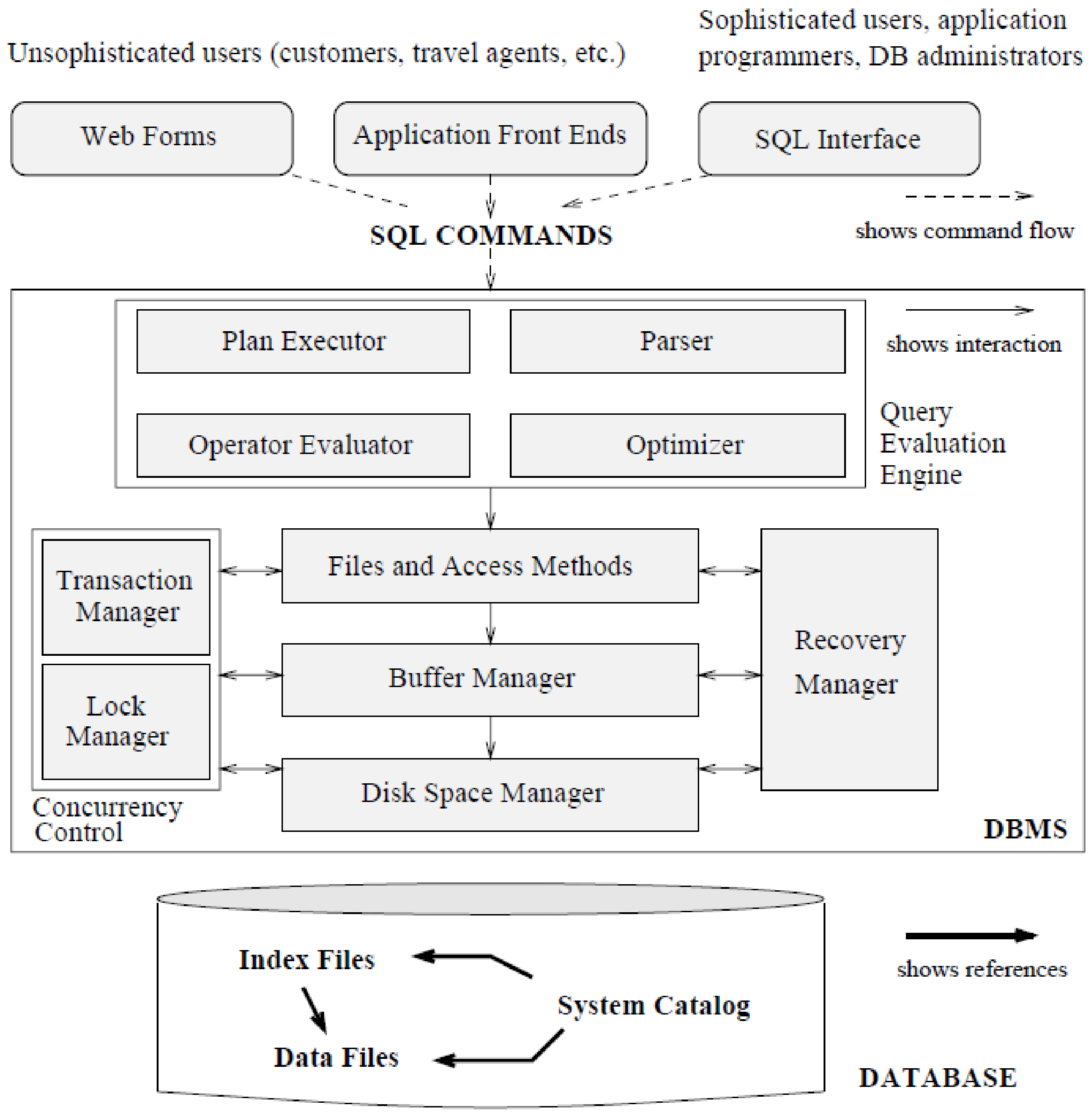
Storage and Indexing

BIRZEIT UNIVERSITY - SAMER ZAIN, PH.D.

Introduction

- **DBMS** abstracts data as a collection of **records** stored in a **file**.
- A file is a set of **pages**, each contain certain **set of records**.
- The **files layer** is responsible or data organization for fast data retrieval.
- **File organization**: a way of organizing records in a file.
- Each file organization makes certain operations efficient, but other operations expensive.

