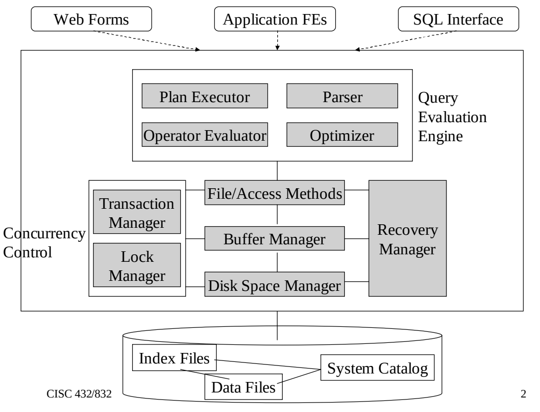
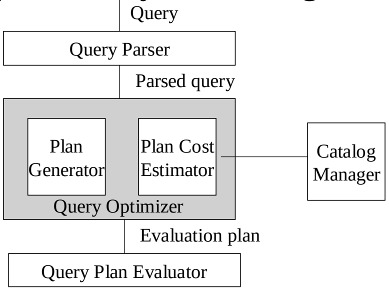
Query Evaluation and Optimization

An Overview



Steps in Query Processing



Schema for Examples

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

Overview

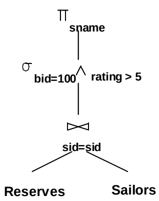
- *Evaluation Plan*: *Tree of R.A. ops, with alg for each op.*
  - Each operator typically implemented using a `pull' interface: when an operator is `pulled' for the next output tuples, it `pulls' on its inputs and computes them.
- Two main issues in query optimization:
  - For a given query, what plans are considered?
    - Need 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!
- System R approach discussed in text.

Example

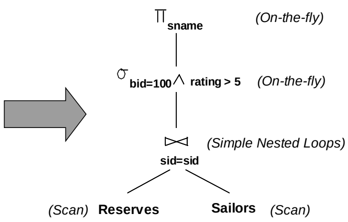
SELECT S.sname
FROM Reserves R, Sailors S
WHERE R.sid = S.sid
AND R.bid = 100 AND S.rating > 5

What is an equivalent relational algebra query?

Example (cont.)



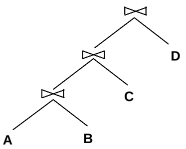
Query Tree



Evaluation Plan

Pipelined Evaluation

- Result of one operator *pipelined* to another without creating temporary table
- Lower overhead than *materialization*
- Unary operator is *on-the-fly* if input pipelined.



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 <u>access path</u> is a method of retrieving tuples:
  - File scan, or index that matches a selection (in the query)

(day<8/9/94 AND rname='Paul') OR bid=5 OR sid=3

- Selection conditions are first converted to <u>*conjunctive normal form*</u> (CNF):

(day<8/9/94 OR bid=5 OR sid=3) AND (rname='Paul' OR bid=5 OR sid=3)

Access Paths (Cont.)

- A tree index <u>*matches*</u> (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 <u>*matches*</u> (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*.

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 an 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, cost is little more than 100 I/Os; if unclustered, upto 10000 I/Os!

```
SELECT *
FROM   Reserves R
WHERE  R.rname < 'C%'
```

Projection

- 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.
- 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: Nested Loops

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

- *Blocked Nested Loops*: Read a block of outer relation and match inner relation against its tuples
  - Cost: $B_R + (B_R * B_S)$

Join: Nested Loops (cont.)

- *Indexed Nested Loops*: If there is an index on the join column of one relation (say S), can make it the inner and exploit the index.
  - Cost: $B_R + ((B_R * bfr_R)$ * cost of finding matching S tuples)
- 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 (assuming Alt. (2) or (3) for data entries) depends on clustering.
  - Clustered index: 1 I/O (typical), unclustered: upto 1 I/O per matching S tuple.

Query Optimization

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.

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.

Size Estimation and Reduction Factors

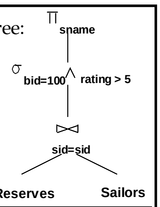
- Consider a query block:

```
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.
  - Implicit assumption that *terms* are independent!
  - Term *col=value* has RF *1/NKeys(I)*, given index I on *col*
  - Term *col1=col2* has RF *1/MAX(NKeys(I1), NKeys(I2))*
  - Term *col>value* has RF *(High(I)-value)/(High(I)-Low(I))*

Motivating Example

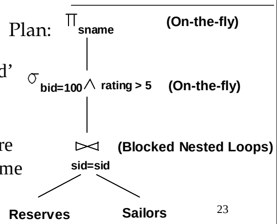
RA Tree:



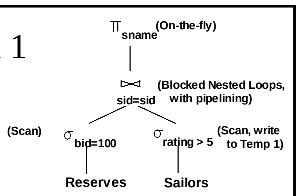

```
SELECT S.sname
FROM Reserves R, Sailors S
WHERE R.sid=S.sid AND
   R.bid=100 AND S.rating>5
```

- Cost: 500+500*1000 I/Os
- By no means the worst plan!
- Misses several opportunities: selections could have been `pushed' earlier, no use is made of any available indexes, etc.
- *Goal of optimization:* To find more efficient plans that compute the same answer.

Plan:

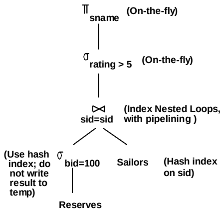


Alternative Plan 1 (Push Selects)



- Cost of plan:
  - Scan Reserves (1000) - produces 10 pages, if we have 100 boats, uniform distribution.
  - Scan Sailors (500) + write temp T1 (250 pages, if we have 10 ratings).
  - BNL: 10 * 250 = 2500
  - Total: 1000 + 500 + 250 + 2500 = 4250 page I/Os.

Alternative Plan 2 (With Indexes)



- With clustered index on *bid* of Reserves, we get 100,000/100 = 1000 tuples on 1000/100 = 10 pages.
- INL with ***pipelining*** (outer is not materialized).
  - –Projecting out unnecessary fields from outer doesn't help.
- Join column *sid* is a key for Sailors.
  - –At most one matching tuple, unclustered index on *sid* OK.
- Decision not to push *rating>5* before the join is based on availability of *sid* index on Sailors.
- Cost: Selection of Reserves tuples (10 I/Os); for each, must get matching Sailors tuple (1000*1.2); total 1210 I/Os.

Summary

- There are several alternative evaluation algorithms for each relational operator.
- A query is evaluated by converting it to a tree of operators and evaluating the operators in the tree.
- Must understand query optimization in order to fully 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.