Overview of Query Evaluation

Chapter 12
Sina Meraji
Query Evaluation

• How could we evaluate the following query?

\[ \pi_{\text{Date}} (\sigma_{\text{R.SID} = \text{S.SID} \text{ and Rating} = 10} (\text{R} \times \text{S})) \]

\[
\text{Sailors (sid: integer, sname: string, rating: integer, age: real)}
\]
\[
\text{Reserves (sid: integer, bid: integer, day: dates, rname: string)}
\]
Schema for Examples

Sailors \((sid: \text{integer}, \ sname: \text{string}, \ rating: \text{integer}, \ age: \text{real})\)
Reserves \((sid: \text{integer}, \ bid: \text{integer}, \ day: \text{dates}, \ rname: \text{string})\)

- 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.
Overview of Query Evaluation

- **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 in query optimization:
  - 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.
Some Common Techniques

- Algorithms for evaluating relational operators use some simple ideas extensively:
  - **Indexing:** Can use WHERE conditions to retrieve small set of tuples (selections, joins)
  - **Iteration:** Sometimes, faster to scan all tuples even if there is an index. (And sometimes, we can scan the data entries in an index instead of the table itself.)
  - **Partitioning:** By using sorting or hashing, we can partition the input tuples and replace an expensive operation by similar operations on smaller inputs.

*Watch for these techniques as we discuss query evaluation!*
Statistics and Catalogs

- Need information about the relations and indexes involved. **Catalogs** typically contain at least:
  - # tuples (NTuples) and # pages (NPages) for each relation.
  - # distinct key values (NKeys) and NPages for each index.
  - Index height, low/high key values (Low/High) for each tree index.

- Catalogs updated periodically.
  - Updating whenever data changes is too expensive; lots of approximation anyway, so slight inconsistency ok.

- More detailed information (e.g., histograms of the values in some field) are sometimes stored.
Access Paths

- An **access path** is a method of retrieving tuples:
  - File scan, or index that matches a selection (in the query)
- A tree index **matches** (a conjunction of) terms that involve only attributes in a *prefix* of the search key.
  - E.g., Tree index on `<a, b, c>` matches the selection `a=5 AND b=3`, and `a=5 AND b>6`, but not `b=3`.
- A hash index **matches** (a conjunction of) terms that has a term `attribute = value` for every attribute in the search key of the index.
  - E.g., Hash index on `<a, b, c>` matches `a=5 AND b=3 AND c=5`; but it does not match `b=3`, or `a=5 AND b=3`, or `a>5 AND b=3 AND c=5`. 
A Note on Complex Selections

\[(\text{day}<8/9/94 \ \text{AND} \ \text{rname}=\text{‘Paul’}) \ \text{OR} \ \text{bid}=5 \ \text{OR} \ \text{sid}=3\]

• Selection conditions are first converted to **conjunctive normal form (CNF):**

\[(\text{day}<8/9/94 \ \text{OR} \ \text{bid}=5 \ \text{OR} \ \text{sid}=3) \ \text{AND} \ (\text{rname}=\text{‘Paul’} \ \text{OR} \ \text{bid}=5 \ \text{OR} \ \text{sid}=3)\]

• We only discuss case with no ORs; see text if you are curious about the general case.
One Approach to Selections

• Find the *most selective access path*, retrieve tuples using it, and apply any remaining terms that don’t match the index:
  – *Most selective access path*: An index or file scan that we estimate will require the fewest page I/Os.
  – Terms that match this index reduce the number of tuples retrieved; other terms are used to discard some retrieved tuples, but do not affect number of tuples/pages fetched.
  – Consider *day<8/9/94 AND bid=5 AND sid=3*. A B+ tree index on *day* can be used; then, *bid=5* and *sid=3* must be checked for each retrieved tuple. Similarly, a hash index on <*bid*, *sid*> could be used; *day<8/9/94* must then be checked.
Using an Index for Selections

- Cost depends on #qualifying tuples, and clustering.
  - Cost of finding qualifying data entries (typically small) plus cost of retrieving records (could be large w/o clustering).
  - In example, assuming uniform distribution of names, about 10% of tuples qualify (100 pages, 10000 tuples). With a clustered index on rname, cost is little more than 100 I/Os; if unclustered, upto 10000 I/Os!

```
SELECT *  
FROM Reserves R  
WHERE R.rname <= 'C%'
```
The expensive part is removing duplicates.

- SQL systems don’t remove duplicates unless the keyword DISTINCT is specified in a query.

