Politecnico di Torino

Database Management Systems

Oracle Optimizer

Tania Cerquitelli
tania.cerquitelli@polito.it

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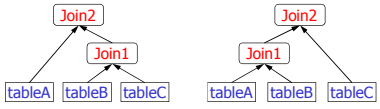
Optimizer objective

- A SQL statement can be executed in many different ways
- The query optimizer determines the most efficient way to execute a SQL statement after considering many factors (e.g., objects referenced, conditions specified in the query)
- The output from the optimizer is a plan that describes an optimum method of execution (i.e., minimum execution cost)
- The cost is an estimated value proportional to the expected resource use (i.e., I/O, CPU, and memory) needed to execute the statement with a particular plan

Plan Generator

- Its main function is to
  - try out different possible plans for a given query
  - and pick the one that has the lowest cost
- Many plans are possible because of combinations of different
  - access paths
  - join methods
  - join orders



- It uses an internal cutoff to reduce the number of plans explored
  - the cutoff is based on the cost of the current best plan
  - if cutoff is high, more plans are explored, and vice versa

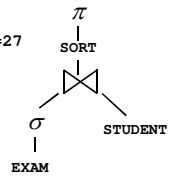
Optimizer operations

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 sub-queries 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
Choice of access paths	For each table accessed by the statement, the optimizer chooses one or more of available access paths to obtain data
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
Choice of join methods	For a join statement that joins more than two tables, the optimizer chooses which join method is exploited to perform the required operation

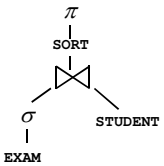
Example

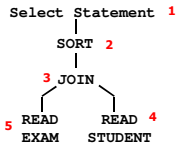
```
STUDENT (SId, SSurname, SName)
COURSE (CCode, PId, Year, Semester)
EXAM (CCode, SId, Date, Score)
```

```
Query: SELECT SName, S.Sid
       FROM EXAM E, STUDENT S
       WHERE S.Sid=E.Sid and Score>=27
       ORDER BY SName
```



Example





Id	Pid	Operation	Cost
1	/	Select Statement	100
2	1	Sort	90
3	2	Join	70
4	3	Read STUDENT	40
5	3	Read EXAM + Selection	20

Access Paths for the Query Optimizer

- Access paths allow the retrieval of data from the database
  - Index access paths should be used for statements that retrieve a small subset of table rows
  - Full scans are more efficient when accessing a large portion of the table
- Data can be retrieved in any table by means of the following access paths
  - Full Table Scans
  - Index Scans
  - Rowid Scans

Full Table Scans

- This type of scan reads all rows from a table and filters out those that do not meet the selection criteria
- Each row is examined to determine whether it satisfies the statement's **`WHERE`** clause
- Physical blocks are adjacent and they are read sequentially
- Larger I/O calls are allowed, i.e., many blocks (multiblock) are read in a single I/O call
- Multiblock reads can be used to speed up the process
- The size of multiblock is initialized by the parameter **`DB_FILE_MULTIBLOCK_READ_COUNT`**

Assessing I/O for Blocks

- Oracle does I/O by blocks
  - Generally multiple rows are stored in each block. The total number of rows could be clustered together in a few blocks, or they could be spread out over a larger number of blocks.
- The optimizer decision to use full table scans is influenced by the percentage of blocks accessed, not rows. This is called the **index clustering factor**
- 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
  - Low clustering factor: individual rows are concentrated within fewer blocks in the table.
  - High clustering factor: individual rows are scattered more randomly across blocks in the table. 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.

Effects of Clustering Factor on Cost

- Assume the following situation
  - There is a table with 9 rows
  - There is a non-unique index on column 1
  - Column 1 currently stores the values A, B, and C
  - Oracle stores the table using only 3 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

Effects of Clustering Factor on Cost

- Case 2. If the same rows in the table are rearranged so that the index values are scattered across the table blocks (rather than clustered together), then the **index clustering factor** is higher, as in the following schema.

Block 1	Block 2	Block 3
A B C	A B C	A B C

When the Optimizer Uses Full Table Scans

- Lack of index
- Retrieval of a large amount of data stored in the target table
  - If the query will access most of the blocks in the table, the optimizer uses a full table scan, even though indexes might be available
  - Full table scans can use larger I/O calls, and making fewer large I/O calls is cheaper than making many smaller calls
- Small table
  - If a table has less than **`DB_FILE_MULTIBLOCK_READ_COUNT`** blocks it can be read in a single I/O call, then a full table scan might be cheaper than an index range scan

Oracle indexes

- System indexes (secondary indexes) created automatically on the primary key attributes
  - SYS_#
- Primary indexes
  - Clustered Btree (physical sort)
  - Hash (bucket)
- Secondary indexes
  - Btree
  - Bitmap
  - Hash

```
CREATE INDEX IndexName ON Table (Column, …);

DROP INDEX IndexName;
```


