Overview of Query Evaluation

Chapter 12

Overview of Query Evaluation

- *Query Plan:*
  - *Tree of relational algebra operators*
  - *with choice of algorithm for each operator.*
- Example: What are the names of sailors who have reserved boat 103
  - What are the operators

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

Overview of Query Evaluation

- 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!

- Each operator is typically implemented using a `pull’ interface: when an operator is `pulled’ for the next output tuples, it `pulls’ on its inputs and computes them.

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.

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.

Statistics and Catalogs

- Catalogs are 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.

A Note on Complex Selections

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

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

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

- We only discuss case with no ORs; see text if you are curious about the general case.

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*.

The Selection Operator

- *Most selective access path:* An index or file scan that we estimate will require the fewest page I/Os.
- Find the *most selective access path*, retrieve tuples using it, and apply any remaining terms that don't match the index:
  - 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.

The Selection Operator: Reduction factor

- *Reduction factor.* The fraction of tuples in a table that satisfy a given conjunct
  - When there are several primary conjuncts, the total reduction factor is the product of all reduction factors (approximately)
- If there is no available information about the reduction factor, we can assume either uniform distribution, or simply reduction factor is set to a default value (0.1)
  - More sophisticated techniques use histograms
- Based on the reduction factor, we may decide upon several index choices

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

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

- Projection is: (1) Dropping unwanted columns, and (2) Removing duplicates
- The expensive part is removing duplicates.
  - SQL systems don't remove duplicates unless the keyword DISTINCT is specified in a query.
- If no duplicate elimination is needed, an iteration is performed either on the table or an index whose key contains all the projection fields

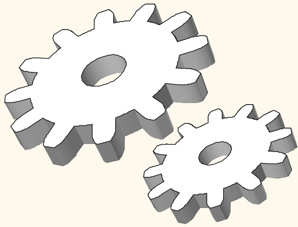
Projection with duplicate elimination

- *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!

Join:



```
SELECT  S.sid, S.name, R.bid
FROM    Sailors S, Reserves R
WHERE   S.sid=R.sid
```

- Join is the most *common* and most *expensive* query operator
- Joins are widely studied and systems support several join algorithms
- A straightforward way for the join is an exhaustive nested loop

For each tuple r in R do
    For each tuple s in S
        if $r_{.sid}$ == $s_{.sid}$ do
            add <r, s> to result

Join: Index 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.

- 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.

Examples of Index Nested Loops

- Assuming the availability of hash index on both tables:
  - Page size = 80 tuples/Sailors and 100 tuples/Reserves
  - Cardinality of Sailors = 40,000 ➔ 500 pages
  - Cardinality of Reserves = 100,000 ➔ 1000 pages
  - Retrieving a page through hashing costs 1.2 I/O

- 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 (the exactly one) matching Sailors tuple. Total: 1000 + 100,000 * 2.2 = 221,000 I/Os.

Examples of Index Nested Loops

- 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.
  - Clustered: 500 + 40,000 * 2.2 = 88,500 I/Os
  - Unclustered: 500 + 40,000 * 3.7 = 148,500 I/Os

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

- Sort R and S on the join column, then scan them to do a ``merge'' (on join col.), and output result tuples.

