CS315: DATABASE SYSTEMS
QUERY PROCESSING

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Mon 12:00-13:15, Tue 9:00-10:15

Query

- Query in a high-level language is first parsed and validated

  select cpi **from** students **where** cpi > 9;

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- Query code is finally generated and processed

Query Cost

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  - Disk accesses
  - CPU time
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    - Write cost can be more since data is verified
- For s seeks and b block transfers, simply estimated as $s \times t_s + b \times t_b$
- Ignores CPU time and buffer management issues

Selection

- LINEAR SEARCH
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- Cost for a relation containing b blocks
  - 1 seek
  - b transfers
- If equality on key, then $b/2$ transfers on average

Selection (contd.)

- BINARY SEARCH
- Applicable for comparison on the ordering attribute
- *Equality*

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- Binary search
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- Cost for locating the first record is
  - $\lceil \log_2 b \rceil$ seeks
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- If one block does not contain all records, add required number of additional transfers to the cost
- *Greater than*

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- *Greater than*
  - Add required number of additional transfers
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  - Scan from beginning till matching record

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  where m is the total number of blocks containing matching records
- For key, $m = 1$
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- *Lesser than* ($A \leq v$) using secondary index
  - $h+1$ seeks and $h+1$ transfers to locate v
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- Negation of comparison is just another comparison

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- When the relation fits in memory, QUICKSORT can be used
- When it does not, external sorting algorithms are used
- EXTERNAL MERGESORT or EXTERNAL SORT-MERGE is the most used

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- Merge $m - 1$ runs ($(m - 1)$-way merge)
  - Read in first block of $m - 1$ runs
  - Output the first record to *buffer* block (m-th block in memory)
  - Continue till buffer block is full
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  - When a block of a particular run is exhausted, read in the next block of the run

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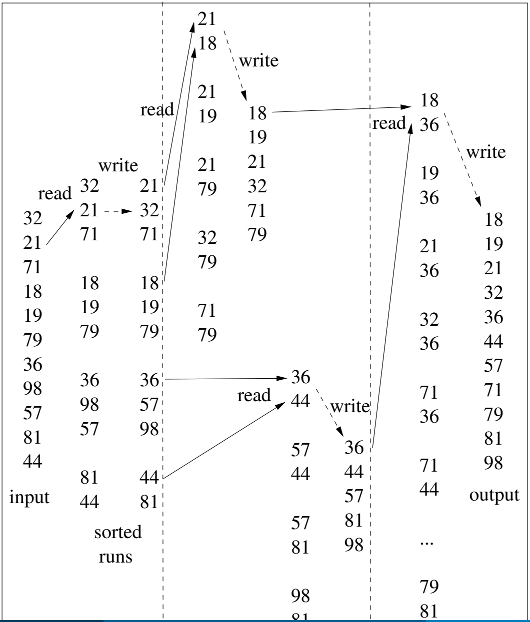
  - When a block of a particular run is exhausted, read in the next block of the run
- Continue with $(m-1)$-way merge till the number of sorted runs is *less than m*
- The last $(m-1)$-way merge sorts the relation

Example


input
32 21 71 18 19 79 36 98 57 81 44
read
32 21 71
18 19 79
36 98 57
81 44
write
21 32 71
18 19 79
36 57 98
44 81
sorted runs
read
21 18
21 19
21 79
32 79
71 79
write
18 19 21 32 71 79
read
36 44
57 44
57 81
98 81
write
36 44 57 81 98
read
18 36
19 36
21 36
32 36
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...
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- Therefore, total number of seeks is $2n + 2br$

Join

- Different join algorithms
  - NESTED-LOOP JOIN
  - BLOCK NESTED-LOOP JOIN
  - INDEXED NESTED-LOOP JOIN
  - MERGE JOIN
  - HASH JOIN
- Choice depends on cost estimates

Nested-Loop Join

- Applicable for any kind of join
- For each record $t_r \in r$ and for each record $t_s \in s$, if $t_r \bowtie t_s$ satisfies the join condition, add it to result
- Outer relation r: outer loop; inner relation s: inner loop

Block Nested-Loop Join

- Applicable for any kind of join
- Block version of the nested-loop algorithm
- For each block $l_r \in r$ and for each block $l_s \in s$, test if every record $t_r \in l_r$ and $t_s \in l_s$ satisfies the join condition; if so, add to the result

