INFS7901
Database Principles

Indexing

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Intro to Indexing

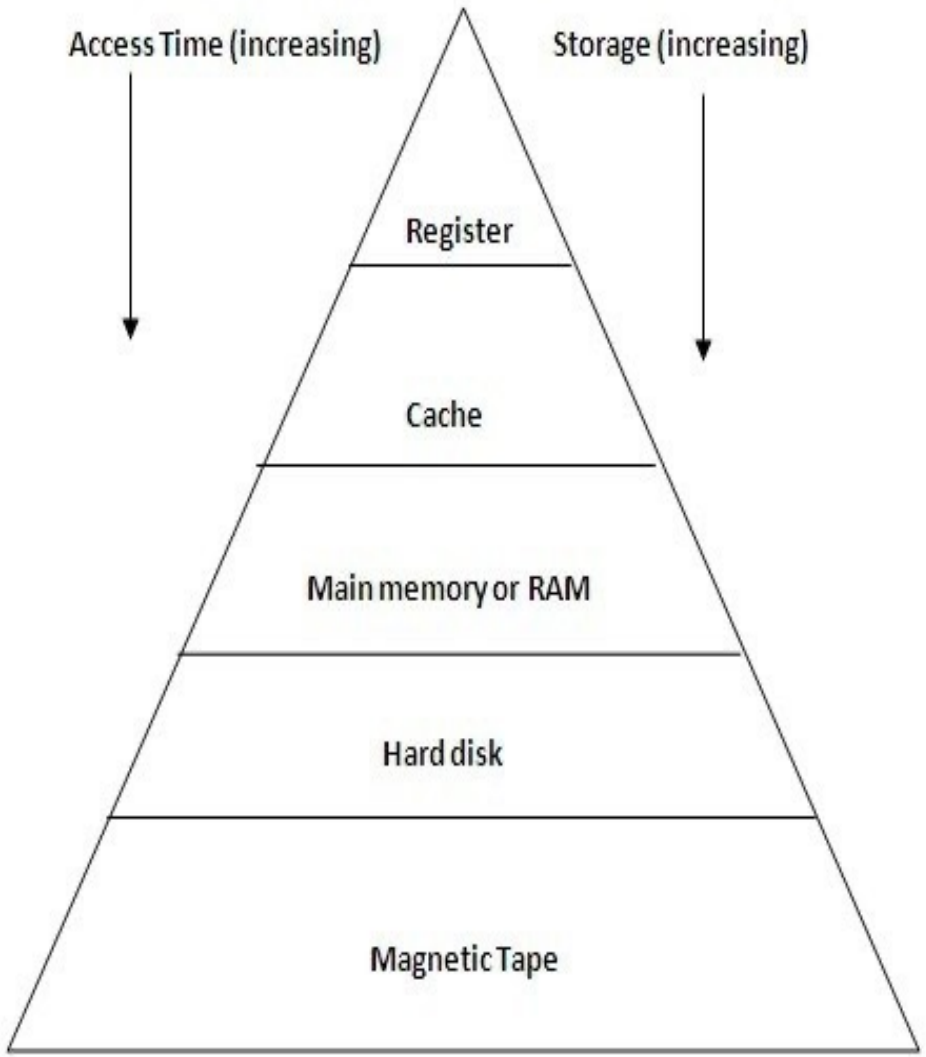
Single-level Indexes

Multi-level Indexes

Indexes on Multiple Keys

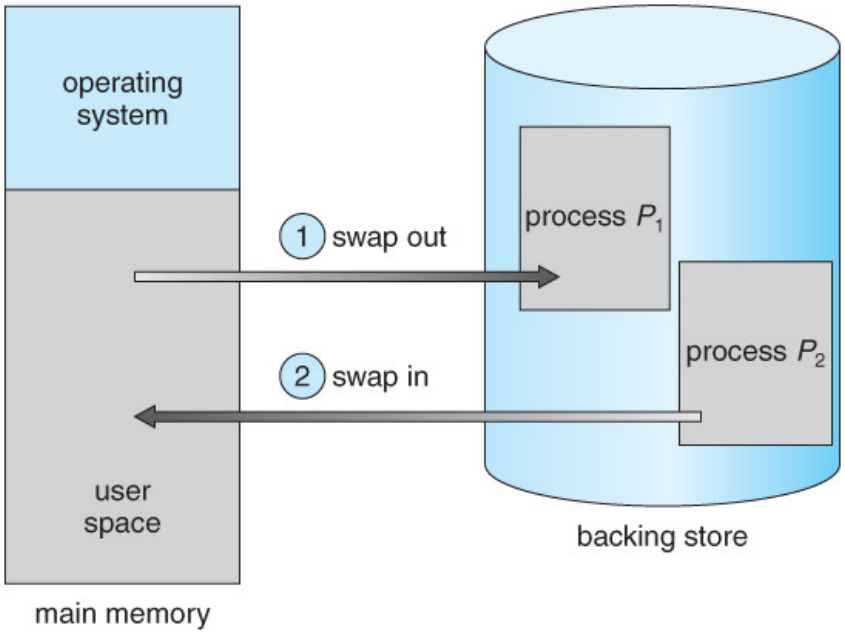
Storage Hierarchy

- **Internal register** is for holding the temporary results and variables.
- **Cache** is used by the CPU for memory which is being accessed repeatedly.
- **RAM** is used to stores data and machine code currently being used.
- **Hard disk** is used to keep data permanently in this memory - not directly accessed by the CPU.
- **Magnetic tape** is usually used for backing up large data.



Operating System - Memory Management

- **Memory management,** a form of resource management, is the process of controlling and coordinating computer memory to optimize overall system performance.



File Organization

- **Primary file organizations:** determine how the file records are physically placed on the disk
  - unordered file: adding records as they are inserted. Also called a heap file.
  - Ordered file: ordered by value of a specific field.

- **Secondary organizations**: allow efficient access to file records based on alternate fields than those that have been used for the primary file organization.

