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Fine Tune Oracle Execution Plans for Performance Gains

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Senior DBA

Who Am I?

- Senior DBA for Confio Software
  - JanisGriffin@confio.com
  - @**D**o**B**out**A**nything
- Current - 24+ Years in Oracle
- Former – Database Design & Implementation
- Specialize in Performance Tuning
- Review Database Performance for Customers and Prospects
- Common Thread – How do I tune it?

Agenda

- What are Execution Plans
- How to View Them
- Interpret Plan Details / Tips / Techniques
- Tune – Case Study
- Additional Tools

What are Execution Plans

- Execution plans provide the **sequence of operations** performed in order to run SQL Statements. They show:
  - Order of the tables referenced in the statement
  - Access method for each table in the statement
    - INDEX
    - INLIST ITERATOR
    - TABLE ACCESS
    - VIEW
  - Join method in statement accessing multiple tables
    - HASH JOIN
    - MERGE JOIN
    - NESTED LOOPS
  - Data manipulations
    - CONCATENATION
    - COUNT
    - FILTER
    - SORT

Execution Plan Information

- Operation - Name of the internal action performed in each step.
  - First Row is always:
    - DELETE STATEMENT
    - INSERT STATEMENT
    - SELECT STATEMENT
    - UPDATE STATEMENT
- Options
  - Variation of Operation
- Object_name
  - Table or Index
- Parent_id
  - Related Operations
- More Information
  - Not listed here

Operation List:
AND-EQUAL
CONNECT BY
CONCATENATION
COUNT
DOMAIN INDEX
FILTER
FIRST ROW
FOR UPDATE
HASH JOIN
INDEX
ITERATOR INTERSECTION
MERGE JOIN
MINUS
NESTED LOOPS
PARTITION
REMOTE
SEQUENCE
SORT
TABLE ACCESS
UNION
VIEW

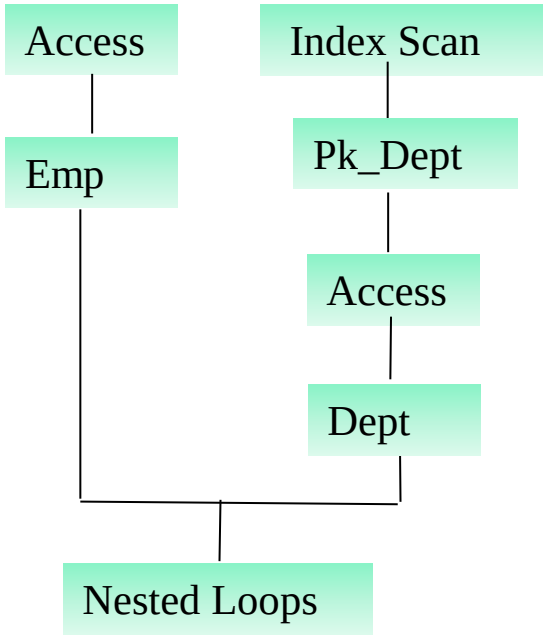
Option Examples:
AGGREGATE
ALL
BY INDEX ROWID
BY LOCAL INDEX ROWID
BY USER ROWID
CARTESIAN
FAST FULL SCAN
FULL
FULL OUTER
FULL SCAN
GROUP BY
ITERATOR
ORDER BY
OUTER
PARTITION
RANGE SCAN
SAMPLE FAST FULL SCAN
SKIP SCAN
UNIQUE

What are Execution Plans

- Optimizer's detailed steps to execute a SQL Statement

```
SELECT e.empno EID, e.ename "Employee_name",
          d.dname "Department", e.hiredate "Hired_Date"
FROM  emp e,  dept d
WHERE  d.deptno = '40'
AND e.deptno = d.deptno;
```

```
-------------------------------------------------------------
 Id  | Operation & Option                        | Name
-------------------------------------------------------------
  0 | SELECT STATEMENT                          |
  1 |   NESTED LOOPS                            |
  2 |     TABLE ACCESS BY INDEX ROWID           | DEPT
  3 |       INDEX UNIQUE SCAN                   | PK_DEPT
  4 |     TABLE ACCESS FULL                     | EMP
```



How To View Plans

- EXPLAIN PLAN
  - Estimated plan - can be wrong for many reasons
    - Explain Plan For … *sql statement*
    - Set autotrace *(on | trace | exp | stat | off)*
- V$SQL_PLAN (Oracle 9i+)
  - Actual execution plan
  - Use DBMS_XPLAN for display

DBMS_XPLAN - Table Functions to Format & Display Plans

DISPLAY - contents of a plan table.
DISPLAY_AWR – the plan of a stored SQL statement in AWR.
DISPLAY_CURSOR - the execution plan of any loaded cursor.
DISPLAY_SQL_PLAN_BASELINE – 1+ plans for a SQL statement
DISPLAY_SQLSET - multi-plans of statements in SQL tuning set

- Tracing (all versions) / TKPROF
  - Get all sorts of good information
  - Works when you know a problem will occur
- Historical Plans – AWR, Confio Ignite
  - Shows plan changes over time

DBMS_XPLAN – 11g

- New Functions 11g

BUILD_PLAN_XML	Return the last plan, or a named plan, explained as XML
DISPLAY	Shows the last plan explained – EXPLAIN PLAN ** Only FUNCTION in Oracle 9i
DISPLAY_AWR	Format & display the plan of a stored SQL statement in AWR
DISPLAY_CURSOR	Format & display the execution plan of any loaded cursor
DISPLAY_PLAN	Return the last plan, or a named plan, explained as a CLOB
DISPLAY_SQLSET	Format & display the execution plan of statements stored in a SQL tuning set
DISPLAY_SQL_PLAN_BASELINE	Displays one or more plans for the specified SQL statement
FORMAT_NUMBER	Returns a number as a string
FORMAT_NUMBER2	Returns a number as a string formatted with a leading space (CHR(32))
FORMAT_SIZE	Undocumented
FORMAT_SIZE2	Undocumented
FORMAT_TIME_S	Undocumented
PREPARE_PLAN_XML_QUERY	- function to build the XML version of a select query that is run before the display function to retrieve and display the execution plan of a SQL
PREPARE_RECORDS	Used Internally
VALIDATE_FORMAT	Used Internally

Execution Plan Details

SELECT e.empno EID, e.ename "Employee_name, d.dname "Department", e.hiredate "Date_Hired"
FROM emp e, dept d WHERE d.deptno = :P1 AND e.deptno = d.deptno;

SET AUTOTRACE TRACEONLY:

```
Execution Plan
----------------------------------------------------------
Plan hash value: 568005898

-------------------------------------------------------------------------------------
| Id  | Operation                    | Name    | Rows  | Bytes | Cost (%CPU)| Time     |
-------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT             |         |  1503 | 54108 |    15   (0)| 00:00:01 |
|   1 |  NESTED LOOPS                |         |  1503 | 54108 |    15   (0)| 00:00:01 |
|   2 |   TABLE ACCESS BY INDEX ROWID| DEPT    |     1 |    11 |     2   (0)| 00:00:01 |
|*  3 |    INDEX UNIQUE SCAN         | PK_DEPT |     1 |       |     1   (0)| 00:00:01 |
|*  4 |   TABLE ACCESS FULL          | EMP     |  1503 | 37575 |    13   (0)| 00:00:01 |
-------------------------------------------------------------------------------------

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

   3 - access("D"."DEPTNO"=TO_NUMBER(:P1))
   4 - filter("E"."DEPTNO"=TO_NUMBER(:P1))


Statistics
----------------------------------------------------------
          0  recursive calls
          0  db block gets
        312  consistent gets
          0  physical reads
          0  redo size
     124547  bytes sent via SQL*Net to client
       3413  bytes received via SQL*Net from client
        265  SQL*Net roundtrips to/from client
          0  sorts (memory)
          0  sorts (disk)
       3958  rows processed
```

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Need Table & Index Info

- Understand objects in execution plans.
  - Table & Segment sizes
  - Number of Rows
  - Indexes & their column order
  - Column data types
  - Cardinality of columns / Data Skew
  - Statistic Gathering
  - Histograms?
- Use TuningStats.sql
  - http://support.confio.com/kb/1534
- Run it for expensive data access targets

Table & Column Statistics

```
SELECT column_name, num_distinct, num_nulls, num_buckets, density, sample_size
FROM user_tab_columns
WHERE table_name = 'EMP'
ORDER BY column_name;
```

COLUMN_NAME	NUM_DISTINCT	NUM_NULLS	NUM_BUCKETS	DENSITY	SAMPLE_SIZE
COMM	1534	4430	1	.00065189	1583
DEPTNO	4	0	4	.000083153	6013
EMPNO	6013	0	1	.000166306	6013
ENAME	6013	0	254	.000166306	6013
HIREDATE	88	0	1	.011363636	6013
JOB	22	0	22	.000083153	6013
MGR	6	6000	1	.166666667	13
SAL	6000	0	1	.000166667	6013

SELECT count(*) FROM EMP;

```
  COUNT(*)
------------
      6013
```

SELECT 6013/4 dist FROM DUAL;

```
      DIST
------
1503
```

SELECT DEPTNO, count(*) FROM EMP
GROUP BY DEPTNO;

DEPTNO	COUNT(*)
10	77
20	1500
30	478
40	3958

Would an index on EMP.DEPTNO increase performance?

