10

Optimizer Statistics Concepts

Oracle Database **optimizer statistics** describe details about the database and its objects.

Introduction to Optimizer Statistics

The optimizer **cost model** relies on statistics collected about the objects involved in a query, and the database and host where the query runs.

The optimizer uses statistics to get an estimate of the number of rows (and number of bytes) retrieved from a table, partition, or index. The optimizer estimates the cost for the access, determines the cost for possible plans, and then picks the execution plan with the lowest cost.

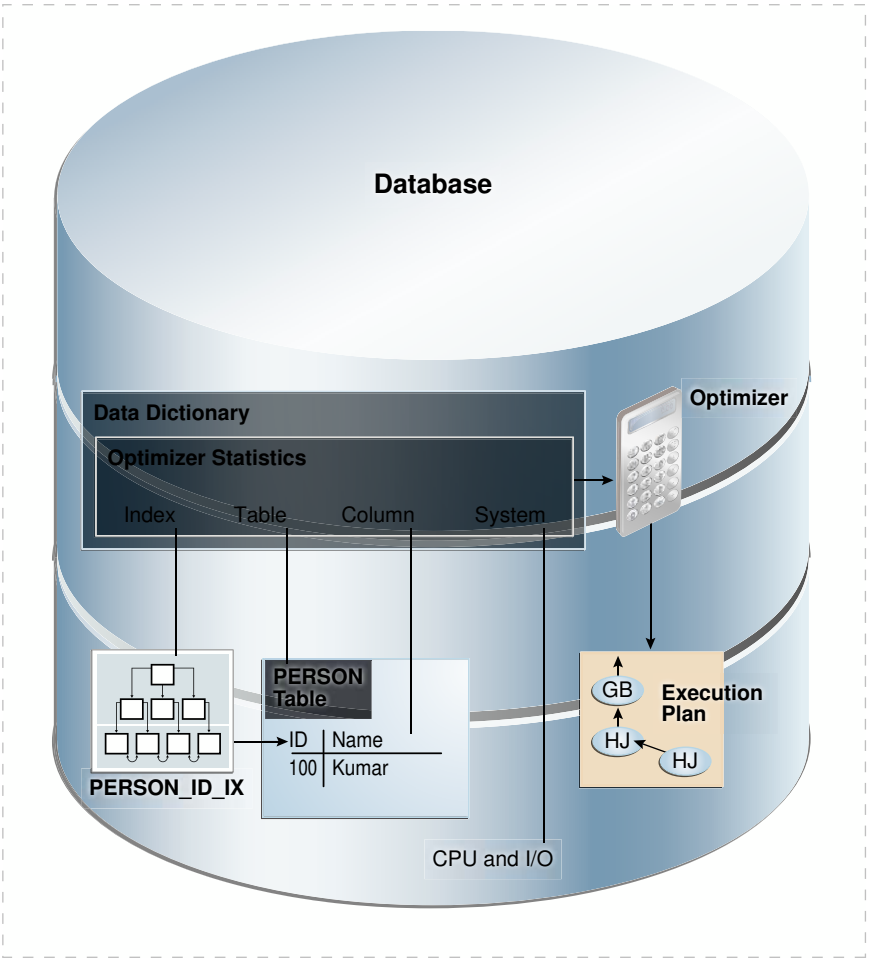
Optimizer statistics include the following:

- Table statistics
  - Number of rows
  - Number of blocks
  - Average row length
- Column statistics
  - Number of distinct values (NDV) in a column
  - Number of nulls in a column
  - Data distribution (histogram)
  - Extended statistics
- Index statistics
  - Number of leaf blocks
  - Number of levels
  - Index clustering factor
- System statistics
  - I/O performance and utilization
  - CPU performance and utilization

As shown in Figure 10-1, the database stores optimizer statistics for tables, columns, indexes, and the system in the data dictionary. You can access these statistics using data dictionary views.

> **Note:**
>
> The optimizer statistics are different from the performance statistics visible through `V$` views.

Figure 10-1 Optimizer Statistics



About Optimizer Statistics Types

The optimizer collects statistics on different types of database objects and characteristics of the database environment.

Table Statistics

Table statistics contain metadata that the optimizer uses when developing an execution plan.

Permanent Table Statistics

In Oracle Database, **table statistics** include information about rows and blocks.

The optimizer uses these statistics to determine the cost of table scans and table joins. The database tracks all relevant statistics about permanent tables. For example, table statistics stored in `DBA_TAB_STATISTICS` track the following:

- Number of rows

  The database uses the row count stored in `DBA_TAB_STATISTICS` when determining cardinality.

- Average row length
- Number of data blocks

  The optimizer uses the number of data blocks with the `DB_FILE_MULTIBLOCK_READ_COUNT` initialization parameter to determine the base table access cost.
- Number of empty data blocks

`DBMS_STATS.GATHER_TABLE_STATS` commits before gathering statistics on permanent tables.

Example 10-1 Table Statistics

This example queries table statistics for the `sh.customers` table.

```
SELECT NUM_ROWS, AVG_ROW_LEN, BLOCKS,
       EMPTY_BLOCKS, LAST_ANALYZED
FROM   DBA_TAB_STATISTICS
WHERE  OWNER='SH'
AND    TABLE_NAME='CUSTOMERS';
```

Sample output appears as follows:

```
  NUM_ROWS AVG_ROW_LEN     BLOCKS EMPTY_BLOCKS LAST_ANAL
---------- ----------- ---------- ------------ ---------
     55500         189       1517            0 25-MAY-17
```

> **See Also:**
>
> - "About Optimizer Initialization Parameters"
> - "Gathering Schema and Table Statistics"
> - *Oracle Database Reference* for a description of the `DBA_TAB_STATISTICS` view and the `DB_FILE_MULTIBLOCK_READ_COUNT` initialization parameter

Temporary Table Statistics

`DBMS_STATS` can gather statistics for both permanent and global temporary tables, but additional considerations apply to the latter.

Types of Temporary Tables

Temporary tables are classified as global, private, or cursor-duration.

In all types of temporary table, the data is only visible to the session that inserts it. The tables differ as follows:

- A **global temporary table** is an explicitly created persistent object that stores intermediate session-private data for a specific duration.

  The table is global because the definition is visible to all sessions. The `ON COMMIT` clause of `CREATE GLOBAL TEMPORARY TABLE` indicates whether the table is transaction-specific (`DELETE ROWS`) or session-specific (`PRESERVE ROWS`). Optimizer statistics for global temporary tables can be shared or session-specific.

- A **private temporary table** is an explicitly created object, defined by private memory-only metadata, that stores intermediate session-private data for a specific duration.

  The table is private because the definition is visible only to the session that created the table. The `ON COMMIT` clause of `CREATE PRIVATE TEMPORARY TABLE` indicates whether the table is transaction-specific (`DROP DEFINITION`) or session-specific (`PRESERVE DEFINITION`).

- A **cursor-duration temporary table** is an implicitly created memory-only object that is associated with a cursor.

  Unlike global and private temporary tables, `DBMS_STATS` cannot gather statistics for cursor-duration temporary tables.

The tables differ in where they store data, how they are created and dropped, and in the duration and visibility of metadata. Note that the database allocates storage space when a session first inserts data into a global temporary table, not at table creation.

Table 10-1 Important Characteristics of Temporary Tables

Characteristic	Global Temporary Table	Private Temporary Table	Cursor-Duration Temporary Table
Visibility of Data	Session inserting data	Session inserting data	Session inserting data
Storage of Data	Persistent	Memory or tempfiles, but only for the duration of the session or transaction	Only in memory
Visibility of Metadata	All sessions	Session that created table (in `USER_PRIVATE_TEMP_TABLES` view, which is based on a `V$` view)	Session executing cursor
Duration of Metadata	Until table is explicitly dropped	Until table is explicitly dropped, or end of session (`PRESERVE DEFINITION`) or transaction (`DROP DEFINITION`)	Until cursor ages out of shared pool
Creation of Table	`CREATE GLOBAL TEMPORARY TABLE` (supports `AS SELECT`)	`CREATE PRIVATE TEMPORARY TABLE` (supports `AS SELECT`)	Implicitly created when optimizer considers it useful
Effect of Creation on Existing Transactions	No implicit commit	No implicit commit	No implicit commit
Naming Rules	Same as for permanent tables	Must begin with `ORA$PTT_`	Internally generated unique name
Dropping of Table	`DROP GLOBAL TEMPORARY TABLE`	`DROP PRIVATE TEMPORARY TABLE`, or implicitly dropped at end of session (`PRESERVE DEFINITION`) or transaction (`DROP DEFINITION`)	Implicitly dropped at end of session

See Also:

- "Cursor-Duration Temporary Tables"
- *Oracle Database Administrator's Guide* to learn how to manage temporary tables

Statistics for Global Temporary Tables

DBMS_STATS collects the same types of statistics for global temporary tables as for permanent tables.

> **Note:**
>
> You cannot collect statistics for private temporary tables.

The following table shows how global temporary tables differ in how they gather and store optimizer statistics, depending on whether the tables are scoped to a transaction or session.

Table 10-2 Optimizer Statistics for Global Temporary Tables

Characteristic	Transaction-Specific	Session-Specific
Effect of DBMS_STATS collection	Does not commit	Commits
Storage of statistics	Memory only	Dictionary tables
Histogram creation	Not supported	Supported

The following procedures do not commit for transaction-specific temporary tables, so that rows in these tables are not deleted:

- GATHER_TABLE_STATS
- DELETE_*obj*_STATS, where *obj* is TABLE, COLUMN, or INDEX
- SET_*obj*_STATS, where *obj* is TABLE, COLUMN, or INDEX
- GET_*obj*_STATS, where *obj* is TABLE, COLUMN, or INDEX

The preceding program units observe the GLOBAL_TEMP_TABLE_STATS statistics preference. For example, if the table preference is set to SESSION, then SET_TABLE_STATS sets the session statistics, and GATHER_TABLE_STATS *preserves* all rows in a transaction-specific temporary table. If the table preference is set to SHARED, however, then SET_TABLE_STATS sets the shared statistics, and GATHER_TABLE_STATS *deletes* all rows from a transaction-specific temporary table.