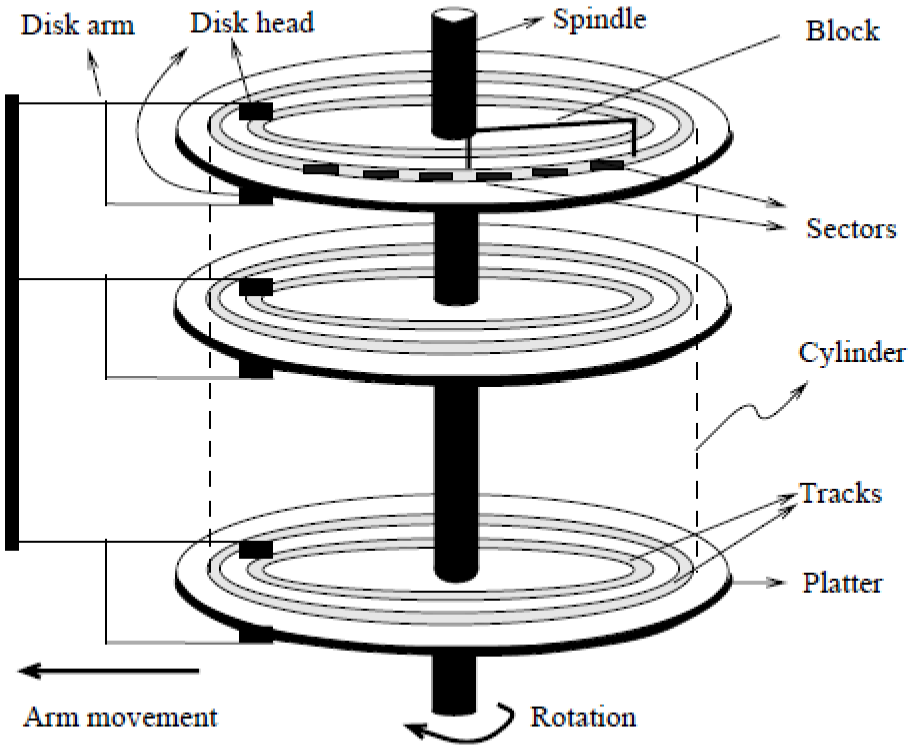


Introduction..2

- For example, suppose that we have a file of employees (name, age, and salary).
- If we want to retrieve employees based on **age**, then sorting the records based on age is a good idea.
- But if we want to retrieve employees based on **salary**, then we need to **scan the entire file**.
- Further, keeping the file sorted on age can be **expensive** is the file is modified frequently.
- We use **indexing** to access records of data in additional ways.
- We can build **more than one** index on the same data file, each with a different **search key.**

