Lecture 6: Query optimization, query tuning

Rasmus Pagh

Today's lecture

- Exercises left over from last time.
- Query optimization:
  - Overview of query evaluation
  - Estimating sizes of intermediate results
  - A typical query optimizer
- Query tuning:
  - Providing good access paths
  - Rewriting queries

Basics of query evaluation

How to evaluate a query:

1. Rewrite the query to (extended) relational algebra.
2. Determine algorithms for computing intermediate results in the cheapest way.
3. Execute the algorithms and you have the result!

Complications, 1

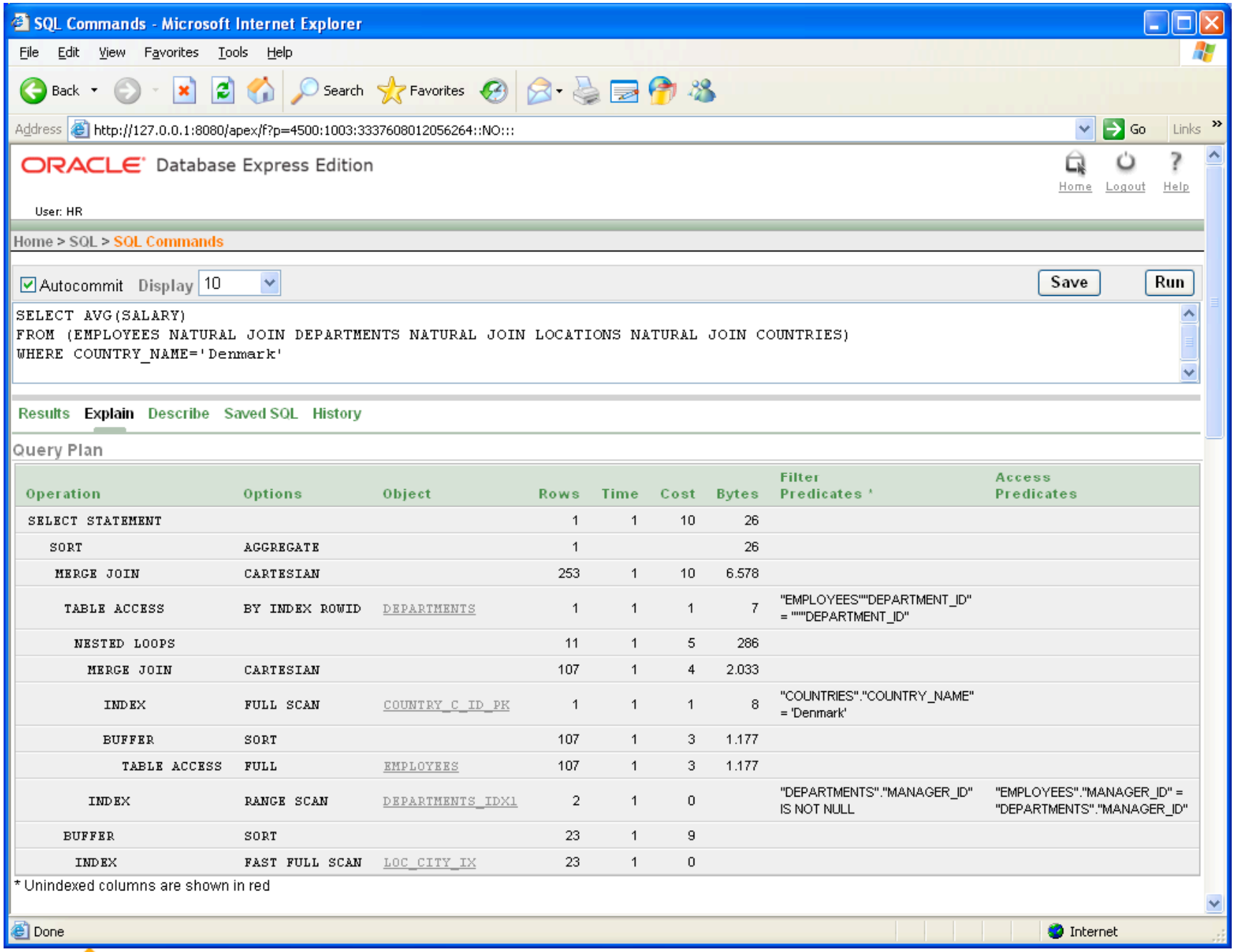
”Rewrite the query to (extended) relational algebra.”

