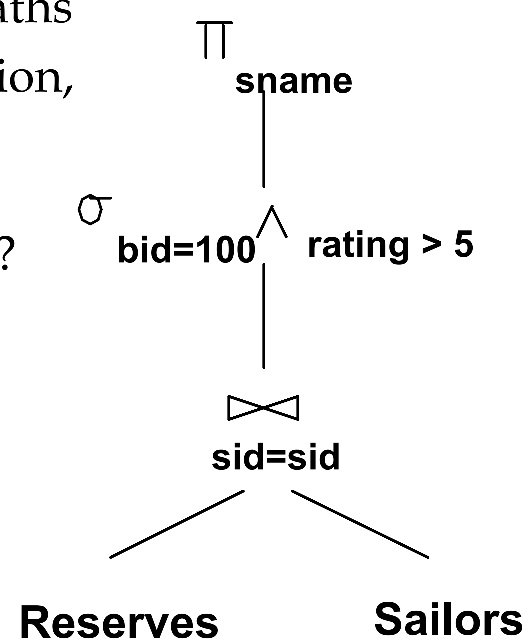
Overview of Query Evaluation

Chapter 12

Overview of Query Evaluation

- *Query:*
  SELECT sname
  FROM Reserves R, Sailors S
  WHERE R.sid=S.sid
  AND R.bid = 100 AND S.rating > 5
- *Plan: Tree of relational algebra ops, with an algorithm for each*
  - Each "pulls" tuples from tables via "access paths"
  - An access path might involve an index, iteration, sorting, or other approaches.
- 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 optimal plan.
- Practically: Want to avoid poor plans!



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.

Today's Working Example

- Consider database with the following two tables:

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

- Assume each tuple of Reserves is 40 bytes, a page holds, at most, 100 records, each Sailors' tuple is 50 bytes, and a page holds no more than 80 records
- Furthermore, assume
  1000 pages of Reserves (< 100,000 records), and
  500 pages of Sailors (< 40, 000 records)

Example's Catalog

Attribute_Cat(*attr_name*: string, *rel_name*: string, *type*: string, *position*: integer)

- The system catalog is itself a collection of relations/tables (ex. Table attributes, table statistics, etc.)
- Catalog tables can be queried just like any other table
- Relational algebra operations can be used to examine Query evaluation tradeoffs

Attribute_Cat			
attr_name	*rel_name*	*type*	*position*
attr_name	Attribute_Cat	string	1
rel_name	Attribute_Cat	string	2
type	Attribute_Cat	string	3
postion	Attribute_Cat	integer	4
sid	Sailors	integer	1
sname	Sailors	string	2
rating	Sailors	integer	3
age	Sailors	real	4
sid	Reserves	integer	1
bid	Reserves	integer	2
day	Reserves	date	3
rname	Reserves	string	4

Access Paths

- An access path is a method of retrieving tuples:
  - File scan, or index search that matches the given query's selection
- 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

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

- Selection conditions are first converted to

  Conjunctive Normal Form (CNF),

  "ORs of AND clauses" or "sum of products"

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

- "AND" terms allow us to optimally choose indices "OR" terms can be tested sequentially in iterations.

One Approach to Selections

- Find the *most selective access path*, retrieve tuples using it, and apply any remaining unmatched terms
  - *Most selective access path:* Either an index traversal or file scan that we *estimate* requires the fewest page I/Os.
  - Terms that match this index reduce the number of tuples *retrieved*; other unmatched terms are used to discard 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 checked for each retrieved tuple.
    - Similarly, a hash index on <*bid, sid*> could be used;
      then *day*<8/9/94 checked.

Which is faster?

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).
  - For 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

- Expensive part is eliminating duplicates.
  - SQL systems don't remove duplicates unless the keyword DISTINCT is specified in a query.

```
SELECT  DISTINCT
        R.sid, R.bid
FROM    Reserves R
```

- Sorting Approach
  - Sort on <sid, bid> and remove duplicates. (Can optimize by dropping unwanted attributes while sorting.)
- Hashing Approach
  - Hash on <sid, bid> during scan to create partitions. Ignore hash-key collisions.
- With an index containing both R.sid and R.bid, you can step through the leafs (if tree) compressing duplicates, or directory of a Hash, however, may be cheaper to sort data entries!

Join: Index Nested Loops

foreach tuple r in R:

  foreach tuple s in S:

    if r_i ***op*** s_j add <r, s> to result

- If there is an index on the join attribute of one relation (say S), can make it the inner loop to exploit the index.
  - Cost: M + (($M*p_R$) * cost of finding matching S tuples)
  - M=#pages of R, p_R=# R tuples per page
- For each R tuple, cost of probing S index is ~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 total (typical)
  - Unclustered: upto 1 I/O per matching S tuple.