> **See Also:**
>
> - "Gathering Schema and Table Statistics"
> - *Oracle Database Concepts* to learn about global temporary tables
> - *Oracle Database PL/SQL Packages and Types Reference* to learn about the DBMS_STATS.GATHER_TABLE_STATS procedure

Shared and Session-Specific Statistics for Global Temporary Tables

Starting in Oracle Database 12c, you can set the table-level preference GLOBAL_TEMP_TABLE_STATS to make statistics on a global temporary table shared (SHARED) or session-specific (SESSION).

When GLOBAL_TEMP_TABLE_STATS is SESSION, you can gather optimizer statistics for a global temporary table in one session, and then use the statistics for this session only. Meanwhile, users can continue to maintain a shared version of the statistics. During optimization, the optimizer first checks whether a global temporary table has session-specific statistics. If yes, then the optimizer uses them. Otherwise, the optimizer uses shared statistics if they exist.

> **Note:**
>
> In releases before Oracle Database 12c, the database did not maintain optimizer statistics for global temporary tables and non-global temporary tables differently. The database maintained one version of the statistics shared by all sessions, even though data in different sessions could differ.

Session-specific optimizer statistics have the following characteristics:

- Dictionary views that track statistics show both the shared statistics and the session-specific statistics in the current session.

  The views are DBA_TAB_STATISTICS, DBA_IND_STATISTICS, DBA_TAB_HISTOGRAMS, and DBA_TAB_COL_STATISTICS (each view has a corresponding USER_ and ALL_ version). The SCOPE column shows whether statistics are session-specific or shared. Session-specific statistics must be stored in the data dictionary so that multiple processes can access them in Oracle RAC.

- CREATE ... AS SELECT automatically gathers optimizer statistics. When GLOBAL_TEMP_TABLE_STATS is set to SHARED, however, you must gather statistics manually using DBMS_STATS.
- Pending statistics are not supported.
- Other sessions do not share a cursor that uses the session-specific statistics.

  Different sessions can share a cursor that uses *shared* statistics, as in releases earlier than Oracle Database 12c. The same session can share a cursor that uses session-specific statistics.
- By default, GATHER_TABLE_STATS for the temporary table immediately invalidates previous cursors compiled in the same session. However, this procedure does not invalidate cursors compiled in other sessions.

> **See Also:**
>
> - *Oracle Database PL/SQL Packages and Types Reference* to learn about the GLOBAL_TEMP_TABLE_STATS preference
> - *Oracle Database Reference* for a description of the DBA_TAB_STATISTICS view

Column Statistics

Column statistics track information about column values and data distribution.

The optimizer uses column statistics to generate accurate **cardinality** estimates and make better decisions about index usage, join orders, join methods, and so on. For example, statistics in `DBA_TAB_COL_STATISTICS` track the following:

- Number of distinct values
- Number of nulls
- High and low values
- Histogram-related information

The optimizer can use extended statistics, which are a special type of column statistics. These statistics are useful for informing the optimizer of logical relationships among columns.

> **See Also:**
>
> - "Histograms "
> - "About Statistics on Column Groups"
> - *Oracle Database Reference* for a description of the `DBA_TAB_COL_STATISTICS` view

Index Statistics

The **index statistics** include information about the number of index levels, the number of index blocks, and the relationship between the index and the data blocks. The optimizer uses these statistics to determine the cost of index scans.

Types of Index Statistics

The `DBA_IND_STATISTICS` view tracks index statistics.

Statistics include the following:

- Levels

  The `BLEVEL` column shows the number of blocks required to go from the root block to a leaf block. A B-tree index has two types of blocks: branch blocks for searching and leaf blocks that store values. See *Oracle Database Concepts* for a conceptual overview of B-tree indexes.
- Distinct keys

  This columns tracks the number of distinct indexed values. If a unique constraint is defined, and if no `NOT NULL` constraint is defined, then this value equals the number of non-null values.
- Average number of leaf blocks for each distinct indexed key
- Average number of data blocks pointed to by each distinct indexed key

> **See Also:**
>
> *Oracle Database Reference* for a description of the `DBA_IND_STATISTICS` view

Example 10-2 Index Statistics

This example queries some index statistics for the `cust_lname_ix` and `customers_pk` indexes on the `sh.customers` table (sample output included):

```
SELECT INDEX_NAME, BLEVEL, LEAF_BLOCKS AS "LEAFBLK", DISTINCT_KEYS AS
"DIST_KEY",
       AVG_LEAF_BLOCKS_PER_KEY AS "LEAFBLK_PER_KEY",
       AVG_DATA_BLOCKS_PER_KEY AS "DATABLK_PER_KEY"
FROM   DBA_IND_STATISTICS
WHERE  OWNER = 'SH'
AND    INDEX_NAME IN ('CUST_LNAME_IX','CUSTOMERS_PK');

INDEX_NAME     BLEVEL LEAFBLK DIST_KEY LEAFBLK_PER_KEY DATABLK_PER_KEY
-------------- ------ ------- -------- --------------- ---------------
CUSTOMERS_PK        1     115    55500               1               1
CUST_LNAME_IX       1     141      908               1              10
```

Index Clustering Factor

For a B-tree index, the **index clustering factor** measures the physical grouping of rows in relation to an index value, such as last name.

The index clustering factor helps the optimizer decide whether an index scan or full table scan is more efficient for certain queries). A low clustering factor indicates an efficient index scan.

A clustering factor that is close to the number of *blocks* in a table indicates that the rows are physically ordered in the table blocks by the index key. If the database performs a full table scan, then the database tends to retrieve the rows as they are stored on disk sorted by the index key. A clustering factor that is close to the number of *rows* indicates that the rows are scattered randomly across the database blocks in relation to the index key. If the database performs a full table scan, then the database would not retrieve rows in any sorted order by this index key.

The clustering factor is a property of a specific index, not a table. If multiple indexes exist on a table, then the clustering factor for one index might be small while the factor for another index is large. An attempt to reorganize the table to improve the clustering factor for one index may degrade the clustering factor of the other index.

Example 10-3 Index Clustering Factor

This example shows how the optimizer uses the index clustering factor to determine whether using an index is more effective than a full table scan.

1. Start SQL*Plus and connect to a database as `sh`, and then query the number of rows and blocks in the `sh.customers` table (sample output included):

   ```
   SELECT  table_name, num_rows, blocks
   FROM    user_tables
   WHERE   table_name='CUSTOMERS';

   TABLE_NAME                       NUM_ROWS     BLOCKS
   ------------------------------ ---------- ----------
   CUSTOMERS                           55500       1486
   ```

2. Create an index on the `customers.cust_last_name` column.

For example, execute the following statement:

```
CREATE INDEX CUSTOMERS_LAST_NAME_IDX ON customers(cust_last_name);
```

3. Query the index clustering factor of the newly created index.

   The following query shows that the `customers_last_name_idx` index has a high clustering factor because the clustering factor is significantly more than the number of blocks in the table:

```
SELECT index_name, blevel, leaf_blocks, clustering_factor
FROM   user_indexes
WHERE  table_name='CUSTOMERS'
AND    index_name= 'CUSTOMERS_LAST_NAME_IDX';

INDEX_NAME                      BLEVEL LEAF_BLOCKS CLUSTERING_FACTOR
------------------------------ ---------- ----------- -----------------
CUSTOMERS_LAST_NAME_IDX                 1         141              9859
```

4. Create a new copy of the `customers` table, with rows ordered by `cust_last_name`.

   For example, execute the following statements:

```
DROP TABLE customers3 PURGE;
CREATE TABLE customers3 AS
  SELECT *
  FROM   customers
  ORDER BY cust_last_name;
```

5. Gather statistics on the `customers3` table.

   For example, execute the `GATHER_TABLE_STATS` procedure as follows:

```
EXEC DBMS_STATS.GATHER_TABLE_STATS(null,'CUSTOMERS3');
```

6. Query the number of rows and blocks in the `customers3` table .

   For example, enter the following query (sample output included):

```
SELECT    TABLE_NAME, NUM_ROWS, BLOCKS
FROM      USER_TABLES
WHERE     TABLE_NAME='CUSTOMERS3';

TABLE_NAME                     NUM_ROWS     BLOCKS
------------------------------ ---------- ----------
CUSTOMERS3                        55500       1485
```

7. Create an index on the `cust_last_name` column of `customers3`.

   For example, execute the following statement:

```
CREATE INDEX CUSTOMERS3_LAST_NAME_IDX ON customers3(cust_last_name);
```

8. Query the index clustering factor of the `customers3_last_name_idx` index.

The following query shows that the `customers3_last_name_idx` index has a lower clustering factor:

```
SELECT INDEX_NAME, BLEVEL, LEAF_BLOCKS, CLUSTERING_FACTOR
FROM   USER_INDEXES
WHERE  TABLE_NAME = 'CUSTOMERS3'
AND    INDEX_NAME = 'CUSTOMERS3_LAST_NAME_IDX';

INDEX_NAME                       BLEVEL LEAF_BLOCKS CLUSTERING_FACTOR
------------------------------ ---------- ----------- -----------------
CUSTOMERS3_LAST_NAME_IDX                1         141              1455
```

The table `customers3` has the same data as the original `customers` table, but the index on `customers3` has a much lower clustering factor because the data in the table is ordered by the `cust_last_name`. The clustering factor is now about 10 times the number of blocks instead of 70 times.

