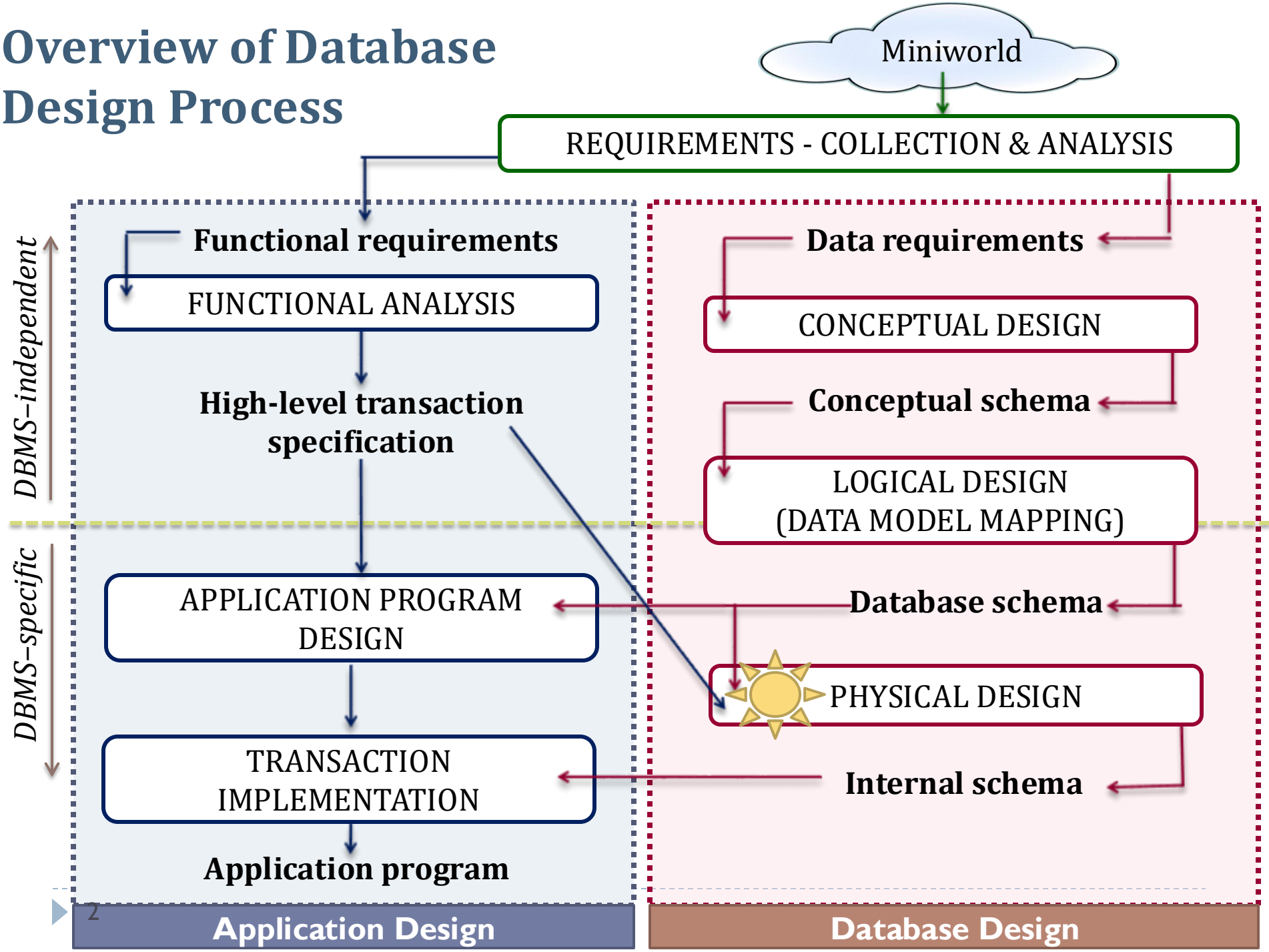
Data Storage, Indexing Structures for Files