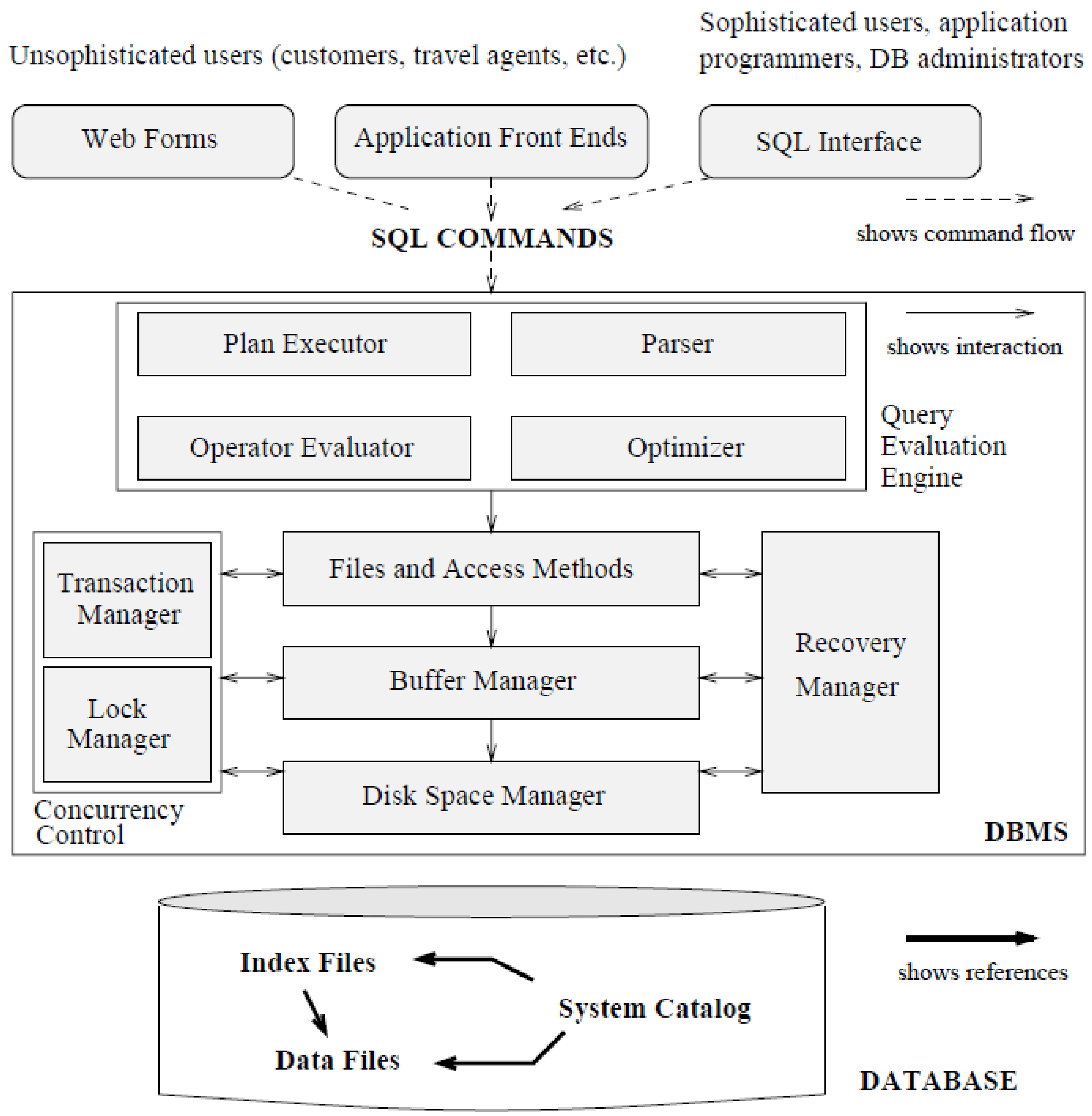
Data on External Storage

- **Hard disks** are the primary storage devices for DBMS
- The **taps** are used for archiving.
- The unit of information read from or written from disk is a **page**.
- A page is **typically 4KB** or **8KB**
- The cost of page I/O is the **most expensive** operation.
- Disks have **fixed cost per page**.
- Each record in a file has a unique identifier called **rid**.
- Using the **rid**, we can identify the **page address**



Data on External Storage ..2

- ❑The **buffer manager** is responsible for loading a page into memory.
- ❑When the files layer wants to access a certain page, it asks the **buffer manager** to load it into memory (if it is not already there)
- ❑ Space on disk is managed by **disk space manager.**



File Organization and Indexing

- As noted before, **DBMS (Files Layer)** abstracts data as **files of records.**
- Files can be created and destroyed, records added and deleted.
- Files also support scans.
- A relation (table) is stored as a file of records.
- the **file layer** stores records in a file in a **set of pages**.
- The file layer tracks pages and the records inside them.

Heap Files and Indexes

- A **heap file** is the simplest file organization: records are stored **randomly** across the pages.
- A heap file supports retrieval of all records or retrieval of particular record using rid.
- An **index** is a **data structure** that allows **fast retrieval** of data records.
- An **index** is based on a **search key**.
- We can create several indexes for same data file, each with different search key.

Indexes ..2

- Consider as an example our employee records.
- We can store the records in a file organized as an index on employee **age**.
- Additionally, we can create a separate index file based on **salary**, to speed up operations that involve retrieving employees based on salaries.
- The first file contains the actual employee records. While the second file contains **data entries**.
- A **data entry** is associated with **key** value K, and contains enough information to locate data records.
- We can **efficiently search** an index to find the desired data entries. We then use the data entries to locate the data records.