9. Query the `customers` table.

   For example, execute the following query (sample output included):

```
SELECT cust_first_name, cust_last_name
FROM   customers
WHERE  cust_last_name BETWEEN 'Puleo' AND 'Quinn';

CUST_FIRST_NAME      CUST_LAST_NAME
-------------------- ----------------------------------------
Vida                 Puleo
Harriett             Quinlan
Madeleine            Quinn
Caresse              Puleo
```

10. Display the cursor for the query.

    For example, execute the following query (partial sample output included):

```
SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY_CURSOR());

-------------------------------------------------------------------------------
| Id | Operation                 | Name      | Rows |Bytes|Cost (%CPU)| Time   |
-------------------------------------------------------------------------------
|   0| SELECT STATEMENT          |           |      |     | 405 (100)|        |
|*  1|  TABLE ACCESS STORAGE FULL| CUSTOMERS |  2335|35025| 405   (1)|00:00:01|
-------------------------------------------------------------------------------
```

The preceding plan shows that the optimizer did not use the index on the original `customers` tables.

11. Query the `customers3` table.

    For example, execute the following query (sample output included):

```
SELECT cust_first_name, cust_last_name
FROM   customers3
WHERE  cust_last_name BETWEEN 'Puleo' AND 'Quinn';
```

```
CUST_FIRST_NAME      CUST_LAST_NAME
-------------------- ----------------------------------------
Vida                 Puleo
Harriett             Quinlan
Madeleine            Quinn
Caresse              Puleo
```

12. Display the cursor for the query.

    For example, execute the following query (partial sample output included):

```
SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY_CURSOR());

-------------------------------------------------------------------------------------------
|Id| Operation                    | Name                     |Rows|Bytes|Cost(%CPU)| Time|
-------------------------------------------------------------------------------------------
| 0| SELECT STATEMENT             |                          |    |     |69(100)|        |
| 1|  TABLE ACCESS BY INDEX ROWID|CUSTOMERS3                |2335|35025|69(0)   |00:00:01|
|*2|   INDEX RANGE SCAN           |CUSTOMERS3_LAST_NAME_IDX|2335|     |7(0)    |00:00:01|
-------------------------------------------------------------------------------------------
```

    The result set is the same, but the optimizer chooses the index. The plan cost is much less than the cost of the plan used on the original `customers` table.

13. Query `customers` with a hint that forces the optimizer to use the index.

    For example, execute the following query (partial sample output included):

```
SELECT /*+ index (Customers CUSTOMERS_LAST_NAME_IDX) */ cust_first_name,
       cust_last_name
FROM   customers
WHERE  cust_last_name BETWEEN 'Puleo' and 'Quinn';

CUST_FIRST_NAME      CUST_LAST_NAME
-------------------- ----------------------------------------
Vida                 Puleo
Caresse              Puleo
Harriett             Quinlan
Madeleine            Quinn
```

14. Display the cursor for the query.

    For example, execute the following query (partial sample output included):

```
SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY_CURSOR());

-------------------------------------------------------------------------------------------
| Id | Operation                | Name                     |Rows|Bytes|Cost(%CPU)|Time    |
-------------------------------------------------------------------------------------------
| 0| SELECT STATEMENT             |                          |    |     |422(100)|        |
| 1|  TABLE ACCESS BY INDEX ROWID|CUSTOMERS                 |335 |35025|422(0)  |00:00:01|
|*2|   INDEX RANGE SCAN           |CUSTOMERS_LAST_NAME_IDX|2335|     |7(0)    |00:00:01|
-------------------------------------------------------------------------------------------
```

    The preceding plan shows that the cost of using the index on `customers` is higher than the cost of a full table scan. Thus, using an index does not necessarily improve performance.

The index clustering factor is a measure of whether an index scan is more effective than a full table scan.

Effect of Index Clustering Factor on Cost: Example

This example illustrates how the index clustering factor can influence the cost of table access.

Consider the following scenario:

- A table contains 9 rows that are stored in 3 data blocks.
- The `col1` column currently stores the values `A`, `B`, and `C`.
- A nonunique index named `col1_idx` exists on `col1` for this table.

Example 10-4 Collocated Data

Assume that the rows are stored in the data blocks as follows:

```
Block 1       Block 2       Block 3
-------       -------       -------
A  A  A       B  B  B       C  C  C
```

In this example, the index clustering factor for `col1_idx` is low. The rows that have the same indexed column values for `col1` are in the same data blocks in the table. Thus, the cost of using an index range scan to return all rows with value `A` is low because only one block in the table must be read.

Example 10-5 Scattered Data

Assume that the same rows are scattered across the data blocks as follows:

```
Block 1       Block 2       Block 3
-------       -------       -------
A  B  C       A  C  B       B  A  C
```

In this example, the index clustering factor for `col1_idx` is higher. The database must read all three blocks in the table to retrieve all rows with the value `A` in `col1`.

> **See Also:**
>
> *Oracle Database Reference* for a description of the `DBA_INDEXES` view

System Statistics

The **system statistics** describe hardware characteristics such as I/O and CPU performance and utilization.

System statistics enable the query optimizer to more accurately estimate I/O and CPU costs when choosing execution plans. The database does not invalidate previously parsed SQL statements when updating system statistics. The database parses all new SQL statements using new statistics.

> **See Also:**
>
> - "Gathering System Statistics Manually"
> - *Oracle Database Reference*

User-Defined Optimizer Statistics

The **extensible optimizer** enables authors of user-defined functions and indexes to create statistics collection, selectivity, and cost functions.

The optimizer cost model is extended to integrate information supplied by the user to assess CPU and the I/O cost. Statistics types act as interfaces for user-defined functions that influence the choice of execution plan. However, to use a statistics type, the optimizer requires a mechanism to bind the type to a database object such as a column, standalone function, object type, index, indextype, or package. The SQL statement `ASSOCIATE STATISTICS` allows this binding to occur.

Functions for user-defined statistics are relevant for columns that use both standard SQL data types and object types, and for domain indexes. When you associate a statistics type with a column or domain index, the database calls the statistics collection method in the statistics type whenever `DBMS_STATS` gathers statistics.

> **See Also:**
>
> "Gathering Schema and Table Statistics"

How the Database Gathers Optimizer Statistics

Oracle Database provides several mechanisms to gather statistics.

DBMS_STATS Package

The `DBMS_STATS` PL/SQL package collects and manages optimizer statistics.

This package enables you to control what and how statistics are collected, including the degree of parallelism, sampling methods, and granularity of statistics collection in partitioned tables.

> **Note:**
>
> Do not use the `COMPUTE` and `ESTIMATE` clauses of the `ANALYZE` statement to collect optimizer statistics. These clauses have been deprecated. Instead, use `DBMS_STATS`.

Statistics gathered with the `DBMS_STATS` package are required for the creation of accurate execution plans. For example, table statistics gathered by `DBMS_STATS` include the number of rows, number of blocks, and average row length.

By default, Oracle Database uses automatic optimizer statistics collection. In this case, the database automatically runs `DBMS_STATS` to collect optimizer statistics for all schema objects for which statistics are missing or stale. The process eliminates many manual tasks associated with managing the optimizer, and significantly reduces the risks of generating suboptimal execution plans because of missing or stale statistics. You can also update and manage optimizer statistics by manually executing `DBMS_STATS`.

Oracle Database 19c introduces high-frequency automatic optimizer statistics collection. This lightweight task periodically gathers statistics for stale objects. The default interval is 15 minutes. In contrast to the automated statistics collection job, the high-frequency task does not perform actions such as purging statistics for non-existent objects or invoking Optimizer Statistics Advisor. You can set preferences for the high-frequency task using the `DBMS_STATS.SET_GLOBAL_PREFS` procedure, and view metadata using `DBA_AUTO_STAT_EXECUTIONS`.

See Also:

- "Configuring Automatic Optimizer Statistics Collection"
- "Gathering Optimizer Statistics Manually"
- *Oracle Database Administrator's Guide* to learn more about automated maintenance tasks
- *Oracle Database PL/SQL Packages and Types Reference* to learn about `DBMS_STATS`

Supplemental Dynamic Statistics

By default, when optimizer statistics are missing, stale, or insufficient, the database automatically gathers **dynamic statistics** during a parse. The database uses **recursive SQL** to scan a small random sample of table blocks.

Note:

Dynamic statistics *augment* statistics rather than providing an alternative to them.

Dynamic statistics supplement optimizer statistics such as table and index block counts, table and join cardinalities (estimated number of rows), join column statistics, and `GROUP BY` statistics. This information helps the optimizer improve plans by making better estimates for predicate cardinality.

Dynamic statistics are beneficial in the following situations:

- An execution plan is suboptimal because of complex predicates.
- The sampling time is a small fraction of total execution time for the query.
- The query executes many times so that the sampling time is amortized.

Online Statistics Gathering

In some circumstances, DDL and DML operations automatically trigger online statistics gathering.

Online Statistics Gathering for Bulk Loads

The database can gather table statistics automatically during the following types of bulk loads: `INSERT INTO ... SELECT` using a direct path insert, and `CREATE TABLE AS SELECT`.

By default, a parallel insert uses a direct path insert. You can force a direct path insert by using the `/*+APPEND*/` hint.

> **See Also:**
>
> *Oracle Database Data Warehousing Guide* to learn more about bulk loads

Purpose of Online Statistics Gathering for Bulk Loads

Data warehouse applications typically load large amounts of data into the database. For example, a sales data warehouse might load data every day, week, or month.

In releases earlier than Oracle Database 12c, the best practice was to gather statistics manually after a bulk load. However, many applications did not gather statistics after the load because of negligence or because they waited for the maintenance window to initiate collection. Missing statistics are the leading cause of suboptimal execution plans.

Automatic statistics gathering during bulk loads has the following benefits:

- Improved performance

  Gathering statistics during the load avoids an additional table scan to gather table statistics.
- Improved manageability

  No user intervention is required to gather statistics after a bulk load.

Global Statistics During Inserts into Partitioned Tables

When inserting rows into a partitioned table, the database gathers global statistics during the insert.

For example, if `sales` is a partitioned table, and if you run `INSERT INTO sales SELECT`, then the database gathers global statistics. However, the database does not gather partition-level statistics.