Histograms

exec dbms_stats.gather_schema_stats(-ownname => 'SCOTT',
options => 'GATHER AUTO', estimate_percent => dbms_stats.auto_sample_size,
method_opt => 'for all columns size auto' ...

COLUMN_NAME	NUM_DISTINCT	NUM_NULLS	NUM_BUCKETS	DENSITY	SAMPLE_SIZE	HISTOGRAM
COMM	1534	4430	1	.00065189	1583	NONE
DEPTNO	4	0	4	.000083153	6013	FREQUENCY
EMPNO	6013	0	1	.000166306	6013	NONE
ENAME	6013	0	254	.000166306	6013	HEIGHT BALANCED
HIREDATE	88	0	1	.011363636	6013	NONE
JOB	22	0	22	.000083153	6013	FREQUENCY
MGR	6	6000	1	.166666667	13	NONE
SAL	6000	0	1	.000166667	6013	NONE

exec dbms_stats.gather_table_stats(ownname => 'SCOTT',
tabname => 'EMP', method_opt=>'FOR COLUMNS deptno SIZE 2');

COLUMN_NAME	NUM_DISTINCT	NUM_NULLS	NUM_BUCKETS	DENSITY	SAMPLE_SIZE	HISTOGRAM
COMM	1534	4430	1	.00065189	1583	NONE
DEPTNO	4	0	2	.201057724	6013	HEIGHT BALANCED
EMPNO	6013	0	1	.000166306	6013	NONE
ENAME	6013	0	254	.000166306	6013	HEIGHT BALANCED
HIREDATE	88	0	1	.011363636	6013	NONE
JOB	22	0	22	.000083153	6013	FREQUENCY
MGR	6	6000	1	.166666667	13	NONE
SAL	6000	0	1	.000166667	6013	NONE

Extra Info - Bind Values

- V$SQL_BIND_CAPTURE
  - STATISTICS_LEVEL = TYPICAL or ALL
  - Collected at 15 minute intervals

```
SELECT name, position, datatype_string, value_string
FROM   v$sql_bind_capture
WHERE sql_id = '0zz5h1003f2dw';

NAME         POSITION  DATATYPE_STRING          VALUE_STRING
-----------  --------  -----------------------  ----------------
:P1                 1  VARCHAR2(128)                        40
```

```
EMP Columns:
Name                 Type
-------------------- ------------
EMPNO                NUMBER(4)
ENAME
VARCHAR2(10)
JOB                  VARCHAR2(9)
MGR                  NUMBER(4)
HIREDATE             DATE
SAL                  NUMBER(7,2)
COMM                 NUMBER(7,2)
DEPTNO               NUMBER(2)
```

- Bind Values also provided by tracing
  - Level 4 – bind values
  - Level 8 – wait information
  - Level 12 – bind values and wait information

Execution Plan Details

SELECT e.empno EID, e.ename "Employee_name, d.dname "Department", e.hiredate "Date_Hired"
FROM emp e, dept dWHERE d.deptno = :P1 AND e.deptno = d.deptno;

Actual Plan: V$SQL_PLAN using dbms_xplan.display_cursor

```
SQL>
SQL> select * from table(dbms_xplan.display_cursor('bbh4gphampy33',0));

SQL_ID  bbh4gphampy33, child number 0
-------------------------------------
SELECT e.empno EID, e.ename "Employee_name",  d.dname "Department",
e.hiredate "Date_Hired" FROM  emp e,  dept d WHERE  d.deptno =  :P1 AND
e.deptno = d.deptno

Plan hash value: 568005898

-----------------------------------------------------------------------------------------
| Id  | Operation                    | Name    | Rows  | Bytes | Cost (%CPU)| Time     |
-----------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT             |         |       |       |    15 (100)|          |
|   1 |  NESTED LOOPS                |         |  3958 |   139K|    15   (0)| 00:00:01 |
|   2 |   TABLE ACCESS BY INDEX ROWID| DEPT    |     1 |    11 |     2   (0)| 00:00:01 |
|*  3 |    INDEX UNIQUE SCAN         | PK_DEPT |     1 |       |     1   (0)| 00:00:01 |
|*  4 |   TABLE ACCESS FULL          | EMP     |  3958 | 98950 |    13   (0)| 00:00:01 |
-----------------------------------------------------------------------------------------

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

   3 - access("D"."DEPTNO"=TO_NUMBER(:P1))
   4 - filter("E"."DEPTNO"=TO_NUMBER(:P1))
```

Plans Not Created Equal

```
SELECT company, attribute FROM data_out WHERE segment = :B1
```

- Wait Time – 100% on "db file scattered read"
- Plan from EXPLAIN PLAN

```
SELECT STATEMENT Optimizer=ALL_ROWS (Cost=1 Card=1 Bytes=117)
   TABLE ACCESS (BY INDEX ROWID) OF 'DATA_OUT' (TABLE) (Cost=1 Card=1 Bytes=117)
     INDEX (UNIQUE SCAN) OF 'IX1_DATA_OUT' (INDEX (UNIQUE)) (Cost=1 Card=1)
```

- Plan from V$SQL_PLAN using DBMS_XPLAN

```
select * from table(dbms_xplan.display_cursor('az7r9s3wpqg7n',0));

-------------------------------------------------------------------------------
| Id  | Operation          | Name     | Rows  | Bytes | Cost (%CPU)| Time     |
-------------------------------------------------------------------------------
|   0 | SELECT STATEMENT   |          |       |       |   370 (100)|          |
|*  1 |  TABLE ACCESS FULL| DATA_OUT |     1 |   117 |   370   (4)| 00:00:05 |
-------------------------------------------------------------------------------

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

   1 - filter(TO_BINARY_DOUBLE("SEGMENT")=:B1)
```

Execution Plans Can Change

- With Oracle optimizer, execution plans can change as the underlying inputs to the optimizer change.
  - Same Sql – Different Schemas
    - Same schema changes i.e. adding / dropping indexes
  - Same Sql – Different Costs
    - Data volume & Statistic Changes over time
    - Bind variable types and values
    - Initialization parameters (set globally or session level)
  - V$SQL_SHARED_CURSOR
    - Can give clues to why plan changed
    - Approximately 60 columns showing mismatches /differences

Tuning List – How to

- Find the Expensive Operators
  - Examine Costs / Row Count / Time
  - Table Access Full?
- Review Filter and Access Predicates
  - Shows how query is interpreted, e.g. bind variables
  - Can help Diagnose Data Type Issues
- Evaluate Object Stats
  - Table Definitions
  - Sizes and Row Counts
- Determine Existing Indexes
  - Index Definitions
  - Index Selectivity
- Evaluate Column Stats
  - Limiting Factors from WHERE Clause
- Review Join Columns – Are they indexed / data scew?

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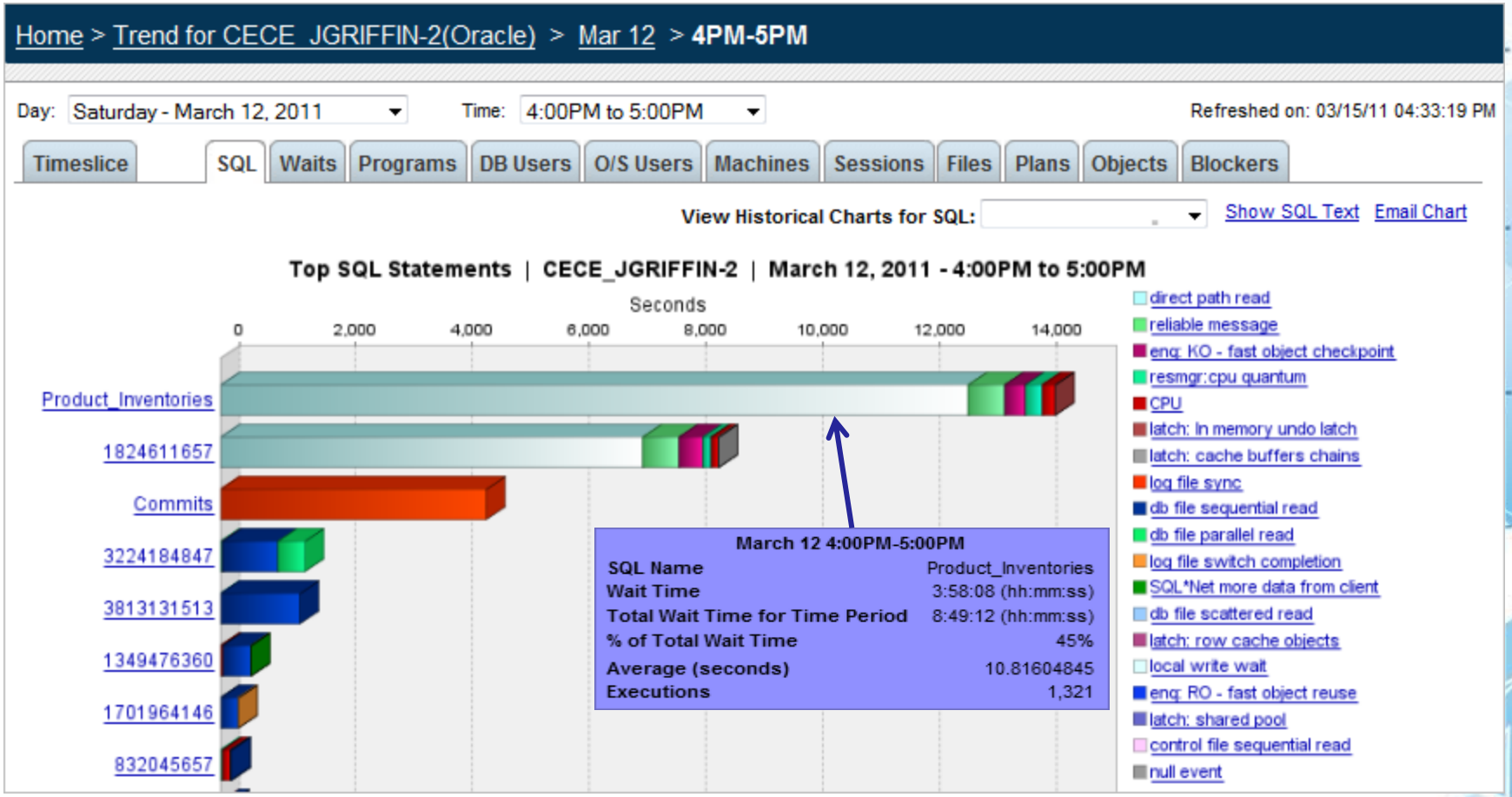
Example SQL Statement