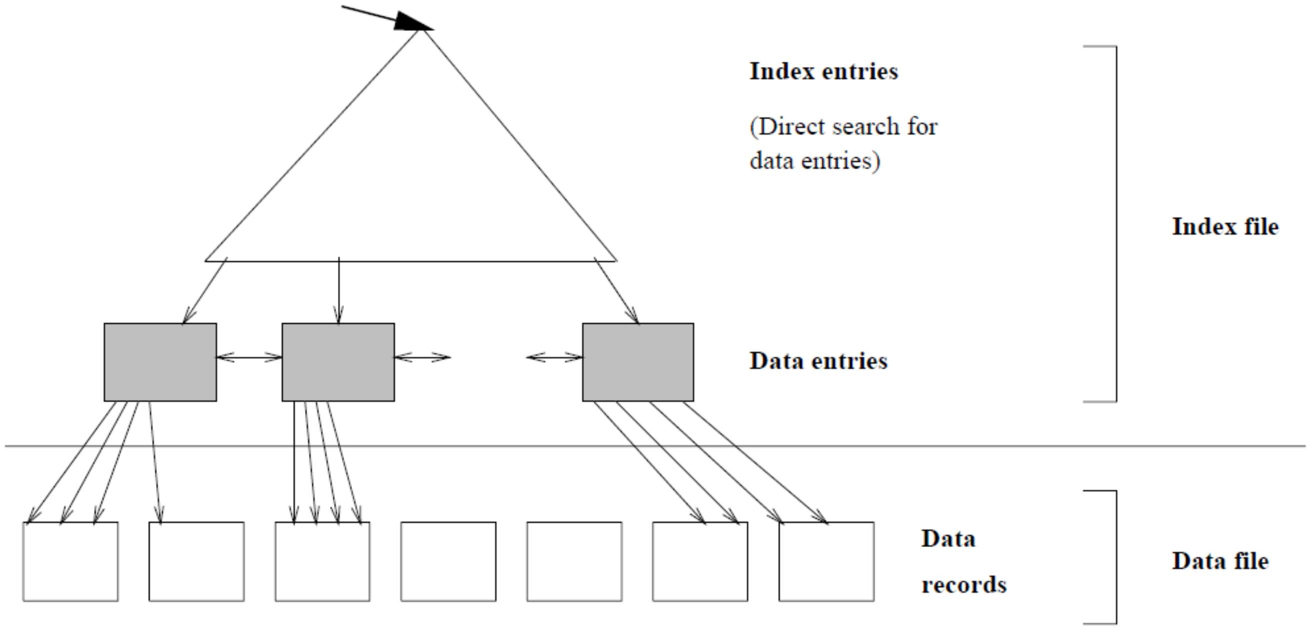
Indexes..3

- **Data Entries** in an index can be as one of the following:
- Alternative (1): a data entry is an actual data record associated with search key.
- Alternative (2): a data entry is a (K, rid) where K is the search key and rid is record id.
- Alternative (3): a data entry is a (K, rid list)
- If we want to have more than one index on a file of records, at most we can have one Alternative(1), why?