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Example

- r: 40000 tuples at 200 per block:

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- r: 40000 tuples at 200 per block: 200 blocks
- s: 25000 tuples at 100 per block:

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- *r*: 40000 tuples at 200 per block: 200 blocks
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- Total is 16 seeks and 2200 transfers

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- Total is 16 seeks and 2200 transfers
- If s made outer, 20 seeks and 2250 transfers

Indexed Nested-Loop Join

- Indexed version of the block nested-loop algorithm
- Applicable when inner relation has an index on the joining attribute
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- Most effective when the join condition is equality

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- Cost for r is $n = \lceil b_r/(m-1) \rceil$ seeks and b_r transfers
- Therefore, total is $n + n_r \times c_s$ seeks and $b_r + n_r \times c_t$ transfers
- If index is available on both relations, like block nested-loop, smaller relation should be outer
- Generally, all levels of B+-tree are held in memory except the last
  - Then, cost of index search falls to $c_s = c_t = 1$

Example

- r: 40000 tuples at 200 per block:

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- s: 25000 tuples at 100 per block:

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- Number of runs is

Example

- r: 40000 tuples at 200 per block: 200 blocks
- s: 25000 tuples at 100 per block: 250 blocks
- Available memory is $m = 25$ for outer and enough for inner
- Outer should be s
- Number of runs is $n = \lceil 250/25 \rceil = 10$

Example

- r: 40000 tuples at 200 per block: 200 blocks
- s: 25000 tuples at 100 per block: 250 blocks
- Available memory is $m = 25$ for outer and enough for inner
- Outer should be s
- Number of runs is $n = \lceil 250/25 \rceil = 10$
- In each run, r requires 1 seek and 1 transfer
- Total is 25000 seeks and 25000 transfers

Example

- r: 40000 tuples at 200 per block: 200 blocks
- s: 25000 tuples at 100 per block: 250 blocks
- Available memory is $m = 25$ for outer and enough for inner
- Outer should be s
- Number of runs is $n = \lceil 250/25 \rceil = 10$
- In each run, r requires 1 seek and 1 transfer
- Total is 25000 seeks and 25000 transfers
- s requires 10 seeks and 250 transfers

Example

- r: 40000 tuples at 200 per block: 200 blocks
- s: 25000 tuples at 100 per block: 250 blocks
- Available memory is $m = 25$ for outer and enough for inner
- Outer should be s
- Number of runs is $n = \lceil 250/25 \rceil = 10$
- In each run, r requires 1 seek and 1 transfer
- Total is 25000 seeks and 25000 transfers
- s requires 10 seeks and 250 transfers
- Total is 25010 seeks and 25250 transfers

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- Relations need to be sorted according to the joining attribute
- Proceed in sorted order on two relations
- If records match, output; otherwise, advance to next record
- Join step is similar to merge step in mergesort
- If relations are not sorted, secondary index on attributes can be used
- HYBRID MERGE JOIN algorithm merges sorted records in one relation with B+-tree leaves of other relation

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- However, blocks may be read in an interleaved manner
- If $m' = m/2$ blocks of memory are available for each relation, cost is $\lceil b_r/m' \rceil + \lceil b_s/m' \rceil$ seeks and $b_r + b_s$ transfers

Example

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Example

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Example

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- Available memory is $m' = 13$ for each
- Number of seeks for r is $\lceil 250/13 \rceil = 20$
- Number of seeks for s is $\lceil 200/13 \rceil = 16$

Example

- r: 40000 tuples at 200 per block: 200 blocks
- s: 25000 tuples at 100 per block: 250 blocks
- Available memory is $m' = 13$ for each
- Number of seeks for r is $\lceil 250/13 \rceil = 20$
- Number of seeks for s is $\lceil 200/13 \rceil = 16$
- Total is

Example

- r: 40000 tuples at 200 per block: 200 blocks
- s: 25000 tuples at 100 per block: 250 blocks
- Available memory is $m' = 13$ for each
- Number of seeks for r is $\lceil 250/13 \rceil = 20$
- Number of seeks for s is $\lceil 200/13 \rceil = 16$
- Total is 36 seeks and 450 transfers

Hash Join

- Applicable only when the join condition is *equality*
- If record t_r and t_s match, they must hash to same value, and thus, only partitions with the same hash value need to be compared
- PARTITION HASH JOIN Hash function h to partition records of *both* relations into n partitions: $h : t \in (r \cup s) \rightarrow \{0, \ldots, n-1\}$

