

Relational Query Optimization

Chapter 15

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)

- Similar to old schema; *rname* added for variations.
- 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.
- Nested blocks are usually treated as calls to a subroutine, made once per outer tuple. (This is an oversimplification, but serves for now.)

```
SELECT S.sname
FROM Sailors S
WHERE S.age IN
  (SELECT MAX (S2.age)
   FROM Sailors S2
   WHERE S.Rating=S2.Rating)
```

Outer block

Nested block

- ❖ For each block, the plans considered are:
 - All available access methods, for each reln in FROM clause.
 - All *left-deep join trees* (i.e., all ways to join the relations one-at-a-time, with the inner reln in the FROM clause, considering all reln permutations and join methods.)

Relational Algebra Equivalences

- Allow us to choose different join orders and to 'push' selections and projections ahead of joins.
 - *Selections*: $\sigma_{c1 \wedge \dots \wedge cn}(R) \equiv \sigma_{c1}(\dots \sigma_{cn}(R))$ (*Cascade*)
 $\sigma_{c1}(\sigma_{c2}(R)) \equiv \sigma_{c2}(\sigma_{c1}(R))$ (*Commute*)
 - ❖ *Projections*: $\pi_A(R) \equiv \pi_A(\dots(\pi_{ABC}(R)))$ (*Cascade*)
 - ❖ *Joins*: $R \bowtie (S \bowtie T) \equiv (R \bowtie S) \bowtie T$ (*Associative*)
 $(R \bowtie S) \equiv (S \bowtie R)$ (*Commute*)
- ☐ Show that: $R \bowtie (S \bowtie T) \equiv (T \bowtie R) \bowtie S$

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 matches 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 on answers if user says DISTINCT.)

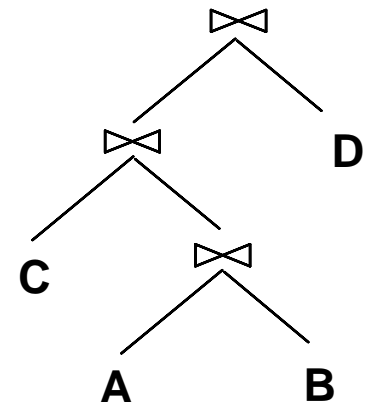
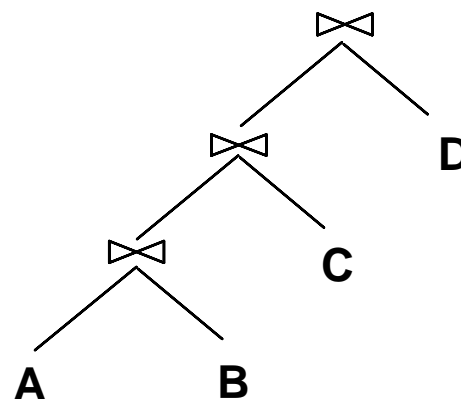
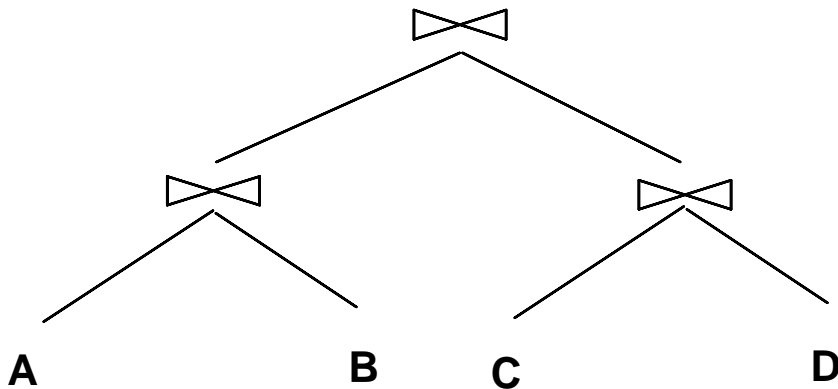
Example

```
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. (This is the **cost**.)
 - Unclustered index: $(1/NKeys(I)) * (NPages(I)+NTuples(R)) = (1/10) * (50+40000)$ pages are retrieved.
- Doing a **file scan**:
 - We retrieve all file pages (500).

Queries Over Multiple Relations

- Fundamental decision in System R: only left-deep join trees 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.



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 (Contd.)

- ORDER BY, GROUP BY, aggregates etc. handled as a final step, using either an 'interestingly ordered' plan or an additional 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

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

- Consider a query block:
- 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


```

SELECT sname
FROM Reserves R, Sailors S
WHERE R.sid = S.sid and
      bid = 100 and rating > 5

```

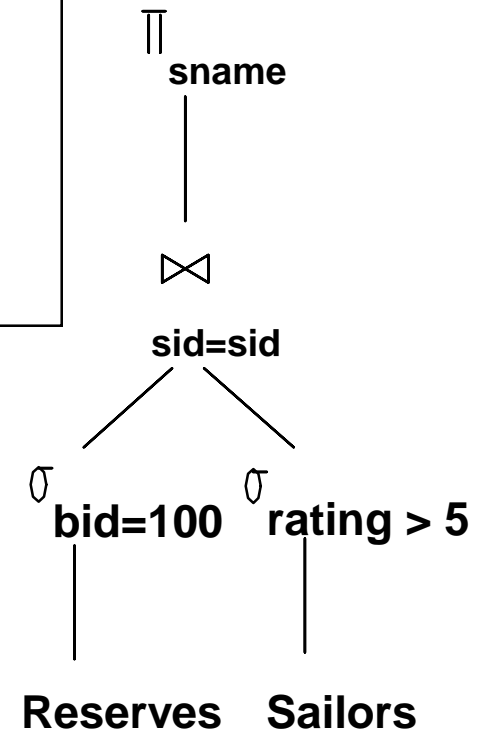
Sailors:

B+ tree on *rating*

Hash on *sid*

Reserves:

B+ tree on *bid*



• Pass1:

- *Sailors*: B+ tree matches *rating*>5, probably cheapest. However, if selection is expected to retrieve a lot of tuples, and index is unclustered, file scan may be cheaper.
 - *sid* is an interesting order, so hash on *sid* kept even if higher cost than *rating* index
- *Reserves*: B+ tree on *bid* matches *bid*=100; 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.
 - ◆ *Reserves as outer*: Hash index can be used to get Sailors tuples that satisfy *sid* = outer tuple's *sid* value (selection on *rating* moved **after** join)
Alternative is BNL with $\sigma_{\text{rating}>5}(\text{Sailors})$
 - ◆ *Sailors as outer*: block-nested loop to join with $\sigma_{\text{bid}=100}(\text{Reserves})$

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 to optimize:

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

^{*value*}
Equivalent non-nested query:

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

- 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.*

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 (Contd.)

- 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'.