Query Optimization

The System R Optimizer

Highlights of System R Optimizer

- Impact:
  - Most widely used currently; works well for < 10 joins.
- Cost estimation: Approximate art at best.
  - Statistics, maintained in system catalogs, used to estimate cost of operations and result sizes.
  - Considers combination of CPU and I/O costs.
- Plan Space: Too large, must be pruned.
  - Only the space of *left-deep plans* is considered.
    - Left-deep plans allow output of each operator to be *pipelined* into the next operator without storing it in a temporary relation.
  - Cartesian products avoided.

Overview of Query Optimization

- *Plan: Tree of R.A. ops, with choice of alg for each op.*
  - Each operator typically implemented using a `pull' interface: when an operator is `pulled' for the next output tuples, it `pulls' on its inputs and computes them.
- Two main issues:
  - For a given query, what plans are considered?
    - Algorithm to search plan space for cheapest (estimated) plan.
  - How is the cost of a plan estimated?
- Ideally: Want to find best plan. Practically: Avoid worst plans!
- We will study the System R approach.

Schema for Examples

Sailors (*sid*: integer, *sname*: string, *rating*: integer, *age*: real)
Reserves (*sid*: integer, *bid*: integer, *day*: dates, *rname*: string)
Boats (*bid*: integer, *bname*: string, *colour*: string)

- Reserves:
  - Each tuple is 40 bytes long, 100 tuples per page, 1000 pages.
- Sailors:
  - Each tuple is 50 bytes long, 80 tuples per page, 500 pages.

Query Blocks: Units of Optimization

- An SQL query is parsed into a collection of *query blocks*, and these are optimized one block at a time.
- Query block is an SQL query with no nesting, one SELECT, one FROM and at most one WHERE, HAVING, GROUP BY
- Nested blocks are usually treated as calls to a subroutine, made once per outer tuple. (This is an over-simplification, but serves for now.)

```
SELECT S.sname
FROM Sailors S
WHERE S.age IN
    (SELECT MAX (S2.age)
     FROM Sailors S2
     GROUP BY S2.rating)
```

Outer block *Nested block*

Query Blocks

For each sailor with the highest rating (over all salilors) and at least 2 reservations for red boats, find the sailor id and the earliest date on which the sailor has a reservation for a red boat.

```
SELECT S.sid, MIN (R.day)
FROM Sailors S, Reserves R, Boats B
WHERE S.sid = R.sid AND R.bid = B.bid AND B.colour = ‘red’
        AND S.rating = (SELECT MAX S2.rating
                                 FROM Sailors S2)
GROUP BY S.sid
HAVING COUNT(*) > 1
```

Query Blocks (cont.)

```
SELECT S.sid, MIN (R.day)
FROM Sailors S, Reserves R, Boats B
WHERE S.sid = R.sid AND R.bid = B.bid AND B.colour = ‘red’
          AND S.rating = Reference to nested block
GROUP BY S.sid                                          Inner block
HAVING COUNT(*) > 1
```

Outer block

Translating Query Blocks

✎$_{\text{S.sid,MIN(R.day)}}$ (
HAVING $_{\text{COUNT(*) > 2}}$ (
GROUP BY $_{\text{S.sid}}$ (
☞$_{\text{S.sid=R.sid} \cap \text{R.bid=B.Bid} \cap \text{B.colour='red'} \cap \text{S.rating=value\_from\_nested\_block}}$ (
$S \times R \times B$))))

A query is essentially treated as a ✎☞× expression!
(remaining ops applied to results of expression)

Relational Algebra Equivalences

- Allow us to choose different join orders and to `push’ selections and projections ahead of joins.
- *Selections*: $\sigma_{c1 \wedge \ldots \wedge cn}(R) \equiv \sigma_{c1}(\ \ldots\ \sigma_{cn}(R))$
  (*Cascade*) $\sigma_{c1}(\sigma_{c2}(R)) \equiv \sigma_{c2}(\sigma_{c1}(R))$ (*Commute*)
- *Projections:* $\pi_{a1}(R) \equiv \pi_{a1}(\ \ldots(\pi_{an}(R)))$ (*Cascade*)
- *Joins:* $R \bowtie (S \bowtie T) \equiv (R \bowtie S) \bowtie T$ (*Associative*)
  $(R \bowtie S) \equiv (S \bowtie R)$ (*Commute*)