Assume a different case in which you use partition-extended syntax to insert rows into a specific partition or subpartition. The database gathers statistics on the partition during the insert. However, the database does not gather global statistics.

Assume that you run `INSERT INTO sales PARTITION (sales_q4_2000) SELECT`. The database gathers statistics during the insert. If the `INCREMENTAL` preference is enabled for `sales`, then the database also gathers a synopsis for `sales_q4_2000`. Statistics are immediately available after

the insert. However, if you roll back the transaction, then the database automatically deletes statistics gathered during the bulk load.

> **See Also:**
>
> - "Considerations for Incremental Statistics Maintenance"
> - *Oracle Database SQL Language Reference* for `INSERT` syntax and semantics

Histogram Creation After Bulk Loads

After gathering online statistics, the database does not automatically create histograms.

If histograms are required, then after the bulk load Oracle recommends running `DBMS_STATS.GATHER_TABLE_STATS` with `options=>GATHER AUTO`. For example, the following program gathers statistics for the `myt` table:

```
EXEC DBMS_STATS.GATHER_TABLE_STATS(user, 'MYT', options=>'GATHER AUTO');
```

The preceding PL/SQL program only gathers missing or stale statistics. The database does not gather table and basic column statistics collected during the bulk load.

> **Note:**
>
> You can set the table preference `options` to `GATHER AUTO` on the tables that you plan to bulk load. In this way, you need not explicitly set the `options` parameter when running `GATHER_TABLE_STATS`.

> **See Also:**
>
> - "Gathering Schema and Table Statistics"
> - *Oracle Database Data Warehousing Guide* to learn more about bulk loads

Restrictions for Online Statistics Gathering for Bulk Loads

In certain cases, bulk loads do not automatically gather optimizer statistics.

Specifically, bulk loads do *not* gather statistics automatically when any of the following conditions applies to the target table, partition, or subpartition:

- The object contains data. Bulk loads *only* gather online statistics automatically when the object is empty.
- It is in an Oracle-owned schema such as `SYS`.
- It is one of the following types of tables: nested table, index-organized table (IOT), external table, or global temporary table defined as `ON COMMIT DELETE ROWS`.

> **Note:**
>
> The database *does* gather online statistics automatically for the *internal* partitions of a hybrid partitioned table.

- It has a `PUBLISH` preference set to `FALSE`.
- Its statistics are locked.
- It is loaded using a multitable `INSERT` statement.

> **See Also:**
>
> - "Gathering Schema and Table Statistics"
> - *Oracle Database PL/SQL Packages and Types Reference* to learn more about `DBMS_STATS.SET_TABLE_PREFS`

User Interface for Online Statistics Gathering for Bulk Loads

By default, the database gathers statistics during bulk loads.

You can enable the feature at the statement level by using the `GATHER_OPTIMIZER_STATISTICS` hint. You can disable the feature at the statement level by using the `NO_GATHER_OPTIMIZER_STATISTICS` hint. For example, the following statement disables online statistics gathering for bulk loads:

```
CREATE TABLE employees2 AS
  SELECT /*+NO_GATHER_OPTIMIZER_STATISTICS*/ * FROM employees
```

> **See Also:**
>
> *Oracle Database SQL Language Reference* to learn about the `GATHER_OPTIMIZER_STATISTICS` and `NO_GATHER_OPTIMIZER_STATISTICS` hints

Online Statistics Gathering for Partition Maintenance Operations

Oracle Database provides analogous support for online statistics during specific partition maintenance operations.

For `MOVE`, `COALESCE`, and `MERGE`, the database maintains global and partition-level statistics as follows:

- If the partition uses either incremental or non-incremental statistics, then the database makes a direct update to the `BLOCKS` value in the global table statistics. Note that this update is not a statistics gathering operation.
- The database generates fresh statistics for the resulting partition. If incremental statistics are enabled, then the database maintains partition synopses.

For `TRUNCATE` or `DROP PARTITION`, the database updates the `BLOCKS` and `NUM_ROWS` values in the global table statistics. The update does not require a gathering statistics operation. The statistics update occurs when either incremental or non-incremental statistics are used.

> **Note:**
>
> The database does not maintain partition-level statistics for maintenance operations that have multiple destination segments.

> **See Also:**
>
> *Oracle Database VLDB and Partitioning Guide* to learn more about partition maintenance operations

Real-Time Statistics

Oracle Database can automatically gather real-time statistics during conventional DML operations.

> **See Also:**
>
> *Oracle Database Licensing Information User Manual* for details on which features are supported for different editions and services

Purpose of Real-Time Statistics

Online statistics, whether for bulk loads or conventional DML, aim to reduce the possibility of the optimizer being misled by stale statistics.

Oracle Database 12c introduced online statistics gathering for `CREATE TABLE AS SELECT` statements and direct-path inserts. Oracle Database 19c introduces real-time statistics, which extend online support to conventional DML statements. Because statistics can go stale between `DBMS_STATS` jobs, real-time statistics help the optimizer generate more optimal plans.

Whereas bulk load operations gather all necessary statistics, real-time statistics *augment* rather than replace traditional statistics. For this reason, you must continue to gather statistics regularly using `DBMS_STATS`, preferably using the AutoTask job.

How Real-Time Statistics Work

Oracle Database dynamically computes values for the most essential statistics during DML operations.

Consider a scenario in which a transaction is currently adding tens of thousands of rows to the `oe.orders` table. Real-time statistics records important changes in statistics, such as maximum column values. This enables the optimizer to obtain more accurate cost estimates.

Existing cursors are not marked invalid when real-time statistics values change.

Regression Models for Real-Time Statistics

As of release 21c, Oracle Database automatically builds regression models to predict the number of distinct values (NDV) for statistics on volatile tables. The use of models enables the optimizer to produce accurate estimates of NDV at low cost.

> **Note:**
>
> The time required to build a regression model may vary. The first step in the process is to model how a column's NDV is seen to change over time. This relies on the information about NDV changes that is derived from the statistics history. If the information immediately available is not sufficient, then the build of the model remains pending until enough historical information has been collected.

Using DBMS_STATS to Delete, Export, and Import Regression Models

Regression models are built automatically by the database as needed and do not require intervention by the DBA. However, you can use `DBMS_STATS` to delete, import, or export regression models. The default `stat_category` includes the default parameter value `MODELS` along with the previously supported values `OBJECT_STATS`, `SYNOPSES` and `REALTIME_STATS`. These are the relevant APIs:

```
DBMS_STATS.DELETE_*_STATS
DBMS_STATS_EXPORT_*_STATS
DBMS_STATS.IMPORT_*_STATS
```

Dictionary Views for Examining Real-Time Statistics Models

As of Oracle Database 21c, these new dictionary views are available for examining saved real-time statistics models.

- `ALL_TAB_COL_STAT_MODELS`
- `DBA_TAB_COL_STAT_MODELS`
- `USER_TAB_COL_STAT_MODELS`

> **See Also:**
>
> - DBMS_STATS in the *Oracle Database PL/SQL Packages and Types Reference*.
> - Oracle Database Reference for descriptions of the dictionary views listed above.

User Interface for Real-Time Statistics

You can use manage and access real-time statistics through PL/SQL packages, data dictionary views, and hints.

OPTIMIZER_REAL_TIME_STATISTICS Initialization Parameter

When the `OPTIMIZER_REAL_TIME_STATISTICS` initialization parameter is set to `TRUE`, Oracle Database automatically gathers real-time statistics during conventional DML operations. The default setting is `FALSE`, which means real-time statistics are disabled.

DBMS_STATS

By default, `DBMS_STATS` subprograms include real-time statistics. You can also specify parameters to include only these statistics.

Table 10-3 Subprograms for Real-Time Statistics

Subprogram	Description
`EXPORT_TABLE_STATS` and `EXPORT_SCHEMA_STATS`	These subprograms enable you to export statistics. By default, the `stat_category` parameter includes real-time statistics. The `REALTIME_STATS` value specifies only real-time statistics.
`IMPORT_TABLE_STATS` and `IMPORT_SCHEMA_STATS`	These subprograms enable you to import statistics. By default, the `stat_category` parameter includes real-time statistics. The `REALTIME_STATS` value specifies only real-time statistics.
`DELETE_TABLE_STATS` and `DELETE_SCHEMA_STATS`	These subprograms enable you to delete statistics. By default, the `stat_category` parameter includes real-time statistics. The `REALTIME_STATS` value specifies only real-time statistics.
`DIFF_TABLE_STATS_IN_STATTAB`	This function compares table statistics from two sources. The statistics always include real-time statistics.
`DIFF_TABLE_STATS_IN_HISTORY`	This function compares statistics for a table as of two specified timestamps. The statistics always include real-time statistics.

Views

Real-time statistics can be viewed in the data dictionary table statistics views such as USER_TAB_STATISTICS and USER_TAB_COL_STATISTICS when the NOTES columns is STATS_ON_CONVENTIONAL_DML, as described in the table below.

The `DBA_*` views have `ALL_*` and `USER_*` versions.

Table 10-4 Views for Real-Time Statistics

View	Description
`DBA_TAB_COL_STATISTICS`	This view displays column statistics and histogram information extracted from `DBA_TAB_COLUMNS`. Real-time statistics are indicated by `STATS_ON_CONVENTIONAL_DML` in the `NOTES` column.

Table 10-4 (Cont.) Views for Real-Time Statistics

View	Description
DBA_TAB_STATISTICS	This view displays optimizer statistics for the tables accessible to the current user. Real-time statistics are indicated by STATS_ON_CONVENTIONAL_DML in the NOTES column.

Hints

The NO_GATHER_OPTIMIZER_STATISTICS hint prevents the collection of real-time statistics.

