Workload Repository report.
- A high soft parse rate could be in the rate of 300 a second or more. Unnecessary soft parses also limit application scalability. Optimally, a SQL statement should be soft parsed once in each session and executed many times.

Using Wait Event Statistics to Drill Down to Bottlenecks

Whenever an Oracle process waits for something, it records the wait using one of a set of predefined wait events. These wait events are grouped in wait classes. The Idle wait class groups all events that a process waits for when it does not have work to do and is waiting for more work to perform. Non-idle events indicate nonproductive time spent waiting for a resource or action to complete.

Note: Not all symptoms can be evidenced by wait events. See "Additional Statistics" on page 10-18 for the statistics that can be checked.

The most effective way to use wait event data is to order the events by the wait time. This is only possible if TIMED_STATISTICS is set to true. Otherwise, the wait events can only be ranked by the number of times waited, which is often not the ordering that best represents the problem.

See Also:

- "Setting the Level of Statistics Collection" on page 10-7 for information about STATISTICS_LEVEL settings
- *Oracle Database Reference* for information on the STATISTICS_LEVEL initialization parameter

To get an indication of where time is spent, follow these steps:

1. Examine the data collection for V$SYSTEM_EVENT. The events of interest should be ranked by wait time.

   Identify the wait events that have the most significant percentage of wait time. To determine the percentage of wait time, add the total wait time for all wait events, excluding idle events, such as Null event, SQL*Net message from client, SQL*Net message to client, and SQL*Net more data to client. Calculate the relative percentage of the five most prominent events by dividing each event's wait time by the total time waited for all events.

   See Also:

   - "Idle Wait Events" on page 10-48 for the list of idle wait events
   - Description of the V$EVENT_NAME view in *Oracle Database Reference*
   - Detailed wait event information in *Oracle Database Reference*

   Alternatively, look at the Top 5 Timed Events section at the beginning of the Automatic Workload Repository report. This section automatically orders the wait events (omitting idle events), and calculates the relative percentage:

```
Top 5 Timed Events
~~~~~~~~~~~~~~~~~~                                                 % Total
Event                                             Waits    Time (s) Call Time
----------------------------------------- ------------ ----------- ---------
CPU time                                                         559     88.80
log file parallel write                         2,181          28      4.42
SQL*Net more data from client                 516,611          27      4.24
db file parallel write                         13,383          13      2.04
```

```
db file sequential read                          563           2       .27
```

In some situations, there might be a few events with similar percentages. This can provide extra evidence if all the events are related to the same type of resource request (for example, all I/O related events).

2. Look at the number of waits for these events, and the average wait time. For example, for I/O related events, the average time might help identify whether the I/O system is slow. The following example of this data is taken from the Wait Event section of the Automatic Workload Repository report:

```
                                                          Avg
                                                Total Wait wait    Waits
Event                            Waits  Timeouts   Time (s) (ms)     /txn
---------------------------- --------- --------- ---------- ------ ---------
log file parallel write          2,181         0         28     13      41.2
SQL*Net more data from clie    516,611         0         27      0 9,747.4
db file parallel write          13,383         0         13      1     252.5
```

3. The top wait events identify the next places to investigate. A table of common wait events is listed in Table 10–1. It is usually a good idea to also have quick look at high-load SQL.

4. Examine the related data indicated by the wait events to see what other information this data provides. Determine whether this information is consistent with the wait event data. In most situations, there is enough data to begin developing a theory about the potential causes of the performance bottleneck.

5. To determine whether this theory is valid, cross-check data you have already examined with other statistics available for consistency. The appropriate statistics vary depending on the problem, but usually include load profile-related data in V$SYSSTAT, operating system statistics, and so on. Perform cross-checks with other data to confirm or refute the developing theory.

Table of Wait Events and Potential Causes

Table 10–1 links wait events to possible causes and gives an overview of the Oracle data that could be most useful to review next.

Table 10–1 Wait Events and Potential Causes

Wait Event	General Area	Possible Causes	Look for / Examine
buffer busy waits	Buffer cache, DBWR	Depends on buffer type. For example, waits for an index block may be caused by a primary key that is based on an ascending sequence.	Examine V$SESSION while the problem is occurring to determine the type of block in contention.
free buffer waits	Buffer cache, DBWR, I/O	Slow DBWR (possibly due to I/O?) Cache too small	Examine write time using operating system statistics. Check buffer cache statistics for evidence of too small cache.
db file scattered read	I/O, SQL statement tuning	Poorly tuned SQL Slow I/O system	Investigate V$SQLAREA to see whether there are SQL statements performing many disk reads. Cross-check I/O system and V$FILESTAT for poor read time.
db file sequential read	I/O, SQL statement tuning	Poorly tuned SQL Slow I/O system	Investigate V$SQLAREA to see whether there are SQL statements performing many disk reads. Cross-check I/O system and V$FILESTAT for poor read time.
enqueue waits (waits starting with enq:)	Locks	Depends on type of enqueue	Look at V$ENQUEUE_STAT.
library cache latch waits: library cache, library cache pin, and library cache lock	Latch contention	SQL parsing or sharing	Check V$SQLAREA to see whether there are SQL statements with a relatively high number of parse calls or a high number of child cursors (column VERSION_COUNT). Check parse statistics in V$SYSSTAT and their corresponding rate for each second.
log buffer space	Log buffer, I/O	Log buffer small Slow I/O system	Check the statistic redo buffer allocation retries in V$SYSSTAT. Check configuring log buffer section in configuring memory chapter. Check the disks that house the online redo logs for resource contention.
log file sync	I/O, over-committing	Slow disks that store the online logs Un-batched commits	Check the disks that house the online redo logs for resource contention. Check the number of transactions (commits + rollbacks) each second, from V$SYSSTAT.

You may also want to review the following Oracle Metalink notices on buffer busy waits (34405.1) and free buffer waits (62172.1):

- http://metalink.oracle.com/metalink/plsql/ml2_documents.showDocument?p_database_id=NOT&p_id=34405.1
- http://metalink.oracle.com/metalink/plsql/ml2_documents.showDocument?p_database_id=NOT&p_id=62172.1

You can also access these notices and related notices by searching for "busy buffer waits" and "free buffer waits" at:

`http://metalink.oracle.com`

See Also:

- "Wait Events Statistics" on page 10-21 for detailed information on each event listed in Table 10–1 and for other information to cross-check
- *Oracle Database Reference* for information about dynamic performance views

Additional Statistics

There are a number of statistics that can indicate performance problems that do not have corresponding wait events.

Redo Log Space Requests Statistic

The V$SYSSTAT statistic `redo log space requests` indicates how many times a server process had to wait for space in the online redo log, not for space in the redo log buffer. A significant value for this statistic and the wait events should be used as an indication that checkpoints, DBWR, or archiver activity should be tuned, not LGWR. Increasing the size of log buffer does not help.

Read Consistency

Your system might spend excessive time rolling back changes to blocks in order to maintain a consistent view. Consider the following scenarios:

- If there are many small transactions and an active long-running query is running in the background on the same table where the changes are happening, then the query might need to roll back those changes often, in order to obtain a read-consistent image of the table. Compare the following V$SYSSTAT statistics to determine whether this is happening:

  - `consistent changes` statistic indicates the number of times a database block has rollback entries applied to perform a consistent read on the block. Workloads that produce a great deal of `consistent changes` can consume a great deal of resources.
  - `consistent gets` statistic counts the number of logical reads in consistent mode.

- If there are few very, large rollback segments, then your system could be spending a lot of time rolling back the transaction table during delayed block cleanout in order to find out exactly which SCN a transaction was committed. When Oracle commits a transaction, all modified blocks are not necessarily updated with the commit SCN immediately. In this case, it is done later on demand when the block is read or updated. This is called delayed block cleanout.

  The ratio of the following V$SYSSTAT statistics should be close to 1:

```
ratio = transaction tables consistent reads - undo records applied /
        transaction tables consistent read rollbacks
```

  The recommended solution is to use automatic undo management.

- If there are insufficient rollback segments, then there is rollback segment (header or block) contention. Evidence of this problem is available by the following:
  - Comparing the number of WAITS to the number of GETS in V$ROLLSTAT; the proportion of WAITS to GETS should be small.
  - Examining V$WAITSTAT to see whether there are many WAITS for buffers of CLASS 'undo header'.

  The recommended solution is to use automatic undo management.

Table Fetch by Continued Row

You can detect migrated or chained rows by checking the number of `table fetch continued row` statistic in V$SYSSTAT. A small number of chained rows (less than 1%) is unlikely to impact system performance. However, a large percentage of chained rows can affect performance.

Chaining on rows larger than the block size is inevitable. You might want to consider using tablespace with larger block size for such data.

However, for smaller rows, you can avoid chaining by using sensible space parameters and good application design. For example, do *not* insert a row with key

values filled in and nulls in most other columns, then update that row with the real data, causing the row to grow in size. Rather, insert rows filled with data from the start.

If an UPDATE statement increases the amount of data in a row so that the row no longer fits in its data block, then Oracle tries to find another block with enough free space to hold the entire row. If such a block is available, then Oracle moves the entire row to the new block. This is called migrating a row. If the row is too large to fit into any available block, then Oracle splits the row into multiple pieces and stores each piece in a separate block. This is called chaining a row. Rows can also be chained when they are inserted.

Migration and chaining are especially detrimental to performance with the following:

- UPDATE statements that cause migration and chaining to perform poorly
- Queries that select migrated or chained rows because these must perform additional input and output

The definition of a sample output table named CHAINED_ROWS appears in a SQL script available on your distribution medium. The common name of this script is UTLCHN1.SQL, although its exact name and location varies depending on your platform. Your output table must have the same column names, datatypes, and sizes as the CHAINED_ROWS table.

Increasing PCTFREE can help to avoid migrated rows. If you leave more free space available in the block, then the row has room to grow. You can also reorganize or re-create tables and indexes that have high deletion rates. If tables frequently have rows deleted, then data blocks can have partially free space in them. If rows are inserted and later expanded, then the inserted rows might land in blocks with deleted rows but still not have enough room to expand. Reorganizing the table ensures that the main free space is totally empty blocks.

Note: PCTUSED is not the opposite of PCTFREE.

See Also:

- *Oracle Database Concepts* for more information on PCTUSED
- *Oracle Database Administrator's Guide* for information on reorganizing tables

Parse-Related Statistics

The more your application parses, the more potential for contention exists, and the more time your system spends waiting. If `parse time CPU` represents a large percentage of the CPU time, then time is being spent parsing instead of executing statements. If this is the case, then it is likely that the application is using literal SQL and so SQL cannot be shared, or the shared pool is poorly configured.

See Also: Chapter 7, "Memory Configuration and Use"

There are a number of statistics available to identify the extent of time spent parsing by Oracle. Query the parse related statistics from `V$SYSSTAT`. For example:

```
SELECT NAME, VALUE
  FROM V$SYSSTAT
 WHERE NAME IN (  'parse time cpu', 'parse time elapsed',
                  'parse count (hard)', 'CPU used by this session' );
```

There are various ratios that can be computed to assist in determining whether parsing may be a problem:

- parse time CPU / parse time elapsed

  This ratio indicates how much of the time spent parsing was due to the parse operation itself, rather than waiting for resources, such as latches. A ratio of one is good, indicating that the elapsed time was not spent waiting for highly contended resources.

- parse time CPU / CPU used by this session

  This ratio indicates how much of the total CPU used by Oracle server processes was spent on parse-related operations. A ratio closer to zero is good, indicating that the majority of CPU is not spent on parsing.

Wait Events Statistics

The `V$SESSION`, `V$SESSION_WAIT`, `V$SESSION_EVENT`, and `V$SYSTEM_EVENT` views provide information on what resources were waited for, and, if the configuration parameter `TIMED_STATISTICS` is set to `true`, how long each resource was waited for.

See Also:

- "Setting the Level of Statistics Collection" on page 10-7 for information about STATISTICS_LEVEL settings
- *Oracle Database Reference* for a description of the V$ views and the Oracle wait events

Investigate wait events and related timing data when performing reactive performance tuning. The events with the most time listed against them are often strong indications of the performance bottleneck.

The following views contain related, but different, views of the same data:

- V$SESSION lists session information for each current session. It lists either the event currently being waited for or the event last waited for on each session. This view also contains information on blocking sessions.
- V$SESSION_WAIT is a current state view. It lists either the event currently being waited for or the event last waited for on each session
- V$SESSION_EVENT lists the cumulative history of events waited for on each session. After a session exits, the wait event statistics for that session are removed from this view.
- V$SYSTEM_EVENT lists the events and times waited for by the whole instance (that is, all session wait events data rolled up) since instance startup.

Because V$SESSION_WAIT is a current state view, it also contains a finer-granularity of information than V$SESSION_EVENT or V$SYSTEM_EVENT. It includes additional identifying data for the current event in three parameter columns: P1, P2, and P3.

For example, V$SESSION_EVENT can show that session 124 (SID=124) had many waits on the db file scattered read, but it does not show which file and block number. However, V$SESSION_WAIT shows the file number in P1, the block number read in P2, and the number of blocks read in P3 (P1 and P2 let you determine for which segments the wait event is occurring).

This chapter concentrates on examples using V$SESSION_WAIT. However, Oracle recommends capturing performance data over an interval and keeping this data for performance and capacity analysis. This form of rollup data is queried from the V$SYSTEM_EVENT view by Automatic Workload Repository. See "Automatic Workload Repository" on page 5-10.

Most commonly encountered events are described in this chapter, listed in case-sensitive alphabetical order. Other event-related data to examine is also included. The case used for each event name is that which appears in the V$SYSTEM_EVENT view.

> **See Also:** *Oracle Database Reference* for a description of the V$SYSTEM_EVENT view

SQL*Net Events

The following events signify that the database process is waiting for acknowledgment from a database link or a client process:

- SQL*Net break / reset to client
- SQL*Net break / reset to dblink
- SQL*Net message from client
- SQL*Net message from dblink
- SQL*Net message to client
- SQL*Net message to dblink
- SQL*Net more data from client
- SQL*Net more data from dblink
- SQL*Net more data to client
- SQL*Net more data to dblink

If these waits constitute a significant portion of the wait time on the system or for a user experiencing response time issues, then the network or the middle-tier could be a bottleneck.

Events that are client-related should be diagnosed as described for the event SQL*Net message from client. Events that are dblink-related should be diagnosed as described for the event SQL*Net message from dblink.

SQL*Net message from client

Although this is an idle event, it is important to explain when this event can be used to diagnose what is not the problem. This event indicates that a server process is waiting for work from the client process. However, there are several situations where this event could accrue most of the wait time for a user experiencing poor

response time. The cause could be either a network bottleneck or a resource bottleneck on the client process.

Network Bottleneck A network bottleneck can occur if the application causes a lot of traffic between server and client and the network latency (time for a round-trip) is high. Symptoms include the following:

- Large number of waits for this event
- Both the database and client process are idle (waiting for network traffic) most of the time

To alleviate network bottlenecks, try the following:

- Tune the application to reduce round trips.
- Explore options to reduce latency (for example, terrestrial lines opposed to VSAT links).
- Change system configuration to move higher traffic components to lower latency links.

Resource Bottleneck on the Client Process If the client process is using most of the resources, then there is nothing that can be done in the database. Symptoms include the following:

- Number of waits might not be large, but the time waited might be significant
- Client process has a high resource usage

In some cases, you can see the wait time for a waiting user tracking closely with the amount of CPU used by the client process. The term client here refers to any process other than the database process (middle-tier, desktop client) in the n-tier architecture.

SQL*Net message from dblink

This event signifies that the session has sent a message to the remote node and is waiting for a response from the database link. This time could go up because of the following:

- Network bottleneck

  For information, see "SQL*Net message from client" on page 10-23.

- Time taken to execute the SQL on the remote node

It is useful to see the SQL being run on the remote node. Login to the remote database, find the session created by the database link, and examine the SQL statement being run by it.

- Number of round trip messages

  Each message between the session and the remote node adds latency time and processing overhead. To reduce the number of messages exchanged, use array fetches and array inserts.

SQL*Net more data to client

The server process is sending more data or messages to the client. The previous operation to the client was also a send.

> **See Also:** *Oracle Net Services Administrator's Guide* for a detailed discussion on network optimization

buffer busy waits

This wait indicates that there are some buffers in the buffer cache that multiple processes are attempting to access concurrently. Query V$WAITSTAT for the wait statistics for each class of buffer. Common buffer classes that have buffer busy waits include data block, segment header, undo header, and undo block.

Check the following V$SESSION_WAIT parameter columns:

- P1 - File ID
- P2 - Block ID
- P3 - Class ID

Causes

To determine the possible causes, first query V$SESSION to identify the value of ROW_WAIT_OBJ# when the session waits for buffer busy waits. For example:

```
SELECT row_wait_obj#
  FROM V$SESSION
 WHERE EVENT = 'buffer busy waits';
```

To identify the object and object type contended for, query DBA_OBJECTS using the value for ROW_WAIT_OBJ# that is returned from V$SESSION. For example:

```
SELECT owner, object_name, subobject_name, object_type
  FROM DBA_OBJECTS
```

```
 WHERE data_object_id = &row_wait_obj;
```

Actions

The action required depends on the class of block contended for and the actual segment.

segment header If the contention is on the segment header, then this is most likely free list contention.

Automatic segment-space management in locally managed tablespaces eliminates the need to specify the PCTUSED, FREELISTS, and FREELIST GROUPS parameters. If possible, switch from manual space management to automatic segment-space management (ASSM).

The following information is relevant if you are unable to use automatic segment-space management (for example, because the tablespace uses dictionary space management).

A free list is a list of free data blocks that usually includes blocks existing in a number of different extents within the segment. Free lists are composed of blocks in which free space has not yet reached PCTFREE or used space has shrunk below PCTUSED. Specify the number of process free lists with the FREELISTS parameter. The default value of FREELISTS is one. The maximum value depends on the data block size.

To find the current setting for free lists for that segment, run the following:

```
SELECT SEGMENT_NAME, FREELISTS
  FROM DBA_SEGMENTS
 WHERE SEGMENT_NAME = segment name
   AND SEGMENT_TYPE = segment type;
```

Set free lists, or increase the number of free lists. If adding more free lists does not alleviate the problem, then use free list groups (even in single instance this can make a difference). If using Oracle Real Application Clusters, then ensure that each instance has its own free list group(s).

> **See Also:** *Oracle Database Concepts* for information on automatic segment-space management, free lists, PCTFREE, and PCTUSED

data block If the contention is on tables or indexes (not the segment header):

- Check for right-hand indexes. These are indexes that are inserted into at the same point by many processes. For example, those that use sequence number generators for the key values.
- Consider using automatic segment-space management (ASSM), global hash partitioned indexes, or increasing free lists to avoid multiple processes attempting to insert into the same block.

undo header For contention on rollback segment header:

- If you are not using automatic undo management, then add more rollback segments.

undo block For contention on rollback segment block:

- If you are not using automatic undo management, then consider making rollback segment sizes larger.

db file scattered read

This event signifies that the user process is reading buffers into the SGA buffer cache and is waiting for a physical I/O call to return. A `db file scattered read` issues a scattered read to read the data into multiple discontinuous memory locations. A scattered read is usually a multiblock read. It can occur for a fast full scan (of an index) in addition to a full table scan.

The `db file scattered read` wait event identifies that a full scan is occurring. When performing a full scan into the buffer cache, the blocks read are read into memory locations that are not physically adjacent to each other. Such reads are called scattered read calls, because the blocks are scattered throughout memory. This is why the corresponding wait event is called 'db file scattered read'. Multiblock (up to `DB_FILE_MULTIBLOCK_READ_COUNT` blocks) reads due to full scans into the buffer cache show up as waits for 'db file scattered read'.

Check the following `V$SESSION_WAIT` parameter columns:

- `P1` - The absolute file number
- `P2` - The block being read
- `P3` - The number of blocks (should be greater than 1)

Actions

On a healthy system, physical read waits should be the biggest waits after the idle waits. However, also consider whether there are direct read waits (signifying full

table scans with parallel query) or db file scattered read waits on an operational (OLTP) system that should be doing small indexed accesses.

Other things that could indicate excessive I/O load on the system include the following:

- Poor buffer cache hit ratio
- These wait events accruing most of the wait time for a user experiencing poor response time

Managing Excessive I/O

There are several ways to handle excessive I/O waits. In the order of effectiveness, these are as follows:

1. Reduce the I/O activity by SQL tuning
2. Reduce the need to do I/O by managing the workload
3. Gather system statistics with DBMS_STATS package, allowing the query optimizer to accurately cost possible access paths that use full scans
4. Use Automatic Storage Management
5. Add more disks to reduce the number of I/Os for each disk
6. Alleviate I/O hot spots by redistributing I/O across existing disks

See Also: Chapter 8, "I/O Configuration and Design"

The first course of action should be to find opportunities to reduce I/O. Examine the SQL statements being run by sessions waiting for these events, as well as statements causing high physical I/Os from V$SQLAREA. Factors that can adversely affect the execution plans causing excessive I/O include the following:

- Improperly optimized SQL
- Missing indexes
- High degree of parallelism for the table (skewing the optimizer toward scans)
- Lack of accurate statistics for the optimizer
- Setting the value for DB_FILE_MULTIBLOCK_READ_COUNT initialization parameter too high which favors full scans

Inadequate I/O Distribution

Besides reducing I/O, also examine the I/O distribution of files across the disks. Is I/O distributed uniformly across the disks, or are there hot spots on some disks? Are the number of disks sufficient to meet the I/O needs of the database?

See the total I/O operations (reads and writes) by the database, and compare those with the number of disks used. Remember to include the I/O activity of LGWR and ARCH processes.

Finding the SQL Statement executed by Sessions Waiting for I/O

Use the following query to determine, at a point in time, which sessions are waiting for I/O:

```
SELECT SQL_ADDRESS, SQL_HASH_VALUE
  FROM V$SESSION
 WHERE EVENT LIKE 'db file%read';
```

Finding the Object Requiring I/O

To determine the possible causes, first query V$SESSION to identify the value of ROW_WAIT_OBJ# when the session waits for db file scattered read. For example:

```
SELECT row_wait_obj#
  FROM V$SESSION
 WHERE EVENT = 'db file scattered read';
```

To identify the object and object type contended for, query DBA_OBJECTS using the value for ROW_WAIT_OBJ# that is returned from V$SESSION. For example:

```
SELECT owner, object_name, subobject_name, object_type
  FROM DBA_OBJECTS
 WHERE data_object_id = &row_wait_obj;
```

db file sequential read

This event signifies that the user process is reading a buffer into the SGA buffer cache and is waiting for a physical I/O call to return. A sequential read is a single-block read.

Single block I/Os are usually the result of using indexes. Rarely, full table scan calls could get truncated to a single block call due to extent boundaries, or buffers already present in the buffer cache. These waits would also show up as 'db file sequential read'.

Check the following V$SESSION_WAIT parameter columns:

- P1 - The absolute file number
- P2 - The block being read
- P3 - The number of blocks (should be 1)

> **See Also:** "db file scattered read" on page 10-27 for information on managing excessive I/O, inadequate I/O distribution, and finding the SQL causing the I/O and the segment the I/O is performed on

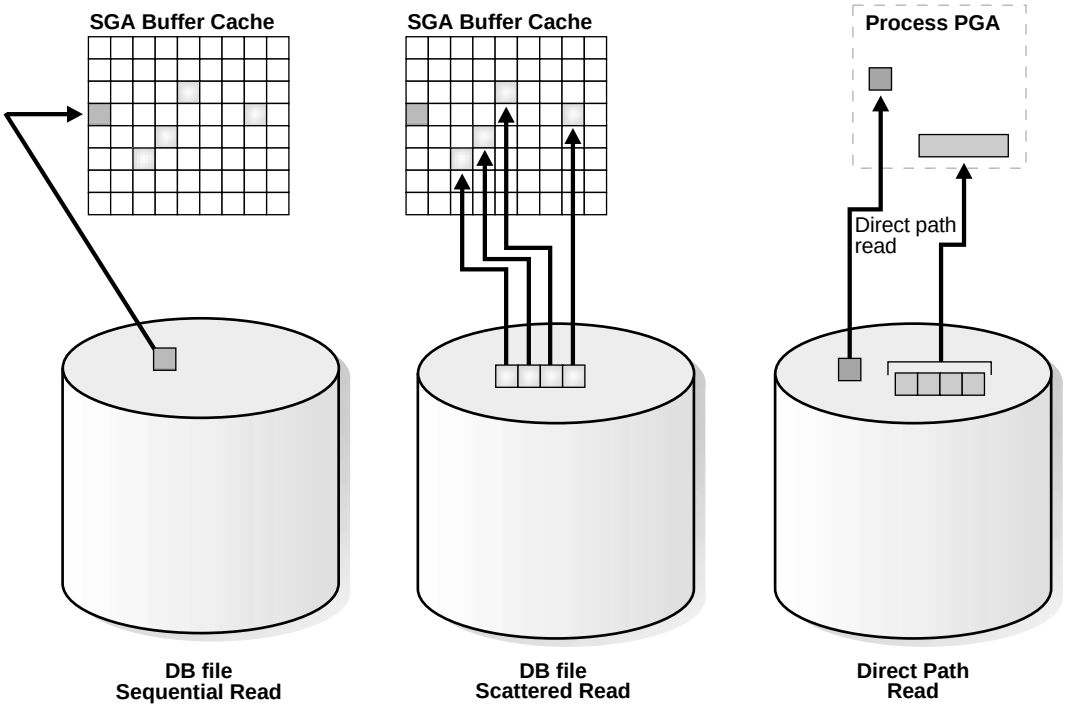
Actions

On a healthy system, physical read waits should be the biggest waits after the idle waits. However, also consider whether there are db file sequential reads on a large data warehouse that should be seeing mostly full table scans with parallel query.

Figure 10–1 depicts the differences between the following wait events:

- db file sequential read (single block read into one SGA buffer)
- db file scattered read (multiblock read into many discontinuous SGA buffers)
- direct read (single or multiblock read into the PGA, bypassing the SGA)

Figure 10–1 Scattered Read, Sequential Read, and Direct Path Read



direct path read and direct path read temp

When a session is reading buffers from disk directly into the PGA (opposed to the buffer cache in SGA), it waits on this event. If the I/O subsystem does not support asynchronous I/Os, then each wait corresponds to a physical read request.

If the I/O subsystem supports asynchronous I/O, then the process is able to overlap issuing read requests with processing the blocks already existing in the PGA. When the process attempts to access a block in the PGA that has not yet been read from disk, it then issues a wait call and updates the statistics for this event. Hence, the number of waits is not necessarily the same as the number of read requests (unlike `db file scattered read` and `db file sequential read`).

Check the following `V$SESSION_WAIT` parameter columns:

- `P1` - File_id for the read call

- P2 - Start block_id for the read call
- P3 - Number of blocks in the read call

Causes

This happens in the following situations:

- The sorts are too large to fit in memory and some of the sort data is written out directly to disk. This data is later read back in, using direct reads.
- Parallel slaves are used for scanning data.
- The server process is processing buffers faster than the I/O system can return the buffers. This can indicate an overloaded I/O system.

Actions

The file_id shows if the reads are for an object in TEMP tablespace (sorts to disk) or full table scans by parallel slaves. This is the biggest wait for large data warehouse sites. However, if the workload is not a DSS workload, then examine why this is happening.

Sorts to Disk Examine the SQL statement currently being run by the session experiencing waits to see what is causing the sorts. Query V$TEMPSEG_USAGE to find the SQL statement that is generating the sort. Also query the statistics from V$SESSTAT for the session to determine the size of the sort. See if it is possible to reduce the sorting by tuning the SQL statement. If WORKAREA_SIZE_POLICY is MANUAL, then consider increasing the SORT_AREA_SIZE for the system (if the sorts are not too big) or for individual processes. If WORKAREA_SIZE_POLICY is AUTO, then investigate whether to increase PGA_AGGREGATE_TARGET. See "PGA Memory Management" on page 7-50.

Full Table Scans If tables are defined with a high degree of parallelism, then this could skew the optimizer to use full table scans with parallel slaves. Check the object being read into using the direct path reads. If the full table scans are a valid part of the workload, then ensure that the I/O subsystem is configured adequately for the degree of parallelism. Consider using disk striping if you are not already using it or Automatic Storage Management (ASM).

Hash Area Size For query plans that call for a hash join, excessive I/O could result from having HASH_AREA_SIZE too small. If WORKAREA_SIZE_POLICY is MANUAL, then consider increasing the HASH_AREA_SIZE for the system or for individual

processes. If WORKAREA_SIZE_POLICY is AUTO, then investigate whether to increase PGA_AGGREGATE_TARGET.

See Also:

- "Managing Excessive I/O" on page 10-28
- "PGA Memory Management" on page 7-50

direct path write and direct path write temp

When a process is writing buffers directly from PGA (as opposed to the DBWR writing them from the buffer cache), the process waits on this event for the write call to complete. Operations that could perform direct path writes include when a sort goes to disk, during parallel DML operations, direct-path INSERTs, parallel create table as select, and some LOB operations.

Like direct path reads, the number of waits is not the same as number of write calls issued if the I/O subsystem supports asynchronous writes. The session waits if it has processed all buffers in the PGA and is unable to continue work until an I/O request completes.

See Also: *Oracle Database Administrator's Guide* for information on direct-path inserts

Check the following V$SESSION_WAIT parameter columns:

- P1 - File_id for the write call
- P2 - Start block_id for the write call
- P3 - Number of blocks in the write call

Causes

This happens in the following situations:

- Sorts are too large to fit in memory and are written to disk
- Parallel DML are issued to create/populate objects
- Direct path loads

Actions

For large sorts see "Sorts to Disk" on page 10-32.

For parallel DML, check the I/O distribution across disks and make sure that the I/O subsystem is adequately configured for the degree of parallelism.

enqueue (enq:) waits

Enqueues are locks that coordinate access to database resources. This event indicates that the session is waiting for a lock that is held by another session.

The name of the enqueue is included as part of the wait event name, in the form `enq: enqueue_type - related_details`. In some cases, the same enqueue type can be held for different purposes, such as the following related `TX` types:

- `enq: TX - allocate ITL entry`
- `enq: TX - contention`
- `enq: TX - index contention`
- `enq: TX - row lock contention`

The `V$EVENT_NAME` view provides a complete list of all the `enq:` wait events.

You can check the following `V$SESSION_WAIT` parameter columns for additional information:

- `P1` - Lock `TYPE` (or name) and `MODE`
- `P2` - Resource identifier ID1 for the lock
- `P3` - Resource identifier ID2 for the lock

> **See Also:** *Oracle Database Reference* for information about Oracle enqueues

Finding Locks and Lock Holders

Query `V$LOCK` to find the sessions holding the lock. For every session waiting for the event enqueue, there is a row in `V$LOCK` with `REQUEST <> 0`. Use one of the following two queries to find the sessions holding the locks and waiting for the locks.

If there are enqueue waits, you can see these using the following statement:

```
SELECT * FROM V$LOCK WHERE request > 0;
```

To show only holders and waiters for locks being waited on, use the following:

```
SELECT DECODE(request,0,'Holder: ','Waiter: ') ||
          sid sess, id1, id2, lmode, request, type
```

```
   FROM V$LOCK
 WHERE (id1, id2, type) IN (SELECT id1, id2, type FROM V$LOCK WHERE request > 0)
   ORDER BY id1, request;
```

Actions

The appropriate action depends on the type of enqueue.

ST enqueue If the contended-for enqueue is the ST enqueue, then the problem is most likely to be dynamic space allocation. Oracle dynamically allocates an extent to a segment when there is no more free space available in the segment. This enqueue is only used for dictionary managed tablespaces.

To solve contention on this resource:

- Check to see whether the temporary (that is, sort) tablespace uses TEMPFILES. If not, then switch to using TEMPFILES.
- Switch to using locally managed tablespaces if the tablespace that contains segments that are growing dynamically is dictionary managed.

  > **See Also:** *Oracle Database Concepts* for detailed information on TEMPFILEs and locally managed tablespaces

- If it is not possible to switch to locally managed tablespaces, then ST enqueue resource usage can be decreased by changing the next extent sizes of the growing objects to be large enough to avoid constant space allocation. To determine which segments are growing constantly, monitor the EXTENTS column of the DBA_SEGMENTS view for all SEGMENT_NAMEs. See *Oracle Database Administrator's Guide* for information about displaying information about space usage.
- Preallocate space in the segment, for example, by allocating extents using the ALTER TABLE ALLOCATE EXTENT SQL statement.

HW enqueue The HW enqueue is used to serialize the allocation of space beyond the high water mark of a segment.

- V$SESSION_WAIT.P2 / V$LOCK.ID1 is the tablespace number.
- V$SESSION_WAIT.P3 / V$LOCK.ID2 is the relative dba of segment header of the object for which space is being allocated.

If this is a point of contention for an object, then manual allocation of extents solves the problem.

TM enqueue The most common reason for waits on TM locks tend to involve foreign key constraints where the constrained columns are not indexed. Index the foreign key columns to avoid this problem.

TX enqueue These are acquired exclusive when a transaction initiates its first change and held until the transaction does a `COMMIT` or `ROLLBACK`.

- Waits for TX in mode 6: occurs when a session is waiting for a row level lock that is already held by another session. This occurs when one user is updating or deleting a row, which another session wishes to update or delete. This type of TX enqueue wait corresponds to the wait event `enq: TX - row lock contention`.

  The solution is to have the first session already holding the lock perform a `COMMIT` or `ROLLBACK`.

- Waits for TX in mode 4 can occur if the session is waiting for an ITL (interested transaction list) slot in a block. This happens when the session wants to lock a row in the block but one or more other sessions have rows locked in the same block, and there is no free ITL slot in the block. Usually, Oracle dynamically adds another ITL slot. This may not be possible if there is insufficient free space in the block to add an ITL. If so, the session waits for a slot with a TX enqueue in mode 4. This type of TX enqueue wait corresponds to the wait event `enq: TX - allocate ITL entry`.

  The solution is to increase the number of ITLs available, either by changing the `INITRANS` or `MAXTRANS` for the table (either by using an `ALTER` statement, or by re-creating the table with the higher values).

- Waits for TX in mode 4 can also occur if a session is waiting due to potential duplicates in `UNIQUE` index. If two sessions try to insert the same key value the second session has to wait to see if an `ORA-0001` should be raised or not. This type of TX enqueue wait corresponds to the wait event `enq: TX - row lock contention`.

  The solution is to have the first session already holding the lock perform a `COMMIT` or `ROLLBACK`.

- Waits for TX in mode 4 is also possible if the session is waiting due to shared bitmap index fragment. Bitmap indexes index key values and a range of ROWIDs. Each 'entry' in a bitmap index can cover many rows in the actual table. If two sessions want to update rows covered by the same bitmap index fragment, then the second session waits for the first transaction to either `COMMIT` or `ROLLBACK` by waiting for the TX lock in mode 4. This type of TX

enqueue wait corresponds to the wait event `enq: TX - row lock contention`.

- Waits for TX in Mode 4 can also occur waiting for a `PREPARED` transaction.
- Waits for TX in mode 4 also occur when a transaction inserting a row in an index has to wait for the end of an index block split being done by another transaction. This type of TX enqueue wait corresponds to the wait event `enq: TX - index contention`.

  See Also: *Oracle Database Application Developer's Guide - Fundamentals* for more information about referential integrity and locking data explicitly

free buffer waits

This wait event indicates that a server process was unable to find a free buffer and has posted the database writer to make free buffers by writing out dirty buffers. A dirty buffer is a buffer whose contents have been modified. Dirty buffers are freed for reuse when DBWR has written the blocks to disk.

Causes

DBWR may not be keeping up with writing dirty buffers in the following situations:

- The I/O system is slow.
- There are resources it is waiting for, such as latches.
- The buffer cache is so small that DBWR spends most of its time cleaning out buffers for server processes.
- The buffer cache is so big that one DBWR process is not enough to free enough buffers in the cache to satisfy requests.

Actions

If this event occurs frequently, then examine the session waits for DBWR to see whether there is anything delaying DBWR.

Writes If it is waiting for writes, then determine what is delaying the writes and fix it. Check the following:

- Examine `V$FILESTAT` to see where most of the writes are happening.

- Examine the host operating system statistics for the I/O system. Are the write times acceptable?

If I/O is slow:

- Consider using faster I/O alternatives to speed up write times.
- Spread the I/O activity across large number of spindles (disks) and controllers. See Chapter 8, "I/O Configuration and Design" for information on balancing I/O.

Cache is Too Small It is possible DBWR is very active because the cache is too small. Investigate whether this is a probable cause by looking to see if the buffer cache hit ratio is low. Also use the V$DB_CACHE_ADVICE view to determine whether a larger cache size would be advantageous. See "Sizing the Buffer Cache" on page 7-8.

Cache Is Too Big for One DBWR If the cache size is adequate and the I/O is already evenly spread, then you can potentially modify the behavior of DBWR by using asynchronous I/O or by using multiple database writers.

Consider Multiple Database Writer (DBWR) Processes or I/O Slaves

Configuring multiple database writer processes, or using I/O slaves, is useful when the transaction rates are high or when the buffer cache size is so large that a single DBW*n* process cannot keep up with the load.

DB_WRITER_PROCESSES The DB_WRITER_PROCESSES initialization parameter lets you configure multiple database writer processes (from DBW0 to DBW9 and from DBWa to DBWj). Configuring multiple DBWR processes distributes the work required to identify buffers to be written, and it also distributes the I/O load over these processes. Multiple db writer processes are highly recommended for systems with multiple CPUs (at least one db writer for every 8 CPUs) or multiple processor groups (at least as many db writers as processor groups).

Based upon the number of CPUs and the number of processor groups, Oracle either selects an appropriate default setting for DB_WRITER_PROCESSES or adjusts a user-specified setting.

DBWR_IO_SLAVES If it is not practical to use multiple DBWR processes, then Oracle provides a facility whereby the I/O load can be distributed over multiple slave processes. The DBWR process is the only process that scans the buffer cache LRU list for blocks to be written out. However, the I/O for those blocks is performed by the I/O slaves. The number of I/O slaves is determined by the parameter DBWR_IO_SLAVES.

DBWR_IO_SLAVES is intended for scenarios where you cannot use multiple DB_WRITER_PROCESSES (for example, where you have a single CPU). I/O slaves are also useful when asynchronous I/O is not available, because the multiple I/O slaves simulate nonblocking, asynchronous requests by freeing DBWR to continue identifying blocks in the cache to be written. Asynchronous I/O at the operating system level, if you have it, is generally preferred.

DBWR I/O slaves are allocated immediately following database open when the first I/O request is made. The DBWR continues to perform all of the DBWR-related work, apart from performing I/O. I/O slaves simply perform the I/O on behalf of DBWR. The writing of the batch is parallelized between the I/O slaves.

Note: Implementing DBWR_IO_SLAVES requires that extra shared memory be allocated for I/O buffers and request queues. Multiple DBWR processes cannot be used with I/O slaves. Configuring I/O slaves forces only one DBWR process to start.

Choosing Between Multiple DBWR Processes and I/O Slaves Configuring multiple DBWR processes benefits performance when a single DBWR process is unable to keep up with the required workload. However, before configuring multiple DBWR processes, check whether asynchronous I/O is available and configured on the system. If the system supports asynchronous I/O but it is not currently used, then enable asynchronous I/O to see if this alleviates the problem. If the system does not support asynchronous I/O, or if asynchronous I/O is already configured and there is still a DBWR bottleneck, then configure multiple DBWR processes.

Note: If asynchronous I/O is not available on your platform, then asynchronous I/O can be disabled by setting the DISK_ASYNCH_IO initialization parameter to FALSE.

Using multiple DBWRs parallelizes the gathering and writing of buffers. Therefore, multiple DBW*n* processes should deliver more throughput than one DBWR process with the same number of I/O slaves. For this reason, the use of I/O slaves has been deprecated in favor of multiple DBWR processes. I/O slaves should only be used if multiple DBWR processes cannot be configured.

latch events

A latch is a low-level internal lock used by Oracle to protect memory structures. The latch free event is updated when a server process attempts to get a latch, and the latch is unavailable on the first attempt.

There is a dedicated latch-related wait event for the more popular latches that often generate significant contention. For those events, the name of the latch appears in the name of the wait event, such as `latch: library cache` or `latch: cache buffers chains`. This enables you to quickly figure out if a particular type of latch is responsible for most of the latch-related contention. Waits for all other latches are grouped in the generic `latch free` wait event.

> **See Also:** *Oracle Database Concepts* for more information on latches and internal locks

Actions

This event should only be a concern if latch waits are a significant portion of the wait time on the system as a whole, or for individual users experiencing problems.

- Examine the resource usage for related resources. For example, if the library cache latch is heavily contended for, then examine the hard and soft parse rates.
- Examine the SQL statements for the sessions experiencing latch contention to see if there is any commonality.

Check the following `V$SESSION_WAIT` parameter columns:

- `P1` - Address of the latch
- `P2` - Latch number
- `P3` - Number of times process has already slept, waiting for the latch

Example: Find Latches Currently Waited For

```
SELECT EVENT, SUM(P3) SLEEPS, SUM(SECONDS_IN_WAIT) SECONDS_IN_WAIT
  FROM V$SESSION_WAIT
 WHERE EVENT LIKE 'latch%'
  GROUP BY EVENT;
```

A problem with the previous query is that it tells more about session tuning or instant instance tuning than instance or long-duration instance tuning.

The following query provides more information about long duration instance tuning, showing whether the latch waits are significant in the overall database time.

```
SELECT EVENT, TIME_WAITED_MICRO,
       ROUND(TIME_WAITED_MICRO*100/S.DBTIME,1) PCT_DB_TIME
  FROM V$SYSTEM_EVENT,
   (SELECT VALUE DBTIME FROM V$SYS_TIME_MODEL WHERE STAT_NAME = 'DB time') S
 WHERE EVENT LIKE 'latch%'
 ORDER BY PCT_DB_TIME ASC;
```

A more general query that is not specific to latch waits is the following:

```
SELECT EVENT, WAIT_CLASS,
      TIME_WAITED_MICRO,ROUND(TIME_WAITED_MICRO*100/S.DBTIME,1) PCT_DB_TIME
  FROM V$SYSTEM_EVENT E, V$EVENT_NAME N,
    (SELECT VALUE DBTIME FROM V$SYS_TIME_MODEL WHERE STAT_NAME = 'DB time') S
   WHERE E.EVENT_ID = N.EVENT_ID
    AND N.WAIT_CLASS NOT IN ('Idle', 'System I/O')
  ORDER BY PCT_DB_TIME ASC;
```

Table 10–2 Latch Wait Event

Latch	SGA Area	Possible Causes	Look For:
Shared pool, library cache	Shared pool	Lack of statement reuse Statements not using bind variables Insufficient size of application cursor cache Cursors closed explicitly after each execution Frequent logon / logoffs Underlying object structure being modified (for example truncate) Shared pool too small	Sessions (in V$SESSTAT) with high: ▪ parse time CPU ▪ `parse time elapsed` ▪ Ratio of `parse count (hard)` / `execute count` ▪ Ratio of `parse count (total)` / `execute count` Cursors (in V$SQLAREA / V$SQL) with: ▪ High ratio of `PARSE_CALLS` / `EXECUTIONS` ▪ `EXECUTIONS` = 1 differing only in literals in the `WHERE` clause (that is, no bind variables used) ▪ High `RELOADS` ▪ High `INVALIDATIONS` ▪ Large (> 1mb) `SHARABLE_MEM`

Table 10–2 (Cont.) Latch Wait Event

Latch	SGA Area	Possible Causes	Look For:
cache buffers lru chain	Buffer cache LRU lists	Excessive buffer cache throughput. For example, inefficient SQL that accesses incorrect indexes iteratively (large index range scans) or many full table scans	Statements with very high logical I/O or physical I/O, using unselective indexes
		DBWR not keeping up with the dirty workload; hence, foreground process spends longer holding the latch looking for a free buffer	
		Cache may be too small	
cache buffers chains	Buffer cache buffers	Repeated access to a block (or small number of blocks), known as a hot block	Sequence number generation code that updates a row in a table to generate the number, rather than using a sequence number generator
			Index leaf chasing from very many processes scanning the same unselective index with very similar predicate
			Identify the segment the hot block belongs to
row cache objects			

Shared Pool and Library Cache Latch Contention

A main cause of shared pool or library cache latch contention is parsing. There are a number of techniques that can be used to identify unnecessary parsing and a number of types of unnecessary parsing:

Unshared SQL This method identifies similar SQL statements that could be shared if literals were replaced with bind variables. The idea is to either:

- Manually inspect SQL statements that have only one execution to see whether they are similar:

```
SELECT SQL_TEXT
  FROM V$SQLAREA
 WHERE EXECUTIONS < 4
 ORDER BY SQL_TEXT;
```

- Or, automate this process by grouping together what may be similar statements. Do this by estimating the number of bytes of a SQL statement which will likely be the same, and group the SQL statements by that many bytes. For example, the following example groups together statements that differ only after the first 60 bytes.

```
SELECT SUBSTR(SQL_TEXT,1, 60), COUNT(*)
  FROM V$SQLAREA
 WHERE EXECUTIONS < 4
 GROUP BY SUBSTR(SQL_TEXT, 1, 60)
 HAVING COUNT(*) > 1;
```

- Or report distinct SQL statements that have the same execution plan. The following query selects distinct SQL statements that share the same execution plan at least four times. These SQL statements are likely to be using literals instead of bind variables.

```
SELECT SQL_TEXT FROM V$SQL WHERE PLAN_HASH_VALUE IN
  (SELECT PLAN_HASH_VALUE
     FROM V$SQL
    GROUP BY PLAN_HASH_VALUE HAVING COUNT(*) > 4)
  ORDER BY PLAN_HASH_VALUE;
```

Reparsed Sharable SQL check the V$SQLAREA view. Enter the following query:

```
SELECT SQL_TEXT, PARSE_CALLS, EXECUTIONS
  FROM V$SQLAREA
ORDER BY PARSE_CALLS;
```

When the PARSE_CALLS value is close to the EXECUTIONS value for a given statement, you might be continually reparsing that statement. Tune the statements with the higher numbers of parse calls.

By Session Identify unnecessary parse calls by identifying the session in which they occur. It might be that particular batch programs or certain types of applications do most of the reparsing. To do this, run the following query:

```
SELECT pa.SID, pa.VALUE "Hard Parses", ex.VALUE "Execute Count"
  FROM V$SESSTAT pa, V$SESSTAT ex
 WHERE pa.SID = ex.SID
   AND pa.STATISTIC#=(SELECT STATISTIC#
       FROM V$STATNAME WHERE NAME = 'parse count (hard)')
   AND ex.STATISTIC#=(SELECT STATISTIC#
       FROM V$STATNAME WHERE NAME = 'execute count')
   AND pa.VALUE > 0;
```

The result is a list of all sessions and the amount of reparsing they do. For each session identifier (SID), go to V$SESSION to find the name of the program that causes the reparsing.

> **Note:** Because this query counts all parse calls since instance startup, it is best to look for sessions with high *rates* of parse. For example, a connection which has been up for 50 days might show a high parse figure, but a second connection might have been up for 10 minutes and be parsing at a much faster rate.

The output is similar to the following:

```
   SID  Hard Parses  Execute Count
------  -----------  -------------
     7            1             20
     8            3          12690
     6           26            325
    11           84           1619
```

cache buffers lru chain The `cache buffers lru chain` latches protect the lists of buffers in the cache. When adding, moving, or removing a buffer from a list, a latch must be obtained.

For symmetric multiprocessor (SMP) systems, Oracle automatically sets the number of LRU latches to a value equal to one half the number of CPUs on the system. For non-SMP systems, one LRU latch is sufficient.

Contention for the LRU latch can impede performance on SMP machines with a large number of CPUs. LRU latch contention is detected by querying `V$LATCH`, `V$SESSION_EVENT`, and `V$SYSTEM_EVENT`. To avoid contention, consider tuning the application, bypassing the buffer cache for DSS jobs, or redesigning the application.

cache buffers chains The `cache buffers chains` latches are used to protect a buffer list in the buffer cache. These latches are used when searching for, adding, or removing a buffer from the buffer cache. Contention on this latch usually means that there is a block that is greatly contended for (known as a hot block).

To identify the heavily accessed buffer chain, and hence the contended for block, look at latch statistics for the `cache buffers chains` latches using the view `V$LATCH_CHILDREN`. If there is a specific `cache buffers chains` child latch that has many more `GETS`, `MISSES`, and `SLEEPS` when compared with the other child latches, then this is the contended for child latch.

This latch has a memory address, identified by the `ADDR` column. Use the value in the `ADDR` column joined with the `X$BH` table to identify the blocks protected by this

latch. For example, given the address (V$LATCH_CHILDREN.ADDR) of a heavily contended latch, this queries the file and block numbers:

```
SELECT OBJ data_object_id, FILE#, DBABLK,CLASS, STATE, TCH
  FROM X$BH
 WHERE HLADDR = 'address of latch'
  ORDER BY TCH;
```

X$BH.TCH is a touch count for the buffer. A high value for X$BH.TCH indicates a hot block.

Many blocks are protected by each latch. One of these buffers will probably be the hot block. Any block with a high TCH value is a potential hot block. Perform this query a number of times, and identify the block that consistently appears in the output. After you have identified the hot block, query DBA_EXTENTS using the file number and block number, to identify the segment.

After you have identified the hot block, you can identify the segment it belongs to with the following query:

```
SELECT OBJECT_NAME, SUBOBJECT_NAME
  FROM DBA_OBJECTS
 WHERE DATA_OBJECT_ID = &obj;
```

In the query, &obj is the value of the OBJ column in the previous query on X$BH.

row cache objects The row cache objects latches protect the data dictionary.

log file parallel write

This event involves writing redo records to the redo log files from the log buffer.

library cache pin

This event manages library cache concurrency. Pinning an object causes the heaps to be loaded into memory. If a client wants to modify or examine the object, the client must acquire a pin after the lock.

library cache lock

This event controls the concurrency between clients of the library cache. It acquires a lock on the object handle so that either:

- One client can prevent other clients from accessing the same object

- The client can maintain a dependency for a long time which does not allow another client to change the object

This lock is also obtained to locate an object in the library cache.

log buffer space

This event occurs when server processes are waiting for free space in the log buffer, because all the redo is generated faster than LGWR can write it out.

Actions

Modify the redo log buffer size. If the size of the log buffer is already reasonable, then ensure that the disks on which the online redo logs reside do not suffer from I/O contention. The `log buffer space` wait event could be indicative of either disk I/O contention on the disks where the redo logs reside, or of a too-small log buffer. Check the I/O profile of the disks containing the redo logs to investigate whether the I/O system is the bottleneck. If the I/O system is not a problem, then the redo log buffer could be too small. Increase the size of the redo log buffer until this event is no longer significant.

log file switch

There are two wait events commonly encountered:

- log file switch (archiving needed)
- log file switch (checkpoint incomplete)

In both of the events, the LGWR is unable to switch into the next online redo log, and all the commit requests wait for this event.

Actions

For the `log file switch` (`archiving needed`) event, examine why the archiver is unable to archive the logs in a timely fashion. It could be due to the following:

- Archive destination is running out of free space.
- Archiver is not able to read redo logs fast enough (contention with the LGWR).
- Archiver is not able to write fast enough (contention on the archive destination, or not enough ARCH processes). If you have ruled out other possibilities (such as slow disks or a full archive destination) consider increasing the number of ARCn processes. The default is 2.

- If you have mandatory remote shipped archive logs, check whether this process is slowing down because of network delays or the write is not completing because of errors.

Depending on the nature of bottleneck, you might need to redistribute I/O or add more space to the archive destination to alleviate the problem. For the `log file switch` (`checkpoint incomplete`) event:

- Check if DBWR is slow, possibly due to an overloaded or slow I/O system. Check the DBWR write times, check the I/O system, and distribute I/O if necessary. See Chapter 8, "I/O Configuration and Design".
- Check if there are too few, or too small redo logs. If you have a few redo logs or small redo logs (for example two x 100k logs), and your system produces enough redo to cycle through all of the logs before DBWR has been able to complete the checkpoint, then increase the size or number of redo logs. See "Sizing Redo Log Files" on page 4-5.

log file sync

When a user session commits (or rolls back), the session's redo information must be flushed to the redo logfile by LGWR. The server process performing the `COMMIT` or `ROLLBACK` waits under this event for the write to the redo log to complete.

Actions

If this event's waits constitute a significant wait on the system or a significant amount of time waited by a user experiencing response time issues or on a system, then examine the average time waited.

If the average time waited is low, but the number of waits are high, then the application might be committing after every `INSERT`, rather than batching `COMMIT`s. Applications can reduce the wait by committing after 50 rows, rather than every row.

If the average time waited is high, then examine the session waits for the log writer and see what it is spending most of its time doing and waiting for. If the waits are because of slow I/O, then try the following:

- Reduce other I/O activity on the disks containing the redo logs, or use dedicated disks.
- Alternate redo logs on different disks to minimize the effect of the archiver on the log writer.

- Move the redo logs to faster disks or a faster I/O subsystem (for example, switch from RAID 5 to RAID 1).
- Consider using raw devices (or simulated raw devices provided by disk vendors) to speed up the writes.
- Depending on the type of application, it might be possible to batch `COMMIT`s by committing every *N* rows, rather than every row, so that fewer log file syncs are needed.

rdbms ipc reply

This event is used to wait for a reply from one of the background processes.

Idle Wait Events

These events belong to Idle wait class and indicate that the server process is waiting because it has no work. This usually implies that if there is a bottleneck, then the bottleneck is not for database resources. The majority of the idle events should be ignored when tuning, because they do not indicate the nature of the performance bottleneck. Some idle events can be useful in indicating what the bottleneck is not. An example of this type of event is the most commonly encountered idle wait-event `SQL Net message from client`. This and other idle events (and their categories) are listed in Table 10–3.

Table 10–3 Idle Wait Events

Wait Name	Background Process Idle Event	User Process Idle Event	Parallel Query Idle Event	Shared Server Idle Event	Oracle Real Application Clusters Idle Event
dispatcher timer	.	.	.	X	.
pipe get	.	X	.	.	.
pmon timer	X	.	.	.	.
PX Idle Wait	.	.	X	.	.
PX Deq Credit: need buffer	.	.	X	.	.
rdbms ipc message	X	.	.	.	.

Table 10–3 (Cont.) Idle Wait Events

Wait Name	Background Process Idle Event	User Process Idle Event	Parallel Query Idle Event	Shared Server Idle Event	Oracle Real Application Clusters Idle Event
smon timer	X	.	.	.	.
SQL*Net message from client	.	X	.	.	.
virtual circuit status	.	.	.	X	.

See Also: *Oracle Database Reference* for explanations of each idle wait event

11

Tuning Networks

This chapter describes different connection models and introduces networking issues that affect tuning.

This chapter contains the following sections:

Understanding Connection Models

The techniques used to determine the source of problems vary depending on the configuration. You can have a shared server configuration or a dedicated server configuration.

- If you have a shared server configuration, then LSNRCTL services lists dispatchers.
- If you have a dedicated server configuration, then LSNRCTL services lists dedicated servers.

It is possible to connect to dedicated server with a database configured for shared servers by placing the parameter (SERVER = DEDICATED) in the connect descriptor.

Shared Server Configuration

This section discusses the setups for the shared server configuration.

Registering the Dispatchers

The LSNRCTL control utility's services statement lists every dispatcher registered with it. This list includes the dispatchers process ID. You can check the alert log to confirm that the dispatchers have been started successfully.

Note: Remember that PMON can take a minute to register the dispatcher with the listener.

```
LSNRCTL> services
Connecting to
(DESCRIPTION=(ADDRESS=(PROTOCOL=tcp)(HOST=helios)(PORT=1521)))
Services Summary...
Service "sales.us.acme.com" has 1 instance(s).
  Instance "sales", status READY, has 3 handler(s) for this service...
    Handler(s):
      "DEDICATED" established:0 refused:0 state:ready
         LOCAL SERVER
      "D000" established:0 refused:0 current:0 max:10000 state:ready
         DISPATCHER <machine: helios, pid: 1689>
         (ADDRESS=(PROTOCOL=tcp)(HOST=helios)(PORT=52414))
      "D001" established:0 refused:0 current:0 max:10000 state:ready
         DISPATCHER <machine: helios, pid: 1691>
         (ADDRESS=(PROTOCOL=tcp)(HOST=helios)(PORT=52415))
The command completed successfully.
```

See Also: *Oracle Net Services Administrator's Guide* for information on setting the output mode

Configuring Initialization Parameters for Shared Servers

The following list provides information on configuring initialization parameters for shared servers.

- Make sure that the DISPATCHERS line is correctly set. For example:

```
DISPATCHERS = "(DESCRIPTION=(ADDRESS=(PROTOCOL=TCP)
               (HOST=hostname)(PORT=1492)(queuesize=32)))
          (DISPATCHERS = 1)
          (LISTENER = alias)
          (SERVICE = servicename)
          (SESSIONS = 1000)
          (CONNECTIONS = 1000)
          (MULTIPLEX = ON)
          (POOL = ON)
          (TICK = 5)"
```

  One, and only one, of the following attributes is required:

  - PROTOCOL
  - ADDRESS
  - DESCRIPTION

  ADDRESS and DESCRIPTION provide support for the specification of additional network attributes beyond PROTOCOL. In the previous example, the entire DISPATCHERS line can be (PROTOCOL=TCP). The attributes DISPATCHERS, LISTENER, SERVICE, SESSIONS, CONNECTIONS, MULTIPLEX, POOL, and TICKS are all optional.

- Make sure that the optional MAX_DISPATCHERS line is correctly set. For example:

```
MAX_DISPATCHERS = 4
```

  This line should reflect the total number of dispatchers you want to start.

- Make sure that the optional MAX_SHARED_SERVERS line is correctly set. For example:

```
MAX_SHARED_SERVERS = 5
```

This line sets the upper bound on the total number of shared servers PMON can create, based on the peak load of the system. This should be set high enough so that all requests can be serviced, but not so high that the system swaps if they are reached. The purpose of this parameter is to prevent the server from swapping. Run the following script to see what the highwater mark is for the number of servers running, and then set MAX_SHARED_SERVERS to more then this.