- Can be done in many equivalent ways. Some may be ”more equal than others”!
- Size of intermediate results of big importance.
- Queries with corellated subqueries do not really fit into relational algebra.

Complications, 2

”Determine algorithms for computing intermediate results in the cheapest way.”

- Best algorithm depends on the data:
  - No access method (index, table scan,...) always wins.
  - No algorithm for join, grouping, etc. always wins.
  - There are dependencies, e.g. the form of an output from one operator influences the next.
- Query optimizer should make an educated guess for a (near)optimal way of executing the query.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ORACLE Database Express Edition
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Autocommit Display 10
Save Run
SELECT AVG(SALARY)
FROM (EMPLOYEES NATURAL JOIN DEPARTMENTS NATURAL JOIN LOCATIONS NATURAL JOIN COUNTRIES)
WHERE COUNTRY_NAME='Denmark'
Results Explain Describe Saved SQL History
Query Plan
Operation Options Object Rows Time Cost Bytes Filter Predicates * Access Predicates
SELECT STATEMENT 1 1 10 26
SORT AGGREGATE 1 26
MERGE JOIN CARTESIAN 253 1 10 6.578
TABLE ACCESS BY INDEX ROWID DEPARTMENTS 1 1 1 7 "EMPLOYEES""DEPARTMENT_ID" = """DEPARTMENT_ID"
NESTED LOOPS 11 1 5 286
MERGE JOIN CARTESIAN 107 1 4 2.033
INDEX FULL SCAN COUNTRY_C_ID_PK 1 1 1 8 "COUNTRIES"."COUNTRY_NAME" = 'Denmark'
BUFFER SORT 107 1 3 1.177
TABLE ACCESS FULL EMPLOYEES 107 1 3 1.177
INDEX RANGE SCAN DEPARTMENTS_IDX1 2 1 0 "DEPARTMENTS"."MANAGER_ID" IS NOT NULL "EMPLOYEES"."MANAGER_ID" = "DEPARTMENTS"."MANAGER_ID"
BUFFER SORT 23 1 9
INDEX FAST FULL SCAN LOC_CITY_IX 23 1 0
* Unindexed columns are shown in red
Done
Internet

Motivating example (RG)

Schema:

- Sailors(sid, sname, rating, age)
  - 40 bytes/tuple, 100 tuples/page, 1000 pages
- Reserves(sid, bid, day, rname)
  - 50 bytes/tuple, 80 tuples/page, 500 pages

Query:

```
SELECT S.sname
FROM (Reserves NATURAL JOIN Sailors)
WHERE bid=100 AND rating>5
```

Example, cont.

- Simple logical query plan:

$$\pi_{sname}(\sigma_{bid=100 \wedge rating>5}(Reserves \bowtie Sailors))$$

- Physical query plan:
  - Nested loop join.
  - Selection and projection ”on the fly” (pipelined).
- Cost: Around 500*1000 I/Os.

Example, cont.

- New logical query plan (*push* selects):

$$\pi_{sname}(\sigma_{bid=100}(Reserves) \bowtie \sigma_{rating>5}(Sailors))$$

- Physical query plan:
  - Full table scans of Reserves and Sailors.
  - Sort-merge join of selection results
- Cost:
  - 500+1000 I/Os plus sort-merge of selection results
  - Latter cost should be estimated!

Example, cont.

- Another logical query plan:

$$\pi_{sname}(\sigma_{rating>5}(\sigma_{bid=100}(Reserves) \bowtie Sailors))$$

- Assume there is an index on bid and sid.
- Physical query plan:
  - Index scan of Reserves.
  - Index nested loop join with Sailors.
  - Final select and projection ”on the fly”.
- Cost:
  - Around 1 I/O per matching tuple of Reserves for index nested loop join.