Ordered File vs. Unordered File

	insert	*Search order key*	*Search Non-order key*	*delete*
• Ordered File	*O(n)*	*O(log n)*	*O(n)*	*O(n)*
• Unordered File	*O(1)*	*O(n)*	*O(n)*	*O(n)*

Indexing

- Index is an auxiliary file that makes it more efficient to search for a record in the data file.
- The index is *usually* specified on one field of the file.
- The index is called an access path on the field.
  - A **dense index** has an index entry for every search key value (and hence every record) in the data file.
  - A **sparse (or nondense) index** has index entries for only some of the search values

Index Structures

- Types of Single-level Indexes
  - Primary Indexes
  - Clustering Indexes
  - Secondary Indexes

	Ordered Data	Unordered Data
Key	Primary Index	Secondary Index
Non-key	Clustering Index	Secondary Index

- Multilevel Indexes
  - Index on index

- Indexes on Multiple Keys

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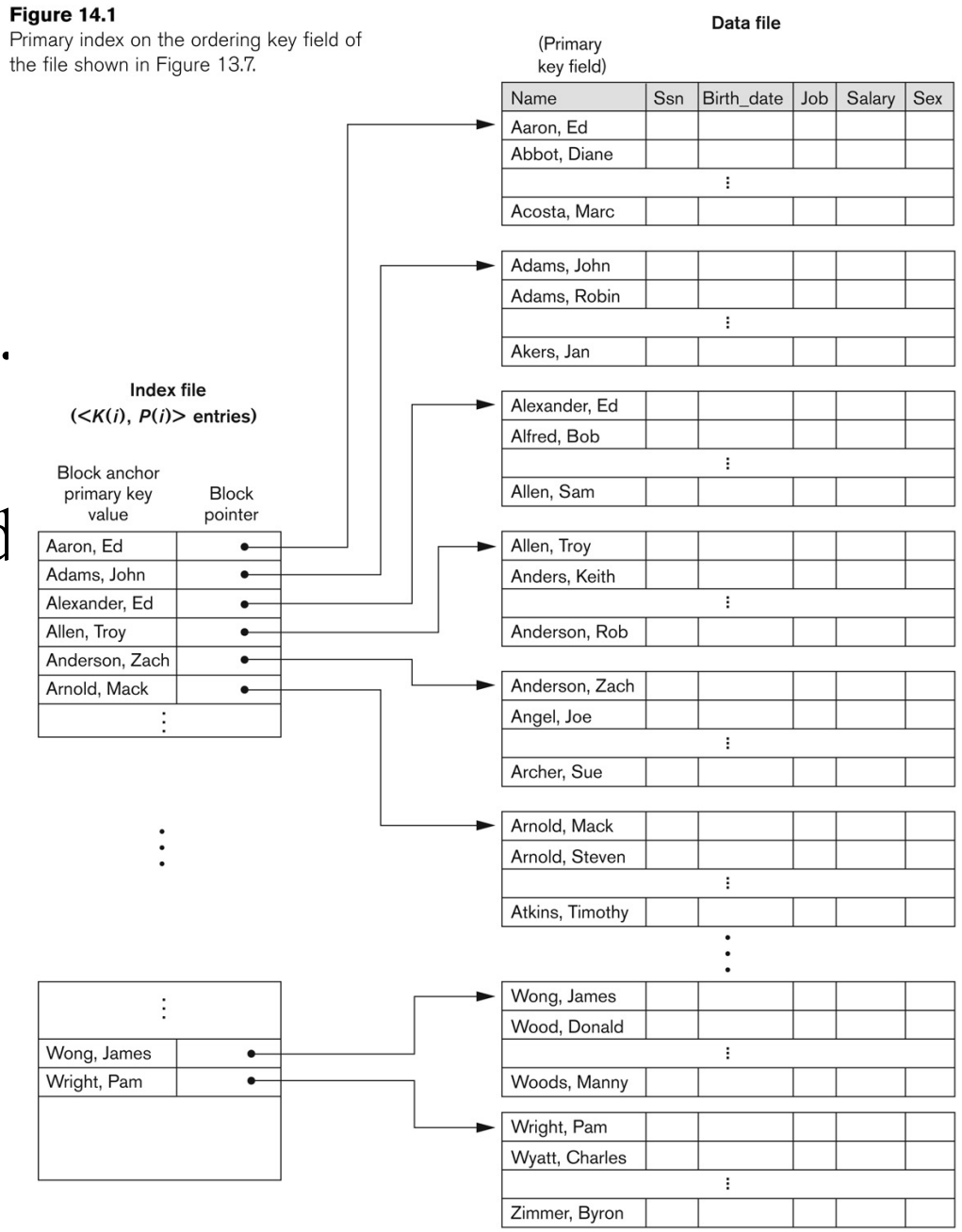
Primary Index

- Defined on an ordered data file, which is sorted using a key field.
- A primary index is an ordered file with 2-field entries <K(i), P(i)>
  - K(i): is the key field
  - P(i): is a pointer to the first record in a data block
- A primary index is a sparse index



Primary Index vs. Data File

- A primary index occupies much less space than a data file because:
  - It is sparse, so few index entries
  - Each entry has only two columns

Even tough both will be using Binary Search, searching a primary index is much faster than search the data file