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- Each of the n partitions should fit into memory
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Example

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  - Partitioning produces $120/10 = 12$ blocks that do not fit
  - Thus, 12 blocks are partitioned again to $12/10 = 2$ blocks each
  - This now fits
  - Thus, 2 passes are required
- Available memory is $m = 4$ blocks
  - Partitioning produces $120/4 = 30$ and then $30/4 = 8$ and then $8/4 = 2$ blocks
  - Thus, 3 passes are required

Cost of Hash Join

- Initial reading of a relation i requires b_i transfers
- Total number of blocks after partitioning is at most

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- Writing them back requires $(b_i + n)$ transfers
- Reading them again during matching requires $(b_i + n)$ transfers
- Therefore, total number of transfers is $3(b_r + b_s) + 4n$
- Assume memory buffer of m blocks
- Partitioning requires $\lceil b_i/m \rceil$ seeks for reading and $\lceil (b_i + n)/m \rceil$ seeks for writing
- Reading n partitions during matching requires n seeks per relation
- Therefore, total number of seeks is $\left\lceil \frac{b_r}{m} \right\rceil + \left\lceil \frac{b_s}{m} \right\rceil + \left\lceil \frac{b_r+n}{m} \right\rceil + \left\lceil \frac{b_s+n}{m} \right\rceil + 2n$

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Cost of Recursive Partitioning

- Number of passes in recursive partitioning is $p = \lfloor \log_m b_s \rfloor$
- During partitioning, total number of block transfers is $2p(b_r + n + b_s + n)$
- Number of seeks during partitioning is $2p(\lceil (b_r + n)/m \rceil + \lceil (b_s + n)/m \rceil)$

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- Number of passes in recursive partitioning is $p = \lfloor \log_m b_s \rfloor$
- During partitioning, total number of block transfers is $2p(b_r + n + b_s + n)$
- Number of seeks during partitioning is $2p(\lceil (b_r + n)/m \rceil + \lceil (b_s + n)/m \rceil)$
- Matching requires $(b_r + n + b_s + n)$ transfers and $n + n$ seeks

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- r: 40000 tuples at 200 per block:

Example

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- s: 25000 tuples at 100 per block:

Example

- r: 40000 tuples at 200 per block: 200 blocks
- s: 25000 tuples at 100 per block: 250 blocks

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- Available memory is 15 for partitions and $m = 10$ for buffering

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Example

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- Available memory is 15 for partitions and $m = 10$ for buffering
- Number of partitions is $n = 15$
- Size of each partition of s is $\lceil 200/15 \rceil = 14$
- Size of each partition of r is

Example

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- Available memory is 15 for partitions and $m = 10$ for buffering
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- Size of each partition of s is $\lceil 200/15 \rceil = 14$
- Size of each partition of r is $\lceil 250/15 \rceil = 17$

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- Build input should be

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- Build input should be s
- Partitioning s requires $200 + (200 + 15) = 415$ transfers
- Number of seeks for s is $(200/10) + (215/10) = 42$

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- Build input should be s
- Partitioning s requires $200 + (200 + 15) = 415$ transfers
- Number of seeks for s is $(200/10) + (215/10) = 42$
- Partitioning r requires 1 pass since it is probe input
- Number of transfers for r is $250 + (250 + 15) = 515$
- Number of seeks for r is $(250/10) + (265/10) = 52$

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- r: 40000 tuples at 200 per block: 200 blocks
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- Partitioning s requires $200 + (200 + 15) = 415$ transfers
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- s: 25000 tuples at 100 per block: 250 blocks
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- Size of each partition of s is $\lceil 200/15 \rceil = 14$
- Size of each partition of r is $\lceil 250/15 \rceil = 17$
- Build input should be s
- Partitioning s requires $200 + (200 + 15) = 415$ transfers
- Number of seeks for s is $(200/10) + (215/10) = 42$
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- Total is 124 seeks and 1410 transfers

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  - If $r ⟗ s$, use both techniques
- Set operations
  - If relations are sorted, scan in order
  - Build hash index on one relation; test records from other relation
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  - Use hashing to organize into groups; then apply aggregation
- Duplicate detection and elimination
  - Use hashing or sorting