File Organizations and Indexing

Chapter 8

"How index-learning turns no student pale
Yet holds the eel of science by the tail."
-- Alexander Pope (1688-1744)

Alternative File Organizations

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

- Heap files: Suitable when typical access is a file scan retrieving all records.
- Sorted Files: Best if records must be retrieved in some order, or only a `range' of records is needed.
- Hashed Files: Good for equality selections.
  - File is a collection of *buckets*. Bucket = *primary* page plus zero or more *overflow* pages.
  - *Hashing function* **h**: **h**(*r*) = bucket in which record *r* belongs. **h** looks at only some of the fields of *r*, called the *search fields.*

Cost Model for Our Analysis

We ignore CPU costs, for simplicity:

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

☛ *Good enough to show the overall trends!*

Assumptions in Our Analysis

- Single record insert and delete.
- Heap Files:
  - Equality selection on key; exactly one match.
  - Insert always at end of file.
- Sorted Files:
  - Files compacted after deletions.
  - Selections on sort field(s).
- Hashed Files:
  - No overflow buckets, 80% page occupancy.

Cost of Operations

	Heap File	Sorted File	Hashed File
Scan all recs			
Equality Search			
Range Search			
Insert			
Delete			

☛ *Several assumptions underlie these (rough) estimates!*

Cost of Operations

	Heap File	Sorted File	Hashed File
Scan all recs	**BD**	**BD**	**1.25 BD**
Equality Search	**0.5 BD**	**D $\log_2 B$**	**D**
Range Search	**BD**	**D ($\log_2 B$ + # of pages with matches)**	**1.25 BD**
Insert	**2D**	**Search + BD**	**2D**
Delete	**Search + D**	**Search + BD**	**2D**

☛ *Several assumptions underlie these (rough) estimates!*

Indexes

- An *index* on a file 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* (minimal set of fields that uniquely identify a record in a relation).
- An index contains a collection of *data entries*, and supports efficient retrieval of all data entries **k*** with a given key value **k**.

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

- Three alternatives:
  ① Data record with key value **k**
  ② **<k**, rid of data record with search key value **k>**
  ③ **<k**, list of rids of data records with search key **k>**
- Choice of alternative for data entries is orthogonal to the indexing technique used to locate data entries with a given key value **k**.
  - Examples of indexing techniques: B+ trees, hash-based structures
  - Typically, index contains auxiliary information that directs searches to the desired data entries

Alternatives for Data Entries (Contd.)

- Alternative 1:
  - 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. (Otherwise, data records duplicated, leading to redundant storage and potential inconsistency.)
  - If data records very large, # of pages containing data entries is high. Implies size of auxiliary information in the index is also large, typically.

Alternatives for Data Entries (Contd.)

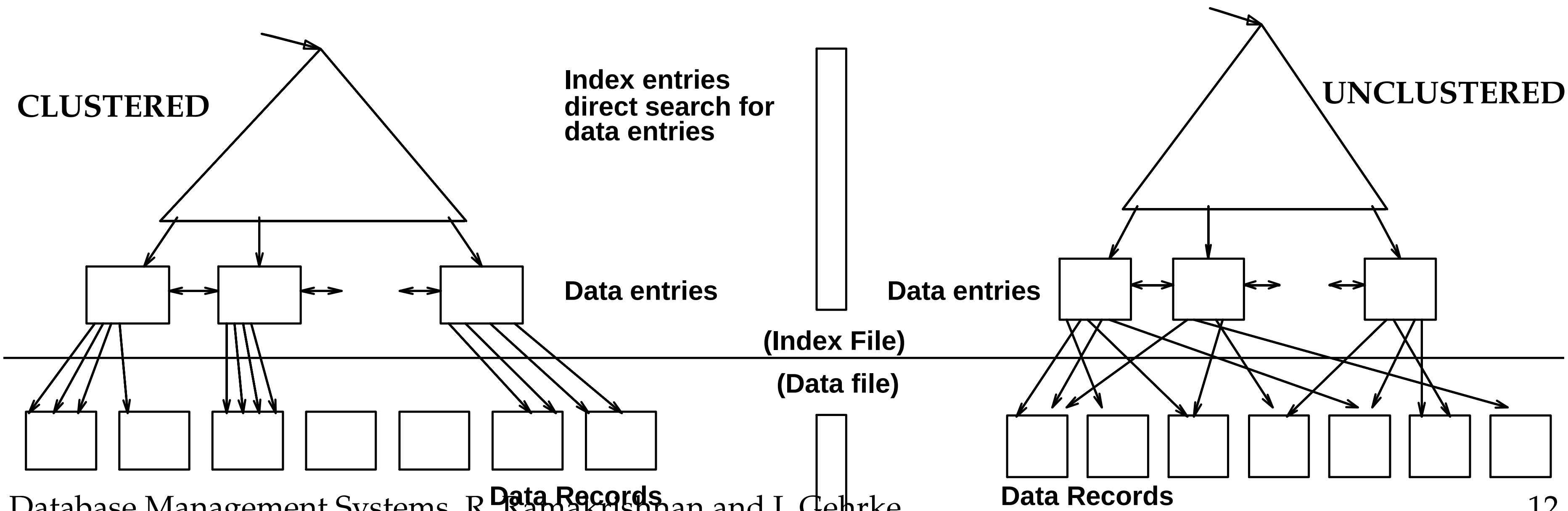
- Alternatives 2 and 3:
  - Data entries typically much smaller than data records. So, better than Alternative 1 with large data records, especially if search keys are small. (Portion of index structure used to direct search is much smaller than with Alternative 1.)
  - If more than one index is required 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.

