Overview of Query Evaluation

Midterm next Tuesday, in class
80 min, open book, open internet, no communication

I expect to post the grades for problem sets #1 and #2 before class on Thursday

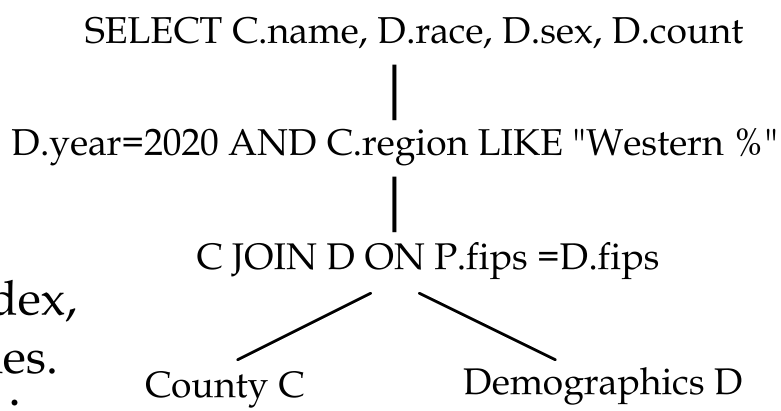
Change of plan for Thursday

Overview of Query Evaluation

- *Query:*

```
SELECT C.name, D.race, D.sex, D.count
FROM County C, Demographics D
WHERE C.fips=D.fips
 AND D.year=2020 AND C.region LIKE "Western %"
```

- *Plan:* *Tree of operations with an algorithm for each*
  - Each operation "pulls" tuples from "relations" 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 an effcient plan.
  - How is the cost of a plan estimated?
- Ideally: Want to find the *optimal* plan.
- Reality: Want to avoid poor plans!

Some Common Techniques

- Algorithms for evaluating queries use the same simple ideas extensively:
  - Indexing: Can use WHERE conditions to retrieve a subset of tuples (selections, joins)
  - Iteration: Sometimes, faster to scan all tuples even if there is an index. (And sometimes, we can scan the search keys of 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 all the tables 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 and high key values (Low/High) for each tree index.
- Catalogs are updated regularly.
  - 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 a simplified database with the following two tables:

  County(*<u>fips</u>*: int, *name*: text, *region*: text)
  Demographics(*<u>fips</u>*: int, *<u>year</u>*: int, *<u>race</u>*: text, *<u>sex</u>*: text, *count*: int)

- Assume each tuple of County is 200 bytes, a page holds, at most, 20 rows, each Demographics tuple is 50 bytes, and a page holds no more than 80 rows
- Furthermore, assume
  6 pages of County (< 120 records), and
  200 pages of Demographics (< 16,000 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
- These queries 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
fips	County	integer	1
name	County	string	2
region	County	string	3
fips	Demographics	integer	1
year	Demographics	integer	2
race	Demographics	string	3
sex	Demographics	string	4
count	Demographics	integer	5

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

year > 2010 AND race="aian" AND (fips=37001 OR fips=37063)

- Selection conditions are first converted to "sum-of-products" form (ORs of AND clauses)

  (year > 2010 AND race='aian' AND fips=37001) OR
  (year > 2010 AND race='aian' AND fips=37063)

- "AND" terms allow us to optimally choose indices "OR" terms can be generated as independent query evaluations over the same tables or a subset

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 *year > 2010 AND AND race='aian'*
    - A B+ tree index on *year* can be used; then, *sex* would be checked for each retrieved tuple.
    - Similarly, a hash index on <*race*> could be used; then *year > 2010* 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 if table isn't clustered on search key).
  - Assume 50% of demographics records are 2010 or after
    - If the table is clustered by *year*, the cost is little more than (0.5 * 200) = 100 I/Os
    - If table isn't clustered by year (say sex), then there are likely 40 per page requiring us to read all 200 pages!
    - In reality, demographics probably are clustered by the year, so the 100 I/Os might not be that far off

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 if table isn't clustered on search key).
  - There are 2097 demographics records for race='*aian*'.
    - A single hash leads us to a hash bucket linked to 2 overflow buckets with these record's page ids
    - In the worst-case these 2097 records are spread across all 200 Demographics table pages.
    - The hash index on Player.name is not very selective for this query
    - However, if records are clustered by <year,race>, we might find all the "aian" records in a subset of pages, getting us back to 100.