> **See Also:**
>
> - "Importing and Exporting Optimizer Statistics"
> - *Oracle Database PL/SQL Packages and Types Reference* to learn about DBMS_STATS subprograms
> - *Oracle Database Reference* to learn about the ALL_TAB_COL_STATISTICS view
> - *Oracle Database Licensing Information User Manual* for details on whether the real-time statistics feature is supported for different editions and services

Real-Time Statistics: Example

In this example, a conventional INSERT statement triggers the collection of real-time statistics.

This example assumes that the sh user has been granted the DBA role, and you have logged in to the database as sh. You perform the following steps:

1. Gather statistics for the sales table:

```
BEGIN
 DBMS_STATS.GATHER_TABLE_STATS('SH', 'SALES');
END;
/
```

2. Query the column-level statistics for sales:

```
SET PAGESIZE 5000
SET LINESIZE 200
COL COLUMN_NAME FORMAT a13
COL LOW_VALUE FORMAT a14
COL HIGH_VALUE FORMAT a14
COL NOTES FORMAT a5
COL PARTITION_NAME FORMAT a13

SELECT COLUMN_NAME, LOW_VALUE, HIGH_VALUE, SAMPLE_SIZE, NOTES
FROM   USER_TAB_COL_STATISTICS
WHERE  TABLE_NAME = 'SALES'
ORDER BY 1, 5;
```

The `Notes` fields are blank, meaning that real-time statistics have not been gathered:

```
COLUMN_NAME    LOW_VALUE      HIGH_VALUE     SAMPLE_SIZE NOTES
-------------- -------------- -------------- ----------- -----
AMOUNT_SOLD    C10729         C2125349              5594
CHANNEL_ID     C103           C10A                918843
CUST_ID        C103           C30B0B                5595
PROD_ID        C10E           C20231                5593
PROMO_ID       C122           C20A64              918843
QUANTITY_SOLD C102            C102                  5593
TIME_ID        77C60101010101 78650C1F010101        5593

7 rows selected.
```

3. Query the table-level statistics for `sales`:

```
SELECT NVL(PARTITION_NAME, 'GLOBAL') PARTITION_NAME, NUM_ROWS, BLOCKS,
NOTES
FROM   USER_TAB_STATISTICS
WHERE  TABLE_NAME = 'SALES'
ORDER BY 1, 4;
```

The `Notes` fields are blank, meaning that real-time statistics have not been gathered:

```
PARTITION_NAM   NUM_ROWS     BLOCKS NOTES
------------- ---------- ---------- -----
GLOBAL            918843       3315
SALES_1995             0          0
SALES_1996             0          0
SALES_H1_1997          0          0
SALES_H2_1997          0          0
SALES_Q1_1998      43687        162
SALES_Q1_1999      64186        227
SALES_Q1_2000      62197        222
SALES_Q1_2001      60608        222
SALES_Q1_2002          0          0
SALES_Q1_2003          0          0
SALES_Q2_1998      35758        132
SALES_Q2_1999      54233        187
SALES_Q2_2000      55515        197
SALES_Q2_2001      63292        227
SALES_Q2_2002          0          0
SALES_Q2_2003          0          0
SALES_Q3_1998      50515        182
SALES_Q3_1999      67138        232
SALES_Q3_2000      58950        212
SALES_Q3_2001      65769        242
SALES_Q3_2002          0          0
SALES_Q3_2003          0          0
SALES_Q4_1998      48874        192
SALES_Q4_1999      62388        217
SALES_Q4_2000      55984        202
SALES_Q4_2001      69749        260
SALES_Q4_2002          0          0
SALES_Q4_2003          0          0
```

```
29 rows selected.
```

4. Load 918,843 rows into `sales` by using a conventional `INSERT` statement:

```
INSERT INTO sales(prod_id, cust_id, time_id, channel_id, promo_id,
                  quantity_sold, amount_sold)
  SELECT prod_id, cust_id, time_id, channel_id, promo_id,
         quantity_sold * 2, amount_sold * 2
  FROM   sales;
COMMIT;
```

5. Obtain the execution plan from the cursor:

```
SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY_CURSOR(format=>'TYPICAL'));
```

The plan shows `LOAD TABLE CONVENTIONAL` in Step 1 and `OPTIMIZER STATISTICS GATHERING` in Step 2, which means that the database gathered real-time statistics during the conventional insert:

```
-------------------------------------------------------------------------------------------
|Id| Operation                         | Name|Rows|Bytes|Cost (%CPU)|Time| Pstart|Pstop|
-------------------------------------------------------------------------------------------
| 0| INSERT STATEMENT                  |     |    |     |910 (100)|        |     |     |
| 1|  LOAD TABLE CONVENTIONAL          |SALES|    |     |          |        |     |     |
| 2|   OPTIMIZER STATISTICS GATHERING  |     |918K|  25M|910   (2)|00:00:01|     |     |
| 3|    PARTITION RANGE ALL            |     |918K|  25M|910   (2)|00:00:01|   1 |  28 |
| 4|     TABLE ACCESS FULL             |SALES|918K|  25M|910   (2)|00:00:01|   1 |  28 |
-------------------------------------------------------------------------------------------
```

6. For the purposes of testing, force the database to write optimizer statistics to the data dictionary immediately.

```
EXEC DBMS_STATS.FLUSH_DATABASE_MONITORING_INFO;
```

7. Query the column-level statistics for `sales`.

```
SET PAGESIZE 5000
SET LINESIZE 200
COL COLUMN_NAME FORMAT a13
COL LOW_VALUE FORMAT a14
COL HIGH_VALUE FORMAT a14
COL NOTES FORMAT a25
COL PARTITION_NAME FORMAT a13

SELECT COLUMN_NAME, LOW_VALUE, HIGH_VALUE, SAMPLE_SIZE, NOTES
FROM   USER_TAB_COL_STATISTICS
WHERE  TABLE_NAME = 'SALES'
ORDER BY 1, 5;
```

Now the `Notes` fields show `STATS_ON_CONVENTIONAL_DML`, meaning that the database gathered real-time statistics during the insert:

```
COLUMN_NAME    LOW_VALUE      HIGH_VALUE     SAMPLE_SIZE NOTES
-------------- -------------- -------------- ----------- -------------------------
AMOUNT_SOLD    C10729         C224422D              9073 STATS_ON_CONVENTIONAL_DML
AMOUNT_SOLD    C10729         C2125349              5702
CHANNEL_ID     C103           C10A                  9073 STATS_ON_CONVENTIONAL_DML
CHANNEL_ID     C103           C10A                918843
CUST_ID        C103           C30B0B                9073 STATS_ON_CONVENTIONAL_DML
CUST_ID        C103           C30B0B                5702
PROD_ID        C10E           C20231                9073 STATS_ON_CONVENTIONAL_DML
PROD_ID        C10E           C20231                5701
PROMO_ID       C122           C20A64                9073 STATS_ON_CONVENTIONAL_DML
PROMO_ID       C122           C20A64              918843
QUANTITY_SOLD  C102           C103                  9073 STATS_ON_CONVENTIONAL_DML
QUANTITY_SOLD  C102           C102                  5701
TIME_ID        77C60101010101 78650C1F010101        9073 STATS_ON_CONVENTIONAL_DML
TIME_ID        77C60101010101 78650C1F010101        5701
```

The sample size is 9073, which is roughly 1% of the 918,843 rows inserted. In `QUANTITY_SOLD` and `AMOUNT_SOLD`, the high and low values combine the manually gathered statistics and the real-time statistics.

8. Query the table-level statistics for `sales`.

```
SELECT NVL(PARTITION_NAME, 'GLOBAL') PARTITION_NAME, NUM_ROWS, BLOCKS,
NOTES
FROM   USER_TAB_STATISTICS
WHERE  TABLE_NAME = 'SALES'
ORDER BY 1, 4;
```

The `Notes` field shows that real-time statistics have been gathered at the global level, showing the number of rows as 1,837,686:

```
PARTITION_NAM   NUM_ROWS     BLOCKS NOTES
------------- ---------- ---------- -------------------------
GLOBAL           1837686       3315 STATS_ON_CONVENTIONAL_DML
GLOBAL            918843       3315
SALES_1995             0          0
SALES_1996             0          0
SALES_H1_1997          0          0
SALES_H2_1997          0          0
SALES_Q1_1998      43687        162
SALES_Q1_1999      64186        227
SALES_Q1_2000      62197        222
SALES_Q1_2001      60608        222
SALES_Q1_2002          0          0
SALES_Q1_2003          0          0
SALES_Q2_1998      35758        132
SALES_Q2_1999      54233        187
SALES_Q2_2000      55515        197
SALES_Q2_2001      63292        227
SALES_Q2_2002          0          0
SALES_Q2_2003          0          0
```

```
SALES_Q3_1998      50515        182
SALES_Q3_1999      67138        232
SALES_Q3_2000      58950        212
SALES_Q3_2001      65769        242
SALES_Q3_2002          0          0
SALES_Q3_2003          0          0
SALES_Q4_1998      48874        192
SALES_Q4_1999      62388        217
SALES_Q4_2000      55984        202
SALES_Q4_2001      69749        260
SALES_Q4_2002          0          0
SALES_Q4_2003          0          0
```

9. Query the `quantity_sold` column:

```
SELECT COUNT(*) FROM sales WHERE quantity_sold > 50;
```

10. Obtain the execution plan from the cursor:

```
SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY_CURSOR(format=>'TYPICAL'));
```

The `Note` field shows that the query used the real-time statistics.

```
Plan hash value: 3519235612

-------------------------------------------------------------------------------
|Id| Operation           |Name|Rows|Bytes|Cost (%CPU)|Time|Pstart|Pstop|
-------------------------------------------------------------------------------
| 0| SELECT STATEMENT     |       |    |   |921 (100)|        |   |    |
| 1|  SORT AGGREGATE      |       |   1|  3|         |        |   |    |
| 2|   PARTITION RANGE ALL|       |  11|  3|921   (3)|00:00:01| 1 | 28 |
|*3|    TABLE ACCESS FULL | SALES |  11|  3|921   (3)|00:00:01| 1 | 28 |
-------------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   3 - filter("QUANTITY_SOLD">50)

Note
-----
   - dynamic statistics used: stats for conventional DML
```

> **See Also:**
>
> *Oracle Database Reference* to learn about `USER_TAB_COL_STATISTICS`and `USER_TAB_STATISTICS`.