Index Scans

- The index contains the indexed value and the rowids of rows in the table having that value
- An index scan retrieves data from an index based on the value of one or more columns in the index
  - Oracle searches the index for the indexed column values accessed by the statement
  - If the statement accesses only columns of the index, the indexed column values are read directly from the index, otherwise the rows in the table are accessed by means of the rowid
- An index scan can be one of the following types
  - Index Unique Scans
  - Index Range Scans
  - Index Full Scans
  - Fast Full Index Scans
  - Bitmap Indexes

Index Unique Scans

- This scan returns at most a single rowid for each indexed value
- 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
- It is used when all columns of a unique (e.g., B-tree) index or an index created as a result of a primary key constraint are specified with equality conditions

Index Range Scans

- An index range scan is a common operation for accessing selective data
- Data is returned in the ascending order of index columns. Multiple rows with identical values are sorted in ascending order by rowid
- The optimizer uses a range scan when it finds one or more leading columns of an index specified in conditions
  - col1 = :b1
  - col1 <= :b1
  - col1 > =:b1
  - and combinations of the preceding conditions for leading columns in the index
- Range scans can use unique or non-unique indexes
- Range scans avoid sorting when index columns constitute the **`ORDER BY`**/**`GROUP BY`** clause

Index Full Scans

- A index 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.
- It 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 (required by **`GROUP BY`**, **`ORDER BY`**, **`MERGE JOIN`**), because the data is ordered by the index key
- It reads the blocks singly (one by one)

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
- A fast full scan is faster than a normal full index scan
  - It reads the entire index using multiblock reads

Bitmap Indexes

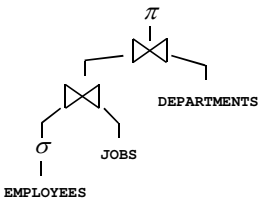
- Bitmap indexes are most effective for queries that contain multiple conditions in the WHERE clause
- They are usually easier to destroy and re-create than to maintain
- A bitmap join uses a bitmap for key values and a mapping function that converts each bit position to a rowid

Rowid Scans

- The **rowid** of a row specifies the data file and data block (i.e., physical address) containing the row and the location of the row in that block
- Locating a row by its rowid is the fastest way to retrieve a single row
- To access a table by rowid (in Oracle)
  - Rowids of the selected rows are obtained through an index scan of one or more of the table's indexes
  - Each selected row is accessed in the table based on the physical address obtained by its rowid

Rowid Scans: Example

```
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;
```



Rowid Scans: Example

```
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;
```

```
| 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")
```


JOIN

- Join Method
  - To join each pair of row sources, Oracle must perform a join operation
  - Join methods include
    - nested loop
    - sort merge
    - 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.

Understanding Statistics

- Optimizer statistics are a collection of data that describe more details about the database and the objects in the database
- Optimizer statistics, stored in the data dictionary, include the following:
  - Table statistics
    - Number of rows
    - Number of blocks
    - Average row length
  - Column statistics
    - Number of distinct values (NDV) in columns
    - Number of nulls in columns
    - Data distribution (histogram)
  - Index statistics
    - Number of leaf blocks
    - Levels
    - Clustering factor
  - System statistics
    - I/O performance and utilization
    - CPU performance and utilization

Statistics on Tables, Indexes and Columns

- 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
  - **`describe table_name`** allows to view the table schema

Column Statistics and Histograms

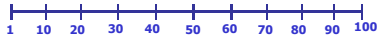
- When gathering statistics on a table, **`DBMS_STATS`** gathers information about the data distribution of the columns within the table (e.g., the maximum value and minimum value of the column)
- For skewed data distributions, histograms can also be created as part of the column statistics to describe the data distribution of a given column

Histograms

- Column statistics may be stored as histograms which 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 non-uniform data distributions
- Oracle uses two types of histograms for column statistics
  - Height-balanced histograms
  - Frequency histograms
- The type of histogram is stored in the **`HISTOGRAM`** column of the **`USER/DBA_TAB_COL_STATISTICS`** views

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 is not uniformly distributed, then the histogram might look similar to

Height-Balanced Histograms

```
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
```

Height-Balanced Histograms

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 **`*USER_HISTOGRAMS`** tables

Frequency Histograms

```
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
```


Choosing an Optimizer Goal

- Optimization for best **throughput**
  - Optimizer chooses the least amount of resources necessary to process all rows accessed by the statement
  - Throughput is more important in batch applications (e.g., Oracle Reports applications) because the user is only concerned with the time necessary for the application to complete
- Optimization for best **response time**
  - Optimizer uses the least amount of resources necessary to process the first row accessed by a SQL statement.
  - Response time is important in interactive applications (e.g., SQL*Plus queries)

OPTIMIZER_MODE Parameter Values

Value	Description
`ALL_ROWS`	The optimizer uses a cost-based approach for all SQL statements in the session. It optimizes with a goal of best **throughput** (minimum resource use to complete the entire statement). Default.
`FIRST_ROWS_n`	The optimizer uses a cost-based approach, 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

- 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;
```