Clustered Indexes

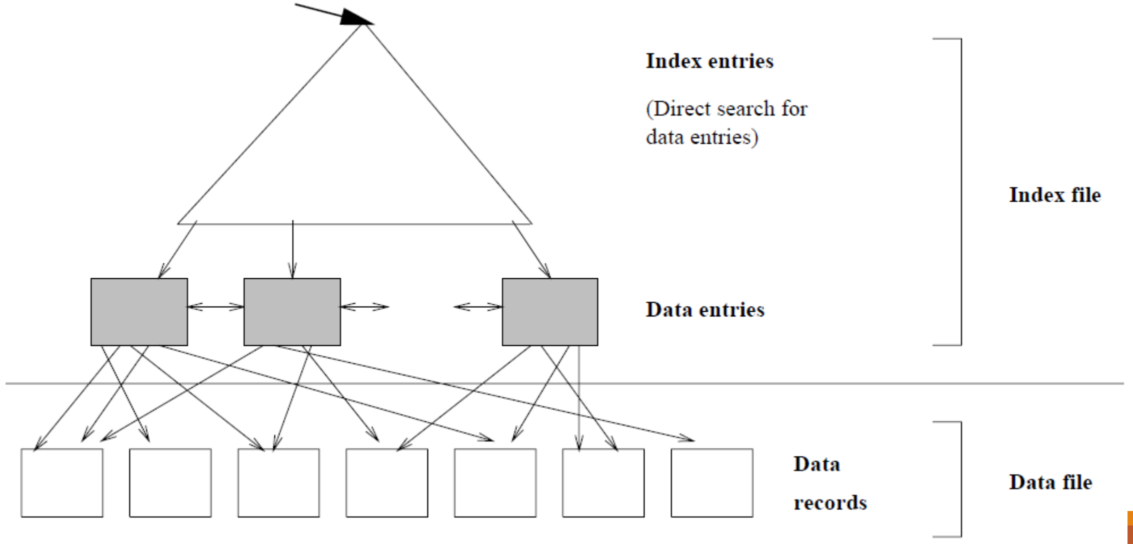
- **Definition**: when a file is organized so that the data records are ordered same as or close to the ordering of data entries of an index, we say that the index is **clustered**.
- An index that uses **Alternative (1)** is clustered by definition.
- An index that uses **Alternative(2) or Alternative(3)** can be clustered only if the data records are sorted on the search key field.
- In practice, indexes that uses Alternative(1) and Alternative(2) are **un-clustered**, why?
- The performance can be very efficient if we are answering a range query using clustered index.

