Query Processing

Introduction to Databases
CompSci 316 Fall 2017

DUKE
COMPUTER SCIENCE

Announcements (Mon., Mar. 20)

- Homework #3
  - 3.1 and 3.2 are due on Wednesday March 22
- Project
  - Milestone 2 due next Monday March 27
  - Feedback posted on private piazza threads

Where are we?

- We are covering DB internals and query processing
- So far:
  - Index: mostly B+ tree
- Today:
  - finish query processing and join algorithms

Query Processing

Overview

- Many different ways of processing the same query
  - Scan? Sort? Hash? Use an index?
  - All have different performance characteristics and/or make different assumptions about data
- Best choice depends on the situation
  - Implement all alternatives
  - Let the query optimizer choose at run-time
  - Often not the "best choice"
  - Optimizer tries NOT to select a "bad choice"

Notation

- Relations: R, S
- Tuples: r, s
- Number of tuples: $|R|, |S|$
- Number of disk blocks: $B(R), B(S)$
- Number of memory blocks available: M
- Cost metric
  - Number of I/O's
  - Memory requirement
- We do not count the cost of final write to disk
- Do not try to memorize the formulas for cost estimation!
  - understand the logic
  - recall the diagram of disk and memory on whiteboard

Scanning-based algorithms

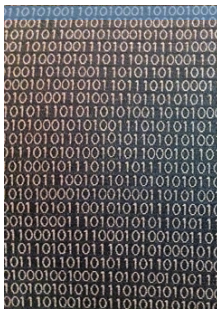


Table scan

- Scan table R and process the query
  - Selection over R
  - Projection of R without duplicate elimination
- I/O's: $B(R)$
  - Trick for selection: stop early if it is a lookup by key
- Memory requirement: 2
- Not counting the cost of writing the result out
  - Same for any algorithm!
  - Maybe not needed—results may be pipelined into another operator

Nested-loop join

$R \bowtie_p S$

- For each block of R, and for each r in the block:
  For each block of S, and for each s in the block:
  Output rs if p evaluates to true over r and s
  - R is called the outer table; S is called the inner table
  - I/O's: $B(R) + |R| \cdot B(S)$
  - Memory requirement: 3

Improvement: block-based nested-loop join

- For each block of R, for each block of S:
  For each r in the R block, for each s in the S block: …
  - I/O's: $B(R) + B(R) \cdot B(S)$
  - Memory requirement: same as before

More improvements

- Stop early if the key of the inner table is being matched
- Make use of available memory
  - Stuff memory with as much of R as possible, stream S by, and join every S tuple with all R tuples in memory
  - I/O's: $B(R) + \left\lceil \frac{B(R)}{M-2} \right\rceil \cdot B(S)$
    - Or, roughly: $B(R) \cdot B(S)/M$
  - Memory requirement: M (as much as possible)
- Which table would you pick as the outer?

Sorting-based algorithms

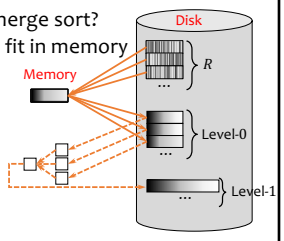
http://en.wikipedia.org/wiki/Mail_sorter#mediaviewer/File:Mail_sorting,1951.jpg

External merge sort

Remember (internal-memory) merge sort?

Problem: sort R, but R does not fit in memory

- Pass 0: read M blocks of R at a time, sort them, and write out a level-0 run
- Pass 1: merge $(M-1)$ level-0 runs at a time, and write out a level-1 run



- Pass 2: merge $(M-1)$ level-1 runs at a time, and write out a level-2 run

…

- Final pass produces one sorted run

Toy example

- 3 memory blocks available; each holds one number
- Input: 1, 7, 4, 5, 2, 8, 3, 6, 9
- Pass 0
  - 1, 7, 4 → 1, 4, 7
  - 5, 2, 8 → 2, 5, 8
  - 9, 6, 3 → 3, 6, 9
- Pass 1
  - 1, 4, 7 + 2, 5, 8 → 1, 2, 4, 5, 7, 8
  - 3, 6, 9
- Pass 2 (final)
  - 1, 2, 4, 5, 7, 8 + 3, 6, 9 → 1, 2, 3, 4, 5, 6, 7, 8, 9

Analysis

- Pass 0: read M blocks of R at a time, sort them, and write out a level-0 run
  - There are $\left\lceil \frac{B(R)}{M} \right\rceil$ level-0 sorted runs
- Pass i: merge $(M-1)$ level-$(i-1)$ runs at a time, and write out a level-i run
  - $(M-1)$ memory blocks for input, 1 to buffer output
  - # of level-i runs = $\left\lceil \frac{\#\text{ of level}-(i-1)\text{ runs}}{M-1} \right\rceil$
- Final pass produces one sorted run

Performance of external merge sort

- Number of passes: $\left\lceil \log_{M-1} \left\lceil \frac{B(R)}{M} \right\rceil \right\rceil + 1$
- I/O's
  - Multiply by $2 \cdot B(R)$: each pass reads the entire relation once and writes it once
  - Subtract $B(R)$ for the final pass
  - Roughly, this is $O(B(R) \times \log_M B(R))$
- Memory requirement: M (as much as possible)