Chapter 8

Overview of Database Design Process



Contents

(*) homework

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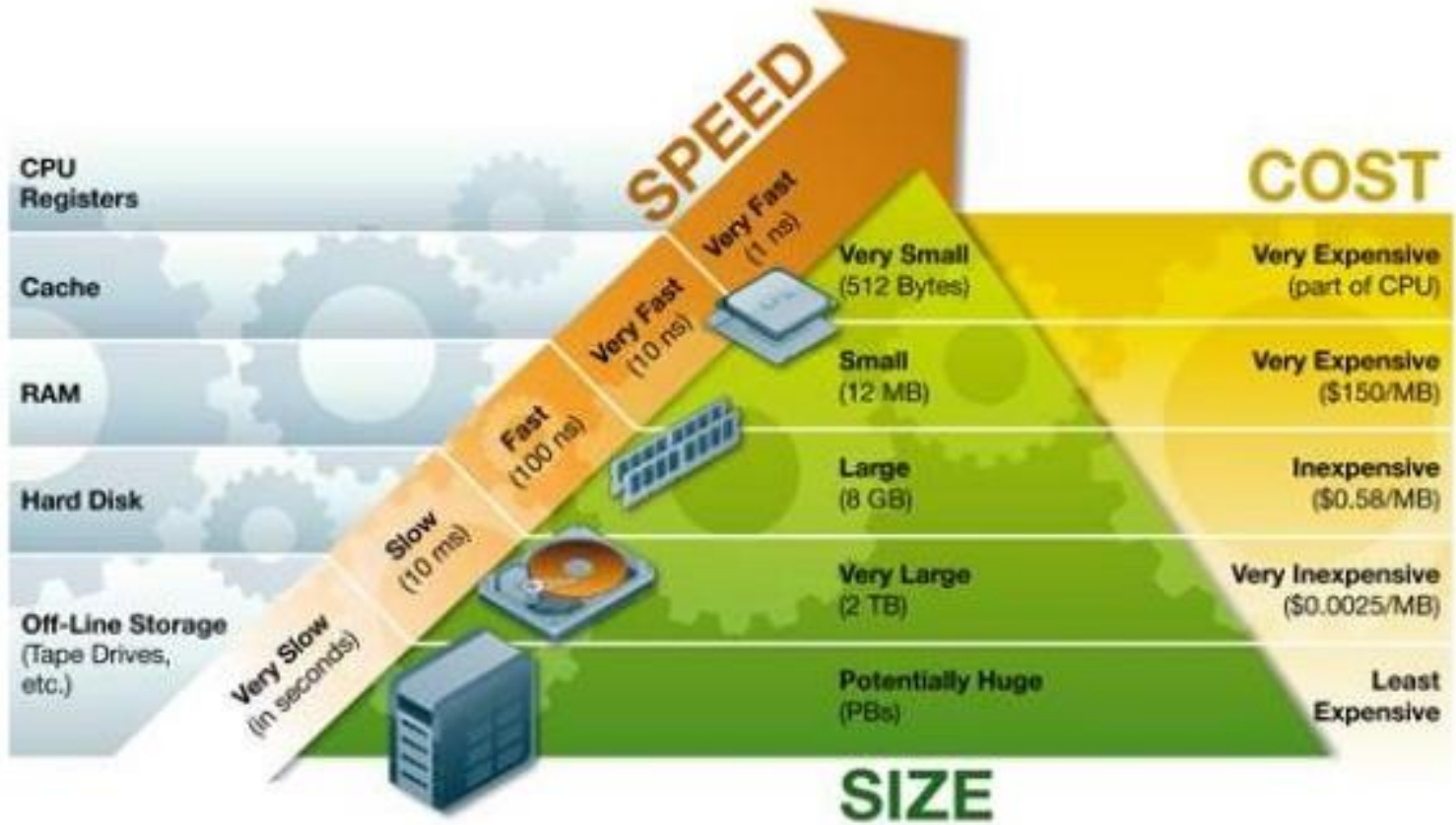
Memory & Storage Hierarchy