Selection

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

```
SELECT DISTINCT race, sex
FROM   Demographics
```

- Sorting Approach
  - Sort on <pid, tid> and remove duplicates.
    (Can optimize by dropping unneeded attributes while sorting.)
- Hashing Approach
  - Hash on <pid, tid> during scan to create partitions.
    Ignore hash-key collisions.
- With an index containing both pid and tid, 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 p in P:
          if ri op pj :
              add <r, p> to result
```

```
foreach tuple p in P:
     foreach tuple r in R:
          if ri op pj :
              add <r, p> to result
```

- If there is an index on the attribute of one relation (say P), if we make it the *inner loop* to exploit the index.
  - Cost: M + (($M*p_R$) * cost of finding matching P tuples)
  - M= #pages of R, p_R=# tuples per R 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 on *race*:
  - Scan County: 6 pages
  - Use index on Demographics:
    - 1.2 I/Os to get page index, plus 120 I/Os
      to get "aian" Demographic records assumes some clustering
    - check year > 2010
  - 6 + (1+1.2) + 120 = 128 I/Os.
- Tree-index on *year*:
  - Scan County: 6 pages
  - Use B+ tree index on Demographics (3 levels + 110 pages)
  - check race = "aian"
  - Total: 3 + 110 = 113 I/Os

Join: Sort-Merge (R JOIN *S* ON *i=j)*

- First, Sort R and S on the join attribute
- Scan both sorted tables while "merging" to output result tuples.
  - Advance scan of R until current R-tuple >= current P tuple, then advance scan of P until current P-tuple >= 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 $<r_i, s_j>$ 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. (Repeated scaning of S group is likely to find needed pages in buffer.)

Example of Sort-Merge Join

pid	name	college	dob
29010	Austin Shepherd	Alabama	1992-05-28
29011	Josh Shirley	Nevada-Las Vegas	1992-01-04
29012	Jameill Showers	Texas-El Paso	--
29013	Trevor Siemian	Northwestern	1991-12-26
29014	Ian Silberman	Boston College	1992-10-10
29015	Shayne Skov	Stanford	1990-07-09

pid	tid	year	starts
29010	1032	2015	0
29011	1006	2015	0
29011	1001	2016	0
29012	1012	2015	0
29013	1004	2015	0
29013	1004	2016	14
29013	1004	2017	10
29013	1032	2018	0
29013	1019	2019	0

We'll use "out-of-core" external sorting (Next lecture's topic)

Pass 1: Read P in 10, 50 block chunks, sort each one, and then write them back, then read R in 8, 50 block chunks, sort each, and write them back (2(400+500))

Pass 2: Read in the head blocks of the 10 sorted P chunks and the heads of 8 sorted R chunks. Merge the tops of the 10 into one block and the tops of the 8 into another (refill any head block when it is exhasted). These two merged blocks are then scanned for matching keys (400+500).

- Cost: M log M + N log N + (M+N)
  - The cost of scanning, M+N, could be M*N (very unlikely!)
- Using only 20 buffer pages, 200 Demographics pages can be sorted in 2 passes; total join cost: 10*20+10 = 210 I/Os.

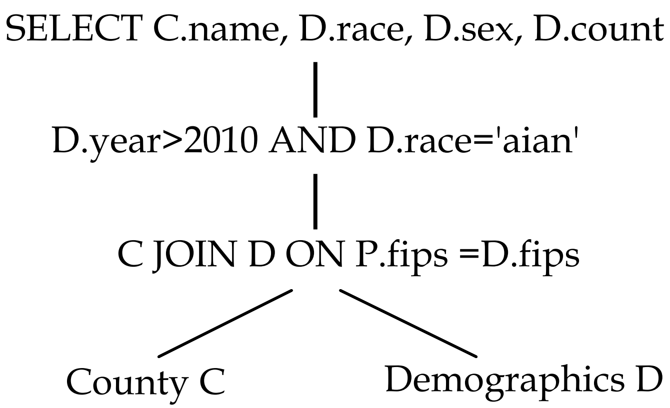
Highlights of Query Optimization

- **Cost estimation:** Approximations are an art.
  - 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.

Alternate Evaluation Trees:



Load 6 County blocks and scan 200 Demographics blocks 206 I/Os using only 7 buffer pages

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.