- Find inventory of products in a specific category at a particular location?

```
SELECT PRODUCTS.PRODUCT_ID, PRODUCT_NAME,
    PRODUCT_DESCRIPTION,CATEGORY_ID, WEIGHT_CLASS,
     WARRANTY_PERIOD,  SUPPLIER_ID, PRODUCT_STATUS,
     LIST_PRICE,MIN_PRICE, CATALOG_URL, QUANTITY_ON_HAND
FROM PRODUCTS,
        INVENTORIES
WHERE INVENTORIES.PRODUCT_ID = PRODUCTS.PRODUCT_ID
AND PRODUCTS.CATEGORY_ID = :B3
AND INVENTORIES.WAREHOUSE_ID = :B2
AND ROWNUM < :B1 ;
```

- Average Execution Time – 10.81 seconds
- Wait Event – Waits 90% on direct path read

Why this SQL Statement?



Actual Plan

```
Execution Plan
----------------------------------------------------------
Plan hash value: 1499855773

-------------------------------------------------------------------------------------------------
| Id  | Operation                     | Name                  | Rows  | Bytes | Cost (%CPU)| Time     |
-------------------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT              |                       |  1294 |  4122K|  3016   (1)| 00:00:37 |
|*  1 |  COUNT STOPKEY                |                       |       |       |            |          |
|*  2 |   HASH JOIN                   |                       |  1294 |  4122K|  3016   (1)| 00:00:37 |
|*  3 |    HASH JOIN RIGHT OUTER      |                       |    10 | 32230 |    24   (5)| 00:00:01 |
|*  4 |     TABLE ACCESS FULL         | PRODUCT_DESCRIPTIONS  |     1 |  2070 |    18   (0)| 00:00:01 |
|   5 |     TABLE ACCESS BY INDEX ROWID| PRODUCT_INFORMATION  |    10 | 11530 |     5   (0)| 00:00:01 |
|*  6 |      INDEX RANGE SCAN         | PROD_CATEGORY_IX      |     4 |       |     1   (0)| 00:00:01 |
|*  7 |    TABLE ACCESS FULL          | INVENTORIES           |  9575 |   364K|  2992   (1)| 00:00:36 |
-------------------------------------------------------------------------------------------------

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

   1 - filter(ROWNUM<TO_NUMBER(:B1))
   2 - access("INVENTORIES"."PRODUCT_ID"="I"."PRODUCT_ID")
   3 - access("D"."PRODUCT_ID"(+)="I"."PRODUCT_ID")
   4 - filter("D"."LANGUAGE_ID"(+)=SYS_CONTEXT('USERENV','LANG'))
   6 - access("I"."CATEGORY_ID"=TO_NUMBER(:B3))
   7 - filter("INVENTORIES"."WAREHOUSE_ID"=TO_NUMBER(:B2))

Note
-----
   - dynamic sampling used for this statement


Statistics
----------------------------------------------------------
         49  recursive calls
          0  db block gets
      11348  consistent gets
         88  physical reads
          0  redo size
       2935  bytes sent via SQL*Net to client
        519  bytes received via SQL*Net from client
          2  SQL*Net roundtrips to/from client
          6  sorts (memory)
          0  sorts (disk)
          6  rows processed
```

```
SELECT  …. columns
FROM PRODUCTS,
       INVENTORIES
WHERE INVENTORIES.PRODUCT_ID = PRODUCTS.PRODUCT_ID
AND PRODUCTS.CATEGORY_ID = :B3
AND INVENTORIES.WAREHOUSE_ID = :B2
AND ROWNUM < :B1
```

Actual Plan – No Statistics

```
Execution Plan
----------------------------------------------------------
Plan hash value: 1499855773

-------------------------------------------------------------------------------------------------------------
| Id  | Operation                     | Name                 | Rows  | Bytes | Cost (%CPU)| Time     |
-------------------------------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT              |                      |  1294 |  4122K|  3016   (1)| 00:00:37 |
|*  1 |  COUNT STOPKEY                |                      |       |       |            |          |
|*  2 |   HASH JOIN                   |                      |  1294 |  4122K|  3016   (1)| 00:00:37 |
|*  3 |    HASH JOIN RIGHT OUTER      |                      |    10 | 32230 |    24   (5)| 00:00:01 |
|*  4 |     TABLE ACCESS FULL         | PRODUCT_DESCRIPTIONS |     1 |  2070 |    18   (0)| 00:00:01 |
|   5 |     TABLE ACCESS BY INDEX ROWID| PRODUCT_INFORMATION |    10 | 11530 |     5   (0)| 00:00:01 |
|*  6 |      INDEX RANGE SCAN         | PROD_CATEGORY_IX     |     4 |       |     1   (0)| 00:00:01 |
|*  7 |    TABLE ACCESS FULL          | INVENTORIES          |  9575 |   364K|  2992   (1)| 00:00:36 |
-------------------------------------------------------------------------------------------------------------

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

   1 - filter(ROWNUM<TO_NUMBER(:B1))
   2 - access("INVENTORIES"."PRODUCT_ID"="I"."PRODUCT_ID")
   3 - access("D"."PRODUCT_ID"(+)="I"."PRODUCT_ID")
   4 - filter("D"."LANGUAGE_ID"(+)=SYS_CONTEXT('USERENV','LANG'))
   6 - access("I"."CATEGORY_ID"=TO_NUMBER(:B3))
   7 - filter("INVENTORIES"."WAREHOUSE_ID"=TO_NUMBER(:B2))

Note
-----
   - dynamic sampling used for this statement

Statistics
----------------------------------------------------------
         49  recursive calls
          0  db block gets
      11348  consistent gets
         88  physical reads
          0  redo size
       2935  bytes sent via SQL*Net to client
        519  bytes received via SQL*Net from client
          2  SQL*Net roundtrips to/from client
          6  sorts (memory)
          0  sorts (disk)
          6  rows processed
```

```
SELECT  …. columns
FROM PRODUCTS,
       INVENTORIES
WHERE INVENTORIES.PRODUCT_ID = PRODUCTS.PRODUCT_ID
AND PRODUCTS.CATEGORY_ID = :B3
AND INVENTORIES.WAREHOUSE_ID = :B2
AND ROWNUM < :B1
```

Understanding the Objects

PRODUCTS View

```
SELECT  i.product_id
,       d.language_id
,       CASE WHEN d.language_id IS NOT NULL
             THEN d.translated_name
             ELSE TRANSLATE(i.product_name USING NCHAR_CS)
        END     AS product_name
,       i.category_id
,       CASE WHEN d.language_id IS NOT NULL
             THEN d.translated_description
             ELSE TRANSLATE(i.product_description USING NCHAR_CS)
        END     AS product_description
,       i.weight_class
,       i.warranty_period
,       i.supplier_id
,       i.product_status
,       i.list_price
,       i.min_price
,       i.catalog_url
FROM    product_information  i
,       product_descriptions d
WHERE   d.product_id  (+) = i.product_id
AND     d.language_id (+) = sys_context('USERENV','LANG')
```

No Statistics

COLUMN_NAME	NUM_DISTINCT	NUM_NULLS	NUM_BUCKETS	DENSITY	SAMPLE_SIZE	HISTOGRAM
PRODUCT_ID						NONE
QUANTITY_ON_HAND						NONE
WAREHOUSE_ID						NONE

DBMS_STATS

```
exec dbms_stats.gather_schema_stats( -
ownname          => 'SOE', -
options          => 'GATHER AUTO', -
estimate_percent => dbms_stats.auto_sample_size, -
method_opt       => 'for all columns size auto', -
cascade          => true, -
degree           => 15 -
)
```