```
SELECT maximum_connections "MAX CONN", servers_started "STARTED", servers_
terminated "TERMINATED", servers_highwater "HIGHWATER" FROM V$SHARED_SERVER_
MONITOR;
```

- Make sure that the optional SHARED_SERVERS line is correctly set. For example:

  ```
  SHARED_SERVERS = 5
  ```

  This is the total number of shared servers started when the database is started. It also represents the total number of shared servers PMON tries to keep. It should be the total number of servers expected to be used when the database is active. MAX_SHARED_SERVERS is intended to handle peak load.

Checking the Connections

Use the LSNRCTL control utility's `services` command to see if there are excessive connection refusals. Check the listener's log file to see if this is a connection problem. For example:

```
LSNRCTL> services
Connecting to
(DESCRIPTION=(ADDRESS=(PROTOCOL=tcp)(HOST=helios)(PORT=1521)))
Services Summary...
Service "sales.us.acme.com" has 1 instance(s).
  Instance "sales", status READY, has 2 handler(s) for this service...
    Handler(s):
      "DEDICATED" established:11 refused:0 state:ready
         LOCAL SERVER
      "D000" established:565 refused:4 current:155 max:10000 state:ready
         DISPATCHER <machine: helios, pid: 5673>
         (ADDRESS=(PROTOCOL=tcp)(HOST=helios)(PORT=38411))
The command completed successfully.
```

Under normal conditions, the number refused should be zero. Shut down the listener and restart it to erase these statistics. If the refused count is increasing after

the listener restarts, then the connections are being refused. If the refused count stays at zero, and if the problem you are troubleshooting is occurring, then your problem is not with the connections being refused.

Checking the Connect/Second Rate

Connection refusals can occur for many reasons. Examine the listener log to see what the connect rate is. Run the listener log analyzer script to check.

The listener is a queue-based process. It receives connect requests from the lower level protocol stack. It has a limited queue stack which is configurable to the operating system maximum. It can only process one connection at a time, and there is a limit to the number of connections a second the process can handle.

If the rate at which the connect requests arrive exceeds that limit, then the requests are queued. The queue stack is also limited, but you can configure it. If there are more listener processes, then the requests made against each individual process are fewer and are handled more quickly.

Increasing the listener queue is done in the `listener.ora` file. The `listener.ora` file can contain many listeners, each by a different name. It is assumed that only one of those listed is having a problem. If not, then apply this method to all applicable listeners. To increase the listener queue, add (`queuesize` = *`number`*) to the `listener.ora` file. For example:

```
listener =
     (address =
          (protocol = tcp)
          (host = sales-pc)
          (port = 1521)
          (queuesize = 20)
     )
```

See Also: *Oracle Net Services Administrator's Guide*

Stop and restart the listener to initialize this new parameter. If you are not currently running a shared server configuration, then consider doing so. It is faster for the listener to handle a client request in a shared server configuration than it is in a dedicated server configuration.

Note: Shared server dispatchers also receive connect requests and can also benefit from tuning the queue size.

The maximum queue size is subject to the maximum size possible for a particular operating system.

Detecting Network Problems

This section encompasses local area network (LAN) and wide area network (WAN) troubleshooting methods.

Using Dynamic Performance Views for Network Performance

Networks entail overhead that adds a certain amount of delay to processing. To optimize performance, you must ensure that your network throughput is fast, and you should try to reduce the number of messages that must be sent over the network. It can be difficult to measure the delay the network adds.

Three dynamic performance views are useful for measuring the network delay:

- V$SESSION_EVENT
- V$SESSION_WAIT
- V$SESSTAT

In V$SESSION_EVENT, the AVERAGE_WAIT column indicates the amount of time that Oracle waits between messages. You can use this statistic as a yardstick to evaluate the effectiveness of the network.

In V$SESSION_WAIT, the EVENT column lists the events for which active sessions are waiting. The "SQLNET message from client" wait event indicates that the shared or foreground process is waiting for a message from a client. If this wait event has occurred, then you can check to see whether the message has been sent by the user or received by Oracle.

You can investigate hang-ups by looking at V$SESSION_WAIT to see what the sessions are waiting for. If a client has sent a message, then you can determine whether Oracle is responding to it or is still waiting for it.

In V$SESSTAT you can see the number of bytes that have been received from the client, the number of bytes sent to the client, and the number of calls the client has made.

Understanding Latency and Bandwidth

The most critical aspects of a network that contribute to performance are latency and bandwidth.

- Latency refers to a time delay; for example, the gap between the time a device requests access to a network and the time it receives permission to transmit.
- Bandwidth is the throughput capacity of a network medium or protocol. Variations in the network signals can cause degradation on the network. Sources of degradation can be cables that are too long or wrong cable type. External noise sources, such as elevators, air handlers, or florescent lights, can also cause problems.

Common Network Topologies

Local Area Network Topologies:

- Ethernet
- Fast Ethernet
- 1 Gigabit Ethernet
- Token Ring
- FDDI
- ATM

Wide Area Network Topologies:

- DSL
- ISDN
- Frame Relay
- T-1, T-3, E-1, E-3
- ATM
- SONAT

Table 11–1 lists the most common ratings for various topologies.

Table 11–1 Bandwidth Ratings

Topology or Carrier	Bandwidth
Ethernet	10 Megabits / second

Table 11–1 (Cont.) Bandwidth Ratings

Topology or Carrier	Bandwidth
Fast Ethernet	100 Megabits / second
1 Gigabit Ethernet	1 Gigabits / second
Token Ring	16 Megabits / second
FDDI	100 Megabits / second
ATM	155 Megabits / second (OC3), 622 Megabits / second (OC12)
T-1 (US only)	1.544 Megabits / second
T-3 (US only)	44.736 Megabits / second
E-1 (non-US)	2.048 Megabits / second
E-3 (non-US)	34.368 Megabits / second
Frame Relay	Committed Information Rate, which can be up to the carrier speed, but usually is not.
DSL	This can be up to the carrier speed.
ISDN	This can be up to the carrier speed. Usually, it is used with slower modems.
Dial Up Modems	56 Kilobits / second. Usually, it is accompanied with data compression for faster throughput.

Solving Network Problems

This section describes several techniques for enhancing performance and solving network problems.

- Finding Network Bottlenecks
- Dissecting Network Bottlenecks
- Using Array Interfaces
- Adjusting Session Data Unit Buffer Size
- Using TCP.NODELAY
- Using Connection Manager

See Also: *Oracle Net Services Administrator's Guide*

Finding Network Bottlenecks

The first step in solving network problem is to understand the overall topology. Gather as much information about the network that you can. This kind of information usually manifests itself as a network diagram. Your diagram should contain the types of network technology used in the Local Area Network and the Wide Area Network. It should also contain addresses of the various network segments.

Examine this information. Obvious network bottlenecks include the following:

- Using a dial-up modem (normal modem or ISDN) to access time critical data.
- A frame relay link is running on a T-1, but has a 9.6 Kilobits CIR so that it only reliably transmits up to 9.6 Kilobits a second and if the rest of the bandwidth is used, then there is a possibly that the data will be lost.
- Data from high speed networks channels through low speed networks.
- There are too many network hops. A router constitutes one hop.
- A 10 Megabit network for a Web site.

There are many problems that can cause a performance breakdown. Follow this checklist:

- Get a network sniffer trace.
- Check the following:
  - Is the bandwidth being exceeded on the network, the client, or the server?
  - Ethernet collisions.
  - Token ring or FDDI ring beacons.
  - Are there many runt frames?
  - The stability of the WAN links.
- Get a bandwidth utilization chart for frame relay, and see if CIR is being exceeded.
- Is any quality of service or packet prioritizing going on?
- Is a firewall in the way somewhere?

If nothing is revealed, then find the network route from the client to the data server. Understanding the travel times on a network gives you an idea as to the time a transaction will take. Client-server communication requires many small packets.

High latency on a network slows the transaction down due to the time interval between sending a request and getting the response.

Use trace route (`traceroute` or equivalent) from the client to the server to get address information for each device in the path.

For example:

```
traceroute usmail05
Tracing route to usmail05.us.oracle.com [144.25.88.200]over a maximum of 30 hops:
  1   <10 ms   <10 ms    10 ms  whq1davis-rtr-749-f1-0-a.us.oracle.com [144.25.216.1]
  2   <10 ms   <10 ms   <10 ms  whq4op3-rtr-723-f0-0.us.oracle.com [144.25.252.23]
  3   220 ms   210 ms   231 ms  usmail05.us.oracle.com [144.25.88.200]

Trace complete.
```

Ping each device in turn to get the timings. Use large packets to get the slowest times. Make sure you set the "don't fragment bit" so that routers do not spend time disassembling and reassembling the packet. Also note that the packet size is 1472. This is for Ethernet. Ethernet packets are 1536 octets (actual 8 bit bytes) in size. ICPM packets (this is what ping is designed to use) have 64 octets of header. Evaluate the area where the slowness seems to occur.

For example:

```
ping -l 1472 -n 1 -f 144.25.216.1
Pinging 144.25.216.1 with 1472 bytes of data:
Reply from 144.25.216.1: bytes=1472 time<10ms TTL=255

ping -l 1472 -n 1 -f 144.25.252.23
Pinging 144.25.252.23 with 1472 bytes of data:
Reply from 144.25.252.23: bytes=1472 time=10ms TTL=254

ping -l 1472 -n 1 -f 144.25.88.200
Pinging 144.25.88.200 with 1472 bytes of data:
Reply from 144.25.88.200: bytes=1472 time=271ms TTL=253
```

The previous example validates trace route. Ideally, you ping from the workstation to 144.25.216.1, from 144.25.216.1 to 144.25.252.23, then from 144.25.252.23 to 144.25.88.200. This would show the exact latency on each segment traveled.

Dissecting Network Bottlenecks

This section helps you determine the problem with your network bottleneck.

Determining if the Problem is with Oracle Net or the Network

Oracle Net tracing reveals whether an error is Oracle-specific or due to conditions that the operating system is passing to the Transparent Network Substrate (Oracle TNS layer).

Enable Oracle Net tracing at the Oracle server, the listener, and at a client suspected of having the problem you are trying to resolve.

To enable tracing at the server, find the `sqlnet.ora` file for the server and create the following lines in it:

```
TRACE_TIMESTAMP_SERVER = ON
TRACE_LEVEL_SERVER = 16
TRACE_UNIQUE_SERVER = ON
```

To enable tracing at the client, find the `sqlnet.ora` file for the client and create the following lines in it:

```
TRACE_TIMESTAMP_CLIENT = ON
TRACE_LEVEL_CLIENT = 16
TRACE_UNIQUE_CLIENT = ON
```

To enable tracing at the listener, find the `listener.ora` file and create the following line in it:

```
TRACE_TIMESTAMP_listener_name = ON
TRACE_LEVEL_listener_name = 16
```

Note: The `TRACE_TIMESTAMP_x` parameters are optional, but they should be included for better debugging

---

Reproduce the problem, so that you generate traces on the client and server. Now analyze the traces generated.

See Also:

- *Oracle Net Services Administrator's Guide* for detailed directions on enabling Oracle Net tracing
- *Oracle Database Error Messages* for definitions to Oracle Net errors noted in the trace file

If the problem is with the network and not Oracle Net, then you must determine the following:

- Does the problem only occur in one location on the local network?
- Does the problem only occur in one area on the WAN?

For example, perhaps the system is fine in the building where the Data Center is located, but it is slow in other buildings that are several miles away.

Not all Oracle error codes represent pure Oracle troubles. `ORA-3113` is the most common error that points to an underlying network problem.

Note: Enabling tracing on the server can generate a large amount of trace files. To prevent this, set up a separate environment that traces itself. This configuration works for dedicated connections.

First, log in to the server's operating system as the Oracle software owner. Create a temporary directory to keep configuration files and trace files that will be created. Copy the `sqlnet.ora`, `listener.ora`, and `tnsnames.ora` to that directory.

Edit the `sqlnet.ora` file to enable tracing. Add to the `sqlnet.ora` file the following line:

```
TRACE_DIRECTORY_SERVER = temporary_directory_just_created
```

Now, modify the `listener.ora` file and change the listening port (for TCP, other protocols, use a similar technique) to an unused port. You need to make a similar modification to the client's `tnsnames.ora` file for the connect string you will be using for this test.

Set the `TNS_ADMIN` environment to point to the temporary directory. Start the listener.

Now all new connections to the new listener send Server traces to this directory. Reproduce the problem.

If you are getting an Oracle error message, then look into the trace file to find the error. For troubleshooting bugs, Oracle Net trace analysis takes some time to fully find the problem. However, high-level simple trace analysis is rather simple.

Determining if the Problem is on the Client or the Server (on Oracle Net)

If the problem is with Oracle Net, then use Oracle Net tracing to show you where the problem lies. If there are errors in the trace files, then do they appear in only the client traces, only in the server traces, or in both?

Errors Only in the Client Trace The problem is on the client. However, if you are getting `ORA-3113` or `ORA-3114` errors, then the problem is on the server.

Errors Only in the Server Trace or Listener Trace The problem is on the server. However, if you are getting `ORA-3113` or `ORA-3114` errors, then the problem is on the client.

Errors in All: Client, Server, and Listener Trace If you are getting `ORA-3113` or `ORA-3114` errors, then the problem is on the Network. Troubleshoot the server first. If it is fine, then the client is at fault.

Checking if the Server is Configured for Shared Servers

The shared server architecture can be more complex to troubleshoot. Check the initialization parameter file for any shared server parameters. Look at the operating system to see if any of the shared server processes are present.

Check for dispatchers by looking for names such as `ora_d000`, `ora_d001`, and so on. For example:

```
ps -ef | grep ora_d
```

Check for shared servers by looking for names such as `ora_s000`, `ora_s001`, and so on. For example:

```
ps -ef | grep ora_s
```

See Also:

- "Shared Server Configuration" on page 11-2 for more information on tuning the shared server
- *Oracle Database Concepts* and *Oracle Net Services Administrator's Guide* for more information on shared server concepts and parameters

Using Array Interfaces

Reduce network calls by using array interfaces. Instead of fetching one row at a time, it is more efficient to fetch 10 rows with a single network round trip.

See Also: *Oracle Call Interface Programmer's Guide* for more information on array interfaces

Adjusting Session Data Unit Buffer Size

Before sending data across the network, Oracle Net buffers data into the Session Data Unit (SDU). It sends the data stored in this buffer when the buffer is full or when an application tries to read the data. When large amounts of data are being retrieved and when packet size is consistently the same, it might speed retrieval to adjust the default SDU size.

Optimal SDU size depends on the normal transport size. Use a sniffer to find out the frame size, or set tracing on to its highest level to check the number of packets sent and received and to determine whether they are fragmented. Tune your system to limit the amount of fragmentation.

Use Oracle Net Configuration Assistant to configure a change to the default SDU size on both the client and the server; SDU size is generally the same on both.

See Also: *Oracle Net Services Administrator's Guide*

Using TCP.NODELAY

When a session is established, Oracle Net packages and sends data between server and client using packets. The `TCP.NODELAY` parameter, which causes packets to be flushed on to the network more frequently, is enabled by default. Although Oracle Net supports many networking protocols, TCP tends to have the best scalability.

Using Connection Manager

In Oracle Net, you can use the Connection Manager to conserve system resources by multiplexing. *Multiplexing* means funneling many client sessions through a single transport connection to a server destination. This way, you can increase the number of sessions that a process can handle. This applies only to shared server configurations. Alternately, you can use Connection Manager to control client access to dedicated servers. Connection Manager provides multiple protocol support allowing a client and server with different networking protocols to communicate.

See Also: *Oracle Net Services Administrator's Guide* for more information on Connection Manager

Part IV

Optimizing SQL Statements

Part IV provides information on understanding and managing your SQL statements for optimal performance and discusses Oracle SQL-related performance tools.

The chapters in this part are:

12

SQL Tuning Overview

This chapter discusses goals for tuning, how to identify high-resource SQL statements, explains what should be collected, and provides tuning suggestions.

This chapter contains the following sections:

See Also:

- *Oracle Database Concepts* for an overview of SQL
- *Oracle 2 Day DBA* for information on monitoring and tuning the database

Introduction to SQL Tuning

An important facet of database system performance tuning is the tuning of SQL statements. SQL tuning involves three basic steps:

- Identifying high load or top SQL statements that are responsible for a large share of the application workload and system resources, by reviewing past SQL execution history available in the system.
- Verifying that the execution plans produced by the query optimizer for these statements perform reasonably.
- Implementing corrective actions to generate better execution plans for poorly performing SQL statements.

These three steps are repeated until the system performance reaches a satisfactory level or no more statements can be tuned.

Goals for Tuning

The objective of tuning a system is either to reduce the response time for end users of the system, or to reduce the resources used to process the same work. You can accomplish both of these objectives in several ways:

- Reduce the Workload
- Balance the Workload
- Parallelize the Workload

Reduce the Workload

SQL tuning commonly involves finding more efficient ways to process the same workload. It is possible to change the execution plan of the statement without altering the functionality to reduce the resource consumption.

Two examples of how resource usage can be reduced are:

1. If a commonly executed query needs to access a small percentage of data in the table, then it can be executed more efficiently by using an index. By creating such an index, you reduce the amount of resources used.
2. If a user is looking at the first twenty rows of the 10,000 rows returned in a specific sort order, and if the query (and sort order) can be satisfied by an index, then the user does not need to access and sort the 10,000 rows to see the first 20 rows.

Balance the Workload

Systems often tend to have peak usage in the daytime when real users are connected to the system, and low usage in the nighttime. If noncritical reports and batch jobs can be scheduled to run in the nighttime and their concurrency during day time reduced, then it frees up resources for the more critical programs in the day.

Parallelize the Workload

Queries that access large amounts of data (typical data warehouse queries) often can be parallelized. This is extremely useful for reducing the response time in low concurrency data warehouse. However, for OLTP environments, which tend to be high concurrency, this can adversely impact other users by increasing the overall resource usage of the program.

Identifying High-Load SQL

This section describes the steps involved in identifying and gathering data on high-load SQL statements. High-load SQL are poorly-performing, resource-intensive SQL statements that impact the performance of the Oracle database. High-load SQL statements can be identified by:

- Automatic Database Diagnostic Monitor
- Automatic Workload Repository
- V$SQL view
- Custom Workload
- SQL Trace

Identifying Resource-Intensive SQL

The first step in identifying resource-intensive SQL is to categorize the problem you are attempting to fix:

- Is the problem specific to a single program (or small number of programs)
- Is the problem generic over the application?

Tuning a Specific Program

If you are tuning a specific program (GUI or 3GL), then identifying the SQL to examine is a simple matter of looking at the SQL executed within the program. Oracle Enterprise Manager provides tools for identifying resource intensive SQL statements, generating explain plans, and evaluating SQL performance.

See Also:

- *Oracle Enterprise Manager Concepts* for information about the tools available for monitoring and tuning SQL applications
- Chapter 13, "Automatic SQL Tuning" for information on automatic SQL tuning features

If it is not possible to identify the SQL (for example, the SQL is generated dynamically), then use `SQL_TRACE` to generate a trace file that contains the SQL executed, then use `TKPROF` to generate an output file.

The SQL statements in the `TKPROF` output file can be ordered by various parameters, such as the execution elapsed time (`exeela`), which usually assists in the identification by ordering the SQL statements by elapsed time (with highest elapsed time SQL statements at the top of the file). This makes the job of identifying the poorly performing SQL easier if there are many SQL statements in the file.

See Also: Chapter 20, "Using Application Tracing Tools"

Tuning an Application / Reducing Load

If your whole application is performing suboptimally, or if you are attempting to reduce the overall CPU or I/O load on the database server, then identifying resource-intensive SQL involves the following steps:

1. Determine which period in the day you would like to examine; typically this is the application's peak processing time.
2. Gather operating system and Oracle statistics at the beginning and end of that period. The minimum of Oracle statistics gathered should be file I/O (`V$FILESTAT`), system statistics (`V$SYSSTAT`), and SQL statistics (`V$SQLAREA` or `V$SQL`, `V$SQLTEXT`, `V$SQL_PLAN`, and `V$SQL_PLAN_STATISTICS`).

   See Also: Chapter 6, "Automatic Performance Diagnostics" for information on how to use Oracle tools to gather Oracle instance performance data

3. Using the data collected in step two, identify the SQL statements using the most resources. A good way to identify candidate SQL statements is to query V$SQLAREA. V$SQLAREA contains resource usage information for all SQL statements in the shared pool. The data in V$SQLAREA should be ordered by resource usage. The most common resources are:
   - Buffer gets (V$SQLAREA.BUFFER_GETS, for high CPU using statements)
   - Disk reads (V$SQLAREA.DISK_READS, for high I/O statements)
   - Sorts (V$SQLAREA.SORTS, for many sorts)

One method to identify which SQL statements are creating the highest load is to compare the resources used by a SQL statement to the total amount of that resource used in the period. For BUFFER_GETS, divide each SQL statement's BUFFER_GETS by the total number of buffer gets during the period. The total number of buffer gets in the system is available in the V$SYSSTAT table, for the statistic session logical reads.

Similarly, it is possible to apportion the percentage of disk reads a statement performs out of the total disk reads performed by the system by dividing V$SQL_AREA.DISK_READS by the value for the V$SYSSTAT statistic physical reads. The SQL sections of the Automatic Workload Repository report include this data, so you do not need to perform the percentage calculations manually.

> **See Also:** *Oracle Database Reference* for information about dynamic performance views

After you have identified the candidate SQL statements, the next stage is to gather information that is necessary to examine the statements and tune them.

Gathering Data on the SQL Identified

If you are most concerned with CPU, then examine the top SQL statements that performed the most BUFFER_GETS during that interval. Otherwise, start with the SQL statement that performed the most DISK_READS.

Information to Gather During Tuning

The tuning process begins by determining the structure of the underlying tables and indexes. The information gathered includes the following:

1. Complete SQL text from V$SQLTEXT

2. Structure of the tables referenced in the SQL statement, usually by describing the table in SQL*Plus
3. Definitions of any indexes (columns, column orderings), and whether the indexes are unique or nonunique
4. Optimizer statistics for the segments (including the number of rows each table, selectivity of the index columns), including the date when the segments were last analyzed
5. Definitions of any views referred to in the SQL statement
6. Repeat steps two, three, and four for any tables referenced in the view definitions found in step five
7. Optimizer plan for the SQL statement (either from `EXPLAIN PLAN`, `V$SQL_PLAN`, or the `TKPROF` output)
8. Any previous optimizer plans for that SQL statement

Note: It is important to generate and review execution plans for all of the key SQL statements in your application. Doing so lets you compare the optimizer execution plans of a SQL statement when the statement performed well to the plan when that the statement is not performing well. Having the comparison, along with information such as changes in data volumes, can assist in identifying the cause of performance degradation.

Automatic SQL Tuning Features

Because the manual SQL tuning process poses many challenges to the application developer, the SQL tuning process has been automated by the automatic SQL Tuning manageability features. Theses features have been designed to work equally well for OLTP and Data Warehouse type applications. See Chapter 13, "Automatic SQL Tuning".

ADDM

Automatic Database Diagnostic Monitor (ADDM) analyzes the information collected by the AWR for possible performance problems with the Oracle database, including high-load SQL statements. See "Automatic Database Diagnostic Monitor" on page 6-3.

SQL Tuning Advisor

SQL Tuning Advisor allows a quick and efficient technique for optimizing SQL statements without modifying any statements. See "SQL Tuning Advisor" on page 13-6.

SQL Tuning Sets

When multiple SQL statements are used as input to ADDM or SQL Tuning Advisor, a SQL Tuning Set (STS) is constructed and stored. The STS includes the set of SQL statements along with their associated execution context and basic execution statistics. See "SQL Tuning Sets" on page 13-12.

SQLAccess Advisor

In addition to the SQL Tuning Advisor, Oracle provides the SQLAccess Advisor, which is a tuning tool that provides advice on materialized views, indexes, and materialized view logs. The SQLAccess Advisor helps you achieve your performance goals by recommending the proper set of materialized views, materialized view logs, and indexes for a given workload. In general, as the number of materialized views and indexes and the space allocated to them is increased, query performance improves. The SQLAccess Advisor considers the trade-offs between space usage and query performance and recommends the most cost-effective configuration of new and existing materialized views and indexes.

To access the SQLAccess Advisor through Oracle Enterprise Manager Database Control:

- Click the **Advisor Central** link under **Related Links** at the bottom of the **Database** pages.
- On the **Advisor Central** page, you can click the **SQLAccess Advisor** link to analyze a workload source.

  See Also: *Oracle Data Warehousing Guide* for more information on SQLAccess Advisor

Developing Efficient SQL Statements

This section describes ways you can improve SQL statement efficiency:

- Verifying Optimizer Statistics
- Reviewing the Execution Plan
- Restructuring the SQL Statements

- Restructuring the Indexes
- Modifying or Disabling Triggers and Constraints
- Restructuring the Data
- Maintaining Execution Plans Over Time
- Visiting Data as Few Times as Possible

Note: The guidelines described in this section are oriented to production SQL that will be executed frequently. Most of the techniques that are discouraged here can legitimately be employed in ad hoc statements or in applications run infrequently where performance is not critical.

Verifying Optimizer Statistics

The query optimizer uses statistics gathered on tables and indexes when determining the optimal execution plan. If these statistics have not been gathered, or if the statistics are no longer representative of the data stored within the database, then the optimizer does not have sufficient information to generate the best plan.

Things to check:

- If you gather statistics for some tables in your database, then it is probably best to gather statistics for all tables. This is especially true if your application includes SQL statements that perform joins.
- If the optimizer statistics in the data dictionary are no longer representative of the data in the tables and indexes, then gather new statistics. One way to check whether the dictionary statistics are stale is to compare the real cardinality (row count) of a table to the value of `DBA_TABLES.NUM_ROWS`. Additionally, if there is significant data skew on predicate columns, then consider using histograms.

Reviewing the Execution Plan

When tuning (or writing) a SQL statement in an OLTP environment, the goal is to drive from the table that has the most selective filter. This means that there are fewer rows passed to the next step. If the next step is a join, then this means that fewer rows are joined. Check to see whether the access paths are optimal.

When examining the optimizer execution plan, look for the following:

- The plan is such that the driving table has the best filter.
- The join order in each step means that the fewest number of rows are being returned to the next step (that is, the join order should reflect, where possible, going to the best not-yet-used filters).
- The join method is appropriate for the number of rows being returned. For example, nested loop joins through indexes may not be optimal when many rows are being returned.
- Views are used efficiently. Look at the SELECT list to see whether access to the view is necessary.
- There are any unintentional Cartesian products (even with small tables).
- Each table is being accessed efficiently:

  Consider the predicates in the SQL statement and the number of rows in the table. Look for suspicious activity, such as a full table scans on tables with large number of rows, which have predicates in the where clause. Determine why an index is not used for such a selective predicate.

  A full table scan does not mean inefficiency. It might be more efficient to perform a full table scan on a small table, or to perform a full table scan to leverage a better join method (for example, hash_join) for the number of rows returned.

If any of these conditions are not optimal, then consider restructuring the SQL statement or the indexes available on the tables.

Restructuring the SQL Statements

Often, rewriting an inefficient SQL statement is easier than modifying it. If you understand the purpose of a given statement, then you might be able to quickly and easily write a new statement that meets the requirement.

Compose Predicates Using AND and =

To improve SQL efficiency, use equijoins whenever possible. Statements that perform equijoins on untransformed column values are the easiest to tune.

Avoid Transformed Columns in the WHERE Clause

Use untransformed column values. For example, use:

```
WHERE a.order_no = b.order_no
```

rather than:

```
WHERE TO_NUMBER (SUBSTR(a.order_no, INSTR(b.order_no, '.') - 1))
= TO_NUMBER (SUBSTR(a.order_no, INSTR(b.order_no, '.') - 1))
```

Do not use SQL functions in predicate clauses or WHERE clauses. Any expression using a column, such as a function having the column as its argument, causes the optimizer to ignore the possibility of using an index on that column, even a unique index, unless there is a function-based index defined that can be used.

Avoid mixed-mode expressions, and beware of implicit type conversions. When you want to use an index on the VARCHAR2 column charcol, but the WHERE clause looks like this:

```
AND charcol = numexpr
```

where numexpr is an expression of number type (for example, 1, USERENV('SESSIONID'), numcol, numcol+0,...), Oracle translates that expression into:

```
AND TO_NUMBER(charcol) = numexpr
```

Avoid the following kinds of complex expressions:

- col1 = NVL (:b1,col1)
- NVL (col1, -999) = ...
- TO_DATE(), TO_NUMBER(), and so on

These expressions prevent the optimizer from assigning valid cardinality or selectivity estimates and can in turn affect the overall plan and the join method.

Add the predicate versus using NVL() technique.

For example:

```
SELECT employee_num, full_name Name, employee_id
  FROM mtl_employees_current_view
  WHERE (employee_num = NVL (:b1,employee_num)) AND (organization_id=:1)
  ORDER BY employee_num;
```

Also:

```
SELECT employee_num, full_name Name, employee_id
  FROM mtl_employees_current_view
  WHERE (employee_num = :b1) AND (organization_id=:1)
  ORDER BY employee_num;
```

When you need to use SQL functions on filters or join predicates, do not use them on the columns on which you want to have an index; rather, use them on the opposite side of the predicate, as in the following statement:

```
TO_CHAR(numcol) = varcol
```

rather than

```
varcol = TO_CHAR(numcol)
```

> **See Also:** Chapter 16, "Using Indexes and Clusters" for more information on function-based indexes

Write Separate SQL Statements for Specific Tasks

SQL is not a procedural language. Using one piece of SQL to do many different things usually results in a less-than-optimal result for each task. If you want SQL to accomplish different things, then write various statements, rather than writing one statement to do different things depending on the parameters you give it.

> **Note:** Oracle Forms and Reports are powerful development tools that allow application logic to be coded using PL/SQL (triggers or program units). This helps reduce the complexity of SQL by allowing complex logic to be handled in the Forms or Reports. You can also invoke a server side PL/SQL package that performs the few SQL statements in place of a single large complex SQL statement. Because the package is a server-side unit, there are no issues surrounding client to database round-trips and network traffic.

It is always better to write separate SQL statements for different tasks, but if you must use one SQL statement, then you can make a very complex statement slightly less complex by using the `UNION ALL` operator.

Optimization (determining the execution plan) takes place before the database knows what values will be substituted into the query. An execution plan cannot, therefore, depend on what those values are. For example:

```
SELECT info
FROM tables
WHERE ...
    AND somecolumn BETWEEN DECODE(:loval, 'ALL', somecolumn, :loval)
```

```
    AND DECODE(:hival, 'ALL', somecolumn, :hival);
```

Written as shown, the database cannot use an index on the somecolumn column, because the expression involving that column uses the same column on both sides of the BETWEEN.

This is not a problem if there is some other highly selective, indexable condition you can use to access the driving table. Often, however, this is not the case. Frequently, you might want to use an index on a condition like that shown but need to know the values of :loval, and so on, in advance. With this information, you can rule out the ALL case, which should not use the index.

If you want to use the index whenever real values are given for :loval and :hival (if you expect narrow ranges, even ranges where :loval often equals :hival), then you can rewrite the example in the following logically equivalent form:

```
SELECT /* change this half of UNION ALL if other half changes */ info
FROM tables
WHERE ...
    AND somecolumn BETWEEN :loval AND :hival
    AND (:hival != 'ALL' AND :loval != 'ALL')
UNION ALL
SELECT /* Change this half of UNION ALL if other half changes. */ info
FROM tables
WHERE ...
    AND (:hival = 'ALL' OR :loval = 'ALL');
```

If you run EXPLAIN PLAN on the new query, then you seem to get both a desirable and an undesirable execution plan. However, the first condition the database evaluates for either half of the UNION ALL is the combined condition on whether :hival and :loval are ALL. The database evaluates this condition before actually getting any rows from the execution plan for that part of the query.

When the condition comes back false for one part of the UNION ALL query, that part is not evaluated further. Only the part of the execution plan that is optimum for the values provided is actually carried out. Because the final conditions on :hival and :loval are guaranteed to be mutually exclusive, only one half of the UNION ALL actually returns rows. (The ALL in UNION ALL is logically valid because of this exclusivity. It allows the plan to be carried out without an expensive sort to rule out duplicate rows for the two halves of the query.)

Use of EXISTS versus IN for Subqueries

In certain circumstances, it is better to use `IN` rather than `EXISTS`. In general, if the selective predicate is in the subquery, then use `IN`. If the selective predicate is in the parent query, then use `EXISTS`.

Note: This discussion is most applicable in an OLTP environment, where the access paths either to the parent SQL or subquery are through indexed columns with high selectivity. In a DSS environment, there can be low selectivity in the parent SQL or subquery, and there might not be any indexes on the join columns. In a DSS environment, consider using semijoins for the `EXISTS` case.

See Also: *Oracle Data Warehousing Guide*

Sometimes, Oracle can rewrite a subquery when used with an `IN` clause to take advantage of selectivity specified in the subquery. This is most beneficial when the most selective filter appears in the subquery and there are indexes on the join columns. Conversely, using `EXISTS` is beneficial when the most selective filter is in the parent query. This allows the selective predicates in the parent query to be applied before filtering the rows against the `EXISTS` criteria.

Note: You should verify the optimizer cost of the statement with the actual number of resources used (`BUFFER_GETS`, `DISK_READS`, `CPU_TIME` from `V$SQL` or `V$SQLAREA`). Situations such as data skew (without the use of histograms) can adversely affect the optimizer's estimated cost for an operation.

"Example 1: Using IN - Selective Filters in the Subquery" and "Example 2: Using EXISTS - Selective Predicate in the Parent" are two examples that demonstrate the benefits of `IN` and `EXISTS`. Both examples use the same schema with the following characteristics:

- There is a unique index on the `employees.employee_id` field.
- There is an index on the `orders.customer_id` field.
- There is an index on the `employees.department_id` field.
- The `employees` table has 27,000 rows.

- The orders table has 10,000 rows.
- The OE and HR schemas, which own these segments, were both analyzed with COMPUTE.

Example 1: Using IN - Selective Filters in the Subquery This example demonstrates how rewriting a query to use IN can improve performance. This query identifies all employees who have placed orders on behalf of customer 144.

The following SQL statement uses EXISTS:

```
SELECT /* EXISTS example */
         e.employee_id, e.first_name, e.last_name, e.salary
  FROM employees e
 WHERE EXISTS (SELECT 1 FROM orders o                  /* Note 1 */
                 WHERE e.employee_id = o.sales_rep_id   /* Note 2 */
                   AND o.customer_id = 144);           /* Note 3 */
```

Notes:

- Note 1: This shows the line containing EXISTS.
- Note 2: This shows the line that makes the subquery a correlated subquery.
- Note 3: This shows the line where the correlated subqueries include the highly selective predicate customer_id = *number*.

The following plan output is the execution plan (from V$SQL_PLAN) for the preceding statement. The plan requires a full table scan of the employees table, returning many rows. Each of these rows is then filtered against the orders table (through an index).

```
  ID OPERATION            OPTIONS         OBJECT_NAME            OPT       COST
---- -------------------- --------------- ---------------------- --- ----------
   0 SELECT STATEMENT                                            CHO
   1  FILTER
   2   TABLE ACCESS       FULL            EMPLOYEES              ANA        155
   3   TABLE ACCESS       BY INDEX ROWID  ORDERS                 ANA          3
   4    INDEX             RANGE SCAN      ORD_CUSTOMER_IX        ANA          1
```

Rewriting the statement using IN results in significantly fewer resources used.

The SQL statement using IN:

```
SELECT /* IN example */
       e.employee_id, e.first_name, e.last_name, e.salary
  FROM employees e
 WHERE e.employee_id IN (SELECT o.sales_rep_id         /* Note 4 */
                           FROM orders o
                          WHERE o.customer_id = 144);  /* Note 3 */
```

Note:

- Note 3: This shows the line where the correlated subqueries include the highly selective predicate `customer_id` = *`number`*
- Note 4: This indicates that an `IN` is being used. The subquery is no longer correlated, because the `IN` clause replaces the join in the subquery.

The following plan output is the execution plan (from V$SQL_PLAN) for the preceding statement. The optimizer rewrites the subquery into a view, which is then joined through a unique index to the `employees` table. This results in a significantly better plan, because the view (that is, subquery) has a selective predicate, thus returning only a few `employee_ids`. These `employee_ids` are then used to access the `employees` table through the unique index.

```
  ID OPERATION            OPTIONS         OBJECT_NAME            OPT       COST
---- -------------------- --------------- ---------------------- --- ----------
   0 SELECT STATEMENT                                            CHO
   1  NESTED LOOPS                                                            5
   2   VIEW                                                                   3
   3    SORT               UNIQUE                                             3
   4     TABLE ACCESS      FULL            ORDERS                 ANA         1
   5   TABLE ACCESS        BY INDEX ROWID  EMPLOYEES              ANA         1
   6    INDEX              UNIQUE SCAN     EMP_EMP_ID_PK          ANA
```

Example 2: Using EXISTS - Selective Predicate in the Parent This example demonstrates how rewriting a query to use EXISTS can improve performance. This query identifies all employees from department 80 who are sales reps who have placed orders.

The following SQL statement uses `IN`:

```
SELECT /* IN example */
       e.employee_id, e.first_name, e.last_name, e.department_id, e.salary
  FROM employees e
```

```
 WHERE e.department_id = 80                                    /* Note 5 */
   AND e.job_id        = 'SA_REP'                              /* Note 6 */
   AND e.employee_id IN (SELECT o.sales_rep_id FROM orders o); /* Note 4 */
```

Note:

- Note 4: This indicates that an `IN` is being used. The subquery is no longer correlated, because the `IN` clause replaces the join in the subquery.
- Note 5 and 6: These are the selective predicates in the parent SQL.

The following plan output is the execution plan (from V$SQL_PLAN) for the preceding statement. The SQL statement was rewritten by the optimizer to use a view on the `orders` table, which requires sorting the data to return all unique `employee_ids` existing in the `orders` table. Because there is no predicate, many `employee_ids` are returned. The large list of resulting `employee_ids` are then used to access the `employees` table through the unique index.

```
  ID OPERATION            OPTIONS         OBJECT_NAME            OPT       COST
---- -------------------- --------------- ---------------------- --- ----------
   0 SELECT STATEMENT                                            CHO
   1  NESTED LOOPS                                                          125
   2   VIEW                                                                 116
   3    SORT               UNIQUE                                           116
   4     TABLE ACCESS      FULL            ORDERS                 ANA        40
   5   TABLE ACCESS        BY INDEX ROWID  EMPLOYEES              ANA         1
   6    INDEX              UNIQUE SCAN     EMP_EMP_ID_PK          ANA
```

The following SQL statement uses EXISTS:

```
 SELECT /* EXISTS example */
        e.employee_id, e.first_name, e.last_name, e.salary
   FROM employees e
  WHERE e.department_id = 80                              /* Note 5 */
    AND e.job_id        = 'SA_REP'                        /* Note 6 */
    AND EXISTS (SELECT 1                                  /* Note 1 */
                  FROM orders o
                 WHERE e.employee_id = o.sales_rep_id);  /* Note 2 */
```

Note:

- Note 1: This shows the line containing EXISTS.
- Note 2: This shows the line that makes the subquery a correlated subquery.
- Note 5 & 6:These are the selective predicates in the parent SQL.

The following plan output is the execution plan (from V$SQL_PLAN) for the preceding statement. The cost of the plan is reduced by rewriting the SQL statement to use an EXISTS. This plan is more effective, because two indexes are used to satisfy the predicates in the parent query, thus returning only a few employee_ids. The employee_ids are then used to access the orders table through an index.

```
  ID OPERATION            OPTIONS         OBJECT_NAME            OPT       COST
---- -------------------- --------------- ---------------------- --- ----------
   0 SELECT STATEMENT                                            CHO
   1  FILTER
   2   TABLE ACCESS       BY INDEX ROWID  EMPLOYEES              ANA         98
   3    AND-EQUAL
   4     INDEX            RANGE SCAN      EMP_JOB_IX             ANA
   5     INDEX            RANGE SCAN      EMP_DEPARTMENT_IX      ANA
   6   INDEX              RANGE SCAN      ORD_SALES_REP_IX       ANA          8
```

Note: An even more efficient approach is to have a concatenated index on department_id and job_id. This eliminates the need to access two indexes and reduces the resources used.

Controlling the Access Path and Join Order with Hints

You can influence the optimizer's choices by setting the optimizer approach and goal, and by gathering representative statistics for the query optimizer. Sometimes, the application designer, who has more information about a particular application's data than is available to the optimizer, can choose a more effective way to execute a SQL statement. You can use hints in SQL statements to specify how the statement should be executed.

Hints, such as /*+FULL */ control access paths. For example:

```
SELECT /*+ FULL(e) */ e.last_name
  FROM employees e
```

```
 WHERE e.job_id = 'CLERK';
```

> **See Also:** Chapter 14, "The Query Optimizer" and Chapter 17, "Optimizer Hints"

Join order can have a significant effect on performance. The main objective of SQL tuning is to avoid performing unnecessary work to access rows that do not affect the result. This leads to three general rules:

- Avoid a full-table scan if it is more efficient to get the required rows through an index.
- Avoid using an index that fetches 10,000 rows from the driving table if you could instead use another index that fetches 100 rows.
- Choose the join order so as to join fewer rows to tables later in the join order.

The following example shows how to tune join order effectively:

```
SELECT info
FROM taba a, tabb b, tabc c
WHERE a.acol BETWEEN 100 AND 200
    AND b.bcol BETWEEN 10000 AND 20000
    AND c.ccol BETWEEN 10000 AND 20000
    AND a.key1 = b.key1
    AND a.key2 = c.key2;
```

1. Choose the driving table and the driving index (if any).

   The first three conditions in the previous example are filter conditions applying to only a single table each. The last two conditions are join conditions.

   Filter conditions dominate the choice of driving table and index. In general, the driving table is the one containing the filter condition that eliminates the highest percentage of the table. Thus, because the range of 100 to 200 is narrow compared with the range of `acol`, but the ranges of 10000 and 20000 are relatively large, `taba` is the driving table, all else being equal.

   With nested loop joins, the joins all happen through the join indexes, the indexes on the primary or foreign keys used to connect that table to an earlier table in the join tree. Rarely do you use the indexes on the nonjoin conditions, except for the driving table. Thus, after `taba` is chosen as the driving table, use the indexes on `b.key1` and `c.key2` to drive into `tabb` and `tabc`, respectively.

2. Choose the best join order, driving to the best unused filters earliest.

The work of the following join can be reduced by first joining to the table with the best still-unused filter. Thus, if "bcol BETWEEN ..." is more restrictive (rejects a higher percentage of the rows seen) than "ccol BETWEEN ...", the last join can be made easier (with fewer rows) if tabb is joined before tabc.

3. You can use the ORDERED or STAR hint to force the join order.

See Also: "Hints for Join Orders" on page 17-31

Use Caution When Managing Views

Be careful when joining views, when performing outer joins to views, and when reusing an existing view for a new purpose.

Use Caution When Joining Complex Views Joins to complex views are not recommended, particularly joins from one complex view to another. Often this results in the entire view being instantiated, and then the query is run against the view data.

For example, the following statement creates a view that lists employees and departments:

```
CREATE OR REPLACE VIEW emp_dept
AS
SELECT d.department_id, d.department_name, d.location_id,
     e.employee_id, e.last_name, e.first_name, e.salary, e.job_id
FROM  departments d
     ,employees e
WHERE e.department_id (+) = d.department_id;
```

The following query finds employees in a specified state:

```
SELECT v.last_name, v.first_name, l.state_province
  FROM locations l, emp_dept v
 WHERE l.state_province = 'California'
  AND   v.location_id = l.location_id (+);
```

In the following plan table output, note that the emp_dept view is instantiated:

```
-------------------------------------------------------------------------------
| Operation                 |  Name    |  Rows | Bytes|  Cost  | Pstart| Pstop |
-------------------------------------------------------------------------------
| SELECT STATEMENT          |          |       |      |        |       |       |
|  FILTER                   |          |       |      |        |       |       |
|   NESTED LOOPS OUTER      |          |       |      |        |       |       |
|    VIEW                   |EMP_DEPT  |       |      |        |       |       |
```

```
|     NESTED LOOPS OUTER    |          |       |      |        |       |       |
|      TABLE ACCESS FULL    |DEPARTMEN |       |      |        |       |       |
|      TABLE ACCESS BY INDEX|EMPLOYEES |       |      |        |       |       |
|       INDEX RANGE SCAN    |EMP_DEPAR |       |      |        |       |       |
|    TABLE ACCESS BY INDEX R|LOCATIONS |       |      |        |       |       |
|     INDEX UNIQUE SCAN     |LOC_ID_PK |       |      |        |       |       |
--------------------------------------------------------------------------------
```

Do Not Recycle Views Beware of writing a view for one purpose and then using it for other purposes to which it might be ill-suited. Querying from a view requires all tables from the view to be accessed for the data to be returned. Before reusing a view, determine whether all tables in the view need to be accessed to return the data. If not, then do not use the view. Instead, use the base table(s), or if necessary, define a new view. The goal is to refer to the minimum number of tables and views necessary to return the required data.

Consider the following example:

```
SELECT department_name
FROM emp_dept
WHERE department_id = 10;
```

The entire view is first instantiated by performing a join of the `employees` and `departments` tables and then aggregating the data. However, you can obtain `department_name` and `department_id` directly from the `departments` table. It is inefficient to obtain this information by querying the `emp_dept` view.

Use Caution When Unnesting Subqueries Subquery unnesting merges the body of the subquery into the body of the statement that contains it, allowing the optimizer to consider them together when evaluating access paths and joins.

> **See Also:** *Oracle Data Warehousing Guide* for an explanation of the dangers with subquery unnesting

Use Caution When Performing Outer Joins to Views In the case of an outer join to a multitable view, the query optimizer (in Release 8.1.6 and later) can drive from an outer join column, if an equality predicate is defined on it.

An outer join *within* a view is problematic because the performance implications of the outer join are not visible.

Store Intermediate Results

Intermediate, or staging, tables are quite common in relational database systems, because they temporarily store some intermediate results. In many applications they are useful, but Oracle requires additional resources to create them. Always consider whether the benefit they could bring is more than the cost to create them. Avoid staging tables when the information is not reused multiple times.

Some additional considerations:

- Storing intermediate results in staging tables could improve application performance. In general, whenever an intermediate result is usable by multiple following queries, it is worthwhile to store it in a staging table. The benefit of not retrieving data multiple times with a complex statement already at the second usage of the intermediate result is better than the cost to materialize it.
- Long and complex queries are hard to understand and optimize. Staging tables can break a complicated SQL statement into several smaller statements, and then store the result of each step.
- Consider using materialized views. These are precomputed tables comprising aggregated or joined data from fact and possibly dimension tables.

> **See Also:** *Oracle Data Warehousing Guide* for detailed information on using materialized views

Restructuring the Indexes

Often, there is a beneficial impact on performance by restructuring indexes. This can involve the following:

- Remove nonselective indexes to speed the DML.
- Index performance-critical access paths.
- Consider reordering columns in existing concatenated indexes.
- Add columns to the index to improve selectivity.

Do not use indexes as a panacea. Application developers sometimes think that performance will improve if they create more indexes. If a single programmer creates an appropriate index, then this might indeed improve the application's performance. However, if 50 programmers each create an index, then application performance will probably be hampered.

Modifying or Disabling Triggers and Constraints

Using triggers consumes system resources. If you use too many triggers, then you can find that performance is adversely affected and you might need to modify or disable them.

Restructuring the Data

After restructuring the indexes and the statement, you can consider restructuring the data.

- Introduce derived values. Avoid GROUP BY in response-critical code.
- Review your data design. Change the design of your system if it can improve performance.
- Consider partitioning, if appropriate.

Maintaining Execution Plans Over Time

You can maintain the existing execution plan of SQL statements over time either using stored statistics or stored SQL execution plans. Storing optimizer statistics for tables will apply to all SQL statements that refer to those tables. Storing an execution plan (that is, plan stability) maintains the plan for a single SQL statement. If both statistics and a stored plan are available for a SQL statement, then the optimizer uses the stored plan.

See Also:

- Chapter 15, "Managing Optimizer Statistics"
- Chapter 18, "Using Plan Stability"

Visiting Data as Few Times as Possible

Applications should try to access each row only once. This reduces network traffic and reduces database load. Consider doing the following:

- Combine Multiples Scans with CASE Statements
- Use DML with RETURNING Clause
- Modify All the Data Needed in One Statement

Combine Multiples Scans with CASE Statements

Often, it is necessary to calculate different aggregates on various sets of tables. Usually, this is done with multiple scans on the table, but it is easy to calculate all the aggregates with one single scan. Eliminating n-1 scans can greatly improve performance.

Combining multiple scans into one scan can be done by moving the WHERE condition of each scan into a CASE statement, which filters the data for the aggregation. For each aggregation, there could be another column that retrieves the data.

The following example asks for the count of all employees who earn less then 2000, between 2000 and 4000, and more than 4000 each month. This can be done with three separate queries:

```
SELECT COUNT (*)
  FROM employees
  WHERE salary < 2000;

SELECT COUNT (*)
  FROM employees
  WHERE salary BETWEEN 2000 AND 4000;

SELECT COUNT (*)
  FROM employees
  WHERE salary>4000;
```

However, it is more efficient to run the entire query in a single statement. Each number is calculated as one column. The count uses a filter with the CASE statement to count only the rows where the condition is valid. For example:

```
SELECT COUNT (CASE WHEN salary < 2000
                   THEN 1 ELSE null END) count1,
       COUNT (CASE WHEN salary BETWEEN 2001 AND 4000
                   THEN 1 ELSE null END) count2,
       COUNT (CASE WHEN salary > 4000
                   THEN 1 ELSE null END) count3
  FROM employees;
```

This is a very simple example. The ranges could be overlapping, the functions for the aggregates could be different, and so on.

Use DML with RETURNING Clause

When appropriate, use INSERT, UPDATE, or DELETE... RETURNING to select and modify data with a single call. This technique improves performance by reducing the number of calls to the database.

> **See Also:** *Oracle Database SQL Reference* for syntax on the INSERT, UPDATE, and DELETE statements

Modify All the Data Needed in One Statement

When possible, use array processing. This means that an array of bind variable values is passed to Oracle for repeated execution. This is appropriate for iterative processes in which multiple rows of a set are subject to the same operation.

For example:

```
BEGIN
 FOR pos_rec IN (SELECT *
   FROM order_positions
   WHERE order_id = :id) LOOP
      DELETE FROM order_positions
      WHERE order_id = pos_rec.order_id AND
        order_position = pos_rec.order_position;
 END LOOP;
 DELETE FROM orders
 WHERE order_id = :id;
END;
```

Alternatively, you could define a cascading constraint on orders. In the previous example, one SELECT and *n* DELETEs are executed. When a user issues the DELETE on orders DELETE FROM orders WHERE order_id = :id, the database automatically deletes the positions with a single DELETE statement.

> **See Also:** *Oracle Database Administrator's Guide* or *Oracle Database Heterogeneous Connectivity Administrator's Guide* for information on tuning distributed queries

13

Automatic SQL Tuning

This chapter discusses Oracle automatic SQL tuning features.

This chapter contains the following sections:

> **See Also:** *Oracle 2 Day DBA* for information on monitoring and tuning SQL statements

Automatic SQL Tuning Overview

Automatic SQL Tuning is a new capability of the query optimizer that automates the entire SQL tuning process. Using the newly enhanced query optimizer to tune SQL statements, the automatic process replaces manual SQL tuning, which is a complex, repetitive, and time-consuming function. The Automatic SQL Tuning features are exposed to the user with the SQL Tuning Advisor.

Query Optimizer Modes

The enhanced query optimizer has two modes, normal and tuning mode.

Normal mode

In normal mode, the optimizer compiles the SQL and generates an execution plan. The normal mode of the optimizer generates a reasonable execution plan for the vast majority of SQL statements. Under normal mode the optimizer operates with very strict time constraints, usually a fraction of a second, during which it must find a good execution plan.

Tuning mode

In tuning mode, the optimizer performs additional analysis to check whether the execution plan produced under normal mode can be further improved. The output of the query optimizer is not an execution plan, but a series of actions, along with their rationale and expected benefit for producing a significantly superior plan. When called under the tuning mode, the optimizer is referred to as the Automatic Tuning Optimizer. The tuning performed by the Automatic Tuning Optimizer is called Automatic SQL Tuning.

Under tuning mode, the optimizer can take several minutes to tune a single statement. It is both time and resource intensive to invoke the Automatic Tuning Optimizer every time a query has to be hard-parsed. The Automatic Tuning Optimizer is meant to be used for complex and high-load SQL statements that have non-trivial impact on the entire system. The Automatic Database Diagnostic Monitor (ADDM) proactively identifies high-load SQL statements which are good candidates for Automatic SQL Tuning. See Chapter 6, "Automatic Performance Diagnostics".

Types of Tuning Analysis

Automatic SQL Tuning includes four types of tuning analysis:

- Statistics Analysis
- SQL Profiling
- Access Path Analysis
- SQL Structure Analysis

Statistics Analysis

The query optimizer relies on object statistics to generate execution plans. If these statistics are stale or missing, the optimizer does not have the necessary information it needs and can generate poor execution plans. The Automatic Tuning Optimizer checks each query object for missing or stale statistics, and produces two types of output:

- Recommendations to gather relevant statistics for objects with stale or no statistics.

  Because optimizer statistics are automatically collected and refreshed, this problem may be encountered only when automatic optimizer statistics collection has been turned off. See "Automatic Statistics Gathering" on page 15-3.

- Auxiliary information in the form of statistics for objects with no statistics, and statistic adjustment factor for objects with stale statistics.

This auxiliary information is stored in an object called a SQL Profile.

SQL Profiling

The query optimizer can sometimes produce inaccurate estimates about an attribute of a statement due to lack of information, leading to poor execution plans. Traditionally, users have corrected this problem by manually adding hints to the application code to guide the optimizer into making correct decisions. For packaged applications, changing application code is not an option and the only alternative available is to log a bug with the application vendor and wait for a fix.

Automatic SQL Tuning deals with this problem with its SQL Profiling capability. The Automatic Tuning Optimizer creates a profile of the SQL statement called a SQL Profile, consisting of auxiliary statistics specific to that statement. The query optimizer under normal mode makes estimates about cardinality, selectivity, and cost that can sometimes be off by a significant amount resulting in poor execution plans. SQL Profile addresses this problem by collecting additional information using sampling and partial execution techniques to verify and, if necessary, adjust these estimates.

During SQL Profiling, the Automatic Tuning Optimizer also uses execution history information of the SQL statement to appropriately set optimizer parameter settings, such as changing the OPTIMIZER_MODE initialization parameter setting from ALL_ROWS to FIRST_ROWS for that SQL statement.

The output of this type of analysis is a recommendation to accept the SQL Profile. A SQL Profile, once accepted, is stored persistently in the data dictionary. Note that the SQL Profile is specific to a particular query. If accepted, the optimizer under normal mode uses the information in the SQL Profile in conjunction with regular database statistics when generating an execution plan. The availability of the additional information makes it possible to produce well-tuned plans for corresponding SQL statement without requiring any change to the application code.

The scope of a SQL Profile can be controlled by the CATEGORY profile attribute. This attribute determines which user sessions can apply the profile. You can view the CATEGORY attribute for a SQL Profile in CATEGORY column of the DBA_SQL_PROFILES view. By default, all profiles are created in the DEFAULT category. This means that all user sessions where the SQLTUNE_CATEGORY initialization parameter is set to DEFAULT can use the profile.

By altering the category of a SQL profile, you can determine which sessions are affected by the creation of a profile. For example, by setting the category of a SQL Profile to DEV, only those users sessions where the SQLTUNE_CATEGORY initialization parameter is set to DEV can use the profile. All other sessions do not have access to the SQL Profile and execution plans for SQL statements are not impacted by the SQL profile. This technique enables you to test a SQL Profile in a restricted environment before making it available to other user sessions.

> **See Also:** *Oracle Database Reference* for information on the SQLTUNE_CATEGORY initialization parameter

It is important to note that the SQL Profile does not freeze the execution plan of a SQL statement, as done by stored outlines. As tables grow or indexes are created or dropped, the execution plan can change with the same SQL Profile. The information stored in it continues to be relevant even as the data distribution or access path of the corresponding statement change. However, over a long period of time, its content can become outdated and would have to be regenerated. This can be done by running Automatic SQL Tuning again on the same statement to regenerate the SQL Profile.

SQL Profiles apply to the following statement types:

- SELECT statements

- UPDATE statements
- INSERT statements (only with a SELECT clause)
- DELETE statements
- CREATE TABLE statements (only with the AS SELECT clause)
- MERGE statements (the update or insert operations)

A complete set of functions are provided for management of SQL Profiles. See "Managing SQL Profiles with APIs" on page 13-10.

Access Path Analysis

Indexes can tremendously enhance performance of a SQL statement by reducing the need for full table scans on large tables. Effective indexing is a common tuning technique. The Automatic Tuning Optimizer also explores whether a new index can significantly enhance the performance of a query. If such an index is identified, it recommends its creation.

Because the Automatic Tuning Optimizer does not analyze how its index recommendation can affect the entire SQL workload, it also recommends running a the SQLAccess Advisor utility on the SQL statement along with a representative SQL workload. The SQLAccess Advisor looks at the impact of creating an index on the entire SQL workload before making any recommendations. See "SQLAccess Advisor" on page 12-7.

SQL Structure Analysis

The Automatic Tuning Optimizer identifies common problems with structure of SQL statements than can lead to poor performance. These could be syntactic, semantic, or design problems with the statement. In each of these cases the Automatic Tuning Optimizer makes relevant suggestions to restructure the SQL statements. The alternative suggested is similar, but not equivalent, to the original statement.

For example, the optimizer may suggest to replace UNION operator with UNION ALL or to replace NOT IN with NOT EXISTS. An application developer can then determine if the advice is applicable to their situation or not. For instance, if the schema design is such that there is no possibility of producing duplicates, then the UNION ALL operator is much more efficient than the UNION operator. These changes require a good understanding of the data properties and should be implemented only after careful consideration.

SQL Tuning Advisor

The Automatic SQL Tuning capabilities are exposed through a server utility called the SQL Tuning Advisor. The SQL Tuning Advisor takes one or more SQL statements as an input and invokes the Automatic Tuning Optimizer to perform SQL tuning on the statements. The output of the SQL Tuning Advisor is in the form of an advice or recommendations, along with a rationale for each recommendation and its expected benefit. The recommendation relates to collection of statistics on objects, creation of new indexes, restructuring of the SQL statement, or creation of SQL Profile. A user can choose to accept the recommendation to complete the tuning of the SQL statements.

The SQL Tuning Advisor input can be a single SQL statement or a set of statements. For tuning multiple statements, a SQL Tuning Set (STS) has to be first created. An STS is a database object that stores SQL statements along with their execution context. An STS can be created manually using command line APIs or automatically using Oracle Enterprise Manager. See "SQL Tuning Sets" on page 13-12.

Input Sources

The input for the SQL Tuning Advisor can come from several sources. These input sources include:

- Automatic Database Diagnostic Monitor

  The primary input source is the Automatic Database Diagnostic Monitor (ADDM). By default, ADDM runs proactively once every hour and analyzes key statistics gathered by the Automatic Workload Repository (AWR) over the last hour to identify any performance problems including high-load SQL statements. If a high-load SQL is identified, ADDM recommends running SQL Tuning Advisor on the SQL. See "Automatic Database Diagnostic Monitor" on page 6-3.

- High-load SQL statements

  The second most important input source is the high-load SQL statements captured in Automatic Workload Repository (AWR). The AWR takes regular snapshots of the system activity including high-load SQL statements ranked by relevant statistics, such as CPU consumption and wait time. A user can view the AWR and identify the high-load SQL of interest and run SQL Tuning Advisor on them. By default, the AWR retains data for the last seven days. This means that any high-load SQL that ran within the retention period of the AWR can be located and tuned using this feature. See "Automatic Workload Repository" on page 5-10.

- Cursor cache

  The third likely source of input is the cursor cache. This source is used for tuning recent SQL statements that are yet to be captured in the AWR. The cursor cache and AWR together provide the capability to identify and tune high-load SQL statements from the current time going as far back as the AWR retention allows, which by default is at least 7 days.

- SQL Tuning Set

  Another possible input source for the SQL Tuning Advisor is a user-defined set of SQL statements. This can include SQL statements that are yet to be deployed, with the goal of measuring their individual performance, or identifying the ones whose performance falls short of expectation. When a set of SQL statements are used as input, a SQL Tuning Set (STS) has to be first constructed and stored. See "SQL Tuning Sets" on page 13-12.

Tuning Options

SQL Tuning Advisor provides options to manage the scope and duration of a tuning task. The scope of a tuning task can be set to limited or comprehensive.

- If the limited option is chosen, the SQL Tuning Advisor produces recommendations based on statistics checks, access path analysis, and SQL structure analysis. SQL Profile recommendations are not generated.
- If the comprehensive option is selected, the SQL Tuning Advisor carries out all the analysis it performs under limited scope plus SQL Profiling. With the comprehensive option you can also specify a time limit for the tuning task, which by default is 30 minutes.

Advisor Output

After analyzing the SQL statements, the SQL Tuning Advisor provides advice on optimizing the execution plan, the rationale for the proposed optimization, the estimated performance benefit, and the command to implement the advice. You simply have to choose whether or not to accept the recommendations to optimize the SQL statements.

Accessing the SQL Tuning Advisor with Oracle Enterprise Manager

The primary interface for the SQL Tuning Advisor is the Oracle Enterprise Manager Database Control. To access the SQL Tuning Advisor through Oracle Enterprise Manager Database Control:

- Click the **Advisor Central** link under **Related Links** at the bottom of the **Database** pages.
- On the **Advisor Central** page, you can click the **SQL Tuning Advisor** link to analyze and tune SQL statements.

> **See Also:** *Oracle Enterprise Manager Concepts* and online help for information about monitoring and diagnostic tools available with Oracle Enterprise Manager

Using SQL Tuning Advisor APIs

While the primary interface for the SQL Tuning Advisor is the Oracle Enterprise Manager Database Control, the advisor can be administered with procedures in the `DBMS_SQLTUNE` package. To use the APIs the user must have been granted the DBA role and the `ADVISOR` privilege.

Running SQL Tuning Advisor using `DBMS_SQLTUNE` package is a two-step process:

1. Create a SQL tuning task
2. Execute a SQL tuning task

> **See Also:** *PL/SQL Packages and Types Reference* for detailed information on the `DBMS_SQLTUNE` package

Creating a SQL Tuning Task

You can create tuning tasks from the text of a single SQL statement, a SQL Tuning Set containing multiple statements, a SQL statement selected by SQL identifier from the cursor cache, or a SQL statement selected by SQL identifier from the Automatic Workload Repository.

For example, to use the SQL Tuning Advisor to optimize a specified SQL statement text, you need to create a tuning task with the SQL statement passed as a CLOB argument. For the following PL/SQL code, the user HR has been granted the `ADVISOR` privilege and the function is run as user HR on the `employees` table in the HR schema.

