CS315: Principles of Database Systems
Query Processing

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Query

- When a database query in a high-level language comes, first it is parsed and validated
- Next, a query planner outputs an equivalent expression in relational algebra
  - $\Pi_{bal}(\sigma_{bal<1000}(account))$
  - A query order tree is created
- Then, all equivalent evaluation plans are generated
  - $\Pi_{bal}(\sigma_{bal<1000}(account))$
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- A query optimizer decides on the best evaluation plan among all equivalent plans
  - Uses statistics of data
  - Actual algorithms also influence the choice
- Query code is finally generated and processed

Query cost

- Factors that affect the runtime of the query
  - Disk accesses
  - CPU time
  - Network communication
- Disk access is generally the most dominant factor
- It can be estimated as a total of
  - Number of seeks times average seek cost
  - Number of blocks read times average block read cost
  - Number of blocks written times average block write cost
    - Write cost is 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

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- *Always* applicable

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- Scan all file blocks and test each record

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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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- If one block does not contain all records, add required number of additional transfers to the cost
- *Greater than*

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- If one block does not contain all records, add required number of additional transfers to the cost
- *Greater than*
  - Add required number of additional transfers
- *Lesser than*
  - Scan from beginning till matching record

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- For key, $m = 1$
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- *Equality* using secondary index
  - $h + n$ seeks, where h is the height of the index tree
  - $h + n$ transfers

  where n is the total number of matching records, each in a separate block
- For key, $n = 1$

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- *Greater than* ($A \geq v$) using secondary index
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- Use sibling leaf pointers to locate all other matching records resulting in n more seeks and n more transfers
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- *Negation* of equality

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  - Index selects leaf pointers for which corresponding records will not be retrieved
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  - If some attribute does not have an index, then linear scan
- Negation of conjunction
- *Negation* of equality
  - Linear scan
  - Index selects leaf pointers for which corresponding records will not be retrieved
- Negation of comparison is just another comparison

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- Display purposes
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- Tuples need to be *physically* sorted
- 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
  - Write buffer block to disk
  - When a block of a particular run is exhausted, read in the next block of the run

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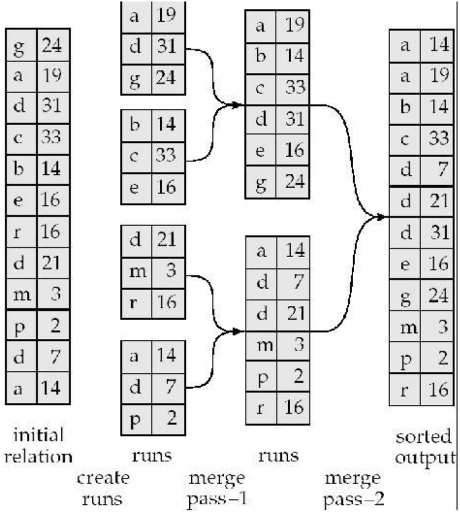
  - When a block of a particular run is exhausted, read in the next block of the run
- Continue with $(M - 1)$-way merge till the number of sorted runs is *less than M*
- The last $(M - 1)$-way merge sorts the relation

Example


g 24
a 19
d 31
c 33
b 14
e 16
r 16
d 21
m 3
p 2
d 7
a 14
initial relation
a 19
d 31
g 24
b 14
c 33
e 16
d 21
m 3
r 16
a 14
d 7
p 2
runs
create runs
a 19
b 14
c 33
d 31
e 16
g 24
a 14
d 7
d 21
m 3
p 2
r 16
runs
merge pass–1
a 14
a 19
b 14
c 33
d 7
d 21
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e 16
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sorted output
merge pass–2

Cost of external mergesort

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- Therefore, total number of merge passes required is $\lceil \log_{M-1} \lceil b/M \rceil \rceil$
- During each of these passes and the first pass, all blocks are read and written
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- Hence, total number of block transfers is

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- During each of these passes and the first pass, all blocks are read and written
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- Hence, total number of block transfers is $2b(\lceil \log_{M-1} \lceil b/M \rceil \rceil + 1)$

Cost of external mergesort (contd.)