Improved in 11g

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Actual Plan – With Statistics

```
Plan hash value: 3363672010

-----------------------------------------------------------------------------------------------------------------
| Id  | Operation                          | Name                 | Rows  | Bytes | Cost (%CPU)| Time     |
-----------------------------------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT                   |                      |       |       |  3007 (100)|          |
|*  1 |  COUNT STOPKEY                     |                      |       |       |            |          |
|*  2 |   HASH JOIN OUTER                  |                      |     1 |  1183 |  3007   (1)| 00:00:37 |
|   3 |    NESTED LOOPS                    |                      |       |       |            |          |
|   4 |     NESTED LOOPS                   |                      |     1 |  1166 |  2988   (1)| 00:00:36 |
|*  5 |      TABLE ACCESS FULL             | INVENTORIES          |   896 | 11648 |  2988   (1)| 00:00:36 |
|*  6 |      INDEX RANGE SCAN              | PROD_CATEGORY_IX     |     1 |       |     0   (0)|          |
|*  7 |     TABLE ACCESS BY INDEX ROWID    | PRODUCT_INFORMATION  |     1 |  1153 |     0   (0)|          |
|*  8 |    TABLE ACCESS FULL               | PRODUCT_DESCRIPTIONS |    10 |   170 |    18   (0)| 00:00:01 |
-----------------------------------------------------------------------------------------------------------------

Predicate Information (identified by operation id):

---------------------------------------------------

   1 - filter(ROWNUM<:B1)
   2 - access("D"."PRODUCT_ID"="I"."PRODUCT_ID")
   5 - filter("INVENTORIES"."WAREHOUSE_ID"=:B2)
   6 - access("I"."CATEGORY_ID"=:B3)
   7 - filter("INVENTORIES"."PRODUCT_ID"="I"."PRODUCT_ID")
   8 - filter("D"."LANGUAGE_ID"=SYS_CONTEXT('USERENV','LANG'))
```

```
Statistics
----------------------------------------------------------
         15  recursive calls
          0  db block gets
      11010  consistent gets
          0  physical reads
          0  redo size
       2935  bytes sent via SQL*Net to client
        519  bytes received via SQL*Net from client
          2  SQL*Net roundtrips to/from client
          0  sorts (memory)
          0  sorts (disk)
          6  rows processed
```

How to tune?

```
SELECT  …. columns
FROM PRODUCTS,
       INVENTORIES
WHERE INVENTORIES.PRODUCT_ID = PRODUCTS.PRODUCT_ID
AND PRODUCTS.CATEGORY_ID = :B3
AND INVENTORIES.WAREHOUSE_ID = :B2
AND ROWNUM < :B1 ;
```

V$SQL_BIND_CAPTURE

NAME	POSITION	DATATYPE_STRING	VALUE_STRING	
:B3	1	NUMBER	136	- category_id
:B2	2	NUMBER	454	- warehouse_id
:B1	3	NUMBER	15	- rownum

INVENTORIES Table Filter (warehouse_id=454) -1000 records

COLUMN_NAME	NUM_DISTINCT	NUM_NULLS	NUM_BUCKETS	DENSITY	SAMPLE_SIZE	HISTOGRAM
PRODUCT_ID	1000	0	1	.001	894861	NONE
QUANTITY_ON_HAND	894861	0	1	1.1175E-06	894861	NONE
WAREHOUSE_ID	999	0	1	.001001001	894861	NONE

```
select  round((1000 / 894861 * 100), 2)  pct_of_inventory from dual;

PCT_OF_INVENTORY
----------------
     .11
```

How to tune?

```
SELECT  .... columns
FROM PRODUCTS,
      INVENTORIES
WHERE INVENTORIES.PRODUCT_ID =
 PRODUCTS.PRODUCT_ID
AND PRODUCTS.CATEGORY_ID = :B3
AND INVENTORIES.WAREHOUSE_ID = :B2
AND ROWNUM < :B1 ;
```

V$SQL_BIND_CAPTURE

NAME	POSITION	DATATYPE_STRING	VALUE_STRING	
:B3	1	NUMBER	136	- category_id

PRODUCT_INFORMATION Table

Filter (category_id = 136) – 6 records

COLUMN_NAME	NUM_DISTINCT	NUM_NULLS	NUM_BUCKETS	DENSITY	SAMPLE_SIZE	HISTOGRAM
CATALOG_URL	1000	0	1	.001	1000	NONE
CATEGORY_ID	196	0	196	.0005	1000	FREQUENCY
LIST_PRICE	910	0	1	.001098901	1000	NONE
MIN_PRICE	916	0	1	.001091703	1000	NONE
PRODUCT_DESCRIPTION	1000	0	1	.001	1000	NONE
PRODUCT_ID	1000	0	1	.001	1000	NONE

USER_TAB_HISTOGRAMS

```
select
     endpoint_value,
     endpoint_number,
     endpoint_number - nvl(prev_number,0) frequency
from     (
     select
          endpoint_value,
          endpoint_number,
          lag(endpoint_number,1) over(
               order by endpoint_number
          ) prev_number
     from
          user_tab_histograms
     where
          table_name = 'PRODUCT_INFORMATION'
     and column_name = 'CATEGORY_ID'
     )
order by
     endpoint_value
```

ENDPOINT_VALUE	ENDPOINT_NUMBER	FREQUENCY
134	676	4
135	683	7
136	689	6
137	693	4
138	697	4
139	699	2
140	706	7

New Plan

CREATE INDEX inventories_ix1 ON inventories(warehouse_id);

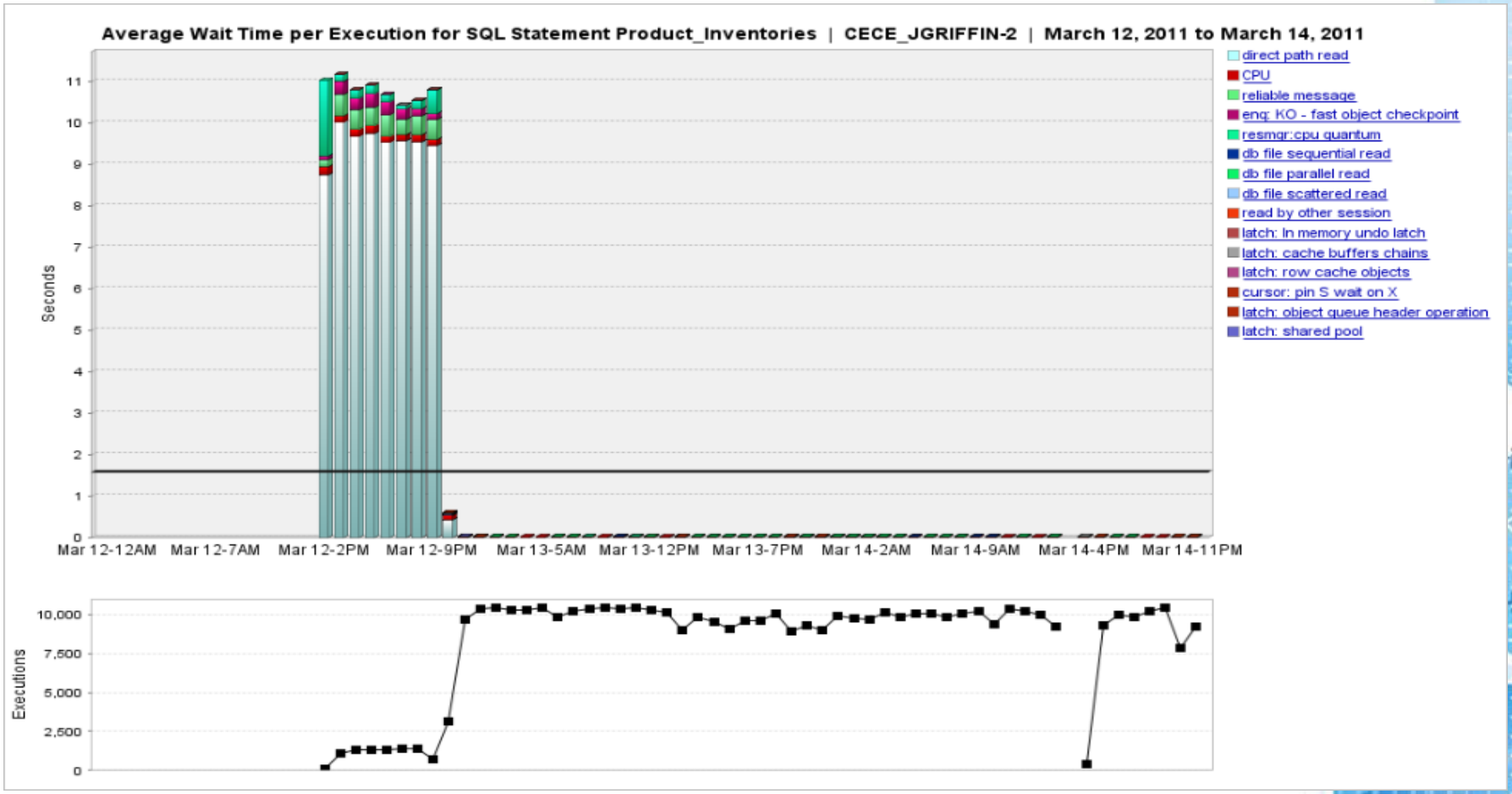
```
Plan hash value: 750880835

-----------------------------------------------------------------------------------------------------------
| Id  | Operation                     | Name                 | Rows  | Bytes | Cost (%CPU)| Time     |
-----------------------------------------------------------------------------------------------------------
|   0 | SELECT STATEMENT              |                      |       |       |   927 (100)|          |
|*  1 |  COUNT STOPKEY                |                      |       |       |            |          |
|*  2 |   HASH JOIN                   |                      |    11 |  2266 |   927   (1)| 00:00:12 |
|*  3 |    HASH JOIN OUTER            |                      |     7 |  1351 |    27   (4)| 00:00:01 |
|   4 |     TABLE ACCESS BY INDEX ROWID| PRODUCT_INFORMATION  |     7 |  1232 |     8   (0)| 00:00:01 |
|*  5 |      INDEX RANGE SCAN         | PROD_CATEGORY_IX     |     7 |       |     1   (0)| 00:00:01 |
|*  6 |     TABLE ACCESS FULL         | PRODUCT_DESCRIPTIONS |    10 |   170 |    18   (0)| 00:00:01 |
|   7 |    TABLE ACCESS BY INDEX ROWID | INVENTORIES          |   896 | 11648 |   900   (0)| 00:00:11 |
|*  8 |     INDEX RANGE SCAN          | INVENTORIES_IX1      |   896 |       |     4   (0)| 00:00:01 |
-----------------------------------------------------------------------------------------------------------

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

   1 - filter(ROWNUM<:B1)
   2 - access("INVENTORIES"."PRODUCT_ID"="I"."PRODUCT_ID")
   3 - access("D"."PRODUCT_ID"="I"."PRODUCT_ID")
   5 - access("I"."CATEGORY_ID"=:B3)
   6 - filter("D"."LANGUAGE_ID"=SYS_CONTEXT('USERENV','LANG'))
   8 - access("INVENTORIES"."WAREHOUSE_ID"=:B2)
```

