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			

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
  $\rightsquigarrow$ *redundant storage*
  $\rightsquigarrow$ *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

1

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

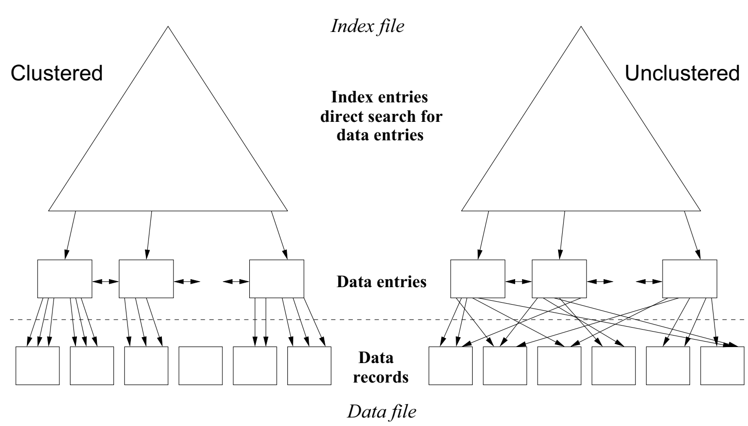
- **Unique** index: search key contains a candidate key

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

2



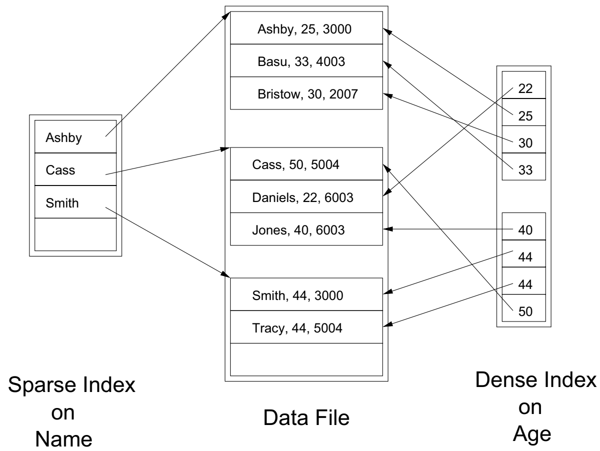
If Alt2 is used for data entries, and data records are stored in a heap file:

- 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

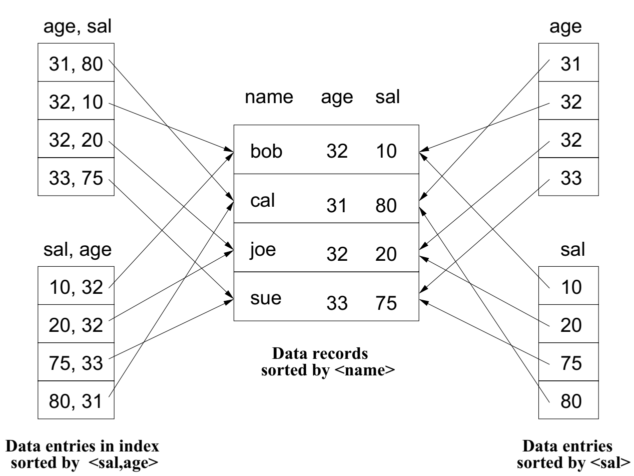
Dense vs. Sparse

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



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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`