ECS 165B: Database System Implementation
Lecture 14

UC Davis
April 28, 2010

Acknowledgements: portions based on slides by Raghu Ramakrishnan and Johannes Gehrke, as well as slides by Zack Ives.

Class Agenda

- Last time:
  - More physical operators: selection, projection, duplicate elimination, aggregates
  - Quiz review
- Today:
  - Quiz #1
  - Query optimization
- Reading
  - Chapter 15 of Ramakrishnan and Gehrke (or Chapter 14 of Silberschatz et al)

Announcements

Reminder: DavisDB Part 2 due Sunday @11:59pm

Statistics re DavisDB Part 1:

AVG	76/100
MEDIAN	82/100
STDEV	25
MIN	26/100
MAX	111/100

Relational Query Optimization

Query Optimization

- Given a SQL query:
  - Build a *logical query plan*: tree of algebraic operations
  - Transform into "better" logical plan
  - Convert into a *physical query plan*, using implementations of operators we've seen in the previous lectures
- Goal: find the physical query plan that has minimum cost
  - In practice: avoid the plans with the highest costs
  - Sources of cost: Interactions with other concurrent tasks; sizes of intermediate results; choices of algorithms, access methods; I/O and CPU; properties of data such as skew, order, placement; …

Optimization Strategies

- Many possible strategies, all boil down to a **search** over the space of possible plans
  - Super-exponential complexity in the # of operators
  - Hence, exhaustive search generally not feasible
- What can you do?
  - Heuristics only: INGRES, Oracle until the mid-90s
  - Randomized, simulated annealing, … : many efforts in the mid-90s
  - **Heuristics plus cost-based join enumeration: System R**
  - Stratifed search (heuristics plus cost-based enumeration of joins and a few other operators): Starbust
  - Unified search (full cost-based search): EXODUS, Volcano, Cascades

Highlights of System R Optimizer

- Historically, the most influential optimizer design
- 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 using heuristics
  - Only the space of *left-deep plans* is considered
  - *Pipelined execution model*: output of each operator is pipelined into the next operator, without storing it in a temporary relation
  - Cartesian products avoided
- Dynamic programming approach

Query Blocks: Units of Optimization in System R

```
select S.name
from Sailors S
where S.age in (select max(S2.age)
                from Sailors S2
                group by S2.rating)
```

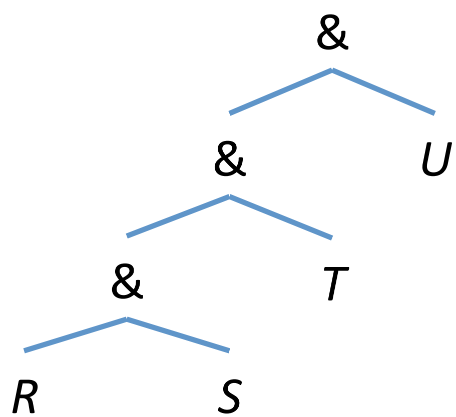
outer block

nested block

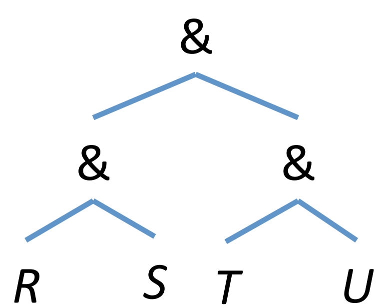
- SQL query parsed into a collection of *query blocks*, to be optimized one block at a time
- Nested blocks treated as calls to a subroutine, made once per outer tuple
- For each block, the plans considered are
  - All available access methods, for each relation in `from` clause
  - All *left-deep join trees*: i.e., all ways to join the relations one-at-a-time, with the inner relation in the from clause, considering all join order permuations and join methods

Left-Deep Join Trees

- Left-deep join tree:



- "Bushy" join tree:



Relational Algebra Equivalences

- Allow us to choose different join orders; to "push" selections and projections ahead of joins; etc

1. $\sigma_{\mathtt{F}_1}(\sigma_{\mathtt{F}_2}(\mathtt{E})) \equiv \sigma_{\mathtt{F}_1 \wedge \mathtt{F}_2}(\mathtt{E})$
2. $\sigma_{\mathtt{F}}(\mathtt{E}_1\ [\cup, \cap, -]\ \mathtt{E}_2) \equiv \sigma_{\mathtt{F}}(\mathtt{E}_1)\ [\cup, \cap, -]\ \sigma_{\mathtt{F}}(\mathtt{E}_2)$
3. $\sigma_{\mathtt{F}}(\mathtt{E}_1 \times \mathtt{E}_2) \equiv \sigma_{\mathtt{F0}}(\sigma_{\mathtt{F1}}(\mathtt{E}_1) \times \sigma_{\mathtt{F2}}(\mathtt{E}_2))$;