March 13 4:00AM-5:00AM	
SQL Name	Product_Inventories
Wait Time	03:12 (mm:ss)
Total Wait Time for Time Period	27:59 (mm:ss)
% of Total Wait Time	11%
Average (seconds)	0.01872988
Executions	10,251

100% on CPU

Did performance improve?

CREATE INDEX inventories_ix1 ON inventories(warehouse_id);



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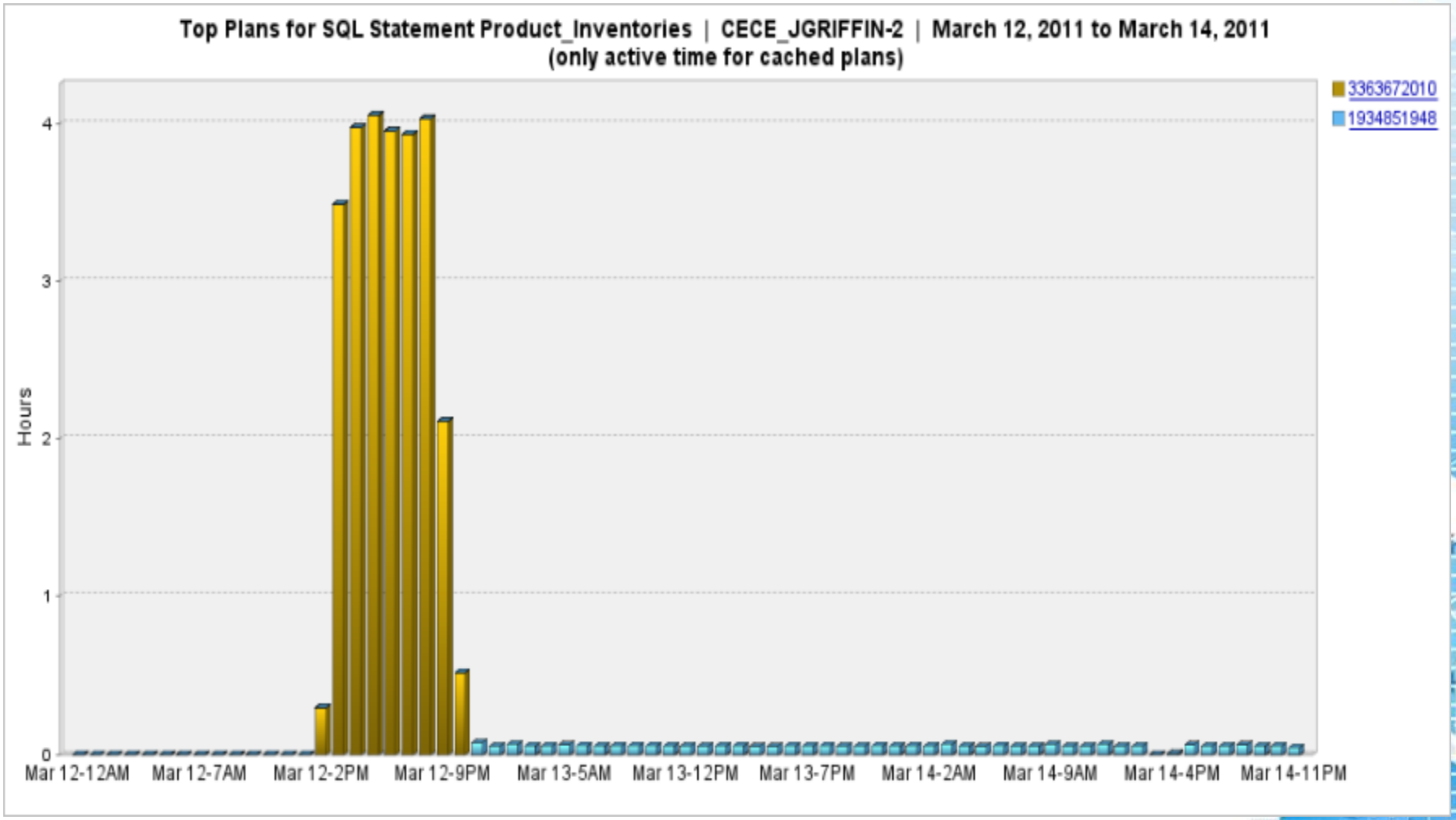
Which is the better Plan?



View using Display Plan

```
EXPLAIN PLAN
SET STATEMENT_ID = 'inventory' FOR
        SELECT PRODUCTS.PRODUCT_ID, PRODUCT_NAME,
        PRODUCT_DESCRIPTION,CATEGORY_ID, WEIGHT_CLASS,
            WARRANTY_PERIOD,  SUPPLIER_ID, PRODUCT_STATUS,
            LIST_PRICE,MIN_PRICE, CATALOG_URL, QUANTITY_ON_HAND
        FROM PRODUCTS,
              INVENTORIES
        WHERE INVENTORIES.PRODUCT_ID = PRODUCTS.PRODUCT_ID
        AND PRODUCTS.CATEGORY_ID = :B3
        AND INVENTORIES.WAREHOUSE_ID = :B2
        AND ROWNUM < :B1;

set pages 0 head off
set linesize 132
set long 1000000
col xplan format a100

spool inventory.html

SELECT dbms_xplan.display_plan(statement_id => 'inventory',type=>'HTML') AS XPLAN
FROM dual;

spool off;
```

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View using Display Plan

SQL Explain Plan Report

file:///c:/users/owner/inventory.html

Plan Hash Value : 1842583762

Id	Operation	Name	Rows	Bytes	Cost	Time
0	SELECT STATEMENT		6001	1260210	1090	00:00:14
* 1	COUNT STOPKEY					
* 2	HASH JOIN RIGHT OUTER		6001	1260210	1090	00:00:14
* 3	TABLE ACCESS FULL	PRODUCT_DESCRIPTIONS	10	180	18	00:00:01
* 4	HASH JOIN		6001	1152192	1071	00:00:13
5	TABLE ACCESS BY INDEX ROWID	INVENTORIES	896	12544	876	00:00:11
* 6	INDEX RANGE SCAN	INVENTORIES_IX1	896		4	00:00:01
7	TABLE ACCESS BY INDEX ROWID	PRODUCT_INFORMATION	6692	1191176	194	00:00:03
* 8	INDEX RANGE SCAN	PROD_CATEGORY_IX	6692		17	00:00:01

Predicate Information (identified by operation id):

- 1 - filter(ROWNUM<TO_NUMBER(:B1))
- 2 - access("D"."PRODUCT_ID"(+)="I"."PRODUCT_ID")
- 3 - filter("D"."LANGUAGE_ID"(+)=SYS_CONTEXT('USERENV','LANG'))
- 4 - access("INVENTORIES"."PRODUCT_ID"="I"."PRODUCT_ID")
- 6 - access("INVENTORIES"."WAREHOUSE_ID"=TO_NUMBER(:B2))
- 8 - access("I"."CATEGORY_ID"=TO_NUMBER(:B3))