Some tricks for sorting

- Double buffering
  - Allocate an additional block for each run
  - Overlap I/O with processing
  - Trade-off: smaller fan-in (more passes)
- Blocked I/O
  - Instead of reading/writing one disk block at time, read/write a bunch ("cluster")
  - More sequential I/O's
  - Trade-off: larger cluster → smaller fan-in (more passes)

Sort-merge join

$R \bowtie_{R.A=S.B} S$

- Sort R and S by their join attributes; then merge
  r, s = the first tuples in sorted R and S
  Repeat until one of R and S is exhausted:
  If $r.A > s.B$ then s = next tuple in S
  else if $r.A < s.B$ then r = next tuple in R
  else output all matching tuples, and
  r, s = next in R and S
- I/O's: sorting + $2B(R) + 2B(S)$
  - In most cases (e.g., join of key and foreign key)
  - Worst case is $B(R) \cdot B(S)$: everything joins

Example of merge join

R:	S:	$R \bowtie_{R.A=S.B} S$:
$r_1.A = 1$	$s_1.B = 1$	$r_1 s_1$
$r_2.A = 3$	$s_2.B = 2$	$r_2 s_3$
$r_3.A = 3$	$s_3.B = 3$	$r_2 s_4$
$r_4.A = 5$	$s_4.B = 3$	$r_3 s_3$
$r_5.A = 7$	$s_5.B = 8$	$r_3 s_4$
$r_6.A = 7$		$r_7 s_5$
$r_7.A = 8$		

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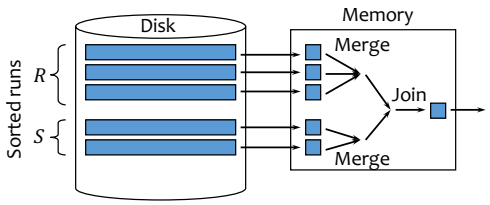
Optimization of SMJ

- Idea: combine join with the (last) merge phase of merge sort
- Sort: produce sorted runs for R and S such that there are fewer than M of them total
- Merge and join: merge the runs of R, merge the runs of S, and merge-join the result streams as they are generated!



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Performance of SMJ

- If SMJ completes in two passes:
  - I/O's: $3 \cdot (B(R) + B(S))$
  - Memory requirement
    - We must have enough memory to accommodate one block from each run: $M > \frac{B(R)}{M} + \frac{B(S)}{M}$
    - $M > \sqrt{B(R) + B(S)}$
- If SMJ cannot complete in two passes:
  - Repeatedly merge to reduce the number of runs as necessary before final merge and join

End of lecture 16

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Other sort-based algorithms

- Union (set), difference, intersection
  - More or less like SMJ
- Duplication elimination
  - External merge sort
    - Eliminate duplicates in sort and merge
- Grouping and aggregation
  - External merge sort, by group-by columns
    - Trick: produce "partial" aggregate values in each run, and combine them during merge
      - This trick doesn't always work though
        - Examples: SUM(DISTINCT …), MEDIAN(…)

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Hashing-based algorithms

http://global.rakuten.com/en/store/citygas/item/041233/

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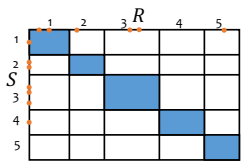
Hash join

$R \bowtie_{R.A=S.B} S$

- Main idea
  - Partition R and S by hashing their join attributes, and then consider corresponding partitions of R and S
  - If $r.A$ and $s.B$ get hashed to different partitions, they don't join



Nested-loop join considers all slots

Hash join considers only those along the diagonal!

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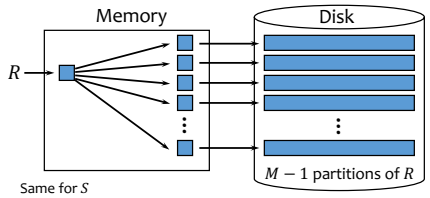
Partitioning phase

- Partition R and S according to the same hash function on their join attributes



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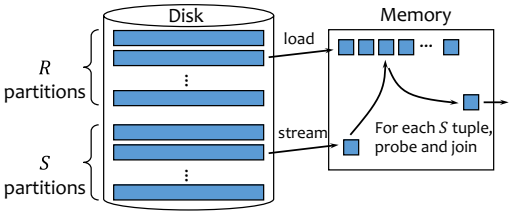
Probing phase

- Read in each partition of R, stream in the corresponding partition of S, join
  - Typically build a hash table for the partition of R
    - Not the same hash function used for partition, of course! **why?**



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Performance of (two-pass) hash join

- If hash join completes in two passes:
  - I/O's: $3 \cdot (B(R) + B(S))$
  - Memory requirement:
    - In the probing phase, we should have enough memory to fit one partition of R: $M - 1 > \frac{B(R)}{M-1}$
    - $M > \sqrt{B(R)} + 1$
    - We can always pick R to be the smaller relation, so:

$$M > \sqrt{\min(B(R), B(S))} + 1$$

End of Lecture 16