Algebraic equivalences

- In the previous examples, we gave several equivalent queries.
- A systematic (and correct!) way of forming equivalent relational algebra expression is based on *algebraic rules*.
- Query optimizers consider a (possibly quite large) space of equivalent plans at run time before deciding how to execute a given query.

Problem session

For each of the following algebraic laws, consider whether it might be useful for rewriting an algebraic expression to have smaller computation time:

1. $\sigma_C(E_1 \cup E_2) = \sigma_C(E_1) \cup \sigma_C(E_2)$.
2. $\sigma_C(E_1 \times E_2) = E_1 \bowtie_C E_2$.
3. $\sigma_C(E_1 - E_2) = \sigma_C(E_1) - \sigma_C(E_2)$.
4. $\sigma_C(E_1 \times E_2) = \sigma_C(E_1) \times E_2$ if E_1 has all attributes in C.
5. $\sigma_C(E_1 \cap E_2) = \sigma_C(E_1) \cap \sigma_C(E_2)$.
6. $\pi_L(E_1 \bowtie E_2) = \pi_L(\pi_{(L \cup A_{E_2}) \cap A_{E_1}}(E_1) \bowtie \pi_{(L \cup A_{E_1}) \cap A_{E_2}}(E_2))$.
7. $\pi_L(\sigma_C(E_1)) = \pi_L(\sigma_C(\pi_A(E_1)))$ where A = attributes mentioned in C.
8. $\delta(E_1 \bowtie E_2) = \delta(E_1) \bowtie \delta(E_2)$.

Simplification

- Core problem: $\sigma\pi\times$–expressions, consisting of equi-joins, selections, and a projection.
- Subqueries either:
  - Eliminated using rewriting, or
  - Handled using a separate $\sigma\pi\times$–expression.
- Grouping, aggregation, duplicate elimination: Handled in a final step.

Single relation access plans

- Example:

$$\pi_{rating,sname}(\sigma_{rating>5 \wedge age=20}(Sailors))$$

- Without an index: Full table scan. (Well, depends on the physical organization.)
- With index:
  - Single index access path
  - Multiple index access path
  - Sorted index access path
  - Index only access path (”covering index”)

Multi-relation access plans

- Similar principle, but now many more possibilities to consider.
- Common approach:
  - Consider subsets of the involved relations, and the conditions that apply to each subset.
  - Estimate the cost of evaluating the $\sigma\pi\times-$ expression restricted to this subset.
  - Need to distinguish between different forms of the output (sorted, unsorted).

Multi-relation access plans, cont.

- In general, cannot consider all possible plans. (Too many!) A common restriction is to consider only *left-deep* evaluation trees.
- If the DBMS does not consider a near-optimal plan, it is likely that this is because of bad *cost estimates*.
- The tuner can influence cost estimates and access plans, but not the optimization method.
- We refer to RG for more details.

Core problem: Size estimation

- The sizes of intermediate results are important for the choices made when planning query execution.
- Time for operations grow (at least) linearly with size of (largest) argument. (Note that we do not have indexes for intermediate results.)
- The total size can even be used as a crude estimate on the running time.

Classical approach: Heuristics

- In the book a number of heuristics for estimating sizes of intermediate results are presented.
- This classical approach works well in some cases, but is unreliable in general.
- The modern approach is based on maintaining suitable statistics summarizing the data. (Focus of lecture.)

Some possible types of statistics

- Random sample of, say 1% of the tuples. (NB. Should fit main memory.)
- The 1000 most frequent values of some attribute, with tuple counts.
- Histogram with number of values in different ranges.
- The *”skew”* of data values.
- Last 5-10 years: ”Sketches”.

On-line vs off-line statistics

- **Off-line**: Statistics only computed periodically, often operator-controlled (e.g. Oracle). Typically involves sorting data according to all attributes.
- **On-line**: Statistics maintained automatically at all times by the DBMS. Focus of this lecture.

Maintaining a random sample

- To get a sample of expected size 1% of full relation:
  - Add a new tuple to the sample with probability 1%.
  - If a sampled tuple is deleted or updated, remember to remove from or update in sample.