Clustered vs Un-Clustered Indexes



Clustered Index

Unclustered Index

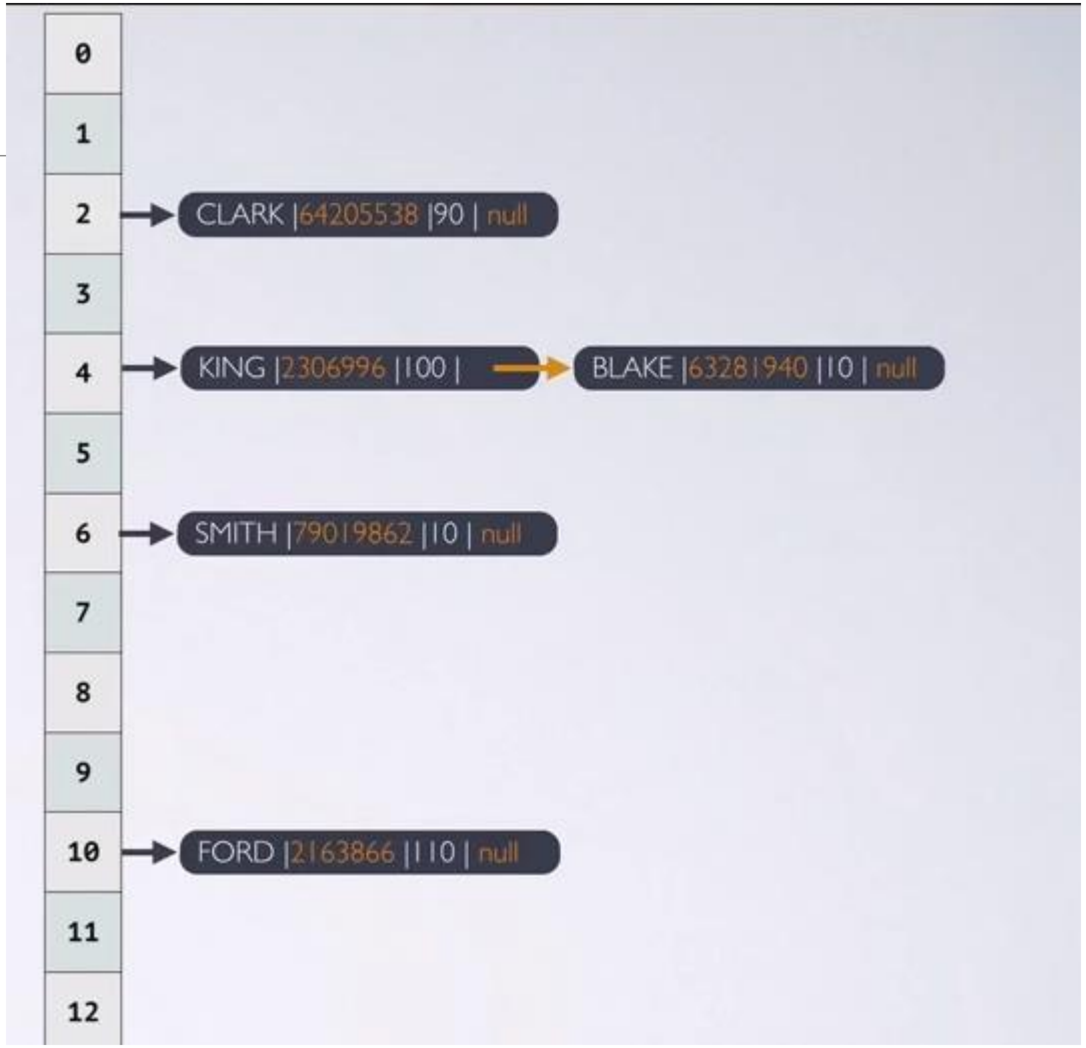


Primary and Secondary Indexes

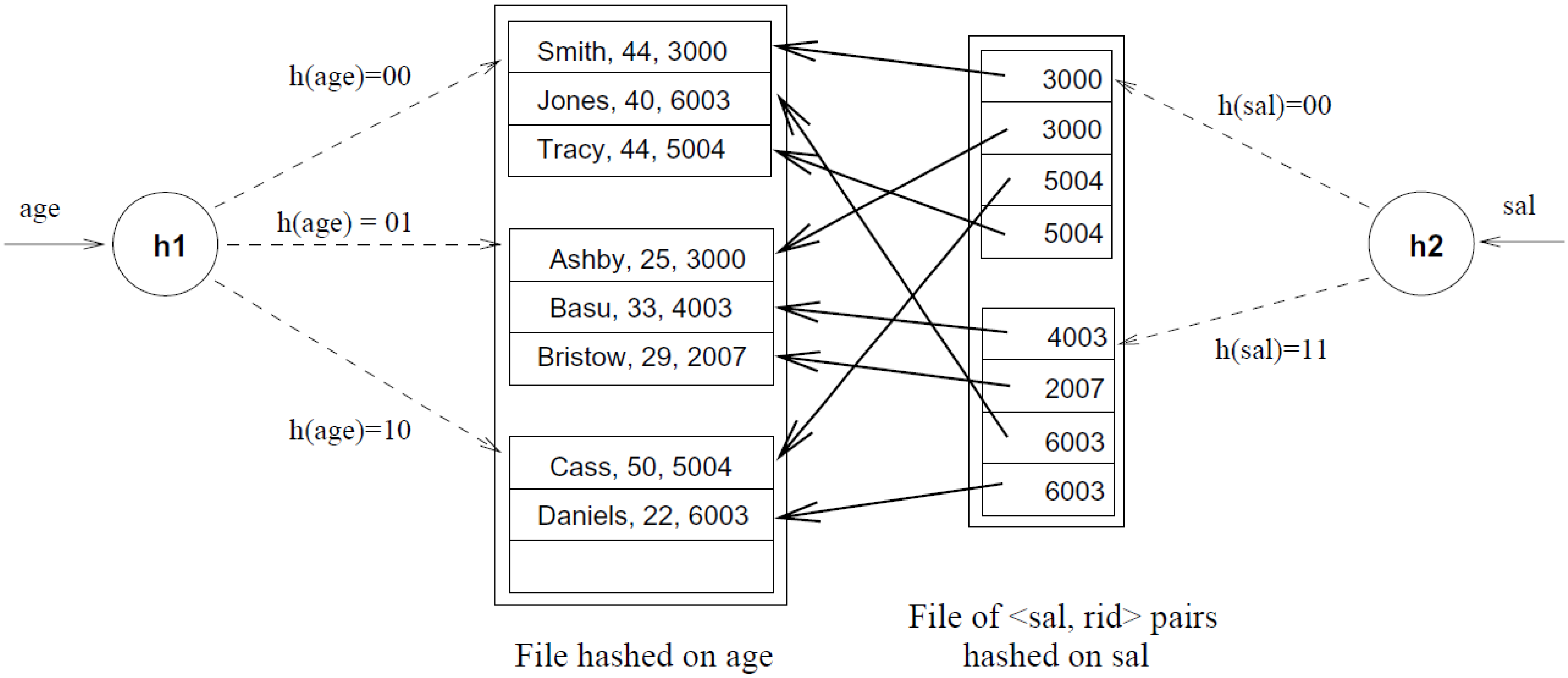
- A **primary index**: is an index on a set of fields that includes the primary key. Other indexes are called secondary indexes.
- Two data entries are said to be duplicate if they contain the same value for search key.
  - A Primary index is guaranteed not to have duplicates.
  - In general, secondary indexes contain duplicates.
  - **Unique index**: an index with no duplicates.