**Sorting Approach:** Sort on <sid, bid> and remove duplicates. (Can optimize this by dropping unwanted information while sorting.)

**Hashing Approach:** Hash on <sid, bid> to create partitions. Load partitions into memory one at a time, build in-memory hash structure, and eliminate duplicates.

**Using Indexes:** If there is an index with both R.sid and R.bid in the search key, may be cheaper to sort data entries!

```
SELECT DISTINCT R.sid, R.bid
FROM Reserves R
```
Join: Index Nested Loops

foreach tuple r in R do
    foreach tuple s in S where r_i == s_j do
        add <r, s> to result

• If there is an index on the join column of one relation (say S), can make it the inner and exploit the index.
  – Cost: $M + ( (M*p_R) * \text{cost of finding matching S tuples} )$
  – $M=\#\text{pages of } R$, $p_R=\# \text{ R tuples per page}$

• For each R tuple, cost of probing S index is about 1.2 for hash index, 2-4 for B+ tree. Cost of then finding S tuples depends on clustering.
  – Clustered index: 1 I/O (typical), unclustered: upto 1 I/O per matching S tuple.
Examples of Index Nested Loops

• Hash-index on \textit{sid} of Sailors (as inner):
  – Scan Reserves: 1000 page I/Os, 100*1000 tuples.
  – For each Reserves tuple: 1.2 I/Os to get data entry in index, plus 1 I/O to get (the exactly one) matching Sailors tuple.
    Total: \((1+1.2)*100000=220,000\) I/Os.

• Hash-index on \textit{sid} of Reserves (as inner):
  – Scan Sailors: 500 page I/Os, 80*500 tuples.
  – For each Sailors tuple: 1.2 I/Os to find index page with data entries, plus cost of retrieving matching Reserves tuples.
    Assuming uniform distribution, 2.5 reservations per sailor \((100,000 \div 40,000)\). Cost of retrieving them is 1 or 2.5 I/Os depending on whether the index is clustered.
Join: Sort-Merge ($R owtie_i S$)

- Sort $R$ and $S$ on the join column, then scan them to do a ``merge'' (on join col.), and output result tuples.
  - Advance scan of $R$ until current $R$-tuple $\geq$ current $S$ tuple, then advance scan of $S$ until current $S$-tuple $\geq$ current $R$ tuple; do this until current $R$ tuple = current $S$ tuple.
  - At this point, all $R$ tuples with same value in $R_i$ (current $R$ group) and all $S$ tuples with same value in $S_j$ (current $S$ group) match; output $<r, s>$ for all pairs of such tuples.
  - Then resume scanning $R$ and $S$.

- $R$ is scanned once; each $S$ group is scanned once per matching $R$ tuple. (Multiple scans of an $S$ group are likely to find needed pages in buffer.)
### Example of Sort-Merge Join

<table>
<thead>
<tr>
<th>sid</th>
<th>sname</th>
<th>rating</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>dustin</td>
<td>7</td>
<td>45.0</td>
</tr>
<tr>
<td>28</td>
<td>yuppy</td>
<td>9</td>
<td>35.0</td>
</tr>
<tr>
<td>31</td>
<td>lubber</td>
<td>8</td>
<td>55.5</td>
</tr>
<tr>
<td>44</td>
<td>guppy</td>
<td>5</td>
<td>35.0</td>
</tr>
<tr>
<td>58</td>
<td>rusty</td>
<td>10</td>
<td>35.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>sid</th>
<th>bid</th>
<th>day</th>
<th>rname</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>103</td>
<td>12/4/96</td>
<td>guppy</td>
</tr>
<tr>
<td>28</td>
<td>103</td>
<td>11/3/96</td>
<td>yuppy</td>
</tr>
<tr>
<td>31</td>
<td>101</td>
<td>10/10/96</td>
<td>dustin</td>
</tr>
<tr>
<td>31</td>
<td>102</td>
<td>10/12/96</td>
<td>lubber</td>
</tr>
<tr>
<td>31</td>
<td>101</td>
<td>10/11/96</td>
<td>lubber</td>
</tr>
<tr>
<td>58</td>
<td>103</td>
<td>11/12/96</td>
<td>dustin</td>
</tr>
</tbody>
</table>

- **Cost:** $M \log M + N \log N + (M+N)$
  - The cost of scanning, $M+N$
  - With 35, 100 or 300 buffer pages, both Reserves and Sailors can be sorted in 2 passes; total join cost: 7500, how?