Estimating selects

- To estimate the size of a select statement $\sigma_C(R)$:
  - Compute $|\sigma_C(R')|$, where R' is the random sample of R.
  - If the sample is 1% of R, the estimate is 100 $|\sigma_C(R')|$, etc.
  - The estimate is reliable if $|\sigma_C(R')|$ is not too small (the bigger, the better).

Estimating join sizes?

- Suppose you want to estimate the size of a join statement $R_1 \bowtie R_2$.
- You have random samples of 1% of each relation.
- **Question**: How do you do the estimation?

Estimating join sizes

- Compute $|R_1' \bowtie R_2'|$, where R_1' and R_2' are samples of R_1 and R_2.

- If samples are 1% of the relations, estimate is

$$100^2 |R_1' \bowtie R_2'|$$

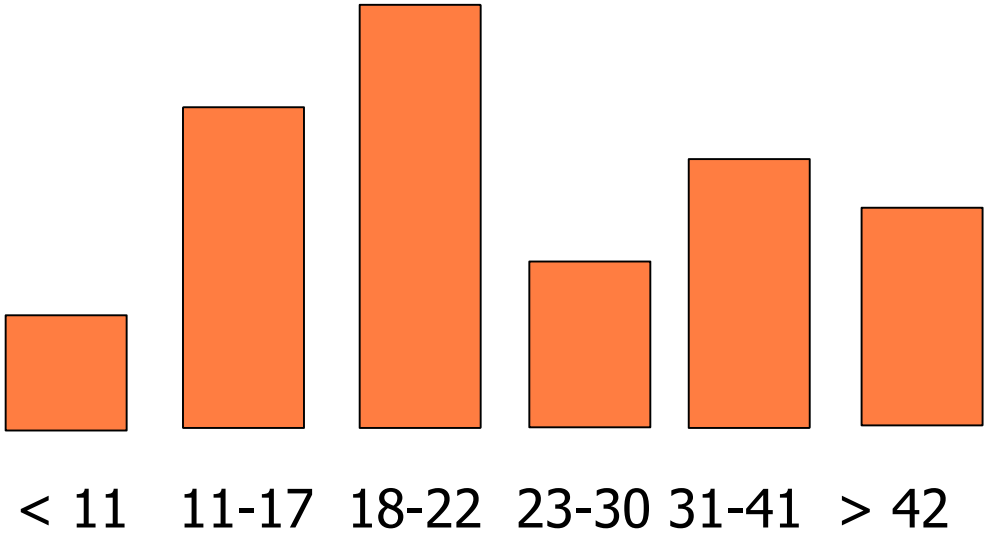
Keeping a sample of bounded size

Reservoir sampling (Vitter ’85):

- Initial sample consists of s tuples.
- A tuple inserted in R is stored in sample with probability s/(|R|+1).
- When storing a new tuple, it replaces a randomly chosen tuple in existing sample (unless sample has size < s due to a deletion).

Histogram

- Number of values/tuples in each of a number of intervals. Widely used.



- Question: How do you use a histogram to estimate selectivity?

Problem session

A mystery. Suppose you are the database administrator of a large company. One day your boss comes to you complaining that the following query takes several hours to run, even though the end result is quite small.

```
SELECT Sales.amount, Events.type
FROM Sales, Events, Goods, Suppliers
WHERE Sales.date=Events.date
      AND Sales.partno=Goods.partno AND Suppliers.sid=Goods.sid
      AND Goods.category='engine' AND Suppliers.country='DK'
```

The query plan looks reasonable:

$$(\sigma_{\text{category='engine'}}(\text{Goods}) \bowtie \sigma_{\text{country='DK'}}(\text{Suppliers})) \bowtie (\text{Sales} \bowtie \text{Events})$$

What do you do? Propose queries on the relations that could help shed light on what the problem is? (Feedback on proposals, tests, etc. from teacher in class.) Propose possible cures.