```
DECLARE
 my_task_name VARCHAR2(30);
 my_sqltext   CLOB;
BEGIN
 my_sqltext := 'SELECT /*+ ORDERED */ * '                      ||
               'FROM employees e, locations l, departments d ' ||
               'WHERE e.department_id = d.department_id AND '  ||
```

```
                    'l.location_id = d.location_id AND '      ||
                    'e.employee_id < :bnd';

 my_task_name := DBMS_SQLTUNE.CREATE_TUNING_TASK(
         sql_text    => my_sqltext,
         bind_list   => sql_binds(anydata.ConvertNumber(100)),
         user_name   => 'HR',
         scope       => 'COMPREHENSIVE',
         time_limit  => 60,
         task_name   => 'my_sql_tuning_task',
         description => 'Task to tune a query on a specified employee');
END;
/
```

In this example, 100 is the value for bind variable `:bnd` passed as function argument of type `SQL_BINDS`, `HR` is the user under which the `CREATE_TUNING_TASK` function analyzes the SQL statement, the scope is set to `COMPREHENSIVE` which means that the advisor also performs SQL Profiling analysis, and 60 is the maximum time in seconds that the function can run. In addition, values for task name and description are provided.

The `CREATE_TUNING_TASK` function returns the task name that you have provided or generates a unique task name. You can use the task name to specify this task when using other APIs. To view the task names associated with a specific owner, you can run the following:

```
SELECT task_name FROM DBA_ADVISOR_LOG WHERE owner = 'HR';
```

Executing a Tuning Task

After you have created a tuning task, you need to execute the task and start the tuning process. For example:

```
BEGIN
  DBMS_SQLTUNE.EXECUTE_TUNING_TASK( task_name => 'my_sql_tuning_task' );
END;
/
```

You can check the status of the task by reviewing the information in the `DBA_ADVISOR_LOG` view or check execution progress of the task in the `V$SESSION_LONGOPS` view. For example:

```
SELECT status FROM DBA_ADVISOR_LOG WHERE task_name = 'my_sql_tuning_task';
```

Displaying the Results of a Tuning Task

After a task has been executed, you display a report of the results with the REPORT_TUNING_TASK function. For example:

```
SET LONG 1000
SET LONGCHUNKSIZE 1000
SET LINESIZE 100
SELECT DBMS_SQLTUNE.REPORT_TUNING_TASK( 'my_sql_tuning_task')
  FROM DUAL;
```

The report contains all the findings and recommendations of Automatic SQL Tuning. For each proposed recommendation, the rationale and benefit is provided along with the SQL commands needed to implement the recommendation.

Additional information about tuning tasks and results can be found in DBA views. See "SQL Tuning Information Views" on page 13-16.

Additional Operations on a Tuning Task

You can use the following APIs for managing SQL tuning tasks:

- INTERRUPT_TUNING_TASK to interrupt a task while executing, causing a normal exit with intermediate results
- CANCEL_TUNING_TASK to cancel a task while executing, removing all results from the task
- RESET_TUNING_TASK to reset a task while executing, removing all results from the task and returning the task to its initial state
- DROP_TUNING_TASK to drop a task, removing all results associated with the task

Managing SQL Profiles with APIs

While SQL Profiles are usually handled by Oracle Enterprise Manager as part of the Automatic SQL Tuning process, SQL Profiles can be managed through the DBMS_SQLTUNE package. To use the SQL Profiles APIs, you need the CREATE ANY SQL_PROFILE, DROP ANY SQL_PROFILE, and ALTER ANY SQL_PROFILE system privileges.

> **See Also:** *PL/SQL Packages and Types Reference* for detailed information on the DBMS_SQLTUNE package

Accepting a SQL Profile

You can use the DBMS_SQLTUNE.ACCEPT_SQL_PROFILE procedure to accept a SQL Profile recommended by the SQL Tuning Advisor. This creates and stores a SQL Profile in the database. For example:

```
DECLARE
 my_sqlprofile_name VARCHAR2(30);
BEGIN
 my_sqlprofile_name := DBMS_SQLTUNE.ACCEPT_SQL_PROFILE (
    task_name => 'my_sql_tuning_task',
    name      => 'my_sql_profile');
END;
```

where my_sql_tuning_task is the name of the SQL tuning task.

You can view information about a SQL Profile in the DBA_SQL_PROFILES view.

Altering a SQL Profile

You can alter the STATUS, NAME, DESCRIPTION, and CATEGORY attributes of an existing SQL Profile with the ALTER_SQL_PROFILE procedure. For example:

```
BEGIN
  DBMS_SQLTUNE.ALTER_SQL_PROFILE(
     name            => 'my_sql_profile',
     attribute_name  => 'STATUS',
     value           => 'DISABLED');
END;
/
```

In this example, my_sql_profile is the name of the SQL Profile that you want to alter. The status attribute is changed to disabled which means the SQL Profile is not used during SQL compilation.

Dropping a SQL Profile

You can drop a SQL Profile with the DROP_SQL_PROFILE procedure. For example:

```
BEGIN
  DBMS_SQLTUNE.DROP_SQL_PROFILE(name => 'my_sql_profile');
END;
/
```

In this example, `my_sql_profile` is the name of the SQL Profile you want to drop. You can also specify whether to ignore errors raised if the name does not exist. For this example, the default value of FALSE is accepted.

SQL Tuning Sets

A SQL Tuning Set (STS) is a database object that includes one or more SQL statements along with their execution statistics and execution context, and could include a user priority ranking. The SQL statements can be loaded into a SQL Tuning Set from different SQL sources, such as the Automatic Workload Repository, the cursor cache, or custom SQL provided by the user. An STS includes:

- A set of SQL statements
- Associated execution context, such as user schema, application module name and action, list of bind values, and the cursor compilation environment
- Associated basic execution statistics, such as elapsed time, CPU time, buffer gets, disk reads, rows processed, cursor fetches, the number of executions, the number of complete executions, optimizer cost, and the command type

SQL statements can be filtered using the application module name and action, or any of the execution statistics. In addition, the SQL statements can be ranked based on any combination of execution statistics.

A SQL Tuning Set can be used as input to the SQL Tuning Advisor, which performs automatic tuning of the SQL statements based on other input parameters specified by the user. While SQL Tuning Sets are usually handled by Oracle Enterprise Manager as part of the Automatic SQL Tuning process, SQL Tuning Sets can be managed with `DBMS_SQLTUNE` package procedures.

Accessing SQL Tuning Sets with Oracle Enterprise Manager

To manage the SQL Tuning Sets through Oracle Enterprise Manager Database Control:

- Click the **Advisor Central** link under **Related Links** at the bottom of the **Database** pages.
  - On the **Advisor Central** page, click the **SQL Tuning Advisor** link.
  - Click the **SQL Tuning Sets** link on the **SQL Tuning Advisor Links** page.
- On the **Administration** page, select the **SQL Tuning Sets** link under **Workload**.

> **See Also:** *Oracle Enterprise Manager Concepts* and online help for information about monitoring and diagnostic tools available with Oracle Enterprise Manager

Managing SQL Tuning Sets

The SQL Tuning Set APIs allow you to mange SQL Tuning Sets to determine performance information about SQL statements running on your system. Typically you would use the STS operations in the following sequence:

- Create a new STS
- Load the STS
- Select the STS to review the contents
- Update the STS if necessary
- Create a tuning task with the STS as input
- Drop the STS when finished

To use the APIs, you need the `ADMINISTER ANY SQL TUNING SET` system privilege.

> **See Also:** *PL/SQL Packages and Types Reference* for detailed information on the `DBMS_SQLTUNE` package

Creating a SQL Tuning Set

The `CREATE_SQLSET` procedure is used to create an empty STS object in the database. For example, the following procedure creates an STS object that could be used to tune I/O intensive SQL statements during a specific period of time:

```
BEGIN
  DBMS_SQLTUNE.CREATE_SQLSET(
    sqlset_name => 'my_sql_tuning_set',
    description  => 'I/O intensive workload');
END;
/
```

where `my_sql_tuning_set` is the name of the STS in the database and `'I/O intensive workload'` is the description assigned to the STS.

Loading a SQL Tuning Set

The `LOAD_SQLSET` procedure populates the STS with selected SQL statements. The standard sources for populating an STS are the workload repository, another STS, or

the cursor cache. For both the workload repository and STS, there are predefined table functions that can be used to select columns from the source to populate a new STS.

In the following example, procedure calls are used to load `my_sql_tuning_set` from an AWR baseline called `peak baseline`. The data has been filtered to include only those SQL statements that have been executed at least 10 times and have a disk-reads to buffer-gets ratio greater than 50% during the baseline period. The SQL statements are ordered by the disk-reads to buffer-gets ratio with only the top 30 SQL statements selected. First a ref cursor is opened to select from the specified baseline. Next the statements and their statistics are loaded from the baseline into the STS.

```
DECLARE
 baseline_cursor DBMS_SQLTUNE.SQLSET_CURSOR;
BEGIN
 OPEN baseline_cursor FOR
    SELECT VALUE(p)
    FROM TABLE (DBMS_SQLTUNE.SELECT_WORKLOAD_REPOSITORY(
                  'peak baseline',
                  'executions >= 10 AND disk_reads/buffer_gets >= 0.5',
                   NULL,
                   'disk_reads/buffer_gets',
                   NULL, NULL, NULL,
                   30)) p;

    DBMS_SQLTUNE.LOAD_SQLSET(
             sqlset_name     => 'my_sql_tuning_set',
             populate_cursor => baseline_cursor);
END;
/
```

Displaying the Contents of a SQL Tuning Set

The `SELECT_SQLSET` table function reads the contents of the STS. After an STS has been created and populated, you can browse through the SQL in the STS using the `SELECT_SQLSET` procedure.

In the following example, the SQL statements in the STS are displayed for statements with a disk-reads to buffer-gets ratio greater than or equal to 75%.

```
SELECT * FROM TABLE(DBMS_SQLTUNE.SELECT_SQLSET(
   'my_sql_tuning_set',
   '(disk_reads/buffer_gets) >= 0.75'));
```

Additional details of the SQL Tuning Sets that have been created and loaded can also be displayed with DBA views, such as DBA_SQLSET, DBA_SQLSET_STATEMENTS, and DBA_SQLSET_BINDS.

Modifying a SQL Tuning Set

SQL statements can be updated and deleted from a SQL Tuning Set based on a search condition. In the following example, the DELETE_SQLSET procedure deletes SQL statements from my_sql_tuning_set that have been executed less than fifty times.

```
BEGIN
  DBMS_SQLTUNE.DELETE_SQLSET(
      sqlset_name  => 'my_sql_tuning_set',
      basic_filter => 'executions < 50');
END;
/
```

Dropping a SQL Tuning Set

The DROP_SQLSET procedure is used to drop an STS that is no longer needed. For example:

```
BEGIN
  DBMS_SQLTUNE.DROP_SQLSET( sqlset_name => 'my_sql_tuning_set' );
END;
/
```

Additional Operations on SQL Tuning Sets

You can use the following APIs to manage an STS:

- Updating the Attributes of an STS

  The UPDATE_SQLSET procedure updates the attribute values of an existing STS identified by STS name and SQL identifier.

- Getting the SQL Information to Create an STS

  The SELECT_WORKLOAD_REPOSITORY function enables the creation of an STS by returning an STS from a snapshot or baseline.

- Adding and Removing a Reference to an STS

  The ADD_SQLSET_REFERENCE function adds a new reference to an existing STS to indicate its use by a client. The function returns the identifier of the

added reference. The REMOVE_SQLSET_REFERENCE procedure is used to deactivate an STS to indicate it is no longer used by the client.

SQL Tuning Information Views

This section summarizes the views that you can display to review information that has been gathered for tuning the SQL statements. You need DBA privileges to access these views.

- Advisor information views, such as DBA_ADVISOR_TASKS, DBA_ADVISOR_FINDINGS, DBA_ADVISOR_RECOMMENDATIONS, and DBA_ADVISOR_RATIONALE views.
- SQL tuning information views, such as DBA_SQLTUNE_STATISTICS, DBA_SQLTUNE_BINDS, and DBA_SQLTUNE_PLANS views.
- SQL Tuning Set views, such as DBA_SQLSET, DBA_SQLSET_BINDS, DBA_SQLSET_STATEMENTS, and DBA_SQLSET_REFERENCES views.
- SQL Profile information is displayed in the DBA_SQL_PROFILES view.
- Dynamic views containing information relevant to the SQL tuning, such as VSQL, VSQLAREA, and V$SQL_BINDS views.

See Also: *Oracle Database Reference* for information on static data dictionary and dynamic views

14

The Query Optimizer

This chapter discusses SQL processing, optimization methods, and how the optimizer chooses a specific plan to execute SQL.

The chapter contains the following sections:

Optimizer Operations

A SQL statement can be executed in many different ways, such as full table scans, index scans, nested loops, and hash joins. The query optimizer determines the most efficient way to execute a SQL statement after considering many factors related to the objects referenced and the conditions specified in the query. This determination is an important step in the processing of any SQL statement and can greatly affect execution time.

Note: The optimizer might not make the same decisions from one version of Oracle to the next. In recent versions, the optimizer might make different decisions, because better information is available.

The output from the optimizer is a plan that describes an optimum method of execution. The Oracle server provides query optimization.

For any SQL statement processed by Oracle, the optimizer performs the operations listed in Table 14–1.

Table 14–1 Optimizer Operations

Operation	Description
Evaluation of expressions and conditions	The optimizer first evaluates expressions and conditions containing constants as fully as possible.
Statement transformation	For complex statements involving, for example, correlated subqueries or views, the optimizer might transform the original statement into an equivalent join statement.
Choice of optimizer goals	The optimizer determines the goal of optimization. See "Choosing an Optimizer Goal" on page 14-3.
Choice of access paths	For each table accessed by the statement, the optimizer chooses one or more of the available access paths to obtain table data. See "Understanding Access Paths for the Query Optimizer" on page 14-18.
Choice of join orders	For a join statement that joins more than two tables, the optimizer chooses which pair of tables is joined first, and then which table is joined to the result, and so on. See "How the Query Optimizer Chooses Execution Plans for Joins" on page 14-30.

You can influence the optimizer's choices by setting the optimizer goal, and by gathering representative statistics for the query optimizer. The optimizer goal is

either throughput or response time. See "Choosing an Optimizer Goal" on page 14-3 and "Query Optimizer Statistics in the Data Dictionary" on page 14-6.

Sometimes, the application designer, who has more information about a particular application's data than is available to the optimizer, can choose a more effective way to execute a SQL statement. The application designer can use hints in SQL statements to specify how the statement should be executed.

See Also:

- *Oracle Database Concepts* for an overview of SQL processing and the optimizer
- *Oracle Data Cartridge Developer's Guide* for information about the extensible optimizer
- "Choosing an Optimizer Goal" on page 14-3 for more information on optimization goals
- Chapter 15, "Managing Optimizer Statistics" for information on gathering and using statistics
- Chapter 17, "Optimizer Hints" for more information about using hints in SQL statements

Choosing an Optimizer Goal

By default, the goal of the query optimizer is the best throughput. This means that it chooses the least amount of resources necessary to process all rows accessed by the statement. Oracle can also optimize a statement with the goal of best response time. This means that it uses the least amount of resources necessary to process the first row accessed by a SQL statement.

Choose a goal for the optimizer based on the needs of your application:

- For applications performed in batch, such as Oracle Reports applications, optimize for best throughput. Usually, throughput is more important in batch applications, because the user initiating the application is only concerned with the time necessary for the application to complete. Response time is less important, because the user does not examine the results of individual statements while the application is running.
- For interactive applications, such as Oracle Forms applications or SQL*Plus queries, optimize for best response time. Usually, response time is important in interactive applications, because the interactive user is waiting to see the first row or first few rows accessed by the statement.

The optimizer's behavior when choosing an optimization approach and goal for a SQL statement is affected by the following factors:

- OPTIMIZER_MODE Initialization Parameter
- Optimizer SQL Hints for Changing the Query Optimizer Goal
- Query Optimizer Statistics in the Data Dictionary

OPTIMIZER_MODE Initialization Parameter

The `OPTIMIZER_MODE` initialization parameter establishes the default behavior for choosing an optimization approach for the instance. The possible values and description are listed in Table 14–2.

Table 14–2 OPTIMIZER_MODE Parameter Values

Value	Description
`ALL_ROWS`	The optimizer uses a cost-based approach for all SQL statements in the session regardless of the presence of statistics and optimizes with a goal of best throughput (minimum resource use to complete the entire statement). This is the default value.
`FIRST_ROWS_`*n*	The optimizer uses a cost-based approach, regardless of the presence of statistics, and optimizes with a goal of best response time to return the first *n* number of rows; *n* can equal 1, 10, 100, or 1000.
`FIRST_ROWS`	The optimizer uses a mix of cost and heuristics to find a best plan for fast delivery of the first few rows. Note: Using heuristics sometimes leads the query optimizer to generate a plan with a cost that is significantly larger than the cost of a plan without applying the heuristic. `FIRST_ROWS` is available for backward compatibility and plan stability; use `FIRST_ROWS_`*n* instead.
`CHOOSE`	This parameter value has been desupported.
`RULE`	This parameter value has been desupported.

You can change the goal of the query optimizer for all SQL statements in a session by changing the parameter value in initialization file or by the `ALTER SESSION SET OPTIMIZER_MODE` statement. For example:

- The following statement in an initialization parameter file changes the goal of the query optimizer for all sessions of the instance to best response time:

  ```
  OPTIMIZER_MODE = FIRST_ROWS_1
  ```

- The following SQL statement changes the goal of the query optimizer for the current session to best response time:

```
ALTER SESSION SET OPTIMIZER_MODE = FIRST_ROWS_1;
```

If the optimizer uses the cost-based approach for a SQL statement, and if some tables accessed by the statement have no statistics, then the optimizer uses internal information, such as the number of data blocks allocated to these tables, to estimate other statistics for these tables.

Optimizer SQL Hints for Changing the Query Optimizer Goal

To specify the goal of the query optimizer for an individual SQL statement, use one of the hints in Table 14–3. Any of these hints in an individual SQL statement can override the OPTIMIZER_MODE initialization parameter for that SQL statement.

Table 14–3 Hints for Changing the Query Optimizer Goal

Hint	Description
FIRST_ROWS(n)	This hint instructs Oracle to optimize an individual SQL statement with a goal of best response time to return the first n number of rows, where n equals any positive integer. The hint uses a cost-based approach for the SQL statement, regardless of the presence of statistic.
ALL_ROWS	This hint explicitly chooses the cost-based approach to optimize a SQL statement with a goal of best throughput.
CPU_COSTING	This hint turns CPU costing on for the SQL statement. This is the default cost model for the optimizer. The optimizer estimates the number and type of I/O operations, the number of CPU cycles the database will perform during execution of the given query, and uses system statistics to convert the number of CPU cycles and number of IOs to the estimated query execution time.
NO_CPU_COSTING	This hint turns CPU costing off for the SQL statement. The optimizer uses the I/O cost model which measures everything in single block reads and ignores CPU cost.
CHOOSE	This hint has been desupported.
RULE	This hint has been desupported.

See Also: Chapter 17, "Optimizer Hints" for information on how to use hints

Query Optimizer Statistics in the Data Dictionary

The statistics used by the query optimizer are stored in the data dictionary. You can collect exact or estimated statistics about physical storage characteristics and data distribution in these schema objects by using the `DBMS_STATS` package.

To maintain the effectiveness of the query optimizer, you must have statistics that are representative of the data. For table columns that contain values with large variations in number of duplicates, called skewed data, you should collect histograms.

The resulting statistics provide the query optimizer with information about data uniqueness and distribution. Using this information, the query optimizer is able to compute plan costs with a high degree of accuracy. This enables the query optimizer to choose the best execution plan based on the least cost.

If no statistics are available when using query optimization, the optimizer will do dynamic sampling depending on the setting of the `OPTMIZER_DYNAMIC_SAMPLING` initialization parameter. This may cause slower parse times so for best performance, the optimizer should have representative optimizer statistics.

See Also:

- Chapter 15, "Managing Optimizer Statistics"
- "Estimating Statistics with Dynamic Sampling" on page 15-16

Enabling and Controlling Query Optimizer Features

This section contains some of the initialization parameters specific to the optimizer. The following sections are especially useful when tuning Oracle applications.

See Also: *Oracle Database Reference* for information about initialization parameters

Enabling Query Optimizer Features

You enable optimizer features by setting the `OPTIMIZER_FEATURES_ENABLE` initialization parameter.

OPTIMIZER_FEATURES_ENABLE Parameter

The `OPTIMIZER_FEATURES_ENABLE` parameter acts as an umbrella parameter for the query optimizer. This parameter can be used to enable a series of optimizer-related features, depending on the release. It accepts one of a list of valid

string values corresponding to the release numbers, such as 8.0.4, 8.1.7, and 9.2.0. For example, the following setting enables the use of the optimizer features in generating query plans in Oracle 10*g*, Release 1.

```
OPTIMIZER_FEATURES_ENABLE=10.0.0;
```

The OPTIMIZER_FEATURES_ENABLE parameter was introduced with the main goal to allow customers to upgrade the Oracle server, yet preserve the old behavior of the query optimizer after the upgrade. For example, when you upgrade the Oracle server from release 8.1.5 to release 8.1.6, the default value of the OPTIMIZER_FEATURES_ENABLE parameter changes from 8.1.5 to 8.1.6. This upgrade results in the query optimizer enabling optimization features based on 8.1.6, as opposed to 8.1.5.

For plan stability or backward compatibility reasons, you might not want the query plans to change because of new optimizer features in a new release. In such a case, you can set the OPTIMIZER_FEATURES_ENABLE parameter to an earlier version. For example, to preserve the behavior of the query optimizer to release 8.1.5, set the parameter as follows:

```
OPTIMIZER_FEATURES_ENABLE=8.1.5;
```

This statement disables all new optimizer features that were added in releases following release 8.1.5.

Note: If you upgrade to a new release and you want to enable the features available with that release, then you do not need to explicitly set the OPTIMIZER_FEATURES_ENABLE initialization parameter.

Oracle Corporation does not recommend explicitly setting the OPTIMIZER_FEATURES_ENABLE parameter to an earlier release. Instead, execution plan or query performance issues should be resolved on a case-by-case basis.

See Also: *Oracle Database Reference* for information about optimizer features that are enabled when you set the OPTIMIZER_FEATURES_ENABLE parameter to each of the release values

Controlling the Behavior of the Query Optimizer

This section lists some initialization parameters that can be used to control the behavior of the query optimizer. These parameters can be used to enable various optimizer features in order to improve the performance of SQL execution.

CURSOR_SHARING

This parameter converts literal values in SQL statements to bind variables. Converting the values improves cursor sharing and can affect the execution plans of SQL statements. The optimizer generates the execution plan based on the presence of the bind variables and not the actual literal values.

DB_FILE_MULTIBLOCK_READ_COUNT

This parameter specifies the number of blocks that are read in a single I/O during a full table scan or index fast full scan. The optimizer uses the value of `DB_FILE_MULTIBLOCK_READ_COUNT` to cost full table scans and index fast full scans. Larger values result in a cheaper cost for full table scans and can result in the optimizer choosing a full table scan over an index scan.

OPTIMIZER_INDEX_CACHING

This parameter controls the costing of an index probe in conjunction with a nested loop. The range of values `0` to `100` for `OPTIMIZER_INDEX_CACHING` indicates percentage of index blocks in the buffer cache, which modifies the optimizer's assumptions about index caching for nested loops and IN-list iterators. A value of `100` infers that 100% of the index blocks are likely to be found in the buffer cache and the optimizer adjusts the cost of an index probe or nested loop accordingly. Use caution when using this parameter because execution plans can change in favor of index caching.

OPTIMIZER_INDEX_COST_ADJ

This parameter can be used to adjust the cost of index probes. The range of values is `1` to `10000`. The default value is `100`, which means that indexes are evaluated as an access path based on the normal costing model. A value of `10` means that the cost of an index access path is one-tenth the normal cost of an index access path.

OPTIMIZER_MODE

This initialization parameter sets the mode of the optimizer at instance startup. The possible values are `RULE`, `CHOOSE`, `ALL_ROWS`, `FIRST_ROWS_`*n*, and `FIRST_ROWS`.

For description of these parameter values, see "OPTIMIZER_MODE Initialization Parameter" on page 14-4.

PGA_AGGREGATE_TARGET

This parameter automatically controls the amount of memory allocated for sorts and hash joins. Larger amounts of memory allocated for sorts or hash joins reduce the optimizer cost of these operations. See "PGA Memory Management" on page 7-50.

STAR_TRANSFORMATION_ENABLED

This parameter, if set to `true`, enables the query optimizer to cost a star transformation for star queries. The star transformation combines the bitmap indexes on the various fact table columns.

> **See Also:** *Oracle Database Reference* for complete information about each parameter

Understanding the Query Optimizer

The query optimizer determines which execution plan is most efficient by considering available access paths and by factoring in information based on statistics for the schema objects (tables or indexes) accessed by the SQL statement. The query optimizer also considers hints, which are optimization suggestions placed in a comment in the statement.

> **See Also:** Chapter 17, "Optimizer Hints" for detailed information on hints

The query optimizer performs the following steps:

1. The optimizer generates a set of potential plans for the SQL statement based on available access paths and hints.
2. The optimizer estimates the cost of each plan based on statistics in the data dictionary for the data distribution and storage characteristics of the tables, indexes, and partitions accessed by the statement.

   The **cost** is an estimated value proportional to the expected resource use needed to execute the statement with a particular plan. The optimizer calculates the cost of access paths and join orders based on the estimated computer resources, which includes I/O, CPU, and memory.

Serial plans with higher costs take more time to execute than those with smaller costs. When using a parallel plan, however, resource use is not directly related to elapsed time.

3. The optimizer compares the costs of the plans and chooses the one with the lowest cost.

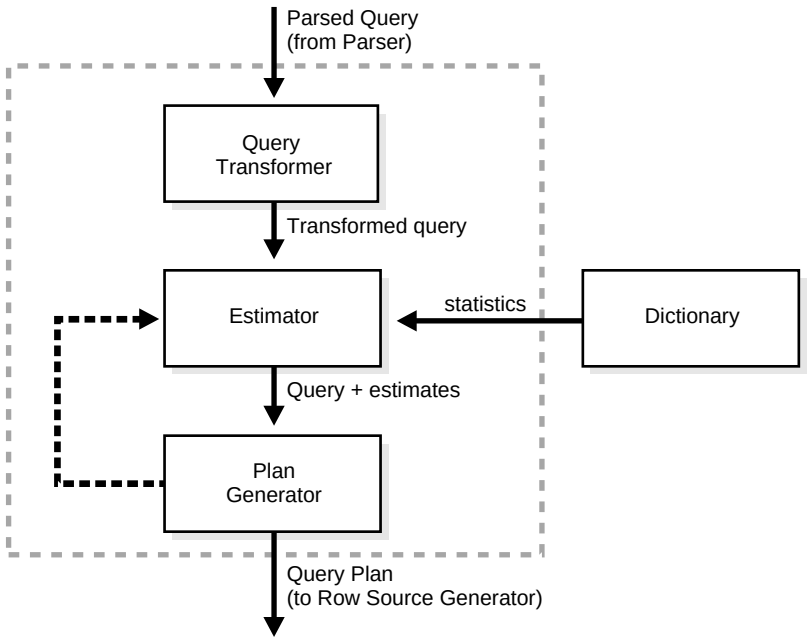
Components of the Query Optimizer

The query optimizer operations include:

- Transforming Queries
- Estimating
- Generating Plans

Query optimizer components are illustrated in Figure 14–1.

Figure 14–1 Query Optimizer Components



Transforming Queries

The input to the query transformer is a parsed query, which is represented by a set of query blocks. The query blocks are nested or interrelated to each other. The form of the query determines how the query blocks are interrelated to each other. The main objective of the query transformer is to determine if it is advantageous to change the form of the query so that it enables generation of a better query plan. Several different query transformation techniques are employed by the query transformer, including:

- View Merging
- Predicate Pushing
- Subquery Unnesting
- Query Rewrite with Materialized Views

Any combination of these transformations can be applied to a given query.

View Merging Each view referenced in a query is expanded by the parser into a separate query block. The query block essentially represents the view definition, and therefore the result of a view. One option for the optimizer is to analyze the view query block separately and generate a view subplan. The optimizer then processes the rest of the query by using the view subplan in the generation of an overall query plan. This technique usually leads to a suboptimal query plan, because the view is optimized separately from rest of the query.

The query transformer then removes the potentially suboptimal plan by merging the view query block into the query block that contains the view. Most types of views are merged. When a view is merged, the query block representing the view is merged into the containing query block. Generating a subplan is no longer necessary, because the view query block is eliminated.

Predicate Pushing For those views that are not merged, the query transformer can push the relevant predicates from the containing query block into the view query block. This technique improves the subplan of the nonmerged view, because the pushed-in predicates can be used either to access indexes or to act as filters.

Subquery Unnesting Often the performance of queries that contain subqueries can be improved by unnesting the subqueries and converting them into joins. Most subqueries are unnested by the query transformer. For those subqueries that are not unnested, separate subplans are generated. To improve execution speed of the overall query plan, the subplans are ordered in an efficient manner.

Query Rewrite with Materialized Views A materialized view is like a query with a result that is materialized and stored in a table. When a user query is found compatible with the query associated with a materialized view, the user query can be rewritten in terms of the materialized view. This technique improves the execution of the user query, because most of the query result has been precomputed. The query transformer looks for any materialized views that are compatible with the user query and selects one or more materialized views to rewrite the user query. The use of materialized views to rewrite a query is cost-based. That is, the query is not rewritten if the plan generated without the materialized views has a lower cost than the plan generated with the materialized views.

Peeking of User-Defined Bind Variables

The query optimizer peeks at the values of user-defined bind variables on the first invocation of a cursor. This feature lets the optimizer determine the selectivity of any `WHERE` clause condition, as well as if literals have been used instead of bind variables. On subsequent invocations of the cursor, no peeking takes place, and the cursor is shared, based on the standard cursor-sharing criteria, even if subsequent invocations use different bind values.

When bind variables are used in a statement, it is assumed that cursor sharing is intended and that different invocations are supposed to use the same execution plan. If different invocations of the cursor would significantly benefit from different execution plans, then bind variables may have been used inappropriately in the SQL statement. Bind peeking works for a specific set of clients, not all clients.

> **See Also:** *Oracle Data Warehousing Guide* for more information on query rewrite

Estimating

The estimator generates three different types of measures:

- Selectivity
- Cardinality
- Cost

These measures are related to each other, and one is derived from another. The end goal of the estimator is to estimate the overall cost of a given plan. If statistics are available, then the estimator uses them to compute the measures. The statistics improve the degree of accuracy of the measures.

Selectivity The first measure, selectivity, represents a fraction of rows from a row set. The row set can be a base table, a view, or the result of a join or a GROUP BY operator. The selectivity is tied to a query predicate, such as `last_name = 'Smith'`, or a combination of predicates, such as `last_name = 'Smith' AND job_type = 'Clerk'`. A predicate acts as a filter that filters a certain number of rows from a row set. Therefore, the selectivity of a predicate indicates how many rows from a row set will pass the predicate test. Selectivity lies in a value range from 0.0 to 1.0. A selectivity of 0.0 means that no rows will be selected from a row set, and a selectivity of 1.0 means that all rows will be selected.

If no statistics are available then the optimizer either uses dynamic sampling or an internal default value, depending on the value of the `OPTIMIZER_DYNAMIC_SAMPLING` initialization parameter. Different internal defaults are used, depending on the predicate type. For example, the internal default for an equality predicate (`last_name = 'Smith'`) is lower than the internal default for a range predicate (`last_name > 'Smith'`). The estimator makes this assumption because an equality predicate is expected to return a smaller fraction of rows than a range predicate. See "Estimating Statistics with Dynamic Sampling" on page 15-16.

When statistics are available, the estimator uses them to estimate selectivity. For example, for an equality predicate (`last_name = 'Smith'`), selectivity is set to the reciprocal of the number *n* of distinct values of `last_name`, because the query selects rows that all contain one out of *n* distinct values. If a histogram is available on the `last_name` column, then the estimator uses it instead of the number of distinct values. The histogram captures the distribution of different values in a column, so it yields better selectivity estimates. Having histograms on columns that contain skewed data (in other words, values with large variations in number of duplicates) greatly helps the query optimizer generate good selectivity estimates.

Cardinality Cardinality represents the number of rows in a row set. Here, the row set can be a base table, a view, or the result of a join or GROUP BY operator.

Cost The cost represents units of work or resource used. The query optimizer uses disk I/O, CPU usage, and memory usage as units of work. So, the cost used by the query optimizer represents an estimate of the number of disk I/Os and the amount of CPU and memory used in performing an operation. The operation can be scanning a table, accessing rows from a table by using an index, joining two tables together, or sorting a row set. The cost of a query plan is the number of work units that are expected to be incurred when the query is executed and its result produced.

The **access path** determines the number of units of work required to get data from a base table. The access path can be a table scan, a fast full index scan, or an index scan. During table scan or fast full index scan, multiple blocks are read from the

disk in a single I/O operation. Therefore, the cost of a table scan or a fast full index scan depends on the number of blocks to be scanned and the multiblock read count value. The cost of an index scan depends on the levels in the B-tree, the number of index leaf blocks to be scanned, and the number of rows to be fetched using the rowid in the index keys. The cost of fetching rows using rowids depends on the index clustering factor. See "Assessing I/O for Blocks, not Rows" on page 14-21.

The **join cost** represents the combination of the individual access costs of the two row sets being joined, plus the cost of the join operation.

> **See Also:** "Understanding Joins" on page 14-29 for more information on joins

Generating Plans

The main function of the plan generator is to try out different possible plans for a given query and pick the one that has the lowest cost. Many different plans are possible because of the various combinations of different access paths, join methods, and join orders that can be used to access and process data in different ways and produce the same result.

A join order is the order in which different join items, such as tables, are accessed and joined together. For example, in a join order of `table1`, `table2`, and `table3`, table `table1` is accessed first. Next, `table2` is accessed, and its data is joined to `table1` data to produce a join of `table1` and `table2`. Finally, `table3` is accessed, and its data is joined to the result of the join between `table1` and `table2`.

The plan for a query is established by first generating subplans for each of the nested subqueries and nonmerged views. Each nested subquery or nonmerged view is represented by a separate query block. The query blocks are optimized separately in a bottom-up order. That is, the innermost query block is optimized first, and a subplan is generated for it. The outermost query block, which represents the entire query, is optimized last.

The plan generator explores various plans for a query block by trying out different access paths, join methods, and join orders. The number of possible plans for a query block is proportional to the number of join items in the `FROM` clause. This number rises exponentially with the number of join items.

The plan generator uses an internal cutoff to reduce the number of plans it tries when finding the one with the lowest cost. The cutoff is based on the cost of the current best plan. If the current best cost is large, then the plan generator tries harder (in other words, explores more alternate plans) to find a better plan with

lower cost. If the current best cost is small, then the plan generator ends the search swiftly, because further cost improvement will not be significant.

The cutoff works well if the plan generator starts with an initial join order that produces a plan with cost close to optimal. Finding a good initial join order is a difficult problem.

Reading and Understanding Execution Plans

To execute a SQL statement, Oracle might need to perform many steps. Each of these steps either retrieves rows of data physically from the database or prepares them in some way for the user issuing the statement. The combination of the steps Oracle uses to execute a statement is called an **execution plan**. An execution plan includes an **access path** for each table that the statement accesses and an ordering of the tables (the **join order**) with the appropriate **join method**.

See Also:

- "Understanding Access Paths for the Query Optimizer" on page 14-18
- Chapter 19, "Using EXPLAIN PLAN"

Overview of EXPLAIN PLAN

You can examine the execution plan chosen by the optimizer for a SQL statement by using the EXPLAIN PLAN statement. When the statement is issued, the optimizer chooses an execution plan and then inserts data describing the plan into a database table. Simply issue the EXPLAIN PLAN statement and then query the output table.

These are the basics of using the EXPLAIN PLAN statement:

- Use the SQL script UTLXPLAN.SQL to create a sample output table called PLAN_TABLE in your schema. See "The PLAN_TABLE Output Table" on page 19-5.
- Include the EXPLAIN PLAN FOR clause prior to the SQL statement. See "Running EXPLAIN PLAN" on page 19-6.
- After issuing the EXPLAIN PLAN statement, use one of the scripts or package provided by Oracle to display the most recent plan table output. See "Displaying PLAN_TABLE Output" on page 19-7.
- The execution order in EXPLAIN PLAN output begins with the line that is the furthest indented to the right. The next step is the parent of that line. If two lines are indented equally, then the top line is normally executed first.

Notes:

- The EXPLAIN PLAN output tables in this chapter were displayed with the `utlxpls.sql` script.
- The steps in the EXPLAIN PLAN output in this chapter may be different on your system. The optimizer may choose different execution plans, depending on database configurations.

Example 14–1 uses EXPLAIN PLAN to examine a SQL statement that selects the `employee_id`, `job_title`, `salary`, and `department_name` for the employees whose IDs are less than 103.

Example 14–1 Using EXPLAIN PLAN

```
EXPLAIN PLAN FOR
SELECT e.employee_id, j.job_title, e.salary, d.department_name
    FROM employees e, jobs j, departments d
    WHERE  e.employee_id < 103
       AND e.job_id = j.job_id
       AND e.department_id = d.department_id;
```

The resulting output table in Example 14–2 shows the execution plan chosen by the optimizer to execute the SQL statement in the example:

Example 14–2 EXPLAIN PLAN Output

```
-------------------------------------------------------------------------------------
| Id  | Operation                     |  Name        | Rows  | Bytes | Cost (%CPU)|
-------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT              |              |     3 |   189 |    10  (10)|
|   1 |  NESTED LOOPS                 |              |     3 |   189 |    10  (10)|
|   2 |   NESTED LOOPS                |              |     3 |   141 |     7  (15)|
|*  3 |    TABLE ACCESS FULL          | EMPLOYEES    |     3 |    60 |     4  (25)|
|   4 |    TABLE ACCESS BY INDEX ROWID| JOBS         |    19 |   513 |     2  (50)|
|*  5 |     INDEX UNIQUE SCAN         | JOB_ID_PK    |     1 |       |            |
|   6 |   TABLE ACCESS BY INDEX ROWID | DEPARTMENTS  |    27 |   432 |     2  (50)|
|*  7 |    INDEX UNIQUE SCAN          | DEPT_ID_PK   |     1 |       |            |
-------------------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------
   3 - filter("E"."EMPLOYEE_ID"<103)
   5 - access("E"."JOB_ID"="J"."JOB_ID")
   7 - access("E"."DEPARTMENT_ID"="D"."DEPARTMENT_ID")
```

Steps in the Execution Plan

Each row in the output table corresponds to a single step in the execution plan. Note that the step Ids with asterisks are listed in the Predicate Information section.

See Also: Chapter 19, "Using EXPLAIN PLAN"

Each step of the execution plan returns a set of rows that either is used by the next step or, in the last step, is returned to the user or application issuing the SQL statement. A set of rows returned by a step is called a row set.

The numbering of the step Ids reflects the order in which they are displayed in response to the `EXPLAIN PLAN` statement. Each step of the execution plan either retrieves rows from the database or accepts rows from one or more row sources as input.

- The following steps in Example 14–2 physically retrieve data from an object in the database:
  - Step 3 reads all rows of the `employees` table.
  - Step 5 looks up each `job_id` in `JOB_ID_PK` index and finds the rowids of the associated rows in the `jobs` table.
  - Step 4 retrieves the rows with rowids that were returned by Step 5 from the `jobs` table.
  - Step 7 looks up each `department_id` in `DEPT_ID_PK` index and finds the rowids of the associated rows in the `departments` table.
  - Step 6 retrieves the rows with rowids that were returned by Step 7 from the `departments` table.
- The following steps in Example 14–2 operate on rows returned by the previous row source:
  - Step 2 performs the nested loop operation on `job_id` in the `jobs` and `employees` tables, accepting row sources from Steps 3 and 4, joining each row from Step 3 source to its corresponding row in Step 4, and returning the resulting rows to Step 2.
  - Step 1 performs the nested loop operation, accepting row sources from Step 2 and Step 6, joining each row from Step 2 source to its corresponding row in Step 6, and returning the resulting rows to Step 1.

See Also:

- "Understanding Access Paths for the Query Optimizer" on page 14-18 for more information on access paths
- "Understanding Joins" on page 14-29 for more information on the methods by which Oracle joins row sources

Understanding Access Paths for the Query Optimizer

Access paths are ways in which data is retrieved from the database. In general, index access paths should be used for statements that retrieve a small subset of table rows, while full scans are more efficient when accessing a large portion of the table. Online transaction processing (OLTP) applications, which consist of short-running SQL statements with high selectivity, often are characterized by the use of index access paths. Decision support systems, on the other hand, tend to use partitioned tables and perform full scans of the relevant partitions.

This section describes the data access paths that can be used to locate and retrieve any row in any table.

- Full Table Scans
- Rowid Scans
- Index Scans
- Cluster Access
- Hash Access
- Sample Table Scans
- How the Query Optimizer Chooses an Access Path

Full Table Scans

This type of scan reads all rows from a table and filters out those that do not meet the selection criteria. During a full table scan, all blocks in the table that are under the high water mark are scanned. The high water mark indicates the amount of used space, or space that had been formatted to receive data. Each row is examined to determine whether it satisfies the statement's `WHERE` clause.

When Oracle performs a full table scan, the blocks are read sequentially. Because the blocks are adjacent, I/O calls larger than a single block can be used to speed up the process. The size of the read calls range from one block to the number of blocks

indicated by the initialization parameter DB_FILE_MULTIBLOCK_READ_COUNT. Using multiblock reads means a full table scan can be performed very efficiently. Each block is read only once.

Example 14–2, "EXPLAIN PLAN Output" on page 14-16 contains an example of a full table scan on the employees table.

Why a Full Table Scan Is Faster for Accessing Large Amounts of Data

Full table scans are cheaper than index range scans when accessing a large fraction of the blocks in a table. This is because full table scans can use larger I/O calls, and making fewer large I/O calls is cheaper than making many smaller calls.

When the Optimizer Uses Full Table Scans

The optimizer uses a full table scan in any of the following cases:

Lack of Index If the query is unable to use any existing indexes, then it uses a full table scan. For example, if there is a function used on the indexed column in the query, the optimizer is unable to use the index and instead uses a full table scan.

If you need to use the index for case-independent searches, then either do not permit mixed-case data in the search columns or create a function-based index, such as UPPER(last_name), on the search column. See "Using Function-based Indexes for Performance" on page 16-10.

Large Amount of Data If the optimizer thinks that the query will access most of the blocks in the table, then it uses a full table scan, even though indexes might be available.

Small Table If a table contains less than DB_FILE_MULTIBLOCK_READ_COUNT blocks under the high water mark, which can be read in a single I/O call, then a full table scan might be cheaper than an index range scan, regardless of the fraction of tables being accessed or indexes present.

High Degree of Parallelism A high degree of parallelism for a table skews the optimizer toward full table scans over range scans. Examine the DEGREE column in ALL_TABLES for the table to determine the degree of parallelism.

Full Table Scan Hints

Use the hint FULL(*table alias*) if you want to force the use of a full table scan. For more information on the FULL hint, see "FULL" on page 17-16.

Parallel Query Execution

When a full table scan is required, response time can be improved by using multiple parallel execution servers for scanning the table. Parallel queries are used generally in low-concurrency data warehousing environments, because of the potential resource usage.

See Also: *Oracle Data Warehousing Guide*

Rowid Scans

The rowid of a row specifies the datafile and data block containing the row and the location of the row in that block. Locating a row by specifying its rowid is the fastest way to retrieve a single row, because the exact location of the row in the database is specified.

To access a table by rowid, Oracle first obtains the rowids of the selected rows, either from the statement's `WHERE` clause or through an index scan of one or more of the table's indexes. Oracle then locates each selected row in the table based on its rowid.

In Example 14–2, "EXPLAIN PLAN Output" on page 14-16, an index scan is performed the `jobs` and `departments` tables. The rowids retrieved are used to return the row data.

When the Optimizer Uses Rowids

This is generally the second step after retrieving the rowid from an index. The table access might be required for any columns in the statement not present in the index.

Access by rowid does not need to follow every index scan. If the index contains all the columns needed for the statement, then table access by rowid might not occur.

Note: Rowids are an internal Oracle representation of where data is stored. They can change between versions. Accessing data based on position is not recommended, because rows can move around due to row migration and chaining and also after export and import. Foreign keys should be based on primary keys. For more information on rowids, see *Oracle Database Application Developer's Guide - Fundamentals*.

Index Scans

In this method, a row is retrieved by traversing the index, using the indexed column values specified by the statement. An index scan retrieves data from an index based on the value of one or more columns in the index. To perform an index scan, Oracle searches the index for the indexed column values accessed by the statement. If the statement accesses only columns of the index, then Oracle reads the indexed column values directly from the index, rather than from the table.

The index contains not only the indexed value, but also the rowids of rows in the table having that value. Therefore, if the statement accesses other columns in addition to the indexed columns, then Oracle can find the rows in the table by using either a table access by rowid or a cluster scan.

An index scan can be one of the following types:

- Assessing I/O for Blocks, not Rows
- Index Unique Scans
- Index Range Scans
- Index Range Scans Descending
- Index Skip Scans
- Full Scans
- Fast Full Index Scans
- Index Joins
- Bitmap Indexes

Assessing I/O for Blocks, not Rows

Oracle does I/O by blocks. Therefore, the optimizer's decision to use full table scans is influenced by the percentage of blocks accessed, not rows. This is called the index clustering factor. If blocks contain single rows, then rows accessed and blocks accessed are the same.

However, most tables have multiple rows in each block. Consequently, the desired number of rows could be clustered together in a few blocks, or they could be spread out over a larger number of blocks.

Although the clustering factor is a property of the index, the clustering factor actually relates to the spread of similar indexed column values within data blocks in the table. A lower clustering factor indicates that the individual rows are

concentrated within fewer blocks in the table. Conversely, a high clustering factor indicates that the individual rows are scattered more randomly across blocks in the table. Therefore, a high clustering factor means that it costs more to use a range scan to fetch rows by rowid, because more blocks in the table need to be visited to return the data. Example 14–3 shows how the clustering factor can affect cost.

Example 14–3 Effects of Clustering Factor on Cost

Assume the following situation:

- There is a table with 9 rows.
- There is a nonunique index on `col1` for table.
- The `c1` column currently stores the values `A`, `B`, and `C`.
- The table only has three Oracle blocks.

Case 1: The index clustering factor is low for the rows as they are arranged in the following diagram.

```
Block 1       Block 2       Block 3
-------       -------       --------
A  A  A       B  B  B       C  C  C
```

This is because the rows that have the same indexed column values for `c1` are located within the same physical blocks in the table. The cost of using a range scan to return all of the rows that have the value `A` is low, because only one block in the table needs to be read.

Case 2: If the same rows in the table are rearranged so that the index values are scattered across the table blocks (rather than colocated), then the index clustering factor is higher.

```
Block 1       Block 2       Block 3
-------       -------       --------
A  B  C       A  B  C       A  B  C
```

This is because all three blocks in the table must be read in order to retrieve all rows with the value `A` in `col1`.

Index Unique Scans

This scan returns, at most, a single rowid. Oracle performs a unique scan if a statement contains a `UNIQUE` or a `PRIMARY KEY` constraint that guarantees that only a single row is accessed.

In Example 14–2, "EXPLAIN PLAN Output" on page 14-16, an index scan is performed on the `jobs` and `departments` tables, using the `job_id_pk` and `dept_id_pk` indexes respectively.

When the Optimizer Uses Index Unique Scans This access path is used when all columns of a unique (B-tree) index or an index created as a result of a primary key constraint are specified with equality conditions.

> **See Also:** *Oracle Database Concepts* for more details on index structures and for detailed information on how a B-tree is searched

Index Unique Scan Hints In general, you should not need to use a hint to do a unique scan. There might be cases where the table is across a database link and being accessed from a local table, or where the table is small enough for the optimizer to prefer a full table scan.

The hint `INDEX(`*`alias index_name`*`)` specifies the index to use, but not an access path (range scan or unique scan). For more information on the `INDEX` hint, see "INDEX" on page 17-17.

Index Range Scans

An index range scan is a common operation for accessing selective data. It can be bounded (bounded on both sides) or unbounded (on one or both sides). Data is returned in the ascending order of index columns. Multiple rows with identical values are sorted in ascending order by rowid.

If data must be sorted by order, then use the `ORDER BY` clause, and do not rely on an index. If an index can be used to satisfy an `ORDER BY` clause, then the optimizer uses this option and avoids a sort.

In Example 14–4, the order has been imported from a legacy system, and you are querying the order by the reference used in the legacy system. Assume this reference is the `order_date`.

Example 14–4 Index Range Scan

```
SELECT order_status, order_id
  FROM orders
 WHERE order_date = :b1;

-------------------------------------------------------------------------------------
| Id  | Operation                   |  Name             | Rows  | Bytes | Cost (%CPU)|
-------------------------------------------------------------------------------------
```

```
|   0 | SELECT STATEMENT            |                    |     1 |    20 |     3  (34)|
|   1 |  TABLE ACCESS BY INDEX ROWID| ORDERS             |     1 |    20 |     3  (34)|
|*  2 |   INDEX RANGE SCAN          | ORD_ORDER_DATE_IX  |     1 |       |     2  (50)|
-------------------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------
   2 - access("ORDERS"."ORDER_DATE"=:Z)
```

This should be a highly selective query, and you should see the query using the index on the column to retrieve the desired rows. The data returned is sorted in ascending order by the rowids for the `order_date`. Because the index column `order_date` is identical for the selected rows here, the data is sorted by rowid.

When the Optimizer Uses Index Range Scans The optimizer uses a range scan when it finds one or more leading columns of an index specified in conditions, such as the following:

- `col1 = :b1`
- `col1 < :b1`
- `col1 > :b1`
- `AND` combination of the preceding conditions for leading columns in the index
- `col1 like 'ASD%'` wild-card searches should not be in a leading position otherwise the condition `col1 like '%ASD'` does not result in a range scan.

Range scans can use unique or nonunique indexes. Range scans avoid sorting when index columns constitute the `ORDER BY` / `GROUP BY` clause.

Index Range Scan Hints A hint might be required if the optimizer chooses some other index or uses a full table scan. The hint `INDEX(`*`table_alias index_name`*`)` specifies the index to use. For more information on the `INDEX` hint, see "INDEX" on page 17-17.

Index Range Scans Descending

An index range scan descending is identical to an index range scan, except that the data is returned in descending order. Indexes, by default, are stored in ascending order. Usually, this scan is used when ordering data in a descending order to return the most recent data first, or when seeking a value less than a specified value.

When the Optimizer Uses Index Range Scans Descending The optimizer uses index range scan descending when an order by descending clause can be satisfied by an index.

Index Range Scan Descending Hints The hint `INDEX_DESC(`*`table_alias index_name`*`)` is used for this access path. For more information on the `INDEX_DESC` hint, see "INDEX_DESC" on page 17-20.

Index Skip Scans

Index skip scans improve index scans by nonprefix columns. Often, scanning index blocks is faster than scanning table data blocks.

Skip scanning lets a composite index be split logically into smaller subindexes. In skip scanning, the initial column of the composite index is not specified in the query. In other words, it is skipped.

The number of logical subindexes is determined by the number of distinct values in the initial column. Skip scanning is advantageous if there are few distinct values in the leading column of the composite index and many distinct values in the nonleading key of the index.

Example 14–5 Index Skip Scan

Consider, for example, a table `employees` (`sex`, `employee_id`, `address`) with a composite index on (`sex`, `employee_id`). Splitting this composite index would result in two logical subindexes, one for `M` and one for `F`.

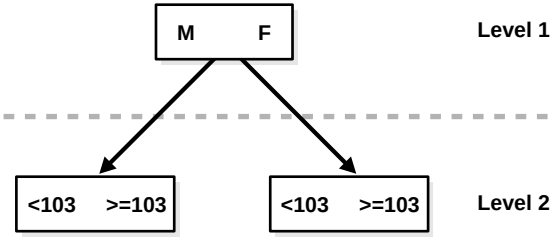
For this example, suppose you have the following index data:

```
('F',98)
('F',100)
('F',102)
('F',104)
('M',101)
('M',103)
('M',105)
```

The index is split logically into the following two subindexes:

- The first subindex has the keys with the value `F`.
- The second subindex has the keys with the value `M`.

Figure 14–2 Index Skip Scan Illustration



The column sex is skipped in the following query:

```
SELECT *
   FROM employees
WHERE employee_id = 101;
```

A complete scan of the index is not performed, but the subindex with the value F is searched first, followed by a search of the subindex with the value M.

Full Scans

A full scan is available if a predicate references one of the columns in the index. The predicate does not need to be an index driver. A full scan is also available when there is no predicate, if both the following conditions are met:

- All of the columns in the table referenced in the query are included in the index.
- At least one of the index columns is not null.

A full scan can be used to eliminate a sort operation, because the data is ordered by the index key. It reads the blocks singly.

Fast Full Index Scans

Fast full index scans are an alternative to a full table scan when the index contains all the columns that are needed for the query, and at least one column in the index key has the NOT NULL constraint. A fast full scan accesses the data in the index itself, without accessing the table. It cannot be used to eliminate a sort operation, because the data is not ordered by the index key. It reads the entire index using multiblock reads, unlike a full index scan, and can be parallelized.

You can specify it with the initialization parameter OPTIMIZER_FEATURES_ENABLE or the INDEX_FFS hint. Fast full index scans cannot be performed against bitmap indexes.

A fast full scan is faster than a normal full index scan in that it can use multiblock I/O and can be parallelized just like a table scan.

Fast Full Index Scan Hints The fast full scan has a special index hint, `INDEX_FFS`, which has the same format and arguments as the regular `INDEX` hint. For more information on the `INDEX_FFS` hint, see "INDEX_FFS" on page 17-21.

Index Joins

An index join is a hash join of several indexes that together contain all the table columns that are referenced in the query. If an index join is used, then no table access is needed, because all the relevant column values can be retrieved from the indexes. An index join cannot be used to eliminate a sort operation.

Index Join Hints You can specify an index join with the `INDEX_JOIN` hint. For more information on the `INDEX_JOIN` hint, see "INDEX_JOIN" on page 17-20.

Bitmap Indexes

A bitmap join uses a bitmap for key values and a mapping function that converts each bit position to a rowid. Bitmaps can efficiently merge indexes that correspond to several conditions in a `WHERE` clause, using Boolean operations to resolve `AND` and `OR` conditions.

Note: Bitmap indexes and bitmap join indexes are available only if you have purchased the Oracle Enterprise Edition.

See Also: *Oracle Data Warehousing Guide* for more information about bitmap indexes

Cluster Access

A cluster scan is used to retrieve, from a table stored in an indexed cluster, all rows that have the same cluster key value. In an indexed cluster, all rows with the same cluster key value are stored in the same data block. To perform a cluster scan, Oracle first obtains the rowid of one of the selected rows by scanning the cluster index. Oracle then locates the rows based on this rowid.

Hash Access

A hash scan is used to locate rows in a hash cluster, based on a hash value. In a hash cluster, all rows with the same hash value are stored in the same data block. To perform a hash scan, Oracle first obtains the hash value by applying a hash function to a cluster key value specified by the statement. Oracle then scans the data blocks containing rows with that hash value.

Sample Table Scans

A sample table scan retrieves a random sample of data from a simple table or a complex SELECT statement, such as a statement involving joins and views. This access path is used when a statement's FROM clause includes the SAMPLE clause or the SAMPLE BLOCK clause. To perform a sample table scan when sampling by rows with the SAMPLE clause, Oracle reads a specified percentage of rows in the table. To perform a sample table scan when sampling by blocks with the SAMPLE BLOCK clause, Oracle reads a specified percentage of table blocks.

Example 14–6 uses a sample table scan to access 1% of the employees table, sampling by blocks.

Example 14–6 Sample Table Scan

```
SELECT *
    FROM employees SAMPLE BLOCK (1);
```

The EXPLAIN PLAN output for this statement might look like this:

```
-------------------------------------------------------------------------
| Id  | Operation            |  Name       | Rows  | Bytes | Cost (%CPU)|
-------------------------------------------------------------------------
|   0 | SELECT STATEMENT     |             |     1 |    68 |     3  (34)|
|   1 |  TABLE ACCESS SAMPLE | EMPLOYEES   |     1 |    68 |     3  (34)|
-------------------------------------------------------------------------
```

How the Query Optimizer Chooses an Access Path

The query optimizer chooses an access path based on the following factors:

- The available access paths for the statement
- The estimated cost of executing the statement, using each access path or combination of paths

To choose an access path, the optimizer first determines which access paths are available by examining the conditions in the statement's WHERE clause and its FROM clause. The optimizer then generates a set of possible execution plans using available access paths and estimates the cost of each plan, using the statistics for the index, columns, and tables accessible to the statement. Finally, the optimizer chooses the execution plan with the lowest estimated cost.

When choosing an access path, the query optimizer is influenced by the following:

- Optimizer Hints

  The optimizer's choice among available access paths can be overridden with hints, except when the statement's FROM clause contains SAMPLE or SAMPLE BLOCK.

  See Also: Chapter 17, "Optimizer Hints" for information about hints in SQL statements

- Old Statistics

  For example, if a table has not been analyzed since it was created, and if it has less than DB_FILE_MULTIBLOCK_READ_COUNT blocks under the high water mark, then the optimizer thinks that the table is small and uses a full table scan. Review the LAST_ANALYZED and BLOCKS columns in the ALL_TABLES table to examine the statistics.

Understanding Joins

Joins are statements that retrieve data from more than one table. A join is characterized by multiple tables in the FROM clause, and the relationship between the tables is defined through the existence of a join condition in the WHERE clause. In a join, one row set is called inner, and the other is called outer.

This section discusses:

- How the Query Optimizer Executes Join Statements
- How the Query Optimizer Chooses Execution Plans for Joins
- Join Methods:
  - Nested Loop Joins
  - Hash Joins
  - Sort Merge Joins

- Cartesian Joins
- Outer Joins

See Also: *Oracle Database SQL Reference* for a discussion of joins

How the Query Optimizer Executes Join Statements

To choose an execution plan for a join statement, the optimizer must make these interrelated decisions:

- Access Paths

  As for simple statements, the optimizer must choose an access path to retrieve data from each table in the join statement.

- Join Method

  To join each pair of row sources, Oracle must perform a join operation. Join methods include nested loop, sort merge, cartesian, and hash joins.

- Join Order

  To execute a statement that joins more than two tables, Oracle joins two of the tables and then joins the resulting row source to the next table. This process is continued until all tables are joined into the result.

See Also: "Understanding Access Paths for the Query Optimizer" on page 14-18

How the Query Optimizer Chooses Execution Plans for Joins

The query optimizer considers the following when choosing an execution plan:

- The optimizer first determines whether joining two or more tables definitely results in a row source containing at most one row. The optimizer recognizes such situations based on `UNIQUE` and `PRIMARY KEY` constraints on the tables. If such a situation exists, then the optimizer places these tables first in the join order. The optimizer then optimizes the join of the remaining set of tables.
- For join statements with outer join conditions, the table with the outer join operator must come after the other table in the condition in the join order. The optimizer does not consider join orders that violate this rule. Similarly, when a subquery has been converted into an antijoin or semijoin, the tables from the subquery must come after those tables in the outer query block to which they

were connected or correlated. However, hash antijoins and semijoins are able to override this ordering condition in certain circumstances.

With the query optimizer, the optimizer generates a set of execution plans, according to possible join orders, join methods, and available access paths. The optimizer then estimates the cost of each plan and chooses the one with the lowest cost. The optimizer estimates costs in the following ways:

- The cost of a nested loops operation is based on the cost of reading each selected row of the outer table and each of its matching rows of the inner table into memory. The optimizer estimates these costs using the statistics in the data dictionary.
- The cost of a sort merge join is based largely on the cost of reading all the sources into memory and sorting them.
- The cost of a hash join is based largely on the cost of building a hash table on one of the input sides to the join and using the rows from the other of the join to probe it.

The optimizer also considers other factors when determining the cost of each operation. For example:

- A smaller sort area size is likely to increase the cost for a sort merge join because sorting takes more CPU time and I/O in a smaller sort area. See "PGA Memory Management" on page 7-50 for information on sizing of SQL work areas.
- A larger multiblock read count is likely to decrease the cost for a sort merge join in relation to a nested loop join. If a large number of sequential blocks can be read from disk in a single I/O, then an index on the inner table for the nested loop join is less likely to improve performance over a full table scan. The multiblock read count is specified by the initialization parameter `DB_FILE_MULTIBLOCK_READ_COUNT`.

With the query optimizer, the optimizer's choice of join orders can be overridden with the `ORDERED` hint. If the `ORDERED` hint specifies a join order that violates the rule for an outer join, then the optimizer ignores the hint and chooses the order. Also, you can override the optimizer's choice of join method with hints.

> **See Also:** Chapter 17, "Optimizer Hints" for more information about optimizer hints

Nested Loop Joins

Nested loop joins are useful when small subsets of data are being joined and if the join condition is an efficient way of accessing the second table.

It is very important to ensure that the inner table is driven from (dependent on) the outer table. If the inner table's access path is independent of the outer table, then the same rows are retrieved for every iteration of the outer loop, degrading performance considerably. In such cases, hash joins joining the two independent row sources perform better.

See Also: "Cartesian Joins" on page 14-36

A nested loop join involves the following steps:

1. The optimizer determines the driving table and designates it as the outer table.
2. The other table is designated as the inner table.
3. For every row in the outer table, Oracle accesses all the rows in the inner table. The outer loop is for every row in outer table and the inner loop is for every row in the inner table. The outer loop appears before the inner loop in the execution plan, as follows:

```
NESTED LOOPS
  outer_loop
  inner_loop
```

Nested Loop Example

This section discusses the outer and inner loops for one of the nested loops in the query in Example 14–1 on page 14-16.