Primary Indexing Question

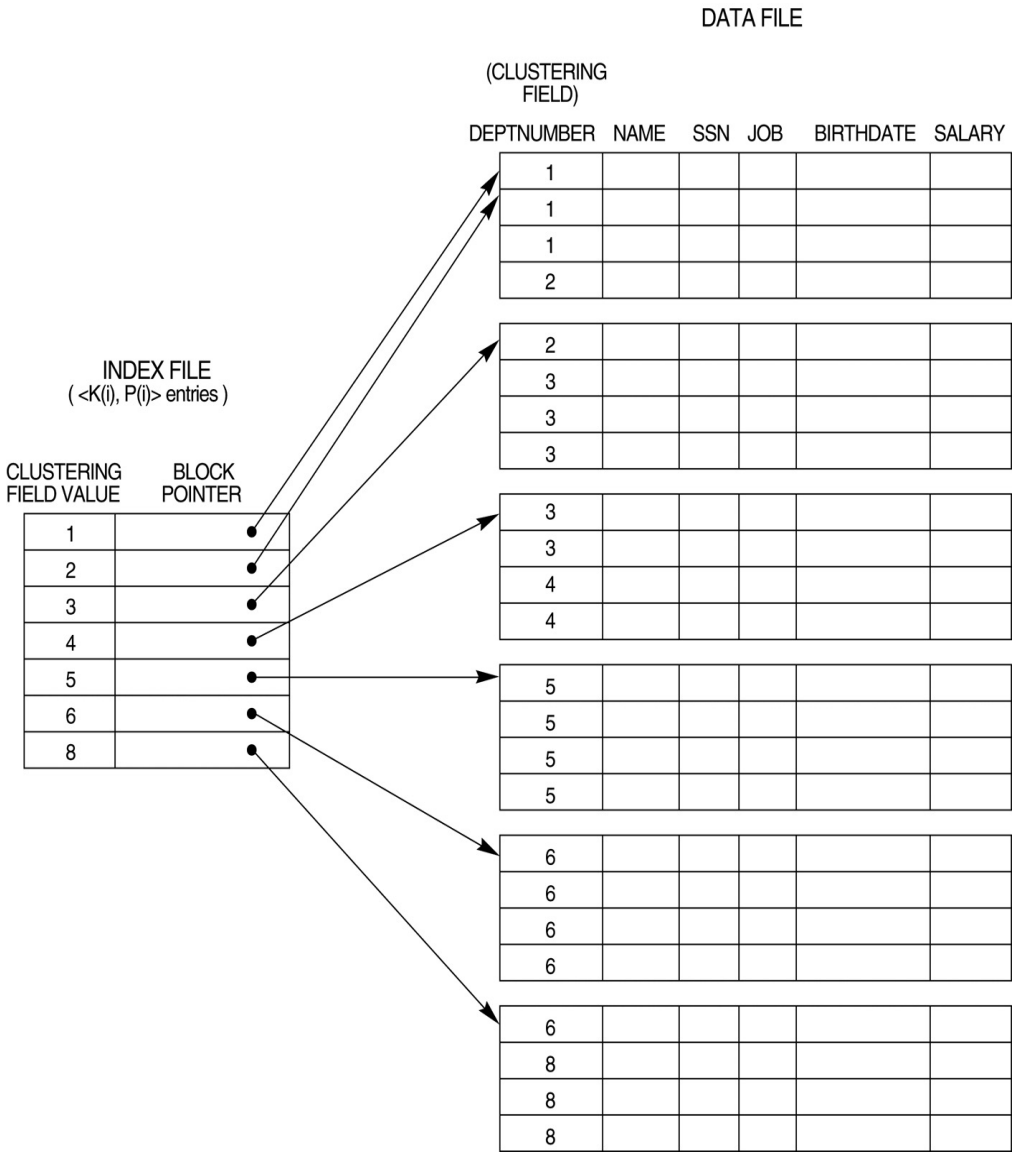
- "There is no point in having a primary index on top of an ordered data file, which is sorted using a key field. We can already use binary search to find things in O(lg n)"
- Do you agree or disagree with the statement above. Justify your answer

Disagree because:

- A primary index occupies much less space than a data file because it is sparse (therefore size is no longer n) and only has two columns. Since it occupies less space, it is possible to fit a bigger portion of it in the primary space, which we have fast access to.