Index Classification

- *Primary* vs. *secondary*: If search key contains primary key, then called primary index.
  - *Unique* index: Search key contains a candidate key.
- *Clustered* vs. *unclustered*: If order of data records is the same as, or `close to', order of data entries, then called clustered index.
  - Alternative 1 implies clustered, but not vice-versa.
  - 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!

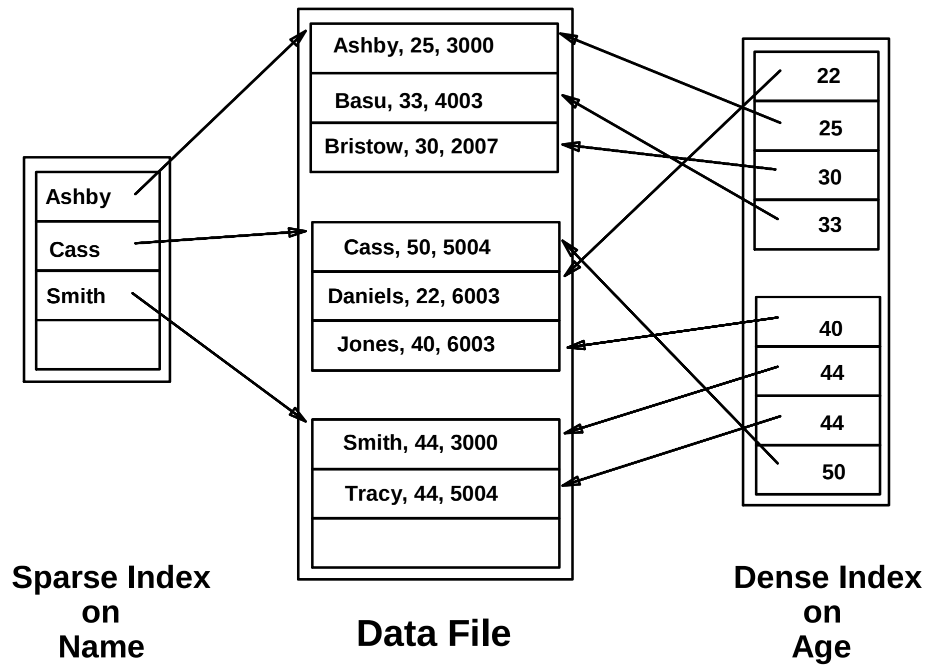
Clustered vs. Unclustered Index

- 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 page for future inserts).
  - Overflow pages may be needed for inserts. (Thus, order of data recs is `close to', but not identical to, the sort order.)



Index Classification (Contd.)

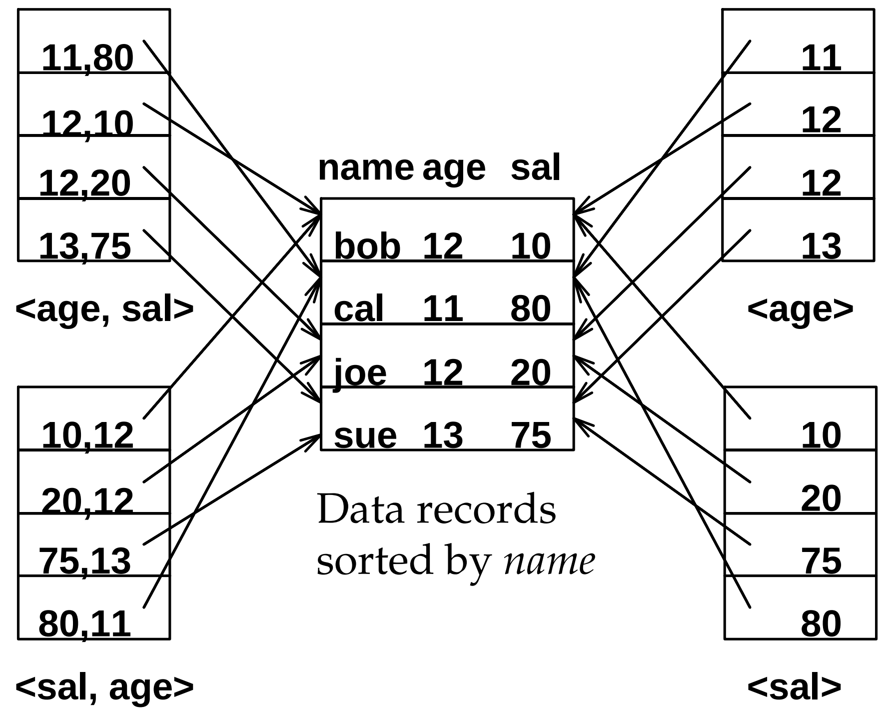
- *Dense* vs. *Sparse*: If there is at least one data entry per search key value (in some data record), then dense.
  - Alternative 1 always leads to dense index.
  - Every sparse index is clustered!
  - Sparse indexes are smaller; however, some useful optimizations are based on dense indexes.



Index Classification (Contd.)

- *Composite Search Keys*: Search on a combination of fields.
  - Equality query: Every field value is equal to a constant value. E.g. wrt <sal,age> 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, or
  - Spatial order.

Examples of composite key indexes using lexicographic order.



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

Data entries sorted by <*sal*>

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 can be actual data records, <key, rid> pairs, or <key, rid-list> pairs.
  - Choice orthogonal to *indexing technique* used to locate data entries with a given key value.
- Can have several indexes on a given file of data records, each with a different search key.
- Indexes can be classified as clustered vs. unclustered, primary vs. secondary, and dense vs. sparse. Differences have important consequences for utility/performance.