```
...
|   2 |   NESTED LOOPS                |             |     3 |   141 |     7  (15)|
|*  3 |    TABLE ACCESS FULL          | EMPLOYEES   |     3 |    60 |     4  (25)|
|   4 |    TABLE ACCESS BY INDEX ROWID| JOBS        |    19 |   513 |     2  (50)|
|*  5 |     INDEX UNIQUE SCAN         | JOB_ID_PK   |     1 |       |            |
...
```

In this example, the outer loop retrieves all the rows of the `employees` table. For every employee retrieved by the outer loop, the inner loop retrieves the associated row in the `jobs` table.

Outer loop In the execution plan in Example 14–2 on page 14-16, the outer loop and the equivalent statement are as follows:

```
3 |    TABLE ACCESS FULL        | EMPLOYEES
```

```
SELECT e.employee_id, e.salary
  FROM employees e
 WHERE e.employee_id < 103
```

Inner loop The execution plan in Example 14–2 on page 14-16 shows the inner loop being iterated for every row fetched from the outer loop, as follows:

```
4 |    TABLE ACCESS BY INDEX ROWID| JOBS
5 |     INDEX UNIQUE SCAN         | JOB_ID_PK

SELECT j.job_title
 FROM jobs j
    WHERE e.job_id = j.job_id
```

When the Optimizer Uses Nested Loop Joins

The optimizer uses nested loop joins when joining small number of rows, with a good driving condition between the two tables. You drive from the outer loop to the inner loop, so the order of tables in the execution plan is important.

The outer loop is the driving row source. It produces a set of rows for driving the join condition. The row source can be a table accessed using an index scan or a full table scan. Also, the rows can be produced from any other operation. For example, the output from a nested loop join can be used as a row source for another nested loop join.

The inner loop is iterated for every row returned from the outer loop, ideally by an index scan. If the access path for the inner loop is not dependent on the outer loop, then you can end up with a Cartesian product; for every iteration of the outer loop, the inner loop produces the same set of rows. Therefore, you should use other join methods when two independent row sources are joined together.

Nested Loop Join Hints

If the optimizer is choosing to use some other join method, you can use the USE_NL(table1 table2) hint, where table1 and table2 are the aliases of the tables being joined.

For some SQL examples, the data is small enough for the optimizer to prefer full table scans and use hash joins. This is the case for the SQL example shown in Example 14–7, "Hash Joins" on page 14-34. However, you can add a USE_NL hint that changes the join method to nested loop. For more information on the USE_NL hint, see "USE_NL" on page 17-33.

Nesting Nested Loops

The outer loop of a nested loop can be a nested loop itself. You can nest two or more outer loops together to join as many tables as needed. Each loop is a data access method, as follows:

```
SELECT STATEMENT
 NESTED LOOP 3
  NESTED LOOP 2          (OUTER LOOP 3.1)
   NESTED LOOP 1         (OUTER LOOP 2.1)
    OUTER LOOP 1.1     - #1
    INNER LOOP 1.2     - #2
   INNER LOOP 2.2      - #3
  INNER LOOP 3.2       - #4
```

Hash Joins

Hash joins are used for joining large data sets. The optimizer uses the smaller of two tables or data sources to build a hash table on the join key in memory. It then scans the larger table, probing the hash table to find the joined rows.

This method is best used when the smaller table fits in available memory. The cost is then limited to a single read pass over the data for the two tables.

When the Optimizer Uses Hash Joins

The optimizer uses a hash join to join two tables if they are joined using an equijoin and if either of the following conditions are true:

- A large amount of data needs to be joined.
- A large fraction of a small table needs to be joined.

In Example 14–7, the table `orders` is used to build the hash table, and `order_items` is the larger table, which is scanned later.

Example 14–7 Hash Joins

```
SELECT o.customer_id, l.unit_price * l.quantity
  FROM orders o ,order_items l
 WHERE l.order_id = o.order_id;

-----------------------------------------------------------------------
| Id  | Operation           |  Name       | Rows  | Bytes | Cost (%CPU)|
-----------------------------------------------------------------------
|   0 | SELECT STATEMENT    |             |   665 | 13300 |     8  (25)|
|*  1 |  HASH JOIN          |             |   665 | 13300 |     8  (25)|
```

```
|   2 |   TABLE ACCESS FULL  | ORDERS       |   105 |   840 |     4  (25)|
|   3 |   TABLE ACCESS FULL  | ORDER_ITEMS  |   665 |  7980 |     4  (25)|
---------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------
   1 - access("L"."ORDER_ID"="O"."ORDER_ID")
```

Hash Join Hints

Apply the USE_HASH hint to advise the optimizer to use a hash join when joining two tables together. See "PGA Memory Management" on page 7-50 for information on sizing of SQL work areas. For more information on the USE_HASH hint, see "USE_HASH" on page 17-35.

Sort Merge Joins

Sort merge joins can be used to join rows from two independent sources. Hash joins generally perform better than sort merge joins. On the other hand, sort merge joins can perform better than hash joins if both of the following conditions exist:

- The row sources are sorted already.
- A sort operation does not have to be done.

However, if a sort merge join involves choosing a slower access method (an index scan as opposed to a full table scan), then the benefit of using a sort merge might be lost.

Sort merge joins are useful when the join condition between two tables is an inequality condition (but not a nonequality) like <, <=, >, or >=. Sort merge joins perform better than nested loop joins for large data sets. You cannot use hash joins unless there is an equality condition.

In a merge join, there is no concept of a driving table. The join consists of two steps:

1. Sort join operation: Both the inputs are sorted on the join key.
2. Merge join operation: The sorted lists are merged together.

If the input is already sorted by the join column, then a sort join operation is not performed for that row source.

When the Optimizer Uses Sort Merge Joins

The optimizer can choose a sort merge join over a hash join for joining large amounts of data if any of the following conditions are true:

- The join condition between two tables is not an equi-join.
- Because of sorts already required by other operations, the optimizer finds it is cheaper to use a sort merge than a hash join.

Sort Merge Join Hints

To advise the optimizer to use a sort merge join, apply the USE_MERGE hint. You might also need to give hints to force an access path.

There are situations where it is better to override the optimize with the USE_MERGE hint. For example, the optimizer can choose a full scan on a table and avoid a sort operation in a query. However, there is an increased cost because a large table is accessed through an index and single block reads, as opposed to faster access through a full table scan.

For more information on the USE_MERGE hint, see "USE_MERGE" on page 17-34.

Cartesian Joins

A Cartesian join is used when one or more of the tables does not have any join conditions to any other tables in the statement. The optimizer joins every row from one data source with every row from the other data source, creating the Cartesian product of the two sets.

When the Optimizer Uses Cartesian Joins

The optimizer uses Cartesian joins when it is asked to join two tables with no join conditions. In some cases, a common filter condition between the two tables could be picked up by the optimizer as a possible join condition. In other cases, the optimizer may decide to generate a Cartesian product of two very small tables that are both joined to the same large table.

Cartesian Join Hints

Applying the ORDERED hint, causes the optimizer uses a Cartesian join. By specifying a table before its join table is specified, the optimizer does a Cartesian join. For more information on the ORDERED hint, see "ORDERED" on page 17-32.

Outer Joins

An outer join extends the result of a simple join. An outer join returns all rows that satisfy the join condition and also returns some or all of those rows from one table for which no rows from the other satisfy the join condition.

Nested Loop Outer Joins

This operation is used when an outer join is used between two tables. The outer join returns the outer (preserved) table rows, even when there are no corresponding rows in the inner (optional) table.

In a regular outer join, the optimizer chooses the order of tables (driving and driven) based on the cost. However, in a nested loop outer join, the order of tables is determined by the join condition. The outer table, with rows that are being preserved, is used to drive to the inner table.

The optimizer uses nested loop joins to process an outer join in the following circumstances:

- It is possible to drive from the outer table to inner table.
- Data volume is low enough to make the nested loop method efficient.

For an example of a nested loop outer join, you can add the USE_NL hint to Example 14–8 to ensure that a nested loop is used. For example:

```
SELECT /*+ USE_NL(c o) */ cust_last_name, sum(nvl2(o.customer_id,0,1)) "Count"
```

Hash Join Outer Joins

The optimizer uses hash joins for processing an outer join if the data volume is high enough to make the hash join method efficient or if it is not possible to drive from the outer table to inner table.

The order of tables is determined by the cost. The outer table, including preserved rows, may be used to build the hash table, or it may be used to probe one.

Example 14–8 shows a typical hash join outer join query. In this example, all the customers with credit limits greater than 1000 are queried. An outer join is needed so that you do not miss the customers who do not have any orders.

Example 14–8 Hash Join Outer Joins

```
SELECT cust_last_name, sum(nvl2(o.customer_id,0,1)) "Count"
  FROM customers c, orders o
 WHERE c.credit_limit > 1000
   AND c.customer_id = o.customer_id(+)
 GROUP BY cust_last_name;

------------------------------------------------------------------------
| Id  | Operation           |  Name       | Rows  | Bytes | Cost (%CPU)|
------------------------------------------------------------------------
|   0 | SELECT STATEMENT    |             |   168 |  3192 |    11  (28)|
```

```
|   1 |  SORT GROUP BY       |             |   168 |  3192 |    11  (28)|
|*  2 |   HASH JOIN OUTER    |             |   260 |  4940 |    10  (20)|
|*  3 |    TABLE ACCESS FULL | CUSTOMERS   |   260 |  3900 |     6  (17)|
|*  4 |    TABLE ACCESS FULL | ORDERS      |   105 |   420 |     4  (25)|
---------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   2 - access("C"."CUSTOMER_ID"="O"."CUSTOMER_ID"(+))
   3 - filter("C"."CREDIT_LIMIT">1000)
   4 - filter("O"."CUSTOMER_ID"(+)>0)
```

The query looks for customers which satisfy various conditions. An outer join returns NULL for the inner table columns along with the outer (preserved) table rows when it does not find any corresponding rows in the inner table. This operation finds all the `customers` rows that do not have any `orders` rows.

In this case, the outer join condition is the following:

```
customers.customer_id = orders.customer_id(+)
```

The components of this condition represent the following:

- The outer table is `customers`.
- The inner table is `orders`.
- The join preserves the `customers` rows, including those rows without a corresponding row in `orders`.

You could use a NOT EXISTS subquery to return the rows. However, because you are querying all the rows in the table, the hash join performs better (unless the NOT EXISTS subquery is not nested).

In Example 14–9, the outer join is to a multitable view. The optimizer cannot drive into the view like in a normal join or push the predicates, so it builds the entire row set of the view.

Example 14–9 Outer Join to a Multitable View

```
SELECT c.cust_last_name, sum(revenue)
  FROM customers c, v_orders o
 WHERE c.credit_limit > 2000
   AND o.customer_id(+) = c.customer_id
 GROUP BY c.cust_last_name;

---------------------------------------------------------------------------
```

```
| Id  | Operation              |  Name        | Rows  | Bytes | Cost (%CPU)|
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT       |              |   144 |  4608 |    16  (32)|
|   1 |  SORT GROUP BY         |              |   144 |  4608 |    16  (32)|
|*  2 |   HASH JOIN OUTER      |              |   663 | 21216 |    15  (27)|
|*  3 |    TABLE ACCESS FULL   | CUSTOMERS    |   195 |  2925 |     6  (17)|
|   4 |    VIEW                | V_ORDERS     |   665 | 11305 |            |
|   5 |     SORT GROUP BY      |              |   665 | 15960 |     9  (34)|
|*  6 |      HASH JOIN         |              |   665 | 15960 |     8  (25)|
|*  7 |       TABLE ACCESS FULL| ORDERS       |   105 |   840 |     4  (25)|
|   8 |       TABLE ACCESS FULL| ORDER_ITEMS  |   665 | 10640 |     4  (25)|
-------------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------
   2 - access("O"."CUSTOMER_ID"(+)="C"."CUSTOMER_ID")
   3 - filter("C"."CREDIT_LIMIT">2000)
   6 - access("O"."ORDER_ID"="L"."ORDER_ID")
   7 - filter("O"."CUSTOMER_ID">0)
```

The view definition is as follows:

```
CREATE OR REPLACE view v_orders AS
SELECT l.product_id, SUM(l.quantity*unit_price) revenue,
       o.order_id, o.customer_id
  FROM orders o, order_items l
 WHERE o.order_id = l.order_id
 GROUP BY l.product_id, o.order_id, o.customer_id;
```

Sort Merge Outer Joins

When an outer join cannot drive from the outer (preserved) table to the inner (optional) table, it cannot use a hash join or nested loop joins. Then it uses the sort merge outer join for performing the join operation.

The optimizer uses sort merge for an outer join:

- If a nested loop join is inefficient. A nested loop join can be inefficient because of data volumes.
- The optimizer finds it is cheaper to use a sort merge over a hash join because of sorts already required by other operations.

Full Outer Joins

A full outer join acts like a combination of the left and right outer joins. In addition to the inner join, rows from both tables that have not been returned in the result of the inner join are preserved and extended with nulls. In other words, full outer joins

let you join tables together, yet still show rows that do not have corresponding rows in the joined tables.

The query in Example 14–10 retrieves all departments and all employees in each department, but also includes:

- Any employees without departments
- Any departments without employees

Example 14–10 Full Outer Join

```
SELECT d.department_id, e.employee_id
  FROM employees e
  FULL OUTER JOIN departments d
    ON e.department_id = d.department_id
 ORDER BY d.department_id;
```

The statement produces the following output:

```
DEPARTMENT_ID EMPLOYEE_ID
------------- -----------
           10         200
           20         201
           20         202
           30         114
           30         115
           30         116
...
          270
          280
                     178
                     207

125 rows selected.
```

15

Managing Optimizer Statistics

This chapter explains why statistics are important for the query optimizer and how to gather and use optimizer statistics with the `DBMS_STATS` package.

The chapter contains the following sections:

Understanding Statistics

Optimizer statistics are a collection of data that describe more details about the database and the objects in the database. These statistics are used by the query optimizer to choose the best execution plan for each SQL statement. Optimizer statistics include the following:

- Table statistics
  - Number of rows
  - Number of blocks
  - Average row length
- Column statistics
  - Number of distinct values (NDV) in column
  - Number of nulls in column
  - Data distribution (histogram)
- Index statistics
  - Number of leaf blocks
  - Levels
  - Clustering factor
- System statistics
  - I/O performance and utilization
  - CPU performance and utilization

Note: The statistics mentioned in this section are optimizer statistics, which are created for the purposes of query optimization and are stored in the data dictionary. These statistics should not be confused with performance statistics visible through V$ views.

The optimizer statistics are stored in the data dictionary. They can be viewed using data dictionary views. See "Viewing Statistics" on page 15-19.

Because the objects in a database can be constantly changing, statistics must be regularly updated so that they accurately describe these database objects. Statistics are maintained automatically by Oracle or you can maintain the optimizer statistics

manually using the DBMS_STATS package. For a description of the automatic and manual processes, see "Automatic Statistics Gathering" on page 15-3 or "Manual Statistics Gathering" on page 15-6.

The DBMS_STATS package also provides procedures for managing statistics. You can save and restore copies of statistics. You can export statistics from one system and import those statistics into another system. For example, you could export statistics from a production system to a test system. In addition, you can lock statistics to prevent those statistics from changing. The lock methods are described in "Locking Statistics for a Table or Schema" on page 15-15.

Automatic Statistics Gathering

The recommended approach to gathering statistics is to allow Oracle to automatically gather the statistics. Oracle gathers statistics on all database objects automatically and maintains those statistics in a regularly-scheduled maintenance job. Automated statistics collection eliminates many of the manual tasks associated with managing the query optimizer, and significantly reduces the chances of getting poor execution plans because of missing or stale statistics.

GATHER_STATS_JOB

Optimizer statistics are automatically gathered with the job GATHER_STATS_JOB. This job gathers statistics on all objects in the database which have:

- Missing statistics
- Stale statistics

This job is created automatically at database creation time and is managed by the Scheduler. This Scheduler runs this job when the maintenance window is opened. By default, the maintenance window opens every night from 10 P.M. to 6 A.M. and all day on weekends. The GATHER_STATS_JOB continues until it finishes, even if it exceeds the allocated time for the maintenance window. The default behavior of the maintenance window can be changed.

> **See Also:** *Oracle Database Administrator's Guide* for information on the Scheduler and maintenance windows tasks

The GATHER_STATS_JOB job gathers optimizer statistics by calling the DBMS_STATS.GATHER_DATABASE_STATS_JOB_PROC procedure. The GATHER_DATABASE_STATS_JOB_PROC procedure collects statistics on database objects when the object has no previously gathered statistics or the existing statistics are

stale because the underlying object has been modified significantly (more than 10% of the rows).The DBMS_STATS.GATHER_DATABASE_STATS_JOB_PROC is an internal procedure, but its operates in a very similar fashion to the DBMS_STATS.GATHER_DATABASE_STATS procedure using the GATHER AUTO option. The primary difference is that the DBMS_STATS.GATHER_DATABASE_STATS_JOB_PROC procedure prioritizes the database objects that require statistics, so that those objects which most need updated statistics are processed first. This ensures that the most-needed statistics are gathered before the maintenance window closes.

Enabling Automatic Statistics Gathering

Automatic statistics gathering is enabled by default when a database is created, or when a database is upgraded from an earlier database release. You can verify that the job exists by viewing the DBA_SCHEDULER_JOBS view:

```
SELECT * FROM DBA_SCHEDULER_JOBS WHERE JOB_NAME = 'GATHER_STATS_JOB';
```

In situations when you want to disable automatic statistics gathering, the most direct approach is to disable the GATHER_STATS_JOB as follows:

```
BEGIN
  DBMS_SCHEDULER.DISABLE('GATHER_STATS_JOB');
END;
/
```

Automatic statistics gathering relies on the modification monitoring feature, described in "Determining Stale Statistics" on page 15-10. If this feature is disabled, then the automatic statistics gathering job is not able to detect stale statistics. This feature is enabled when the STATISTICS_LEVEL parameter is set to TYPICAL or ALL. TYPICAL is the default value.

Considerations When Gathering Statistics

This section discusses:

- When to Use Manual Statistics
- Restoring Previous Versions of Statistics
- Locking Statistics

When to Use Manual Statistics

Automatic statistics gathering should be sufficient for most database objects which are being modified at a moderate speed. However, there are cases where automatic statistics gathering may not be adequate. Because the automatic statistics gathering

runs during an overnight batch window, the statistics on tables which are significantly modified during the day may become stale. There are typically two types of such objects:

- Volatile tables that are being deleted or truncated and rebuilt during the course of the day.
- Objects which are the target of large bulk loads which add 10% or more to the object's total size.

For highly volatile tables, there are two approaches:

- The statistics on these tables can be set to NULL. When Oracle encounters a table with no statistics, Oracle dynamically gathers the necessary statistics as part of query optimization. This dynamic sampling feature is controlled by the OPTIMIZER_DYNAMIC_SAMPLING parameter, and this parameter should be set to a value of 2 or higher. The default value is 2. The statistics can set to NULL by deleting and then locking the statistics:

  ```
  BEGIN
    DBMS_STATS.DELETE_TABLE_STATS('OE','ORDERS');
    DBMS_STATS.LOCK_TABLE_STATS('OE','ORDERS');
  END;
  /
  ```

  See "Dynamic Sampling Levels" on page 15-17 for information about the sampling levels that can be set.

- The statistics on these tables can be set to values that represent the typical state of the table. You should gather statistics on the table when the tables has a representative number of rows, and then lock the statistics.

  This is more effective than the GATHER_STATS_JOB, because any statistics generated on the table during the overnight batch window may not be the most appropriate statistics for the daytime workload.

For tables which are being bulk-loaded, the statistics-gathering procedures should be run on those tables immediately following the load process, preferably as part of the same script or job that is running the bulk load.

For external tables, statistics are not collected during GATHER_SCHEMA_STATS, GATHER_DATABASE_STATS, and automatic statistics gathering processing. However, you can collect statistics on an individual external table using GATHER_TABLE_STATS. Sampling on external tables is not supported so the ESTIMATE_PERCENT option should be explicitly set to NULL. Because data manipulation is not

allowed against external tables, it is sufficient to analyze external tables when the corresponding file changes.

If the monitoring feature is disabled by setting STATISTICS_LEVEL to BASIC, automatic statistics gathering cannot detect stale statistics. In this case statistics need to be manually gathered. See "Determining Stale Statistics" on page 15-10 for information on the automatic monitoring facility.

Another area in which statistics need to be manually gathered are the system statistics. These statistics are not automatically gathered. See "System Statistics" on page 15-11 for more information.

Statistics on fixed objects, such as the dynamic performance tables, need to be manually collected using GATHER_FIXED_OBJECTS_STATS procedure. Fixed objects record current database activity; statistics gathering should be done when database has representative activity.

Restoring Previous Versions of Statistics

Whenever statistics in dictionary are modified, old versions of statistics are saved automatically for future restoring. Statistics can be restored using RESTORE procedures of DBMS_STATS package. See "Restoring Previous Versions of Statistics" on page 15-13 for more information.

Locking Statistics

In some cases, you may want to prevent any new statistics from being gathered on a table or schema by the DBMS_STATS_JOB process, such as highly volatile tables discussed in "When to Use Manual Statistics" on page 15-4. In those cases, the DBMS_STATS package provides procedures for locking the statistics for a table or schema. See "Locking Statistics for a Table or Schema" on page 15-15 for more information.

Manual Statistics Gathering

If you choose not to use automatic statistics gathering, then you need to manually collect statistics in all schemas, including system schemas. If the data in your database changes regularly, you also need to gather statistics regularly to ensure that the statistics accurately represent characteristics of your database objects.

Gathering Statistics with DBMS_STATS Procedures

Statistics are gathered using the DBMS_STATS package. This PL/SQL package package is also used to modify, view, export, import, and delete statistics.

Note: Do not use the COMPUTE and ESTIMATE clauses of ANALYZE statement to collect optimizer statistics. These clauses are supported solely for backward compatibility and may be removed in a future release. The DBMS_STATS package collects a broader, more accurate set of statistics, and gathers statistics more efficiently.

You may continue to use ANALYZE statement to for other purposes not related to optimizer statistics collection:

- To use the VALIDATE or LIST CHAINED ROWS clauses
- To collect information on free list blocks

The DBMS_STATS package can gather statistics on table and indexes, and well as individual columns and partitions of tables. It does not gather cluster statistics; however, you can use DBMS_STATS to gather statistics on the individual tables instead of the whole cluster.

When you generate statistics for a table, column, or index, if the data dictionary already contains statistics for the object, then Oracle updates the existing statistics. The older statistics are saved and can be restored later if necessary. See "Restoring Previous Versions of Statistics" on page 15-13.

When gathering statistics on system schemas, you can use the procedure DBMS_STATS.GATHER_DICTIONARY_STATS. This procedure gather statistics for all system schemas, including SYS and SYSTEM, and other optional schemas, such as CTXSYS and DRSYS.

When statistics are updated for a database object, Oracle invalidates any currently parsed SQL statements that access the object. The next time such a statement executes, the statement is re-parsed and the optimizer automatically chooses a new execution plan based on the new statistics. Distributed statements accessing objects with new statistics on remote databases are not invalidated. The new statistics take effect the next time the SQL statement is parsed.

Table 15–1 lists the procedures in the DBMS_STATS package for gathering statistics on database objects:

Table 15–1 Statistics Gathering Procedures in the DBMS_STATS Package

Procedure	Collects
GATHER_INDEX_STATS	Index statistics
GATHER_TABLE_STATS	Table, column, and index statistics
GATHER_SCHEMA_STATS	Statistics for all objects in a schema
GATHER_DICTIONARY_STATS	Statistics for all dictionary objects
GATHER_DATABASE_STATS	Statistics for all objects in a database

> **See Also:** *PL/SQL Packages and Types Reference* for syntax and examples of all DBMS_STATS procedures

When using any of these procedures, there are several important considerations for statistics gathering:

- Statistics Gathering Using Sampling
- Parallel Statistics Gathering
- Statistics on Partitioned Objects
- Column Statistics and Histograms
- Determining Stale Statistics
- User-defined Statistics

Statistics Gathering Using Sampling

The statistics-gathering operations can utilize sampling to estimate statistics. Sampling is an important technique for gathering statistics. Gathering statistics without sampling requires full table scans and sorts of entire tables. Sampling minimizes the resources necessary to gather statistics.

Sampling is specified using the ESTIMATE_PERCENT argument to the DBMS_STATS procedures. While the sampling percentage can be set to any value, Oracle Corporation recommends setting the ESTIMATE_PERCENT parameter of the DBMS_STATS gathering procedures to DBMS_STATS.AUTO_SAMPLE_SIZE to maximize performance gains while achieving necessary statistical accuracy. AUTO_SAMPLE_SIZE lets Oracle determine the best sample size necessary for good statistics, based on the statistical property of the object. Because each type of statistics has different requirements, the size of the actual sample taken may not be the same across the

table, columns, or indexes. For example, to collect table and column statistics for all tables in the OE schema with auto-sampling, you could use:

```
EXECUTE DBMS_STATS.GATHER_SCHEMA_STATS('OE',DBMS_STATS.AUTO_SAMPLE_SIZE);
```

When the ESTIMATE_PERCENT parameter is manually specified, the DBMS_STATS gathering procedures may automatically increase the sampling percentage if the specified percentage did not produce a large enough sample. This ensures the stability of the estimated values by reducing fluctuations.

Parallel Statistics Gathering

The statistics-gathering operations can run either serially or in parallel. The degree of parallelism can be specified with the DEGREE argument to the DBMS_STATS gathering procedures. Parallel statistics gathering can be used in conjunction with sampling. Oracle Corporation recommends setting the DEGREE parameter to DBMS_STATS.AUTO_DEGREE. This setting allows Oracle to choose an appropriate degree of parallelism based on the size of the object and the settings for the parallel-related init.ora parameters.

Note that certain types of index statistics are not gathered in parallel, including cluster indexes, domain indexes, and bitmap join indexes.

Statistics on Partitioned Objects

For partitioned tables and indexes, DBMS_STATS can gather separate statistics for each partition, as well as global statistics for the entire table or index. Similarly, for composite partitioning, DBMS_STATS can gather separate statistics for subpartitions, partitions, and the entire table or index.The type of partitioning statistics to be gathered is specified in the GRANULARITY argument to the DBMS_STATS gathering procedures.

Depending on the SQL statement being optimized, the optimizer can choose to use either the partition (or subpartition) statistics or the global statistics. Both types of statistics are important for most applications, and Oracle Corporation recommends setting the GRANULARITY parameter to AUTO to gather both types of partition statistics.

Column Statistics and Histograms

When gathering statistics on a table, DBMS_STATS gathers information about the data distribution of the columns within the table. The most basic information about the data distribution is the maximum value and minimum value of the column. However, this level of statistics may be insufficient for the optimizer's needs if the

data within the column is skewed. For skewed data distributions, histograms can also be created as part of the column statistics to describe the data distribution of a given column. Histograms are described in more details in "Viewing Histograms" on page 15-20.

Histograms are specified using the METHOD_OPT argument of the DBMS_STATS gathering procedures. Oracle Corporation recommends setting the METHOD_OPT to FOR ALL COLUMNS SIZE AUTO. With this setting, Oracle automatically determines which columns require histograms and the number of buckets (size) of each histogram. You can also manually specify which columns should have histograms and the size of each histogram.

Determining Stale Statistics

Statistics must be regularly gathered on database objects as those database objects are modified over time. In order to determine whether or not a given database object needs new database statistics, Oracle provides a table monitoring facility. This monitoring is enabled by default when STATISTICS_LEVEL is set to TYPICAL or ALL. Monitoring tracks the approximate number of INSERTs, UPDATEs, and DELETEs for that table, as well as whether the table has been truncated, since the last time statistics were gathered. The information about changes of tables can be viewed in the USER_TAB_MODIFICATIONS view. Following a data-modification, there may be a few minutes delay while Oracle propagates the information to this view. Use the DBMS_STATS.FLUSH_DATABASE_MONITORING_INFO procedure to immediately reflect the outstanding monitored information kept in the memory.

The GATHER_DATABASE_STATS or GATHER_SCHEMA_STATS procedures gather new statistics for tables with stale statistics when the OPTIONS parameter is set to GATHER STALE or GATHER AUTO. If a monitored table has been modified more than 10%, then these statistics are considered stale and gathered again.

User-defined Statistics

You can create user-defined optimizer statistics to support user-defined indexes and functions. When you associate a statistics type with a column or domain index, Oracle calls the statistics collection method in the statistics type whenever statistics are gathered for database objects.

You should gather new column statistics on a table after creating a function-based index, to allow Oracle to collect column statistics equivalent information for the expression. This is done by calling the statistics-gathering procedure with the METHOD_OPT argument set to FOR ALL HIDDEN COLUMNS.

See Also: *Oracle Data Cartridge Developer's Guide* for details about implementing user-defined statistics

When to Gather Statistics

When gathering statistics manually, you not only need to determine how to gather statistics, but also when and how often to gather new statistics.

For an application in which tables are being incrementally modified, you may only need to gather new statistics every week or every month. The simplest way to gather statistics in these environment is to use a script or job scheduling tool to regularly run the `GATHER_SCHEMA_STATS` and `GATHER_DATABASE_STATS` procedures. The frequency of collection intervals should balance the task of providing accurate statistics for the optimizer against the processing overhead incurred by the statistics collection process.

For tables which are being substantially modified in batch operations, such as with bulk loads, statistics should be gathered on those tables as part of the batch operation. The `DBMS_STATS` procedure should be called as soon as the load operation completes.

For partitioned tables, there are often cases in which only a single partition is modified. In those cases, statistics can be gathered only on those partitions rather than gathering statistics for the entire table. However, gathering global statistics for the partitioned table may still be necessary.

See Also: *PL/SQL Packages and Types Reference* for more information about the `GATHER_SCHEMA_STATS` and `GATHER_DATABASE_STATS` procedures in the `DBMS_STATS` package

System Statistics

System statistics describe the system's hardware characteristics, such as I/O and CPU performance and utilization, to the query optimizer. When choosing an execution plan, the optimizer estimates the I/O and CPU resources required for each query. System statistics enable the query optimizer to more accurately estimate I/O and CPU costs, enabling the query optimizer to choose a better execution plan.

When Oracle gathers system statistics, it analyzes system activity in a specified period of time. The statistics are collected using the `DBMS_STATS.GATHER_SYSTEM_STATS` procedure. Oracle Corporation highly recommends that you gather system statistics.

Note: You must have DBA privileges to update dictionary system statistics.

Table 15–2 lists the optimizer system statistics gathered by the DBMS_STATS package and the options for gathering or manually setting specific system statistics.

Table 15–2 Optimizer System Statistics in the DBMS_STAT Package

Parameter Name	Description	Initialization	Options for Gathering or Setting Statistics
cpuspeed	CPU speed is the average number of CPU cycles per second.	At system startup	Set `gathering_mode` = `NOWORKLOAD`, `INTERVAL`, or `START|STOP`, or set statistics manually.
ioseektim	I/O seek time equals seek time + latency time + OS overhead time.	At system startup	Set `gathering_mode` = `NOWORKLOAD` or set statistics manually.
iotfrspeed	I/O transfer speed is the rate at which an Oracle database can read data in the single read request.	At system startup	Set `gathering_mode` = `NOWORKLOAD` or set statistics manually.
maxthr	Maximum I/O throughput is the maximum throughput that the I/O subsystem can deliver.	None	Set `gathering_mode` = `NOWORKLOAD`, `INTERVAL`, or `START|STOP`, or set statistics manually.
slavethr	Slave I/O throughput is the average parallel slave I/O throughput.	None	Set `gathering_mode` = `INTERVAL` or `START|STOP`, or set statistics manually.
sreadtim	Single block read time is the average time to read a single block randomly.	None	Set `gathering_mode` = `INTERVAL` or `START|STOP`, or set statistics manually.
mreadtim	Multiblock read is the average time to read a multiblock sequentially.	None	Set `gathering_mode` = `INTERVAL` or `START|STOP`, or set statistics manually.
mbrc	Multiblock count is the average multiblock read count sequentially.	None	Set `gathering_mode` = `INTERVAL` or `START|STOP`, or set statistics manually.

Unlike table, index, or column statistics, Oracle does not invalidate already parsed SQL statements when system statistics get updated. All new SQL statements are parsed using new statistics.

See Also: *PL/SQL Packages and Types Reference* for detailed information on the procedures in the DBMS_STATS package for implementing system statistics

Managing Statistics

This section discusses:

- Restoring Previous Versions of Statistics
- Exporting and Importing Statistics
- Restoring Statistics Versus Importing or Exporting Statistics
- Locking Statistics for a Table or Schema
- Setting Statistics
- Handling Missing Statistics

Restoring Previous Versions of Statistics

Whenever statistics in dictionary are modified, old versions of statistics are saved automatically for future restoring. Statistics can be restored using RESTORE procedures of DBMS_STATS package. These procedures use a time stamp as an argument and restore statistics as of that time stamp. This is useful in case newly collected statistics leads to some sub-optimal execution plans and the administrator wants to revert to the previous set of statistics.

There are dictionary views that display the time of statistics modifications. These views are useful in determining the time stamp to be used for statistics restoration.

- Catalog view DBA_OPTSTAT_OPERATIONS contain history of statistics operations performed at schema and database level using DBMS_STATS.
- The views *_TAB_STATS_HISTORY views (ALL, DBA, or USER) contain a history of table statistics modifications.

The old statistics are purged automatically at regular intervals based on the statistics history retention setting and the time of the recent analysis of the system. Retention is configurable using the ALTER_STATS_HISTORY_RETENTION procedure of DBMS_STATS. The default value is 31 days, which means that you would be able to restore the optimizer statistics to any time in last 31 days.

Automatic purging is enabled when STATISTICS_LEVEL parameter is set to TYPICAL or ALL. If automatic purging is disabled, the old versions of statistics need to be purged manually using the PURGE_STATS procedure.

The other DBMS_STATS procedures related to restoring and purging statistics are:

- PURGE_STATS: This procedure can be used to manually purge old versions beyond a time stamp.

- GET_STATS_HISTORY_RENTENTION: This function can be used to get the current statistics history retention value.
- GET_STATS_HISTORY_AVAILABILTY: This function gets the oldest time stamp where statistics history is available. Users cannot restore statistics to a time stamp older than the oldest time stamp.

When restoring previous versions of statistics, the following limitations apply:

- RESTORE procedures cannot restore user-defined statistics.
- Old versions of statistics are not stored when the ANALYZE command has been used for collecting statistics.

Exporting and Importing Statistics

Statistics can be exported and imported from the data dictionary to user-owned tables. This enables you to create multiple versions of statistics for the same schema. It also enables you to copy statistics from one database to another database. You may want to do this to copy the statistics from a production database to a scaled-down test database.

Note: Exporting and importing statistics is a distinct concept from the EXP and IMP utilities of the database. The DBMS_STATS export and import packages do utilize IMP and EXP dump files.

Before exporting statistics, you first need to create a table for holding the statistics. This statistics table is created using the procedure DBMS_STATS.CREATE_STAT_TABLE. After this table is created, then you can export statistics from the data dictionary into your statistics table using the DBMS_STATS.EXPORT_*_STATS procedures. The statistics can then be imported using the DBMS_STATS.IMPORT_*_STATS procedures.

Note that the optimizer does not use statistics stored in a user-owned table. The only statistics used by the optimizer are the statistics stored in the data dictionary. In order to have the optimizer use the statistics in a user-owned tables, you must import those statistics into the data dictionary using the statistics import procedures.

In order to move statistics from one database to another, you must first export the statistics on the first database, then copy the statistics table to the second database, using the EXP and IMP utilities or other mechanisms, and finally import the statistics into the second database.

Note: The EXP and IMP utilities export and import optimizer statistics from the database along with the table. One exception is that statistics are not exported with the data if a table has columns with system-generated names.

Restoring Statistics Versus Importing or Exporting Statistics

The functionality for restoring statistics is similar in some respects to the functionality of importing and exporting statistics. In general, you should use the restore capability when:

- You want to recover older versions of the statistics. For example, to restore the optimizer behavior to an earlier date.
- You want the database to manage the retention and purging of statistics histories.

You should use `EXPORT/IMPORT_*_STATS` procedures when:

- You want to experiment with multiple sets of statistics and change the values back and forth.
- You want to move the statistics from one database to another database. For example, moving statistics from a production system to a test system.
- You want to preserve a known set of statistics for a longer period of time than the desired retention date for restoring statistics.

Locking Statistics for a Table or Schema

Statistics for a table or schema can be locked. Once statistics are locked, no modifications can be made to those statistics until the statistics have been unlocked. These locking procedures are useful in a static environment in which you want to guarantee that the statistics never change.

The `DBMS_STATS` package provides two procedures for locking and two procedures for unlocking statistics:

- `LOCK_SCHEMA_STATS`
- `LOCK_TABLE_STATS`
- `UNLOCK_SCHEMA_STATS`
- `UNLOCK_TABLE_STATS`

Setting Statistics

You can set table, column, index, and system statistics using the SET_*_STATISTICS procedures. Setting statistics in the manner is not recommended, because inaccurate or inconsistent statistics can lead to poor performance.

Estimating Statistics with Dynamic Sampling

The purpose of dynamic sampling is to improve server performance by determining more accurate estimates for predicate selectivity and statistics for tables and indexes. The statistics for tables and indexes include table block counts, applicable index block counts, table cardinalities, and relevant join column statistics. These more accurate estimates allow the optimizer to produce better performing plans.

You can use dynamic sampling to:

- Estimate single-table predicate selectivities when collected statistics cannot be used or are likely to lead to significant errors in estimation.
- Estimate statistics for tables and relevant indexes without statistics.
- Estimate statistics for tables and relevant indexes whose statistics are too out of date to trust.

This dynamic sampling feature is controlled by the OPTIMIZER_DYNAMIC_SAMPLING parameter. For dynamic sampling to automatically gather the necessary statistics, this parameter should be set to a value of 2 or higher. The default value is 2. See "Dynamic Sampling Levels" on page 15-17 for information about the sampling levels that can be set.

How Dynamic Sampling Works

The primary performance attribute is compile time. Oracle determines at compile time whether a query would benefit from dynamic sampling. If so, a recursive SQL statement is issued to scan a small random sample of the table's blocks, and to apply the relevant single table predicates to estimate predicate selectivities. The sample cardinality can also be used, in some cases, to estimate table cardinality. Any relevant column and index statistics are also collected.

Depending on the value of the OPTIMIZER_DYNAMIC_SAMPLING initialization parameter, a certain number of blocks are read by the dynamic sampling query.

> **See Also:** *Oracle Database Reference* for details about this initialization parameter

When to Use Dynamic Sampling

For a query that normally completes quickly (in less than a few seconds), you will not want to incur the cost of dynamic sampling. However, dynamic sampling can be beneficial under any of the following conditions:

- A better plan can be found using dynamic sampling.
- The sampling time is a small fraction of total execution time for the query.
- The query will be executed many times.

Dynamic sampling can be applied to a subset of a single table's predicates and combined with standard selectivity estimates of predicates for which dynamic sampling is not done.

How to Use Dynamic Sampling to Improve Performance

You control dynamic sampling with the `OPTIMIZER_DYNAMIC_SAMPLING` parameter, which can be set to a value from `0` to `10`. The default is `2`.

- A value of `0` means dynamic sampling will not be done.
- Increasing the value of the parameter results in more aggressive application of dynamic sampling, in terms of both the type of tables sampled (analyzed or unanalyzed) and the amount of I/O spent on sampling.

Dynamic sampling is repeatable if no rows have been inserted, deleted, or updated in the table being sampled. The parameter `OPTIMIZER_FEATURES_ENABLE` turns off dynamic sampling if set to a version prior to 9.2.0.

Dynamic Sampling Levels

The sampling levels are as follows if the dynamic sampling level used is from a cursor hint or from the `OPTIMIZER_DYNAMIC_SAMPLING` initialization parameter:

- Level 0: Do not use dynamic sampling.
- Level 1: Sample all tables that have not been analyzed if the following criteria are met: (1) there is at least 1 unanalyzed table in the query; (2) this unanalyzed table is joined to another table or appears in a subquery or non-mergeable view; (3) this unanalyzed table has no indexes; (4) this unanalyzed table has more blocks than the number of blocks that would be used for dynamic sampling of this table. The number of blocks sampled is the default number of dynamic sampling blocks (32).
- Level 2: Apply dynamic sampling to all unanalyzed tables. The number of blocks sampled is two times the default number of dynamic sampling blocks.

- Level 3: Apply dynamic sampling to all tables that meet Level 2 criteria, plus all tables for which standard selectivity estimation used a guess for some predicate that is a potential dynamic sampling predicate. The number of blocks sampled is the default number of dynamic sampling blocks. For unanalyzed tables, the number of blocks sampled is two times the default number of dynamic sampling blocks.
- Level 4: Apply dynamic sampling to all tables that meet Level 3 criteria, plus all tables that have single-table predicates that reference 2 or more columns. The number of blocks sampled is the default number of dynamic sampling blocks. For unanalyzed tables, the number of blocks sampled is two times the default number of dynamic sampling blocks.
- Levels 5, 6, 7, 8, and 9: Apply dynamic sampling to all tables that meet the previous level criteria using 2, 4, 8, 32, or 128 times the default number of dynamic sampling blocks respectively.
- Level 10: Apply dynamic sampling to all tables that meet the Level 9 criteria using all blocks in the table.

The sampling levels are as follows if the dynamic sampling level used is from a table hint:

- Level 0: Do not use dynamic sampling.
- Level 1: The number of blocks sampled is the default number of dynamic sampling blocks (32).
- Levels 2, 3, 4, 5, 6, 7, 8, and 9: The number of blocks sampled is 2, 4, 8, 16, 32, 64, 128, or 256 times the default number of dynamic sampling blocks respectively.
- Level 10: Read all blocks in the table.

> **See Also:** "DYNAMIC_SAMPLING" on page 17-47 for information about setting the sampling levels with the `DYNAMIC_SAMPLING` hint

Handling Missing Statistics

When Oracle encounters a table with missing statistics, Oracle dynamically gathers the necessary statistics needed by the optimizer. However, for certain types of tables, Oracle does not perform dynamic sampling. These include remote tables and external tables. In those cases and also when dynamic sampling has been disabled, the optimizer uses default values for its statistics, shown in Table 15–3 and Table 15–4.

Table 15–3 Default Table Values When Statistics Are Missing

Table Statistic	Default Value Used by Optimizer
Cardinality	num_of_blocks * (block_size - cache_layer) / avg_row_len
Average row length	100 bytes
Number of blocks	100 or actual value based on the extent map
Remote cardinality	2000 rows
Remote average row length	100 bytes

Table 15–4 Default Index Values When Statistics Are Missing

Index Statistic	Default Value Used by Optimizer
Levels	1
Leaf blocks	25
Leaf blocks/key	1
Data blocks/key	1
Distinct keys	100
Clustering factor	800

Viewing Statistics

This section discusses:

- Statistics on Tables, Indexes and Columns
- Viewing Histograms

Statistics on Tables, Indexes and Columns

Statistics on tables, indexes, and columns are stored in the data dictionary. To view statistics in the data dictionary, query the appropriate data dictionary view (USER, ALL, or DBA). These DBA_* views include the following:

- DBA_TABLES
- DBA_OBJECT_TABLES
- DBA_TAB_STATISTICS

- DBA_TAB_COL_STATISTICS
- DBA_TAB_HISTOGRAMS
- DBA_INDEXES
- DBA_IND_STATISTICS
- DBA_CLUSTERS
- DBA_TAB_PARTITIONS
- DBA_TAB_SUBPARTITIONS
- DBA_IND_PARTITIONS
- DBA_IND_SUBPARTITIONS
- DBA_PART_COL_STATISTICS
- DBA_PART_HISTOGRAMS
- DBA_SUBPART_COL_STATISTICS
- DBA_SUBPART_HISTOGRAMS

See Also: *Oracle Database Reference* for information on the statistics in these views

Viewing Histograms

Column statistics may be stored as histograms. These histograms provide accurate estimates of the distribution of column data. Histograms provide improved selectivity estimates in the presence of data skew, resulting in optimal execution plans with nonuniform data distributions.

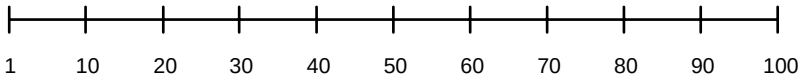
Oracle uses two types of histograms for column statistics: height-balanced histograms and frequency histograms. The type of histogram is stored in the `HISTOGRAM` column of the `*TAB_COL_STATISTICS` views (`USER` and `DBA`). This column can have values of `HEIGHT BALANCED`, `FREQUENCY`, or `NONE`.

Height-Balanced Histograms

In a height-balanced histogram, the column values are divided into bands so that each band contains approximately the same number of rows. The useful information that the histogram provides is where in the range of values the endpoints fall.

Consider a column C with values between 1 and 100 and a histogram with 10 buckets. If the data in C is uniformly distributed, then the histogram looks similar to Figure 15–1, where the numbers are the endpoint values.

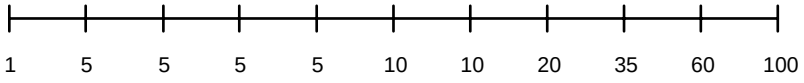
Figure 15–1 height-Balanced Histogram with Uniform Distribution



The number of rows in each bucket is one tenth the total number of rows in the table. Four-tenths of the rows have values that are between 60 and 100 in this example of uniform distribution.

If the data is not uniformly distributed, then the histogram might look similar to Figure 15–2.

Figure 15–2 height-Balanced Histogram with Non-Uniform Distribution



In this case, most of the rows have the value 5 for the column. Only 1/10 of the rows have values between 60 and 100.

Height-balanced histograms can be viewed using the *TAB_HISTOGRAMS tables, as shown in Example 15–1.

Example 15–1 Viewing Height-Balanced Histogram Statistics

```
BEGIN
  DBMS_STATS.GATHER_table_STATS (OWNNAME => 'OE', TABNAME => 'INVENTORIES',
  METHOD_OPT => 'FOR COLUMNS SIZE 10 quantity_on_hand');
END;
/

SELECT column_name, num_distinct, num_buckets, histogram
  FROM USER_TAB_COL_STATISTICS
 WHERE table_name = 'INVENTORIES' AND column_name = 'QUANTITY_ON_HAND';

COLUMN_NAME                    NUM_DISTINCT NUM_BUCKETS HISTOGRAM
------------------------------ ------------ ----------- ---------------
QUANTITY_ON_HAND                        237          10 HEIGHT BALANCED
```

```
SELECT endpoint_number, endpoint_value
  FROM USER_HISTOGRAMS
 WHERE table_name = 'INVENTORIES' and column_name = 'QUANTITY_ON_HAND'
  ORDER BY endpoint_number;

ENDPOINT_NUMBER ENDPOINT_VALUE
--------------- --------------
              0              0
              1             27
              2             42
              3             57
              4             74
              5             98
              6            123
              7            149
              8            175
              9            202
             10            353
```

In the query output, one row corresponds to one bucket in the histogram.

Frequency Histograms

In a frequency histogram, each value of the column corresponds to a single bucket of the histogram. Each bucket contains the number of occurrences of that single value. Frequency histograms are automatically created instead of height-balanced histograms when the number of distinct values is less than or equal to the number of histogram buckets specified. Frequency histograms can be viewed using the *TAB_HISTOGRAMS tables, as shown in Example 15–2.

Example 15–2 Viewing Frequency Histogram Statistics

```
BEGIN
  DBMS_STATS.GATHER_table_STATS (OWNNAME => 'OE', TABNAME => 'INVENTORIES',
  METHOD_OPT => 'FOR COLUMNS SIZE 20 warehouse_id');
END;
/

SELECT column_name, num_distinct, num_buckets, histogram
  FROM USER_TAB_COL_STATISTICS
 WHERE table_name = 'INVENTORIES' AND column_name = 'WAREHOUSE_ID';

COLUMN_NAME                    NUM_DISTINCT NUM_BUCKETS HISTOGRAM
------------------------------ ------------ ----------- ---------------
WAREHOUSE_ID                              9           9 FREQUENCY
```

```
SELECT endpoint_number, endpoint_value
  FROM USER_HISTOGRAMS
 WHERE table_name = 'INVENTORIES' and column_name = 'WAREHOUSE_ID'
  ORDER BY endpoint_number;

ENDPOINT_NUMBER ENDPOINT_VALUE
--------------- --------------
             36              1
            213              2
            261              3
            370              4
            484              5
            692              6
            798              7
            984              8
           1112              9
```

16

Using Indexes and Clusters

This chapter provides an overview of data access methods using indexes and clusters that can enhance or degrade performance.

The chapter contains the following sections:

Understanding Index Performance

This section describes the following:

Tuning the Logical Structure

Although query optimization helps avoid the use of nonselective indexes within query execution, the SQL engine must continue to maintain all indexes defined against a table, regardless of whether they are used. Index maintenance can present a significant CPU and I/O resource demand in any write-intensive application. In other words, do not build indexes unless necessary.

To maintain optimal performance, drop indexes that an application is not using. You can find indexes that are not being used by using the `ALTER INDEX MONITORING USAGE` functionality over a period of time that is representative of your workload. This monitoring feature records whether or not an index has been used. If you find that an index has not been used, then drop it. Make sure you are monitoring a representative workload to avoid dropping an index which is used, but not by the workload you sampled.

Also, indexes within an application sometimes have uses that are not immediately apparent from a survey of statement execution plans. An example of this is a foreign key index on a parent table, which prevents share locks from being taken out on a child table.

See Also:

- *Oracle Database SQL Reference* for information on the `ALTER INDEX MONITORING USAGE` statement
- *Oracle Database Application Developer's Guide - Fundamentals* for information on foreign keys

If you are deciding whether to create new indexes to tune statements, then you can also use the `EXPLAIN PLAN` statement to determine whether the optimizer will choose to use these indexes when the application is run. If you create new indexes to tune a statement that is currently parsed, then Oracle invalidates the statement.

When the statement is next parsed, the optimizer automatically chooses a new execution plan that could potentially use the new index. If you create new indexes on a remote database to tune a distributed statement, then the optimizer considers these indexes when the statement is next parsed.

Note that creating an index to tune one statement can affect the optimizer's choice of execution plans for other statements. For example, if you create an index to be used by one statement, then the optimizer can choose to use that index for other statements in the application as well. For this reason, reexamine the application's performance and execution plans, and rerun the SQL trace facility after you have tuned those statements that you initially identified for tuning.

Index Tuning using the SQLAccess Advisor

The SQLAccess Advisor is an alternative to manually determining which indexes are required. This advisor recommends a set of indexes when invoked from **Advisor Central** in Oracle Enterprise Manager or run through the `DBMS_ADVISOR` package APIs. The SQLAccess Advisor either recommends using a workload or it generates a hypothetical workload for a specified schema. Various workload sources are available, such as the current contents of the SQL Cache, a user defined set of SQL statements, or a SQL Tuning set. Given a workload, the SQLAccess Advisor generates a set of recommendations from which you can select the indexes that are to be implemented. An implementation script is provided that can be executed manually or automatically through Oracle Enterprise Manager.

See Also: *Oracle Data Warehousing Guide* for information on the SQLAccess Advisor

Choosing Columns and Expressions to Index

A key is a column or expression on which you can build an index. Follow these guidelines for choosing keys to index:

- Consider indexing keys that are used frequently in `WHERE` clauses.
- Consider indexing keys that are used frequently to join tables in SQL statements. For more information on optimizing joins, see the section "Using Hash Clusters for Performance" on page 16-15.
- Choose index keys that have high selectivity. The selectivity of an index is the percentage of rows in a table having the same value for the indexed key. An index's selectivity is optimal if few rows have the same value.

  Note: Oracle automatically creates indexes, or uses existing indexes, on the keys and expressions of unique and primary keys that you define with integrity constraints.

  Indexing low selectivity columns can be helpful if the data distribution is skewed so that one or two values occur much less often than other values.
- Do not use standard B-tree indexes on keys or expressions with few distinct values. Such keys or expressions usually have poor selectivity and therefore do not optimize performance unless the frequently selected key values appear less frequently than the other key values. You can use bitmap indexes effectively in such cases, unless the index is modified frequently, as in a high concurrency OLTP application.
- Do not index columns that are modified frequently. `UPDATE` statements that modify indexed columns and `INSERT` and `DELETE` statements that modify indexed tables take longer than if there were no index. Such SQL statements must modify data in indexes as well as data in tables. They also generate additional undo and redo.
- Do not index keys that appear only in `WHERE` clauses with functions or operators. A `WHERE` clause that uses a function, other than `MIN` or `MAX`, or an operator with an indexed key does not make available the access path that uses the index except with function-based indexes.
- Consider indexing foreign keys of referential integrity constraints in cases in which a large number of concurrent `INSERT`, `UPDATE`, and `DELETE` statements access the parent and child tables. Such an index allows `UPDATE`s and `DELETE`s on the parent table without share locking the child table.

- When choosing to index a key, consider whether the performance gain for queries is worth the performance loss for INSERTs, UPDATEs, and DELETEs and the use of the space required to store the index. You might want to experiment by comparing the processing times of the SQL statements with and without indexes. You can measure processing time with the SQL trace facility.

  See Also: *Oracle Database Application Developer's Guide - Fundamentals* for more information on the effects of foreign keys on locking

Choosing Composite Indexes

A composite index contains more than one key column. Composite indexes can provide additional advantages over single-column indexes:

- Improved selectivity

  Sometimes two or more columns or expressions, each with poor selectivity, can be combined to form a composite index with higher selectivity.

- Reduced I/O

  If all columns selected by a query are in a composite index, then Oracle can return these values from the index without accessing the table.

A SQL statement can use an access path involving a composite index if the statement contains constructs that use a leading portion of the index.

Note: This is no longer the case with index skip scans. See "Index Skip Scans" on page 14-25.

A leading portion of an index is a set of one or more columns that were specified first and consecutively in the list of columns in the CREATE INDEX statement that created the index. Consider this CREATE INDEX statement:

```
CREATE INDEX comp_ind
ON table1(x, y, z);
```

- x, xy, and xyz combinations of columns are leading portions of the index
- yz, y, and z combinations of columns are *not* leading portions of the index

Choosing Keys for Composite Indexes

Follow these guidelines for choosing keys for composite indexes:

- Consider creating a composite index on keys that are used together frequently in WHERE clause conditions combined with AND operators, especially if their combined selectivity is better than the selectivity of either key individually.
- If several queries select the same set of keys based on one or more key values, then consider creating a composite index containing all of these keys.

Of course, consider the guidelines associated with the general performance advantages and trade-offs of indexes described in the previous sections.

Ordering Keys for Composite Indexes

Follow these guidelines for ordering keys in composite indexes:

- Create the index so the keys used in WHERE clauses make up a leading portion.
- If some keys are used in WHERE clauses more frequently, then be sure to create the index so that the more frequently selected keys make up a leading portion to allow the statements that use only these keys to use the index.
- If all keys are used in the WHERE clauses equally often but the data is physically ordered on one of the keys, then place that key first in the composite index.

Writing Statements That Use Indexes

Even after you create an index, the optimizer cannot use an access path that uses the index simply because the index exists. The optimizer can choose such an access path for a SQL statement only if it contains a construct that makes the access path available. To allow the query optimizer the option of using an index access path, ensure that the statement contains a construct that makes such an access path available.

Writing Statements That Avoid Using Indexes

In some cases, you might want to prevent a SQL statement from using an access path that uses an existing index. You might want to do this if you know that the index is not very selective and that a full table scan would be more efficient. If the statement contains a construct that makes such an index access path available, then you can force the optimizer to use a full table scan through one of the following methods:

- Use the NO_INDEX hint to give the query optimizer maximum flexibility while disallowing the use of a certain index.
- Use the FULL hint to force the optimizer to choose a full table scan instead of an index scan.
- Use the INDEX or INDEX_COMBINE hints to force the optimizer to use one index or a set of listed indexes instead of another.

> **See Also:** Chapter 17, "Optimizer Hints" for more information on the NO_INDEX, FULL, INDEX, INDEX_COMBINE, and AND_EQUAL hints

Parallel execution uses indexes effectively. It does not perform parallel index range scans, but it does perform parallel index lookups for parallel nested loop join execution. If an index is very selective (there are few rows for each index entry), then it might be better to use sequential index lookup rather than parallel table scan.

Re-creating Indexes

You might want to re-create an index to compact it and minimize fragmented space, or to change the index's storage characteristics. When creating a new index that is a subset of an existing index or when rebuilding an existing index with new storage characteristics, Oracle might use the existing index instead of the base table to improve the performance of the index build.

Note: To avoid calling DBMS_STATS after the index creation or rebuild, include the COMPUTE STATISTICS statement on the CREATE or REBUILD.

However, there are cases where it can be beneficial to use the base table instead of the existing index. Consider an index on a table on which a lot of DML has been performed. Because of the DML, the size of the index can increase to the point where each block is only 50% full, or even less. If the index refers to most of the columns in the table, then the index could actually be larger than the table. In this case, it is faster to use the base table rather than the index to re-create the index.

Use the ALTER INDEX ... REBUILD statement to reorganize or compact an existing index or to change its storage characteristics. The REBUILD statement uses the existing index as the basis for the new one. All index storage statements are

supported, such as STORAGE (for extent allocation), TABLESPACE (to move the index to a new tablespace), and INITRANS (to change the initial number of entries).

Usually, ALTER INDEX ... REBUILD is faster than dropping and re-creating an index, because this statement uses the fast full scan feature. It reads all the index blocks using multiblock I/O, then discards the branch blocks. A further advantage of this approach is that the old index is still available for queries while the rebuild is in progress.

> **See Also:** *Oracle Database SQL Reference* for more information about the CREATE INDEX and ALTER INDEX statements, as well as restrictions on rebuilding indexes

Compacting Indexes

You can coalesce leaf blocks of an index by using the ALTER INDEX statement with the COALESCE option. This option lets you combine leaf levels of an index to free blocks for reuse. You can also rebuild the index online.

> **See Also:** *Oracle Database SQL Reference* and *Oracle Database Administrator's Guide* for more information about the syntax for this statement

Using Nonunique Indexes to Enforce Uniqueness

You can use an existing nonunique index on a table to enforce uniqueness, either for UNIQUE constraints or the unique aspect of a PRIMARY KEY constraint. The advantage of this approach is that the index remains available and valid when the constraint is disabled. Therefore, enabling a disabled UNIQUE or PRIMARY KEY constraint does not require rebuilding the unique index associated with the constraint. This can yield significant time savings on enable operations for large tables.

Using a nonunique index to enforce uniqueness also lets you eliminate redundant indexes. You do not need a unique index on a primary key column if that column already is included as the prefix of a composite index. You can use the existing index to enable and enforce the constraint. You also save significant space by not duplicating the index. However, if the existing index is partitioned, then the partitioning key of the index must also be a subset of the UNIQUE key; otherwise, Oracle creates an additional unique index to enforce the constraint.

Using Enabled Novalidated Constraints

An enabled novalidated constraint behaves similarly to an enabled validated constraint for new data. Placing a constraint in the enabled novalidated state signifies that any new data entered into the table must conform to the constraint. Existing data is not checked. By placing a constraint in the enabled novalidated state, you enable the constraint without locking the table.

If you change a constraint from disabled to enabled, then the table must be locked. No new DML, queries, or DDL can occur, because there is no mechanism to ensure that operations on the table conform to the constraint during the enable operation. The enabled novalidated state prevents operations violating the constraint from being performed on the table.

An enabled novalidated constraint can be validated with a parallel, consistent-read query of the table to determine whether any data violates the constraint. No locking is performed, and the enable operation does not block readers or writers to the table. In addition, enabled novalidated constraints can be validated in parallel: Multiple constraints can be validated at the same time and each constraint's validity check can be determined using parallel query.

Use the following approach to create tables with constraints and indexes:

1. Create the tables with the constraints. NOT NULL constraints can be unnamed and should be created enabled and validated. All other constraints (CHECK, UNIQUE, PRIMARY KEY, and FOREIGN KEY) should be named and created disabled.

   Note: By default, constraints are created in the ENABLED state.

2. Load old data into the tables.
3. Create all indexes, including indexes needed for constraints.
4. Enable novalidate all constraints. Do this to primary keys before foreign keys.
5. Allow users to query and modify data.
6. With a separate ALTER TABLE statement for each constraint, validate all constraints. Do this to primary keys before foreign keys. For example,

```
CREATE TABLE t (a NUMBER CONSTRAINT apk PRIMARY KEY DISABLE,
b NUMBER NOT NULL);
CREATE TABLE x (c NUMBER CONSTRAINT afk REFERENCES t DISABLE);
```

Now you can use Import or Fast Loader to load data into table t.