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

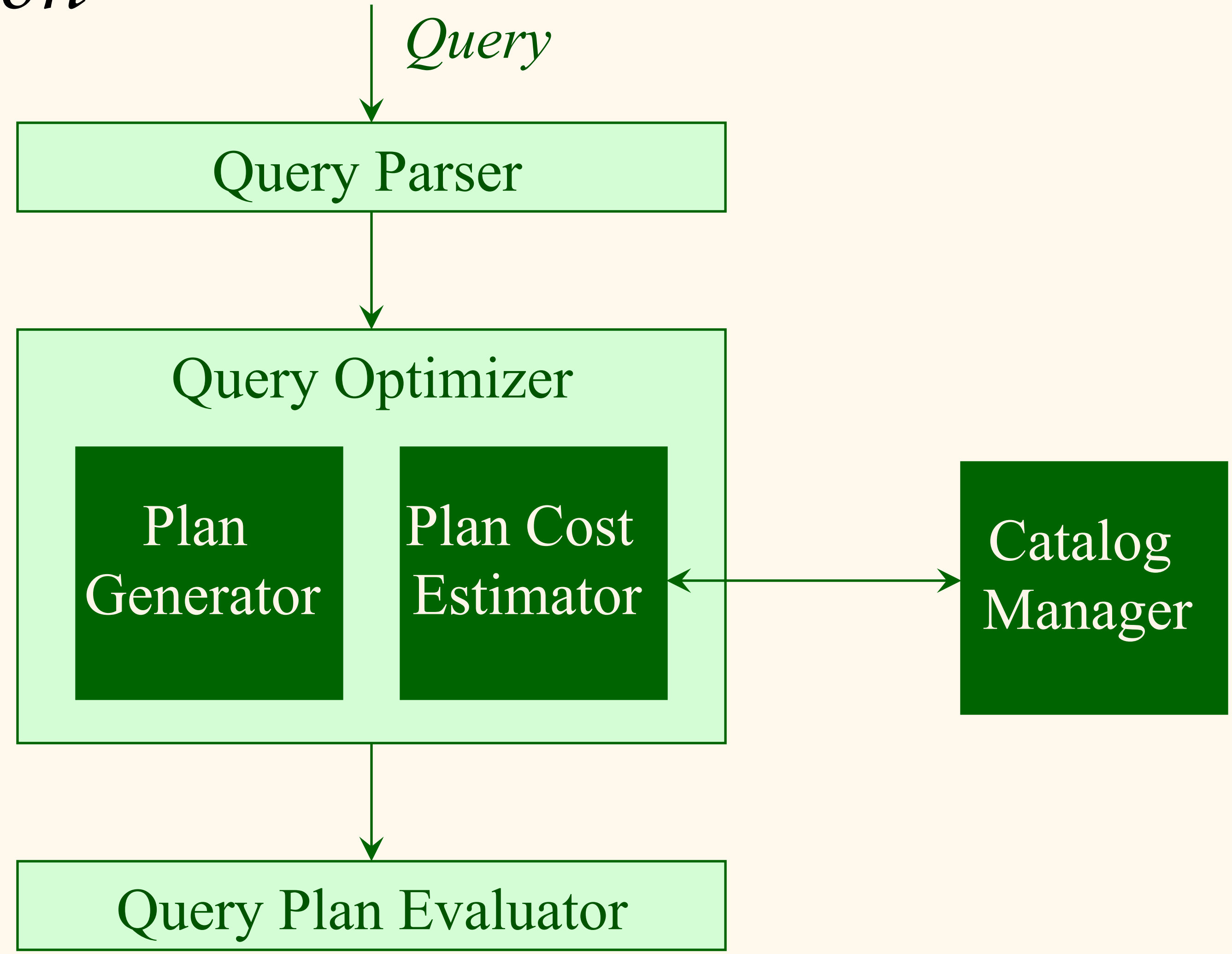
Cost of Sort-Merge Join

- *Sorting* takes two passes, for each pass, we need to scan (read and write) each data record:
  - Cost for sorting Reserves: 2 * 2 * 1000 = 4000
  - Cost for sorting Sailors: 2 * 2 * 500 = 2000
- *Merging* needs only one global pass over the two tables with read only
  - Merging cost = 1000+500 = 1500
- Total cost = 4000 + 2000 + 1500 = 7500
- Why bother by indexing..??!!

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.

Query Planning, Optimization, and Evaluation



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))*

Schema for Examples

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

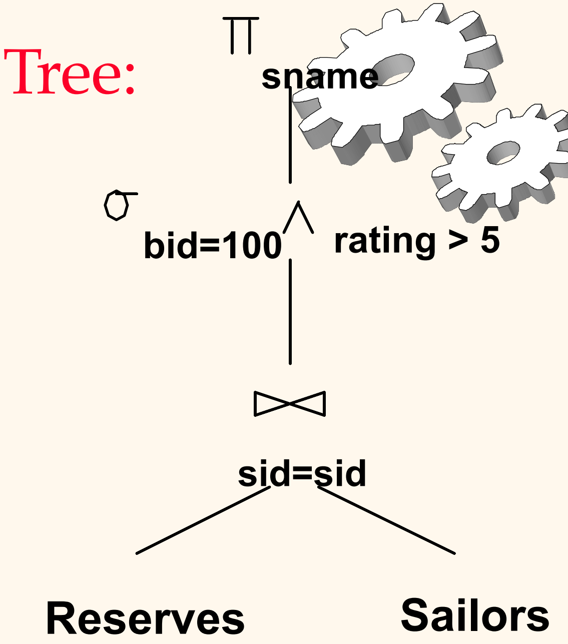
- Reserves:
  - Each tuple is 40 bytes long, 100 tuples per page, 1000 pages.
- Sailors:
  - Each tuple is 50 bytes long, 80 tuples per page, 500 pages.