Examples of Index Nested Loops

- Hash-index (Alt. 2) on *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 (exactly one) matching Sailors tuple.
  - Total: 1000 + (1+1.2)*100000 = 221,000 I/Os.
- Hash-index (Alt. 2) on *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 / 40,000). Cost of retrieving them is 1 or 2.5 I/Os depending on whether the index is clustered.
  - Total: 500 + (1.2 + 1)*40000 = 88,500 I/Os (clustered)
500 + (1.2 + 2.5)*40000 = 148,500 I/Os (unclustered)

Join: Sort-Merge ($R \bowtie_{i=j} S$)

- Sort R and S on the join column
- Scan them while "merging" (on join col.) and outputting resulting tuples.
  - Advance scan of R until current R-tuple >= current S tuple, then advance scan of S until current S-tuple >= current R tuple; do this until current R tuple = current S tuple.
  - At this point, all R tuples with same value in Ri (*current R group*) and all S tuples with same value in Sj (*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

sid	sname	rating	age
22	dustin	7	45.0
28	yuppy	9	35.0
31	lubber	8	55.5
44	guppy	5	35.0
58	rusty	10	35.0

sid	bid	day	rname
28	103	12/4/96	guppy
28	103	11/3/96	yuppy
31	101	10/10/96	dustin
31	102	10/12/96	lubber
31	101	10/11/96	lubber
58	103	11/12/96	dustin

Note importance of out-of-core external sorting (Next lecture's topic)

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

Highlights of Query Optimization

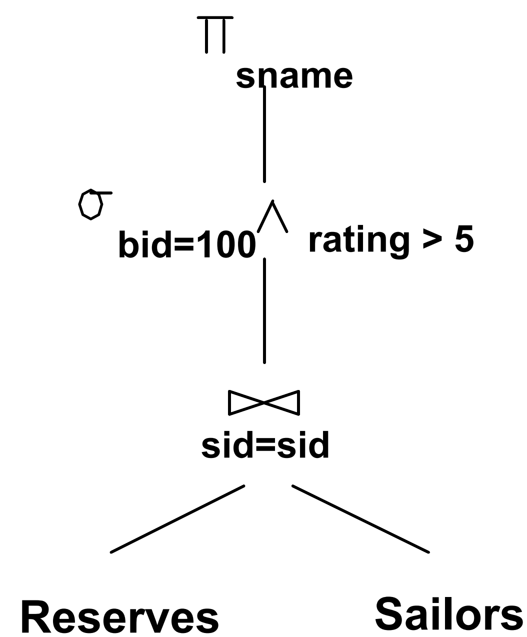
- Cost estimation: Approximate art at best.
  - Statistics, maintained in system catalogs, used to estimate cost of operations and result sizes.
  - Considers combination of CPU and I/O costs.
- Plan Space: Too large, must be pruned.
  - Only the space of *left-deep plans* is considered.
    - Left-deep plans allow output of each operator to be *pipelined* into the next operator without storing it in a temporary relation.
  - Actual Cartesian products avoided.

Cost Estimation

- For each plan considered, we must estimate cost:
  - *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.

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

RA Tree:



Size Estimation and Reduction Factors

- Consider a query block:

  SELECT attribute list
  FROM relation list
  WHERE $term_1$ AND ... AND $term_k$

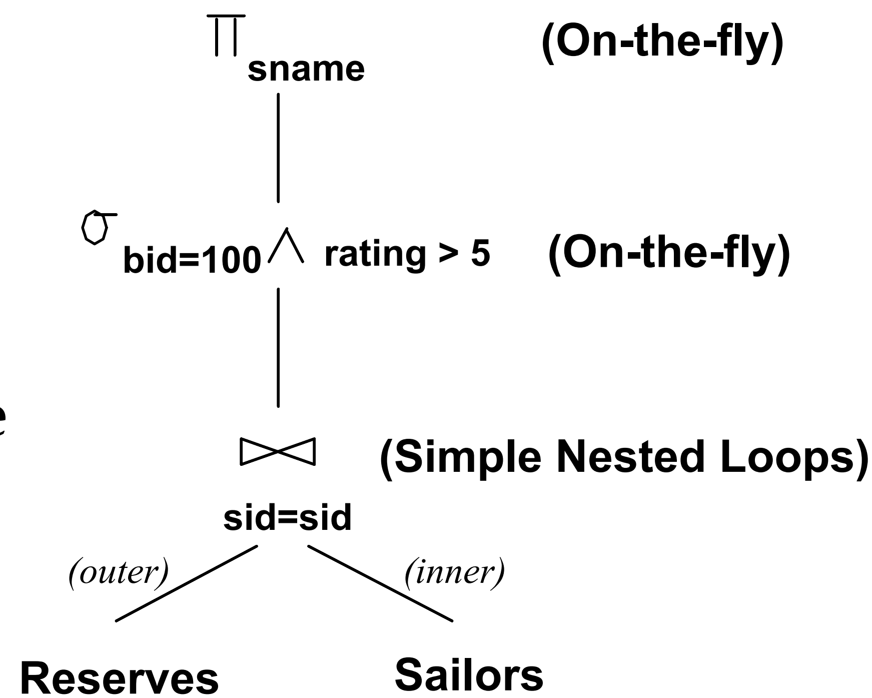
- Maximum # tuples in result is the product of the cardinalities of relations in the **FROM** clause.
- *Reduction factor (RF)* associated with each *term* reflects the impact of the *term* in reducing result size. *Result cardinality* = Max # tuples $* RF_1 * RF_2 * \ldots RF_k$.
  - Implicit assumption 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