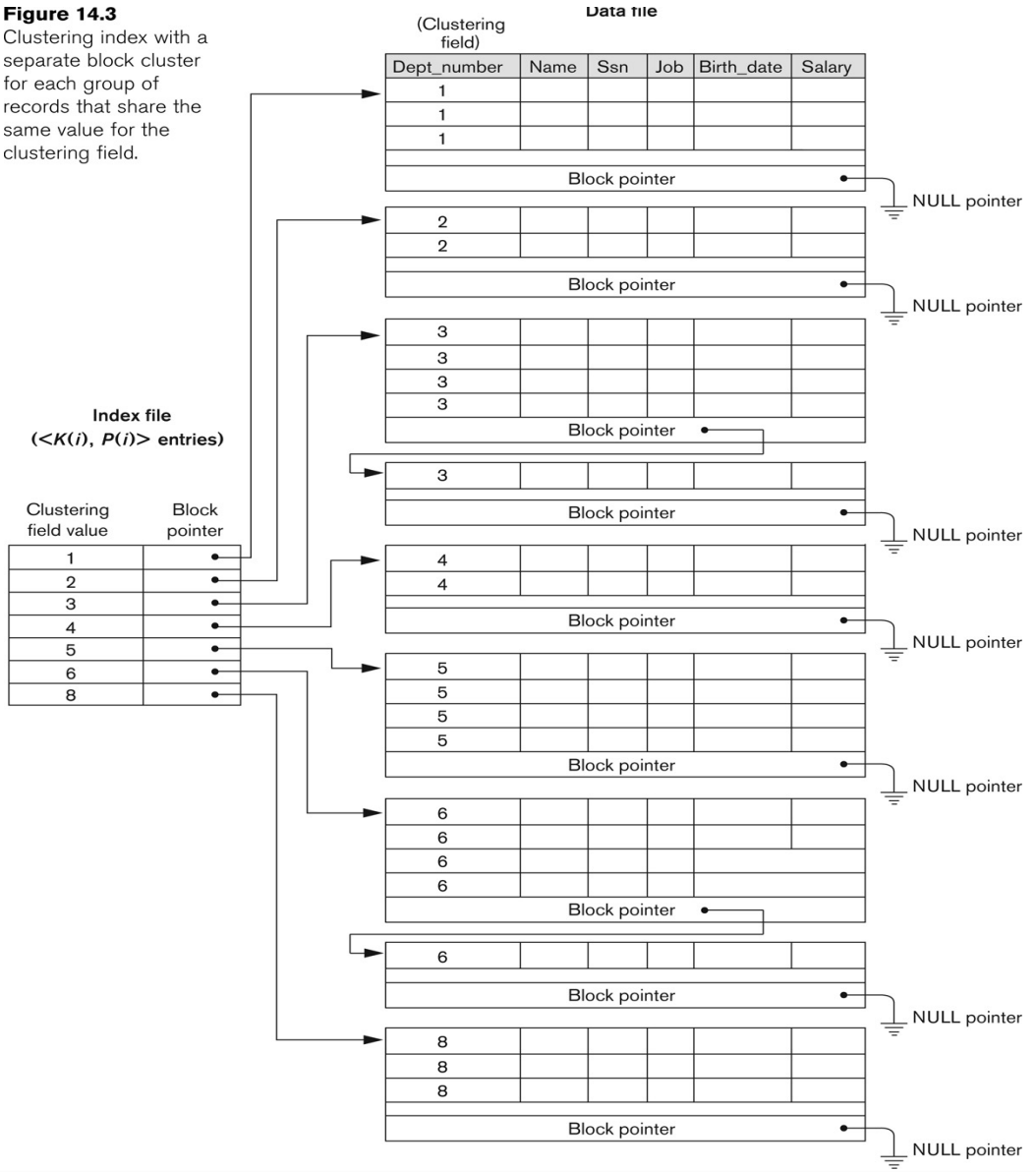
Clustering Index

- Defined on an ordered data file, which is sorted using a non-key field.
- A clustering index is an ordered file with 2-field entries <K(i), P(i)>
  - K(i): is the ordered field
  - P(i): is a pointer to the first block with that value
- A clustering index is a sparse index



Clustering Index

- Since records are ordered, insertion and deletion cause problems
- To overcome the problem of insertion:
  - Reserve blocks for each distinct value.



Secondary Index

- A secondary index provides a secondary means of accessing a file for which some primary access already exists.

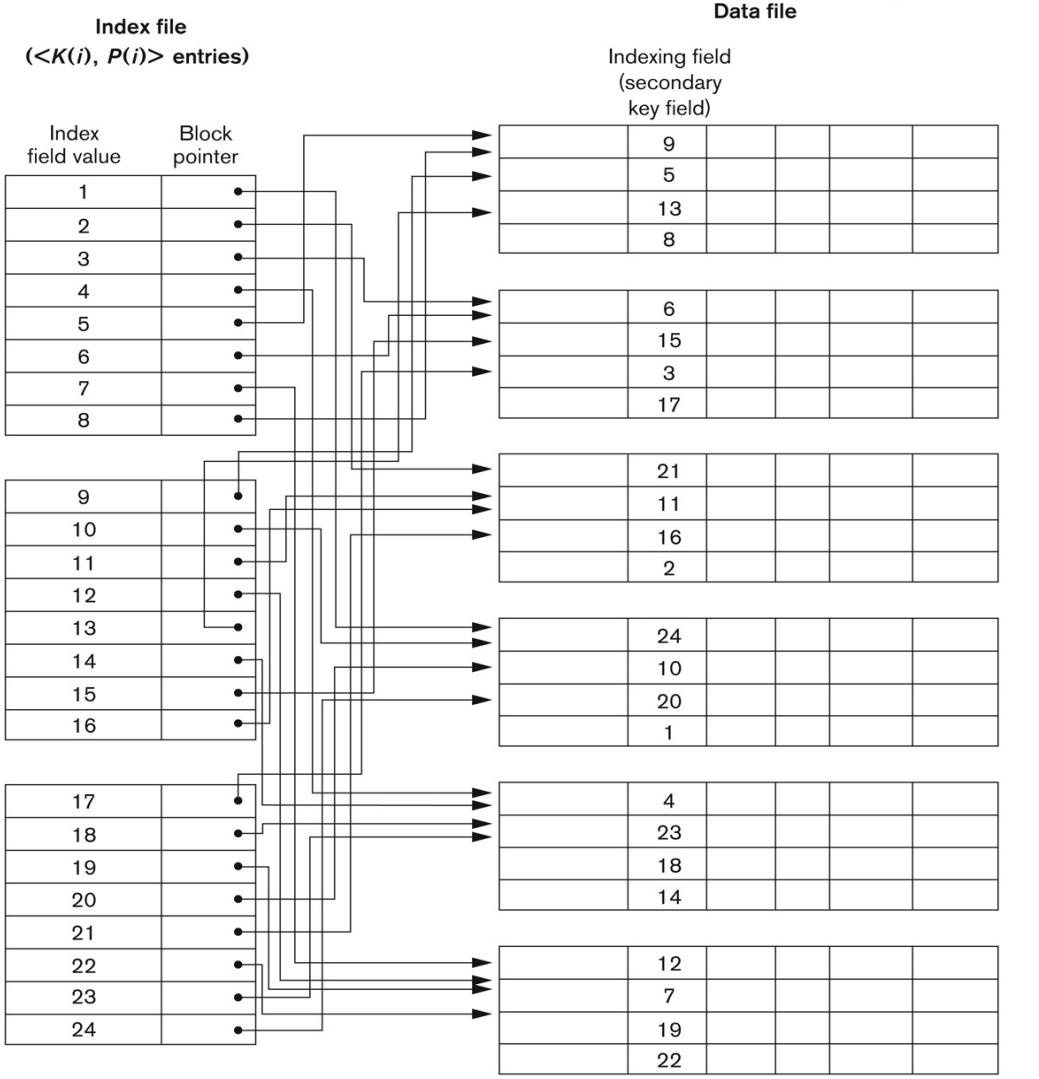
- The secondary index may be on a field which is a candidate key and has a unique value in every record, or a non-key with duplicate values.