Hash-Based Indexing

- One way to implement indexing is hashing.
- For instance, if the files of employees is hashed on names, we can find all records of employee name John.
- The record are arranged in buckets ,with each bucket has one or more related pages.
- To identify a bucket, we apply hash function to the search key.
- We can retrieve required page in single I/O operation.



Hash-Based Index Example



- Note that the search key can be any set of fields.
- Also note the search key need not uniquely identify record.

Tree-Based Indexing

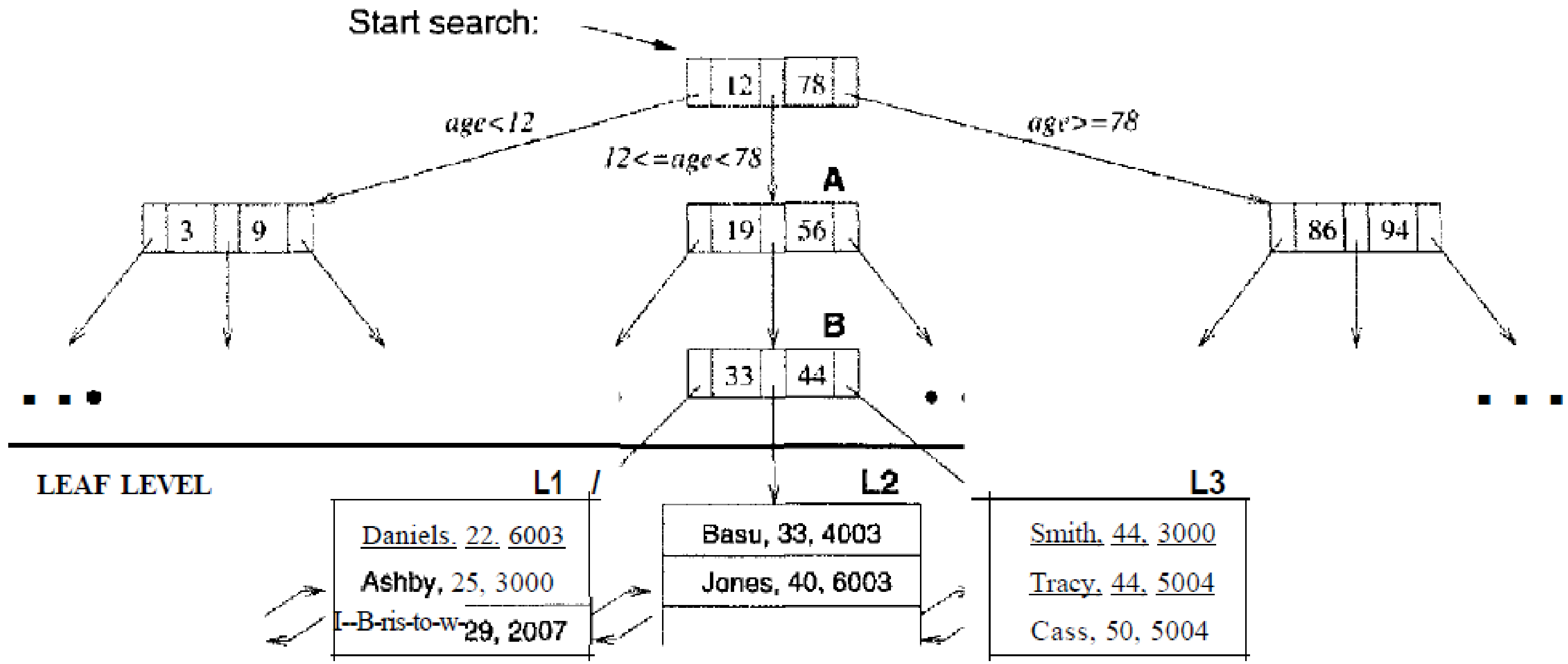


Figure 8.3 Tree Structured Index

- Another way to arrange data entries in an index is using a **tree data structure**.
- The data entries are arranged in sorted order on search key.
- Note that L1, L2, and L3 are connected via double linked lists.
- Number of I/O = length of path + number of leaf pages.