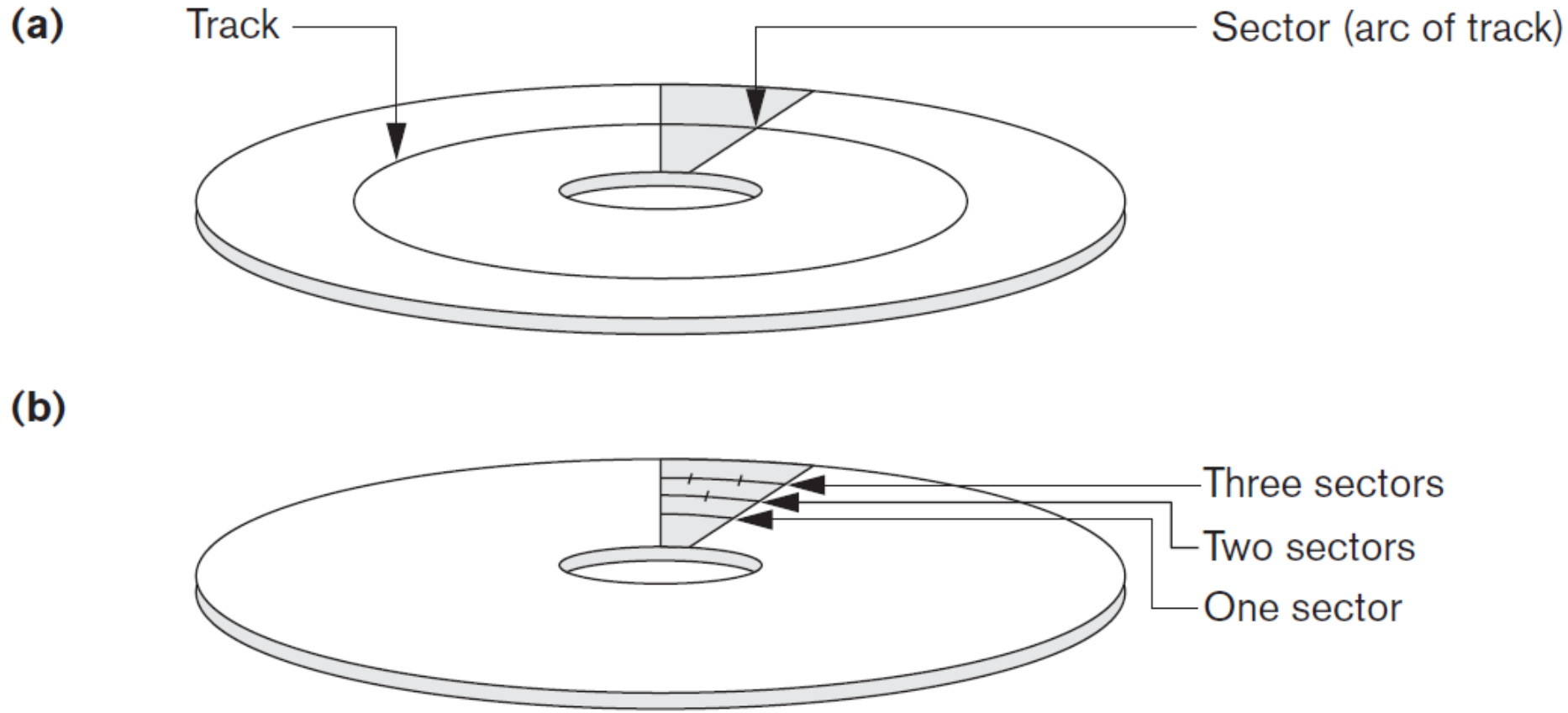


Source: http://www.ts.avnet.com/uk/products_and_solutions/storage/hierarchy.html

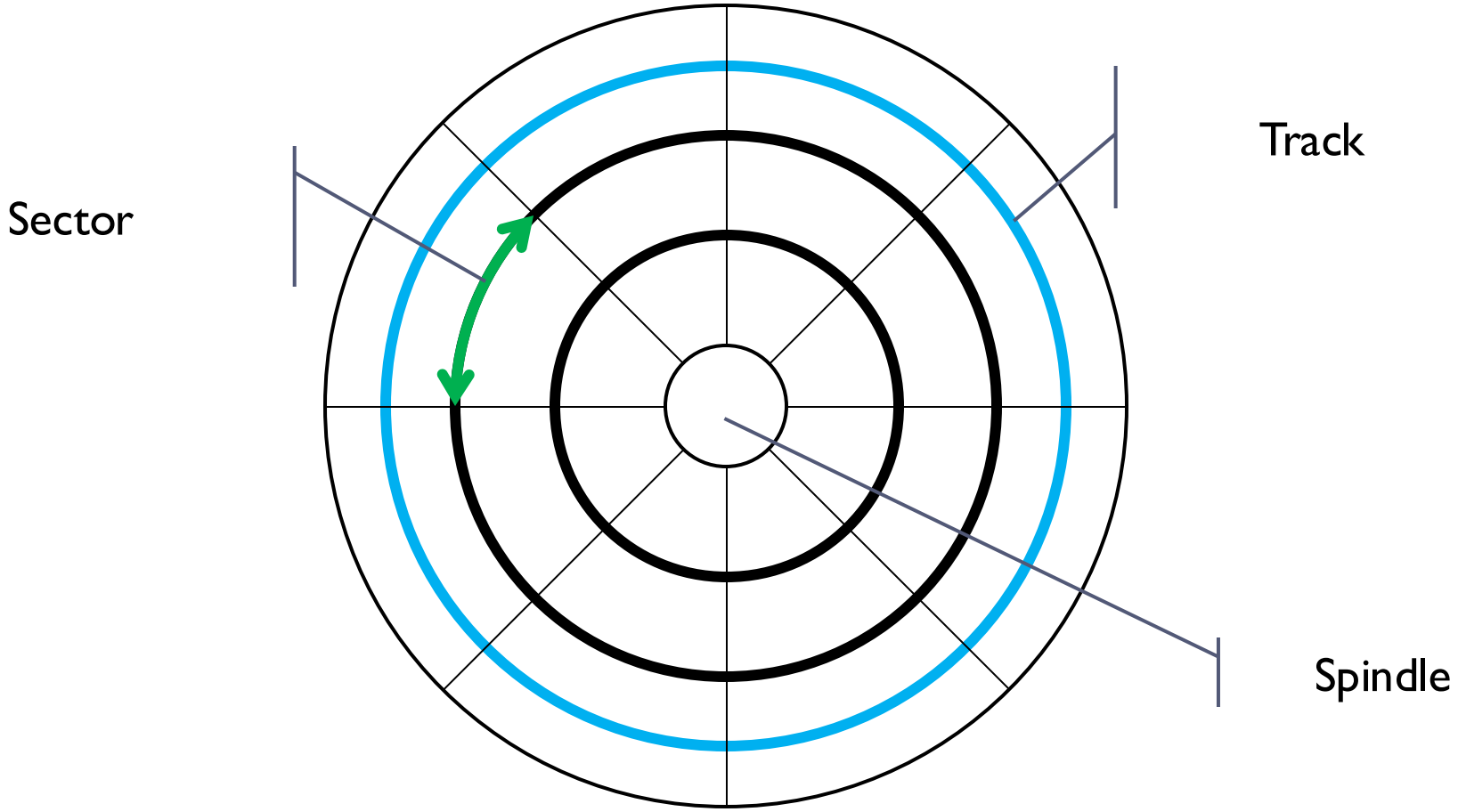
Disk Storage Devices

- Preferred secondary storage device for high storage capacity and low cost.
- Data stored as magnetized areas on magnetic disk surfaces.
- A *disk pack* contains several magnetic disks connected to a rotating spindle.
- Disks are divided into concentric circular *tracks* on each disk *surface* .
  - Track capacities vary typically from 4 to 50 Kbytes.

Disk Storage Devices (cont.)



Disk Storage Devices (cont.)