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

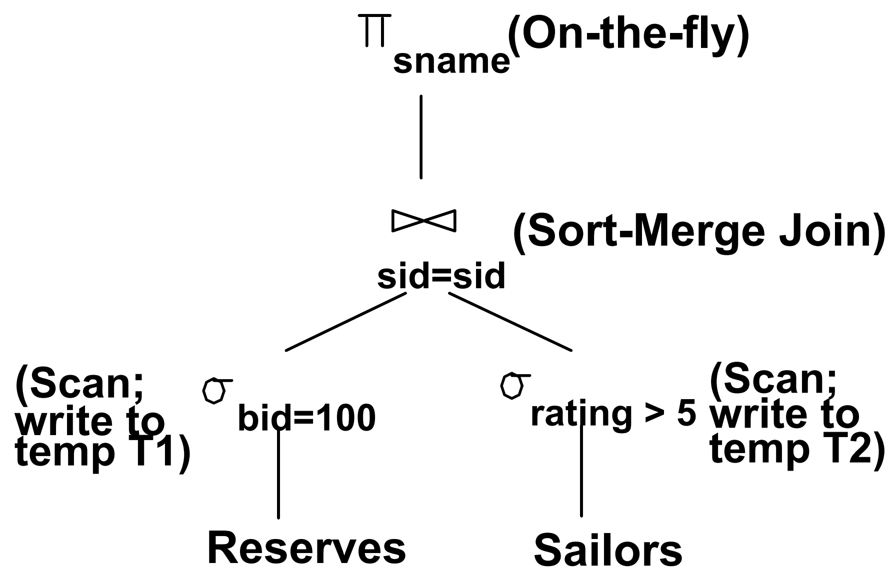
- Cost: 500+500*1000 I/Os
- By no means the worst plan!
- Misses several opportunities: selections could have been "pushed" earlier, no use is made of any available indexes, etc.
- *Goal of optimization:* To find more efficient plans that compute the same answer.

Plan:



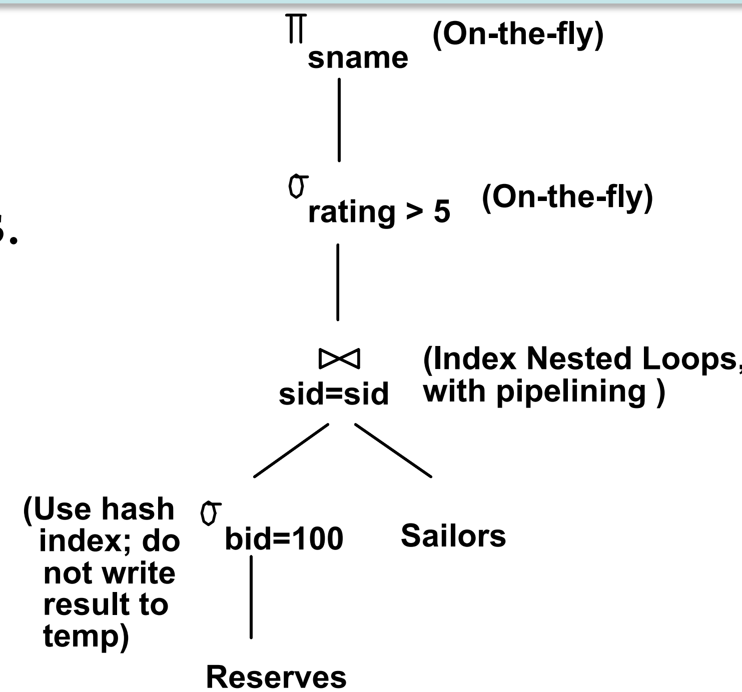
Alternative Plan 1 (No Indexes)

- ***Main difference:*** *Push selects.*
- With 5 buffers, cost of plan:
  - Scan Reserves (1000) + write temp T1 (10 pages, if we have 100 boats, assumes uniform distribution).
  - Scan Sailors (500) + write temp T2 (250 pages, if we have 10 ratings).
  - Sort T1 (2*2*10), sort T2 (2*4*250), merge (10+250)
  - Total: 4060 page I/Os.



- If we used BNL join, join cost = 10+4*250, total cost = 2770.
- If we \`push' projections, T1 has only *sid*, T2 only *sid* and *sname*:
  - T1 fits in 3 pages, cost of BNL drops to under 250 pages, total < 2000.

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.