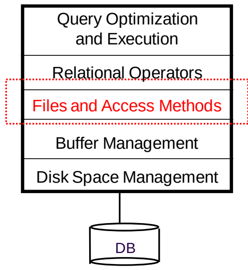
File Organizations and Indexing

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

Context



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 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	$((\log_2 B)+B)D$	
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 Breakdown

- What selections does the index 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>

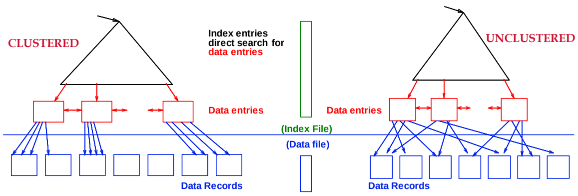
- Easier to maintain than Alt 1.
- If more than one index is required on a given file, at most one index can use Alternative 1; rest must use Alternatives 2 or 3.
- Alternative 3 more compact than Alternative 2, but leads to *variable sized data entries* even if search keys are of fixed length.
- Even 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 Operations

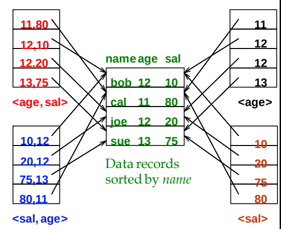
B: The number of data pages
R: Number of records per page
D: (Average) time to read or write disk page

	Heap File	Sorted File	Clustered File
Scan all records	BD	BD	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.



Data records sorted by *name*

Data entries in index sorted by <*sal,age*>

Data entries sorted by <*sal*>

Summary

- File Layer manages access to records in pages.
  - Record and page formats depend on fixed vs. variable-length.
  - Free space management an important issue.
  - Slotted page format supports variable length records and allows records to move on page.
- 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*
- Differences have important consequences for utility/performance.
- Catalog relations store information about relations, indexes and views.