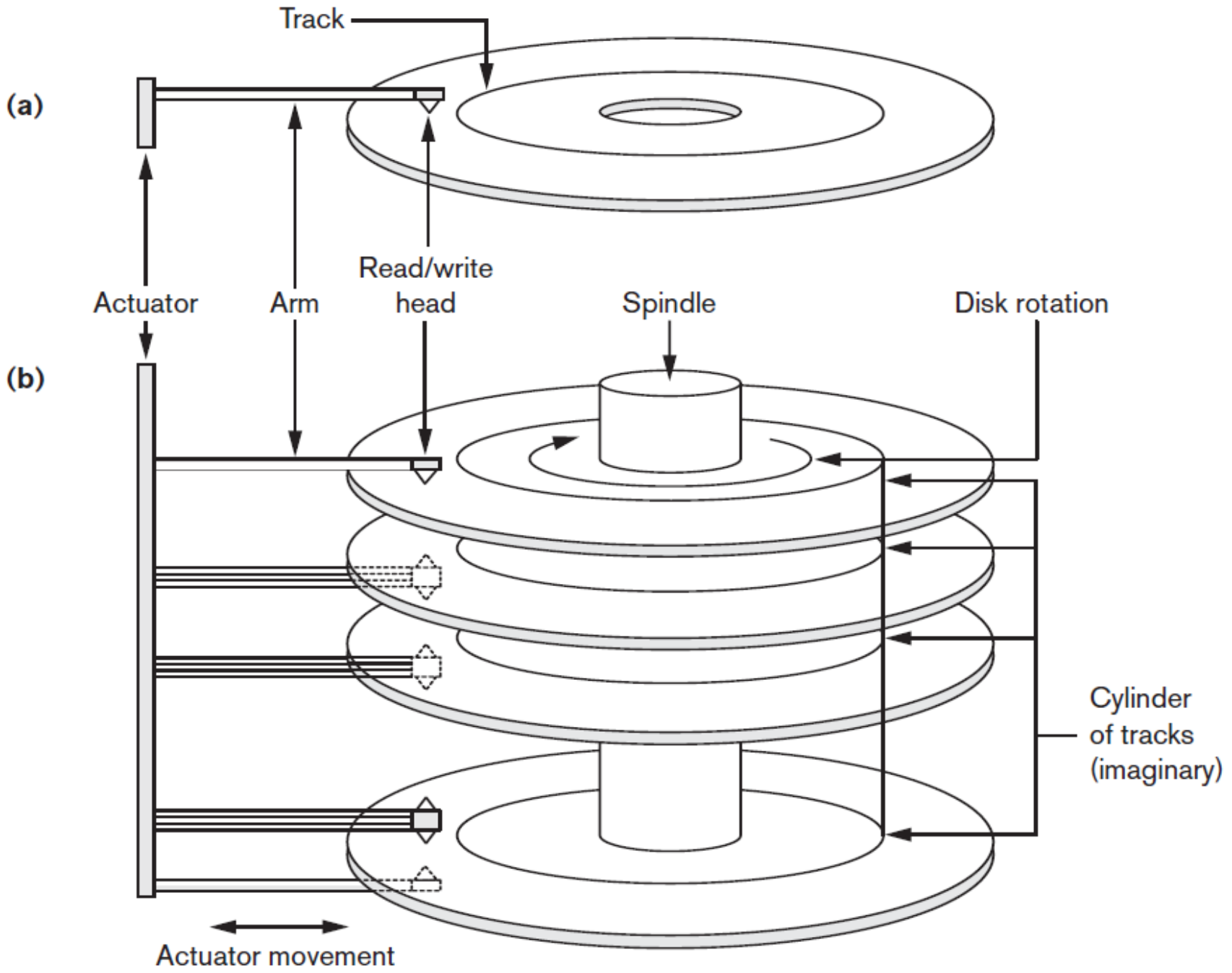


Disk Storage Devices (cont.)

- A track is divided into smaller **blocks** or **sectors.**
  - because a track usually contains a large amount of information .
- A track is divided into **blocks**.
  - The block size B is fixed for each system.
    - Typical block sizes range from B=512 bytes to B=4096 bytes.
  - Whole blocks are transferred between disk and main memory for processing.

Disk Storage Devices (cont.)

- A **read-write head** moves to the track that contains the block to be transferred.
  - Disk rotation moves the block under the read-write head for reading or writing.
- A physical disk block (hardware) address consists of:
  - a cylinder number (imaginary collection of tracks of same radius from all recorded surfaces)
  - the track number or surface number (within the cylinder)
  - and block number (within track).
- Reading or writing a disk block is time consuming because of the seek time s and rotational delay (latency) **rd**.
- *Double buffering* can be used to speed up the transfer of contiguous disk blocks.


Track
(a)
Actuator
Arm
Read/write
head
Spindle
Disk rotation
(b)
Cylinder
of tracks
(imaginary)
Actuator movement

