Lecture 11:
Course overview

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The lectures at a glance

- SR: Tree Indexes.
- RP: Hash Indexes, Index Tuning
- SR: Data storage, external sorting, lower bound.
- SR: Implementation of relational operations
- RP: Query Optimization, Query tuning
- RP: Concurrency control
- SR: Spatial databases
- SR: Temporal databases
- SR: Text indexing
- RP: Decision support, OLAP
- RP: ITU research in databases
- Invited lecture

B-trees

- Indexing is a key database technology.
- Conventional indexes (e.g., ISAM) work well when there are few updates.
- B-trees (and variants) are more flexible
  - The choice of most DBMSs
    - Range queries.
    - Deterministic/reliable.
  - Theoretically “optimal”: $O(\log_B N)$ I/Os per operation.
  - Buffering can be used to achieve fast updates, at the cost of increasing the height of the tree.

Hash indexes

- External memory hash tables generalize hash tables as you know them. We looked at different schemes:
  - Static hashing
  - Extendible hashing
  - Linear hashing
  - Newer techniques:
    Buffering, two-choice hashing
- Faster than B-trees in some situations.
- Need to understand to choose!

Rule of thumb 1:
Index the most selective attribute

- Argument: Using an index on a selective attribute will help reducing the amount of data to consider.
- Example:

```
SELECT count(*) FROM R
WHERE a>'UXS' AND b BETWEEN 100 AND 200
```

- Counterexamples:
  - Full table scan may be faster than an index
  - It may not be possible/best to apply an index.

Rule of thumb 2:
Cluster the most important index of a relation

- Argument:
  - Range and multipoint queries are faster.
  - Usually sparse, uses less space.
- Counterexamples:
  - May be slower on queries ”covered” by a dense index.
  - If there are many updates, the cost of maintaining the clustering may be high.
  - Clustering does not help for point queries.
  - Can cluster according to several attributes by duplicating the relation!

Rule of thumb 3:
Prefer a hash index over a B-tree if point queries are more important than range queries

- Argument:
  - Hash index uses fewer I/Os per operation than a B-tree.
  - Joins, especially, can create many point queries.
- Counterexamples:
  - If a real-time guarantee is needed, hashing can be a bad choice.
  - Might be best to have **both** a B-tree and a hash index.

Rule of thumb 4:
Balance the increased cost of updating with the decreased cost of searching

- Argument: The savings provided by an index should be bigger than the cost.
- Counterexample:
  - If updates come when the system has excess capacity, we might be willing to work harder to have indexes at the peaks.
- If buffered B-trees are used, the cost per update of maintaining an index may be rather low. Especially if binary (!) trees are used.

External sorting

- External sorting is important; DBMS may dedicate part of buffer pool for sorting!
- External merge sort minimizes disk I/O cost:
  - Pass 0: Produces sorted ***runs*** of size ***B*** (# buffer pages). Later passes: ***merge*** runs.
  - # of runs merged at a time depends on ***B*** and ***block size***.
  - In practice, # of runs rarely more than 2 or 3.

Buffer management

- Disks provide cheap, non-volatile storage.
  - Random access, but cost depends on location of page on disk; important to arrange data sequentially to minimize seek and rotation delays.
- Buffer manager brings pages into RAM.
  - Page stays in RAM until released by requestor.
  - Written to disk when frame chosen for replacement (which is sometime after requestor releases the page).
  - Choice of frame to replace based on replacement policy.
  - Tries to pre-fetch several pages at a time.

Relational algebra operations

- The building blocks in DBMS query evaluation are algorithms that implement relational algebra operations.
- May be based on:
  - sorting,
  - hashing, or
  - using existing indexes
- The DBMS knows the characteristics of each approach, and attempts to use the best one in a given setting.

Query optimizer

- A virtue of relational DBMSs: queries are composed of a few basic operators; the implementation of these operators can be carefully tuned (and it is important to do this!).
- Many alternative implementation techniques for each operator; no universally superior technique for most operators.
- Must consider available alternatives for each operation in a query and choose best one based on system statistics, etc.