When the Database Gathers Optimizer Statistics

The database collects optimizer statistics at various times and from various sources.

Sources for Optimizer Statistics

The optimizer uses several different sources for optimizer statistics.

The sources are as follows:

- `DBMS_STATS` execution, automatic or manual

  This PL/SQL package is the primary means of gathering optimizer statistics.

- SQL compilation

  During SQL compilation, the database can augment the statistics previously gathered by `DBMS_STATS`. In this stage, the database runs additional queries to obtain more accurate information on how many rows in the tables satisfy the `WHERE` clause predicates in the SQL statement.

- SQL execution

  During execution, the database can further augment previously gathered statistics. In this stage, Oracle Database collects the number of rows produced by every row source during the execution of a SQL statement. At the end of execution, the optimizer determines whether the estimated number of rows is inaccurate enough to warrant reparsing at the next statement execution. If the cursor is marked for reparsing, then the optimizer uses actual row counts from the previous execution instead of estimates.

- SQL profiles

  A SQL profile is a collection of auxiliary statistics on a query. The profile stores these supplemental statistics in the data dictionary. The optimizer uses SQL profiles during optimization to determine the most optimal plan.

The database stores optimizer statistics in the data dictionary and updates or replaces them as needed. You can query statistics in data dictionary views.

> **See Also:**
>
> - "When the Database Samples Data"
> - "About SQL Profiles"
> - *Oracle Database PL/SQL Packages and Types Reference* to learn about the `DBMS_STATS.GATHER_TABLE_STATS` procedure

SQL Plan Directives

A **SQL plan directive** is additional information and instructions that the optimizer can use to generate a more optimal plan.

The directive is a “note to self” by the optimizer that it is misestimating cardinalities of certain types of predicates, and also a reminder to `DBMS_STATS` to gather statistics needed to correct the misestimates in the future. For example, when joining two tables that have a data skew in their join columns, a SQL plan directive can direct the optimizer to use dynamic statistics to obtain a more accurate join cardinality estimate.

When the Database Creates SQL Plan Directives

The database creates SQL plan directives automatically based on information learned during automatic reoptimization. If a cardinality misestimate occurs during SQL execution, then the database creates SQL plan directives.

For each new directive, the `DBA_SQL_PLAN_DIRECTIVES.STATE` column shows the value `USABLE`. This value indicates that the database can use the directive to correct misestimates.

The optimizer defines a SQL plan directive on a query expression, for example, filter predicates on two columns being used together. A directive is not tied to a specific SQL statement or SQL ID. For this reason, the optimizer can use directives for statements that are not identical. For example, directives can help the optimizer with queries that use similar patterns, such as queries that are identical except for a select list item.

The Notes section of the execution plan indicates the number of SQL plan directives used for a statement. Obtain more information about the directives by querying the `DBA_SQL_PLAN_DIRECTIVES` and `DBA_SQL_PLAN_DIR_OBJECTS` views.

> **See Also:**
>
> *Oracle Database Reference* to learn more about `DBA_SQL_PLAN_DIRECTIVES`

How the Database Uses SQL Plan Directives

When compiling a SQL statement, if the optimizer sees a directive, then it obeys the directive by gathering additional information.

The optimizer uses directives in the following ways:

- Dynamic statistics

  The optimizer uses dynamic statistics whenever it does not have sufficient statistics corresponding to the directive. For example, the cardinality estimates for a query whose predicate contains a specific pair of columns may be significantly wrong. A SQL plan directive indicates that the whenever a query that contains these columns is parsed, the optimizer needs to use dynamic sampling to avoid a serious cardinality misestimate.

  Dynamic statistics have some performance overhead. Every time the optimizer hard parses a query to which a dynamic statistics directive applies, the database must perform the extra sampling.

  Starting in Oracle Database 12c Release 2 (12.2), the database writes statistics from adaptive dynamic sampling to the SQL plan directives store, making them available to other queries.

- Column groups

  The optimizer examines the query corresponding to the directive. If there is a missing column group, and if the `DBMS_STATS` preference `AUTO_STAT_EXTENSIONS` is set to `ON` (the default is `OFF`) for the affected table, then the optimizer automatically creates this column group the next time `DBMS_STATS` gathers statistics on the table. Otherwise, the optimizer does not automatically create the column group.

  If a column group exists, then the next time this statement executes, the optimizer uses the column group statistics in place of the SQL plan directive when possible (equality

predicates, GROUP BY, and so on). In subsequent executions, the optimizer may create additional SQL plan directives to address other problems in the plan, such as join or GROUP BY cardinality misestimates.

> **Note:**
>
> Currently, the optimizer monitors only column groups. The optimizer does not create an extension on expressions.

When the problem that occasioned a directive is solved, either because a better directive exists or because a histogram or extension exists, the DBA_SQL_PLAN_DIRECTIVES.STATE value changes from USABLE to SUPERSEDED. More information about the directive state is exposed in the DBA_SQL_PLAN_DIRECTIVES.NOTES column.

> **See Also:**
>
> - "Managing Extended Statistics"
> - "About Statistics on Column Groups"
> - *Oracle Database PL/SQL Packages and Types Reference* to learn more about the AUTO_STAT_EXTENSIONS preference for DBMS_STATS.SET_TABLE_STATS

SQL Plan Directive Maintenance

The database automatically creates SQL plan directives. You cannot create them manually.

The database initially creates directives in the shared pool. The database periodically writes the directives to the SYSAUX tablespace. The database automatically purges any SQL plan directive that is not used after the specified number of weeks (SPD_RETENTION_WEEKS), which is 53 by default.

You can manage directives by using the DBMS_SPD package. For example, you can:

- Enable and disable SQL plan directives (ALTER_SQL_PLAN_DIRECTIVE)
- Change the retention period for SQL plan directives (SET_PREFS)
- Export a directive to a staging table (PACK_STGTAB_DIRECTIVE)
- Drop a directive (DROP_SQL_PLAN_DIRECTIVE)
- Force the database to write directives to disk (FLUSH_SQL_PLAN_DIRECTIVE)

> **See Also:**
>
> *Oracle Database PL/SQL Packages and Types Reference* to learn about the DBMS_SPD package

How the Optimizer Uses SQL Plan Directives: Example

This example shows how the database automatically creates and uses SQL plan directives for SQL statements.

Assumptions

You plan to run queries against the `sh` schema, and you have privileges on this schema and on data dictionary and `V$` views.

To see how the database uses a SQL plan directive:

1. Query the `sh.customers` table.

   ```
   SELECT /*+gather_plan_statistics*/ *
   FROM   customers
   WHERE  cust_state_province='CA'
   AND    country_id='US';
   ```

   The `gather_plan_statistics` hint shows the actual number of rows returned from each operation in the plan. Thus, you can compare the optimizer estimates with the actual number of rows returned.

2. Query the plan for the preceding query.

   The following example shows the execution plan (sample output included):

```
SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY_CURSOR(FORMAT=>'ALLSTATS LAST'));

PLAN_TABLE_OUTPUT
------------------------------------
SQL_ID  b74nw722wjvy3, child number 0
------------------------------------
select /*+gather_plan_statistics*/ * from customers where
CUST_STATE_PROVINCE='CA' and country_id='US'

Plan hash value: 1683234692
-------------------------------------------------------------------------------------------
| Id| Operation         | Name     |Starts|E-Rows|A-Rows| Time       | Buffers| Reads |
-------------------------------------------------------------------------------------------
| 0 | SELECT STATEMENT  |          |  1 |      |     29 |00:00:00.01 |     17 |    14 |
|*1 |  TABLE ACCESS FULL| CUSTOMERS |  1 |   8 |     29 |00:00:00.01 |     17 |    14 |
-------------------------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   1 - filter(("CUST_STATE_PROVINCE"='CA' AND "COUNTRY_ID"='US'))
```

   The actual number of rows (`A-Rows`) returned by each operation in the plan varies greatly from the estimates (`E-Rows`). This statement is a candidate for automatic reoptimization.

3. Check whether the `customers` query can be reoptimized.

The following statement queries the `V$SQL.IS_REOPTIMIZABLE` value (sample output included):

```
SELECT SQL_ID, CHILD_NUMBER, SQL_TEXT, IS_REOPTIMIZABLE
FROM   V$SQL
WHERE  SQL_TEXT LIKE 'SELECT /*+gather_plan_statistics*/%';

SQL_ID        CHILD_NUMBER SQL_TEXT    I
------------- ------------ ---------- -
b74nw722wjvy3            0 select /*+g Y
                           ather_plan_
                           statistics*
                           / * from cu
                           stomers whe
                           re CUST_STA
                           TE_PROVINCE
                           ='CA' and c
                           ountry_id='
                           US'
```

The `IS_REOPTIMIZABLE` column is marked `Y`, so the database will perform a hard parse of the `customers` query on the next execution. The optimizer uses the execution statistics from this initial execution to determine the plan. The database persists the information learned from reoptimization as a SQL plan directive.