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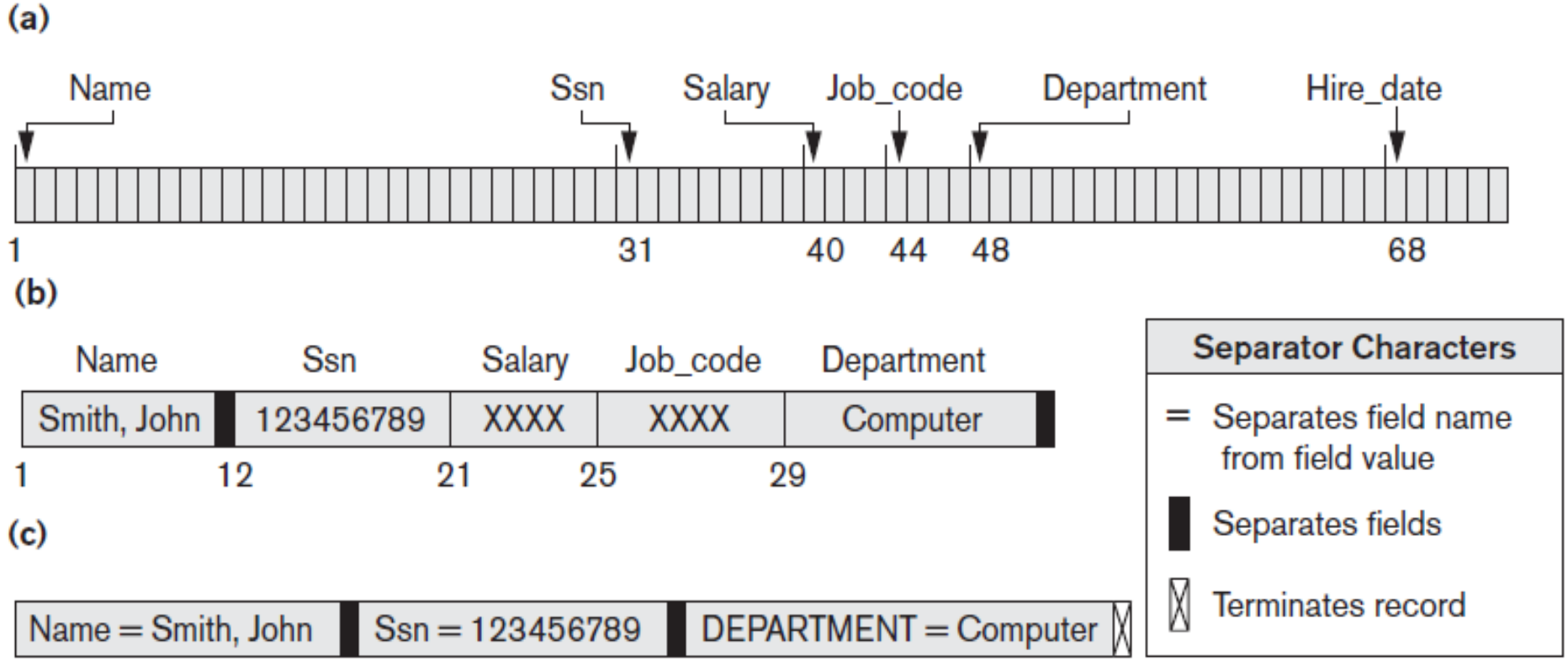
(*) homework

Records

- Fixed and variable length records.
- Records contain fields which have values of a particular type.
  - E.g., amount, date, time, age.
- Fields themselves may be fixed length or variable length.
- Variable length fields can be mixed into one record:
  - Separator characters or length fields are needed so that the record can be “parsed”.

Records (cont.)