```
CREATE UNIQUE INDEX tai ON t (a);
CREATE INDEX tci ON x (c);
ALTER TABLE t MODIFY CONSTRAINT apk ENABLE NOVALIDATE;
ALTER TABLE x MODIFY CONSTRAINT afk ENABLE NOVALIDATE;
```

At this point, users can start performing INSERTs, UPDATEs, DELETEs, and SELECTs on table t.

```
ALTER TABLE t ENABLE CONSTRAINT apk;
ALTER TABLE x ENABLE CONSTRAINT afk;
```

Now the constraints are enabled and validated.

> **See Also:** *Oracle Database Concepts* for a complete discussion of integrity constraints

Using Function-based Indexes for Performance

A function-based index includes columns that are either transformed by a function, such as the UPPER function, or included in an expression, such as col1 + col2. With a function-based index, you can store computation-intensive expressions in the index.

Defining a function-based index on the transformed column or expression allows that data to be returned using the index when that function or expression is used in a WHERE clause or an ORDER BY clause. This allows Oracle to bypass computing the value of the expression when processing SELECT and DELETE statements. Therefore, a function-based index can be beneficial when frequently-executed SQL statements include transformed columns, or columns in expressions, in a WHERE or ORDER BY clause.

Oracle treats descending indexes as function-based indexes. The columns marked DESC are sorted in descending order.

For example, function-based indexes defined with the UPPER(*column_name*) or LOWER(*column_name*) keywords allow case-insensitive searches. The index created in the following statement:

```
CREATE INDEX uppercase_idx ON employees (UPPER(last_name));
```

facilitates processing queries such as:

```
SELECT * FROM employees
    WHERE UPPER(last_name) = 'MARKSON';
```

See Also:

- *Oracle Database Application Developer's Guide - Fundamentals* and *Oracle Database Administrator's Guide* for more information on using function-based indexes
- *Oracle Database SQL Reference* for more information on the `CREATE INDEX` statement

Using Partitioned Indexes for Performance

Similar to partitioned tables, partitioned indexes improve manageability, availability, performance, and scalability. They can either be partitioned independently (global indexes) or automatically linked to a table's partitioning method (local indexes).

Oracle supports both range and hash partitioned global indexes. In a range partitioned global index, each index partition contains values defined by a partition bound. In a hash partitioned global index, each partition contains values determined by the Oracle hash function.

The hash method can improve performance of indexes where a small number leaf blocks in the index have high contention in multiuser OLTP environment. In some OLTP applications, index insertions happen only at the right edge of the index. This could happen when the index is defined on monotonically increasing columns. In such situations right edge of the index becomes a hotspot because of contention for index pages, buffers, latches for update, and additional index maintenance activity, which results in performance degradation.

With hash partitioned global indexes index entries are hashed to different partitions based on partitioning key and the number of partitions. This spreads out contention over number of defined partitions, resulting in increased throughput. Hash-partitioned global indexes would benefit TPC-H refresh functions that are executed as massive PDMLs into huge fact tables because contention for buffer latches would be spread out over multiple partitions.

With hash partitioning, an index entry will be mapped to a particular index partition based on the hash value generated by Oracle. The syntax to create hash-partitioned global index is very similar to hash-partitioned table. Queries involving equality and `IN` predicates on index partitioning key can efficiently use global hash partitioned index to answer queries quickly.

See Also: *Oracle Database Concepts* and *Oracle Database Administrator's Guide* for more information on global indexes tables

Using Index-Organized Tables for Performance

An index-organized table differs from an ordinary table in that the data for the table is held in its associated index. Changes to the table data, such as adding new rows, updating rows, or deleting rows, result only in updating the index. Because data rows are stored in the index, index-organized tables provide faster key-based access to table data for queries that involve exact match or range search or both.

Global hash-partitioned indexes are supported for index-organized tables and can provide performance benefits in a multiuser OLTP environment.

> **See Also:** *Oracle Database Concepts* and *Oracle Database Administrator's Guide* for more information on index-organized tables

Using Bitmap Indexes for Performance

Bitmap indexes can substantially improve performance of queries that have all of the following characteristics:

- The `WHERE` clause contains multiple predicates on low- or medium-cardinality columns.
- The individual predicates on these low- or medium-cardinality columns select a large number of rows.
- The bitmap indexes used in the queries have been created on some or all of these low- or medium-cardinality columns.
- The tables in the queries contain many rows.

You can use multiple bitmap indexes to evaluate the conditions on a single table. Bitmap indexes are thus highly advantageous for complex *ad hoc* queries that contain lengthy `WHERE` clauses. Bitmap indexes can also provide optimal performance for aggregate queries and for optimizing joins in star schemas.

> **See Also:** *Oracle Database Concepts* and *Oracle Data Warehousing Guide* for more information on bitmap indexing

Using Bitmap Join Indexes for Performance

In addition to a bitmap index on a single table, you can create a bitmap join index, which is a bitmap index for the join of two or more tables. A bitmap join index is a space-saving way to reduce the volume of data that must be joined, by performing

restrictions in advance. For each value in a column of a table, a bitmap join index stores the rowids of corresponding rows in another table. In a data warehousing environment, the join condition is an equi-inner join between the primary key column(s) of the dimension tables and the foreign key column(s) in the fact table.

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

> **See Also:** *Oracle Data Warehousing Guide* for examples and restrictions of bitmap join indexes

Using Domain Indexes for Performance

Domain indexes are built using the indexing logic supplied by a user-defined indextype. An indextype provides an efficient mechanism to access data that satisfy certain operator predicates. Typically, the user-defined indextype is part of an Oracle option, like the Spatial option. For example, the `SpatialIndextype` allows efficient search and retrieval of spatial data that overlap a given bounding box.

The cartridge determines the parameters you can specify in creating and maintaining the domain index. Similarly, the performance and storage characteristics of the domain index are presented in the specific cartridge documentation.

Refer to the appropriate cartridge documentation for information such as the following:

- What datatypes can be indexed?
- What indextypes are provided?
- What operators does the indextype support?
- How can the domain index be created and maintained?
- How do we efficiently use the operator in queries?
- What are the performance characteristics?

Note: You can also create index types with the `CREATE INDEXTYPE` statement.

See Also: *Oracle Spatial User's Guide and Reference* for information about the `SpatialIndextype`

Using Clusters for Performance

Clusters are groups of one or more tables that are physically stored together because they share common columns and usually are used together. Because related rows are physically stored together, disk access time improves.

To create a cluster, use the `CREATE CLUSTER` statement.

See Also: *Oracle Database Concepts* for more information on clusters

Follow these guidelines when deciding whether to cluster tables:

- Cluster tables that are accessed frequently by the application in join statements.
- Do not cluster tables if the application joins them only occasionally or modifies their common column values frequently. Modifying a row's cluster key value takes longer than modifying the value in an unclustered table, because Oracle might need to migrate the modified row to another block to maintain the cluster.
- Do not cluster tables if the application often performs full table scans of only one of the tables. A full table scan of a clustered table can take longer than a full table scan of an unclustered table. Oracle is likely to read more blocks, because the tables are stored together.
- Cluster master-detail tables if you often select a master record and then the corresponding detail records. Detail records are stored in the same data block(s) as the master record, so they are likely still to be in memory when you select them, requiring Oracle to perform less I/O.
- Store a detail table alone in a cluster if you often select many detail records of the same master. This measure improves the performance of queries that select detail records of the same master, but does not decrease the performance of a full table scan on the master table. An alternative is to use an index organized table.
- Do not cluster tables if the data from all tables with the same cluster key value exceeds more than one or two Oracle blocks. To access a row in a clustered table, Oracle reads all blocks containing rows with that value. If these rows take

up multiple blocks, then accessing a single row could require more reads than accessing the same row in an unclustered table.

- Do not cluster tables when the number of rows for each cluster key value varies significantly. This causes waste of space for the low cardinality key value; it causes collisions for the high cardinality key values. Collisions degrade performance.

Consider the benefits and drawbacks of clusters with respect to the needs of the application. For example, you might decide that the performance gain for join statements outweighs the performance loss for statements that modify cluster key values. You might want to experiment and compare processing times with the tables both clustered and stored separately.

> **See Also:** *Oracle Database Administrator's Guide* for more information on creating clusters

Using Hash Clusters for Performance

Hash clusters group table data by applying a hash function to each row's cluster key value. All rows with the same cluster key value are stored together on disk. Consider the benefits and drawbacks of hash clusters with respect to the needs of the application. You might want to experiment and compare processing times with a particular table as it is stored in a hash cluster, and as it is stored alone with an index.

Follow these guidelines for choosing when to use hash clusters:

- Use hash clusters to store tables accessed frequently by SQL statements with `WHERE` clauses, if the `WHERE` clauses contain equality conditions that use the same column or combination of columns. Designate this column or combination of columns as the cluster key.
- Store a table in a hash cluster if you can determine how much space is required to hold all rows with a given cluster key value, including rows to be inserted immediately as well as rows to be inserted in the future.
- Use sorted hash clusters, where rows corresponding to each value of the hash function are sorted on a specific columns in ascending order, when response time can be improved on operations with this sorted clustered data.
- Do not store a table in a hash cluster if the application often performs full table scans and if you must allocate a great deal of space to the hash cluster in anticipation of the table growing. Such full table scans must read all blocks

allocated to the hash cluster, even though some blocks might contain few rows. Storing the table alone reduces the number of blocks read by full table scans.

- Do not store a table in a hash cluster if the application frequently modifies the cluster key values. Modifying a row's cluster key value can take longer than modifying the value in an unclustered table, because Oracle might need to migrate the modified row to another block to maintain the cluster.

Storing a single table in a hash cluster can be useful, regardless of whether the table is joined frequently with other tables, as long as hashing is appropriate for the table based on the considerations in this list.

See Also:

- *Oracle Database Administrator's Guide* for information on managing hash clusters
- *Oracle Database SQL Reference* for information on the CREATE CLUSTER statement

17

Optimizer Hints

Optimizer hints can be used with SQL statements to alter execution plans. This chapter explains how to use hints to force various approaches.

The chapter contains the following sections:

Understanding Optimizer Hints

Hints let you make decisions usually made by the optimizer. As an application designer, you might know information about your data that the optimizer does not know. Hints provide a mechanism to direct the optimizer to choose a certain query execution plan based on the specific criteria.

For example, you might know that a certain index is more selective for certain queries. Based on this information, you might be able to choose a more efficient execution plan than the optimizer. In such a case, use hints to force the optimizer to use the optimal execution plan.

See "Using Optimizer Hints" on page 17-12 for the discussion of the types and usage of hints. The hints are grouped into the following categories:

- Hints for Optimization Approaches and Goals
- Hints for Access Paths
- Hints for Query Transformations
- Hints for Join Orders
- Hints for Join Operations
- Hints for Parallel Execution
- Additional Hints

Note: The use of hints involves extra code that must be managed, checked, and controlled.

See Also:

- Chapter 6, "Automatic Performance Diagnostics" for information on analyzing and tuning SQL statements.
- *Oracle Enterprise Manager Concepts* for information on monitoring and tuning with Oracle Enterprise Manager features

Type of Hints

Hints falls into the following general classifications:

- Single-table

Single-table hints are specified on one table or view. INDEX and USE_NL are examples of single-table hints.

- Multi-table

  Multi-table hints are like single-table hints, except that the hint can specify one or more tables or views. LEADING is an example of a multi-table hint. Note that USE_NL(table1 table2) is not considered a multi-table hint because it is actually a shortcut for USE_NL(table1) and USE_NL(table2).

- Query block

  Query block hints operate on single query blocks. STAR_TRANSFORMATION and UNNEST are examples of query block hints.

- Statement

  Statement hints apply to the entire SQL statement. ALL_ROWS is an example of a statement hint.

Specifying Hints

Hints apply only to the optimization of the block of a statement in which they appear. A statement block is any one of the following statements or parts of statements:

- A simple SELECT, UPDATE, or DELETE statement
- A parent statement or subquery of a complex statement
- A part of a compound query

For example, a compound query consisting of two component queries combined by the UNION operator has two blocks, one for each component query. For this reason, hints in the first component query apply only to its optimization, not to the optimization of the second component query.

The following sections discuss the use of hints in more detail.

- Hint Syntax
- Specifying a Full Set of Hints
- Specifying a Query Block in a Hint
- Specifying Global Table Hints
- Specifying Complex Index Hints

Hint Syntax

You can send hints for a SQL statement to the optimizer by enclosing them in a comment within the statement.

> **See Also:** *Oracle Database SQL Reference* for more information on comments

A block in a statement can have only one comment containing hints following the SELECT, UPDATE, MERGE, or DELETE keyword.

> **Exception:** The APPEND hint always follows the INSERT keyword, and the PARALLEL hint can follow the INSERT keyword.

The following syntax shows hints contained in both styles of comments that Oracle supports within a statement block.

```
{DELETE|INSERT|MERGE|SELECT|UPDATE} /*+ hint [text] [hint[text]]... */
```

or

```
{DELETE|INSERT|MERGE|SELECT|UPDATE} --+ hint [text] [hint[text]]...
```

where:

- DELETE, INSERT, SELECT, MERGE, and UPDATE are keywords that begin a statement block. Comments containing hints can appear only after these keywords.
- + causes Oracle to interpret the comment as a list of hints. The plus sign must immediately follow the comment delimiter; no space is permitted.
- hint is one of the hints discussed in this section. If the comment contains multiple hints, then each hint must be separated from the others by at least one space.
- text is other commenting text that can be interspersed with the hints.

The --+ hint format requires that the hint be on only one line.

If you specify hints incorrectly, then Oracle ignores them but does not return an error. For example:

- Oracle ignores hints if the comment containing them does not follow a DELETE, INSERT, SELECT, MERGE, or UPDATE keyword.

- Oracle ignores hints containing syntax errors, but considers other correctly specified hints within the same comment.
- Oracle ignores combinations of conflicting hints, but considers other hints within the same comment.
- Oracle ignores hints in all SQL statements in those environments that use PL/SQL version 1, such as Forms version 3 triggers, Oracle Forms 4.5, and Oracle Reports 2.5. These hints can be passed to the server, but the server ignores them.

See Also:

- "Using Optimizer Hints" on page 17-12 for the syntax of each hint
- "INDEX" on page 17-17 and following sections, for conditions specific to index type

Specifying a Full Set of Hints

When using hints, in some cases, you might need to specify a full set of hints in order to ensure the optimal execution plan. For example, if you have a very complex query, which consists of many table joins, and if you specify only the `INDEX` hint for a given table, then the optimizer needs to determine the remaining access paths to be used, as well as the corresponding join methods. Therefore, even though you gave the `INDEX` hint, the optimizer might not necessarily use that hint, because the optimizer might have determined that the requested index cannot be used due to the join methods and access paths selected by the optimizer.

In Example 17–1, the `ORDERED` hint specifies the exact join order to be used; the join methods to be used on the different tables are also specified.

Example 17–1 Specifying a Full Set of Hints

```
SELECT /*+ LEADING(e2 e1) USE_NL(e1) INDEX(e1 emp_emp_id_pk)
           USE_MERGE(j) FULL(j) */
    e1.first_name, e1.last_name, j.job_id, sum(e2.salary) total_sal
  FROM employees e1, employees e2, job_history j
  WHERE e1.employee_id = e2.manager_id
    AND e1.employee_id = j.employee_id
    AND e1.hire_date = j.start_date
  GROUP BY e1.first_name, e1.last_name, j.job_id
  ORDER BY total_sal;
```

Specifying a Query Block in a Hint

To identify a query block in a query, an optional query block name can be used in a hint to specify the query block to which the hint applies. The syntax of the query block argument is of the form *@queryblock*, where *queryblock* is an identifier that specifies a query block in the query. The *queryblock* identifier can either be system-generated or user-specified.

- The system-generated identifier can be obtained by using EXPLAIN PLAN for the query. Pre-transformation query block names can be determined by running EXPLAIN PLAN for the query using the NO_QUERY_TRANSFORMATION hint. See "NO_QUERY_TRANSFORMATION" on page 17-24.
- The user-specified name can be set with the QB_NAME hint. See "QB_NAME" on page 17-46.

In Example 17–2, the query block name is used with the NO_UNNEST hint to specify a query block in a SELECT statement on the view.

Example 17–2 Using a Query Block in a Hint

```
CREATE OR REPLACE VIEW v AS
  SELECT e1.first_name, e1.last_name, j.job_id, sum(e2.salary) total_sal
    FROM employees e1,
      ( SELECT *
          FROM employees e3) e2, job_history j
         WHERE e1.employee_id = e2.manager_id
          AND e1.employee_id = j.employee_id
          AND e1.hire_date = j.start_date
          AND e1.salary = ( SELECT max(e2.salary)
                            FROM employees e2
                            WHERE e2.department_id = e1.department_id )
  GROUP BY e1.first_name, e1.last_name, j.job_id
  ORDER BY total_sal;
```

After running EXPLAIN PLAN for the query and displaying the plan table output, you can determine the system-generated query block identifier. For example, a query block name is displayed in the following plan table output:

```
SELECT PLAN_TABLE_OUTPUT FROM TABLE(DBMS_XPLAN.DISPLAY(NULL, NULL, 'SERIAL'));
...
Query Block Name / Object Alias (identified by operation id):
-------------------------------------------------------------
...
  10 - SEL$4        / E2@SEL$4
```

After the query block name is determined it can be used in the following SQL statement:

```
SELECT /*+ NO_UNNEST( @SEL$4 ) */
  *
 FROM v;
```

Specifying Global Table Hints

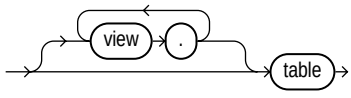
Hints that specify a table generally refer to tables in the DELETE, SELECT, or UPDATE query block in which the hint occurs, not to tables inside any views referenced by the statement. When you want to specify hints for tables that appear inside views, Oracle recommends using global hints instead of embedding the hint in the view. Table hints described in this chapter can be transformed into a global hint by using an extended `tablespec` syntax that includes view names with the table name.

In addition, an optional query block name can precede the `tablespec` syntax. See "Specifying a Query Block in a Hint" on page 17-6.

Hints that specify a table use the following syntax:

Figure 17–1 Tablespec Syntax

tablespec::=



where:

- `view` specifies a view name
- `table` specifies the name or alias of the table

If the view path is specified, the hint is resolved from left to right, where the first view must be present in the FROM clause, and each subsequent view must be specified in the FROM clause of the preceding view.

For example, in Example 17–3 a view `v` is created to return the first and last name of the employee, his or her first job and the total salary of all direct reports of that employee for each employee with the highest salary in his or her department. When querying the data, you want to force the use of the index `emp_job_ix` for the table `e3` in view `e2`.

Example 17–3 Using Global Hints Example

```
CREATE OR REPLACE VIEW v AS
SELECT
    e1.first_name, e1.last_name, j.job_id, sum(e2.salary) total_sal
FROM employees e1,
        ( SELECT *
          FROM employees e3) e2, job_history j
WHERE e1.employee_id = e2.manager_id
     AND e1.employee_id = j.employee_id
     AND e1.hire_date = j.start_date
     AND e1.salary = ( SELECT
                       max(e2.salary)
                       FROM employees e2
                       WHERE e2.department_id = e1.department_id)
GROUP BY e1.first_name, e1.last_name, j.job_id
ORDER BY total_sal;
```

By using the global hint structure, you can avoid the modification of view `v` with the specification of the index hint in the body of view `e2`. To force the use of the index `emp_job_ix` for the table `e3`, you can use one of the following:

```
SELECT /*+ INDEX(v.e2.e3 emp_job_ix) */  *
  FROM v;

SELECT /*+ INDEX(@SEL$2 e2.e3 emp_job_ix) */ *
  FROM v;

SELECT /*+ INDEX(@SEL$3 e3 emp_job_ix) */ *
  FROM v;
```

The global hint syntax also applies to unmergeable views as in Example 17–4.

Example 17–4 Using Global Hints with NO_MERGE

```
CREATE OR REPLACE VIEW v1 AS
  SELECT *
    FROM employees
    WHERE employee_id < 150;

CREATE OR REPLACE VIEW v2 AS
  SELECT v1.employee_id employee_id, departments.department_id department_id
    FROM v1, departments
    WHERE v1.department_id = departments.department_id;

SELECT /*+ NO_MERGE(v2) INDEX(v2.v1.employees emp_emp_id_pk)
```

```
                        FULL(v2.departments) */ *
  FROM v2
  WHERE department_id = 30;
```

The hints cause v2 not to be merged and specify access path hints for the employee and department tables. These hints are pushed down into the (nonmerged) view v2.

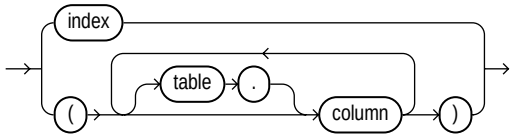
See Also: "Using Hints with Views" on page 17-10

Specifying Complex Index Hints

Hints that specify an index can use either a simple index name or a parenthesized list of columns as follows:

Figure 17–2 Indexspec Syntax

indexspec::=



where:

- `table` specifies the name
- `column` specifies the name of a column in the specified table
  - The columns can optionally be prefixed with table qualifiers allowing the hint to specify bitmap join indexes where the index columns are on a different table than the indexed table. If tables qualifiers are present, they must be base tables, not aliases in the query.
  - Each column in an index specification must be a base column in the specified table, not an expression. Function-based indexes cannot be hinted using a column specification unless the columns specified in the index specification form the prefix of a function-based index.
- `index` specifies an index name

The hint is resolved as follows:

- If an index name is specified, only that index is considered.

- If a column list is specified and an index exists whose columns match the specified columns in number and order, only that index is considered. If no such index exists, then any index on the table with the specified columns as the prefix in the order specified is considered. In either case, the behavior is exactly as if the user had specified the same hint individually on all the matching indexes.

For example, in Example 17–3 the `job_history` table has a single-column index on the `employee_id` column and a concatenated index on `employee_id` and `start_date` columns. To use either of these indexes, the query can be hinted as follows:

```
SELECT /*+ INDEX(v.j jhist_employee_ix (employee_id start_date)) */ * FROM v;
```

Using Hints with Views

Oracle does not encourage the use of hints inside or on views (or subqueries). This is because you can define views in one context and use them in another. Also, such hints can result in unexpected execution plans. In particular, hints inside views or on views are handled differently, depending on whether the view is mergeable into the top-level query.

If you want to specify a hint for a table in a view or subquery, then the global hint syntax is recommended. See "Specifying Global Table Hints" on page 17-7.

If you decide, nonetheless, to use hints with views, the following sections describe the behavior in each case.

- Hints and Complex Views
- Hints and Mergeable Views
- Hints and Nonmergeable Views

Hints and Complex Views

By default, hints do not propagate inside a complex view. For example, if you specify a hint in a query that selects against a complex view, then that hint is not honored, because it is not pushed inside the view.

Note: If the view is a single-table, then the hint is not propagated.

Unless the hints are inside the base view, they might not be honored from a query against the view.

Hints and Mergeable Views

This section describes hint behavior with mergeable views.

Optimization Approaches and Goal Hints in Views

Optimization approach and goal hints can occur in a top-level query or inside views.

- If there is such a hint in the top-level query, then that hint is used regardless of any such hints inside the views.
- If there is no top-level optimizer mode hint, then mode hints in referenced views are used as long as all mode hints in the views are consistent.
- If two or more mode hints in the referenced views conflict, then all mode hints in the views are discarded and the session mode is used, whether default or user-specified.

Access Path and Join Hints on Views

Access path and join hints on referenced views are ignored, unless the view contains a single table (or references an Additional Hints view with a single table). For such single-table views, an access path hint or a join hint on the view applies to the table inside the view.

Access Path and Join Hints Inside Views

Access path and join hints can appear in a view definition.

- If the view is an inline view (that is, if it appears in the `FROM` clause of a `SELECT` statement), then all access path and join hints inside the view are preserved when the view is merged with the top-level query.
- For views that are non-inline views, access path and join hints in the view are preserved only if the referencing query references no other tables or views (that is, if the `FROM` clause of the `SELECT` statement contains only the view).

Parallel Execution Hints on Views

`PARALLEL`, `NO_PARALLEL`, `PARALLEL_INDEX`, and `NO_PARALLEL_INDEX` hints on views are applied recursively to all the tables in the referenced view. Parallel execution hints in a top-level query override such hints inside a referenced view.

Parallel Execution Hints Inside Views

PARALLEL, NO_PARALLEL, PARALLEL_INDEX, and NO_PARALLEL_INDEX hints inside views are preserved when the view is merged with the top-level query. Parallel execution hints on the view in a top-level query override such hints inside a referenced view.

Hints and Nonmergeable Views

With nonmergeable views, optimization approach and goal hints inside the view are ignored; the top-level query decides the optimization mode.

Because nonmergeable views are optimized separately from the top-level query, access path and join hints inside the view are preserved. For the same reason, access path hints on the view in the top-level query are ignored.

However, join hints on the view in the top-level query are preserved because, in this case, a nonmergeable view is similar to a table.

Using Optimizer Hints

This section discusses how to use the optimizer hints. The hints can be categorized as follows:

- Hints for Optimization Approaches and Goals
- Hints for Access Paths
- Hints for Query Transformations
- Hints for Join Orders
- Hints for Join Operations
- Hints for Parallel Execution
- Additional Hints

Hints for Optimization Approaches and Goals

The hints described in this section let you choose between optimization approaches and goals.

- ALL_ROWS
- FIRST_ROWS(n)
- RULE

If a SQL statement has a hint specifying an optimization approach and goal, then the optimizer uses the specified approach regardless of the presence or absence of statistics, the value of the OPTIMIZER_MODE initialization parameter, and the OPTIMIZER_MODE parameter of the ALTER SESSION statement.

> **Note:** The optimizer goal applies only to queries submitted directly. Use hints to specify the access path for any SQL statements submitted from within PL/SQL. The ALTER SESSION... SET OPTIMIZER_MODE statement does not affect SQL that is run from within PL/SQL.

If you specify either the ALL_ROWS or the FIRST_ROWS(*n*) hint in a SQL statement, and if the data dictionary does not have statistics about tables accessed by the statement, then the optimizer uses default statistical values, such as allocated storage for such tables, to estimate the missing statistics and to subsequently choose an execution plan. These estimates might not be as accurate as those gathered by the DBMS_STATS package, so you should use the DBMS_STATS package to gather statistics.

If you specify hints for access paths or join operations along with either the ALL_ROWS or FIRST_ROWS(*n*) hint, then the optimizer gives precedence to the access paths and join operations specified by the hints.

See "Optimization Approaches and Goal Hints in Views" on page 17-11 for hint behavior with mergeable views.

ALL_ROWS

The ALL_ROWS hint explicitly chooses the query optimization approach to optimize a statement block with a goal of best throughput (that is, minimum total resource consumption).

all_rows_hint::=

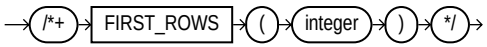
For example, the optimizer uses the query optimization approach to optimize this statement for best throughput:

```
SELECT /*+ ALL_ROWS */ employee_id, last_name, salary, job_id
  FROM employees
  WHERE employee_id = 7566;
```

FIRST_ROWS(*n*)

The FIRST_ROWS(*n*) hint instructs Oracle to optimize an individual SQL statement for fast response, choosing the plan that returns the first *n* rows most efficiently.

first_rows_hint::=



where *integer* specifies the number of rows to return.

For example, the optimizer uses the query optimization approach to optimize this statement for best response time:

```
SELECT /*+ FIRST_ROWS(10) */ employee_id, last_name, salary, job_id
  FROM employees
  WHERE department_id = 20;
```

In this example each department contains many employees. The user wants the first 10 employees of department 20 to be displayed as quickly as possible.

The optimizer ignores this hint in DELETE and UPDATE statement blocks and in SELECT statement blocks that contain any of the following syntax:

- Set operators (UNION, INTERSECT, MINUS, UNION ALL)
- GROUP BY clause
- FOR UPDATE clause
- Aggregate functions
- DISTINCT operator
- ORDER BY clauses, when there is no index on the ordering columns

These statements cannot be optimized for best response time, because Oracle must retrieve all rows accessed by the statement before returning the first row. If you specify this hint in any of these statements, then the optimizer uses the query optimization approach and optimizes for best throughput.

> **Note:** The FIRST_ROWS hint, which optimizes for the best plan to return the first single row, is retained for backward compatibility and plan stability.

RULE

The RULE hint disables the use of the query optimizer. This hint is unsupported and should not be used.

rule_hint::=

Hints for Access Paths

Each hint described in this section suggests an access path for a table.

- FULL
- CLUSTER
- HASH
- INDEX
- NO_INDEX
- INDEX_ASC
- INDEX_COMBINE
- INDEX_JOIN
- INDEX_DESC
- INDEX_FFS
- NO_INDEX_FFS
- INDEX_SS
- INDEX_SS_ASC
- INDEX_SS_DESC
- NO_INDEX_SS

Specifying one of these hints causes the optimizer to choose the specified access path only if the access path is available based on the existence of an index or cluster and on the syntactic constructs of the SQL statement. If a hint specifies an unavailable access path, then the optimizer ignores it.

You must specify the table to be accessed exactly as it appears in the statement. If the statement uses an alias for the table, then use the alias rather than the table

name in the hint. The table name within the hint should not include the schema name if the schema name is present in the statement.

See "Access Path and Join Hints on Views" on page 17-11 and "Access Path and Join Hints Inside Views" on page 17-11 for hint behavior with mergeable views.

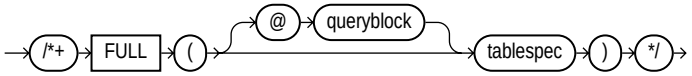
Note: For access path hints, Oracle ignores the hint if you specify the SAMPLE option in the FROM clause of a SELECT statement.

See Also: *Oracle Database SQL Reference* for more information on the SAMPLE option

FULL

The FULL hint explicitly chooses a full table scan for the specified table.

full_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7.

For example:

```
SELECT /*+ FULL(e) */ employee_id, last_name
  FROM employees e
  WHERE last_name LIKE :b1;
```

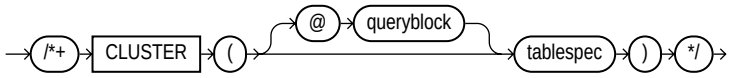
Oracle performs a full table scan on the employees table to execute this statement, even if there is an index on the last_name column that is made available by the condition in the WHERE clause.

Note: Because the employees table has alias e the hint must refer to the table by its alias rather than by its name. Also, do not specify schema names in the hint even if they are specified in the FROM clause.

CLUSTER

The CLUSTER hint explicitly chooses a cluster scan to access the specified table. It applies only to clustered objects.

cluster_hint::=

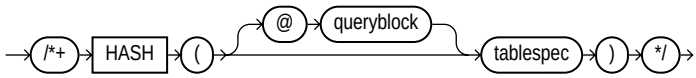


For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

HASH

The HASH hint explicitly chooses a hash scan to access the specified table. It applies only to tables stored in a cluster.

hash_hint::=

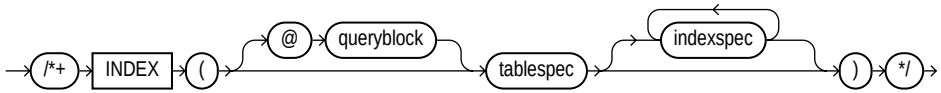


For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

INDEX

The `INDEX` hint explicitly chooses an index scan for the specified table. You can use the `INDEX` hint for domain, B-tree, bitmap, and bitmap join indexes. However, Oracle recommends using `INDEX_COMBINE` rather than `INDEX` for the combination of multiple indexes, because it is a more versatile hint.

index_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying

Global Table Hints" on page 17-7. For a description of the `indexspec` syntax, see "Specifying Complex Index Hints" on page 17-9.

This hint can optionally specify one or more indexes:

- If this hint specifies a single available index, then the optimizer performs a scan on this index. The optimizer does not consider a full table scan or a scan on another index on the table.
- If this hint specifies a list of available indexes, then the optimizer considers the cost of a scan on each index in the list and then performs the index scan with the lowest cost. The optimizer can also choose to scan multiple indexes from this list and merge the results, if such an access path has the lowest cost. The optimizer does not consider a full table scan or a scan on an index not listed in the hint.
- If this hint specifies no indexes, then the optimizer considers the cost of a scan on each available index on the table and then performs the index scan with the lowest cost. The optimizer can also choose to scan multiple indexes and merge the results, if such an access path has the lowest cost. The optimizer does not consider a full table scan.

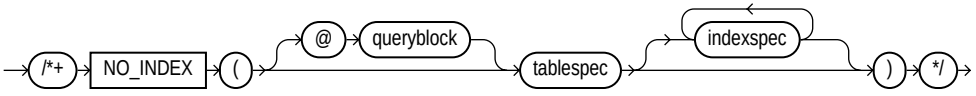
For example:

```
SELECT /*+ INDEX (employees emp_department_ix)*/
       employee_id, department_id
  FROM employees
  WHERE department_id > 50;
```

NO_INDEX

The `NO_INDEX` hint explicitly disallows a set of indexes for the specified table.

no_index_hint::=



Each parameter serves the same purpose as in the INDEX hint on page 17-17 with the following modifications:

- If this hint specifies a single available index, then the optimizer does not consider a scan on this index. Other indexes not specified are still considered.

- If this hint specifies a list of available indexes, then the optimizer does not consider a scan on any of the specified indexes. Other indexes not specified in the list are still considered.
- If this hint specifies no indexes, then the optimizer does not consider a scan on any index on the table. This behavior is the same as a NO_INDEX hint that specifies a list of all available indexes for the table.

The NO_INDEX hint applies to function-based, B-tree, bitmap, cluster, or domain indexes. If a NO_INDEX hint and an index hint (INDEX, INDEX_ASC, INDEX_DESC, INDEX_COMBINE, or INDEX_FFS) both specify the same indexes, then both the NO_INDEX hint and the index hint are ignored for the specified indexes and the optimizer considers the specified indexes.

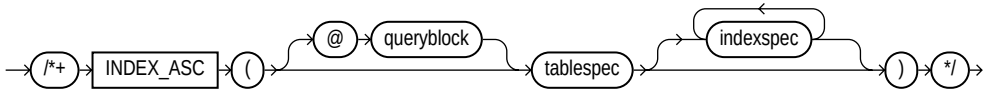
For example:

```
SELECT /*+ NO_INDEX(employees emp_empid) */ employee_id
  FROM employees
  WHERE employee_id > 200;
```

INDEX_ASC

The INDEX_ASC hint explicitly chooses an index scan for the specified table. If the statement uses an index range scan, then Oracle scans the index entries in ascending order of their indexed values.

index_asc_hint::=



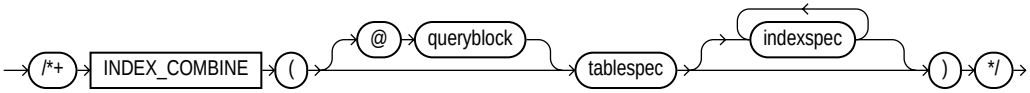
Each parameter serves the same purpose as in the INDEX hint on page 17-17.

Because the default behavior for a range scan is to scan index entries in ascending order of their indexed values, this hint does not specify anything more than the INDEX hint. However, you might want to use the INDEX_ASC hint to specify ascending range scans explicitly should the default behavior change.

INDEX_COMBINE

The INDEX_COMBINE hint explicitly chooses a bitmap access path for the table. If no indexes are given as arguments for the INDEX_COMBINE hint, then the optimizer uses whatever boolean combination of indexes has the best cost estimate for the table. If certain indexes are given as arguments, then the optimizer tries to use some boolean combination of those particular indexes.

index_combine_hint::=



Each parameter serves the same purpose as in the INDEX hint on page 17-17.

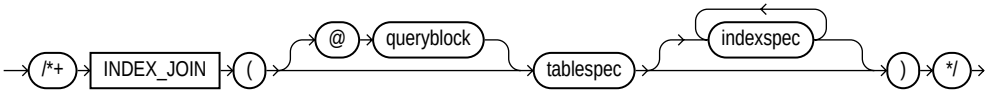
For example:

```
SELECT /*+ INDEX_COMBINE(e emp_manager_ix emp_department_ix) */ *
  FROM employees e
  WHERE manager_id = 108
     OR department_id = 110;
```

INDEX_JOIN

The `INDEX_JOIN` hint explicitly instructs the optimizer to use an index join as an access path. For the hint to have a positive effect, a sufficiently small number of indexes must exist that contain all the columns required to resolve the query.

index_join_hint::=



Each parameter serves the same purpose as in the INDEX hint on page 17-17.

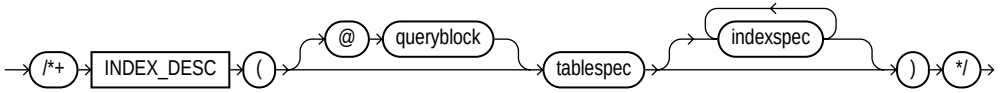
For example, the following query uses an index join to access the `manager_id` and `department_id` columns, both of which are indexed in the `employees` table.

```
SELECT /*+ INDEX_JOIN(e emp_manager_ix emp_department_ix) */ department_id
  FROM employees e
  WHERE manager_id < 110
    AND department_id < 50;
```

INDEX_DESC

The `INDEX_DESC` hint explicitly chooses an index scan for the specified table. If the statement uses an index range scan, then Oracle scans the index entries in descending order of their indexed values. In a partitioned index, the results are in descending order within each partition.

index_desc_hint::=



Each parameter serves the same purpose as in the INDEX hint on page 17-17.

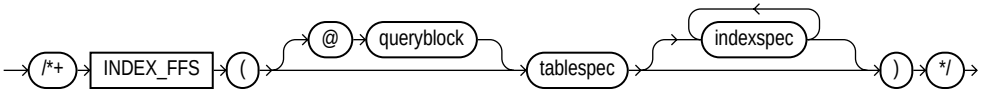
For example:

```
SELECT /*+ INDEX_DESC(e emp_name_ix) */ *
  FROM employees e;
```

INDEX_FFS

The INDEX_FFS hint causes a fast full index scan to be performed rather than a full table scan.

index_ffs_hint::=



Each parameter serves the same purpose as in the INDEX hint on page 17-17.

For example:

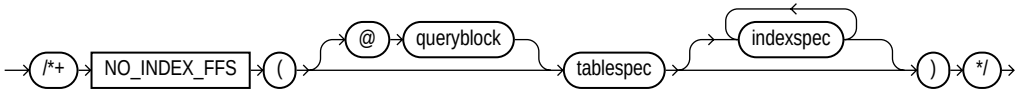
```
SELECT /*+ INDEX_FFS(e emp_name_ix) */ first_name
  FROM employees e;
```

See Also: "Full Scans" on page 14-26

NO_INDEX_FFS

The NO_INDEX_FFS hint causes the optimizer to exclude a fast full index scan of the specified indexes on the specified table.

no_index_ffs_hint::=



Each parameter serves the same purpose as in the INDEX hint on page 17-17.

For example:

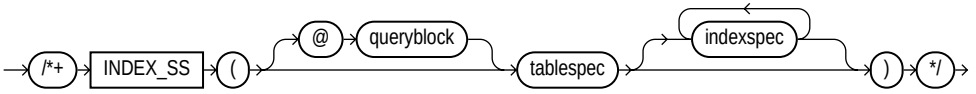
```
SELECT /*+ NO_INDEX_FFS(items item_order_ix) */ order_id
```

```
  FROM order_items items;
```

INDEX_SS

The INDEX_SS hint explicitly chooses an index skip scan for the specified table. If the statement uses an index range scan, then Oracle scans the index entries in ascending order of their indexed values. In a partitioned index, the results are in ascending order within each partition.

index_ss_hint::=



Each parameter serves the same purpose as in the INDEX hint on page 17-17.

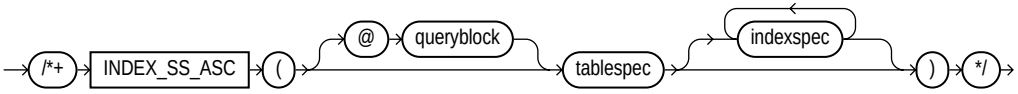
For example:

```
SELECT /*+ INDEX_SS(e emp_name_ix) */ last_name
  FROM employees e
  WHERE first_name = 'Steven';
```

INDEX_SS_ASC

The INDEX_SS_ASC hint explicitly chooses an index skip scan for the specified table. If the statement uses an index range scan, then Oracle scans the index entries in ascending order of their indexed values. In a partitioned index, the results are in ascending order within each partition.

index_ss_asc_hint::=



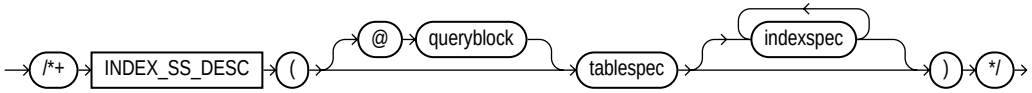
Each parameter serves the same purpose as in the INDEX hint on page 17-17.

Because the default behavior for a range scan is to scan index entries in ascending order of their indexed values, this hint does not specify anything more than the INDEX_SS hint. However, you might want to use the INDEX_SS_ASC hint to specify ascending range scans explicitly should the default behavior change.

INDEX_SS_DESC

The INDEX_SS_DESC hint explicitly chooses an index skip scan for the specified table. If the statement uses an index range scan, then Oracle scans the index entries in descending order of their indexed values. In a partitioned index, the results are in descending order within each partition.

index_ss_desc_hint::=



Each parameter serves the same purpose as in the INDEX hint on page 17-17.

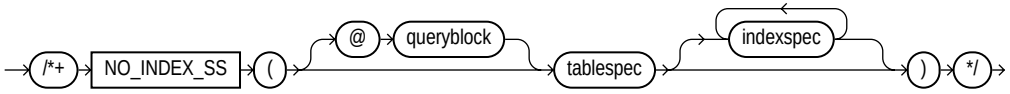
For example:

```
SELECT /*+ INDEX_SS_DESC(e emp_name_ix) */ last_name
  FROM employees e
  WHERE first_name = 'Steven';
```

NO_INDEX_SS

The NO_INDEX_SS hint causes the optimizer to exclude a skip scan of the specified indexes on the specified table.

no_index_ss_desc_hint::=



Each parameter serves the same purpose as in the INDEX hint on page 17-17.

Hints for Query Transformations

Each hint described in this section suggests a SQL query transformation.

- NO_QUERY_TRANSFORMATION
- USE_CONCAT
- NO_EXPAND
- REWRITE
- NO_REWRITE

- MERGE
- NO_MERGE
- STAR_TRANSFORMATION
- NO_STAR_TRANSFORMATION
- FACT
- NO_FACT
- UNNEST
- NO_UNNEST

NO_QUERY_TRANSFORMATION

The NO_QUERY_TRANSFORMATION hint causes the optimizer to skip all query transformations including but not limited to OR expansion, view merging, subquery unnesting, star transformation and materialized view rewrite.

no_query_transformation::=

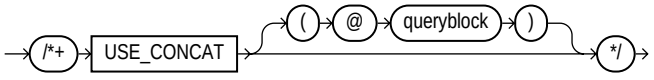
For example:

```
SELECT /*+ NO_QUERY_TRANSFORMATION */ employee_id, last_name
  FROM (SELECT *
        FROM employees e) v
  WHERE v.last_name = 'Smith';
```

USE_CONCAT

The USE_CONCAT hint forces combined OR conditions in the WHERE clause of a query to be transformed into a compound query using the UNION ALL set operator. Generally, this transformation occurs only if the cost of the query using the concatenations is cheaper than the cost without them; the USE_CONCAT hint overrides the cost consideration.

use_concat_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6.

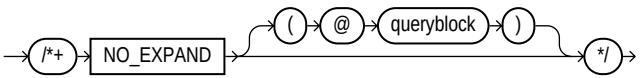
For example:

```
SELECT /*+ USE_CONCAT */ *
  FROM employees e
  WHERE manager_id = 108
     OR department_id = 110;
```

NO_EXPAND

The NO_EXPAND hint prevents the optimizer from considering OR-expansion for queries having OR conditions or IN-lists in the WHERE clause. Usually, the optimizer considers using OR expansion and uses this method if it decides that the cost is lower than not using it.

no_expand_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6.

For example:

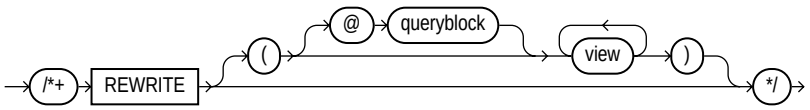
```
SELECT /*+ NO_EXPAND */ *
  FROM employees e, departments d
  WHERE e.manager_id = 108
     OR d.department_id = 110;
```

REWRITE

The REWRITE hint forces the optimizer to rewrite a query in terms of materialized views, when possible, without cost consideration. Use the REWRITE hint with or without a view list. If you use REWRITE with a view list and the list contains an eligible materialized view, then Oracle uses that view regardless of its cost.

Oracle does not consider views outside of the list. If you do not specify a view list, then Oracle searches for an eligible materialized view and always uses it regardless of the cost of the final plan.

rewrite_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6.

See Also:

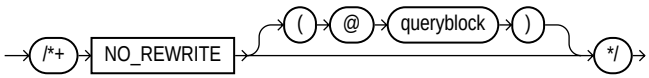
- *Oracle Database Concepts* and *Oracle Database Advanced Replication* for more information on materialized views
- *Oracle Data Warehousing Guide* for more information on using `REWRITE` with materialized views

NO_REWRITE

The `NO_REWRITE` hint disables query rewrite for the query block, overriding the setting of the parameter `QUERY_REWRITE_ENABLED`.

Note: The `NO_REWRITE` hint disables the use of function-based indexes.

no_rewrite_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6.

For example:

```
SELECT /*+ NO_REWRITE */ sum(s.amount_sold) AS dollars
  FROM sales s, times t
  WHERE s.time_id = t.time_id
  GROUP BY t.calendar_month_desc;
```

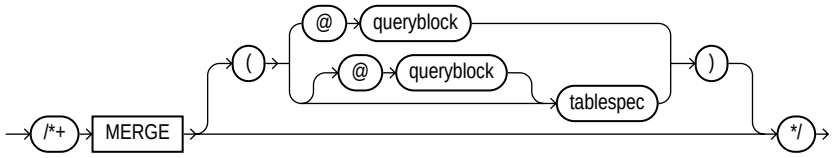
Note: The `NOREWRITE` hint has been deprecated. Use the `NO_REWRITE` hint.

MERGE

The MERGE hint lets you merge views in a query.

If a view's query block contains a GROUP BY clause or DISTINCT operator in the SELECT list, then the optimizer can merge the view into the accessing statement only if complex view merging is enabled. Complex merging can also be used to merge an IN subquery into the accessing statement if the subquery is uncorrelated.

merge_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7.

For example:

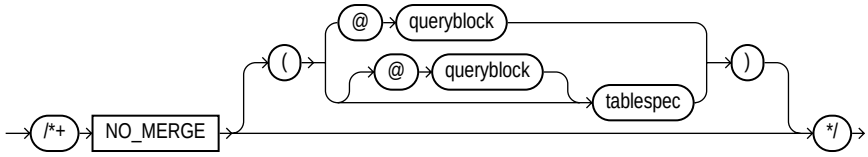
```
SELECT /*+ MERGE(v) */ e1.last_name, e1.salary, v.avg_salary
  FROM employees e1,
    (SELECT department_id, avg(salary) avg_salary
       FROM employees e2
       GROUP BY department_id) v
  WHERE e1.department_id = v.department_id AND e1.salary > v.avg_salary;
```

When the MERGE hint is used without an argument, it should be placed in the view query block. When MERGE is used with the view name as an argument, it should be placed in the surrounding query.

NO_MERGE

The NO_MERGE hint causes Oracle not to merge mergeable views.

no_merge_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7.

This hint lets the user have more influence over the way in which the view is accessed.

For example:

```
SELECT /*+NO_MERGE(seattle_dept)*/ e1.last_name, seattle_dept.department_name
  FROM employees e1,
    (SELECT location_id, department_id, department_name
       FROM departments
       WHERE location_id = 1700) seattle_dept
  WHERE e1.department_id = seattle_dept.department_id;
```

This causes view seattle_dept not to be merged.

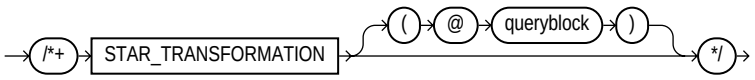
When the NO_MERGE hint is used without an argument, it should be placed in the view query block. When NO_MERGE is used with the view name as an argument, it should be placed in the surrounding query.

STAR_TRANSFORMATION

The STAR_TRANSFORMATION hint makes the optimizer use the best plan in which the transformation has been used. Without the hint, the optimizer could make a query optimization decision to use the best plan generated without the transformation, instead of the best plan for the transformed query.

Even if the hint is given, there is no guarantee that the transformation will take place. The optimizer only generates the subqueries if it seems reasonable to do so. If no subqueries are generated, then there is no transformed query, and the best plan for the untransformed query is used, regardless of the hint.

star_transformation_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6.

For example:

```
SELECT /*+ STAR_TRANSFORMATION */  *
  FROM sales s, times t, products p, channels c
```

```
WHERE s.time_id = t.time_id
  AND s.prod_id = p.product_id
  AND s.channel_id = c.channel_id
  AND p.product_status = 'obsolete';
```

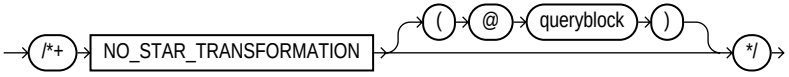
See Also:

- *Oracle Database Concepts* for a full discussion of star transformation.
- *Oracle Database Reference* for more information on the STAR_TRANSFORMATION_ENABLED initialization parameter.

NO_STAR_TRANSFORMATION

The NO_STAR_TRANSFORMATION hint causes the optimizer to not do star query transformation.

no_star_transformation_hint::=

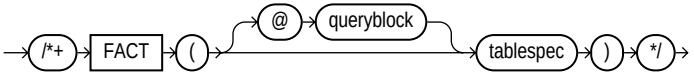


For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6.

FACT

The FACT hint is used in the context of the star transformation to indicate to the transformation that the hinted table should be considered as a fact table.

fact_hint::=

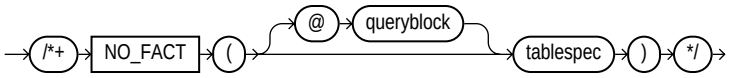


For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7.

NO_FACT

The NO_FACT hint is used in the context of the star transformation to indicate to the transformation that the hinted table should not be considered as a fact table.

no_fact_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

UNNEST

The `UNNEST` hint specifies subquery unnesting. Subquery unnesting unnests and merges the body of the subquery into the body of the query block that contains it, allowing the optimizer to consider them together when evaluating access paths and joins.

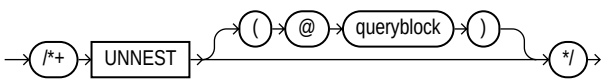
If the `UNNEST` hint is used, Oracle first verifies if the statement is valid. If the statement is not valid, then subquery unnesting cannot proceed. The statement must then must pass a heuristic and query optimization tests.

The `UNNEST` hint tells Oracle to check the subquery block for validity only. If the subquery block is valid, then subquery unnesting is enabled without checking the heuristics or costs.

See Also:

- *Oracle Database SQL Reference* for more information on unnesting nested subqueries and the conditions that make a subquery block valid
- "Subquery Unnesting" on page 14-11

unnest_hint::=

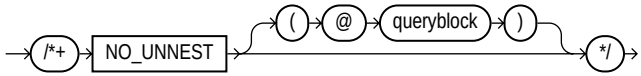


For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6.

NO_UNNEST

Use of the `NO_UNNEST` hint turns off unnesting for specific subquery blocks.

no_unnest_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6.

Hints for Join Orders

The hints in this section suggest join orders:

- LEADING
- ORDERED

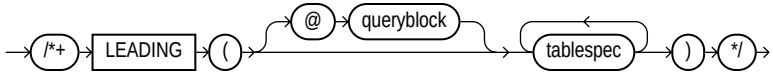
The `LEADING` hint is more versatile and preferred to the `ORDERED` hint.

LEADING

The `LEADING` hint specifies the set of tables to be used as the prefix in the execution plan. This hint is more versatile than the `ORDERED` hint.

The `LEADING` hint is ignored if the tables specified cannot be joined first in the order specified because of dependencies in the join graph. If you specify two or more conflicting `LEADING` hints, then all of them are ignored. If the `ORDERED` hint is specified, it overrides all `LEADING` hints.

leading_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

For example:

```
SELECT /*+ LEADING(e j) */ *
    FROM employees e, departments d, job_history j
    WHERE e.department_id = d.department_id
      AND e.hire_date = j.start_date;
```

ORDERED

The ORDERED hint causes Oracle to join tables in the order in which they appear in the FROM clause.

If you omit the ORDERED hint from a SQL statement performing a join, then the optimizer chooses the order in which to join the tables. You might want to use the ORDERED hint to specify a join order if you know something about the number of rows selected from each table that the optimizer does not. Such information lets you choose an inner and outer table better than the optimizer could.

ordered_hint::=

The following query is an example of the use of the ORDERED hint:

```
SELECT  /*+ORDERED */ o.order_id, c.customer_id, l.unit_price * l.quantity
  FROM customers c, order_items l, orders o
  WHERE c.cust_last_name = :b1
    AND o.customer_id = c.customer_id
    AND o.order_id = l.order_id;
```

Hints for Join Operations

Each hint described in this section suggests a join operation for a table.

- USE_NL
- NO_USE_NL
- USE_NL_WITH_INDEX
- USE_MERGE
- NO_USE_MERGE
- USE_HASH
- NO_USE_HASH

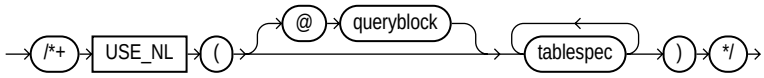
Use of the USE_NL and USE_MERGE hints is recommended with any join order hint. See "Hints for Join Orders" on page 17-31. Oracle uses these hints when the referenced table is forced to be the inner table of a join; the hints are ignored if the referenced table is the outer table.

See "Access Path and Join Hints on Views" on page 17-11 and "Access Path and Join Hints Inside Views" on page 17-11 for hint behavior with mergeable views.

USE_NL

The USE_NL hint causes Oracle to join each specified table to another row source with a nested loops join, using the specified table as the inner table.

use_nl_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7.

In the following example where a nested loop is forced through a hint, orders is accessed through a full table scan and the filter condition l.order_id = h.order_id is applied to every row. For every row that meets the filter condition, order_items is accessed through the index order_id.