4. Display the directives for the `sh` schema.

   The following example uses `DBMS_SPD` to write the SQL plan directives to disk, and then shows the directives for the `sh` schema only:

```
EXEC DBMS_SPD.FLUSH_SQL_PLAN_DIRECTIVE;

SELECT TO_CHAR(d.DIRECTIVE_ID) dir_id, o.OWNER AS "OWN", o.OBJECT_NAME AS "OBJECT",
       o.SUBOBJECT_NAME col_name, o.OBJECT_TYPE, d.TYPE, d.STATE, d.REASON
FROM   DBA_SQL_PLAN_DIRECTIVES d, DBA_SQL_PLAN_DIR_OBJECTS o
WHERE  d.DIRECTIVE_ID=o.DIRECTIVE_ID
AND    o.OWNER IN ('SH')
ORDER BY 1,2,3,4,5;

DIR_ID              OW OBJECT    COL_NAME   OBJECT TYPE          STATE  REASON
------------------- -- --------- ---------- ------ ------------- ------ ------------
1484026771529551585 SH CUSTOMERS COUNTRY_ID COLUMN DYNAMIC_SAMPL USABLE SINGLE TABLE
                                                                        CARDINALITY
                                                                        MISESTIMATE
1484026771529551585 SH CUSTOMERS CUST_STATE COLUMN DYNAMIC_SAMPL USABLE SINGLE TABLE
                                 _PROVINCE                              CARDINALITY
                                                                        MISESTIMATE
1484026771529551585 SH CUSTOMERS            TABLE  DYNAMIC_SAMPL USABLE SINGLE TABLE
                                                                        CARDINALITY
                                                                        MISESTIMATE
```

Initially, the database stores SQL plan directives in memory, and then writes them to disk every 15 minutes. Thus, the preceding example calls `DBMS_SPD.FLUSH_SQL_PLAN_DIRECTIVE` to force the database to write the directives to the `SYSAUX` tablespace.

Monitor directives using the views `DBA_SQL_PLAN_DIRECTIVES` and `DBA_SQL_PLAN_DIR_OBJECTS`. Three entries appear in the views, one for the `customers` table itself, and one for each of the correlated columns. Because the `customers` query has the `IS_REOPTIMIZABLE` value of `Y`, if you reexecute the statement, then the database will hard parse it again, and then generate a plan based on the previous execution statistics.

5. Query the `customers` table again.

   For example, enter the following statement:

```
SELECT /*+gather_plan_statistics*/ *
FROM   customers
WHERE  cust_state_province='CA'
AND    country_id='US';
```

6. Query the plan in the cursor.

   The following example shows the execution plan (sample output included):

```
SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY_CURSOR(FORMAT=>'ALLSTATS LAST'));

PLAN_TABLE_OUTPUT
------------------------------------
SQL_ID  b74nw722wjvy3, child number 1
------------------------------------
select /*+gather_plan_statistics*/ * from customers where
CUST_STATE_PROVINCE='CA' and country_id='US'

Plan hash value: 1683234692
-----------------------------------------------------------------------------
|Id| Operation         |Name    |Start|E-Rows|A-Rows|  A-Time  |Buffers|
-----------------------------------------------------------------------------
| 0| SELECT STATEMENT  |        |  1|      |    29|00:00:00.01|     17|
|*1|  TABLE ACCESS FULL|CUSTOMERS|  1|    29|    29|00:00:00.01|     17|
-----------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   1 - filter(("CUST_STATE_PROVINCE"='CA' AND "COUNTRY_ID"='US'))

Note
-----
   - cardinality feedback used for this statement
```

   The `Note` section indicates that the database used reoptimization for this statement. The estimated number of rows (`E-Rows`) is now correct. The SQL plan directive has not been used yet.

7. Query the cursors for the `customers` query.

   For example, run the following query (sample output included):

```
SELECT SQL_ID, CHILD_NUMBER, SQL_TEXT, IS_REOPTIMIZABLE
FROM   V$SQL
WHERE  SQL_TEXT LIKE 'SELECT /*+gather_plan_statistics*/%';
```

```
SQL_ID        CHILD_NUMBER SQL_TEXT    I
------------- ------------ ---------- -
b74nw722wjvy3            0 select /*+g Y
                           ather_plan_
                           statistics*
                           / * from cu
                           stomers whe
                           re CUST_STA
                           TE_PROVINCE
                           ='CA' and c
                           ountry_id='
                           US'

b74nw722wjvy3            1 select /*+g N
                           ather_plan_
                           statistics*
                           / * from cu
                           stomers whe
                           re CUST_STA
                           TE_PROVINCE
                           ='CA' and c
                           ountry_id='
                           US'
```

A new plan exists for the `customers` query, and also a new child cursor.

8. Confirm that a SQL plan directive exists and is usable for other statements.

   For example, run the following query, which is similar but not identical to the original `customers` query (the state is `MA` instead of `CA`):

```
SELECT /*+gather_plan_statistics*/ CUST_EMAIL
FROM   CUSTOMERS
WHERE  CUST_STATE_PROVINCE='MA'
AND    COUNTRY_ID='US';
```

9. Query the plan in the cursor.

   The following statement queries the cursor (sample output included).:

```
SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY_CURSOR(FORMAT=>'ALLSTATS LAST'));

PLAN_TABLE_OUTPUT
------------------------------------
SQL_ID  3tk6hj3nkcs2u, child number 0
------------------------------------
Select /*+gather_plan_statistics*/ cust_email From   customers Where
cust_state_province='MA' And    country_id='US'

Plan hash value: 1683234692

-----------------------------------------------------------------------------
|Id | Operation         | Name    |Starts|E-Rows|A-Rows|A-Time|Buffers|
-----------------------------------------------------------------------------
| 0 | SELECT STATEMENT  |           |  1 |    |  2 |00:00:00.01|   16 |
|*1 |  TABLE ACCESS FULL| CUSTOMERS |  1 | 2 |  2 |00:00:00.01|   16 |
-----------------------------------------------------------------------------
```

```
Predicate Information (identified by operation id):
---------------------------------------------------

   1 - filter(("CUST_STATE_PROVINCE"='MA' AND "COUNTRY_ID"='US'))

Note
-----
   - dynamic sampling used for this statement (level=2)
   - 1 Sql Plan Directive used for this statement
```

The `Note` section of the plan shows that the optimizer used the SQL directive for this statement, and also used dynamic statistics.

> **See Also:**
>
> - "Automatic Reoptimization"
> - "Managing SQL Plan Directives"
> - *Oracle Database Reference* to learn about `DBA_SQL_PLAN_DIRECTIVES`, `V$SQL`, and other database views
> - *Oracle Database Reference* to learn about `DBMS_SPD`

How the Optimizer Uses Extensions and SQL Plan Directives: Example

The example shows how the database uses a SQL plan directive until the optimizer verifies that an extension exists and the statistics are applicable.

At this point, the directive changes its status to `SUPERSEDED`. Subsequent compilations use the statistics instead of the directive.

Assumptions

This example assumes you have already followed the steps in "How the Optimizer Uses SQL Plan Directives: Example".

To see how the optimizer uses an extension and SQL plan directive:

1. Gather statistics for the `sh.customers` table.

   For example, execute the following PL/SQL program:

   ```
   BEGIN
     DBMS_STATS.GATHER_TABLE_STATS('SH','CUSTOMERS');
   END;
   /
   ```

2. Check whether an extension exists on the `customers` table.

   For example, execute the following query (sample output included):

   ```
   SELECT TABLE_NAME, EXTENSION_NAME, EXTENSION
   FROM   DBA_STAT_EXTENSIONS
   ```

```
WHERE  OWNER='SH'
AND    TABLE_NAME='CUSTOMERS';

TABLE_NAM EXTENSION_NAME                   EXTENSION
--------- ------------------------------ ----------------------
CUSTOMERS SYS_STU#S#WF25Z#QAHIHE#MOFFMM_ ("CUST_STATE_PROVINCE",
                                          "COUNTRY_ID")
```

The preceding output indicates that a column group extension exists on the `cust_state_province` and `country_id` columns.

3. Query the state of the SQL plan directive.

   Example 10-6 queries the data dictionary for information about the directive.

   Although column group statistics exist, the directive has a state of `USABLE` because the database has not yet recompiled the statement. During the next compilation, the optimizer verifies that the statistics are applicable. If they are applicable, then the status of the directive changes to `SUPERSEDED`. Subsequent compilations use the statistics instead of the directive.

4. Query the `sh.customers` table.

   ```
   SELECT /*+gather_plan_statistics*/ *
   FROM   customers
   WHERE  cust_state_province='CA'
   AND    country_id='US';
   ```

5. Query the plan in the cursor.

   Example 10-7 shows the execution plan (sample output included).

   The `Note` section shows that the optimizer used the directive and not the extended statistics. During the compilation, the database verified the extended statistics.

6. Query the state of the SQL plan directive.

   Example 10-8 queries the data dictionary for information about the directive.

   The state of the directive, which has changed to `SUPERSEDED`, indicates that the corresponding column or groups have an extension or histogram, or that another SQL plan directive exists that can be used for the directive.

7. Query the `sh.customers` table again, using a slightly different form of the statement.

   For example, run the following query:

   ```
   SELECT /*+gather_plan_statistics*/ /* force reparse */ *
   FROM   customers
   WHERE  cust_state_province='CA'
   AND    country_id='US';
   ```

   If the cursor is in the shared SQL area, then the database typically shares the cursor. To force a reparse, this step changes the SQL text slightly by adding a comment.

8. Query the plan in the cursor.

   Example 10-9 shows the execution plan (sample output included).

The absence of a `Note` shows that the optimizer used the extended statistics instead of the SQL plan directive. If the directive is not used for 53 weeks, then the database automatically purges it.