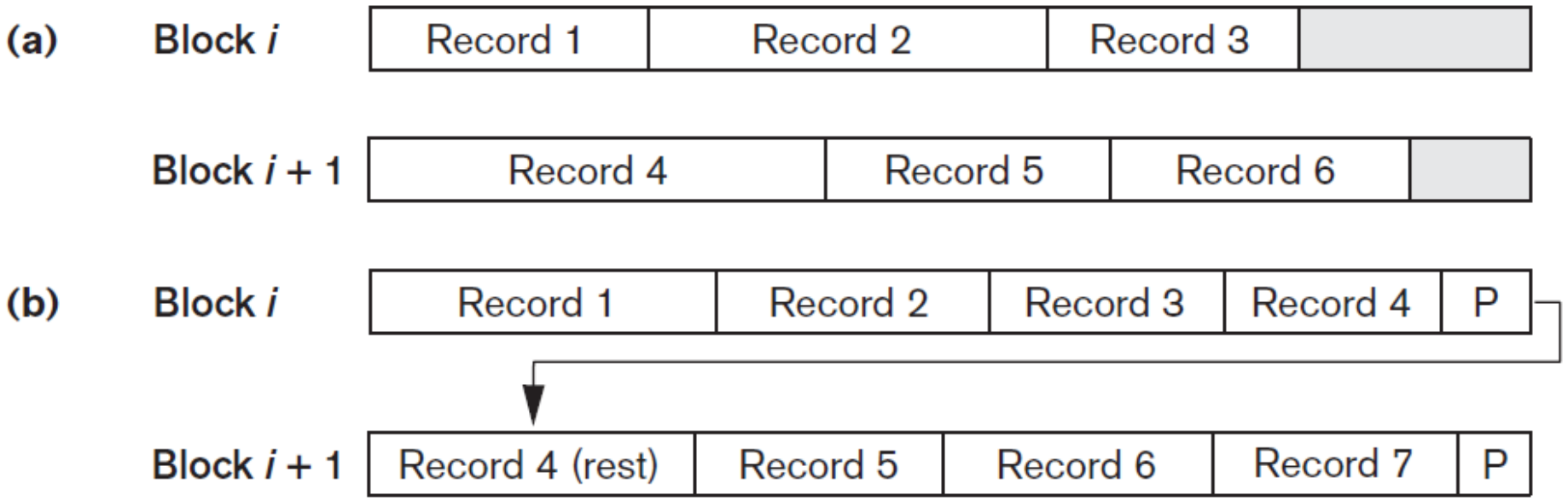


(a)A fixed-length record with 6 fields and size of 71 bytes.
(b)A record with 2 variable-length fields and 3 fixed-length fields.
(c)A variable-field record with 3 types of separator characters.

Blocking

- **Blocking:** refers to storing a number of records in one block on the disk.
- **Blocking factor (*bfr*):** refers to the number of records per block.
- There may be empty space in a block if an integral number of records do not fit in one block.
- **Spanned Records:** refer to records that exceed the size of one or more blocks and hence span a number of blocks.

Blocking (cont.)



(a)Unspanned records
(b)Spanned records

Files of Records

- A **file** is a *sequence* of records, where each record is a collection of data values (or data items).
- A **file descriptor** (or **file header**) includes information that describes the file, such as the *field names* and their *data types*, and the addresses of the file blocks on disk.
- Records are stored on disk blocks.
- The **blocking factor bfr** for a file is the (average) number of file records stored in a disk block.
- A file can have **fixed-length** records or **variable-length** records.

Files of Records (cont.)

- File records can be **unspanned** or **spanned**:
  - **Unspanned**: no record can span two blocks
  - **Spanned**: a record can be stored in more than one block
- The physical disk blocks that are allocated to hold the records of a file can be *contiguous, linked, or indexed*.
- In a file of fixed-length records, all records have the same format. Usually, unspanned blocking is used with such files.
- Files of variable-length records require additional information to be stored in each record, such as **separator characters** and **field types**.
  - Usually spanned blocking is used with such files.

Contents

Operation on Files

- **OPEN:** Reads the file for access, and associates a pointer that will refer to a *current* file record at each point in time.
- **FIND:** Searches for the first file record that satisfies a certain condition, and makes it the current file record.
- **FINDNEXT:** Searches for the next file record (from the current record) that satisfies a certain condition, and makes it the current file record.
- **READ:** Reads the current file record into a program variable.
- **INSERT:** Inserts a new record into the file, and makes it the current file record.

Operation on Files (cont.)

- **DELETE:** Removes the current file record from the file, usually by marking the record to indicate that it is no longer valid.
- **MODIFY:** Changes the values of some fields of the current file record.
- **CLOSE:** Terminates access to the file.
- **REORGANIZE:** Reorganizes the file records. For example, the records marked deleted are physically removed from the file or a new organization of the file records is created.
- **READ_ORDERED:** Read the file blocks in order of a specific field of the file.