```
SELECT /*+ USE_NL(l h) */ h.customer_id, l.unit_price * l.quantity
  FROM orders h ,order_items l
  WHERE l.order_id = h.order_id;
```

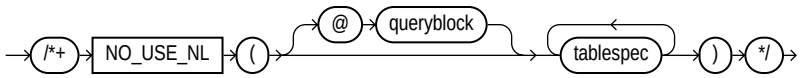
Adding an INDEX hint to the query could avoid the full table scan on orders, resulting in an execution plan similar to one used on larger systems, even though it might not be particularly efficient here.

NO_USE_NL

The NO_USE_NL hint causes the optimizer to exclude nested loops join to join each specified table to another row source using the specified table as the inner table.

When this hint is used, only hash join and sort-merge joins will be considered for the specified tables. However, in some cases tables can only be joined using nested loops. In such cases, the optimizer ignores the hint for those tables.

no_use_nl_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7.

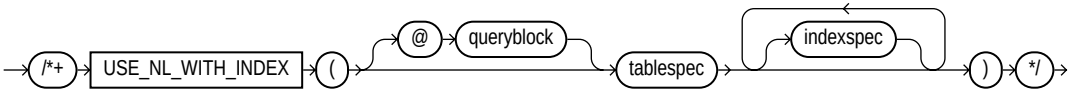
For example:

```
SELECT /*+ NO_USE_NL(l h) */ *
  FROM orders h, order_items l
  WHERE l.order_id = h.order_id
    AND l.order_id > 3500;
```

USE_NL_WITH_INDEX

The `USE_NL_WITH_INDEX` hint will cause the optimizer to join the specified table to another row source with a nested loops join using the specified table as the inner table but only under the following condition. If no index is specified, the optimizer must be able to use some index with at least one join predicate as the index key. If an index is specified, the optimizer must be able to use that index with at least one join predicate as the index key.

use_nl_with_index_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7. For a description of the `indexspec` syntax, see "Specifying Complex Index Hints" on page 17-9.

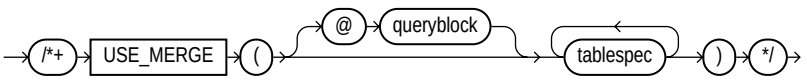
For example:

```
SELECT /*+ USE_NL_WITH_INDEX(l item_product_ix) */ *
  FROM orders h, order_items l
  WHERE l.order_id = h.order_id
    AND l.order_id > 3500;
```

USE_MERGE

The `USE_MERGE` hint causes Oracle to join each specified table with another row source using a sort-merge join.

use_merge_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

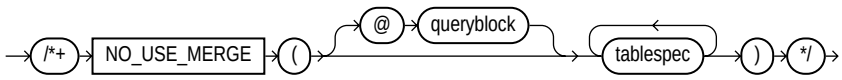
For example:

```
SELECT /*+ USE_MERGE(employees departments) */ *
  FROM employees, departments
  WHERE employees.department_id = departments.department_id;
```

NO_USE_MERGE

The NO_USE_MERGE hint causes the optimizer to exclude sort-merge join to join each specified table to another row source using the specified table as the inner table.

no_use_merge_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

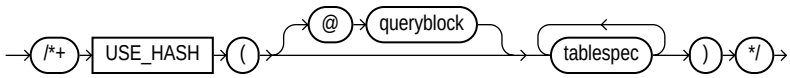
For example:

```
SELECT /*+ NO_USE_MERGE(e d) */ *
  FROM employees e, departments d
  WHERE e.department_id = d.department_id
  ORDER BY d.department_id;
```

USE_HASH

The USE_HASH hint causes Oracle to join each specified table with another row source using a hash join.

use_hash_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

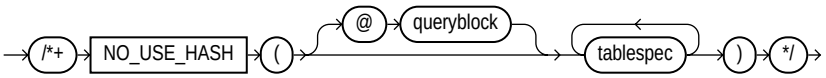
For example:

```
SELECT /*+ USE_HASH(l h) */ *
  FROM orders h, order_items l
  WHERE l.order_id = h.order_id
    AND l.order_id > 3500;
```

NO_USE_HASH

The NO_USE_HASH hint causes the optimizer to exclude hash join to join each specified table to another row source using the specified table as the inner table.

no_use_hash_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

For example:

```
SELECT /*+ NO_USE_HASH(e d) */ *
  FROM employees e, departments d
  WHERE e.department_id = d.department_id;
```

Hints for Parallel Execution

The hints described in this section determine how statements are parallelized or not parallelized when using parallel execution.

- PARALLEL
- NO_PARALLEL
- PQ_DISTRIBUTE
- PARALLEL_INDEX
- NO_PARALLEL_INDEX

See "Parallel Execution Hints on Views" on page 17-11 and "Parallel Execution Hints Inside Views" on page 17-12 for hint behavior with mergeable views.

> **See Also:** *Oracle Data Warehousing Guide* for more information on parallel execution

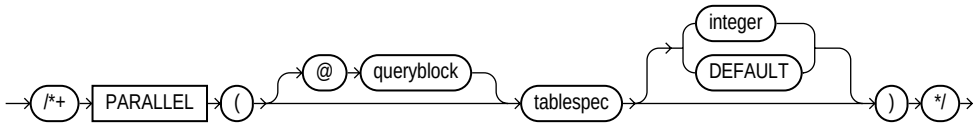
PARALLEL

The PARALLEL hint lets you specify the desired number of concurrent servers that can be used for a parallel operation. The hint applies to the SELECT, INSERT, UPDATE, and DELETE portions of a statement, as well as to the table scan portion.

> **Note:** The number of servers that can be used is twice the value in the PARALLEL hint, if sorting or grouping operations also take place.

If any parallel restrictions are violated, then the hint is ignored.

parallel_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7.

The integer value specifies the degree of parallelism for the given table. Specifying DEFAULT or no value signifies that the query coordinator should examine the settings of the initialization parameters to determine the default degree of parallelism. In the following example, the PARALLEL hint overrides the degree of parallelism specified in the employees table definition:

```
SELECT /*+ FULL(hr_emp) PARALLEL(hr_emp, 5) */ last_name
  FROM employees hr_emp;
```

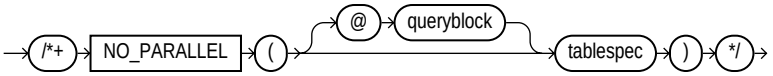
In the next example, the PARALLEL hint overrides the degree of parallelism specified in the employees table definition and tells the optimizer to use the default degree of parallelism determined by the initialization parameters.

```
SELECT /*+ FULL(hr_emp) PARALLEL(hr_emp, DEFAULT) */ last_name
  FROM employees hr_emp;
```

NO_PARALLEL

The NO_PARALLEL hint overrides a PARALLEL specification in the table clause.

no_parallel_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

The following example illustrates the `NO_PARALLEL` hint:

```
SELECT /*+ NO_PARALLEL(hr_emp) */ last_name
  FROM employees hr_emp;
```

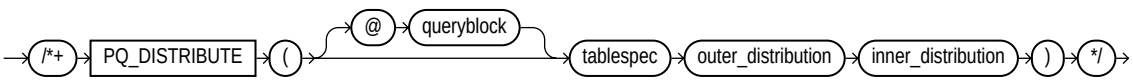
Note: The `NOPARALLEL` hint has been deprecated. Use the `NO_PARALLEL` hint.

PQ_DISTRIBUTE

The `PQ_DISTRIBUTE` hint improves the performance of parallel join operations. Do this by specifying how rows of joined tables should be distributed among producer and consumer query servers. Using this hint overrides decisions the optimizer would normally make.

Use the `EXPLAIN PLAN` statement to identify the distribution chosen by the optimizer. The optimizer ignores the distribution hint, if both tables are serial.

pq_distribute_hint::=



where:

- `outer_distribution` is the distribution for the outer table.
- `inner_distribution` is the distribution for the inner table.

For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

See Also: *Oracle Database Concepts* for more information on how Oracle parallelizes join operations

There are six combinations for table distribution. Only a subset of distribution method combinations for the joined tables is valid, as explained in Table 17–1.

Table 17–1 Distribution Hint Combinations

Distribution	Interpretation
Hash, Hash	Maps the rows of each table to consumer query servers, using a hash function on the join keys. When mapping is complete, each query server performs the join between a pair of resulting partitions. This hint is recommended when the tables are comparable in size and the join operation is implemented by hash-join or sort merge join.
Broadcast, None	All rows of the outer table are broadcast to each query server. The inner table rows are randomly partitioned. This hint is recommended when the outer table is very small compared to the inner table. As a general rule, use the Broadcast / None hint when *inner table size * number of query servers > outer table size*.
None, Broadcast	All rows of the inner table are broadcast to each consumer query server. The outer table rows are randomly partitioned. This hint is recommended when the inner table is very small compared to the outer table. As a general rule, use the None / Broadcast hint when *inner table size * number of query servers < outer table size*.
Partition, None	Maps the rows of the outer table, using the partitioning of the inner table. The inner table must be partitioned on the join keys. This hint is recommended when the number of partitions of the outer table is equal to or nearly equal to a multiple of the number of query servers; for example, 14 partitions and 15 query servers. **Note:** The optimizer ignores this hint if the inner table is not partitioned or not equijoined on the partitioning key.
None, Partition	Maps the rows of the inner table using the partitioning of the outer table. The outer table must be partitioned on the join keys. This hint is recommended when the number of partitions of the outer table is equal to or nearly equal to a multiple of the number of query servers; for example, 14 partitions and 15 query servers. **Note:** The optimizer ignores this hint if the outer table is not partitioned or not equijoined on the partitioning key.
None, None	Each query server performs the join operation between a pair of matching partitions, one from each table. Both tables must be equipartitioned on the join keys.

For example: Given two tables, `r` and `s`, that are joined using a hash-join, the following query contains a hint to use hash distribution:

```
SELECT /*+ORDERED PQ_DISTRIBUTE(s HASH, HASH) USE_HASH (s)*/ column_list
  FROM r,s
  WHERE r.c=s.c;
```

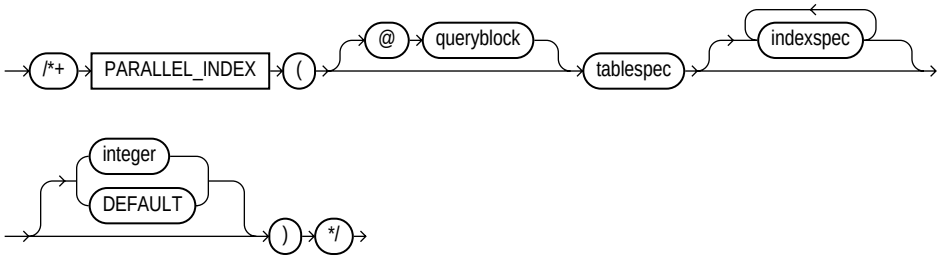
To broadcast the outer table r, the query is:

```
SELECT /*+ORDERED PQ_DISTRIBUTE(s BROADCAST, NONE) USE_HASH (s) */ column_list
  FROM r,s
  WHERE r.c=s.c;
```

PARALLEL_INDEX

The PARALLEL_INDEX hint specifies the desired number of concurrent servers that can be used to parallelize index range scans for partitioned indexes.

parallel_index_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7. For a description of the indexspec syntax, see "Specifying Complex Index Hints" on page 17-9.

The integer value specifies the degree of parallelism for the given index. Specifying DEFAULT or no value signifies the query coordinator should examine the settings of the initialization parameters to determine the default degree of parallelism.

For example:

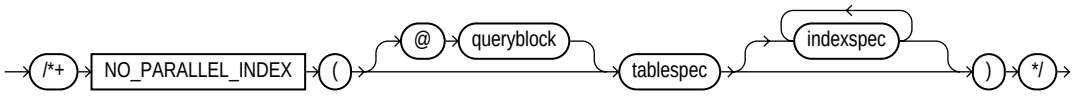
```
SELECT /*+ PARALLEL_INDEX(table1, index1, 3) */
```

In this example, there are three parallel execution processes to be used.

NO_PARALLEL_INDEX

The NO_PARALLEL_INDEX hint overrides a PARALLEL attribute setting on an index to avoid a parallel index scan operation.

no_parallel_index_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7. For a description of the `indexspec` syntax, see "Specifying Complex Index Hints" on page 17-9.

Note: The `NOPARALLEL_INDEX` hint has been deprecated. Use the `NO_PARALLEL_INDEX` hint.

Additional Hints

Several additional hints are included in this section:

- APPEND
- NOAPPEND
- CACHE
- NOCACHE
- PUSH_PRED
- NO_PUSH_PRED
- PUSH_SUBQ
- NO_PUSH_SUBQ
- QB_NAME
- CURSOR_SHARING_EXACT
- DRIVING_SITE
- DYNAMIC_SAMPLING
- SPREAD_MIN_ANALYSIS

APPEND

The `APPEND` hint lets you enable direct-path `INSERT` if your database is running in serial mode. Your database is in serial mode if you are not using Enterprise Edition.

Conventional INSERT is the default in serial mode, and direct-path INSERT is the default in parallel mode.

In direct-path INSERT, data is appended to the end of the table, rather than using existing space currently allocated to the table. As a result, direct-path INSERT can be considerably faster than conventional INSERT.

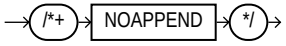
append_hint::=

> **See Also:** *Oracle Database Administrator's Guide* for information on direct-path inserts

NOAPPEND

The NOAPPEND hint enables conventional INSERT by disabling parallel mode for the duration of the INSERT statement. (Conventional INSERT is the default in serial mode, and direct-path INSERT is the default in parallel mode).

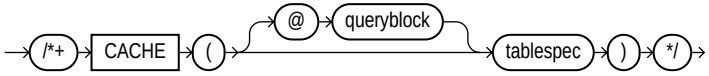
noappend_hint::=



CACHE

The CACHE hint specifies that the blocks retrieved for the table are placed at the most recently used end of the LRU list in the buffer cache when a full table scan is performed. This option is useful for small lookup tables.

cache_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7.

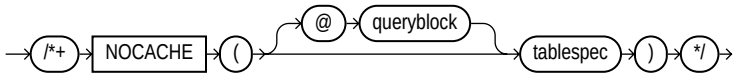
In the following example, the CACHE hint overrides the table's default caching specification:

```
SELECT /*+ FULL (hr_emp) CACHE(hr_emp) */ last_name
  FROM employees hr_emp;
```

NOCACHE

The NOCACHE hint specifies that the blocks retrieved for the table are placed at the least recently used end of the LRU list in the buffer cache when a full table scan is performed. This is the normal behavior of blocks in the buffer cache.

nocache_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7.

For example:

```
SELECT /*+ FULL(hr_emp) NOCACHE(hr_emp) */ last_name
  FROM employees hr_emp;
```

> **Note:** The CACHE and NOCACHE hints affect system statistics table scans(long tables) and table scans(short tables), as shown in the V$SYSSTAT view.

Automatic Caching of Small Tables Small tables are automatically cached, according to the criteria in Table 17–2.

Table 17–2 Table Caching Criteria

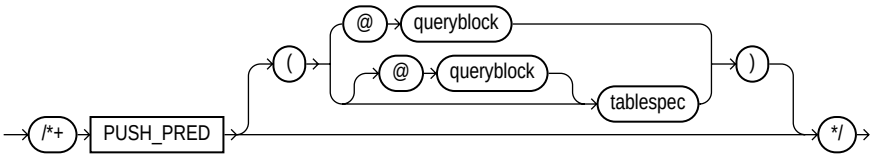
Table Size	Size Criteria	Caching
Small	Number of blocks < 20 or 2% of total cached blocks, whichever is larger	If STATISTICS_LEVEL is se to TYPICAL or higher, Oracle decides whether to cache a table depending on the table scan history. The table is cached only if a future table scan is likely to find the cached blocks. If STATISTICS_LEVEL is set to BASIC, the table is not cached.
Medium	Larger than a small table, but < 10% of total cached blocks	Oracle decides whether to cache a table on the basis of its table scan and workload history. It caches the table only if a future table scan is likely to find the cached blocks.
Large	> 10% of total cached blocks	Not cached

Automatic caching of small tables is disabled for tables that are created or altered with the CACHE attribute.

PUSH_PRED

The PUSH_PRED hint forces pushing of a join predicate into the view.

push_pred_hint::=



For a description of the queryblock syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the tablespec syntax, see "Specifying Global Table Hints" on page 17-7.

For example:

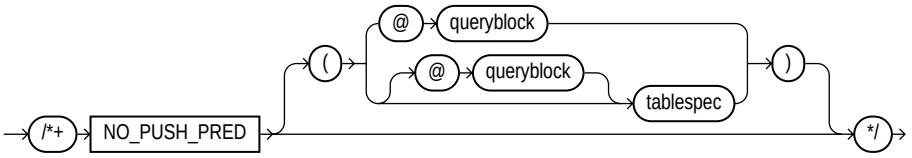
```
SELECT /*+ NO_MERGE(v) PUSH_PRED(v) */ *
    FROM employees e,
         (SELECT manager_id
            FROM employees
         ) v
  WHERE e.manager_id = v.manager_id(+)
    AND e.employee_id = 100;
```

When the PUSH_PRED hint is used without an argument, it should be placed in the view query block. When PUSH_PRED is used with the view name as an argument, it should be placed in the surrounding query.

NO_PUSH_PRED

The NO_PUSH_PRED hint prevents pushing of a join predicate into the view.

no_push_pred_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

For example:

```
SELECT /*+ NO_MERGE(v) NO_PUSH_PRED(v) */ *
    FROM employees e,
         (SELECT manager_id
            FROM employees
         ) v
  WHERE e.manager_id = v.manager_id(+)
    AND e.employee_id = 100;
```

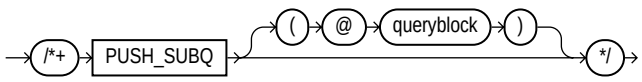
When the NO_PUSH_PRED hint is used without an argument, it should be placed in the view query block. When NO_PUSH_PRED is used with the view name as an argument, it should be placed in the surrounding query.

PUSH_SUBQ

The PUSH_SUBQ hint causes non-merged subqueries to be evaluated at the earliest possible step in the execution plan. Generally, subqueries that are not merged are executed as the last step in the execution plan. If the subquery is relatively inexpensive and reduces the number of rows significantly, then it improves performance to evaluate the subquery earlier.

This hint has no effect if the subquery is applied to a remote table or one that is joined using a merge join.

push_subq_hint::=

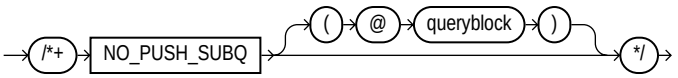


For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6.

NO_PUSH_SUBQ

The NO_PUSH_SUBQ hint causes non-merged subqueries to be evaluated as the last step in the execution plan. If the subquery is relatively expensive or does not reduce the number of rows significantly, then it improves performance to evaluate the subquery last.

no_push_subq_hint::=

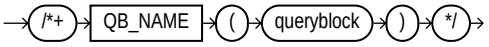


For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6.

QB_NAME

Use the `QB_NAME` hint to define a name for a query block. This name can then be used in another query block to hint tables appearing in the named query block.

qb_name::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6.

If two or more query blocks have the same name, or if the same query block is hinted twice with different names, all the names and the hints referencing them are ignored. Query blocks that are not named using this hint have unique system-generated names. These names can be displayed in the plan table and can also be used to hint tables within the query block, or in query block hints.

For example:

```
SELECT /*+ QB_NAME(qb) FULL(@qb e) */ employee_id, last_name
  FROM employees e
  WHERE last_name = 'Smith';
```

CURSOR_SHARING_EXACT

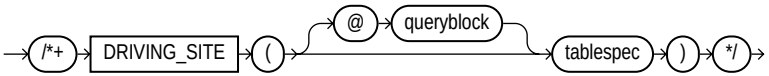
Oracle can replace literals in SQL statements with bind variables, if it is safe to do so. This is controlled with the `CURSOR_SHARING` startup parameter. The `CURSOR_SHARING_EXACT` hint causes this behavior to be switched off. In other words, Oracle executes the SQL statement without any attempt to replace literals by bind variables.

cursor_sharing_exact_hint::=

DRIVING_SITE

The `DRIVING_SITE` hint forces query execution to be done for the table at a different site than that selected by Oracle.

driving_site_hint::=



For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

For example:

```
SELECT /*+ DRIVING_SITE(departments) */ *
  FROM employees, departments@rsite
  WHERE employees.department_id = departments.department_id;
```

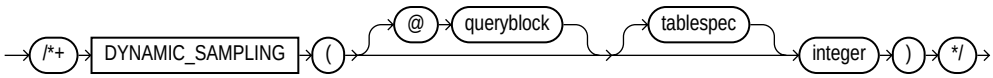
If this query is executed without the hint, then rows from `departments` are sent to the local site, and the join is executed there. With the hint, the rows from `employees` are sent to the remote site, and the query is executed there, returning the result to the local site.

This hint is useful if you are using distributed query optimization.

DYNAMIC_SAMPLING

The `DYNAMIC_SAMPLING` hint lets you control dynamic sampling to improve server performance by determining more accurate predicate selectivity and statistics for tables and indexes. You can set the value of `DYNAMIC_SAMPLING` to a value from 0 to 10. The higher the level, the more effort the compiler puts into dynamic sampling and the more broadly it is applied. Sampling defaults to cursor level unless you specify a table.

dynamic_sampling_hint::=



`integer` is a value from `0` to `10` indicating the degree of sampling. For a description of the `queryblock` syntax, see "Specifying a Query Block in a Hint" on page 17-6. For a description of the `tablespec` syntax, see "Specifying Global Table Hints" on page 17-7.

If the cardinality statistic exists, it is used. Otherwise, the DYNAMIC_SAMPLING hint enables dynamic sampling to estimate the cardinality statistic.

To apply dynamic sampling to a specific table, use the following form of the hint:

```
SELECT /*+ dynamic_sampling(employees 1) */ *
  FROM employees
  WHERE ..,
```

If there is a table hint, dynamic sampling is used unless the table is analyzed and there are no predicates on the table. For example, the following query will not result in any dynamic sampling if employees is analyzed:

```
SELECT /*+ dynamic_sampling(e 1) */ count(*)
  FROM employees e;
```

The cardinality statistic is used, if it exists. If there is a predicate, dynamic sampling is done with a table hint and cardinality is not estimated.

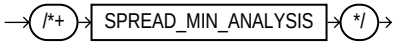
> **See Also:** "Estimating Statistics with Dynamic Sampling" on page 15-16 for information about dynamic sampling and the sampling levels that can be set

SPREAD_MIN_ANALYSIS

This hint omits some of the compile time optimizations of the rules, mainly detailed dependency graph analysis, on spreadsheets. Some optimizations such as creating filters to selectively populate spreadsheet access structures and limited rule pruning are still used.

This hint reduces compilation time because spreadsheet analysis may be lengthy if the number of rules is significantly large, such as more than several hundreds.

spread_min_analysis_hint::=



18

Using Plan Stability

This chapter describes how to use plan stability to preserve performance characteristics. Plan stability also facilitates migration from the rule-based optimizer to the query optimizer when you upgrade to a new Oracle release.

This chapter contains the following topics:

Using Plan Stability to Preserve Execution Plans

Plan stability prevents certain database environment changes from affecting the performance characteristics of applications. Such changes include changes in optimizer statistics, changes to the optimizer mode settings, and changes to parameters affecting the sizes of memory structures, such as `SORT_AREA_SIZE` and `BITMAP_MERGE_AREA_SIZE`. Plan stability is most useful when you cannot risk any performance changes in an application.

Plan stability preserves execution plans in stored outlines. An outline is implemented as a set of optimizer hints that are associated with the SQL statement. If the use of the outline is enabled for the statement, Oracle automatically considers the stored hints and tries to generate an execution plan in accordance with those hints.

Oracle can create a public or private stored outline for one or all SQL statements. The optimizer then generates equivalent execution plans from the outlines when you enable the use of stored outlines. You can group outlines into categories and control which category of outlines Oracle uses to simplify outline administration and deployment.

The plans Oracle maintains in stored outlines remain consistent despite changes to a system's configuration or statistics. Using stored outlines also stabilizes the generated execution plan if the optimizer changes in subsequent Oracle releases.

Note: If you develop applications for mass distribution, then you can use stored outlines to ensure that all customers access the same execution plans.

Using Hints with Plan Stability

The degree to which plan stability controls execution plans is dictated by how much the Oracle hint mechanism controls execution plans, because Oracle uses hints to record stored plans.

There is a one-to-one correspondence between SQL text and its stored outline. If you specify a different literal in a predicate, then a different outline applies. To avoid this, replace literals in applications with bind variables.

> **See Also:** Oracle can allow similar statements to share SQL by replacing literals with system-generated bind variables. This works with plan stability if the outline was generated using the CREATE_STORED_OUTLINES parameter, not the CREATE OUTLINE statement. Also, the outline must have been created with the CURSOR_SHARING parameter set to SIMILAR, and the parameter must also set to SIMILAR when attempting to use the outline. See Chapter 7, "Memory Configuration and Use" for more information.

Plan stability relies on preserving execution plans at a point in time when performance is satisfactory. In many environments, however, attributes for datatypes such as dates or order numbers can change rapidly. In these cases, permanent use of an execution plan can result in performance degradation over time as the data characteristics change.

This implies that techniques that rely on preserving plans in dynamic environments are somewhat contrary to the purpose of using query optimization. Query optimization attempts to produce execution plans based on statistics that accurately reflect the state of the data. Thus, you must balance the need to control plan stability with the benefit obtained from the optimizer's ability to adjust to changes in data characteristics.

How Outlines Use Hints

An outline consists primarily of a set of hints that is equivalent to the optimizer's results for the execution plan generation of a particular SQL statement. When Oracle creates an outline, plan stability examines the optimization results using the same data used to generate the execution plan. That is, Oracle uses the input to the execution plan to generate an outline, and not the execution plan itself.

Note: Oracle creates the USER_OUTLINES and USER_OUTLINE_HINTS views in the SYS tablespace based on data in the OL$ and OL$HINTS tables, respectively. Direct manipulation of the OL$, OL$HINTS, and OL$NODES tables is prohibited.

You can embed hints in SQL statements, but this has no effect on how Oracle uses outlines. Oracle considers a SQL statement that you revised with hints to be different from the original SQL statement stored in the outline.

Storing Outlines

Oracle stores outline data in the OL$, OL$HINTS, and OL$NODES tables. Unless you remove them, Oracle retains outlines indefinitely.

The only effect outlines have on caching execution plans is that the outline's category name is used in addition to the SQL text to identify whether the plan is in cache. This ensures that Oracle does not use an execution plan compiled under one category to execute a SQL statement that Oracle should compile under a different category.

Enabling Plan Stability

Settings for several parameters, especially those ending with the suffix _ENABLED, must be consistent across execution environments for outlines to function properly. These parameters are:

- QUERY_REWRITE_ENABLED
- STAR_TRANSFORMATION_ENABLED
- OPTIMIZER_FEATURES_ENABLE

Using Supplied Packages to Manage Stored Outlines

The DBMS_OUTLN and DBMS_OUTLN_EDIT package provides procedures used for managing stored outlines and their outline categories.

Users need the EXECUTE_CATALOG_ROLE role to execute DBMS_OUTLN, but public has execute privileges on DBMS_OUTLN_EDIT. The DBMS_OUTLN_EDIT package is an invoker's rights package.

Some of the useful DBMS_OUTLN and DBMS_OUTLN_EDIT procedures are:

- CLEAR_USED - Clears specified outline
- DROP_BY_CAT - Drops outlines that belong to a specified category
- UPDATE_BY_CAT - Changes the category of outlines in one specified category to a new specified category
- EXACT_TEXT_SIGNATURES - Computes an outline signature according to an exact text matching scheme
- GENERATE_SIGNATURE - Generates a signature for the specified SQL text

See Also:

- *PL/SQL Packages and Types Reference* for detailed information on using DBMS_OUTLN package procedures
- *PL/SQL Packages and Types Reference* for detailed information on using DBMS_OUTLN_EDIT package procedures

Creating Outlines

Oracle can automatically create outlines for all SQL statements, or you can create them for specific SQL statements. In either case, the outlines derive their input from the optimizer.

Oracle creates stored outlines automatically when you set the initialization parameter CREATE_STORED_OUTLINES to true. When activated, Oracle creates outlines for all compiled SQL statements. You can create stored outlines for specific statements using the CREATE OUTLINE statement.

When creating or editing a private outline, the outline data is written to global temporary tables in the SYSTEM schema. These tables are accessible with the OL$, OL$HINTS, and OL$NODES synonyms.

Note: You must ensure that schemas in which outlines are to be created have the CREATE ANY OUTLINE privilege. Otherwise, despite having turned on the CREATE_STORED_OUTLINE initialization parameter, you will not find outlines in the database after you run the application.

Also, the default system tablespace can become exhausted if the CREATE_STORED_OUTLINES initialization parameter is enabled and the running application has an abundance of literal SQL statements. If this happens, use the DBMS_OUTLN.DROP_UNUSED procedure to remove those literal SQL outlines.

See Also:

- *Oracle Database SQL Reference* for more information on the CREATE OUTLINE statement
- *PL/SQL Packages and Types Reference* for more information on the DBMS_OUTLN and DBMS_OUTLN_EDIT packages
- "Moving from RBO to the Query Optimizer" on page 18-12 for information on moving from the rule-based optimizer to the query optimizer
- *Oracle Enterprise Manager Concepts* for information on the Outline Management and Outline Editor tools, which let you create, edit, delete, and manage stored outlines with an easy-to-use graphical interface

Using Category Names for Stored Outlines

Outlines can be categorized to simplify the management task. The CREATE OUTLINE statement allows for specification of a category. The DEFAULT category is chosen if unspecified. Likewise, the CREATE_STORED_OUTLINES initialization parameter lets you specify a category name, where specifying true produces outlines in the DEFAULT category.

If you specify a category name using the CREATE_STORED_OUTLINES initialization parameter, then Oracle assigns all subsequently created outlines to that category until you reset the category name. Set the parameter to false to suspend outline generation.

If you set CREATE_STORED_OUTLINES to true, or if you use the CREATE OUTLINE statement without a category name, then Oracle assigns outlines to the category name of DEFAULT.

Using and Editing Stored Outlines

When you activate the use of stored outlines, Oracle always uses the query optimizer. This is because outlines rely on hints, and to be effective, most hints require the query optimizer.

To use stored outlines when Oracle compiles a SQL statement, set the system parameter USE_STORED_OUTLINES to true or to a category name. If you set USE_STORED_OUTLINES to true, then Oracle uses outlines in the default category. If you specify a category with the USE_STORED_OUTLINES parameter, then Oracle uses outlines in that category until you reset the parameter to another category

name or until you suspend outline use by setting USE_STORED_OUTLINES to false. If you specify a category name and Oracle does not find an outline in that category that matches the SQL statement, then Oracle searches for an outline in the default category.

If you want to use a specific outline rather than all the outlines in a category, use the ALTER OUTLINE statement to enable the specific outline. If you want to use the outlines in a category except for a specific outline, use the ALTER OUTLINE statement to disable the specific outline in the category that is being used. The ALTER OUTLINE statement can also rename a stored outline, reassign it to a different category, or regenerate it.

> **See Also:** *Oracle Database SQL Reference* for information on the ALTER OUTLINE statement

The designated outlines only control the compilation of SQL statements that have outlines. If you set USE_STORED_OUTLINES to false, then Oracle does not use outlines. When you set USE_STORED_OUTLINES to false and you set CREATE_STORED_OUTLINES to true, Oracle creates outlines but does not use them.

The USE_PRIVATE_OUTLINES parameter lets you control the use of private outlines. A private outline is an outline seen only in the current session and whose data resides in the current parsing schema. Any changes made to such an outline are not seen by any other session on the system, and applying a private outline to the compilation of a statement can only be done in the current session with the USE_PRIVATE_OUTLINES parameter. Only when you explicitly choose to save your edits back to the public area are they seen by the rest of the users.

While the optimizer usually chooses optimal plans for queries, there are times when users know things about the execution environment that are inconsistent with the heuristics that the optimizer follows. By editing outlines directly, you can tune the SQL query without having to alter the application.

When the USE_PRIVATE_OUTLINES parameter is enabled and an outlined SQL statement is issued, the optimizer retrieves the outline from the session private area rather than the public area used when USE_STORED_OUTLINES is enabled. If no outline exists in the session private area, then the optimizer will not use an outline to compile the statement.

Any CREATE OUTLINE statement requires the CREATE ANY OUTLINE privilege. Specification of the FROM clause also requires the SELECT privilege. This privilege should be granted only to those users who would have the authority to view SQL text and hint text associated with the outlined statements. This role is required for

the CREATE OUTLINE FROM command unless the issuer of the command is also the owner of the outline.

When you begin an editing session, USE_PRIVATE_OUTLINES should be set to the category to which the outline being edited belongs. When you are finished editing, this parameter should be set to `false` to restore the session to normal outline lookup according to the USE_STORED_OUTLINES parameter.

> **Note:** The USE_STORED_OUTLINES and USE_PRIVATE_OUTLINES parameters are system or session specific. They are not initialization parameters. For more information on these parameters, see the *Oracle Database SQL Reference.*

You also can use the Oracle Enterprise Manager Outline Editor to update outlines.

> **See Also:** *Oracle Enterprise Manager Concepts* for information on Oracle Enterprise Manager GUI tools

Example of Editing Outlines

Assume that you want to edit the outline `ol1`. The steps are as follows:

1. Connect to a schema from which the outlined statement can be executed, and ensure that the CREATE ANY OUTLINE and SELECT privileges have been granted.
2. Clone the outline being edited to the private area using the following:

   ```
   CREATE PRIVATE OUTLINE p_ol1 FROM ol1;
   ```

3. Edit the outline, either with the Outline Editor in Enterprise Manager or manually by querying the local OL$HINTS tables and performing DML against the appropriate hint rows. If you want to change join order, modify the appropriate LEADING hint. See "LEADING" on page 17-31.
4. If manually editing the outline, then resynchronize the stored outline definition using the following so-called identity statement:

   ```
   CREATE PRIVATE OUTLINE p_ol1 FROM PRIVATE p_ol1;
   ```

   You can also use DBMS_OUTLN_EDIT.REFRESH_PRIVATE_OUTLINE or ALTER SYSTEM FLUSH SHARED_POOL to accomplish this.

5. Test the edits. Set USE_PRIVATE_OUTLINES=TRUE, and issue the outline statement or run EXPLAIN PLAN on the statement.
6. If you want to preserve these edits for public use, then publicize the edits with the following statement.

   ```
   CREATE OR REPLACE OUTLINE ol1 FROM PRIVATE p_ol1;
   ```

7. Disable private outline usage by setting the following:

   ```
   USE_PRIVATE_OUTLINES=FALSE
   ```

See Also:

- *Oracle Database Reference* for syntax when using the CREATE_STORED_OUTLINES initialization parameter
- *Oracle Database SQL Reference* for SQL syntax when using the USE_STORED_OUTLINES and USE_PRIVATE_OUTLINES parameters
- *PL/SQL Packages and Types Reference* for more information on the DBMS_OUTLN and DBMS_OUTLN_EDIT packages

How to Tell If an Outline Is Being Used

You can test if an outline is being used with the V$SQL view. Query the OUTLINE_CATEGORY column in conjunction with the SQL statement. If an outline was applied, then this column contains the category to which the outline belongs. Otherwise, it is NULL. The OUTLINE_SID column tells you if this particular cursor is using a public outline (value is 0) or a private outline (session's SID of the corresponding session using it).

For example:

```
SELECT OUTLINE_CATEGORY, OUTLINE_SID
  FROM V$SQL
  WHERE SQL_TEXT LIKE 'SELECT COUNT(*) FROM emp%';
```

Viewing Outline Data

You can access information about outlines and related hint data that Oracle stores in the data dictionary from the following views:

- USER_OUTLINES

- USER_OUTLINE_HINTS
- ALL_OUTLINES
- ALL_OUTLINE_HINTS
- DBA_OUTLINES
- DBA_OUTLINE_HINTS

Use the following syntax to obtain outline information from the USER_OUTLINES view, where the outline category is mycat:

```
SELECT NAME, SQL_TEXT
  FROM USER_OUTLINES
  WHERE CATEGORY='mycat';
```

Oracle responds by displaying the names and text of all outlines in category mycat.

To see all generated hints for the outline name1, use the following syntax:

```
SELECT HINT
  FROM USER_OUTLINE_HINTS
  WHERE NAME='name1';
```

You can check the flags in _OUTLINES views for information on compatibility, format, and whether an outline is enabled. For example, check the ENABLED field in the USER_OUTLINES view to determine whether an outline is enabled or not.

```
SELECT NAME, CATEGORY, ENABLED FROM USER_OUTLINES;
```

> **See Also:** *Oracle Database Reference* for information on views related to outlines

Moving Outline Tables

Oracle creates the USER_OUTLINES and USER_OUTLINE_HINTS views based on data in the OL$ and OL$HINTS tables, respectively. Oracle creates these tables, and also the OL$NODES table, in the SYSTEM tablespace using a schema called OUTLN. If outlines use too much space in the SYSTEM tablespace, then you can move them. To do this, create a separate tablespace and move the outline tables into it using the following process.

1. The default system tablespace could become exhausted if the CREATE_STORED_OUTLINES parameter is on and if the running application has many literal SQL statements. If this happens, then use the DBMS_OUTLN.DROP_UNUSED procedure to remove those literal SQL outlines.

2. Use the Oracle Export utility to export the OL$, OL$HINTS, and OL$NODES tables:

```
EXP OUTLN/outln_password
    FILE = exp_file TABLES = 'OL$' 'OL$HINTS' 'OL$NODES'
```

3. Start SQL*Plus and connect to the database.

```
CONNECT OUTLN/outln_password;
```

4. Remove the previous OL$, OL$HINTS, and OL$NODES tables:

```
DROP TABLE OL$;
DROP TABLE OL$HINTS;
DROP TABLE OL$NODES;
```

5. Create a new tablespace for the tables:

```
CONNECT SYSTEM/system_password;
CREATE TABLESPACE outln_ts
  DATAFILE 'tspace.dat' SIZE 2M
  DEFAULT STORAGE (INITIAL 10K NEXT 20K MINEXTENTS 1 MAXEXTENTS 999
                   PCTINCREASE 10)
  ONLINE;
```

6. Enter the following statement to change the default tablespace:

```
ALTER USER OUTLN DEFAULT TABLESPACE outln_ts;
```

7. To force the import into the OUTLN_TS tablespace, set quota for the SYSTEM tablespace to 0K for the OUTLN user. You will also need to revoke the UNLIMITED TABLESPACE privilege and all roles, such as the RESOURCE role, that have unlimited tablespace privileges or quotas. Set a quota for the OUTLN tablespace.

8. Import the OL$, OL$HINTS, and OL$NODES tables:

```
IMP OUTLN/outln_password
    FILE = exp_file TABLES = (OL$, OL$HINTS, OL$NODES)
```

When the import process has finished, the OL$, OL$HINTS, and OL$NODES tables are re-created in the schema named OUTLN and now reside in a new tablespace called OUTLN_TS.

At the completion of the process, you may want to adjust the tablespace quotas for the OUTLN user appropriately by adding any privileges and roles that were removed in a previous step.

See Also:

- *Oracle Database Utilities* for detailed information on using the `EXPORT` and `IMPORT` utilities, note the section on reorganizing tablespaces under the discussion of the `IMPORT` utility
- *PL/SQL Packages and Types Reference* for detailed information on using the `DBMS_OUTLN` package

Using Plan Stability with Query Optimizer Upgrades

This section describes procedures you can use to significantly improve performance by taking advantage of query optimizer functionality. Plan stability provides a way to preserve a system's targeted execution plans with satisfactory performance while also taking advantage of new query optimizer features for the rest of the SQL statements.

While there are classes of SQL statements and features where an exact reproduction of the original execution plan is not guaranteed, plan stability can still be a highly useful part of the migration process. Before the migration, outline capturing of execution plan should be turned on until all or most of the applications SQL-statement have been covered. If, after the migration, there are performance problems for some specific SQL-statement, the use of the stored outline for that statement can be turned on as a way of restoring the old behavior. The use of stored outlines is not always the best way of resolving a migration related performance problem because it prevents plans from adapting to changing data properties, but it adds to the arsenal of techniques that can be used to address such problems.

Topics covered in this section are:

- Moving from RBO to the Query Optimizer
- Moving to a New Oracle Release under the Query Optimizer

Moving from RBO to the Query Optimizer

If an application was developed using the rule-based optimizer, then a considerable amount of effort might have gone into manually tuning the SQL statements to optimize performance. You can use plan stability to leverage the effort that has already gone into performance tuning by preserving the behavior of the application when upgrading from rule-based to query optimization.

By creating outlines for an application before switching to query optimization, the plans generated by the rule-based optimizer can be used, while statements

generated by newly written applications developed after the switch use query plans. To create and use outlines for an application, use the following process.

> **Note:** *Carefully read this procedure and consider its implications before executing it!*

1. Ensure that schemas in which outlines are to be created have the CREATE ANY OUTLINE privilege. For example, from SYS:

   ```
   GRANT CREATE ANY OUTLINE TO user-name
   ```

2. Execute syntax similar to the following to designate; for example, the RBOCAT outline category.

   ```
   ALTER SESSION SET CREATE_STORED_OUTLINES = rbocat;
   ```

3. Run the application long enough to capture stored outlines for all important SQL statements.
4. Suspend outline generation:

   ```
   ALTER SESSION SET CREATE_STORED_OUTLINES = FALSE;
   ```

5. Gather statistics with the DBMS_STATS package.
6. Alter the parameter OPTIMIZER_MODE to CHOOSE.
7. Enter the following syntax to make Oracle use the outlines in category RBOCAT:

   ```
   ALTER SESSION SET USE_STORED_OUTLINES = rbocat;
   ```

8. Run the application.

   Subject to the limitations of plan stability, access paths for this application's SQL statements should be unchanged.

> **Note:** If a query was not executed in step 2, then you can capture the old behavior of the query even after switching to query optimization. To do this, change the optimizer mode to RULE, create an outline for the query, and then change the optimizer mode back to CHOOSE.

Moving to a New Oracle Release under the Query Optimizer

When upgrading to a new Oracle release under query optimization, there is always a possibility that some SQL statements will have their execution plans changed due to changes in the optimizer. While such changes benefit performance, you might have applications that perform so well that you would consider any changes in their behavior to be an unnecessary risk. For such applications, you can create outlines before the upgrade using the following procedure.

> **Note:** *Carefully read this procedure and consider its implications before running it!*

1. Enter the following syntax to enable outline creation:

   ```
   ALTER SESSION SET CREATE_STORED_OUTLINES = ALL_QUERIES;
   ```

2. Run the application long enough to capture stored outlines for all critical SQL statements.
3. Enter this syntax to suspend outline generation:

   ```
   ALTER SESSION SET CREATE_STORED_OUTLINES = FALSE;
   ```

4. Upgrade the production system to the new version of the RDBMS.
5. Run the application.

After the upgrade, you can enable the use of stored outlines, or alternatively, you can use the outlines that were stored as a backup if you find that some statements exhibit performance degradation after the upgrade.

With the latter approach, you can selectively use the stored outlines for such problematic statements as follows:

1. For each problematic SQL statement, change the CATEGORY of the associated stored outline to a category name similar to this:

   ```
   ALTER OUTLINE outline_name CHANGE CATEGORY TO problemcat;
   ```

2. Enter this syntax to make Oracle use outlines from the category `problemcat`.

   ```
   ALTER SESSION SET USE_STORED_OUTLINES = problemcat;
   ```

Upgrading with a Test System

A test system, separate from the production system, can be useful for conducting experiments with optimizer behavior in conjunction with an upgrade. You can migrate statistics from the production system to the test system using import/export. This can alleviate the need to fill the tables in the test system with data.

You can move outlines between the systems by category. For example, after you create outlines in the `problemcat` category, export them by category using the query-based export option. This is a convenient and efficient way to export only selected outlines from one database to another without exporting all outlines in the source database. To do this, issue these statements:

```
EXP OUTLN/outln_password FILE=exp-file TABLES= 'OL$' 'OL$HINTS' 'OL$NODES'
QUERY='WHERE CATEGORY="problemcat"'
```

19

Using EXPLAIN PLAN

This chapter introduces execution plans, describes the SQL statement `EXPLAIN PLAN`, and explains how to interpret its output. This chapter also provides procedures for managing outlines to control application performance characteristics.

This chapter contains the following sections:

- Understanding EXPLAIN PLAN
- The PLAN_TABLE Output Table
- Running EXPLAIN PLAN
- Displaying PLAN_TABLE Output
- Reading EXPLAIN PLAN Output
- Viewing Parallel Execution with EXPLAIN PLAN
- Viewing Bitmap Indexes with EXPLAIN PLAN
- Viewing Partitioned Objects with EXPLAIN PLAN
- PLAN_TABLE Columns

See Also:

- *Oracle Database SQL Reference* for the syntax of the `EXPLAIN PLAN` statement
- Chapter 14, "The Query Optimizer"

Understanding EXPLAIN PLAN

The EXPLAIN PLAN statement displays execution plans chosen by the Oracle optimizer for SELECT, UPDATE, INSERT, and DELETE statements. A statement's execution plan is the sequence of operations Oracle performs to run the statement.

The row source tree is the core of the execution plan. It shows the following information:

- An ordering of the tables referenced by the statement
- An access method for each table mentioned in the statement
- A join method for tables affected by join operations in the statement
- Data operations like filter, sort, or aggregation

In addition to the row source tree, the plan table contains information about the following:

- Optimization, such as the cost and cardinality of each operation
- Partitioning, such as the set of accessed partitions
- Parallel execution, such as the distribution method of join inputs

The EXPLAIN PLAN results let you determine whether the optimizer selects a particular execution plan, such as, nested loops join. It also helps you to understand the optimizer decisions, such as why the optimizer chose a nested loops join instead of a hash join, and lets you understand the performance of a query.

Note: Oracle Performance Manager charts and Oracle SQL Analyze can automatically create and display explain plans for you. For more information on using explain plans, see *Oracle Enterprise Manager Concepts*.

How Execution Plans Can Change

With the query optimizer, execution plans can and do change as the underlying optimizer inputs change. EXPLAIN PLAN output shows how Oracle runs the SQL statement when the statement was explained. This can differ from the plan during actual execution for a SQL statement, because of differences in the execution environment and explain plan environment.

Execution plans can differ due to the following:

- Different Schemas

- Different Costs

Different Schemas

- The execution and explain plan happen on different databases.
- The user explaining the statement is different from the user running the statement. Two users might be pointing to different objects in the same database, resulting in different execution plans.
- Schema changes (usually changes in indexes) between the two operations.

Different Costs

Even if the schemas are the same, the optimizer can choose different execution plans if the costs are different. Some factors that affect the costs include the following:

- Data volume and statistics
- Bind variable types and values
- Initialization parameters - set globally or at session level

Minimizing Throw-Away

Examining an explain plan lets you look for throw-away in cases such as the following:

- Full scans
- Unselective range scans
- Late predicate filters
- Wrong join order
- Late filter operations

For example, in the following explain plan, the last step is a very unselective range scan that is executed 76563 times, accesses 11432983 rows, throws away 99% of them, and retains 76563 rows. Why access 11432983 rows to realize that only 76563 rows are needed?

Example 19–1 Looking for Throw-Away in an Explain Plan

```
Rows      Execution Plan
--------  ---------------------------------------------------
```

```
    12  SORT AGGREGATE
     2   SORT GROUP BY
 76563    NESTED LOOPS
 76575     NESTED LOOPS
    19      TABLE ACCESS FULL CN_PAYRUNS_ALL
 76570      TABLE ACCESS BY INDEX ROWID CN_POSTING_DETAILS_ALL
 76570       INDEX RANGE SCAN (object id 178321)
 76563     TABLE ACCESS BY INDEX ROWID CN_PAYMENT_WORKSHEETS_ALL
11432983     INDEX RANGE SCAN (object id 186024)
```

Looking Beyond Execution Plans

The execution plan operation alone cannot differentiate between well-tuned statements and those that perform poorly. For example, an EXPLAIN PLAN output that shows that a statement uses an index does not necessarily mean that the statement runs efficiently. Sometimes indexes can be extremely inefficient. In this case, you should examine the following:

- The columns of the index being used
- Their selectivity (fraction of table being accessed)

It is best to use EXPLAIN PLAN to determine an access plan, and then later prove that it is the optimal plan through testing. When evaluating a plan, examine the statement's actual resource consumption.

Using V$SQL_PLAN Views

In addition to running the EXPLAIN PLAN command and displaying the plan, you can use the V$SQL_PLAN views to display the execution plan of a SQL statement:

After the statement has executed, you can display the plan by querying the V$SQL_PLAN view. V$SQL_PLAN contains the execution plan for every statement stored in the cursor cache. Its definition is similar to the PLAN_TABLE. See "PLAN_TABLE Columns" on page 19-23.

The advantage of V$SQL_PLAN over EXPLAIN PLAN is that you do not need to know the compilation environment that was used to execute a particular statement. For EXPLAIN PLAN, you would need to set up an identical environment to get the same plan when executing the statement.

The V$SQL_PLAN_STATISTICS view provides the actual execution statistics for every operation in the plan, such as the number of output rows and elapsed time. All statistics, except the number of output rows, are cumulative. For example, the statistics for a join operation also includes the statistics for its two inputs. The

statistics in V$SQL_PLAN_STATISTICS are available for cursors that have been compiled with the STATISTICS_LEVEL initialization parameter set to ALL.

The V$SQL_PLAN_STATISTICS_ALL view enables side by side comparisons of the estimates that the optimizer provides for the number of rows and elapsed time. This view combines both V$SQL_PLAN and V$SQL_PLAN_STATISTICS information for every cursor.

See Also:

- *Oracle Database Reference* for more information on V$SQL_PLAN views
- *Oracle Database Reference* for information on the STATISTICS_LEVEL initialization parameter

EXPLAIN PLAN Restrictions

Oracle does not support EXPLAIN PLAN for statements performing implicit type conversion of date bind variables. With bind variables in general, the EXPLAIN PLAN output might not represent the real execution plan.

From the text of a SQL statement, TKPROF cannot determine the types of the bind variables. It assumes that the type is CHARACTER, and gives an error message if this is not the case. You can avoid this limitation by putting appropriate type conversions in the SQL statement.

See Also: Chapter 20, "Using Application Tracing Tools"

The PLAN_TABLE Output Table

The PLAN_TABLE is automatically created as a global temporary table to hold the output of an EXPLAIN PLAN statement for all users. PLAN_TABLE is the default sample output table into which the EXPLAIN PLAN statement inserts rows describing execution plans. See "PLAN_TABLE Columns" on page 19-23 for a description of the columns in the table.

While a PLAN_TABLE table is automatically set up for each user, you can use the SQL script `utlxplan.sql` to manually create a local PLAN_TABLE in your schema. The exact name and location of this script depends on your operating system. On Unix, it is located in the `$ORACLE_HOME/rdbms/admin` directory.

For example, run the commands in Example 19–2 from a SQL*Plus session to create the PLAN_TABLE in the HR schema.

Example 19–2 Creating a PLAN_TABLE

```
CONNECT HR/your_password
@$ORACLE_HOME/rdbms/admin/utlxplan.sql

Table created.
```

Oracle Corporation recommends that you drop and rebuild your local PLAN_TABLE table after upgrading the version of the database because the columns might change. This can cause scripts to fail or cause TKPROF to fail, if you are specifying the table.

If you want an output table with a different name, first create PLAN_TABLE manually with the `utlxplan.sql` script and then rename the table with the RENAME SQL statement. For example:

```
RENAME PLAN_TABLE TO my_plan_table;
```

Running EXPLAIN PLAN

To explain a SQL statement, use the EXPLAIN PLAN FOR clause immediately before the statement. For example:

```
EXPLAIN PLAN FOR
  SELECT last_name FROM employees;
```

This explains the plan into the PLAN_TABLE table. You can then select the execution plan from PLAN_TABLE. See "Displaying PLAN_TABLE Output" on page 19-7.

Identifying Statements for EXPLAIN PLAN

With multiple statements, you can specify a statement identifier and use that to identify your specific execution plan. Before using SET STATEMENT ID, remove any existing rows for that statement ID.

In Example 19–3, `st1` is specified as the statement identifier:

Example 19–3 Using EXPLAIN PLAN with the STATEMENT ID Clause

```
EXPLAIN PLAN
  SET STATEMENT_ID = 'st1' FOR
SELECT last_name FROM employees;
```

Specifying Different Tables for EXPLAIN PLAN

You can specify the INTO clause to specify a different table.

Example 19–4 Using EXPLAIN PLAN with the INTO Clause

```
EXPLAIN PLAN
  INTO my_plan_table
 FOR
SELECT last_name FROM employees;
```

You can specify a statement Id when using the INTO clause.

```
EXPLAIN PLAN
   SET STATEMENT_ID = 'st1'
   INTO my_plan_table
 FOR
SELECT last_name FROM employees;
```

> **See Also:** *Oracle Database SQL Reference* for a complete description of EXPLAIN PLAN syntax.

Displaying PLAN_TABLE Output

After you have explained the plan, use the following SQL scripts or PL/SQL package provided by Oracle to display the most recent plan table output:

- UTLXPLS.SQL

  This script displays the plan table output for serial processing. Example 14–2, "EXPLAIN PLAN Output" on page 14-16 is an example of the plan table output when using the UTLXPLS.SQL script.

- UTLXPLP.SQL

  This script displays the plan table output including parallel execution columns.

- DBMS_XPLAN.DISPLAY procedure

  This procedure accepts options for displaying the plan table output. You can specify:

  - A plan table name if you are using a table different than PLAN_TABLE
  - A statement Id if you have set a statement Id with the EXPLAIN PLAN
  - A format option that determines the level of detail: BASIC, SERIAL, and TYPICAL, ALL,

Some examples of the use of DBMS_XPLAN to display PLAN_TABLE output are:

```
SELECT PLAN_TABLE_OUTPUT FROM TABLE(DBMS_XPLAN.DISPLAY());

SELECT PLAN_TABLE_OUTPUT
  FROM TABLE(DBMS_XPLAN.DISPLAY('MY_PLAN_TABLE', 'st1','TYPICAL'));
```

> **See Also:** *PL/SQL Packages and Types Reference* for more information on the DBMS_XPLAN package

Customizing PLAN_TABLE Output

If you have specified a statement identifier, then you can write your own script to query the PLAN_TABLE. For example:

- Start with ID = 0 and given STATEMENT_ID.
- Use the CONNECT BY clause to walk the tree from parent to child, the join keys being STATEMENT_ID = PRIOR STATEMENT_ID and PARENT_ID = PRIOR ID.
- Use the pseudo-column LEVEL (associated with CONNECT BY) to indent the children.