Sketch-based estimation

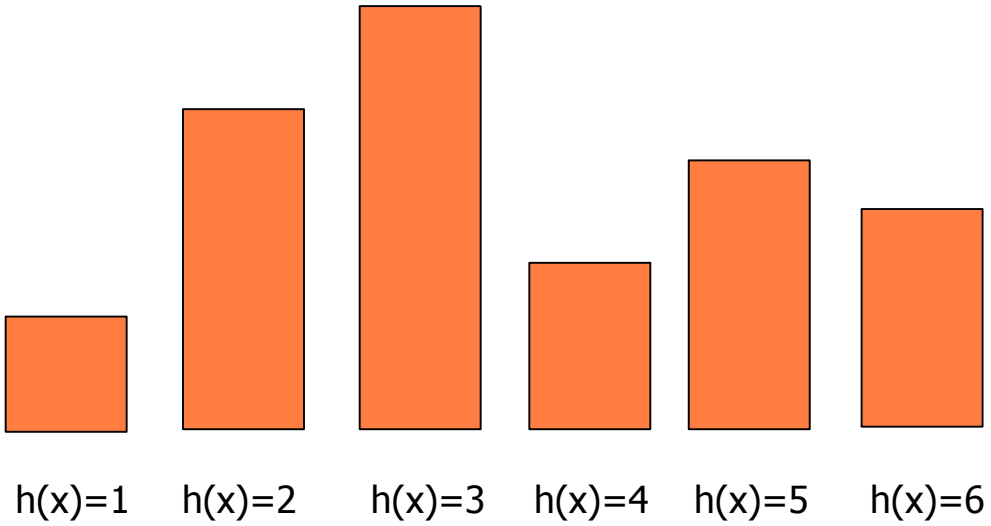
- Idea:
  Maintain some information about the relations (a ”sketch”) that:
  - Is much smaller than the size of the relations themselves. (Smaller than a useful sample.)
  - Can easily be updated when tuples are inserted and deleted.
  - Allows accurate prediction of sizes of subresults (key: joins, selections).

Aside: Approximate answers

- In some applications, we may be happy with an approximation of an aggregate, say, and need only access the sketch.
- In some applications (e.g. data streams) we must accept some inaccuracy do be able to get answers.
- Not focus here.

Random histograms

- A basic technique used in sketching is a histogram where the column for each key is chosen at random, using a hash function.



Count-min sketches (CM'05)

- Sketch of an attribute A of relation R.
- The sketch consists of k independent, random histograms $X_i[1..n]$. , using hash functions $h_1,...,h_k$.
- An (over)estimate of $|\sigma_{A=y}(R)|$ is $\min_i(X_i[h_i(y)])$.
- The estimate is not too far off if most of the tuples have values from a small set (size n, say) - i.e. there is high *skew*. (See paper RD07.)

Unbiased sketches

- Suppose we want an estimate whose expected value is $|\sigma_{A=y}(R)|$.
- Fast-Count idea (Thorup-Zhang '04):
  - Subtract the expected "noise" from $X_i[h_i(y)]$.
  - To reduce error, take mean for i=1,...,k.
- Alternative (Fast-AGMS '96, '05):
  - Consider the *difference* of two values from the random histogram.
  - By symmetry, they have the same expected noise, and the result is unbiased!
- In both cases, we get a guarantee (see RD07): Estimate is "close" with "good" probability, depending on how much space is used.

Join size from sketches

- For Fast-Count, Fast-AGMS the ”inner product” of the (unbiased) estimator vectors is an estimator for the join size:

$$(-3,2,0,4)\cdot(-2,-1,3,2) =$$
$$-3\cdot(-2)+2\cdot(-1)+0\cdot 3+4\cdot 2 = 12$$

- Estimator has large variance. We reduce variance by taking the mean of many estimators.
- Sometimes, a *median* of means gives better (provable) guarantees.

Skimming

- Better accuracy can be obtained if the sketch:
  - Identifies high-frequency items, and keep explicit count of each.
  - Use the random histogram only for items that are not high frequency.

When does sketching work?

