File Organisation and Indexing

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Introduction to Databases

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Data Storage Principles

- Database relations are implemented as **files** of **records**.
- This is still an *abstraction:* the real storage medium are **disks**, which consist of **pages** (ca. 0.5–5 kbytes)
- Pages are *read* from disk and *written* to disk: high cost operations!
- Mapping: each record has a **record identity (rid)**, which identifies the *page* where it is stored and its *offset* on that page
- The DBMS reads (and writes) *entire pages* and stores a number of them in a **buffer pool**
- The **buffer manager** decides which pages to load into the buffer

  (Replacement policy: e.g., "least recently used" or "clock")

Alternative File Organisations

Alternatives are *ideal for some situation*, and *not so good in others:*

Heap Files: *No order on records.* Suitable when typical access is a file scan retrieving all records.

Sorted Files: *Sorted by a specific record field* (key). Best if records must be retrieved in some order, or only a "range" of records is needed.

Hashed Files:

- File is a collection of **buckets.**

  (Bucket = *primary* page plus zero or more *overflow* pages.)
- **Hashing function** h: computes $h(r) =$ bucket into which record r belongs (looks at only some of the fields of r, the *search fields.*)

Good for equality selections.

Cost Model

We ignore CPU costs, for simplicity:

- P: number of **data pages**
- D: (average) time to read or write **disk page**

Simplifications:

- Measuring number of page I/O's ignores
  gains of pre-fetching blocks of pages
  $\leadsto$ even I/O cost is only approximated
- Average case analysis *(based on several simplistic assumptions)*

Good enough to show 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:**
  - Selections on sort field(s)
  - Files compacted after deletions
- **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			

Cost of Operations

	Heap File	Sorted File	Hashed File
Scan all recs	$P \times D$	$P \times D$	$1.25\ P \times D$
Equality Search	$0.5\ P \times D$	$D \times \log_2 P$	D
Range Search	$P \times D$	$D(\log_2 P +$ number of pages with matches)	$1.25\ P \times D$
Insert	$2\ D$	Search $+ P \times D$	$2\ D$
Delete	Search $+ D$	Search $+ P \times D$	$2\ D$

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.

Data Entries in Indexes

Three alternatives:

- Data record with key value K
- $\langle K, r \rangle$, where r is rid of a record with search key value K
- $\langle K, [r_1, \ldots, r_n] \rangle$, where $[r_1, \ldots, r_n]$ is a list or rid's of records with search key value 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: B$+$-trees, hash-based structures
- Index may contain auxiliary information that directs searches

Data Entries in Indexes: Alternative 1

"Data record with key value K"

- Means: **index structure** is a **file organisation** for data records (like heap files or sorted files)

- For a given collection of data, **at most one index** can use this.

  Otherwise, duplication of data records
  $\leadsto$ *redundant storage*
  $\leadsto$ *potential inconsistency*

- If: large data records
  $\Longrightarrow$ high number of pages containing data entries
  $\Longrightarrow$ large size of auxiliary information

Data Entries in Indexes: Alternatives 2 and 3

"$\langle K, r\rangle$" or "$\langle K, [r_1, \ldots, r_n]\rangle$", with rids r, $r_1, \ldots, r_n$

- Typically, **data entries** are much **smaller than data records**
  $\Longrightarrow$ better than Alt1 (with large data records),
  especially if search keys are small

  Portion of index structure to direct search
  is much smaller than with Alt1.

- If more than one index is required on a given file, **at most one** index can use **Alt1**; the **rest** must use Alt2 or Alt3

- Alt3 is **more compact** than Alt2, but leads to **variable sized data entries** even if search keys are of fixed length