```
SELECT cardinality "Rows",
   lpad(' ',level-1)||operation||' '||options||' '||object_name "Plan"
  FROM PLAN_TABLE
CONNECT BY prior id = parent_id
        AND prior statement_id = statement_id
  START WITH id = 0
        AND statement_id = 'st1'
  ORDER BY id;

   Rows Plan
------- ---------------------------------------
        SELECT STATEMENT
         TABLE ACCESS FULL EMPLOYEES
```

The NULL in the Rows column indicates that the optimizer does not have any statistics on the table. Analyzing the table shows the following:

```
   Rows Plan
------- ---------------------------------------
  16957 SELECT STATEMENT
  16957  TABLE ACCESS FULL EMPLOYEES
```

You can also select the COST. This is useful for comparing execution plans or for understanding why the optimizer chooses one execution plan over another.

Note: These simplified examples are not valid for recursive SQL.

Reading EXPLAIN PLAN Output

This section uses EXPLAIN PLAN examples to illustrate execution plans. The statement in Example 19–5 is used to display the execution plans.

Example 19–5 Statement to display the EXPLAIN PLAN

```
SELECT PLAN_TABLE_OUTPUT
  FROM TABLE(DBMS_XPLAN.DISPLAY(NULL, 'statement_id','BASIC'));
```

Examples of the output from this statement are shown in Example 19–6 and Example 19–7.

Example 19–6 EXPLAIN PLAN for Statement Id ex_plan1

```
EXPLAIN PLAN
  SET statement_id = 'ex_plan1' FOR
SELECT phone_number FROM employees
 WHERE phone_number LIKE '650%';

---------------------------------------
| Id  | Operation         | Name      |
---------------------------------------
|   0 | SELECT STATEMENT  |           |
|   1 |  TABLE ACCESS FULL| EMPLOYEES |
---------------------------------------
```

This plan shows execution of a SELECT statement. The table employees is accessed using a full table scan.

- Every row in the table employees is accessed, and the WHERE clause criteria is evaluated for every row.
- The SELECT statement returns the rows meeting the WHERE clause criteria.

Example 19–7 EXPLAIN PLAN for Statement Id ex_plan2

```
EXPLAIN PLAN
  SET statement_id = 'ex_plan2' FOR
```

```
SELECT last_name FROM employees
 WHERE last_name LIKE 'Pe%';

SELECT PLAN_TABLE_OUTPUT
  FROM TABLE(DBMS_XPLAN.DISPLAY(NULL, 'ex_plan2','BASIC'));

---------------------------------------
| Id  | Operation        | Name        |
---------------------------------------
|   0 | SELECT STATEMENT |             |
|   1 |  INDEX RANGE SCAN| EMP_NAME_IX |
---------------------------------------
```

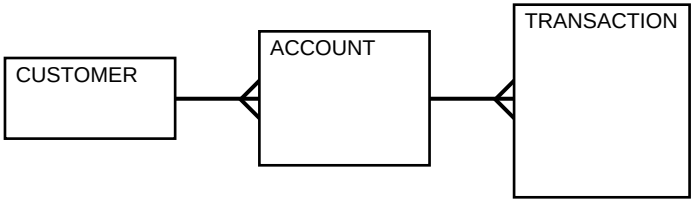
This plan shows execution of a SELECT statement.

- Index EMP_NAME_IX is used in a range scan operation to evaluate the WHERE clause criteria.
- The SELECT statement returns rows satisfying the WHERE clause conditions.

Viewing Parallel Execution with EXPLAIN PLAN

Tuning a parallel query begins much like a non-parallel query tuning exercise by choosing the driving table. However, the rules governing the choice are different. In the non-parallel case, the best driving table is typically the one that produces fewest number of rows after limiting conditions are applied. The small number of rows are joined to larger tables using non-unique indexes. For example, consider a table hierarchy consisting of CUSTOMER, ACCOUNT, and TRANSACTION.

Figure 19–1 A Table Hierarchy



CUSTOMER is the smallest table while TRANSACTION is the largest. A typical OLTP query might be to retrieve transaction information about a particular customer's account. The query would drive from the CUSTOMER table. The goal in this case is

to minimize logical I/O, which typically minimizes other critical resources including physical I/O and CPU time.

For parallel queries, the choice of the driving table is usually the largest table because parallel query can be utilized. Obviously, it would not be efficient to use parallel query on the query, because only a few rows from each table are ultimately accessed. However, what if it were necessary to identify all customers that had transactions of a certain type last month? It would be more efficient to drive from the TRANSACTION table because there are no limiting conditions on the customer table. The rows from the TRANSACTION table would be joined to the ACCOUNT table, and finally to the CUSTOMER table. In this case, the indexes utilized on the ACCOUNT and CUSTOMER table are likely to be highly selective primary key or unique indexes, rather than non-unique indexes used in the first query. Because the TRANSACTION table is large and the column is un-selective, it would be beneficial to utilize parallel query driving from the TRANSACTION table.

Parallel operations include:

- PARALLEL_TO_PARALLEL
- PARALLEL_TO_SERIAL

  A PARALLEL_TO_SERIAL operation which is always the step that occurs when rows from a parallel operation are consumed by the query coordinator. Another type of operation that does not occur in this query is a SERIAL operation. If these types of operations occur, consider making them parallel operations to improve performance because they too are potential bottlenecks.

- PARALLEL_FROM_SERIAL
- PARALLEL_TO_PARALLEL

  PARALLEL_TO_PARALLEL operations generally produce the best performance as long as the workloads in each step are relatively equivalent.

- PARALLEL_COMBINED_WITH_CHILD
- PARALLEL_COMBINED_WITH_PARENT

  A PARALLEL_COMBINED_WITH_PARENT operation occurs when the step is performed simultaneously with the parent step.

If a parallel step produces many rows, the query coordinator (QC) may not be able to consume them as fast as they are being produced. There is little that can be done to improve this.

See Also: See the OTHER_TAG column in Table 19–1, " PLAN_ TABLE Columns" on page 19-23

Viewing Parallel Queries with EXPLAIN PLAN

When using EXPLAIN PLAN with parallel queries, one parallel plan is compiled and executed. This plan is derived from the serial plan by allocating row sources specific to the parallel support in the Query Coordinator (QC) plan. The table queue row sources (PX Send and PX Receive), the granule iterator, and buffer sorts, required by the two slave set PQ model, are directly inserted into the parallel plan. This plan is the exact same plan for all the slaves if executed in parallel or for the QC if executed in serial.

Example 19–8 is a simple query for illustrating an EXPLAIN PLAN for a parallel query.

Example 19–8 Parallel Query Explain Plan

```
CREATE TABLE emp2 AS SELECT * FROM employees;
ALTER TABLE emp2 PARALLEL 2;

EXPLAIN PLAN FOR
  SELECT SUM(salary) FROM emp2 GROUP BY department_id;
SELECT PLAN_TABLE_OUTPUT FROM TABLE(DBMS_XPLAN.DISPLAY());
```

```
-------------------------------------------------------------------------------------------------
| Id  | Operation                | Name     | Rows  | Bytes | Cost  |    TQ  |IN-OUT| PQ Distrib |
-------------------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT         |          |    41 |  1066 |     4 |        |      |            |
|   1 |  PX COORDINATOR          |          |       |       |       |        |      |            |
|   2 |   PX SEND QC (RANDOM)    | :TQ10001 |    41 |  1066 |     4 |  Q1,01 | P->S | QC (RAND)  |
|   3 |    SORT GROUP BY         |          |    41 |  1066 |     4 |  Q1,01 | PCWP |            |
|   4 |     PX RECEIVE           |          |    41 |  1066 |     4 |  Q1,01 | PCWP |            |
|   5 |      PX SEND HASH        | :TQ10000 |    41 |  1066 |     4 |  Q1,00 | P->P | HASH       |
|   6 |       SORT GROUP BY      |          |    41 |  1066 |     4 |  Q1,00 | PCWP |            |
|   7 |        PX BLOCK ITERATOR |          |    41 |  1066 |     1 |  Q1,00 | PCWC |            |
|   8 |         TABLE ACCESS FULL| EMP2     |    41 |  1066 |     1 |  Q1,00 | PCWP |            |
-------------------------------------------------------------------------------------------------
```

The table EMP2 is scanned in parallel by one set of slaves while the aggregation for the GROUP BY is done by the second set. The PX BLOCK ITERATOR row source represents the splitting up of the table EMP2 into pieces so as to divide the scan workload between the parallel scan slaves. The PX SEND and PX RECEIVE row sources represent the pipe that connects the two slave sets as rows flow up from the parallel scan, get repartitioned through the HASH table queue, and then read by and

aggregated on the top slave set. The PX SEND QC row source represents the aggregated values being sent to the QC (Query Coordinator) in random (RAND) order. The PX COORDINATOR row source represents the QC or Query Coordinator which controls and schedules the parallel plan appearing below it in the plan tree.

Viewing Bitmap Indexes with EXPLAIN PLAN

Index row sources using bitmap indexes appear in the EXPLAIN PLAN output with the word BITMAP indicating the type of the index. Consider the sample query and plan in Example 19–9.

Example 19–9 EXPLAIN PLAN with Bitmap Indexes

```
EXPLAIN PLAN FOR
    SELECT * FROM t
    WHERE c1 = 2
    AND c2 <> 6
    OR c3 BETWEEN 10 AND 20;

SELECT STATEMENT
   TABLE ACCESS T BY INDEX ROWID
      BITMAP CONVERSION TO ROWID
         BITMAP OR
            BITMAP MINUS
               BITMAP MINUS
                  BITMAP INDEX C1_IND SINGLE VALUE
                  BITMAP INDEX C2_IND SINGLE VALUE
               BITMAP INDEX C2_IND SINGLE VALUE
            BITMAP MERGE
               BITMAP INDEX C3_IND RANGE SCAN
```

In this example, the predicate c1=2 yields a bitmap from which a subtraction can take place. From this bitmap, the bits in the bitmap for c2 = 6 are subtracted. Also, the bits in the bitmap for c2 IS NULL are subtracted, explaining why there are two MINUS row sources in the plan. The NULL subtraction is necessary for semantic correctness unless the column has a NOT NULL constraint. The TO ROWIDS option is used to generate the ROWIDs that are necessary for the table access.

Note: Queries using bitmap join index indicate the bitmap join index access path. The operation for bitmap join index is the same as bitmap index.

Viewing Partitioned Objects with EXPLAIN PLAN

Use EXPLAIN PLAN to see how Oracle accesses partitioned objects for specific queries.

Partitions accessed after pruning are shown in the PARTITION START and PARTITION STOP columns. The row source name for the range partition is PARTITION RANGE. For hash partitions, the row source name is PARTITION HASH.

A join is implemented using partial partition-wise join if the DISTRIBUTION column of the plan table of one of the joined tables contains PARTITION(KEY). Partial partition-wise join is possible if one of the joined tables is partitioned on its join column and the table is parallelized.

A join is implemented using full partition-wise join if the partition row source appears before the join row source in the EXPLAIN PLAN output. Full partition-wise joins are possible only if both joined tables are equi-partitioned on their respective join columns. Examples of execution plans for several types of partitioning follow.

Examples of Displaying Range and Hash Partitioning with EXPLAIN PLAN

Consider the following table, emp_range, partitioned by range on hire_date to illustrate how pruning is displayed. Assume that the tables employees and departments from the Oracle sample schema exist.

```
CREATE TABLE emp_range
PARTITION BY RANGE(hire_date)
(
PARTITION emp_p1 VALUES LESS THAN (TO_DATE('1-JAN-1992','DD-MON-YYYY')),
PARTITION emp_p2 VALUES LESS THAN (TO_DATE('1-JAN-1994','DD-MON-YYYY')),
PARTITION emp_p3 VALUES LESS THAN (TO_DATE('1-JAN-1996','DD-MON-YYYY')),
PARTITION emp_p4 VALUES LESS THAN (TO_DATE('1-JAN-1998','DD-MON-YYYY')),
PARTITION emp_p5 VALUES LESS THAN (TO_DATE('1-JAN-2001','DD-MON-YYYY'))
)
AS SELECT * FROM employees;
```

For the first example, consider the following statement:

```
EXPLAIN PLAN FOR
  SELECT * FROM emp_range;
```

Oracle displays something similar to the following:

```
-------------------------------------------------------------------------------
| Id  | Operation           | Name      | Rows  | Bytes | Cost  | Pstart| Pstop |
-------------------------------------------------------------------------------
```

```
|   0 | SELECT STATEMENT    |           |   105 | 13965 |     2 |       |       |
|   1 |  PARTITION RANGE ALL|           |   105 | 13965 |     2 |     1 |     5 |
|   2 |   TABLE ACCESS FULL | EMP_RANGE |   105 | 13965 |     2 |     1 |     5 |
-------------------------------------------------------------------------------
```

A partition row source is created on top of the table access row source. It iterates over the set of partitions to be accessed. In this example, the partition iterator covers all partitions (option ALL), because a predicate was not used for pruning. The PARTITION_START and PARTITION_STOP columns of the PLAN_TABLE show access to all partitions from 1 to 5.

For the next example, consider the following statement:

```
EXPLAIN PLAN FOR
  SELECT * FROM emp_range
  WHERE hire_date >= TO_DATE('1-JAN-1996','DD-MON-YYYY');
```

```
-------------------------------------------------------------------------------
| Id  | Operation               | Name      | Rows  | Bytes | Cost  | Pstart| Pstop |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT        |           |     3 |   399 |     2 |       |       |
|   1 |  PARTITION RANGE ITERATOR|           |     3 |   399 |     2 |     4 |     5 |
|*  2 |   TABLE ACCESS FULL     | EMP_RANGE |     3 |   399 |     2 |     4 |     5 |
-------------------------------------------------------------------------------
```

In the previous example, the partition row source iterates from partition 4 to 5, because we prune the other partitions using a predicate on hire_date.

Finally, consider the following statement:

```
EXPLAIN PLAN FOR
  SELECT * FROM emp_range
  WHERE hire_date < TO_DATE('1-JAN-1992','DD-MON-YYYY');
```

```
-------------------------------------------------------------------------------
| Id  | Operation              | Name      | Rows  | Bytes | Cost  | Pstart| Pstop |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT       |           |     1 |   133 |     2 |       |       |
|   1 |  PARTITION RANGE SINGLE|           |     1 |   133 |     2 |     1 |     1 |
|*  2 |   TABLE ACCESS FULL    | EMP_RANGE |     1 |   133 |     2 |     1 |     1 |
-------------------------------------------------------------------------------
```

In the previous example, only partition 1 is accessed and known at compile time; thus, there is no need for a partition row source.

Plans for Hash Partitioning

Oracle displays the same information for hash partitioned objects, except the partition row source name is PARTITION HASH instead of PARTITION RANGE. Also, with hash partitioning, pruning is only possible using equality or IN-list predicates.

Examples of Pruning Information with Composite Partitioned Objects

To illustrate how Oracle displays pruning information for composite partitioned objects, consider the table emp_comp that is range partitioned on hiredate and subpartitioned by hash on deptno.

```
CREATE TABLE emp_comp PARTITION BY RANGE(hire_date)
      SUBPARTITION BY HASH(department_id) SUBPARTITIONS 3
(
PARTITION emp_p1 VALUES LESS THAN (TO_DATE('1-JAN-1992','DD-MON-YYYY')),
PARTITION emp_p2 VALUES LESS THAN (TO_DATE('1-JAN-1994','DD-MON-YYYY')),
PARTITION emp_p3 VALUES LESS THAN (TO_DATE('1-JAN-1996','DD-MON-YYYY')),
PARTITION emp_p4 VALUES LESS THAN (TO_DATE('1-JAN-1998','DD-MON-YYYY')),
PARTITION emp_p5 VALUES LESS THAN (TO_DATE('1-JAN-2001','DD-MON-YYYY'))
)
AS SELECT * FROM employees;
```

For the first example, consider the following statement:

```
EXPLAIN PLAN FOR
  SELECT * FROM emp_comp;

-------------------------------------------------------------------------------
| Id  | Operation           | Name     | Rows  | Bytes | Cost  | Pstart| Pstop |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT    |          | 10120 |  1314K|    78 |       |       |
|   1 |  PARTITION RANGE ALL|          | 10120 |  1314K|    78 |     1 |     5 |
|   2 |   PARTITION HASH ALL|          | 10120 |  1314K|    78 |     1 |     3 |
|   3 |    TABLE ACCESS FULL| EMP_COMP | 10120 |  1314K|    78 |     1 |    15 |
-------------------------------------------------------------------------------
```

This example shows the plan when Oracle accesses all subpartitions of all partitions of a composite object. Two partition row sources are used for that purpose: a range partition row source to iterate over the partitions and a hash partition row source to iterate over the subpartitions of each accessed partition.

In the following example, the range partition row source iterates from partition 1 to 5, because no pruning is performed. Within each partition, the hash partition row source iterates over subpartitions 1 to 3 of the current partition. As a result, the table

access row source accesses subpartitions 1 to 15. In other words, it accesses all subpartitions of the composite object.

```
EXPLAIN PLAN FOR
  SELECT * FROM emp_comp
  WHERE hire_date = TO_DATE('15-FEB-1998', 'DD-MON-YYYY');

-------------------------------------------------------------------------------------
| Id  | Operation              | Name     | Rows  | Bytes | Cost  | Pstart| Pstop |
-------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT       |          |    20 |  2660 |    17 |       |       |
|   1 |  PARTITION RANGE SINGLE|          |    20 |  2660 |    17 |     5 |     5 |
|   2 |   PARTITION HASH ALL   |          |    20 |  2660 |    17 |     1 |     3 |
|*  3 |    TABLE ACCESS FULL   | EMP_COMP |    20 |  2660 |    17 |    13 |    15 |
-------------------------------------------------------------------------------------
```

In the previous example, only the last partition, partition 5, is accessed. This partition is known at compile time, so we do not need to show it in the plan. The hash partition row source shows accessing of all subpartitions within that partition; that is, subpartitions 1 to 3, which translates into subpartitions 13 to 15 of the emp_comp table.

Now consider the following statement:

```
EXPLAIN PLAN FOR
  SELECT * FROM emp_comp WHERE department_id = 20;

-------------------------------------------------------------------------------------
| Id  | Operation              | Name     | Rows  | Bytes | Cost  | Pstart| Pstop |
-------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT       |          |   101 | 13433 |    78 |       |       |
|   1 |  PARTITION RANGE ALL   |          |   101 | 13433 |    78 |     1 |     5 |
|   2 |   PARTITION HASH SINGLE|          |   101 | 13433 |    78 |     3 |     3 |
|*  3 |    TABLE ACCESS FULL   | EMP_COMP |   101 | 13433 |    78 |       |       |
-------------------------------------------------------------------------------------
```

In the previous example, the predicate deptno = 20 enables pruning on the hash dimension within each partition, so Oracle only needs to access a single subpartition. The number of that subpartition is known at compile time, so the hash partition row source is not needed.

Finally, consider the following statement:

```
VARIABLE dno NUMBER;
EXPLAIN PLAN FOR
  SELECT * FROM emp_comp WHERE department_id = :dno;

-------------------------------------------------------------------------------------
```

```
| Id  | Operation              | Name     | Rows  | Bytes | Cost  | Pstart| Pstop |
-------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT       |          |   101 | 13433 |    78 |       |       |
|   1 |  PARTITION RANGE ALL   |          |   101 | 13433 |    78 |     1 |     5 |
|   2 |   PARTITION HASH SINGLE|          |   101 | 13433 |    78 |   KEY |   KEY |
|*  3 |    TABLE ACCESS FULL   | EMP_COMP |   101 | 13433 |    78 |       |       |
-------------------------------------------------------------------------------------
```

The last two examples are the same, except that `deptno` = 20 has been replaced by `department_id` = :dno. In this last case, the subpartition number is unknown at compile time, and a hash partition row source is allocated. The option is `SINGLE` for that row source, because Oracle accesses only one subpartition within each partition. The `PARTITION_START` and `PARTITION_STOP` is set to `KEY`. This means that Oracle determines the number of the subpartition at run time.

Examples of Partial Partition-wise Joins

In the following example, `emp_range_did` is joined on the partitioning column `department_id` and is parallelized. This enables use of partial partition-wise join, because the `dept2` table is not partitioned. Oracle dynamically partitions the dept2 table before the join.

Example 19–10 Partial Partition-Wise Join with Range Partition

```
CREATE TABLE dept2 AS SELECT * FROM departments;
ALTER TABLE dept2 PARALLEL 2;

CREATE TABLE emp_range_did PARTITION BY RANGE(department_id)
   (PARTITION emp_p1 VALUES LESS THAN (150),
    PARTITION emp_p5 VALUES LESS THAN (MAXVALUE) )
  AS SELECT * FROM employees;

ALTER TABLE emp_range_did PARALLEL 2;

EXPLAIN PLAN FOR
SELECT /*+ PQ_DISTRIBUTE(d NONE PARTITION) ORDERED */ e.last_name,
                      d.department_name
   FROM emp_range_did e , dept2 d
   WHERE e.department_id = d.department_id ;
```

```
-----------------------------------------------------------------------------------------------------
| Id| Operation                   |Name         |Rows | Bytes |Cost|Pstart|Pstop|   TQ  |IN-OUT|PQ Distrib |
-----------------------------------------------------------------------------------------------------
|  0| SELECT STATEMENT            |             | 284 | 16188 |  6 |      |     |       |      |           |
|  1|  PX COORDINATOR             |             |     |       |    |      |     |       |      |           |
```

```
|  2|   PX SEND QC (RANDOM)        |:TQ10001     | 284 | 16188 |  6 |      |     | Q1,01 | P->S | QC (RAND) |
|* 3|    HASH JOIN                 |             | 284 | 16188 |  6 |      |     | Q1,01 | PCWP |           |
|  4|     PX PARTITION RANGE ALL   |             | 284 |  7668 |  2 |    1 |   2 | Q1,01 | PCWC |           |
|  5|      TABLE ACCESS FULL       |EMP_RANGE_DID| 284 |  7668 |  2 |    1 |   2 | Q1,01 | PCWP |           |
|  6|     BUFFER SORT              |             |     |       |    |      |     | Q1,01 | PCWC |           |
|  7|      PX RECEIVE              |             |  21 |   630 |  2 |      |     | Q1,01 | PCWP |           |
|  8|       PX SEND PARTITION (KEY)|:TQ10000     |  21 |   630 |  2 |      |     |       | S->P |PART (KEY) |
|  9|        TABLE ACCESS FULL     |DEPT2        |  21 |   630 |  2 |      |     |       |      |           |
-------------------------------------------------------------------------------------------------------------
```

The execution plan shows that the table `dept2` is scanned serially and all rows with the same partitioning column value of `emp_range_did` (`department_id`) are sent through a PART (KEY), or partition key, table queue to the same slave doing the partial partition-wise join.

In the following example, `emp_comp` is joined on the partitioning column and is parallelized. This enables use of partial partition-wise join, because the `dept2` table is not partitioned. Oracle dynamically partitions the `dept2` table before the join.

Example 19–11 Partial Partition-Wise Join with Composite Partition

```
ALTER TABLE emp_comp PARALLEL 2;

EXPLAIN PLAN FOR
SELECT /*+ PQ_DISTRIBUTE(d NONE PARTITION) ORDERED */ e.last_name,
          d.department_name
  FROM emp_comp e, dept2 d
 WHERE e.department_id = d.department_id;
SELECT PLAN_TABLE_OUTPUT FROM TABLE(DBMS_XPLAN.DISPLAY());
```

```
-------------------------------------------------------------------------------------------------------------
| Id | Operation                   | Name     | Rows | Bytes | Cost |Pstart|Pstop|    TQ  |IN-OUT| PQ Distrib
|
-------------------------------------------------------------------------------------------------------------
|  0 | SELECT STATEMENT            |          |  445 | 17800 |    5 |      |     |        |      |           |
|  1 |  PX COORDINATOR             |          |      |       |      |      |     |        |      |           |
|  2 |   PX SEND QC (RANDOM)       |:TQ10001  |  445 | 17800 |    5 |      |     |  Q1,01 | P->S | QC (RAND) |
|* 3 |    HASH JOIN                |          |  445 | 17800 |    5 |      |     |  Q1,01 | PCWP |           |
|  4 |     PX PARTITION RANGE ALL  |          |  107 |  1070 |    3 |    1 |   5 |  Q1,01 | PCWC |           |
|  5 |      PX PARTITION HASH ALL  |          |  107 |  1070 |    3 |    1 |   3 |  Q1,01 | PCWC |           |
|  6 |       TABLE ACCESS FULL     |EMP_COMP  |  107 |  1070 |    3 |    1 |  15 |  Q1,01 | PCWP |           |
|  7 |     PX RECEIVE              |          |   21 |   630 |    1 |      |     |  Q1,01 | PCWP |           |
|  8 |      PX SEND PARTITION (KEY)|:TQ10000  |   21 |   630 |    1 |      |     |  Q1,00 | P->P |PART (KEY) |
|  9 |       PX BLOCK ITERATOR     |          |   21 |   630 |    1 |      |     |  Q1,00 | PCWC |           |
| 10 |        TABLE ACCESS FULL    |DEPT2     |   21 |   630 |    1 |      |     |  Q1,00 | PCWP |           |
-------------------------------------------------------------------------------------------------------------
```

The plan shows that the optimizer selects partial partition-wise join from one of two columns. The PX SEND node type is PARTITION(KEY) and the PQ Distrib column contains the text PART (KEY), or partition key. This implies that the table dept2 is re-partitioned based on the join column department_id to be sent to the parallel slaves executing the scan of EMP_COMP and the join.

Note that in both Example 19–10 and Example 19–11 the PQ_DISTRIBUTE hint is used to explicitly force a partial partition-wise join because the query optimizer could have chosen a different plan based on cost in this query.

Examples of Full Partition-wise Joins

In the following example, emp_comp and dept_hash are joined on their hash partitioning columns. This enables use of full partition-wise join. The PARTITION HASH row source appears on top of the join row source in the plan table output.

The PX PARTITION HASH row source appears on top of the join row source in the plan table output while the PX PARTITION RANGE row source appears over the scan of emp_comp. Each parallel slave performs the join of an entire hash partition of emp_comp with an entire partition of dept_hash.

Example 19–12 Full Partition-Wise Join

```
CREATE TABLE dept_hash
   PARTITION BY HASH(department_id)
   PARTITIONS 3
   PARALLEL 2
   AS SELECT * FROM departments;

EXPLAIN PLAN FOR SELECT /*+ PQ_DISTRIBUTE(e NONE NONE) ORDERED */ e.last_name,
       d.department_name
  FROM emp_comp e, dept_hash d
 WHERE e.department_id = d.department_id;
```

```
-----------------------------------------------------------------------------------------------------------
| Id | Operation                | Name      | Rows |Bytes |Cost |Pstart|Pstop |   TQ  |IN-OUT| PQ Distrib |
-----------------------------------------------------------------------------------------------------------
|  0 | SELECT STATEMENT         |           |  106 | 2544 |   8 |      |      |       |      |            |
|  1 |  PX COORDINATOR          |           |      |      |     |      |      |       |      |            |
|  2 |   PX SEND QC (RANDOM)    | :TQ10000  |  106 | 2544 |   8 |      |      | Q1,00 | P->S | QC (RAND)  |
|  3 |    PX PARTITION HASH ALL |           |  106 | 2544 |   8 |    1 |    3 | Q1,00 | PCWC |            |
|* 4 |     HASH JOIN            |           |  106 | 2544 |   8 |      |      | Q1,00 | PCWP |            |
|  5 |      PX PARTITION RANGE ALL|         |  107 | 1070 |   3 |    1 |    5 | Q1,00 | PCWC |            |
|  6 |       TABLE ACCESS FULL  | EMP_COMP  |  107 | 1070 |   3 |    1 |   15 | Q1,00 | PCWP |            |
|  7 |      TABLE ACCESS FULL   | DEPT_HASH |   27 |  378 |   4 |    1 |    3 | Q1,00 | PCWP |            |
-----------------------------------------------------------------------------------------------------------
```

Examples of INLIST ITERATOR and EXPLAIN PLAN

An INLIST ITERATOR operation appears in the EXPLAIN PLAN output if an index implements an IN-list predicate. For example:

```
SELECT * FROM emp WHERE empno IN (7876, 7900, 7902);
```

The EXPLAIN PLAN output appears as follows:

```
OPERATION          OPTIONS           OBJECT_NAME
---------------    ---------------   --------------
SELECT STATEMENT
INLIST ITERATOR
TABLE ACCESS       BY ROWID          EMP
INDEX              RANGE SCAN        EMP_EMPNO
```

The INLIST ITERATOR operation iterates over the next operation in the plan for each value in the IN-list predicate. For partitioned tables and indexes, the three possible types of IN-list columns are described in the following sections.

When the IN-List Column is an Index Column

If the IN-list column empno is an index column but not a partition column, then the plan is as follows (the IN-list operator appears before the table operation but after the partition operation):

```
OPERATION        OPTIONS              OBJECT_NAME PARTITION_START PARTITION_STOP
---------------- ------------         ----------- --------------- --------------
SELECT STATEMENT
PARTITION RANGE  ALL                                KEY(INLIST)     KEY(INLIST)
INLIST ITERATOR
TABLE ACCESS     BY LOCAL INDEX ROWID EMP          KEY(INLIST)     KEY(INLIST)
INDEX            RANGE SCAN           EMP_EMPNO    KEY(INLIST)     KEY(INLIST)
```

The KEY(INLIST) designation for the partition start and stop keys specifies that an IN-list predicate appears on the index start/stop keys.

When the IN-List Column is an Index and a Partition Column

If empno is an indexed and a partition column, then the plan contains an INLIST ITERATOR operation before the partition operation:

```
OPERATION        OPTIONS              OBJECT_NAME PARTITION_START PARTITION_STOP
---------------- ------------         ----------- --------------- --------------
SELECT STATEMENT
INLIST ITERATOR
```

```
PARTITION RANGE  ITERATOR                        KEY(INLIST)     KEY(INLIST)
TABLE ACCESS     BY LOCAL INDEX ROWID EMP        KEY(INLIST)     KEY(INLIST)
INDEX            RANGE SCAN           EMP_EMPNO  KEY(INLIST)     KEY(INLIST)
```

When the IN-List Column is a Partition Column

If empno is a partition column and there are no indexes, then no INLIST ITERATOR operation is allocated:

```
OPERATION         OPTIONS        OBJECT_NAME   PARTITION_START   PARTITION_STOP
---------------   ------------   -----------   ---------------   -------------
SELECT STATEMENT
PARTITION RANGE   INLIST                       KEY(INLIST)       KEY(INLIST)
TABLE ACCESS      FULL           EMP           KEY(INLIST)       KEY(INLIST)
```

If emp_empno is a bitmap index, then the plan is as follows:

```
OPERATION          OPTIONS           OBJECT_NAME
---------------    ---------------   -------------
SELECT STATEMENT
INLIST ITERATOR
TABLE ACCESS       BY INDEX ROWID    EMP
BITMAP CONVERSION  TO ROWIDS
BITMAP INDEX       SINGLE VALUE      EMP_EMPNO
```

Example of Domain Indexes and EXPLAIN PLAN

You can also use EXPLAIN PLAN to derive user-defined CPU and I/O costs for domain indexes. EXPLAIN PLAN displays these statistics in the OTHER column of PLAN_TABLE.

For example, assume table emp has user-defined operator CONTAINS with a domain index emp_resume on the resume column, and the index type of emp_resume supports the operator CONTAINS. Then the query:

```
SELECT * FROM emp WHERE CONTAINS(resume, 'Oracle') = 1
```

might display the following plan:

```
OPERATION            OPTIONS      OBJECT_NAME     OTHER
-----------------    -----------  ------------    ---------------
SELECT STATEMENT
TABLE ACCESS         BY ROWID     EMP
DOMAIN INDEX                      EMP_RESUME      CPU: 300, I/O: 4
```

PLAN_TABLE Columns

The PLAN_TABLE used by the EXPLAIN PLAN statement contains the columns listed in Table 19–1.

Table 19–1 PLAN_TABLE Columns

Column	Type	Description
STATEMENT_ID	VARCHAR2(30)	Value of the optional STATEMENT_ID parameter specified in the EXPLAIN PLAN statement.
PLAN_ID	NUMBER	Unique identifier of a plan in the database.
TIMESTAMP	DATE	Date and time when the EXPLAIN PLAN statement was generated.
REMARKS	VARCHAR2(80)	Any comment (of up to 80 bytes) you want to associate with each step of the explained plan. This column is used to indicate whether an outline or SQL Profile was used for the query. If you need to add or change a remark on any row of the PLAN_TABLE, then use the UPDATE statement to modify the rows of the PLAN_TABLE.
OPERATION	VARCHAR2(30)	Name of the internal operation performed in this step. In the first row generated for a statement, the column contains one of the following values: ■ DELETE STATEMENT ■ INSERT STATEMENT ■ SELECT STATEMENT ■ UPDATE STATEMENT See Table 19–3 for more information on values for this column.
OPTIONS	VARCHAR2(225)	A variation on the operation described in the OPERATION column. See Table 19–3 for more information on values for this column.
OBJECT_NODE	VARCHAR2(128)	Name of the database link used to reference the object (a table name or view name). For local queries using parallel execution, this column describes the order in which output from operations is consumed.
OBJECT_OWNER	VARCHAR2(30)	Name of the user who owns the schema containing the table or index.
OBJECT_NAME	VARCHAR2(30)	Name of the table or index.

Table 19–1 (Cont.) PLAN_TABLE Columns

Column	Type	Description
OBJECT_ALIAS	VARCHAR2(65)	Unique alias of a table or view in a SQL statement. For indexes, it is the object alias of the underlying table.
OBJECT_INSTANCE	NUMERIC	Number corresponding to the ordinal position of the object as it appears in the original statement. The numbering proceeds from left to right, outer to inner with respect to the original statement text. View expansion results in unpredictable numbers.
OBJECT_TYPE	VARCHAR2(30)	Modifier that provides descriptive information about the object; for example, NON-UNIQUE for indexes.
OPTIMIZER	VARCHAR2(255)	Current mode of the optimizer.
SEARCH_COLUMNS	NUMBERIC	Not currently used.
ID	NUMERIC	A number assigned to each step in the execution plan.
PARENT_ID	NUMERIC	The ID of the next execution step that operates on the output of the ID step.
DEPTH	NUMERIC	Depth of the operation in the row source tree that the plan represents. The value can be used for indenting the rows in a plan table report.
POSITION	NUMERIC	For the first row of output, this indicates the optimizer's estimated cost of executing the statement. For the other rows, it indicates the position relative to the other children of the same parent.
COST	NUMERIC	Cost of the operation as estimated by the optimizer's query approach. Cost is not determined for table access operations. The value of this column does not have any particular unit of measurement; it is merely a weighted value used to compare costs of execution plans. The value of this column is a function of the CPU_COST and IO_COST columns.
CARDINALITY	NUMERIC	Estimate by the query optimization approach of the number of rows accessed by the operation.
BYTES	NUMERIC	Estimate by the query optimization approach of the number of bytes accessed by the operation.

Table 19–1 (Cont.) PLAN_TABLE Columns

Column	Type	Description
OTHER_TAG	VARCHAR2(255)	Describes the contents of the OTHER column. Values are: ■ SERIAL (blank) - Serial execution. Currently, SQL is not loaded in the OTHER column for this case. ■ SERIAL_FROM_REMOTE (S -> R) - Serial execution at a remote site. ■ PARALLEL_FROM_SERIAL (S -> P) - Serial execution. Output of step is partitioned or broadcast to parallel execution servers. ■ PARALLEL_TO_SERIAL (P -> S) - Parallel execution. Output of step is returned to serial query coordinator (QC) process. ■ PARALLEL_TO_PARALLEL (P -> P) - Parallel execution. Output of step is repartitioned to second set of parallel execution servers. ■ PARALLEL_COMBINED_WITH_PARENT (PWP) - Parallel execution; Output of step goes to next step in same parallel process. No interprocess communication to parent. ■ PARALLEL_COMBINED_WITH_CHILD (PWC) - Parallel execution. Input of step comes from prior step in same parallel process. No interprocess communication from child.
PARTITION_START	VARCHAR2(255)	Start partition of a range of accessed partitions. It can take one of the following values: *n* indicates that the start partition has been identified by the SQL compiler, and its partition number is given by *n*. KEY indicates that the start partition will be identified at run time from partitioning key values. ROW REMOVE_LOCATION indicates that the start partition (same as the stop partition) will be computed at run time from the location of each record being retrieved. The record location is obtained by a user or from a global index. INVALID indicates that the range of accessed partitions is empty.

Table 19–1 (Cont.) PLAN_TABLE Columns

Column	Type	Description
PARTITION_STOP	VARCHAR2(255)	Stop partition of a range of accessed partitions. It can take one of the following values: *n* indicates that the stop partition has been identified by the SQL compiler, and its partition number is given by *n*. KEY indicates that the stop partition will be identified at run time from partitioning key values. ROW REMOVE_LOCATION indicates that the stop partition (same as the start partition) will be computed at run time from the location of each record being retrieved. The record location is obtained by a user or from a global index. INVALID indicates that the range of accessed partitions is empty.
PARTITION_ID	NUMERIC	Step that has computed the pair of values of the PARTITION_START and PARTITION_STOP columns.
OTHER	LONG	Other information that is specific to the execution step that a user might find useful. See the OTHER_TAG column.
DISTRIBUTION	VARCHAR2(30)	Method used to distribute rows from producer query servers to consumer query servers. See Table 19–2 for more information on the possible values for this column. For more information about consumer and producer query servers, see *Oracle Data Warehousing Guide*.
CPU_COST	NUMERIC	CPU cost of the operation as estimated by the query optimizer's approach. The value of this column is proportional to the number of machine cycles required for the operation. For statements that use the rule-based approach, this column is null.
IO_COST	NUMERIC	I/O cost of the operation as estimated by the query optimizer's approach. The value of this column is proportional to the number of data blocks read by the operation. For statements that use the rule-based approach, this column is null.
TEMP_SPACE	NUMERIC	Temporary space, in bytes, used by the operation as estimated by the query optimizer's approach. For statements that use the rule-based approach, or for operations that do not use any temporary space, this column is null.
ACCESS_PREDICATES	VARCHAR2(4000)	Predicates used to locate rows in an access structure. For example, start or stop predicates for an index range scan.
FILTER_PREDICATES	VARCHAR2(4000)	Predicates used to filter rows before producing them.

Table 19–1 (Cont.) PLAN_TABLE Columns

Column	Type	Description
PROJECTION	VARCHAR2(4000)	Expressions produced by the operation.
TIME	NUMBER(20,2)	Elapsed time in seconds of the operation as estimated by query optimization. For statements that use the rule-based approach, this column is null.
QBLOCK_NAME	VARCHAR2(30)	Name of the query block, either system-generated or defined by the user with the QB_NAME hint.

Table 19–2 describes the values that can appear in the DISTRIBUTION column:

Table 19–2 Values of DISTRIBUTION Column of the PLAN_TABLE

DISTRIBUTION Text	Interpretation
PARTITION (ROWID)	Maps rows to query servers based on the partitioning of a table or index using the rowid of the row to UPDATE/DELETE.
PARTITION (KEY)	Maps rows to query servers based on the partitioning of a table or index using a set of columns. Used for partial partition-wise join, PARALLEL INSERT, CREATE TABLE AS SELECT of a partitioned table, and CREATE PARTITIONED GLOBAL INDEX.
HASH	Maps rows to query servers using a hash function on the join key. Used for PARALLEL JOIN or PARALLEL GROUP BY.
RANGE	Maps rows to query servers using ranges of the sort key. Used when the statement contains an ORDER BY clause.
ROUND-ROBIN	Randomly maps rows to query servers.
BROADCAST	Broadcasts the rows of the entire table to each query server. Used for a parallel join when one table is very small compared to the other.
QC (ORDER)	The query coordinator (QC) consumes the input in order, from the first to the last query server. Used when the statement contains an ORDER BY clause.
QC (RANDOM)	The query coordinator (QC) consumes the input randomly. Used when the statement does not have an ORDER BY clause.

Table 19–3 lists each combination of OPERATION and OPTIONS produced by the EXPLAIN PLAN statement and its meaning within an execution plan.

Table 19–3 OPERATION and OPTIONS Values Produced by EXPLAIN PLAN

Operation	Option	Description
AND-EQUAL	.	Operation accepting multiple sets of rowids, returning the intersection of the sets, eliminating duplicates. Used for the single-column indexes access path.
BITMAP	CONVERSION	TO ROWIDS converts bitmap representations to actual rowids that can be used to access the table. FROM ROWIDS converts the rowids to a bitmap representation. COUNT returns the number of rowids if the actual values are not needed.
BITMAP	INDEX	SINGLE VALUE looks up the bitmap for a single key value in the index. RANGE SCAN retrieves bitmaps for a key value range. FULL SCAN performs a full scan of a bitmap index if there is no start or stop key.
BITMAP	MERGE	Merges several bitmaps resulting from a range scan into one bitmap.
BITMAP	MINUS	Subtracts bits of one bitmap from another. Row source is used for negated predicates. Can be used only if there are nonnegated predicates yielding a bitmap from which the subtraction can take place. An example appears in "Viewing Bitmap Indexes with EXPLAIN PLAN" on page 19-13.
BITMAP	OR	Computes the bitwise OR of two bitmaps.
BITMAP	AND	Computes the bitwise AND of two bitmaps.
BITMAP	KEY ITERATION	Takes each row from a table row source and finds the corresponding bitmap from a bitmap index. This set of bitmaps are then merged into one bitmap in a following BITMAP MERGE operation.
CONNECT BY	.	Retrieves rows in hierarchical order for a query containing a CONNECT BY clause.
CONCATENATION	.	Operation accepting multiple sets of rows returning the union-all of the sets.
COUNT	.	Operation counting the number of rows selected from a table.
COUNT	STOPKEY	Count operation where the number of rows returned is limited by the ROWNUM expression in the WHERE clause.

Table 19–3 (Cont.) OPERATION and OPTIONS Values Produced by EXPLAIN PLAN

Operation	Option	Description
DOMAIN INDEX	.	Retrieval of one or more rowids from a domain index. The options column contain information supplied by a user-defined domain index cost function, if any.
FILTER	.	Operation accepting a set of rows, eliminates some of them, and returns the rest.
FIRST ROW	.	Retrieval of only the first row selected by a query.
FOR UPDATE	.	Operation retrieving and locking the rows selected by a query containing a FOR UPDATE clause.
HASH JOIN (These are join operations.)	.	Operation joining two sets of rows and returning the result. This join method is useful for joining large data sets of data (DSS, Batch). The join condition is an efficient way of accessing the second table. Query optimizer uses the smaller of the two tables / data sources to build a hash table on the join key in memory. Then it scans the larger table, probing the hash table to find the joined rows.
HASH JOIN	ANTI	Hash (left) antijoin
HASH JOIN	SEMI	Hash (left) semijoin
HASH JOIN	RIGHT ANTI	Hash right antijoin
HASH JOIN	RIGHT SEMI	Hash right semijoin
HASH JOIN	OUTER	Hash (left) outer join
HASH JOIN	RIGHT OUTER	Hash right outer join
INDEX (These are access methods.)	UNIQUE SCAN	Retrieval of a single rowid from an index.
INDEX	RANGE SCAN	Retrieval of one or more rowids from an index. Indexed values are scanned in ascending order.
INDEX	RANGE SCAN DESCENDING	Retrieval of one or more rowids from an index. Indexed values are scanned in descending order.
INDEX	FULL SCAN	Retrieval of all rowids from an index when there is no start or stop key. Indexed values are scanned in ascending order.
INDEX	FULL SCAN DESCENDING	Retrieval of all rowids from an index when there is no start or stop key. Indexed values are scanned in descending order.

Table 19–3 (Cont.) OPERATION and OPTIONS Values Produced by EXPLAIN PLAN

Operation	Option	Description
INDEX	FAST FULL SCAN	Retrieval of all rowids (and column values) using multiblock reads. No sorting order can be defined. Compares to a full table scan on only the indexed columns. Only available with the cost based optimizer.
INDEX	SKIP SCAN	Retrieval of rowids from a concatenated index without using the leading column(s) in the index. Introduced in Oracle9i. Only available with the cost based optimizer.
INLIST ITERATOR	.	Iterates over the next operation in the plan for each value in the IN-list predicate.
INTERSECTION	.	Operation accepting two sets of rows and returning the intersection of the sets, eliminating duplicates.
MERGE JOIN (These are join operations.)	.	Operation accepting two sets of rows, each sorted by a specific value, combining each row from one set with the matching rows from the other, and returning the result.
MERGE JOIN	OUTER	Merge join operation to perform an outer join statement.
MERGE JOIN	ANTI	Merge antijoin.
MERGE JOIN	SEMI	Merge semijoin.
MERGE JOIN	CARTESIAN	Can result from 1 or more of the tables not having any join conditions to any other tables in the statement. Can occur even with a join and it may not be flagged as CARTESIAN in the plan.
CONNECT BY	.	Retrieval of rows in hierarchical order for a query containing a CONNECT BY clause.
MINUS	.	Operation accepting two sets of rows and returning rows appearing in the first set but not in the second, eliminating duplicates.
NESTED LOOPS (These are join operations.)	.	Operation accepting two sets of rows, an outer set and an inner set. Oracle compares each row of the outer set with each row of the inner set, returning rows that satisfy a condition. This join method is useful for joining small subsets of data (OLTP). The join condition is an efficient way of accessing the second table.
NESTED LOOPS	OUTER	Nested loops operation to perform an outer join statement.

Table 19–3 (Cont.) OPERATION and OPTIONS Values Produced by EXPLAIN PLAN

Operation	Option	Description
PARTITION	.	Iterates over the next operation in the plan for each partition in the range given by the PARTITION_START and PARTITION_STOP columns. PARTITION describes partition boundaries applicable to a single partitioned object (table or index) or to a set of equi-partitioned objects (a partitioned table and its local indexes). The partition boundaries are provided by the values of PARTITION_START and PARTITION_STOP of the PARTITION. Refer to Table 19–1 for valid values of partition start / stop.
PARTITION	SINGLE	Access one partition.
PARTITION	ITERATOR	Access many partitions (a subset).
PARTITION	ALL	Access all partitions.
PARTITION	INLIST	Similar to iterator, but based on an IN-list predicate.
PARTITION	INVALID	Indicates that the partition set to be accessed is empty.
PX ITERATOR	BLOCK, CHUNK	Implements the division of an object into block or chunk ranges among a set of parallel slaves
PX COORDINATOR	.	Implements the Query Coordinator which controls, schedules, and executes the parallel plan below it using parallel query slaves. It also represents a serialization point, as the end of the part of the plan executed in parallel and always has a PX SEND QC operation below it.
PX PARTITION	.	Same semantics as the regular PARTITION operation except that it appears in a parallel plan
PX RECEIVE	.	Shows the consumer / receiver slave node reading repartitioned data from a send / producer (QC or slave) executing on a PX SEND node. This information was formerly displayed into the DISTRIBUTION column. See Table 19–2 on page 19-27.
PX SEND	QC (RANDOM), HASH, RANGE	Implements the distribution method taking place between two parallel set of slaves. Shows the boundary between two slave sets and how data is repartitioned on the send / producer side (QC or side. This information was formerly displayed into the DISTRIBUTION column. See Table 19–2 on page 19-27.
REMOTE	.	Retrieval of data from a remote database.
SEQUENCE	.	Operation involving accessing values of a sequence.
SORT	AGGREGATE	Retrieval of a single row that is the result of applying a group function to a group of selected rows.
SORT	UNIQUE	Operation sorting a set of rows to eliminate duplicates.

Table 19–3 (Cont.) OPERATION and OPTIONS Values Produced by EXPLAIN PLAN

Operation	Option	Description
SORT	GROUP BY	Operation sorting a set of rows into groups for a query with a GROUP BY clause.
SORT	JOIN	Operation sorting a set of rows before a merge-join.
SORT	ORDER BY	Operation sorting a set of rows for a query with an ORDER BY clause.
TABLE ACCESS (These are access methods.)	FULL	Retrieval of all rows from a table.
TABLE ACCESS	SAMPLE	Retrieval of sampled rows from a table.
TABLE ACCESS	CLUSTER	Retrieval of rows from a table based on a value of an indexed cluster key.
TABLE ACCESS	HASH	Retrieval of rows from table based on hash cluster key value.
TABLE ACCESS	BY ROWID RANGE	Retrieval of rows from a table based on a rowid range.
TABLE ACCESS	SAMPLE BY ROWID RANGE	Retrieval of sampled rows from a table based on a rowid range.
TABLE ACCESS	BY USER ROWID	If the table rows are located using user-supplied rowids.
TABLE ACCESS	BY INDEX ROWID	If the table is nonpartitioned and rows are located using index(es).
TABLE ACCESS	BY GLOBAL INDEX ROWID	If the table is partitioned and rows are located using only global indexes.
TABLE ACCESS	BY LOCAL INDEX ROWID	If the table is partitioned and rows are located using one or more local indexes and possibly some global indexes. Partition Boundaries: The partition boundaries might have been computed by: A previous PARTITION step, in which case the PARTITION_START and PARTITION_STOP column values replicate the values present in the PARTITION step, and the PARTITION_ID contains the ID of the PARTITION step. Possible values for PARTITION_START and PARTITION_STOP are NUMBER(n), KEY, INVALID. The TABLE ACCESS or INDEX step itself, in which case the PARTITION_ID contains the ID of the step. Possible values for PARTITION_START and PARTITION_STOP are NUMBER(n), KEY, ROW REMOVE_LOCATION (TABLE ACCESS only), and INVALID.

Table 19–3 (Cont.) OPERATION and OPTIONS Values Produced by EXPLAIN PLAN

Operation	Option	Description
UNION	.	Operation accepting two sets of rows and returns the union of the sets, eliminating duplicates.
VIEW	.	Operation performing a view's query and then returning the resulting rows to another operation.

See Also: *Oracle Database Reference* for more information on PLAN_TABLE

20

Using Application Tracing Tools

Oracle provides several tracing tools that can help you monitor and analyze applications running against an Oracle database.

End to End Application Tracing can identify the source of an excessive workload, such as a high load SQL statement, by client identifier, service, module, or action. This isolates the problem to a specific user, service, or application component.

Oracle provides the `trcsess` command-line utility that consolidates tracing information based on specific criteria.

The SQL Trace facility and `TKPROF` are two basic performance diagnostic tools that can help you monitor applications running against the Oracle Server.

This chapter contains the following sections:

> **See Also:** *SQL*Plus User's Guide and Reference* for information about the use of Autotrace to trace and tune SQL*Plus statements

End to End Application Tracing

End to End Application Tracing simplifies the process of diagnosing performance problems in a multitier environments. In multitier environments, a request from an end client is routed to different database sessions by the middle tier making it difficult to track a client across different database sessions. End to End Application Tracing uses a client identifier to uniquely trace a specific end-client through all tiers to the database server.

This feature could identify the source of an excessive workload, such as a high load SQL statement, and allow you to contact the specific user responsible. Also, a user having problems can contact you and then you can identify what that user's session is doing at the database level.

End to End Application Tracing also simplifies management of application workloads by tracking specific modules and actions in a service.

Workload problems can be identified by End to End Application Tracing for:

- Client identifier - specifies an end user based on the logon Id, such as `HR.HR`
- Service - specifies a group of applications with common attributes, service level thresholds, and priorities; or a single application, such as `ACCTG` for an accounting application
- Module - specifies a functional block, such as Accounts Receivable or General Ledger, of an application
- Action - specifies an action, such as an INSERT or UPDATE operation, in a module

After tracing information is written to files, the information can be consolidated by the `trcsess` utility and diagnosed with an analysis utility such as `TKPROF`.

To to create services on single instance Oracle databases, you can use the `CREATE_SERVICE` procedure in the `DBMS_SERVICE` package or set the `SERVICE_NAMES` initialization parameter.

The module and action names are set by the application developer. For example, you would use the `SET_MODULE` and `SET_ACTION` procedures in the `DBMS_APPICATION_INFO` package to set these values in a PL/SQL program.

See Also:

- *Oracle Database Concepts* for information on services
- *Oracle Call Interface Programmer's Guide* for information on setting the necessary parameters in an OCI application
- *PL/SQL Packages and Types Reference* for information on the DBMS_MONITOR, DBMS_SERVICE, and DBMS_APPICATION_INFO packages
- *Oracle Database Reference* for information on V$ views and initialization parameters

Accessing the End to End Tracing with Oracle Enterprise Manager

The primary interface for End to End Application Tracing is the Oracle Enterprise Manager Database Control. To manage End to End Application Tracing through Oracle Enterprise Manager Database Control:

- On the **Performance** page, select the **Top Consumers** link under **Additional Monitoring Links**.
- Click the **Top Services**, **Top Modules**, **Top Actions**, **Top Clients**, or **Top Sessions** links to display the top consumers.
- On the individual **Top Consumers** pages, you can enable and disable statistics gathering and tracing for specific consumers.

See Also: *Oracle Enterprise Manager Concepts* and Oracle Enterprise Manager online help for information on tracing tools available with Oracle Enterprise Manager

Managing End to End Tracing with APIs and Views

While the primary interface for End to End Application Tracing is the Oracle Enterprise Manager Database Control, this feature can be managed with DBMS_MONITOR package APIs.

Enabling and Disabling Statistic Gathering for End to End Tracing

To gather the appropriate statistics using PL/SQL, you need to enable statistics gathering for client identifier, service, module, or action using procedures in the DBMS_MONITOR package.

You can gather statistics by:

- Client identifier
- Service name
- Combination of service, module, and action names

The default level is the session-level statistics gathering. Statistics gathering is global for the database and continues after an instance is restarted.

Statistic Gathering for Client Identifier The procedure CLIENT_ID_STAT_ENABLE enables statistic gathering for a given client identifier. For example, to enable statistics gathering for a specific client identifier:

```
EXECUTE DBMS_MONITOR.CLIENT_ID_STAT_ENABLE(client_id => 'OE.OE');
```

In the example, OE.OE is the client identifier for which you want to collect statistics. You can view client identifiers in the CLIENT_IDENTIFIER column in V$SESSION.

The procedure CLIENT_ID_STAT_DISABLE disables statistic gathering for a given client identifier. For example:

```
EXECUTE DBMS_MONITOR.CLIENT_ID_STAT_DISABLE(client_id => 'OE.OE');
```

Statistic Gathering for Service, Module, and Action The procedure SERV_MOD_ACT_STAT_ENABLE enables statistic gathering for a combination of service, module, and action. For example:

```
EXECUTE DBMS_MONITOR.SERV_MOD_ACT_STAT_ENABLE(service_name => 'ACCTG',
        module_name => 'PAYROLL');

EXECUTE DBMS_MONITOR.SERV_MOD_ACT_STAT_ENABLE(service_name => 'ACCTG',
        module_name => 'GLEDGER', action_name => 'INSERT ITEM');
```

If both of the previous commands are executed, statistics are gathered as follows:

- For the ACCTG service, because accumulation for each service name is the default
- For all actions in the PAYROLL module
- For the INSERT ITEM action within the GLEDGER module

The procedure SERV_MOD_ACT_STAT_DISABLE disables statistic gathering for a combination of service, module, and action. For example:

```
EXECUTE DBMS_MONITOR.SERV_MOD_ACT_STAT_DISABLE(service_name => 'ACCTG',
        module_name => 'GLEDGER', action_name => 'INSERT ITEM');
```

Viewing Gathered Statistics for End to End Application Tracing

The statistics that have been gathered can be displayed with a number of dynamic views.

- The accumulated global statistics for the currently enabled statistics can be displayed with the DBA_ENABLED_AGGREGATIONS view.
- The accumulated statistics for a specified client identifier can be displayed in the V$CLIENT_STATS view.
- The accumulated statistics for a specified service can be displayed in V$SERVICE_STATS view.
- The accumulated statistics for a combination of specified service, module, and action can be displayed in the V$SERV_MOD_ACT_STATS view.
- The accumulated statistics for elapsed time of database calls and for CPU use can be displayed in the V$SVCMETRIC view.

Enabling and Disabling for End to End Tracing

To enable tracing for client identifier, service, module, or action, you need to execute the appropriate procedures in the DBMS_MONITOR package. You can enable tracing for specific diagnosis and workload management by the following criteria:

- Client identifier for specific clients
- Combination of service name, module, and action name
- Session

With the criteria that you provide, specific trace information is captured in a set of trace files and combined into a single output trace file.

Tracing for Client Identifier The CLIENT_ID_TRACE_ENABLE procedure enables tracing globally for the database for a given client identifier. For example:

```
EXECUTE DBMS_MONITOR.CLIENT_ID_TRACE_ENABLE(client_id => 'OE.OE',
        waits => TRUE, binds => FALSE);
```

In this example, OE.OE is the client identifier for which SQL tracing is to be enabled. The TRUE argument specifies that wait information will be present in the trace. The FALSE argument specifies that bind information will not be present in the trace.

The CLIENT_ID_TRACE_DISABLE procedure disables tracing globally for the database for a given client identifier. To disable tracing, for the previous example:

```
EXECUTE DBMS_MONITOR.CLIENT_ID_TRACE_DISABLE(client_id => 'OE.OE');
```

Tracing for Service, Module, and Action The SERV_MOD_ACT_TRACE_ENABLE procedure enables SQL tracing for a given combination of service name, module, and action globally for a database, unless an instance name is specified in the procedure.

