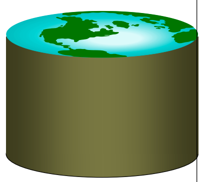
File Organizations and Indexing

Lecture 4
R&G Chapter 8

"If you don't find it in the index, look very carefully through the entire catalogue."

-- Sears, Roebuck, and Co., Consumer's Guide, 1897



Review: Memory, Disks, & Files

- **Everything won't fit in RAM (usually)**
- **Hierarchy of storage, RAM, disk, tape**
- **"Block" - unit of storage in RAM, on disk**
- **Allocate space on disk for fast access**
- **Buffer pool management**
  - Frames in RAM to hold blocks
  - Policy to move blocks between RAM & disk
- **Storing records within blocks**

Today: File Storage

- **How to keep blocks of records on disk**
- ***but* must support operations:**
  - scan all records
  - search for a record id "RID"
  - insert new records
  - delete old records

Alternative File Organizations

Many alternatives exist, *each good for some situations, and not so good in others:*

- Heap files: Suitable when typical access is a file scan retrieving all records.
- Sorted Files: Best for retrieval in *search key* order, or only a `range' of records is needed.
- Clustered Files (with Indexes): Coming soon…

Cost Model for Analysis

We ignore CPU costs, for simplicity:

- **B:** The number of data blocks
- **R:** Number of records per block
- **D:** (Average) time to read or write disk block
- Measuring number of block I/O's ignores gains of pre-fetching and sequential access; thus, even I/O cost is only loosely approximated.
- Average-case analysis; based on several simplistic assumptions.

☛ *Good enough to show the overall trends!*

Some Assumptions in the Analysis

- **Single record insert and delete.**
- **Equality selection - exactly one match (what if more or less???).**
- **Heap Files:**
  - Insert always appends to end of file.
- **Sorted Files:**
  - Files compacted after deletions.
  - Selections on search key.

Cost of Operations

B: The number of data pages
R: Number of records per page
D: (Average) time to read or write disk page

	Heap File	Sorted File	Clustered File
Scan all records			
Equality Search			
Range Search			
Insert			
Delete			

Cost of Operations

B: The number of data pages
R: Number of records per page
D: (Average) time to read or write disk page

	Heap File	Sorted File	Clustered File
Scan all records	BD	BD	
Equality Search			
Range Search			
Insert			
Delete			

Cost of Operations

B: The number of data pages
R: Number of records per page
D: (Average) time to read or write disk page

	Heap File	Sorted File	Clustered File
Scan all records	BD	BD	
Equality Search	0.5 BD	$(\log_2 B) * D$	
Range Search			
Insert			
Delete			

Cost of Operations

B: The number of data pages
R: Number of records per page
D: (Average) time to read or write disk page

	Heap File	Sorted File	Clustered File
Scan all records	BD	BD	
Equality Search	0.5 BD	$(\log_2 B) * D$	
Range Search	BD	$[(\log_2 B) +$ #match pg]*D	
Insert			
Delete			

Cost of Operations

B: The number of data pages
R: Number of records per page
D: (Average) time to read or write disk page

	Heap File	Sorted File	Clustered File
Scan all records	BD	BD	
Equality Search	0.5 BD	$(\log_2 B) * D$	
Range Search	BD	$[(\log_2 B) +$ #match pg]*D	
Insert	2D	$((\log_2 B)+B)D$ *(because R,W 0.5)*	
Delete			

Cost of

B: The number of data pages
R: Number of records per page
D: (Average) time to read or write disk page

	Heap File	Sorted File	Clustered File
Scan all records	BD	BD	
Equality Search	0.5 BD	$(\log_2 B) * D$	
Range Search	BD	$[(\log_2 B) +$ #match pg]*D	
Insert	2D	$((\log_2 B)+B)D$	
Delete	0.5BD + D	$((\log_2 B)+B)D$ *(because R,W 0.5)*	

Indexes

- **Sometimes, we want to retrieve records by specifying the *values in one or more fields*, e.g.,**
  - Find all students in the "CS" department
  - Find all students with a gpa > 3
- **An *index* on a file is a disk-based data structure that speeds up selections on the *search key fields* for the index.**
  - Any subset of the fields of a relation can be the search key for an index on the relation.
  - *Search key* is not the same as *key* (e.g. doesn't have to be unique ID).
- **An index contains a collection of *data entries*, and supports efficient retrieval of all records with a given search key value** k**.**

First Question to Ask About Indexes

- **What kinds of selections do they support?**
  - Selections of form field <op> constant
  - Equality selections (op is =)
  - Range selections (op is one of <, >, <=, >=, BETWEEN)
  - More exotic selections:
    - 2-dimensional ranges ("east of Berkeley and west of Truckee and North of Fresno and South of Eureka")
      - Or n-dimensional
    - 2-dimensional distances ("within 2 miles of Soda Hall")
      - Or n-dimensional
    - Ranking queries ("10 restaurants closest to Berkeley")
    - Regular expression matches, genome string matches, etc.
    - One common n-dimensional index: R-tree
      - Supported in Oracle and Informix
      - See http://gist.cs.berkeley.edu for research on this topic