Database tuning

- The database tuner should
  - Be aware of the range of possibilities the DBMS has in evaluating a query.
  - Consider the possibilities for providing more efficient access paths to be chosen by the optimizer.
  - Know ways of circumventing shortcomings of query optimizers.

Query tuning

Key techniques:

- Denormalization
- Vertical/horizontal partitioning
- Aggregate maintenance
- Query rewriting (examples from SB p. 143-158, 195)
- Sometimes: Optimizer hints

Concurrency control

- DBMSs are distinguished by their design of concurrency control system
  - Pessimistic (locking based) vs optimistic
  - Granularity
- To handle concurrency control problems, an understanding of the system in use is often required.
- SQL offers several *isolation levels*, which can be explained in terms of locking implementations.

Lock tuning

- SB offers this advice on locking:
  - Use special facilities for long reads.
  - Eliminate locking when unnecessary.
  - Use the weakest isolation guarantee the application allows.
  - Change the database schema only during ”quiet periods” (catalog bottleneck).
  - Think about partitioning.
  - Select the appropriate granularity of locking.
  - If possible, chop transactions into smaller pieces.

Spatial data management

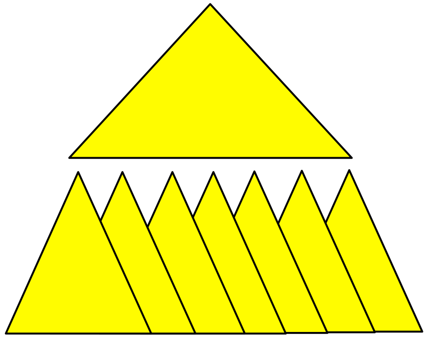
- Spatial data management has many applications, including GIS, CAD/CAM, multimedia indexing.
  - Point and region data
  - Overlap/containment and nearest-neighbor queries
- Many approaches to indexing spatial data
  - R-tree approach is widely used in GIS systems
  - Other approaches include Grid Files, Quad trees, and techniques based on “space-filling” curves.
  - For high-dimensional datasets, unless data has good “contrast”, nearest-neighbor may not be well-separated

Temporal databases

- It is increasingly feasible to never delete data (i.e., keep old versions)
- $\Rightarrow$ Demand for capability to query old data.
- Need indexing capability also for old data!
- There exists a surprisingly efficient way of doing this.

Persistent B-tree

- Persistent B-tree
  - Update current version
  - Query all versions



- Efficient implementation obtained using existence intervals
  - Standard technique

$\Downarrow$

- During *N* operations
  - $O(N/B)$ space
  - $O(\log_B N)$ update
  - $O(\log_B N + T/B)$ query

Text indexing

- Many database applications contain lots of text
- ... but the relational model is not well suited to represent the structure of text.
- Result: Text datatype that may contain long strings that have to be handled in queries.
- We look at two topics:
  - B-trees optimized for strings
  - Full-text indexing

String B-tree

String B-tree performance: [Ferragina-Gross `95]

- Search(P) in $O(p/B + \log_B N + occ/B)$ I/Os
- Update(S) takes $O(s \log_B N)$ I/Os
- Space is $O(N/B)$ disk pages

"Search time" is independent of the length of the strings.

Text indexes

- Indexed string matching problem
  - Word-based
  - Full-text
- Internal memory data structures
  - Suffix array
  - Suffix tree
- External memory data structures
  - Patricia trie and Pat tree
  - Short Pat array
  - String B-tree

Decision support (OLAP)

- OLAP systems are specialized databases for decision support applications.
- Idea: Read-only (or write-rarely), optimized for fast answers to queries.
- Special indexing techniques for read-only data are used (bitmap indexing).
- Precomputation of aggregates important for performance.
- Sampling-based techniques can give early join results and ”on-line aggregation”.

Thesis/project topics

- Five DB related suggestions on the web (www.itu.dk/cla/tiki-index.php?page=ProjectProposals):
  - Computing joins in databases
  - Buffered indexes
  - Filtering - with applications in databases (distr.)
  - Adaptive sorting & adaptive join processing
  - Using multiple disks efficiently
- However: No supervision available at ITU in fall (parental leave).
- I will be happy to help students find an external supervisor.