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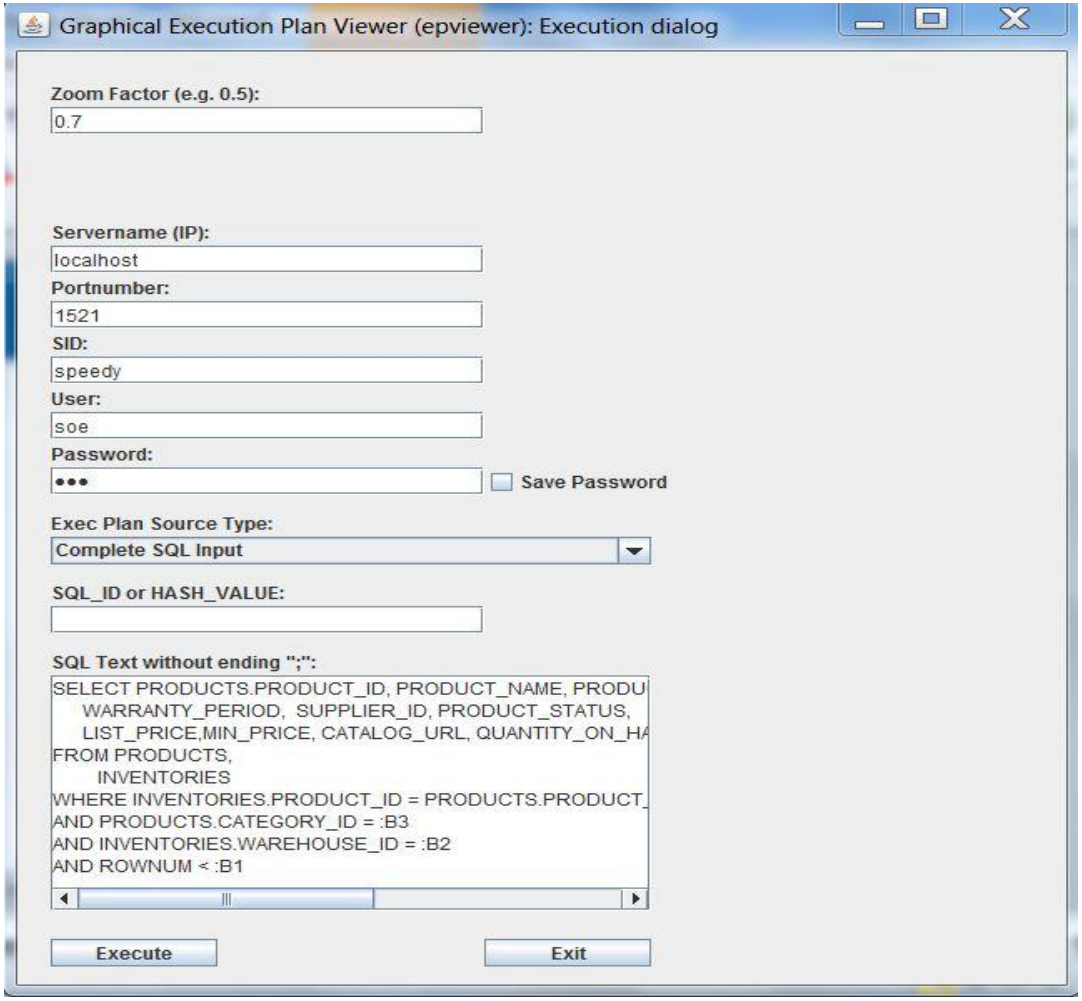
'Free' Graphical Plans

http://www.epviewer.bplaced.net/downloads



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‘Free’ Graphical Plans

March 13 4:00AM-5:00AM	
SQL Name	Product_Inventories
Wait Time	03:12 (mm:ss)
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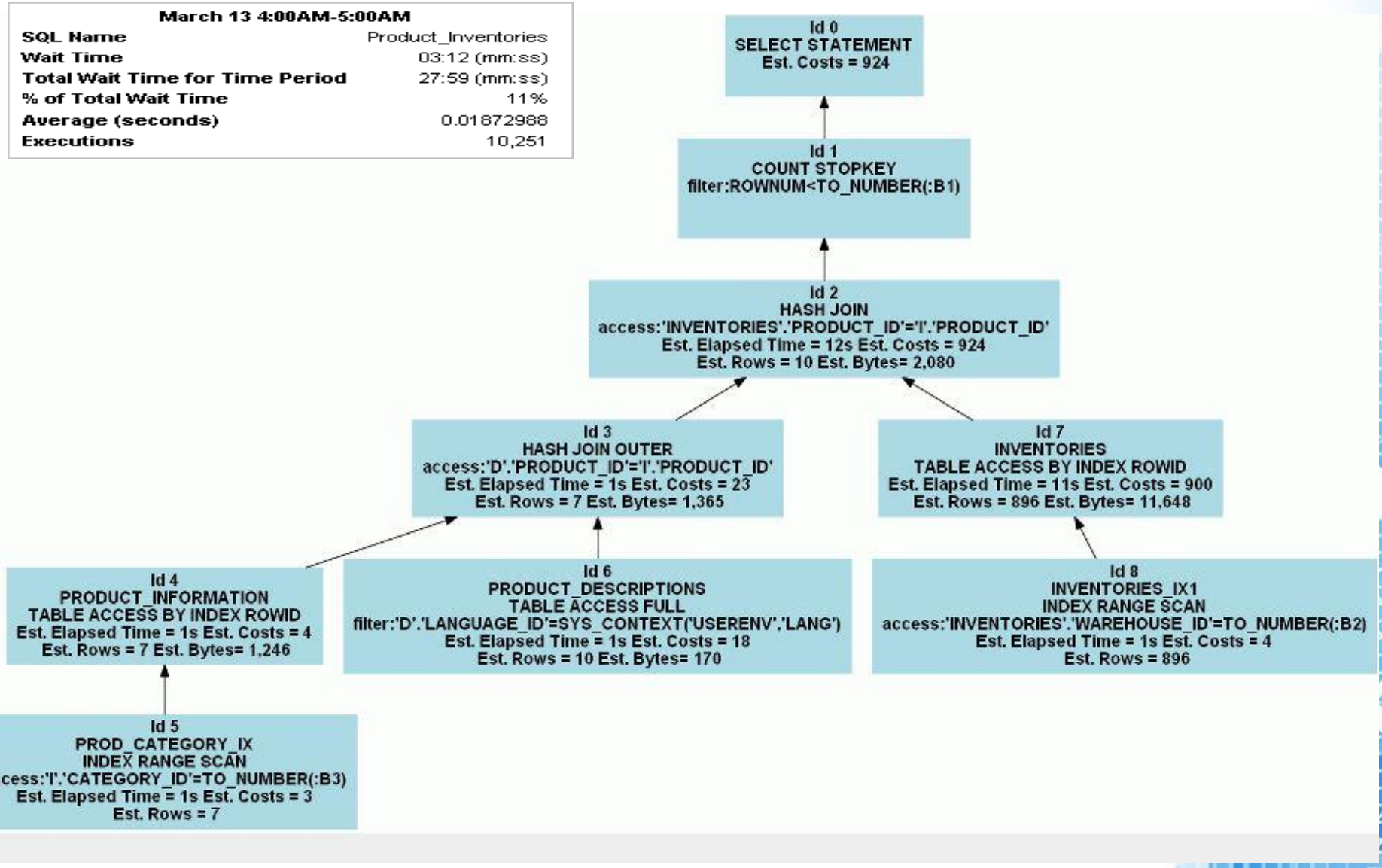
% of Total Wait Time	11%
Average (seconds)	0.01872988
Executions	10,251



Summary

- Execution Plans show the internal steps Oracle takes to run SQL statements
  - Reports how the data is accessed, manipulated and joined
  - Shows Expensive steps with Cost and Time spent.
  - Gives information on Bind Variables (predicate information)
- Viewing actual plans are better then using EXPLAIN PLAN
  - V$SQL_PLAN using DBMS_XPLAN.display_cursor('&sql_id', 0)
  - Tracing / TKPROF
- Gather additional data when tuning an execution plan
  - Table sizes, Index selectivity and column details
  - How Statistic Gathering is performed
  - Bind value from V$SQL_BIND_CAPTURE
- Tune only the execution plans that make a difference
  - Monitor response time – Using Ignite

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Tuning Aids

- DBMS_XPLAN
  - Table Functions
  - New Additions – 11g
- SQL Plan management (DBMS_SPM)
  - Free For Enterprise users
- Oracle - Note: requires Tuning/Diagnostic Packs
  - SQL Tuning Advisor
  - ADDM

DBMS_XPLAN – Functions

- New Functions 11g

BUILD_PLAN_XML	Return the last plan, or a named plan, explained as XML
DISPLAY	Shows the last plan explained – EXPLAIN PLAN ** Only FUNCTION in Oracle 9i
DISPLAY_AWR	Format & display the plan of a stored SQL statement in AWR
DISPLAY_CURSOR	Format & display the execution plan of any loaded cursor
DISPLAY_PLAN	Return the last plan, or a named plan, explained as a CLOB
DISPLAY_SQLSET	Format & display the execution plan of statements stored in a SQL tuning set
DISPLAY_SQL_PLAN_BASELINE	Displays one or more plans for the specified SQL statement
FORMAT_NUMBER	Returns a number as a string
FORMAT_NUMBER2	Returns a number as a string formatted with a leading space (CHR(32))
FORMAT_SIZE	Undocumented
FORMAT_SIZE2	Undocumented
FORMAT_TIME_S	Undocumented
PREPARE_PLAN_XML_QUERY	- function to build the XML version of a select query that is run before the display function to retrieve and display the execution plan of a SQL
PREPARE_RECORDS	Used Internally
VALIDATE_FORMAT	Used Internally