- Includes one entry *for each record* in the data file; hence, it is a *dense index*

Secondary Index on Key

- Defined on a file for which some primary access already exists.
- A secondary index on key field is an **ordered** file with 2-field entries <K(i), P(i)>
  - K(i): is the field
  - P(i): is a pointer to a block or record
- A secondary index must be a dense index

Figure 14.4
A dense secondary index (with block pointers) on a nonordering key field of a file.



Secondary Index on Non-key

- Defined on a file for which some primary access already exists.
- A secondary index on non-key field is a two-level ordered file with 2-field entries <K(i), P(i)>
  - K(i): is the field
  - P(i): is a pointer to a bucket/list of record pointers
- A secondary index must be a dense index

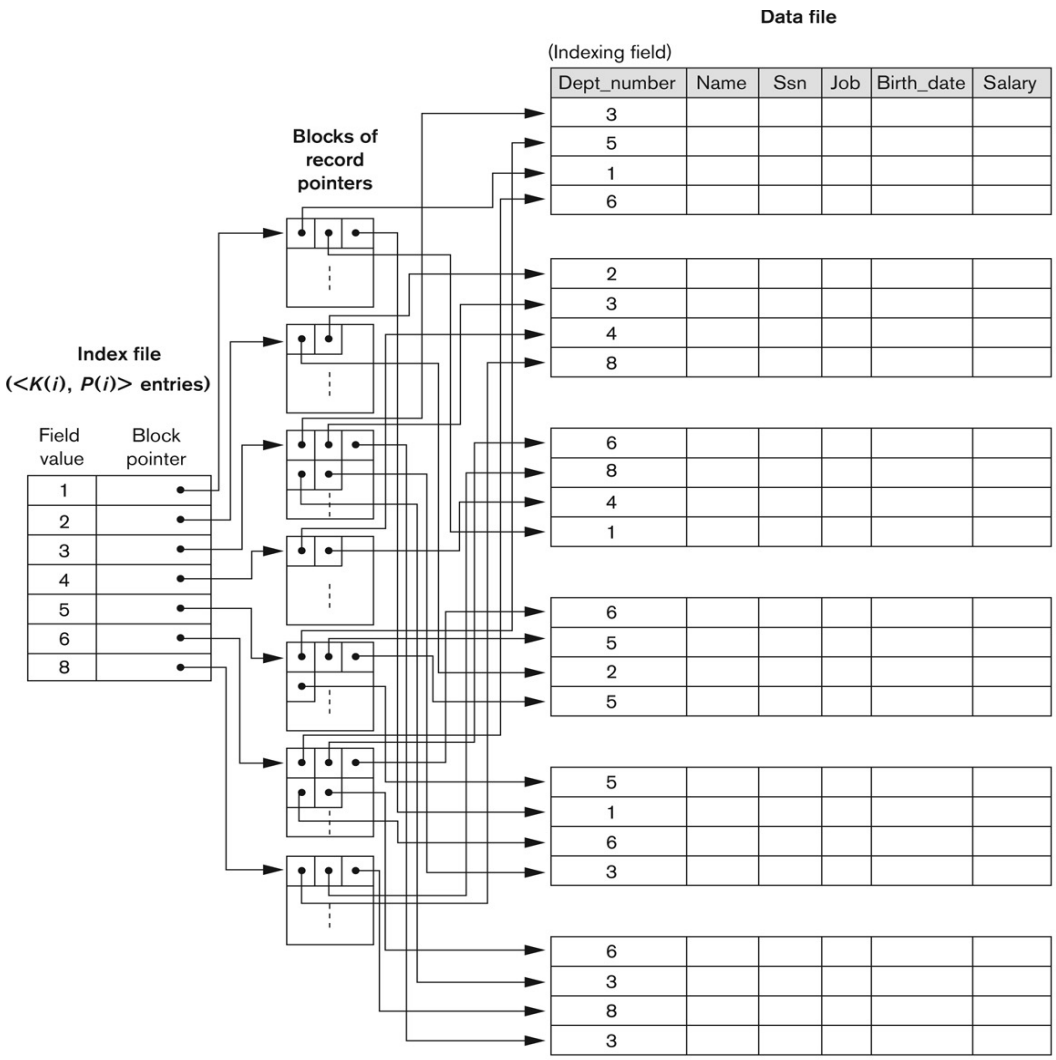


Figure 14.5
A secondary index (with record pointers) on a nonkey field implemented using one level of indirection so that index entries are of fixed length and have unique field values.

Properties of Index Types

Type of Index	Number of (First-level) Index Entries	Dense or Nondense (Sparse)
Primary	Number of blocks in data file	Nondense
Clustering	Number of distinct index field values	Nondense
Secondary (key)	Number of records in data file	Dense
Secondary (nonkey)	Number of records[b] or number of distinct index field values[c]	Dense

Intro to Indexing

Single-level Indexes

Multi-level Indexes

Indexes on Multiple Keys

Multi-Level Indexes

- Because a single-level index is an ordered file:
  - create a primary index to the index itself!
    - original index file is called first-level index
    - index to index is called the second-level index
- Repeat the process until all entries of the top level fit in one disk block
- A multi-level index can be used on any type of first-level index: primary, secondary, clustering