   $\mathtt{F} \equiv \mathtt{F0} \wedge \mathtt{F1} \wedge \mathtt{F2}$, $\mathtt{Fi}$ contains only attributes of $\mathtt{E_i}$, $\mathtt{i} = 1, 2$.
4. $\sigma_{\mathtt{A}=\mathtt{B}}(\mathtt{E}_1 \times \mathtt{E}_2) \equiv \mathtt{E}_1 \underset{\mathtt{A}=\mathtt{B}}{\bowtie} \mathtt{E}_2$
5. $\pi_{\mathbf{A}}(\mathtt{E}_1\ [\cup, \cap, -]\ \mathtt{E}_2) \equiv \pi_{\mathbf{A}}(\mathtt{E}_1)\ [\cup, \cap, -]\ \pi_{\mathbf{A}}(\mathtt{E}_2)$

Relational Algebra Equivalences (2)

6. $\pi_{\mathbf{A}}(\mathtt{E}_1 \times \mathtt{E}_2) \equiv \pi_{\mathbf{A1}}(\mathtt{E}_1) \times \pi_{\mathbf{A2}}(\mathtt{E}_2)$,
   with $\mathbf{Ai} = \mathbf{A} \cap \{$ attributes in $\mathtt{E}_\mathtt{i}\}$, $\mathtt{i} = 1, 2$.

7. $\mathtt{E}_1 \; [\cup, \cap] \; \mathtt{E}_2 \equiv \mathtt{E}_2 \; [\cup, \cap] \; \mathtt{E}_1$
   $(\mathtt{E}_1 \cup \mathtt{E}_2) \cup \mathtt{E}_3 \equiv \mathtt{E}_1 \cup (\mathtt{E}_2 \cup \mathtt{E}_3)$ (the analogous holds for $\cap$)

8. $\mathtt{E}_1 \times \mathtt{E}_2 \equiv \pi_{\mathbf{A1},\mathbf{A2}}(\mathtt{E}_2 \times \mathtt{E}_1)$
   $(\mathtt{E}_1 \times \mathtt{E}_2) \times \mathtt{E}_3 \equiv \mathtt{E}_1 \times (\mathtt{E}_2 \times \mathtt{E}_3)$
   $(\mathtt{E}_1 \times \mathtt{E}_2) \times \mathtt{E}_3 \equiv (\mathtt{E}_1 \times \mathtt{E}_3) \times \mathtt{E}_2$

9. $\mathtt{E}_1 \bowtie \mathtt{E}_2 \equiv \mathtt{E}_2 \bowtie \mathtt{E}_1$ $\quad (\mathtt{E}_1 \bowtie \mathtt{E}_2) \bowtie \mathtt{E}_3 \equiv \mathtt{E}_1 \bowtie (\mathtt{E}_2 \bowtie \mathtt{E}_3)$

(Theoretical aside: is this set of equivalences **complete**?)

Enumeration of Alternative Plans

- There are two main cases:
  - Single-relation plans
  - Multiple-relation plans
- Single-relation plans: queries consist of a combination of selections, projections, and aggregates (no joins)
  - Each available *access path* (file or index scan) is considered, and the one with the least estimated cost is chosen
  - The different operations are carried out together in a pipeline (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

- Must estimate cost of each plan considered
- To do this, must estimate cost of each operation in plan tree
  - Depends on input cardinalities, statistical properties, 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
- Dirty little secret of DBMS world: estimation works well for simple plans, but poorly for complex plans

Queries Over Multiple Relations

- Fundamental heuristic in System R: *only left-deep join trees are considered*
- As the # of joins increases, the # of alternative plans grows very rapidly; we need to restrict the search space
- Left-deep join trees allow us to generate all *fully pipelined* plans
  - i.e., intermediate results not written to temporary files (not "materialized")
  - not all left-deep physical plans are fully pipelined
- Bushy join trees: can't have fully pipelined plans
  - Inner table must always be materialized for each tuple of the outer table
  - So, a plan in which the inner table is the result of a join forces us to materialize the result of that 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
- Enumeration via dynamic programming strategy: *n* passes, where *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
  - Pass *n*: find best way to join result of each (*n*-1)-relation plan (as outer) to the *n*th relation
- For each subset of relations, retain only:
  - Cheapest plan overall, plus
  - Cheapest plan for each "interesting order" of the tuples