Motivating Example

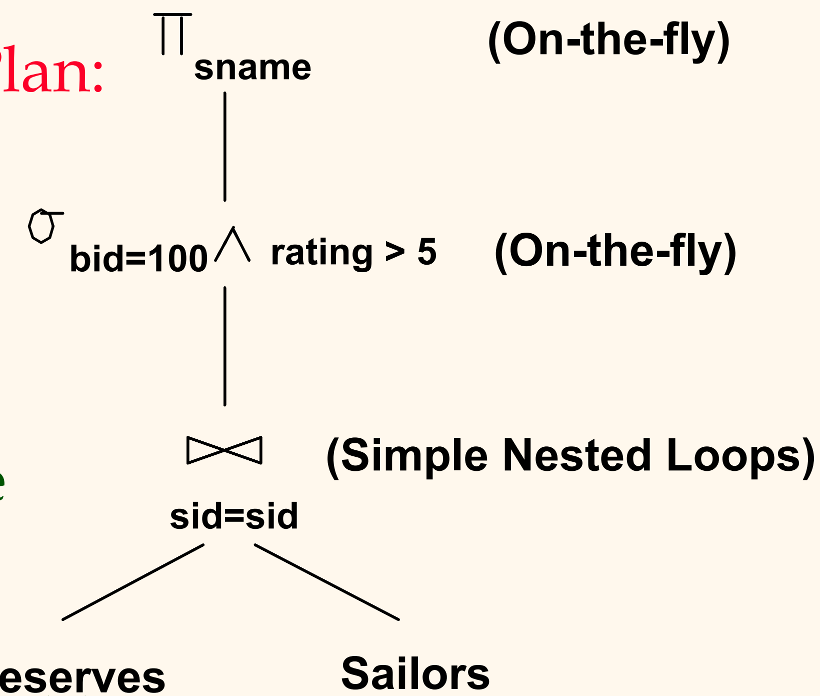
SELECT S.sname
FROM Reserves R, Sailors S
WHERE R.sid=S.sid AND R.bid=100
AND S.rating>5

- 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.

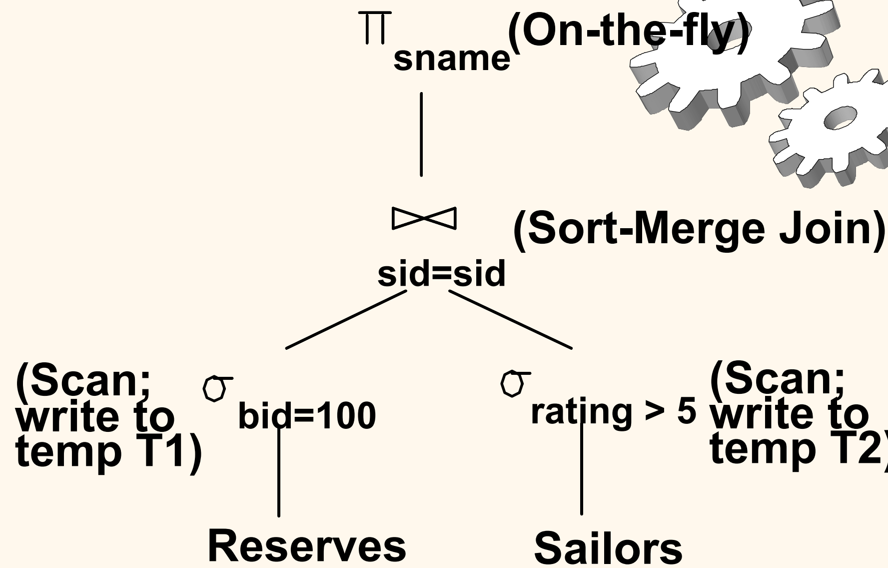
RA Tree:



Plan:

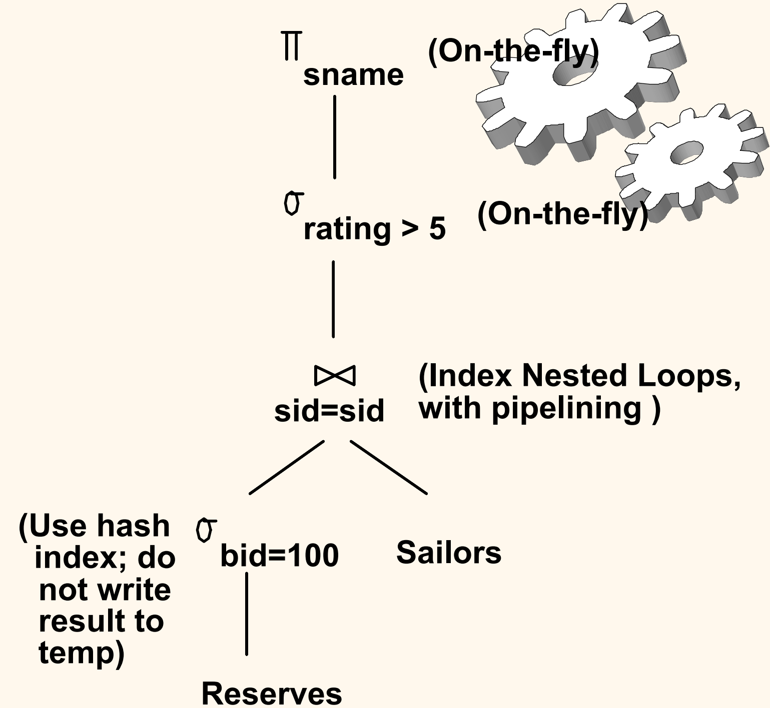


Alternative Plans 1 (No Indexes)



- *Main difference:* push selects.
- Cost of plan
  - Scan Reserves (1000) + write temp T1 (10 pages, if we have 100 boats, uniform distribution).
  - Scan Sailors (500) + write temp T2 (250 pages, if we have 10 ratings).
  - Sort T1 (2*2*10), sort T2 (2*2*250), merge (10+250)
  - Total: 3060 page I/Os.
- 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 Plans 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.