A Two-level Primary Index

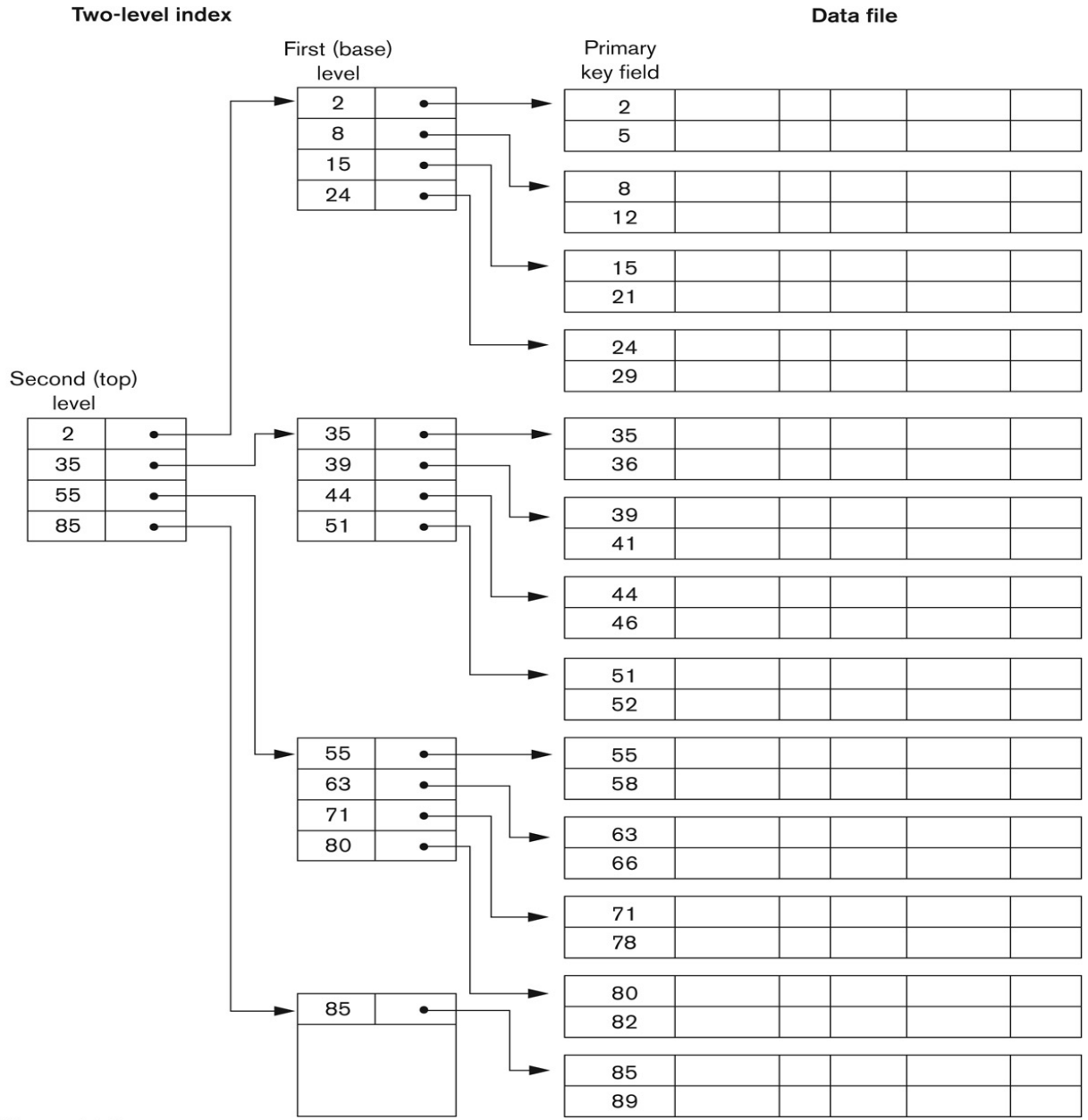


Figure 14.6
A two-level primary index resembling ISAM (Index Sequential Access Method) organization.