Index Classification

- **What selections does it support**
- **Representation of data entries in index**
  - i.e., what kind of info is the index actually storing?
  - 3 alternatives here
- **Clustered vs. Unclustered Indexes**
- **Single Key vs. Composite Indexes**
- **Tree-based, hash-based, other**

Alternatives for Data Entry **k*** in Index

- **Three alternatives:**
  - Actual data record (with key value **k**)
  - <**k**, rid of matching data record>
  - <**k**, list of rids of matching data records>
- **Choice is orthogonal to the indexing technique.**
  - Examples of indexing techniques: B+ trees, hash-based structures, R trees, …
  - Typically, index contains auxiliary information that directs searches to the desired data entries
- **Can have multiple (different) indexes per file.**
  - E.g. file sorted by *age*, with a hash index on *salary* and a B+tree index on *name*.

Alternatives for Data Entries (Contd.)

- **Alternative 1:**
  Actual data record (with key value k**)**
  - If this is used, index structure is a file organization for data records (like Heap files or sorted files).
  - At most one index on a given collection of data records can use Alternative 1.
  - This alternative saves pointer lookups but can be expensive to maintain with insertions and deletions.

Alternatives for Data Entries (Contd.)

Alternative 2
<k**, rid of matching data record>**
and Alternative 3
<k**, list of rids of matching data records>**

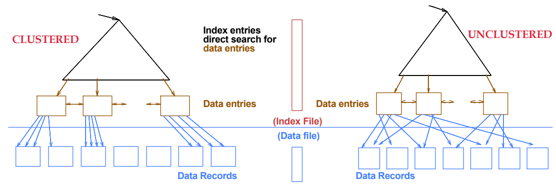
- Easier to maintain than Alt 1.
- If more than one index is required on a given file, at most one index can use Alternative 1; rest must use Alternatives 2 or 3.
- Alternative 3 more compact than Alternative 2, but leads to *variable sized data* entries even if search keys are of fixed length.
- Even worse, for large rid lists the data entry would have to span multiple blocks!

Index Classification

- ***Clustered* vs. *unclustered*: If order of data records is the same as, or `close to', order of index data entries, then called *clustered index*.**
  - A file can be clustered on at most one search key.
  - Cost of retrieving data records through index varies *greatly* based on whether index is clustered or not!
  - Alternative 1 implies clustered, *but not vice-versa*.

Clustered vs. Unclustered Index

- **Suppose that Alternative (2) is used for data entries, and that the data records are stored in a Heap file.**
  - To build clustered index, first sort the Heap file (with some free space on each block for future inserts).
  - Overflow blocks may be needed for inserts. (Thus, order of data recs is `close to', but not identical to, the sort order.)



Unclustered vs. Clustered Indexes

- **What are the tradeoffs????**
- **Clustered Pros**
  - Efficient for range searches
  - May be able to do some types of compression
  - Possible locality benefits (related data?)
  - ???
- **Clustered Cons**
  - Expensive to maintain (on the fly or sloppy with reorganization)

Cost of

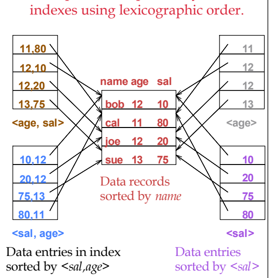
B: The number of data pages
R: Number of records per page
D: (Average) time to read or write disk page

	Heap File	Sorted File	Clustered File
Scan all records	BD	BD	1.5 BD
Equality Search	0.5 BD	$(\log_2 B) * D$	$(\log_F 1.5B) * D$
Range Search	BD	$[(\log_2 B) +$ #match pg$]*D$	$[(\log_F 1.5B) +$ #match pg$]*D$
Insert	2D	$((\log_2 B)+B)D$	$((\log_F 1.5B)+1) * D$
Delete	0.5BD + D	$((\log_2 B)+B)D$ *(because R,W 0.5)*	$((\log_F 1.5B)+1) * D$

Composite Search Keys

- **Search on a combination of fields.**
  - Equality query: Every field value is equal to a constant value. E.g. wrt <age,sal> index:
    - age=20 and sal =75
  - Range query: Some field value is not a constant. E.g.:
    - age > 20; or age=20 and sal > 10
- **Data entries in index sorted by search key to support range queries.**
  - Lexicographic order
  - Like the dictionary, but on fields, not letters!

Examples of composite key indexes using lexicographic order.



Summary

- **Many alternative file organizations exist, each appropriate in some situation.**
- **If selection queries are frequent, sorting the file or building an *index* is important.**
  - Hash-based indexes only good for equality search.
  - Sorted files and tree-based indexes best for range search; also good for equality search. (Files rarely kept sorted in practice; B+ tree index is better.)
- **Index is a collection of data entries plus a way to quickly find entries with given key values.**

Summary (Contd.)

- **Data entries in index can be actual data records, <key, rid> pairs, or <key, rid-list> pairs.**
  - Choice orthogonal to *indexing structure (i.e. tree, hash, etc.)*.
- **Usually have several indexes on a given file of data records, each with a different search key.**
- **Indexes can be classified as**
  - clustered vs. unclustered
  - dense vs. sparse
- **Differences have important consequences for utility/performance.**