```
EXECUTE DBMS_MONITOR.SERV_MOD_ACT_TRACE_ENABLE(service_name => 'ACCTG',
        waits => TRUE, binds => FALSE, instance_name => 'inst1');
```

In this example, the service ACCTG is specified. The module or action name is not specified. The TRUE argument specifies that wait information will be present in the trace. The FALSE argument specifies that bind information will not be present in the trace. The `inst1` instance is specified to enable tracing only for that instance.

To enable tracing for all actions for a given combination of service and module:

```
EXECUTE DBMS_MONITOR.SERV_MOD_ACT_TRACE_ENABLE(service_name => 'ACCTG',
        module_name => 'PAYROLL', waits => TRUE,  binds => FALSE,
        instance_name => 'inst1');
```

The SERV_MOD_ACT_TRACE_DISABLE procedure disables the trace at all enabled instances for a given combination of service name, module, and action name globally. For example, the following disables tracing for the first example in this section:

```
EXECUTE DBMS_MONITOR.SERV_MOD_ACT_TRACE_DISABLE(service_name => 'ACCTG',
        instance_name => 'inst1');
```

This example disables tracing for the second example in this section:

```
EXECUTE DBMS_MONITOR.SERV_MOD_ACT_TRACE_DISABLE(service_name => 'ACCTG',
        module_name => 'PAYROLL', instance_name => 'inst1');
```

Tracing for Session The SESSION_TRACE_ENABLE procedure enables the trace for a given database session identifier (SID), on the local instance.

To enable tracing for a specific session ID and serial number, determine the values for the session that you want to trace:

```
SELECT SID, SERIAL#, USERNAME FROM V$SESSION;

       SID    SERIAL# USERNAME
---------- ---------- ------------------------------
        27         60 OE
...
```

Use the appropriate values to enable tracing for a specific session:

```
EXECUTE DBMS_MONITOR.SESSION_TRACE_ENABLE(session_id => 27, serial_num => 60,
        waits => TRUE, binds => FALSE);
```

The TRUE argument specifies that wait information will be present in the trace. The FALSE argument specifies that bind information will not be present in the trace.

The SESSION_TRACE_DISABLE procedure disables the trace for a given database session identifier (SID) and serial number. For example:

```
EXECUTE DBMS_MONITOR.SESSION_TRACE_DISABLE(session_id => 27, serial_num => 60);
```

Viewing Enabled Traces for End to End Tracing

All outstanding traces can be displayed in an Oracle Enterprise Manager report or with the DBA_ENABLED_TRACES view. In the DBA_ENABLED_TRACES view, you can determine detailed information about how a trace was enabled, including the trace type. The trace type specifies whether the trace is enabled for client identifier, session, service, or a combination of service, module, and action.

Using the trcsess Utility

The trcsess utility consolidates trace output from selected trace files based on several criteria:

- Session Id
- Client Id
- Service name
- Action name
- Module name

After trcsess merges the trace information into a single output file, the output file could be processed by TKPROF.

trcsess is useful for consolidating the tracing of a particular session for performance or debugging purposes. Tracing a specific session is usually not a problem in the dedicated server model as a single dedicated process serves a session during its lifetime. All the trace information for the session can be seen from the trace file belonging to the dedicated server serving it. However, in a shared server configuration a user session is serviced by different processes from time to time. The trace pertaining to the user session is scattered across different trace files

belonging to different processes. This makes it difficult to get a complete picture of the life cycle of a session.

Syntax for trcsess

The syntax for the `trcsess` utility is:

```
trcsess  [output=output_file_name]
         [session=session_id]
         [clientid=client_id]
         [service=service_name]
         [action=action_name]
         [module=module_name]
         [trace_files]
```

where

- `output` specifies the file where the output is generated. If this option is not specified, then standard output is used for the output.
- `session` consolidates the trace information for the session specified. The session identifier is a combination of session index and session serial number, such as `21.2371`. You can locate these values in the `V$SESSION` view.
- `clientid` consolidates the trace information given client Id.
- `service` consolidates the trace information for the given service name.
- `action` consolidates the trace information for the given action name.
- `module` consolidates the trace information for the given module name.
- *`trace_files`* is a list of all the trace file names, separated by spaces, in which `trcsess` should look for trace information. The wild card character * can be used to specify the trace file names. If trace files are not specified, all the files in the current directory are taken as input to `trcsess`.

One of the `session`, `clientid`, `service`, `action`, or `module` options must be specified. If more then one of the `session`, `clientid`, `service`, `action`, or `module` options is specified, then the trace files which satisfies all the criteria specified are consolidated into the output file.

Sample Output of trcsess

This sample output of `trcsess` shows the consolidation of traces for a particular session. In this example the session index and serial number is equal to `21.2371`.

`trcsess` can be invoked with various options. In the following case, all files in current directory are taken as input:

```
trcsess session=21.2371
```

In this case, several trace files are specified:

```
trcsess session=21.2371 main_12359.trc main_12995.trc
```

The sample output is similar to the following:

```
[PROCESS ID = 12359]
*** 2002-04-02 09:48:28.376
PARSING IN CURSOR #1 len=17 dep=0 uid=27 oct=3 lid=27 tim=868373970961
hv=887450622 ad='22683fb4'
select * from cat
END OF STMT
PARSE #1:c=0,e=339,p=0,cr=0,cu=0,mis=0,r=0,dep=0,og=4,tim=868373970944
EXEC #1:c=0,e=221,p=0,cr=0,cu=0,mis=0,r=0,dep=0,og=4,tim=868373971411
FETCH #1:c=0,e=791,p=0,cr=7,cu=0,mis=0,r=1,dep=0,og=4,tim=868373972435
FETCH #1:c=0,e=1486,p=0,cr=20,cu=0,mis=0,r=6,dep=0,og=4,tim=868373986238
*** 2002-04-02 10:03:58.058
XCTEND rlbk=0, rd_only=1
STAT #1 id=1 cnt=7 pid=0 pos=1 obj=0 op='FILTER  '
STAT #1 id=2 cnt=7 pid=1 pos=1 obj=18 op='TABLE ACCESS BY INDEX ROWID OBJ$ '
STAT #1 id=3 cnt=7 pid=2 pos=1 obj=37 op='INDEX RANGE SCAN I_OBJ2 '
STAT #1 id=4 cnt=0 pid=1 pos=2 obj=4 op='TABLE ACCESS CLUSTER TAB$J2 '
STAT #1 id=5 cnt=6 pid=4 pos=1 obj=3 op='INDEX UNIQUE SCAN I_OBJ# '
[PROCESS ID=12995]
*** 2002-04-02 10:04:32.738
Archiving is disabled
Archiving is disabled
```

Understanding SQL Trace and TKPROF

The SQL Trace facility and TKPROF let you accurately assess the efficiency of the SQL statements an application runs. For best results, use these tools with EXPLAIN PLAN rather than using EXPLAIN PLAN alone.

Understanding the SQL Trace Facility

The SQL Trace facility provides performance information on individual SQL statements. It generates the following statistics for each statement:

- Parse, execute, and fetch counts

- CPU and elapsed times
- Physical reads and logical reads
- Number of rows processed
- Misses on the library cache
- Username under which each parse occurred
- Each commit and rollback
- Wait event data for each SQL statement, and a summary for each trace file

If the cursor for the SQL statement is closed, SQL Trace also provides row source information that includes:

- Row operations showing the actual execution plan of each SQL statement
- Number of rows, number of consistent reads, number of physical reads, number of physical writes, and time elapsed for each operation on a row

You can enable the SQL Trace facility for a session or for an instance. When the SQL Trace facility is enabled, performance statistics for all SQL statements executed in a user session or in the instance are placed into trace files.

Oracle provides the `trcsess` command-line utility that consolidates tracing information from several trace files based on specific criteria, such as session or client Id. See "Using the trcsess Utility" on page 20-7.

The additional overhead of running the SQL Trace facility against an application with performance problems is normally insignificant compared with the inherent overhead caused by the application's inefficiency.

Note: Try to enable SQL Trace only for statistics collection and on specific sessions. If you must enable the facility on an entire production environment, then you can minimize performance impact with the following:

- Maintain at least 25% idle CPU capacity.
- Maintain adequate disk space for the `USER_DUMP_DEST` location.
- Stripe disk space over sufficient disks.

Understanding TKPROF

You can run the TKPROF program to format the contents of the trace file and place the output into a readable output file. TKPROF can also:

- Create a SQL script that stores the statistics in the database
- Determine the execution plans of SQL statements

> **Note:** If the cursor for a SQL statement is not closed, TKPROF output does not automatically include the actual execution plan of the SQL statement. In this situation, you can use the EXPLAIN option with TKPROF to generate an execution plan.

TKPROF reports each statement executed with the resources it has consumed, the number of times it was called, and the number of rows which it processed. This information lets you easily locate those statements that are using the greatest resource. With experience or with baselines available, you can assess whether the resources used are reasonable given the work done.

Using the SQL Trace Facility and TKPROF

Follow these steps to use the SQL Trace facility and TKPROF:

1. Set initialization parameters for trace file management.

   See "Step 1: Setting Initialization Parameters for Trace File Management" on page 20-12.

2. Enable the SQL Trace facility for the desired session, and run the application. This step produces a trace file containing statistics for the SQL statements issued by the application.

   See "Step 2: Enabling the SQL Trace Facility" on page 20-14.

3. Run TKPROF to translate the trace file created in Step 2 into a readable output file. This step can optionally create a SQL script that can be used to store the statistics in a database.

   See "Step 3: Formatting Trace Files with TKPROF" on page 20-15.

4. Interpret the output file created in Step 3.

   See "Step 4: Interpreting TKPROF Output" on page 20-20.

5. Optionally, run the SQL script produced in Step 3 to store the statistics in the database.

   See "Step 5: Storing SQL Trace Facility Statistics" on page 20-26.

In the following sections, each of these steps is discussed in depth.

Step 1: Setting Initialization Parameters for Trace File Management

When the SQL Trace facility is enabled for a session, Oracle generates a trace file containing statistics for traced SQL statements for that session. When the SQL Trace facility is enabled for an instance, Oracle creates a separate trace file for each process. Before enabling the SQL Trace facility:

1. Check the settings of the `TIMED_STATISTICS`, `MAX_DUMP_FILE_SIZE`, and `USER_DUMP_DEST` initialization parameters. See Table 20–1.

Table 20–1 Initialization Parameters to Check Before Enabling SQL Trace

Parameter	Description
`TIMED_STATISTICS`	This enables and disables the collection of timed statistics, such as CPU and elapsed times, by the SQL Trace facility, as well as the collection of various statistics in the dynamic performance tables. The default value of false disables timing. A value of true enables timing. Enabling timing causes extra timing calls for low-level operations. This is a dynamic parameter. It is also a session parameter.
`MAX_DUMP_FILE_SIZE`	When the SQL Trace facility is enabled at the instance level, every call to the server produces a text line in a file in the operating system's file format. The maximum size of these files (in operating system blocks) is limited by this initialization parameter. The default is 500. If you find that the trace output is truncated, then increase the value of this parameter before generating another trace file. This is a dynamic parameter. It is also a session parameter.
`USER_DUMP_DEST`	This must fully specify the destination for the trace file according to the conventions of the operating system. The default value is the default destination for system dumps on the operating system.This value can be modified with `ALTER SYSTEM SET USER_DUMP_DEST=` *`newdir`*. This is a dynamic parameter. It is also a session parameter.

See Also:

- "Interpreting Statistics" on page 5-8 for considerations when setting the STATISTICS_LEVEL, DB_CACHE_ADVICE, TIMED_STATISTICS, or TIMED_OS_STATISTICS initialization parameters
- "Setting the Level of Statistics Collection" on page 10-7 for information about STATISTICS_LEVEL settings
- *Oracle Database Reference* for information on the STATISTICS_LEVEL initialization parameter
- *Oracle Database Reference* for information about the dynamic performance V$STATISTICS_LEVEL view

2. Devise a way of recognizing the resulting trace file.

   Be sure you know how to distinguish the trace files by name. Oracle writes them to the user dump destination specified by USER_DUMP_DEST. However, this directory can soon contain many hundreds of files, usually with generated names. It might be difficult to match trace files back to the session or process that created them. You can tag trace files by including in your programs a statement like SELECT '*program_name*' FROM DUAL. You can then trace each file back to the process that created it.

   You can also set the TRACEFILE_IDENTIFIER initialization parameter to specify a custom identifier that becomes part of the trace file name. For example, you can add *my_trace_id* to subsequent trace file names for easy identification with the following:

   ```
   ALTER SESSION SET TRACEFILE_IDENTIFIER = 'my_trace_id';
   ```

   See Also: *Oracle Database Reference* for information on the TRACEFILE_IDENTIFIER initialization parameter

3. If the operating system retains multiple versions of files, then be sure that the version limit is high enough to accommodate the number of trace files you expect the SQL Trace facility to generate.
4. The generated trace files can be owned by an operating system user other than yourself. This user must make the trace files available to you before you can use TKPROF to format them.

See Also:

- "Setting the Level of Statistics Collection" on page 10-7 for information about STATISTICS_LEVEL settings
- *Oracle Database Reference* for information on the STATISTICS_LEVEL initialization parameter

Step 2: Enabling the SQL Trace Facility

Enable the SQL Trace facility for the session by using one of the following:

- DBMS_SESSION.SET_SQL_TRACE procedure
- ALTER SESSION SET SQL_TRACE = TRUE;

Caution: Because running the SQL Trace facility increases system overhead, enable it only when tuning SQL statements, and disable it when you are finished.

You might need to modify an application to contain the ALTER SESSION statement. For example, to issue the ALTER SESSION statement in Oracle Forms, invoke Oracle Forms using the -s option, or invoke Oracle Forms (Design) using the statistics option. For more information on Oracle Forms, see the *Oracle Forms Reference*.

To disable the SQL Trace facility for the session, enter:

```
ALTER SESSION SET SQL_TRACE = FALSE;
```

The SQL Trace facility is automatically disabled for the session when the application disconnects from Oracle.

You can enable the SQL Trace facility for an instance by setting the value of the SQL_TRACE initialization parameter to TRUE in the initialization file.

```
SQL_TRACE = TRUE
```

After the instance has been restarted with the updated initialization parameter file, SQL Trace is enabled for the instance and statistics are collected for all sessions. If the SQL Trace facility has been enabled for the instance, you can disable it for the instance by setting the value of the SQL_TRACE parameter to FALSE.

Note: Setting SQL_TRACE to TRUE can have a severe performance impact. For more information, see *Oracle Database Reference*.

Step 3: Formatting Trace Files with TKPROF

TKPROF accepts as input a trace file produced by the SQL Trace facility, and it produces a formatted output file. TKPROF can also be used to generate execution plans.

After the SQL Trace facility has generated a number of trace files, you can:

- Run TKPROF on each individual trace file, producing a number of formatted output files, one for each session.
- Concatenate the trace files, and then run TKPROF on the result to produce a formatted output file for the entire instance.
- Run the `trcsess` command-line utility to consolidate tracing information from several trace files, then run TKPROF on the result. See "Using the trcsess Utility" on page 20-7.

TKPROF does not report COMMITs and ROLLBACKs that are recorded in the trace file.

Sample TKPROF Output

Sample output from TKPROF is as follows:

```
SELECT * FROM emp, dept
WHERE emp.deptno = dept.deptno;

call   count       cpu    elapsed       disk      query    current        rows
------- ------  -------- ---------- ---------- ----------  ----------  ------
Parse        1      0.16       0.29          3         13          0         0
Execute      1      0.00       0.00          0          0          0         0
Fetch        1      0.03       0.26          2          2          4        14

Misses in library cache during parse: 1
Parsing user id: (8) SCOTT

Rows     Execution Plan
-------  ---------------------------------------------------
    14  MERGE JOIN
     4   SORT JOIN
     4     TABLE ACCESS (FULL) OF 'DEPT'
```

```
14    SORT JOIN
14      TABLE ACCESS (FULL) OF 'EMP'
```

For this statement, TKPROF output includes the following information:

- The text of the SQL statement
- The SQL Trace statistics in tabular form
- The number of library cache misses for the parsing and execution of the statement.
- The user initially parsing the statement.
- The execution plan generated by EXPLAIN PLAN.

TKPROF also provides a summary of user level statements and recursive SQL calls for the trace file.

Syntax of TKPROF

TKPROF is run from the operating system prompt. The syntax is:

```
tkprof filename1 filename2 [waits=yes|no] [sort=option] [print=n]
    [aggregate=yes|no] [insert=filename3] [sys=yes|no] [table=schema.table]
    [explain=user/password] [record=filename4] [width=n]
```

The input and output files are the only required arguments. If you invoke TKPROF without arguments, then online help is displayed. Use the arguments in Table 20–2 with TKPROF.

Table 20–2 TKPROF Arguments

Argument	Description
filename1	Specifies the input file, a trace file containing statistics produced by the SQL Trace facility. This file can be either a trace file produced for a single session, or a file produced by concatenating individual trace files from multiple sessions.
filename2	Specifies the file to which TKPROF writes its formatted output.
WAITS	Specifies whether to record summary for any wait events found in the trace file. Values are YES or NO. The default is YES.
SORTS	Sorts traced SQL statements in descending order of specified sort option before listing them into the output file. If more than one option is specified, then the output is sorted in descending order by the sum of the values specified in the sort options. If you omit this parameter, then TKPROF lists statements into the output file in order of first use. Sort options are listed as follows:

Table 20–2 (Cont.) TKPROF Arguments

Argument	Description
PRSCNT	Number of times parsed.
PRSCPU	CPU time spent parsing.
PRSELA	Elapsed time spent parsing.
PRSDSK	Number of physical reads from disk during parse.
PRSQRY	Number of consistent mode block reads during parse.
PRSCU	Number of current mode block reads during parse.
PRSMIS	Number of library cache misses during parse.
EXECNT	Number of executes.
EXECPU	CPU time spent executing.
EXEELA	Elapsed time spent executing.
EXEDSK	Number of physical reads from disk during execute.
EXEQRY	Number of consistent mode block reads during execute.
EXECU	Number of current mode block reads during execute.
EXEROW	Number of rows processed during execute.
EXEMIS	Number of library cache misses during execute.
FCHCNT	Number of fetches.
FCHCPU	CPU time spent fetching.
FCHELA	Elapsed time spent fetching.
FCHDSK	Number of physical reads from disk during fetch.
FCHQRY	Number of consistent mode block reads during fetch.
FCHCU	Number of current mode block reads during fetch.
FCHROW	Number of rows fetched.
USERID	Userid of user that parsed the cursor.
PRINT	Lists only the first integer sorted SQL statements from the output file. If you omit this parameter, then TKPROF lists all traced SQL statements. This parameter does not affect the optional SQL script. The SQL script always generates insert data for all traced SQL statements.
AGGREGATE	If you specify AGGREGATE = NO, then TKPROF does not aggregate multiple users of the same SQL text.

Table 20–2 (Cont.) TKPROF Arguments

Argument	Description
INSERT	Creates a SQL script that stores the trace file statistics in the database. TKPROF creates this script with the name *filename3*. This script creates a table and inserts a row of statistics for each traced SQL statement into the table.
SYS	Enables and disables the listing of SQL statements issued by the user SYS, or recursive SQL statements, into the output file. The default value of YES causes TKPROF to list these statements. The value of NO causes TKPROF to omit them. This parameter does not affect the optional SQL script. The SQL script always inserts statistics for all traced SQL statements, including recursive SQL statements.
TABLE	Specifies the schema and name of the table into which TKPROF temporarily places execution plans before writing them to the output file. If the specified table already exists, then TKPROF deletes all rows in the table, uses it for the EXPLAIN PLAN statement (which writes more rows into the table), and then deletes those rows. If this table does not exist, then TKPROF creates it, uses it, and then drops it. The specified *user* must be able to issue INSERT, SELECT, and DELETE statements against the table. If the table does not already exist, then the user must also be able to issue CREATE TABLE and DROP TABLE statements. For the privileges to issue these statements, see the *Oracle Database SQL Reference*. This option allows multiple individuals to run TKPROF concurrently with the same user in the EXPLAIN value. These individuals can specify different TABLE values and avoid destructively interfering with each other's processing on the temporary plan table. If you use the EXPLAIN parameter without the TABLE parameter, then TKPROF uses the table PROF$PLAN_TABLE in the schema of the user specified by the EXPLAIN parameter. If you use the TABLE parameter without the EXPLAIN parameter, then TKPROF ignores the TABLE parameter. If no plan table exists, TKPROF creates the table PROF$PLAN_TABLE and then drops it at the end.
EXPLAIN	Determines the execution plan for each SQL statement in the trace file and writes these execution plans to the output file. TKPROF determines execution plans by issuing the EXPLAIN PLAN statement after connecting to Oracle with the user and password specified in this parameter. The specified user must have CREATE SESSION system privileges. TKPROF takes longer to process a large trace file if the EXPLAIN option is used.
RECORD	Creates a SQL script with the specified *filename4* with all of the nonrecursive SQL in the trace file. This can be used to replay the user events from the trace file.
WIDTH	An integer that controls the output line width of some TKPROF output, such as the explain plan. This parameter is useful for post-processing of TKPROF output.

Examples of TKPROF Statement

This section provides two brief examples of TKPROF usage. For an complete example of TKPROF output, see "Sample TKPROF Output" on page 20-32.

TKPROF Example 1 If you are processing a large trace file using a combination of SORT parameters and the PRINT parameter, then you can produce a TKPROF output file containing only the highest resource-intensive statements. For example, the following statement prints the 10 statements in the trace file that have generated the most physical I/O:

```
TKPROF ora53269.trc ora53269.prf SORT = (PRSDSK, EXEDSK, FCHDSK) PRINT = 10
```

TKPROF Example 2 This example runs TKPROF, accepts a trace file named `dlsun12_jane_fg_sqlplus_007.trc`, and writes a formatted output file named `outputa.prf`:

```
TKPROF dlsun12_jane_fg_sqlplus_007.trc OUTPUTA.PRF
EXPLAIN=scott/tiger TABLE=scott.temp_plan_table_a INSERT=STOREA.SQL SYS=NO
SORT=(EXECPU,FCHCPU)
```

This example is likely to be longer than a single line on the screen, and you might need to use continuation characters, depending on the operating system.

Note the other parameters in this example:

- The EXPLAIN value causes TKPROF to connect as the user `scott` and use the EXPLAIN PLAN statement to generate the execution plan for each traced SQL statement. You can use this to get access paths and row source counts.

  > **Note:** If the cursor for a SQL statement is not closed, TKPROF output does not automatically include the actual execution plan of the SQL statement. In this situation, you can use the EXPLAIN option with TKPROF to generate an execution plan.

- The TABLE value causes TKPROF to use the table `temp_plan_table_a` in the schema `scott` as a temporary plan table.
- The INSERT value causes TKPROF to generate a SQL script named STOREA.SQL that stores statistics for all traced SQL statements in the database.
- The SYS parameter with the value of NO causes TKPROF to omit recursive SQL statements from the output file. In this way, you can ignore internal Oracle statements such as temporary table operations.

- The SORT value causes TKPROF to sort the SQL statements in order of the sum of the CPU time spent executing and the CPU time spent fetching rows before writing them to the output file. For greatest efficiency, always use SORT parameters.

Step 4: Interpreting TKPROF Output

This section provides pointers for interpreting TKPROF output.

- Tabular Statistics in TKPROF
- Row Source Operations
- Wait Event Information
- Interpreting the Resolution of Statistics
- Understanding Recursive Calls
- Library Cache Misses in TKPROF
- Statement Truncation in SQL Trace
- Identification of User Issuing the SQL Statement in TKPROF
- Execution Plan in TKPROF
- Deciding Which Statements to Tune

While TKPROF provides a very useful analysis, the most accurate measure of efficiency is the actual performance of the application in question. At the end of the TKPROF output is a summary of the work done in the database engine by the process during the period that the trace was running.

Tabular Statistics in TKPROF

TKPROF lists the statistics for a SQL statement returned by the SQL Trace facility in rows and columns. Each row corresponds to one of three steps of SQL statement processing. Statistics are identified by the value of the CALL column. See Table 20–3.

Table 20–3 CALL Column Values

CALL Value	Meaning
PARSE	Translates the SQL statement into an execution plan, including checks for proper security authorization and checks for the existence of tables, columns, and other referenced objects.

Table 20–3 (Cont.) CALL Column Values

CALL Value	Meaning
EXECUTE	Actual execution of the statement by Oracle. For INSERT, UPDATE, and DELETE statements, this modifies the data. For SELECT statements, this identifies the selected rows.
FETCH	Retrieves rows returned by a query. Fetches are only performed for SELECT statements.

The other columns of the SQL Trace facility output are combined statistics for all parses, all executes, and all fetches of a statement. The sum of query and current is the total number of buffers accessed, also called Logical I/Os (LIOs). See Table 20–4.

Table 20–4 SQL Trace Statistics for Parses, Executes, and Fetches.

SQL Trace Statistic	Meaning
COUNT	Number of times a statement was parsed, executed, or fetched.
CPU	Total CPU time in seconds for all parse, execute, or fetch calls for the statement. This value is zero (0) if TIMED_STATISTICS is not turned on.
ELAPSED	Total elapsed time in seconds for all parse, execute, or fetch calls for the statement. This value is zero (0) if TIMED_STATISTICS is not turned on.
DISK	Total number of data blocks physically read from the datafiles on disk for all parse, execute, or fetch calls.
QUERY	Total number of buffers retrieved in consistent mode for all parse, execute, or fetch calls. Usually, buffers are retrieved in consistent mode for queries.
CURRENT	Total number of buffers retrieved in current mode. Buffers are retrieved in current mode for statements such as INSERT, UPDATE, and DELETE.

Statistics about the processed rows appear in the ROWS column. See Table 20–5.

Table 20–5 SQL Trace Statistics for the ROWS Column

SQL Trace Statistic	Meaning
ROWS	Total number of rows processed by the SQL statement. This total does not include rows processed by subqueries of the SQL statement.

For SELECT statements, the number of rows returned appears for the fetch step. For UPDATE, DELETE, and INSERT statements, the number of rows processed appears for the execute step.

> **Note:** The row source counts are displayed when a cursor is closed. In SQL*Plus, there is only one user cursor, so each statement executed causes the previous cursor to be closed; therefore, the row source counts are displayed. PL/SQL has its own cursor handling and does not close child cursors when the parent cursor is closed. Exiting (or reconnecting) causes the counts to be displayed.

Row Source Operations

Row source operations provide the number of rows processed for each operation executed on the rows and additional row source information, such as physical reads and writes. The following is a sample:

```
Rows     Row Source Operation
-------  ---------------------------------------------------
      0  DELETE  (cr=43141 r=266947 w=25854 time=60235565 us)
  28144   HASH JOIN ANTI (cr=43057 r=262332 w=25854 time=48830056 us)
  51427    TABLE ACCESS FULL STATS$SQLTEXT (cr=3465 r=3463 w=0 time=865083 us)
 647529    INDEX FAST FULL SCAN STATS$SQL_SUMMARY_PK
                    (cr=39592 r=39325 w=0 time=10522877 us) (object id 7409)
```

In this sample TKPROF output, note the following under the Row Source Operation column:

- cr specifies consistent reads performed by the row source
- r specifies physical reads performed by the row source
- w specifies physical writes performed by the row source
- time specifies time in microseconds

Wait Event Information

If wait event information exists, the TKPROF output includes a section similar to the following:

```
Elapsed times include waiting on following events:
  Event waited on                             Times   Max. Wait  Total Waited
  ----------------------------------------   Waited  ----------  ------------
  db file sequential read                      8084        0.12          5.34
  direct path write                             834        0.00          0.00
  direct path write temp                        834        0.00          0.05
  db file parallel read                           8        1.53          5.51
  db file scattered read                       4180        0.07          1.45
  direct path read                             7082        0.00          0.05
  direct path read temp                        7082        0.00          0.44
  rdbms ipc reply                                20        0.00          0.01
  SQL*Net message to client                       1        0.00          0.00
  SQL*Net message from client                     1        0.00          0.00
```

In addition, wait events are summed for the entire trace file at the end of the file.

To ensure that wait events information is written to the trace file for the session, run the following SQL statement:

```
ALTER SESSION SET EVENTS '10046 trace name context forever, level 8';
```

Interpreting the Resolution of Statistics

Timing statistics have a resolution of one hundredth of a second; therefore, any operation on a cursor that takes a hundredth of a second or less might not be timed accurately. Keep this in mind when interpreting statistics. In particular, be careful when interpreting the results from simple queries that execute very quickly.

Understanding Recursive Calls

Sometimes, in order to execute a SQL statement issued by a user, Oracle must issue additional statements. Such statements are called recursive calls or recursive SQL statements. For example, if you insert a row into a table that does not have enough space to hold that row, then Oracle makes recursive calls to allocate the space dynamically. Recursive calls are also generated when data dictionary information is not available in the data dictionary cache and must be retrieved from disk.

If recursive calls occur while the SQL Trace facility is enabled, then TKPROF produces statistics for the recursive SQL statements and marks them clearly as recursive SQL statements in the output file. You can suppress the listing of Oracle internal recursive calls (for example, space management) in the output file by

setting the SYS command-line parameter to NO. The statistics for a recursive SQL statement are included in the listing for that statement, not in the listing for the SQL statement that caused the recursive call. So, when you are calculating the total resources required to process a SQL statement, consider the statistics for that statement as well as those for recursive calls caused by that statement.

Note: Recursive SQL statistics are not included for SQL-level operations. However, recursive SQL statistics *are* included for operations done under the SQL level, such as triggers. For more information, see "Avoiding the Trigger Trap" on page 20-32.

Library Cache Misses in TKPROF

TKPROF also lists the number of library cache misses resulting from parse and execute steps for each SQL statement. These statistics appear on separate lines following the tabular statistics. If the statement resulted in no library cache misses, then TKPROF does not list the statistic. In "Sample TKPROF Output" on page 20-15, the statement resulted in one library cache miss for the parse step and no misses for the execute step.

Statement Truncation in SQL Trace

The following SQL statements are truncated to 25 characters in the SQL Trace file:

```
SET ROLE
GRANT
ALTER USER
ALTER ROLE
CREATE USER
CREATE ROLE
```

Identification of User Issuing the SQL Statement in TKPROF

TKPROF also lists the user ID of the user issuing each SQL statement. If the SQL Trace input file contained statistics from multiple users and the statement was issued by more than one user, then TKPROF lists the ID of the last user to parse the statement. The user ID of all database users appears in the data dictionary in the column ALL_USERS.USER_ID.

Execution Plan in TKPROF

If you specify the EXPLAIN parameter on the TKPROF statement line, then TKPROF uses the EXPLAIN PLAN statement to generate the execution plan of each SQL

statement traced. TKPROF also displays the number of rows processed by each step of the execution plan.

Note: Trace files generated immediately after instance startup contain data that reflects the activity of the startup process. In particular, they reflect a disproportionate amount of I/O activity as caches in the system global area (SGA) are filled. For the purposes of tuning, ignore such trace files.

See Also: Chapter 19, "Using EXPLAIN PLAN" for more information on interpreting execution plans

Deciding Which Statements to Tune

You need to find which SQL statements use the most CPU or disk resource. If the TIMED_STATISTICS parameter is on, then you can find high CPU activity in the CPU column. If TIMED_STATISTICS is not on, then check the QUERY and CURRENT columns.

See Also: "Examples of TKPROF Statement" on page 20-19 for examples of finding resource intensive statements

With the exception of locking problems and inefficient PL/SQL loops, neither the CPU time nor the elapsed time is necessary to find problem statements. The key is the number of block visits, both query (that is, subject to read consistency) and current (that is, not subject to read consistency). Segment headers and blocks that are going to be updated are acquired in current mode, but all query and subquery processing requests the data in query mode. These are precisely the same measures as the instance statistics CONSISTENT GETS and DB BLOCK GETS. You can find high disk activity in the disk column.

The following listing shows TKPROF output for one SQL statement as it appears in the output file:

```
SELECT *
FROM emp, dept
WHERE emp.deptno = dept.deptno;

call   count      cpu    elapsed     disk    query current    rows
---- -------  -------  --------- -------- -------- -------  ------
Parse     11     0.08       0.18        0        0       0         0
Execute   11     0.23       0.66        0        3       6         0
```

```
Fetch     35     6.70       6.83      100   12326       2       824
-------------------------------------------------------------------
total     57     7.01       7.67      100   12329       8       826

Misses in library cache during parse: 0
```

If it is acceptable to have 7.01 CPU seconds and to retrieve 824 rows, then you need not look any further at this trace output. In fact, a major use of TKPROF reports in a tuning exercise is to eliminate processes from the detailed tuning phase.

You can also see that 10 unnecessary parse call were made (because there were 11 parse calls for this one statement) and that array fetch operations were performed. You know this because more rows were fetched than there were fetches performed. A large gap between CPU and elapsed timings indicates Physical I/Os (PIOs).

Step 5: Storing SQL Trace Facility Statistics

You might want to keep a history of the statistics generated by the SQL Trace facility for an application, and compare them over time. TKPROF can generate a SQL script that creates a table and inserts rows of statistics into it. This script contains:

- A CREATE TABLE statement that creates an output table named TKPROF_TABLE.
- INSERT statements that add rows of statistics, one for each traced SQL statement, to the TKPROF_TABLE.

After running TKPROF, you can run this script to store the statistics in the database.

Generating the TKPROF Output SQL Script

When you run TKPROF, use the INSERT parameter to specify the name of the generated SQL script. If you omit this parameter, then TKPROF does not generate a script.

Editing the TKPROF Output SQL Script

After TKPROF has created the SQL script, you might want to edit the script before running it. If you have already created an output table for previously collected statistics and you want to add new statistics to this table, then remove the CREATE TABLE statement from the script. The script then inserts the new rows into the existing table.

If you have created multiple output tables, perhaps to store statistics from different databases in different tables, then edit the CREATE TABLE and INSERT statements to change the name of the output table.

Querying the Output Table

The following CREATE TABLE statement creates the TKPROF_TABLE:

```
CREATE TABLE TKPROF_TABLE (
    DATE_OF_INSERT    DATE,
    CURSOR_NUM        NUMBER,
    DEPTH             NUMBER,
    USER_ID           NUMBER,
    PARSE_CNT         NUMBER,
    PARSE_CPU         NUMBER,
    PARSE_ELAP        NUMBER,
    PARSE_DISK        NUMBER,
    PARSE_QUERY       NUMBER,
    PARSE_CURRENT     NUMBER,
    PARSE_MISS        NUMBER,
    EXE_COUNT         NUMBER,
    EXE_CPU           NUMBER,
    EXE_ELAP          NUMBER,
    EXE_DISK          NUMBER,
    EXE_QUERY         NUMBER,
    EXE_CURRENT       NUMBER,
    EXE_MISS          NUMBER,
    EXE_ROWS          NUMBER,
    FETCH_COUNT       NUMBER,
    FETCH_CPU         NUMBER,
    FETCH_ELAP        NUMBER,
    FETCH_DISK        NUMBER,
    FETCH_QUERY       NUMBER,
    FETCH_CURRENT     NUMBER,
    FETCH_ROWS        NUMBER,
    CLOCK_TICKS       NUMBER,
    SQL_STATEMENT     LONG);
```

Most output table columns correspond directly to the statistics that appear in the formatted output file. For example, the PARSE_CNT column value corresponds to the count statistic for the parse step in the output file.

The columns in Table 20–6 help you identify a row of statistics.

Table 20–6 TKPROF_TABLE Columns for Identifying a Row of Statistics

Column	Description
SQL_STATEMENT	This is the SQL statement for which the SQL Trace facility collected the row of statistics. Because this column has datatype LONG, you cannot use it in expressions or WHERE clause conditions.
DATE_OF_INSERT	This is the date and time when the row was inserted into the table. This value is not exactly the same as the time the statistics were collected by the SQL Trace facility.
DEPTH	This indicates the level of recursion at which the SQL statement was issued. For example, a value of 0 indicates that a user issued the statement. A value of 1 indicates that Oracle generated the statement as a recursive call to process a statement with a value of 0 (a statement issued by a user). A value of *n* indicates that Oracle generated the statement as a recursive call to process a statement with a value of *n*-1.
USER_ID	This identifies the user issuing the statement. This value also appears in the formatted output file.
CURSOR_NUM	Oracle uses this column value to keep track of the cursor to which each SQL statement was assigned.

The output table does not store the statement's execution plan. The following query returns the statistics from the output table. These statistics correspond to the formatted output shown in the section "Sample TKPROF Output" on page 20-15.

```
SELECT * FROM TKPROF_TABLE;
```

Oracle responds with something similar to:

```
DATE_OF_INSERT CURSOR_NUM DEPTH USER_ID PARSE_CNT PARSE_CPU PARSE_ELAP
-------------- ---------- ----- ------- --------- --------- ----------
21-DEC-1998          1      0     8         1        16         22

PARSE_DISK PARSE_QUERY PARSE_CURRENT PARSE_MISS EXE_COUNT EXE_CPU
---------- ----------- ------------- ---------- --------- -------
    3          11           0            1           1         0

EXE_ELAP EXE_DISK EXE_QUERY EXE_CURRENT EXE_MISS EXE_ROWS FETCH_COUNT
-------- -------- --------- ----------- -------- -------- -----------
    0        0        0          0          0        0         1

FETCH_CPU FETCH_ELAP FETCH_DISK FETCH_QUERY FETCH_CURRENT FETCH_ROWS
--------- ---------- ---------- ----------- ------------- ----------
```

```
     2        20          2          2           4          10

SQL_STATEMENT
--------------------------------------------------------------------
SELECT * FROM EMP, DEPT WHERE EMP.DEPTNO = DEPT.DEPTNO
```

Avoiding Pitfalls in TKPROF Interpretation

This section describes some fine points of TKPROF interpretation:

- Avoiding the Argument Trap
- Avoiding the Read Consistency Trap
- Avoiding the Schema Trap
- Avoiding the Time Trap
- Avoiding the Trigger Trap

Avoiding the Argument Trap

If you are not aware of the values being bound at run time, then it is possible to fall into the argument trap. EXPLAIN PLAN cannot determine the type of a bind variable from the text of SQL statements, and it always assumes that the type is `varchar`. If the bind variable is actually a number or a date, then TKPROF can cause implicit data conversions, which can cause inefficient plans to be executed. To avoid this, experiment with different datatypes in the query.

To avoid this problem, perform the conversion yourself.

> **See Also:** "EXPLAIN PLAN Restrictions" on page 19-5 for information about TKPROF and bind variables

Avoiding the Read Consistency Trap

The next example illustrates the read consistency trap. Without knowing that an uncommitted transaction had made a series of updates to the NAME column, it is very difficult to see why so many block visits would be incurred.

Cases like this are not normally repeatable: if the process were run again, it is unlikely that another transaction would interact with it in the same way.

```
SELECT name_id
FROM cq_names
WHERE name = 'FLOOR';
```

```
call     count     cpu     elapsed     disk     query current     rows
----     -----     ---     -------     ----     ----- -------     ----
Parse        1    0.10        0.18        0         0       0        0
Execute      1    0.00        0.00        0         0       0        0
Fetch        1    0.11        0.21        2       101       0        1

Misses in library cache during parse: 1
Parsing user id: 01 (USER1)

Rows     Execution Plan
----     --------- ----
   0     SELECT STATEMENT
   1       TABLE ACCESS (BY ROWID) OF 'CQ_NAMES'
   2         INDEX (RANGE SCAN) OF 'CQ_NAMES_NAME' (NON_UNIQUE)
```

Avoiding the Schema Trap

This example shows an extreme (and thus easily detected) example of the schema trap. At first, it is difficult to see why such an apparently straightforward indexed query needs to look at so many database blocks, or why it should access any blocks at all in current mode.

```
SELECT name_id
FROM cq_names
WHERE name = 'FLOOR';

call        count        cpu      elapsed     disk  query current rows
--------  -------   --------    ---------  ------- ------ ------- ----
Parse           1       0.06         0.10        0      0       0    0
Execute         1       0.02         0.02        0      0       0    0
Fetch           1       0.23         0.30       31     31       3    1

Misses in library cache during parse: 0
Parsing user id: 02  (USER2)

Rows     Execution Plan
-------  ---------------------------------------------------
      0  SELECT STATEMENT
   2340    TABLE ACCESS (BY ROWID) OF 'CQ_NAMES'
      0      INDEX (RANGE SCAN) OF 'CQ_NAMES_NAME' (NON-UNIQUE)
```

Two statistics suggest that the query might have been executed with a full table scan. These statistics are the current mode block visits, plus the number of rows originating from the Table Access row source in the execution plan. The explanation

is that the required index was built after the trace file had been produced, but before TKPROF had been run.

Generating a new trace file gives the following data:

```
SELECT name_id
FROM cq_names
WHERE name = 'FLOOR';

call    count    cpu   elapsed  disk  query current     rows
-----  ------ ------  -------- ----- ------ -------    -----
Parse       1   0.01      0.02     0      0       0        0
Execute     1   0.00      0.00     0      0       0        0
Fetch       1   0.00      0.00     0      2       0        1

Misses in library cache during parse: 0
Parsing user id: 02  (USER2)

Rows     Execution Plan
-------  ---------------------------------------------------
      0  SELECT STATEMENT
      1    TABLE ACCESS (BY ROWID) OF 'CQ_NAMES'
      2      INDEX (RANGE SCAN) OF 'CQ_NAMES_NAME' (NON-UNIQUE)
```

One of the marked features of this correct version is that the parse call took 10 milliseconds of CPU time and 20 milliseconds of elapsed time, but the query apparently took no time at all to execute and perform the fetch. These anomalies arise because the clock tick of 10 milliseconds is too long relative to the time taken to execute and fetch the data. In such cases, it is important to get lots of executions of the statements, so that you have statistically valid numbers.

Avoiding the Time Trap

Sometimes, as in the following example, you might wonder why a particular query has taken so long.

```
UPDATE cq_names SET ATTRIBUTES = lower(ATTRIBUTES)
WHERE ATTRIBUTES = :att

call       count       cpu    elapsed     disk    query current        rows
-------- -------  --------  --------- -------- -------- -------  ----------
Parse          1      0.06       0.24        0        0       0           0
Execute        1      0.62      19.62       22      526      12           7
Fetch          0      0.00       0.00        0        0       0           0
```

```
Misses in library cache during parse: 1
Parsing user id: 02  (USER2)

Rows     Execution Plan
-------  ---------------------------------------------------
      0  UPDATE STATEMENT
   2519  TABLE ACCESS (FULL) OF 'CQ_NAMES'
```

Again, the answer is interference from another transaction. In this case, another transaction held a shared lock on the table `cq_names` for several seconds before and after the update was issued. It takes a fair amount of experience to diagnose that interference effects are occurring. On the one hand, comparative data is essential when the interference is contributing only a short delay (or a small increase in block visits in the previous example). On the other hand, if the interference is contributing only a modest overhead, and the statement is essentially efficient, then its statistics might not need to be analyzed.

Avoiding the Trigger Trap

The resources reported for a statement include those for all of the SQL issued while the statement was being processed. Therefore, they include any resources used within a trigger, along with the resources used by any other recursive SQL, such as that used in space allocation. Avoid trying to tune the DML statement if the resource is actually being consumed at a lower level of recursion.

If a DML statement appears to be consuming far more resources than you would expect, then check the tables involved in the statement for triggers and constraints that could be greatly increasing the resource usage.

Sample TKPROF Output

This section provides an example of `TKPROF` output. Portions have been edited out for the sake of brevity.

Sample TKPROF Header

```
TKPROF: Release 10.1.0.0.0 - Beta on Mon Feb 10 14:43:00 2003

(c) Copyright 2001 Oracle Corporation.  All rights reserved.

Trace file: main_ora_27621.trc
Sort options: default
```

```
********************************************************************************
count    = number of times OCI procedure was executed
cpu      = cpu time in seconds executing
elapsed  = elapsed time in seconds executing
disk     = number of physical reads of buffers from disk
query    = number of buffers gotten for consistent read
current  = number of buffers gotten in current mode (usually for update)
rows     = number of rows processed by the fetch or execute call
********************************************************************************
```

Sample TKPROF Body

```
call     count       cpu    elapsed       disk      query    current        rows
------- ------  -------- ---------- ---------- ---------- ----------  ----------
Parse        1      0.01       0.00          0          0          0           0
Execute      1      0.00       0.00          0          0          0           0
Fetch        0      0.00       0.00          0          0          0           0
------- ------  -------- ---------- ---------- ---------- ----------  ----------
total        2      0.01       0.00          0          0          0           0

Misses in library cache during parse: 1
Optimizer mode: FIRST_ROWS
Parsing user id: 44

Elapsed times include waiting on following events:
  Event waited on                             Times   Max. Wait  Total Waited
  ----------------------------------------   Waited  ----------  ------------
  SQL*Net message to client                       1        0.00          0.00
  SQL*Net message from client                     1       28.59         28.59
********************************************************************************

select condition
from
 cdef$ where rowid=:1

call     count       cpu    elapsed       disk      query    current        rows
------- ------  -------- ---------- ---------- ---------- ----------  ----------
Parse        1      0.00       0.00          0          0          0           0
Execute      1      0.00       0.00          0          0          0           0
Fetch        1      0.00       0.00          0          2          0           1
------- ------  -------- ---------- ---------- ---------- ----------  ----------
total        3      0.00       0.00          0          2          0           1

Misses in library cache during parse: 1
Optimizer mode: CHOOSE
```

```
Parsing user id: SYS   (recursive depth: 1)

Rows     Row Source Operation
-------  ---------------------------------------------------
      1  TABLE ACCESS BY USER ROWID OBJ#(31) (cr=1 r=0 w=0 time=151 us)

********************************************************************************

SELECT last_name, job_id, salary
  FROM employees
WHERE salary =
  (SELECT max(salary) FROM employees)

call     count       cpu    elapsed       disk      query    current        rows
------- ------  -------- ---------- ---------- ---------- ----------  ----------
Parse        1      0.02       0.01          0          0          0           0
Execute      1      0.00       0.00          0          0          0           0
Fetch        2      0.00       0.00          0         15          0           1
------- ------  -------- ---------- ---------- ---------- ----------  ----------
total        4      0.02       0.01          0         15          0           1

Misses in library cache during parse: 1
Optimizer mode: FIRST_ROWS
Parsing user id: 44

Rows     Row Source Operation
-------  ---------------------------------------------------
      1  TABLE ACCESS FULL EMPLOYEES (cr=15 r=0 w=0 time=1743 us)
      1   SORT AGGREGATE (cr=7 r=0 w=0 time=777 us)
    107    TABLE ACCESS FULL EMPLOYEES (cr=7 r=0 w=0 time=655 us)

Elapsed times include waiting on following events:
  Event waited on                             Times   Max. Wait  Total Waited
  ----------------------------------------   Waited  ----------  ------------
  SQL*Net message to client                        2        0.00          0.00
  SQL*Net message from client                      2        9.62          9.62
********************************************************************************

********************************************************************************
 delete
         from stats$sqltext st
        where (hash_value, text_subset) not in
             (select --+ hash_aj
                     hash_value, text_subset
                from stats$sql_summary ss
```

```
               where (   (   snap_id     < :lo_snap
                         or snap_id     > :hi_snap
                         )
                         and dbid            = :dbid
                         and instance_number = :inst_num
                     )
                  or (   dbid            != :dbid
                      or instance_number != :inst_num)
               )

call     count       cpu    elapsed       disk      query    current rows
------- ------  -------- ---------- ---------- ---------- ---------- ----------
Parse        1      0.00       0.00          0          0          0          0
Execute      1     29.60      60.68     266984      43776     131172      28144
Fetch        0      0.00       0.00          0          0          0          0
------- ------  -------- ---------- ---------- ---------- ---------- ----------
total        2     29.60      60.68     266984      43776     131172      28144

Misses in library cache during parse: 1
Misses in library cache during execute: 1
Optimizer mode: CHOOSE
Parsing user id: 22

Rows     Row Source Operation
-------  ---------------------------------------------------
      0  DELETE  (cr=43141 r=266947 w=25854 time=60235565 us)
  28144   HASH JOIN ANTI (cr=43057 r=262332 w=25854 time=48830056 us)
  51427    TABLE ACCESS FULL STATS$SQLTEXT (cr=3465 r=3463 w=0 time=865083 us)
 647529    INDEX FAST FULL SCAN STATS$SQL_SUMMARY_PK
                     (cr=39592 r=39325 w=0 time=10522877 us) (object id 7409)

Elapsed times include waiting on following events:
  Event waited on                             Times   Max. Wait  Total Waited
  ----------------------------------------   Waited  ----------  ------------
  db file sequential read                      8084        0.12          5.34
  direct path write                             834        0.00          0.00
  direct path write temp                        834        0.00          0.05
  db file parallel read                           8        1.53          5.51
  db file scattered read                       4180        0.07          1.45
  direct path read                             7082        0.00          0.05
  direct path read temp                        7082        0.00          0.44
  rdbms ipc reply                                20        0.00          0.01
  SQL*Net message to client                       1        0.00          0.00
  SQL*Net message from client                     1        0.00          0.00
********************************************************************************
```

Sample TKPROF Summary

```
OVERALL TOTALS FOR ALL NON-RECURSIVE STATEMENTS

call     count       cpu    elapsed       disk      query    current        rows
------- ------  -------- ---------- ---------- ---------- ----------  ----------
Parse        4      0.04       0.01          0          0          0           0
Execute      5      0.00       0.04          0          0          0           0
Fetch        2      0.00       0.00          0         15          0           1
------- ------  -------- ---------- ---------- ---------- ----------  ----------
total       11      0.04       0.06          0         15          0           1

Misses in library cache during parse: 4
Misses in library cache during execute: 1
Elapsed times include waiting on following events:
  Event waited on                             Times   Max. Wait  Total Waited
  ----------------------------------------   Waited  ----------  ------------
  SQL*Net message to client                       6        0.00          0.00
  SQL*Net message from client                     5       77.77        128.88

OVERALL TOTALS FOR ALL RECURSIVE STATEMENTS

call     count       cpu    elapsed       disk      query    current        rows
------- ------  -------- ---------- ---------- ---------- ----------  ----------
Parse        1      0.00       0.00          0          0          0           0
Execute      1      0.00       0.00          0          0          0           0
Fetch        1      0.00       0.00          0          2          0           1
------- ------  -------- ---------- ---------- ---------- ----------  ----------
total        3      0.00       0.00          0          2          0           1

Misses in library cache during parse: 1
    5  user  SQL statements in session.
    1  internal SQL statements in session.
    6  SQL statements in session.
********************************************************************************
Trace file: main_ora_27621.trc
Trace file compatibility: 9.00.01
Sort options: default
       1  session in tracefile.
       5  user  SQL statements in trace file.
       1  internal SQL statements in trace file.
       6  SQL statements in trace file.
       6  unique SQL statements in trace file.
      76  lines in trace file.
     128  elapsed seconds in trace file.
```

Glossary

asynchronous I/O

Independent I/O, in which there is no timing requirement for transmission, and other processes can be started before the transmission has finished.

Autotrace

Generates a report on the execution path used by the SQL optimizer and the statement execution statistics. The report is useful to monitor and tune the performance of DML statements.

Automatic Workload Repository

Collects, processes, and maintains performance statistics for problem detection and self-tuning purposes.

bind variable

A variable in a SQL statement that must be replaced with a valid value, or the address of a value, in order for the statement to successfully execute.

block

A unit of data transfer between main memory and disk. Many blocks from one section of memory address space form a segment.

bottleneck

The delay in transmission of data, typically when a system's bandwidth cannot support the amount of information being relayed at the speed it is being processed. There are, however, many factors that can create a bottleneck in a system.

buffer

A main memory address in which the buffer manager caches currently and recently used data read from disk. Over time, a buffer can hold different blocks. When a new block is needed, the buffer manager can discard an old block and replace it with a new one.

buffer pool

A collection of buffers.

cache

Also known as buffer cache. All buffers and buffer pools.

cache recovery

The part of instance recovery where Oracle applies all committed and uncommitted changes in the redo log files to the affected data blocks. Also known as the *rolling forward* phase of instance recovery.

Cartesian product

A join with no join condition results in a Cartesian product, or a cross product. A Cartesian product is the set of all possible combinations of rows drawn one from each table. In other words, for a join of two tables, each row in one table is matched in turn with every row in the other. A Cartesian product for more than two tables is the result of pairing each row of one table with every row of the Cartesian product of the remaining tables. All other kinds of joins are subsets of Cartesian products effectively created by deriving the Cartesian product and then excluding rows that fail the join condition.

compound query

A query that uses set operators (`UNION`, `UNION ALL`, `INTERSECT`, or `MINUS`) to combine two or more simple or complex statements. Each simple or complex statement in a compound query is called a *component query*.

contention

When some process has to wait for a resource that is being used by another process.

dictionary cache

A collection of database tables and views containing reference information about the database, its structures, and its users. Oracle accesses the data dictionary frequently during the parsing of SQL statements. Two special locations in memory are designated to hold dictionary data. One area is called the data dictionary cache,

also known as the row cache because it holds data as rows instead of buffers (which hold entire blocks of data). The other area is the library cache. All Oracle user processes share these two caches for access to data dictionary information.

direct I/O

I/O which bypasses the buffer cache. See "PIO" on page Glossary-5.

distributed statement

A statement that accesses data on two or more distinct nodes/instances of a distributed database. A *remote statement* accesses data on one remote node of a distributed database.

dynamic performance views

The views database administrators create on dynamic performance tables (virtual tables that record current database activity). Dynamic performance views are called fixed views because they cannot be altered or removed by the database administrator.

enqueue

This is another term for a lock.

equijoin

A join condition containing an equality operator.

estimator

Uses statistics to estimate the selectivity, cardinality, and cost of execution plans. The main goal of the estimator is to estimate the overall cost of an execution plan.

EXPLAIN PLAN

A SQL statement that enables examination of the execution plan chosen by the optimizer for DML statements. `EXPLAIN PLAN` causes the optimizer to choose an execution plan and then to put data describing the plan into a database table.

instance recovery

The automatic application of redo log records to Oracle uncommitted data blocks after a crash or system failure.

join

A query that selects data from more than one table. A join is characterized by multiple tables in the `FROM` clause. Oracle pairs the rows from these tables using the

condition specified in the WHERE clause and returns the resulting rows. This condition is called the join condition and usually compares columns of all the joined tables.

latch

A simple, low-level serialization mechanism to protect shared data structures in the System Global Area.

library cache

A memory structure containing shared SQL and PL/SQL areas. The library cache is one of three parts of the shared pool.

LIO

Logical I/O. A block read which may or may not be satisfied from the buffer cache.

literal

A constant value, written at compile-time and read-only at run-time. Literals can be accessed quickly, and are used when modification is not necessary.

MTBF

Mean time between failures. A common database statistic important to tuning I/O.

mirroring

Maintaining identical copies of data on one or more disks. Typically, mirroring is performed on duplicate hard disks at the operating system level, so that if one of the disks becomes unavailable, the other disk can continue to service requests without interruptions.

nonequijoin

A join condition containing something other than an equality operator.

optimizer

Determines the most efficient way to execute SQL statements by evaluating expressions and translating them into equivalent, quicker expressions. The optimizer formulates a set of execution plans and picks the best one for a SQL statement. See Query Optimizer.

outer join

A join condition using the outer join operator (+) with one or more columns of one of the tables. Oracle returns all rows that meet the join condition. Oracle also returns

all rows from the table without the outer join operator for which there are no matching rows in the table with the outer join operator.

paging

A technique for increasing the memory space available by moving infrequently-used parts of a program's working memory from main memory to a secondary storage medium, usually a disk. The unit of transfer is called a page.

parse

A *hard parse* occurs when a SQL statement is executed, and the SQL statement is either not in the shared pool, or it is in the shared pool but it cannot be shared. A SQL statement is not shared if the metadata for the two SQL statements is different. This can happen if a SQL statement is textually identical as a preexisting SQL statement, but the tables referred to in the two statements resolve to physically different tables, or if the optimizer environment is different.

A *soft parse* occurs when a session attempts to execute a SQL statement, and the statement is already in the shared pool, and it can be used (that is, shared). For a statement to be shared, all data, (including metadata, such as the optimizer execution plan) pertaining to the existing SQL statement must be equally applicable to the current statement being issued.

parse call

A call to Oracle to prepare a SQL statement for execution. This includes syntactically checking the SQL statement, optimizing it, and building (or locating) an executable form of that statement.

parser

Performs syntax analysis and semantic analysis of SQL statements, and expands views (referenced in a query) into separate query blocks.

PGA

Program Global Area. A nonshared memory region that contains data and control information for a server process, created when the server process is started.

PIO

Physical I/O. A block read which could not be satisfied from the buffer cache, either because the block was not present or because the I/O is a direct I/O which bypasses the buffer cache.

plan generator

Tries out different possible plans for a given query so that the query optimizer can choose the plan with the lowest cost. It explores different plans for a query block by trying out different access paths, join methods, and join orders.

predicate

A `WHERE` condition in SQL.

Query Optimizer

Generates a set of potential execution plans for SQL statements, estimates the cost of each plan, calls the plan generator to generate the plan, compares the costs, and chooses the plan with the lowest cost. This approach is used when the data dictionary has statistics for at least one of the tables accessed by the SQL statements. The query optimizer is made up of the query transformer, the estimator, and the plan generator.

query transformer

Decides whether to rewrite a user query to generate a better query plan, merges views, and performs subquery unnesting.

RAID

Redundant arrays of inexpensive disks. RAID configurations provide improved data reliability with the option of striping (manually distributing data). Different RAID configurations (levels) are chosen based on performance and cost, and are suited to different types of applications, depending on their I/O characteristics.

RBO

Rule-based optimizer. Chooses an execution plan for SQL statements based on the access paths available and the ranks of these access paths. If there is more than one way, then the RBO uses the operation with the lowest rank.

Note: This feature has been desupported.

---

row source generator

Receives the optimal plan from the optimizer and outputs the execution plan for the SQL statement. A row source is an iterative control structure that processes a set of rows in an iterated manner and produces a row set.

segment

A set of extents allocated for a specific type of database object such as a table, index, or cluster.

simple statement

An INSERT, UPDATE, DELETE, or SELECT statement that involves only a single table.

simple query

A SELECT statement that references only one table and does not make reference to GROUP BY functions.

SGA

System Global Area. A memory region within main memory used to store data for fast access. Oracle uses the shared pool to allocate SGA memory for shared SQL and PL/SQL procedures.

SQL Compiler

Compiles SQL statements into a shared cursor. The SQL Compiler is made up of the parser, the optimizer, and the row source generator.

SQL Profile

A collection of information that enables the query optimizer to create an optimal execution plan for a SQL statement.

SQL statements (identical)

Textually identical SQL statements do not differ in any way.

SQL statements (similar)

Similar SQL statements differ only due to changing literal values. If the literal values were replaced with bind variables, then the SQL statements would be textually identical.

SQL Trace

A basic performance diagnostic tool to help monitor and tune applications running against the Oracle server. SQL Trace lets you assess the efficiency of the SQL statements an application runs and generates statistics for each statement. The trace files produced by this tool are used as input for TKPROF.

SQL Tuning Set (STS)

A database object that includes one or more SQL statements along with their execution statistics and execution context.

SQL*Loader

Reads and interprets input files. It is the most efficient way to load large amounts of data.

Statspack

A set of SQL, PL/SQL, and SQL*Plus scripts that allow the collection, automation, storage, and viewing of performance data. This feature has been replaced by the Automatic Workload Repository.

striping

The interleaving of a related block of data across disks. Proper striping reduces I/O and improves performance.

- Stripe depth is the size of the stripe, sometimes called stripe unit.
- Stripe width is the product of the stripe depth and the number of drives in the striped set.

TKPROF

A diagnostic tool to help monitor and tune applications running against the Oracle Server. TKPROF primarily processes SQL trace output files and translates them into readable output files, providing a summary of user-level statements and recursive SQL calls for the trace files. It can also assess the efficiency of SQL statements, generate execution plans, and create SQL scripts to store statistics in the database.

transaction recovery

The part of instance recovery where Oracle applies the rollback segments to undo the uncommitted changes. Also known as the rolling back phase of instance recovery.

UGA

User Global Area. A memory region in the large pool used for user sessions.

wait events

Statistics that are incremented by a server process/thread to indicate that it had to wait for an event to complete before being able to continue processing. Wait events

are one of the first places for investigation when performing reactive performance tuning.

wait events (idle)

These events indicate that the server process is waiting because it has no work. These events should be ignored when tuning, because they do not indicate the nature of the performance bottleneck.

work area

A private allocation of memory used for sorts, hash joins, and other operations that are memory-intensive. A sort operator uses a work area (the sort area) to perform the in-memory sort of a set of rows. Similarly, a hash-join operator uses a work area (the hash area) to build a hash table from its left input.

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