Query Optimization

Lecture 14

EECS 339

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 variation.
- 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 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*

❖ 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:*** $\sigma_{c1 \wedge \ldots \wedge cn}(R) \equiv \sigma_{c1}(\ \ldots\ \sigma_{cn}(R))$
  (*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)*

☞ 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.

Cardinality Estimation

- Assume uniformity
- Estimate selectivity factor F
- Multiply by # of input tuples
  - Joins relative to cross product

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
```

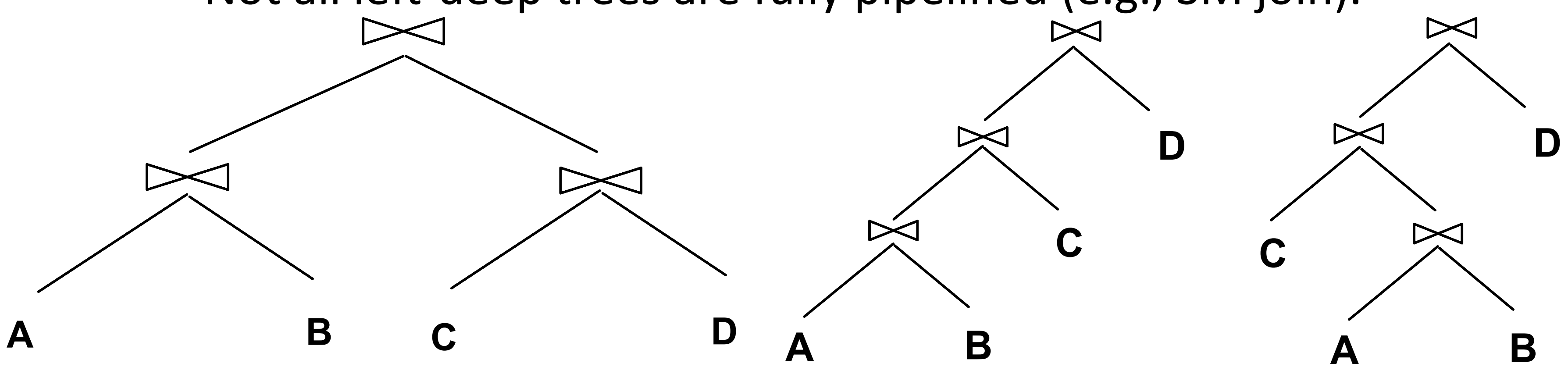
- If we have an index on *rating*:
  - (1/NKeys(I)) * NTuples(R) = (1/10) * 40000 tuples retrieved.
  - Clustered index: (1/NKeys(I)) * (NPages(I)+NPages(R)) = (1/10) * (50+500) pages are retrieved. (This is the ***cost***.)
  - Unclustered index: (1/NKeys(I)) * (NPages(I)+NTuples(R)) = (1/10) * (50+40000) pages are retrieved.
- 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).

Study Break: Cardinality Estimation

- Consider two relations:
  - R(a, b) a = 1...10, b = 1…100
  - S(c, d) c = 1…10, d = 10…20
- Each has 1000 tuples, a uniform dist of values
- Estimate the # of tuples selected where:
  - a = 5
  - b >= 7
  - a = b
  - a = b AND a > 5
  - a = c
  - a = c OR d > 15

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.
    - Not all left-deep trees are fully pipelined (e.g., SM join).



Plan Enumeration (General Case)

- N factorial possibilities for N relations
- Parentheses matter too
- Works out to (2(n-1)-choose-(n-1)) / n
- If only left deep (e.g., ABCD → (((AB)C)D), N!
- Further limit our options by avoiding cartesian products

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'd)

- 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

Join Ordering, as code

```
R ←set of relations to join
For i in {1...|R|}:
    for S in {all length i subsets of R}:
        optcost_s = ∞
        optjoin_S = ø
        for a in S:  //a is a relation
            c_sa = optcost_s-a +
                   min. cost to join (S-a) to a +
                   min. access cost for a
            if c_sa  < optcost_s
                optcost_s = c_sa
                optjoin_s = optjoin(S-a) joined optimally w/ a
```

Pre-computed in previous iteration!

Example

4 Relations: ABCD (only consider NL join)

Optjoin:
A = best way to access A (e.g., sequential scan, or predicate pushdown into index...)
B = " " " " B
C = " " " " C
D = " " " " D

{A,B} = AB or BA
{A,C} = AC or CA
{B,C} = BC or CB
{A,D}
{B,D}
{C,D}

Optjoin

R ←set of relations to join
For i in {1...|R|}:
    for S in {all length i subsets of R}:
        optjoin(S) = a join (S-a), where a is the relation that minimizes:
            cost(optjoin(S-a)) +
            min. cost to join (S-a) to a +
            min. access cost for a

Example (con't)

Optjoin

R ←set of relations to join
For i in {1...|R|}:
    for S in {all length i subsets of R}:
        optjoin(S) = a join (S-a), where a is the relation that minimizes:
            cost(optjoin(S-a)) +
            min. cost to join (S-a) to a +
            min. access cost for a

Optjoin

{A,B,C} = remove A: compare A({B,C}) to ({B,C})A
remove B: compare ({A,C})B to B({A,C})
remove C: compare C({A,B}) to ({A,B})C

{A,C,D} = …

{A,B,D} = …

{B,C,D} = …

…

{A,B,C,D} = remove A: compare A({B,C,D}) to ({B,C,D})A
remove B: compare B({A,C,D}) to ({A,C,D})B
remove C: compare C({A,B,D}) to ({A,B,D})C
remove D: compare D({A,C,C}) to ({A,B,C})D

Complexity

- Number of subsets of set of size n =
  |power set of n| =
  2^n (here, n is number of relations)
- How much work per subset?
  Have to iterate through each element of each subset, so this at most n

$n2^n$ complexity (vs n!)

n=12 ➔ 49K vs 479M

Optjoin

```
R ←set of relations to join
For i in {1...|R|}:
        for S in {all length i subsets of R}:
                optjoin(S) = a join (S-a), where a is
the relation that minimizes:
                        cost(optjoin(S-a)) +
                        min. cost to join (S-a) to a +
                        min. access cost for a
```

Study Break: Join Ordering

- Consider the query:

```
SELECT *
FROM A, B, C
WHERE A.v = B.v AND
B.w = C.w;
```

All tables have 1,000 tuples and 1 column

A has 1,000 unique values, B has 100, C has 500

Using only nested loop joins

- What is the min cost join ordering? Why?

Nested Queries

- 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.*

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

<u>Nested block to optimize:</u>

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

<u>Equivalent non-nested query:</u>

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

Real-World Implementations

- Consider bushy plans
- For selectivity estimates use 1D or 2D histograms
- Some use ML to correct their cardinality estimates

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'.