- General rule-of-thumb:
  Sketching gives accurate results if the size of the set being estimated is sufficiently large.
- Theoretically: Need space $O(N^2/J)$ to accurately predict the size J of a join. (AGMS '96, GGR '04)
- Luckily, if things are not too large, we are often happy without a precise estimate.

Tuning

What can be done to improve the performance of a query?

Key techniques:

- Denormalization
- Vertical/horizontal partitioning
- Aggregate maintenance
- Query rewriting (examples from SB p. 143-158, 195)
- Sometimes: Optimizer hints

Denormalization

- Introduce redundant data in a relation, that could alternatively be computed by a join.
- Saves the join cost.
- Disadvantages:
  - Higher space usage
  - Possibility of inconsistent data

Partitioning

- If many queries need just a subset of the rows and/or a subset of the columns, it may be a good idea (especially if there are full table scans) to:
  - partition horisontally (by row) and/or
  - partition vertically (by column).
- Some DBMSs have features that make the partitioning *transparent*.
- Drawbacks:
  - Higher update costs
  - Higher cost of some queries

Query rewrite examples from SB

Query rewrite, example 1

- SELECT DISTINCT ssnum
  FROM Employee
  WHERE dept='CLA'
- Problem: "DISTINCT" may force a sort operation.
- Solution: If ssnum is unique, DISTINCT can be omitted.
- (SB discusses some general cases in which there is no need for DISTINCT.)

Query rewrite, example 2

- SELECT ssnum
  FROM Employee
  WHERE dept IN
  (SELECT dept FROM ResearchDept)
- Problem: An index on Employee.dept may not be used.
- Alternative query:
  SELECT ssnum
  FROM Employee E, ResearchDept D
  WHERE E.dept=D.dept

Query rewrite, example 3

- The dark side of temporaries:
  SELECT * INTO temp
  FROM Employee
  WHERE salary > 300000;
  SELECT ssnum
  FROM Temp
  WHERE Temp.dept = 'study admin'
- Problems:
  - Forces the creation of a temporary
  - Does not use index on Employee.dept

Query rewrite, example 4

- SELECT ssnum
  FROM Employee E1
  WHERE salary =
  (SELECT max(salary)
  FROM Employee E2
  WHERE E1.dept=E2.dept)
- Problem: Subquery may be executed for each employee (or at least each department)

- Solution ("the light side of temporaries"):

```
SELECT dept,
       max(salary) as m
INTO temp
FROM Employee
GROUP BY dept;

SELECT ssnum
FROM Employee E, temp
WHERE salary=m AND
E.dept=temp.dept
```

Query rewrite, example 5

- SELECT E.ssnum
  FROM Employee E, Student S
  WHERE E.name=S.name
- Better to use a more compact key:
  SELECT E.ssnum
  FROM Employee E, Student S
  WHERE E.ssnum=S.ssnum

Hints

- ”Using optimizer hints” in Oracle.
- Example: Forcing join order.

```
SELECT  /*+ORDERED */ *
FROM customers c, order_items l, orders o
WHERE c.cust_last_name = ’Smith’ AND
        o.cust_id = c.cust_id AND o.order_id = l.order_id;
```

- **Beware**: Best choice may vary depending on parameters of the query, or change over time! Should always prefer that optimizer makes choice.

Hint example

- ```
  SELECT bond.id
  FROM bond, deal
  WHERE bond.interestrate=5.6
      AND bond.dealid = deal.dealid
      AND deal.date = '7/7/1997'
  ```
- Clustered index on interestrate, nonclustered indexes on dealid, and nonclustered index on `date`.
- In absence of accurate statistics, optimizer might use the indexes on `interestrate` and `dealid`.
- Better to use the (very selective) index on `date`. May use force if necessary!
  ```

Conclusion

- The database tuner should
  - Be aware of the range of possibilities the DBMS has in evaluating a query.
  - Consider the possibilities for providing more efficient access paths to be chosen by the optimizer.
  - Know ways of circumventing shortcomings of query optimizers.
- Important mainly for DBMS implementers:
  - How to parse, translate, etc.
  - How the space of query plans is searched.

Exercises

Optimizing join order

Query plans