More Equivalences

- A projection commutes with a selection that only uses attributes retained by the projection.
- Selection between attributes of the two arguments of a cross-product converts cross-product to a join.
- A selection on just attributes of R commutes with $R \bowtie S$. (i.e., $\sigma(R \bowtie S) \equiv \sigma(R) \bowtie S$)
- Similarly, if a projection follows a join $R \bowtie S$, we can `push' it by retaining only attributes of R (and S) that are needed for the join or are kept by the projection.

Enumeration of Alternative Plans

- There are two main cases:
  - Single-relation plans
  - Multiple-relation plans
- For queries over a single relation, queries consist of a combination of selects, projects, and aggregate ops:
  - Each available access path (file scan / index) is considered, and the one with the least estimated cost is chosen.
  - The different operations are essentially carried out together (e.g., if an index is used for a selection, projection is done for each retrieved tuple, and the resulting tuples are *pipelined* into the aggregate computation).

Cost Estimation

- For each plan considered, must estimate cost:
  - Must estimate *cost* of each operation in plan tree.
    - Depends on input cardinalities.
    - We've already discussed how to estimate the cost of operations (sequential scan, index scan, joins, etc.)
  - Must also estimate *size of result* for each operation in tree!
    - Use information about the input relations.
    - For selections and joins, assume independence of predicates.

Cost Estimates for Single-Relation Plans

- Index I on primary key matching selection:
  - *Cost is Height(I)+1 for a B+ tree, about 1.2 for hash index.*
- Clustered index I matching one or more selects:
  - *(NPages(I)+NPages(R)) * product of RF's of matching selects.*
- Non-clustered index I matching one or more selects:
  - *(NPages(I)+NTuples(R)) * product of RF's of matching selects.*
- Sequential scan of file:
  - *NPages(R).*

+ ***Note:*** *Typically, no duplicate elimination on projections! (Exception: Done if user says DISTINCT.)*

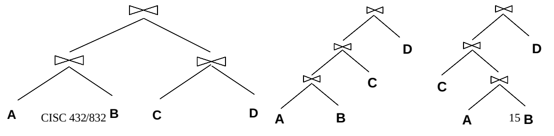
Example

SELECT S.sid
FROM Sailors S
WHERE S.rating=8

- If we have an index on *rating*:
  - (1/NKeys(I)) * NTuples(R) = (1/10) * 40000 tuples retrieved.
  - Clustered index: (1/NKeys(I)) * (NPages(I)+NPages(R)) = (1/10) * (50+500) pages are retrieved.
  - Unclustered index: (1/NKeys(I)) * (NPages(I)+NTuples(R)) = (1/10) * (50+40000) pages are retrieved.
- If we have an index on *sid*:
  - Would have to retrieve all tuples/pages. With a clustered index, the cost is 50+500, with unclustered index, 50+40000.
- Doing a file scan:
  - We retrieve all file pages (500).

Queries Over Multiple Relations

- Fundamental decision in System R: <u>*only left-deep join trees*</u> are considered.
  - As the number of joins increases, the number of alternative plans grows rapidly; *we need to restrict the search space.*
  - Left-deep trees allow us to generate all *fully pipelined* plans.
    - Intermediate results not written to temporary files.
    - Not all left-deep trees are fully pipelined (e.g., SM join).