- Initial pass to created sorted runs reads M blocks at a time
- Therefore, number of seeks is $2\lceil b/M \rceil$ for reading and writing
- During the merge passes, blocks from different runs may not be read consecutively
- Consequently, each read and write for another run moves the disk head away, thereby requiring a seek every time
- Hence, number of seeks for these passes is $2b\lceil \log_{M-1} \lceil b/M \rceil \rceil$
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- Hence, number of seeks for these passes is $2b\lceil \log_{M-1}\lceil b/M \rceil \rceil$
- Therefore, total number of seeks is $2\lceil b/M \rceil + 2b\lceil \log_{M-1}\lceil b/M \rceil \rceil$

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

Cost of nested-loop join

- There are n_i records in b_i blocks for relation i
- Assumption is that only two blocks fit in memory
- Block transfers
  - b_s transfers every time a record t_r is read
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  - Then, $b_r + n_r$ seeks
- Smaller relation should be

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Cost of nested-loop join (contd.)

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Cost of nested-loop join (contd.)

- If both relations fit in memory
  - $b_r + b_s$ transfers and 2 seeks
- If only one relation fits in memory

Cost of nested-loop join (contd.)

- If both relations fit in memory
  - $b_r + b_s$ transfers and 2 seeks
- If only one relation fits in memory
  - Smaller relation is made inner and read first
  - Same cost: $b_r + b_s$ transfers and 2 seeks

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

Cost of block nested-loop join

- Assumption is that only two blocks fit in memory
- Block transfers
  - b_s transfers every time a block l_r is read
  - b_r transfers for blocks in r
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  - Therefore, total is $b_r + b_r$ seeks
- Smaller relation should be outer (like nested-loop join)

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  - $b_r + b_s$ transfers and 2 seeks
- If only one relation fits in memory
  - Smaller relation is made inner and read first
  - Same cost: $b_r + b_s$ transfers and 2 seeks
- No difference between nested-loop join and block nested loop-join

Indexed nested-loop join

- Applicable when inner relation has an index on the joining attribute
- Indexed version of the block nested-loop algorithm
- For each block $l_r \in r$ and for each record $t_r \in l_r$, use index on s to locate records $t_s \in s$ that satisfies the join condition
- Most effective when the join condition is equality

Cost of indexed nested-loop join

- Assumption is that only two blocks fit in memory
- Size of index for relation i is c_i blocks
- Cost is c_s seeks and transfers for selection on index on s for every record in r
- b_r seeks and transfers for blocks in r
- Therefore, total is $b_r + n_r \times c_s$ seeks and $b_r + n_r \times c_s$ transfers

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Merge join or Sort merge join

- Applicable only when the join condition is *equality*
- If necessary, sort the relations 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

Cost of merge join or sort merge join

- Each record is read only once
- Consequently, each block is read only once
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- 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

Hash join

- Applicable only when the join condition is *equality*
- Idea: 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
- Hash function to partition records of *both* relations: PARTITION HASH JOIN
- Algorithm
  - Choose $h_{r,s} : record_{r,s} \rightarrow \{0, \ldots, n-1\}$
  - Output each record of r and s to partition into H_{r_i} and H_{s_i} where $h(t_r) = i$ and $h(t_s) = i$
  - Read partition H_{s_i} and build an in-memory hash index
  - For every record $t_{r_i} \in H_{r_i}$, probe hash index of H_{s_i} to locate matching records
- s is called build input
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- Each partition of build relation must be stored in memory
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- Each partition is then read and re-partitioned
- This is continued till each partition fits into memory

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- Recursive partitioning is employed
- Initially, n_s is chosen to less than or equal to M
- Each partition is then read and re-partitioned
- This is continued till each partition fits into memory
- Hybrid hash join: Retain the first partition of build relation in memory

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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- Therefore, total number of transfers is $3(b_r + b_s) + 4n$

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- Therefore, total number of transfers is $3(b_r + b_s) + 4n$
- Reading relation i requires $\lceil b_i / b_b \rceil$ seeks where b_b is the input buffer size
- Writing relation i requires $\lceil (b_i + n) / b_b \rceil$ seeks where b_b is the output buffer size
- Reading n partitions of relation i requires n seeks
- Therefore, total number of seeks is $2\lceil (b_r + b_s + n) / b_b \rceil + 2n$

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  - If r is the build relation, keep track of which records in hash index have been used; output all non-used records
  - If $r ⟗ s$, use both techniques