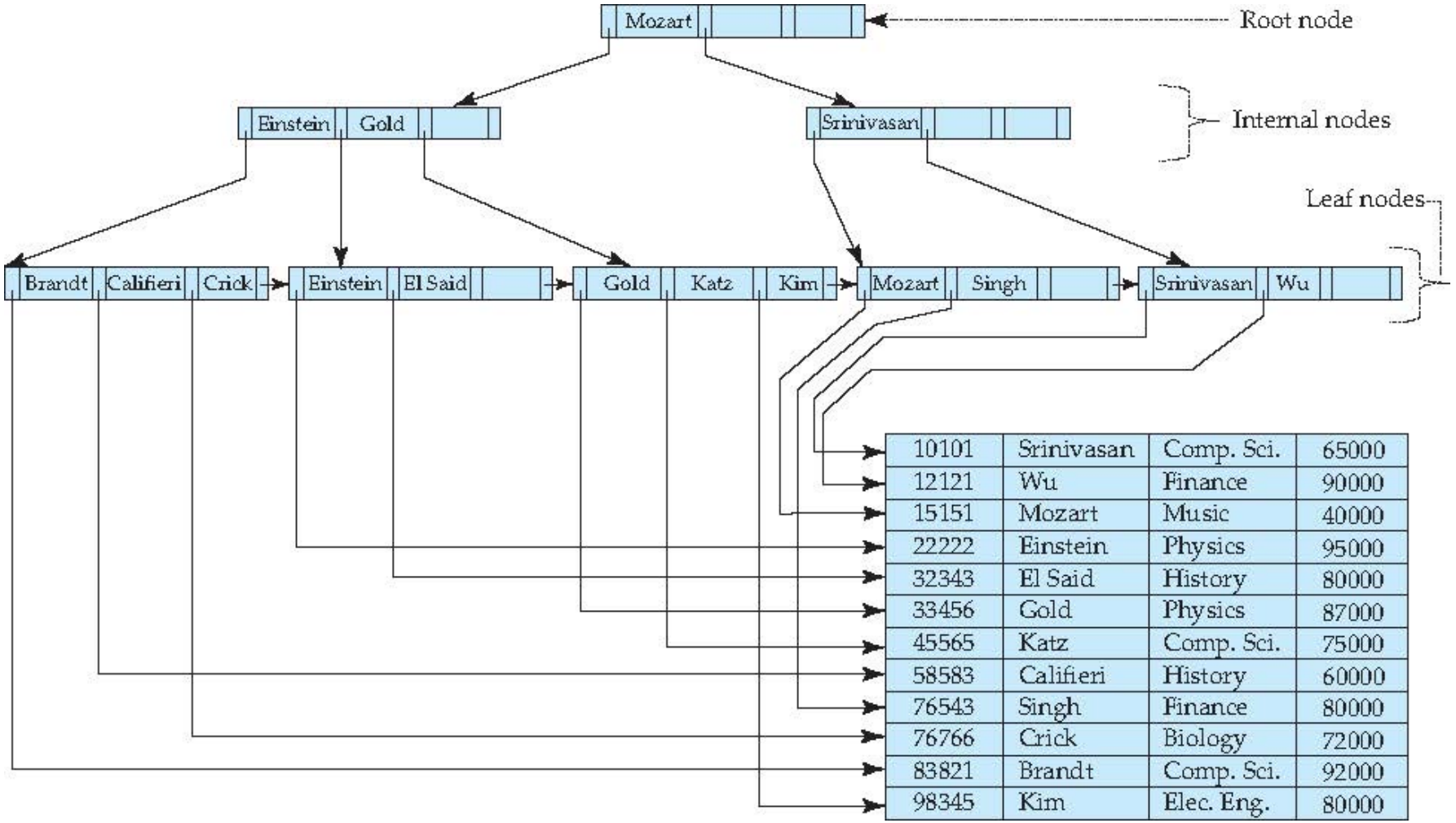
Tree-structured Indexes

- A tree-structured index is one where the search keys are organized into a tree structure.
- Main operations are find, insert, and delete
- Tree-structured indexing techniques support both *range searches* and *equality searches*.

B+ Trees

- B+ Trees are the most widely used index in databases.
- B+ Trees are based on B-Trees, which are a generalization over Binary Search Trees. B+ trees are self balancing with logarithmic (O (log n)) running time for Search, Insert, or Delete operations.
- Advantages
  - Automatically reorganizes itself with small, local, changes, in the face of insertions and deletions.
  - Reorganization of entire file is not required to maintain performance.
- Disadvantage
  - Extra insertion and deletion overhead
  - Space overhead.

B+ Tree Example



10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	80000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	60000
76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

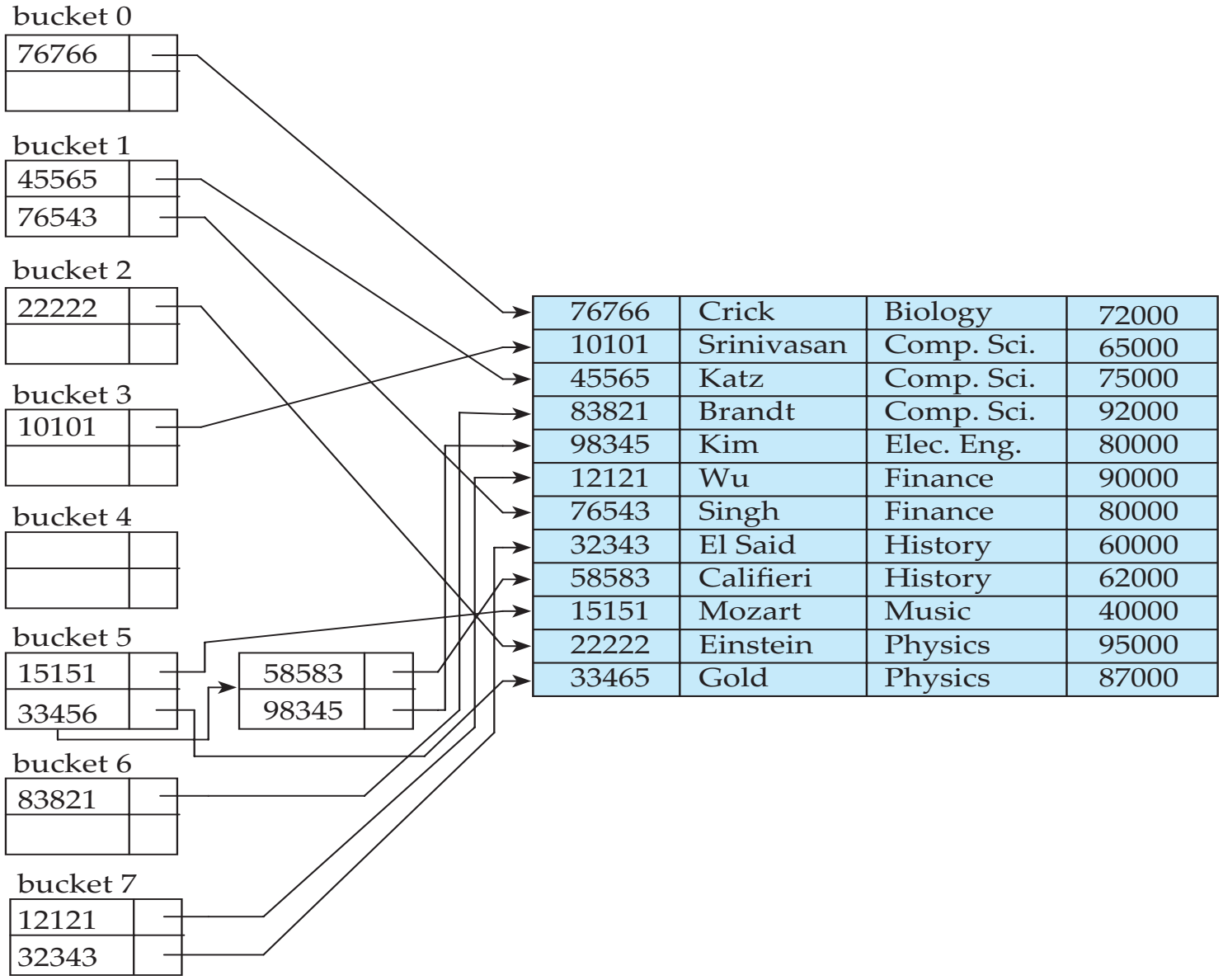
Hashed-based Indexes

- A **hash index** organizes the search keys, with their associated record pointers, into a hash file structure.