> **See Also:**
>
> - "Managing SQL Plan Directives"
> - *Oracle Database Reference* to learn about `DBA_SQL_PLAN_DIRECTIVES`, `V$SQL`, and other database views
> - *Oracle Database Reference* to learn about `DBMS_SPD`

Example 10-6 Display Directives for sh Schema

```
EXEC DBMS_SPD.FLUSH_SQL_PLAN_DIRECTIVE;

SELECT TO_CHAR(d.DIRECTIVE_ID) dir_id, o.OWNER, o.OBJECT_NAME,
       o.SUBOBJECT_NAME col_name, o.OBJECT_TYPE, d.TYPE, d.STATE, d.REASON
FROM   DBA_SQL_PLAN_DIRECTIVES d, DBA_SQL_PLAN_DIR_OBJECTS o
WHERE  d.DIRECTIVE_ID=o.DIRECTIVE_ID
AND    o.OWNER IN ('SH')
ORDER BY 1,2,3,4,5;

DIR_ID              OWN OBJECT_NA COL_NAME   OBJECT  TYPE             STATE  REASON
------------------- --- --------- ---------- ------- ---------------- ------ ------------
1484026771529551585  SH CUSTOMERS COUNTRY_ID  COLUMN DYNAMIC_SAMPLING USABLE SINGLE TABLE
                                                                              CARDINALITY
                                                                              MISESTIMATE
1484026771529551585  SH CUSTOMERS CUST_STATE_ COLUMN DYNAMIC_SAMPLING USABLE SINGLE TABLE
                                  PROVINCE                                    CARDINALITY
                                                                              MISESTIMATE
1484026771529551585  SH CUSTOMERS              TABLE DYNAMIC_SAMPLING USABLE SINGLE TABLE
                                                                              CARDINALITY
                                                                              MISESTIMATE
```

Example 10-7 Execution Plan

```
SQL> SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY_CURSOR(FORMAT=>'ALLSTATS LAST'));

PLAN_TABLE_OUTPUT
------------------------------------
SQL_ID  b74nw722wjvy3, child number 0
------------------------------------
select /*+gather_plan_statistics*/ * from customers where
CUST_STATE_PROVINCE='CA' and country_id='US'

Plan hash value: 1683234692

-----------------------------------------------------------------------------------------
| Id  | Operation         | Name      | Starts | E-Rows | A-Rows |   A-Time   | Buffers |
-----------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT  |           |      1 |        |     29 |00:00:00.01 |      16 |
```

```
|*  1 |  TABLE ACCESS FULL| CUSTOMERS |      1 |     29 |     29 |00:00:00.01 |      16 |
-----------------------------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   1 - filter(("CUST_STATE_PROVINCE"='CA' AND "COUNTRY_ID"='US'))

Note
-----
   - dynamic sampling used for this statement (level=2)
   - 1 Sql Plan Directive used for this statement
```

Example 10-8 Display Directives for sh Schema

```
EXEC DBMS_SPD.FLUSH_SQL_PLAN_DIRECTIVE;

SELECT TO_CHAR(d.DIRECTIVE_ID) dir_id, o.OWNER, o.OBJECT_NAME,
       o.SUBOBJECT_NAME col_name, o.OBJECT_TYPE, d.TYPE, d.STATE, d.REASON
FROM   DBA_SQL_PLAN_DIRECTIVES d, DBA_SQL_PLAN_DIR_OBJECTS o
WHERE  d.DIRECTIVE_ID=o.DIRECTIVE_ID
AND    o.OWNER IN ('SH')
ORDER BY 1,2,3,4,5;

DIR_ID              OWN OBJECT_NA  COL_NAME    OBJECT TYPE     STATE      REASON
------------------- --- ---------  ----------  ------ -------- ---------  ------------
1484026771529551585  SH CUSTOMERS  COUNTRY_ID  COLUMN DYNAMIC_ SUPERSEDED SINGLE TABLE
                                                       SAMPLING           CARDINALITY
                                                                          MISESTIMATE
1484026771529551585  SH CUSTOMERS  CUST_STATE_ COLUMN DYNAMIC_ SUPERSEDED SINGLE TABLE
                                   PROVINCE           SAMPLING           CARDINALITY
                                                                          MISESTIMATE
1484026771529551585  SH CUSTOMERS               TABLE DYNAMIC_ SUPERSEDED SINGLE TABLE
                                                       SAMPLING           CARDINALITY
                                                                          MISESTIMATE
```

Example 10-9 Execution Plan

```
SQL> SELECT * FROM TABLE(DBMS_XPLAN.DISPLAY_CURSOR(FORMAT=>'ALLSTATS LAST'));

PLAN_TABLE_OUTPUT
-------------------------------------
SQL_ID  b74nw722wjvy3, child number 0
-------------------------------------
select /*+gather_plan_statistics*/ * from customers where
CUST_STATE_PROVINCE='CA' and country_id='US'

Plan hash value: 1683234692

-----------------------------------------------------------------------------------------------
| Id  | Operation         | Name      | Starts | E-Rows | A-Rows |   A-Time   | Buffers |
-----------------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT  |           |      1 |        |     29 |00:00:00.01 |      17 |
|*  1 |  TABLE ACCESS FULL| CUSTOMERS |      1 |     29 |     29 |00:00:00.01 |      17 |
```

```
--------------------------------------------------------------------------------

Predicate Information (identified by operation id):
---------------------------------------------------

   1 - filter(("CUST_STATE_PROVINCE"='CA' AND "COUNTRY_ID"='US'))

19 rows selected.
```

When the Database Samples Data

Starting in Oracle Database 12c, the optimizer automatically decides whether dynamic statistics are useful and which sample size to use for all SQL statements.

> **Note:**
>
> In earlier releases, dynamic statistics were called *dynamic sampling*.

The primary factor in the decision to use dynamic statistics is whether available statistics are sufficient to generate an optimal plan. If statistics are insufficient, then the optimizer uses dynamic statistics.

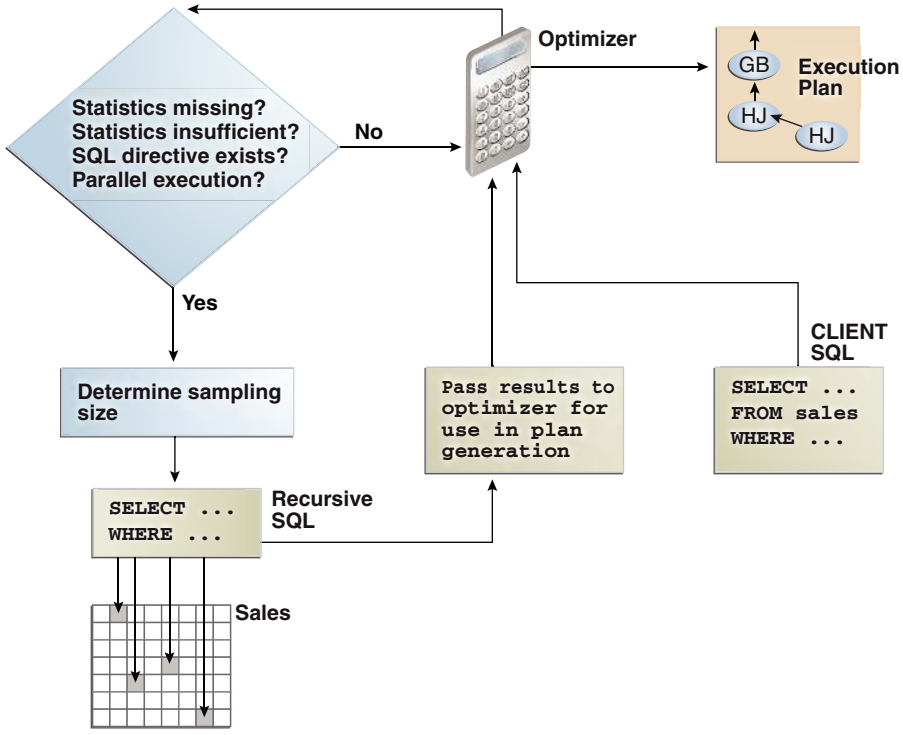
Automatic dynamic statistics are enabled when the `OPTIMIZER_DYNAMIC_SAMPLING` initialization parameter is not set to `0`. By default, the dynamic statistics level is set to `2`.

In general, the optimizer uses default statistics rather than dynamic statistics to compute statistics needed during optimizations on tables, indexes, and columns. The optimizer decides whether to use dynamic statistics based on several factors, including the following:

- The SQL statement uses parallel execution.
- A SQL plan directive exists.

The following diagram illustrates the process of gathering dynamic statistics.

Figure 10-2 Dynamic Statistics



As shown in Figure 10-2, the optimizer automatically gathers dynamic statistics in the following cases:

- Missing statistics

  When tables in a query have no statistics, the optimizer gathers basic statistics on these tables before optimization. Statistics can be missing because the application creates new objects without a follow-up call to `DBMS_STATS` to gather statistics, or because statistics were locked on an object before statistics were gathered.

  In this case, the statistics are not as high-quality or as complete as the statistics gathered using the `DBMS_STATS` package. This trade-off is made to limit the impact on the compile time of the statement.

- Insufficient statistics

  Statistics can be insufficient whenever the optimizer estimates the selectivity of predicates (filter or join) or the `GROUP BY` clause without taking into account correlation between columns, skew in the column data distribution, statistics on expressions, and so on.

  Extended statistics help the optimizer obtain accurate quality cardinality estimates for complex predicate expressions. The optimizer can use dynamic statistics to compensate for the lack of extended statistics or when it cannot use extended statistics, for example, for non-equality predicates.

> **Note:**
>
> The database does not use dynamic statistics for queries that contain the `AS OF` clause.

> **See Also:**
>
> - "Configuring Options for Dynamic Statistics"
> - "About Statistics on Column Groups"
> - *Oracle Database Reference* to learn about the `OPTIMIZER_DYNAMIC_SAMPLING` initialization parameter

How the Database Samples Data

At the beginning of optimization, when deciding whether a table is a candidate for dynamic statistics, the optimizer checks for the existence of persistent SQL plan directives on the table.

For each directive, the optimizer registers a statistics expression that the optimizer computes when determining the cardinality of a predicate involving the table. In Figure 10-2, the database issues a recursive SQL statement to scan a small random sample of the table blocks. The database applies the relevant single-table predicates and joins to estimate predicate cardinalities.

The database persists the results of dynamic statistics as sharable statistics. The database can share the results during the SQL compilation of one query with recompilations of the same query. The database can also reuse the results for queries that have the same patterns.

> **See Also:**
>
> - "Configuring Options for Dynamic Statistics" to learn how to set the dynamic statistics level
> - *Oracle Database Reference* for details about the `OPTIMIZER_DYNAMIC_SAMPLING` initialization parameter