Tree-Based Indexing..2

- **B+ tree** in an index structure in which all paths from root node to leaf in a tree is of **same length**.
- Here, finding the correct leaf is **faster than binary search** of pages in a sorted file.
- This is because each non-leaf node can have large number of node-pointers, and the **height** of tree is rarely more than **three** or **four** in practice.
- The average number of children for a non-leaf node is called **fan-out** of the tree.
- If every non-leaf tree node has N children, and the tree has H height, then the number of leaf pages = N^H
- In practice the average of N (F) = 100, thus the number of leaf nodes = 100 million.
- However, to find correct leaf node we need **4** I/Os, while in sorted file we need over **25**.

Comparison of File Organization

- Now we need to **compare** between different files organizations in terms of simple operations.
- We assume that the file and indexes are organized based on the composite **search key (sal, age)**
- We also assume that all selection operations are based on the composite key (sal, age)
- The operations we consider are:
  - **Scan**: Fetch all records in the file, thus all pages in the file must be fetched from disk into buffer pool.
  - **Search with Equality Selection**: such as "find all employees with salary 1200 and age 40"
  - **Search with Range Selection**: such as "find all employees with age > 35"
  - **Insert new Record**: identify correct page, load it into memory, change it, and write it back.
  - **Delete a Record**: using rid, we locate the related page, load it into memory, change it, and write it back.

Cost Model

- We need to agree on the cost model that we will use to differentiate between files:
  - **B** = Number of data pages.
  - **R** = Number of records per page.
  - **D** = Average time to read a page from disk.
  - **C** = Time to process a record.
  - **H** = time to apply the hash function.
  - **F** = fan-out for a tree based file.

Cost for Heap Files

- **Scan**: the cost = B(D+RC)
- **Search with Equality Selection**:
  - if selection is specified on a candidate key then cost = 0.5B(D +RC)
  - If selection is not specified on candidate key them we need to search entire file.
- **Scan with Range Selection**: cost = B(D+RC) coz we need to search all file.
- **Insert**: We assume that inserts are at end of the file, cost = 2D + C
- **Delete**: cost = cost of search + C+ D

Cost for Sorted Files

- **Scan**: the cost = B(D+RC), again, all pages will be scanned.
- **Search with Equality Selection**:
  - if selection is specified on age then cost = $DLog_2B + CLog_2R$
  - If selection is not specified on age, it is same as heap file.
- **Scan with Range Selection**: cost = B(D+RC) coz we need to search all file.
- **Insert**: we must find correct position in the file, add new record, then rewrite all subsequent pages. Cost = search + B(D + RC)
- **Delete**: cost = cost of search + C+ D

Comparison of I/O Costs

File Type	Scan	Equality Search	Range Search	Insert	Delete
Heap	BD	$0.5BD$	BD	$2D$	$Search+D$
Sorted	BD	$Dlog_2B$	$Dlog2B+\#$ matching pages	$Search + BD$	$Search+BD$
Clustered	$1.5BD$	$DlogF1.5B$	$Dlo9F1.5B+\#$ matching pages	$Search + D$	$Search+D$
Unclustered tree index	$BD(R + 0.15)$	$D(1 + logFO.15B)$	$D(lo9FO.15B+\#$ matching records)	$D(3 + logFO.15B)$	$Search+2D$
Unclustered hash index	$BD(R + 0.125)$	$2D$	BD	$4D$	$Search+2D$

Comparison of I/O Cost..2

- A heap file has good storage efficiency and supports fast scanning and insertion of records. But it is slow for searches and deletions.
- A sorted file also offers good storage efficiency, but insertion and deletion of records is low. Searches are faster than heap files.
- A clustered file offers all the advantages of a sorted file plus supporting inserts and deletes efficiently. but requires more space on disk. Searches are even faster than sorted files.
- Unclustered tree and hash indexes offer fast searches, insertion, and deletion, but scans and range searches with many matches are slow. Hash indexes are a little faster on equality searches, but they do not support range searches