Index Classification

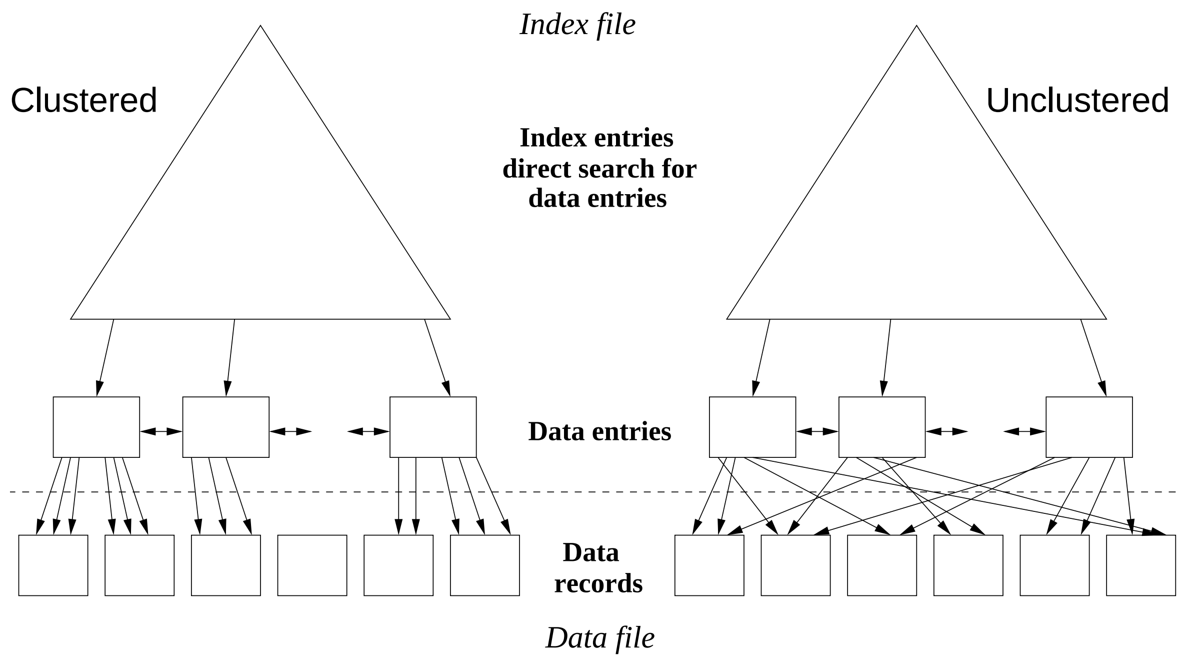
Primary vs. **Secondary:** Primary, if search key contains a primary key

- **Unique** index: search key contains a candidate key

Clustered vs. **Unclustered:** Clustered, if order of data records is the same as, or "close to", order of data entries

- 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



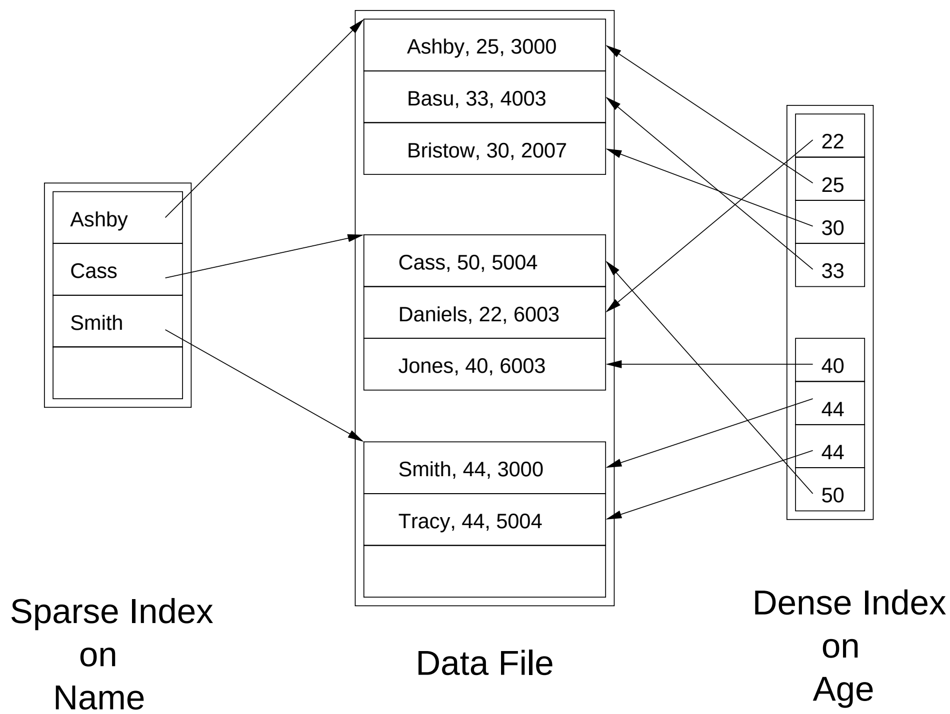
If Alt2 is used for data entries, and data records are stored in a heap file:

- 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
  $\leadsto$ order of data recs is "close to", but not identical to the sort order

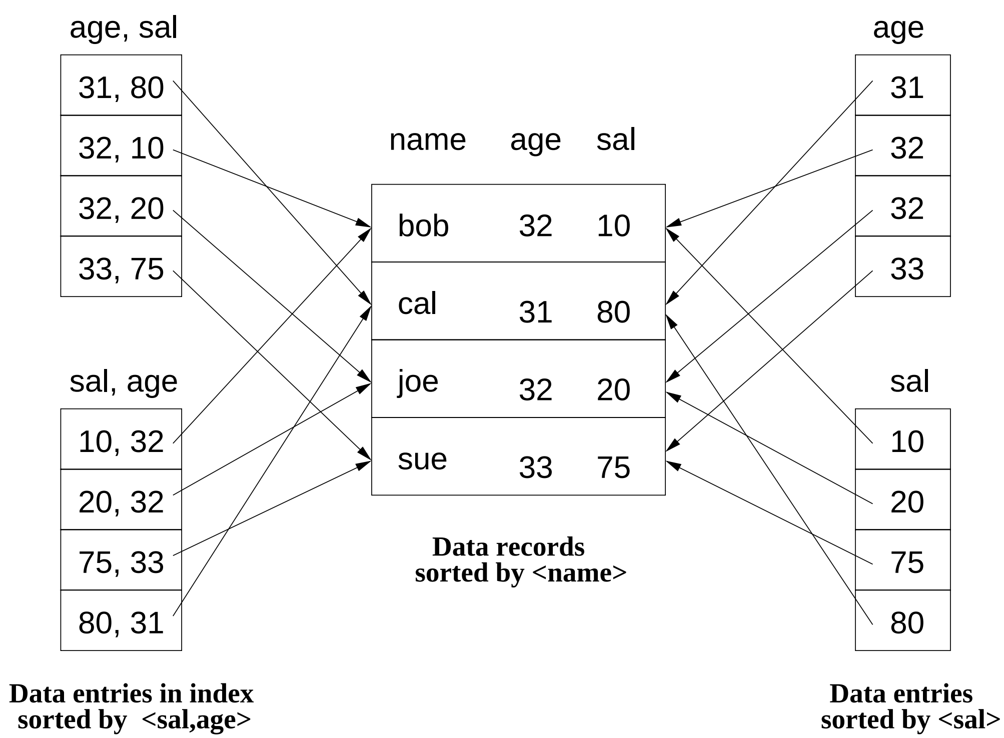
Dense vs. Sparse

Dense, if there is at least one data entry per search key value

- Alternative 1 always leads to dense index
- Every sparse index is clustered
- Sparse indexes are smaller; however, some optimisations are based on dense indexes



Composite Key Indexes



Summary

- Many alternative file organisations 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* (and also equality search)

    (files rarely 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 (Cntd.)

- **Data entries** can be (1) actual data records, (2) $\langle \text{key}, \text{rid} \rangle$-pairs, (3) $\langle \text{key}, \text{rid-list} \rangle$-pairs

  Choice orthogonal to **indexing technique**
  used to locate data entries with a a given key value.

- There may be **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*
  - *dense* vs. *sparse.*

  Differences have important consequences for *utility/performance*

References

These slides are based on Chapter 8 of the book *Database Management Systems* by R. Ramakrishnan and J. Gehrke, and on slides by the authors published at

`www.cs.wisc.edu/~dbbook/openAccess/thirdEdition/slides/slides3ed.html`