Enumeration of Left-Deep Plans

- Left-deep plans differ only in the order of relations, the access method for each relation, and the join method for each join.
- Enumerated using N passes (if N relations joined):
  - Pass 1: Find best 1-relation plan for each relation.
  - Pass 2: Find best way to join result of each 1-relation plan (as outer) to another relation. *(All 2-relation plans.)*
  - Pass N: Find best way to join result of a (N-1)-relation plan (as outer) to the N'th relation. *(All N-relation plans.)*
- For each subset of relations, retain only:
  - Cheapest plan overall, plus
  - Cheapest plan for each *interesting order* of the tuples.

Enumeration of Plans (Cont.)

- ORDER BY, GROUP BY, aggregates etc. handled as a final step, using either an `interestingly ordered' plan or an addional sorting operator.
- An N-1 way plan is not combined with an additional relation unless there is a join condition between them, unless all predicates in WHERE have been used up.
  - i.e., avoid Cartesian products if possible.
- In spite of pruning plan space, this approach is still exponential in the # of tables.

Cost Estimation for Multirelation Plans

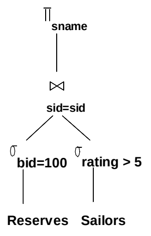
- Consider a query block:

```
SELECT  attribute list
FROM  relation list
WHERE  term1 AND ... AND termk
```

- Maximum # tuples in result is the product of the cardinalities of relations in the FROM clause.
- *Reduction factor (RF)* associated with each *term* reflects the impact of the *term* in reducing result size. *Result cardinality* = Max # tuples * product of all RF's.
- Multirelation plans are built up by joining one new relation at a time.
  - Cost of join method, plus estimation of join cardinality gives us both cost estimate and result size estimate

Example

Sailors:
B+ tree on *rating*
Hash on *sid*
Reserves:
B+ tree on *bid*



- Pass1:
  - *Sailors*: B+ tree matches *rating>5*, and is probably cheapest. However, if this selection is expected to retrieve a lot of tuples, and index is unclustered, file scan may be cheaper.
    - Still, B+ tree plan kept (because tuples are in *rating* order).
  - *Reserves*: B+ tree on *bid* matches *bid=500*; cheapest.
- Pass 2:
  - We consider each plan retained from Pass 1 as the outer, and consider how to join it with the (only) other relation
  - e.g., *Reserves as outer*: Hash index can be used to get Sailors tuples that satisfy *sid* = outer tuple's *sid* value.

Nested Queries

```
SELECT S.sname
FROM Sailors S
WHERE EXISTS
   (SELECT *
    FROM Reserves R
    WHERE R.bid=103
    AND R.sid=S.sid)
```

- Nested block is optimized independently, with the outer tuple considered as providing a selection condition.
- Outer block is optimized with the cost of `calling' nested block computation taken into account.
- Implicit ordering of these blocks means that some good strategies are not considered. *The non-nested version of the query is typically optimized better.*

Nested block to optimize:

```
SELECT *
FROM Reserves R
WHERE R.bid=103
   AND S.sid= outer value
```

Equivalent non-nested query:

```
SELECT S.sname
FROM Sailors S, Reserves R
WHERE S.sid=R.sid
  AND R.bid=103
```

Summary

- Query optimization is an important task in a relational DBMS.
- Must understand optimization in order to understand the performance impact of a given database design (relations, indexes) on a workload (set of queries).
- Two parts to optimizing a query:
  - Consider a set of alternative plans.
    - Must prune search space; typically, left-deep plans only.
  - Must estimate cost of each plan that is considered.
    - Must estimate size of result and cost for each plan node.
    - *Key issues*: Statistics, indexes, operator implementations.

Summary (Cont.)

- Single-relation queries:
  - All access paths considered, cheapest is chosen.
  - *Issues*: Selections that *match* index, whether index key has all needed fields and/or provides tuples in a desired order.
- Multiple-relation queries:
  - All single-relation plans are first enumerated.
    - Selections/projections considered as early as possible.
  - Next, for each 1-relation plan, all ways of joining another relation (as inner) are considered.
  - Next, for each 2-relation plan that is `retained', all ways of joining another relation (as inner) are considered, etc.
  - At each level, for each subset of relations, only best plan for each interesting order of tuples is `retained'.