DBMS_XPLAN – Example

- EXPLAIN PLAN set statement_id = 'prI' for select …
- SELECT dbms_xplan.build_plan_xml(statement_id => 'prI') AS XPLAN FROM dual;

In browser: file:///c:/users/jgriffin/explan/xml.xml

```
- <plan>
  + <operation name="SELECT STATEMENT" id="0" depth="0" pos="925"></operation>
  + <operation name="COUNT" options="STOPKEY" id="1" depth="1" pos="1"></operation>
  + <operation name="HASH JOIN" id="2" depth="2" pos="1"></operation>
  + <operation name="HASH JOIN" options="OUTER" id="3" depth="3" pos="1"></operation>
  + <operation name="TABLE ACCESS" options="BY INDEX ROWID" id="4" depth="4" pos="1"></operation>
  + <operation name="INDEX" options="RANGE SCAN" id="5" depth="5" pos="1"></operation>
  + <operation name="TABLE ACCESS" options="FULL" id="6" depth="4" pos="2"></operation>
  + <operation name="TABLE ACCESS" options="BY INDEX ROWID" id="7" depth="3" pos="2"></operation>
  - <operation name="INDEX" options="RANGE SCAN" id="8" depth="4" pos="1">
      <object>INVENTORIES_IX1</object>
      <card>896</card>
      <cost>4</cost>
      <io_cost>4</io_cost>
      <cpu_cost>207686</cpu_cost>
      <time>00:00:01 </time>
      <project>"INVENTORIES".ROWID[ROWID,10]</project>
      <predicates type="access">"INVENTORIES"."WAREHOUSE_ID"=TO_NUMBER(:B2)</predicates>
      <qblock>SEL$F5BB74E1</qblock>
    </operation>
  </plan>
```

SQL Plan Management –11g

DBMS_SPM manages execution plans & ensures only known or verified plans are used

ALTER_SQL_PLAN_BASELINE	Changes an attribute of a single plan or all plans associated with a SQL statement using the attribute name/value format
CONFIGURE	Set configuration options for the SQL Management Base (SMB) as well as the maintenance of SQL plan baselines
CREATE_STGTAB_BASELINE	Creates a staging table that will be used for the purpose of transporting SQL plan baselines from one system to another
DROP_SQL_PLAN_BASELINE	Drops a single plan, or all plans associated with a SQL statement
EVOLVE_SQL_PLAN_BASELINE	Evolves SQL plan baselines associated with one or more SQL statements
LOAD_PLANS_FROM_CURSOR_CACHE	Loads one or more plans present in the cursor cache for a SQL statement
LOAD_PLANS_FROM_SQLSET	Loads plans stored in a SQL tuning set (STS) into SQL plan baselines
PACK_STGTAB_BASELINE	Packs (exports) SQL plan baselines from SQL management base into a staging table
UNPACK_STGTAB_BASELINE	Unpacks (imports) SQL plan baselines from a staging table into SQL management base

OEM – Tuning Advisor

- Without Statistics

Select	Type	Findings	Recommendations	Rationale	Benefit (%)	New Explain Plan	Compare Explain Plans
◉	Statistics	Table "CSU"."CLASS" was not analyzed.	Consider collecting optimizer statistics for this table.	The optimizer requires up-to-date statistics for the table in order to select a good execution plan.			
○	Statistics	Table "CSU"."REGISTRATION" was not analyzed.	Consider collecting optimizer statistics for this table.	The optimizer requires up-to-date statistics for the table in order to select a good execution plan.			
○	Index	The execution plan of this statement can be improved by creating one or more indices.	Consider running the Access Advisor to improve the physical schema design or creating the recommended index. CSU.CLASS(UPPER("NAME"),"CLASS_LEVEL") CSU.REGISTRATION("SIGNUP_DATE") CSU.REGISTRATION("CLASS_ID","STUDENT_ID") CSU.REGISTRATION("STUDENT_ID","CLASS_ID","CANCELLED")	Creating the recommended indices significantly improves the execution plan of this statement. However, it might be preferable to run "Access Advisor" using a representative SQL workload as opposed to a single statement. This will allow to get comprehensive index recommendations which takes into account index maintenance overhead and additional space consumption.	94.12	oo	oo

- With Statistics

Select	Type	Findings	Recommendations	Rationale	Benefit (%)	New Explain Plan	Compare Explain Plans
◉	Index	The execution plan of this statement can be improved by creating one or more indices.	Consider running the Access Advisor to improve the physical schema design or creating the recommended index. CSU.CLASS(UPPER("NAME"),"CLASS_LEVEL") CSU.REGISTRATION("SIGNUP_DATE") CSU.REGISTRATION("CLASS_ID","STUDENT_ID") CSU.REGISTRATION("STUDENT_ID","CLASS_ID")	Creating the recommended indices significantly improves the execution plan of this statement. However, it might be preferable to run "Access Advisor" using a representative SQL workload as opposed to a single statement. This will allow to get comprehensive index recommendations which takes into account index maintenance overhead and additional space consumption.	91.46	oo	oo

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Manual Run - 10g/11g

```
column sql_id new_value sql_id
select sql_id from v$sql where hash_value = &hash_value;

DECLARE
  l_sql_tune_task_id  VARCHAR2(100);
BEGIN
  l_sql_tune_task_id := DBMS_SQLTUNE.create_tuning_task (
                        sql_id      => '&sql_id',
                        scope       => DBMS_SQLTUNE.scope_comprehensive,
                        time_limit  => 60,
                        task_name   => '&sql_id',
                        description => 'Tuning task for statement 19v5guvsgcd1v.');
  DBMS_OUTPUT.put_line('l_sql_tune_task_id: ' || l_sql_tune_task_id);
END;
/

EXEC DBMS_SQLTUNE.execute_tuning_task(task_name => '&sql_id');

SET LONG 10000;
SET PAGESIZE 1000
SET LINESIZE 200
SELECT DBMS_SQLTUNE.report_tuning_task('&sql_id') AS recommendations FROM dual;
SET PAGESIZE 24

exec DBMS_SQLTUNE.drop_tuning_task (task_name =>'&sql_id');
```