- *Hash-based* indexes are usually the best choice for *equality* selections.
  - No traversal of trees
  - Direct computation of where the record must be.

- Hash-based indexes cannot support range searches efficiently.

Hashed-based Index Example



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Indexes on Multiple Keys

- Assume that we regularly need to run the following query:

```
Select *
from Movie
where MovieID>10 and year <1940
```

- Search strategies:
  - Assuming MovieID has an index, but year doesn't: Find records that satisfy the MovieID condition and then select those satisfying the year condition.
  - Assuming year has an index, but MovieID doesn't: Find records that satisfy the year condition and then select those satisfying the MovieID condition.
  - Assuming both have indexes: Find records from each and then iterate through the smaller list and select those exist in the other list.
- What if we had a joint index on MovieID and year?

Indexes on Multiple Keys

EMPLOYEE (Ssn , Dno, Age, Street, City, Zip_code, Salary)

- Consider the query: List the employees in department number 4 whose age is 59.
- Search strategies:
  - Assuming Dno has an index, but Age doesn't: Find records that satisfy the Dno condition and then select those satisfying age condition.
  - Assuming age has an index, but Dno doesn't: Find records that satisfy the Age condition and then select those satisfying the Dno condition.
  - Assuming both have indexes: Find records from each and the iterate through the smaller list and select those exist in the other list.

- What if we had a joint index on both Dno and Age?

Indexes on Multiple Keys

- **Composite search keys:** each key containing more than one attribute (E.g. <Dno, Age>)

- **Ordered index on multiple attributes:** A lexicographic ordering of tuple values on the composite search key

Example
<3, 20> precedes <4, 25>

Indexes on Multiple Keys

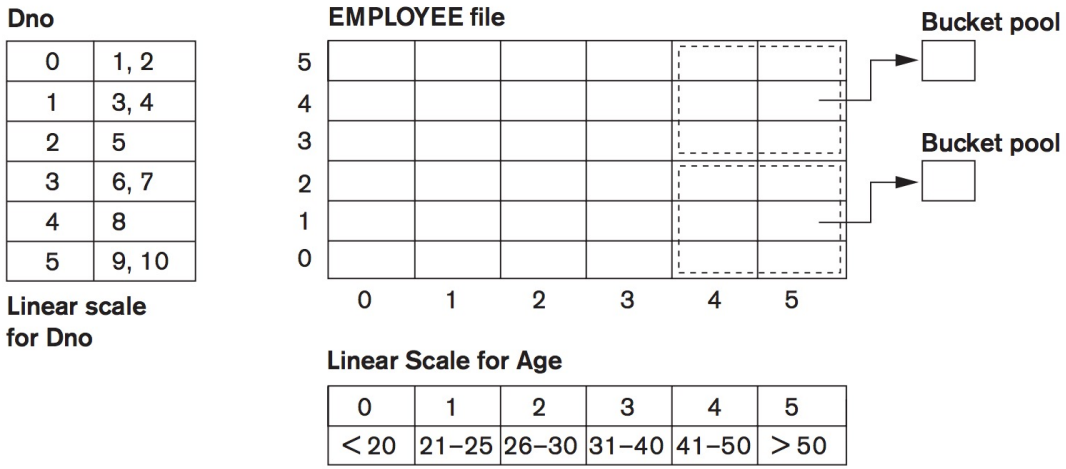
- **Partitioned Hashing**: a key consisting of n components, the hash function is designed to produce a result with n separate hash addresses.

Example:

Suppose Dno and Age are hashed into a 3-bit and 5-bit address
Dno = 4 →hash address '100'
Age = 59 → hash address '10101'
searching for Dno = 4 and Age = 59 → 100 10101
searching for Age = 59 → XXX 10101

Indexes on Multiple Keys

- **Grid Files:** a grid array with one linear scale (or dimension) for each of the search attributes. This method is particularly useful for range queries that would map into a set of cells corresponding to a group of values along the linear scales.



Example:

Dno = 4 and Age = 59 maps into the cell (1, 5)

Dno = 4 maps into row 1

In-class exercise

- Suppose you know that the following queries are the most common queries in the database and that all are roughly equivalent in frequency and importance:
  - Find students with snum < 1000
  - find students in ‘computer science’
  - find students that are younger than 20
  - Find students in ‘computer science’ that are ’20’

Student(snum,sname,major,age)
Class(name,meets_at,room,fid)
Enrolled(snum,cname)

- Given this information, decide which attributes should be indexed and whether each index should be a clustered index or an unclustered index. Assume that both B+ trees and hashed indexes are supported by the DBMS and that both single- and multiple-attribute index search keys are permitted.

Indexing

- Suppose you know that the following queries are the most common queries in the database and that all are roughly equivalent in frequency and importance:

Student(snum,sname,major,age)
Class(name,meets_at,room,fid)
Enrolled(snum,cname)

- Find students with snum < 1000

This is a range query on primary key, so a single-attribute primary index using B+ Tree indexes

- find students in 'computer science'

This is an equality query on non-primary key, so a single-attribute secondary index using hash-based indexes

- find students that are younger than 20

This is a range query on non-primary key, so a single-attribute secondary index using B+ Tree indexes

- Find students in 'computer science' that are 20

This is a query on conjunctive selection constraints, so a non-primary key, so a multi-attribute index using partition hashing or grid files.

CREATE INDEX Syntax

```
CREATE [UNIQUE|FULLTEXT|SPATIAL] INDEX index_name
    [index_type]
    ON tbl_name (index_col_name,...)
    [index_option]
    [algorithm_option | lock_option] ...


index_type:
    USING {BTREE | HASH}

algorithm_option:
    ALGORITHM [=] {DEFAULT|INPLACE|COPY}

lock_option:
    LOCK [=] {DEFAULT|NONE|SHARED|EXCLUSIVE}
```

https://dev.mysql.com/doc/refman/5.7/en/create-index.html