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Advisor Recommendations

```
RECOMMENDATIONS
------------------------------------------------------------------------------
GENERAL INFORMATION SECTION
------------------------------------------------------------------------------
Tuning Task Name    : cpn6dwxd743s1
Tuning Task Owner   : SYS
Workload Type       : Single SQL Statement
Scope               : COMPREHENSIVE
Time Limit(seconds): 60
Completion Status   : COMPLETED
Started at          : 11/10/2010 16:29:44
Completed at        : 11/10/2010 16:29:44

------------------------------------------------------------------------------
Schema Name: DEMO8
SQL ID     : cpn6dwxd743s1
SQL Text   : select NAME,SINCENORMAL from CON_ALERT_DB_STATUS_HISTORY where
             ALERTID=:1 and DBID=:2

------------------------------------------------------------------------------
FINDINGS SECTION (1 finding)
------------------------------------------------------------------------------

1- Index Finding (see explain plans section below)
--------------------------------------------------
  The execution plan of this statement can be improved by creating one or more
  indices.

  Recommendation (estimated benefit: 56.4%)
  -----------------------------------------
  - Consider running the Access Advisor to improve the physical schema design
    or creating the recommended index.
    create index DEMO8.IDX$$_11570001 on DEMO8.CON_ALERT_DB_STATUS_HISTORY("DBI
    D","ALERTID");

  Rationale
  ---------
    Creating the recommended indices significantly improves the execution plan
    of this statement. However, it might be preferable to run "Access Advisor"
    using a representative SQL workload as opposed to a single statement. This
    will allow to get comprehensive index recommendations which takes into
    account index maintenance overhead and additional space consumption.

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

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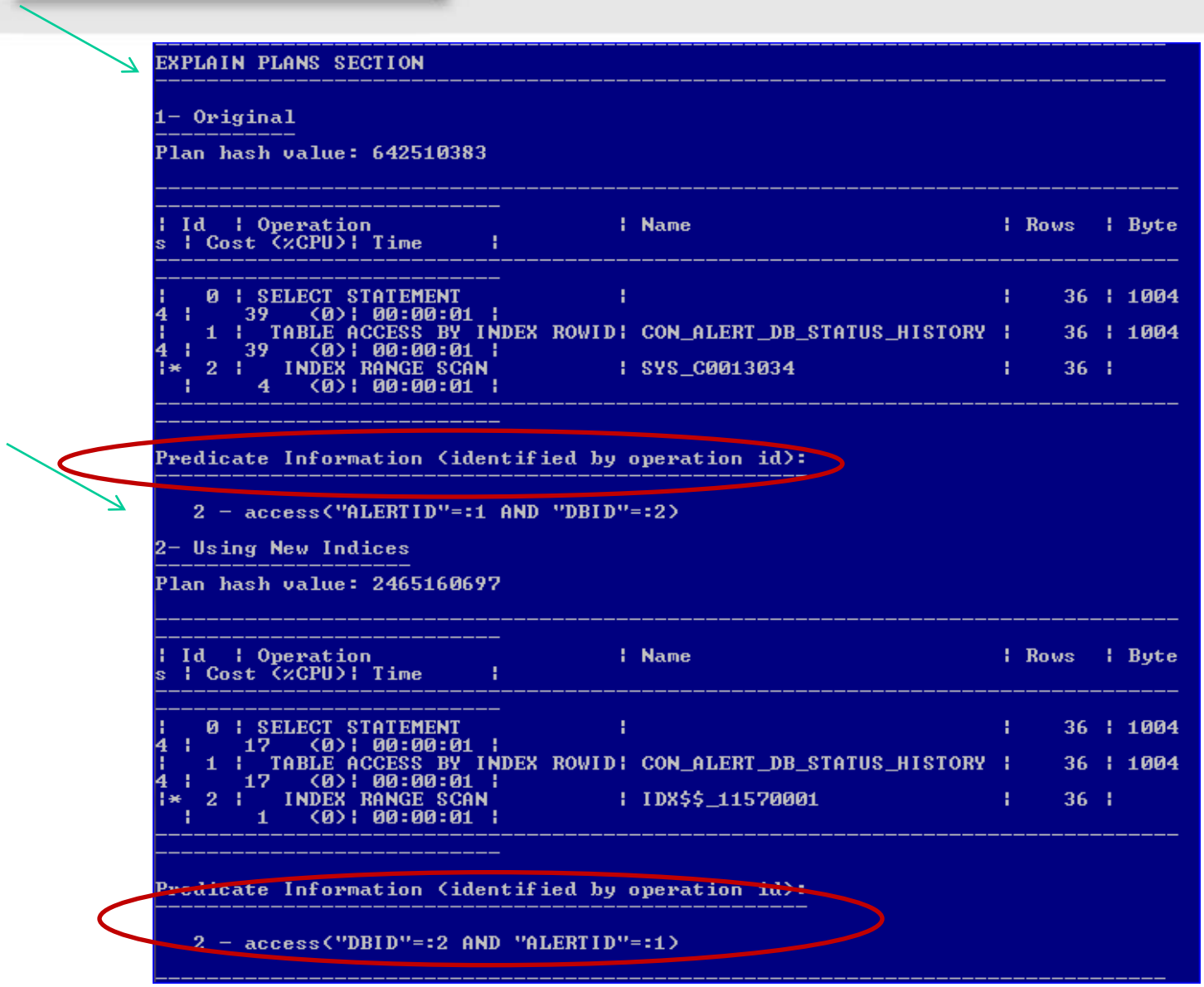
Sql Tuning Advice - New index contains same columns but reversed.



```
EXPLAIN PLANS SECTION
--------------------------------------------------------------------------------

1- Original
-----------
Plan hash value: 642510383

--------------------------------------------------------------------------------
-----------------------------
| Id  | Operation                    | Name                        | Rows  | Byte
s | Cost (%CPU)| Time     |
--------------------------------------------------------------------------------
-----------------------------
|   0 | SELECT STATEMENT             |                             |    36 | 1004
4 |    39   (0)| 00:00:01 |
|   1 |  TABLE ACCESS BY INDEX ROWID| CON_ALERT_DB_STATUS_HISTORY |    36 | 1004
4 |    39   (0)| 00:00:01 |
|*  2 |   INDEX RANGE SCAN           | SYS_C0013034                |    36 |
  |     4   (0)| 00:00:01 |
--------------------------------------------------------------------------------
-----------------------------

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

   2 - access("ALERTID"=:1 AND "DBID"=:2)

2- Using New Indices
--------------------
Plan hash value: 2465160697

--------------------------------------------------------------------------------
-----------------------------
| Id  | Operation                    | Name                        | Rows  | Byte
s | Cost (%CPU)| Time     |
--------------------------------------------------------------------------------
-----------------------------
|   0 | SELECT STATEMENT             |                             |    36 | 1004
4 |    17   (0)| 00:00:01 |
|   1 |  TABLE ACCESS BY INDEX ROWID| CON_ALERT_DB_STATUS_HISTORY |    36 | 1004
4 |    17   (0)| 00:00:01 |
|*  2 |   INDEX RANGE SCAN           | IDX$$_11570001              |    36 |
  |     1   (0)| 00:00:01 |
--------------------------------------------------------------------------------
-----------------------------

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

   2 - access("DBID"=:2 AND "ALERTID"=:1)

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

OEM – ADDM

Select	Type	Findings	Recommendations	Rationale	Benefit (%)	New Explain Plan	Compare Explain Plans
◉	Statistics	Table "CSU"."CLASS" was not analyzed.	Consider collecting optimizer statistics for this table.	The optimizer requires up-to-date statistics for the table in order to select a good execution plan.			
○	Statistics	Table "CSU"."REGISTRATION" was not analyzed.	Consider collecting optimizer statistics for this table.	The optimizer requires up-to-date statistics for the table in order to select a good execution plan.			
○	Index	The execution plan of this statement can be improved by creating one or more indices.	Consider running the Access Advisor to improve the physical schema design or creating the recommended index. CSU.CLASS(UPPER("NAME"),"CLASS_LEVEL") CSU.REGISTRATION("SIGNUP_DATE") CSU.REGISTRATION("CLASS_ID","STUDENT_ID") CSU.REGISTRATION("STUDENT_ID","CLASS_ID","CANCELLED")	Creating the recommended indices significantly improves the execution plan of this statement. However, it might be preferable to run "Access Advisor" using a representative SQL workload as opposed to a single statement. This will allow to get comprehensive index recommendations which takes into account index maintenance overhead and additional space consumption.	94.12		

- With Statistics

Select	Type	Findings	Recommendations	Rationale	Benefit (%)	New Explain Plan	Compare Explain Plans
◉	Index	The execution plan of this statement can be improved by creating one or more indices.	Consider running the Access Advisor to improve the physical schema design or creating the recommended index. CSU.CLASS(UPPER("NAME"),"CLASS_LEVEL") CSU.REGISTRATION("SIGNUP_DATE") CSU.REGISTRATION("CLASS_ID","STUDENT_ID") CSU.REGISTRATION("STUDENT_ID","CLASS_ID")	Creating the recommended indices significantly improves the execution plan of this statement. However, it might be preferable to run "Access Advisor" using a representative SQL workload as opposed to a single statement. This will allow to get comprehensive index recommendations which takes into account index maintenance overhead and additional space consumption.	91.46		

ADDM Commands-11g only

10g, must run the addmrpt.sql in ?/rdbms/admin)

```
var tname VARCHAR2(60);

prompt Enter Start Date (mm/dd/yy hh24)
accept beg_time
prompt Enter End Date (mm/dd/yy hh24)
accept end_time

DECLARE
bsnap NUMBER;
esnap NUMBER;
BEGIN
select distinct BEGIN_SNAP_ID,END_SNAP_ID
into bsnap,esnap
from WRI$_ADV_ADDM_TASKS
where BEGIN_TIME between to_date('&beg_time', 'mm/dd/yy hh24') and  to_date('&end_time', 'mm/dd/yy hh24');


:tname := 'ADDM: '|| bsnap ||'-'||esnap;
  DBMS_ADDM.ANALYZE_DB(:tname, bsnap, esnap);
END;
/

SET LONG 100000
SET PAGESIZE 50000
SELECT DBMS_ADDM.GET_REPORT(:tname) FROM DUAL;
```

ADDM Example – Current Hour

Example of ADDM Out put Analysis for current hour.

Specific findings and suggestions

```
          ADDM Report for Task 'ADDM: 2-3'
          --------------------------------

Analysis Period
---------------

AWR snapshot range from 2 to 3.
Time period starts at 15-NOV-10 04.00.07 PM
Time period ends at 15-NOV-10 05.00.21 PM
Analysis Target
---------------

Database 'CECE' with DB ID 4108810298.
Database version 11.1.0.7.0.
Analysis was requested for all instances, but ADDM analyzed instance cece,
numbered 1 and hosted at JGRIFFIN-2.
See the "Additional Information" section for more information on the requested
instances.

Activity During the Analysis Period
-----------------------------------

Total database time was 1558 seconds.
The average number of active sessions was .43.
ADDM analyzed 1 of the requested 1 instances.

Summary of Findings
-------------------

     Description                      Active Sessions      Recommendations
                                      Percent of Activity
     -------------------------------  -------------------  ---------------
1    Top SQL by DB Time               .22 : 51             5
2    I/O Throughput                   .17 : 39.91          7
3    Checkpoints Due to Log File Size .09 : 21.24          1
4    Undo I/O                         .09 : 20.99          0
5    Top SQL By I/O                   .09 : 20.22          4
6    Row Lock Waits                   .06 : 12.8           1
7    Log File Switches                .05 : 11.29          2
8    Top Segments by I/O              .04 : 9.3            2
9    Hard Parse                       .02 : 5.33           0
10   Commits and Rollbacks            .02 : 4.84           1
```