Contents

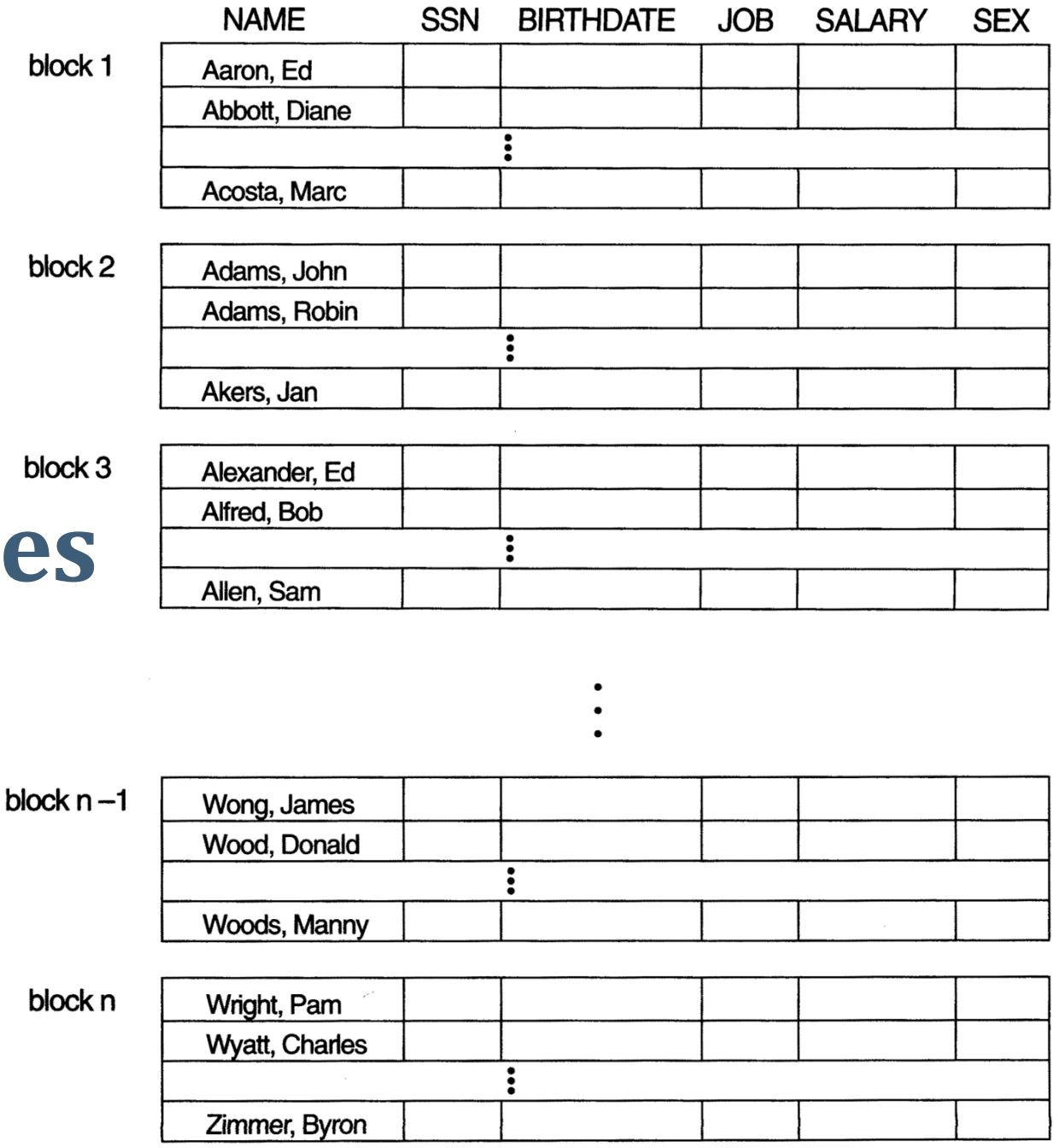
Unordered Files

- Also called a **heap** or a **pile** file.
- New records are inserted at the end of the file.
- A **linear search** through the file records is necessary to search for a record.
  - This requires reading and searching half the file blocks on the average, and is hence quite expensive.
- Record insertion is quite efficient.
- Reading the records in order of a particular field requires sorting the file records.

Ordered Files

- Also called a **sequential** file.
- File records are kept sorted by the values of an *ordering field*.
- Insertion is expensive: records must be inserted in the correct order.
  - It is common to keep a separate unordered *overflow* (or *transaction*) file for new records to improve insertion efficiency; this is periodically merged with the main ordered file.
- A **binary search** can be used to search for a record on its *ordering field* value.
  - This requires reading and searching $\log_2$ of the file blocks on the average, an improvement over linear search.
- Reading the records in order of the ordering field is quite efficient.

Ordered Files (cont.)



Average Access Times

- The following table shows the average access time to access a specific record for a given type of file:

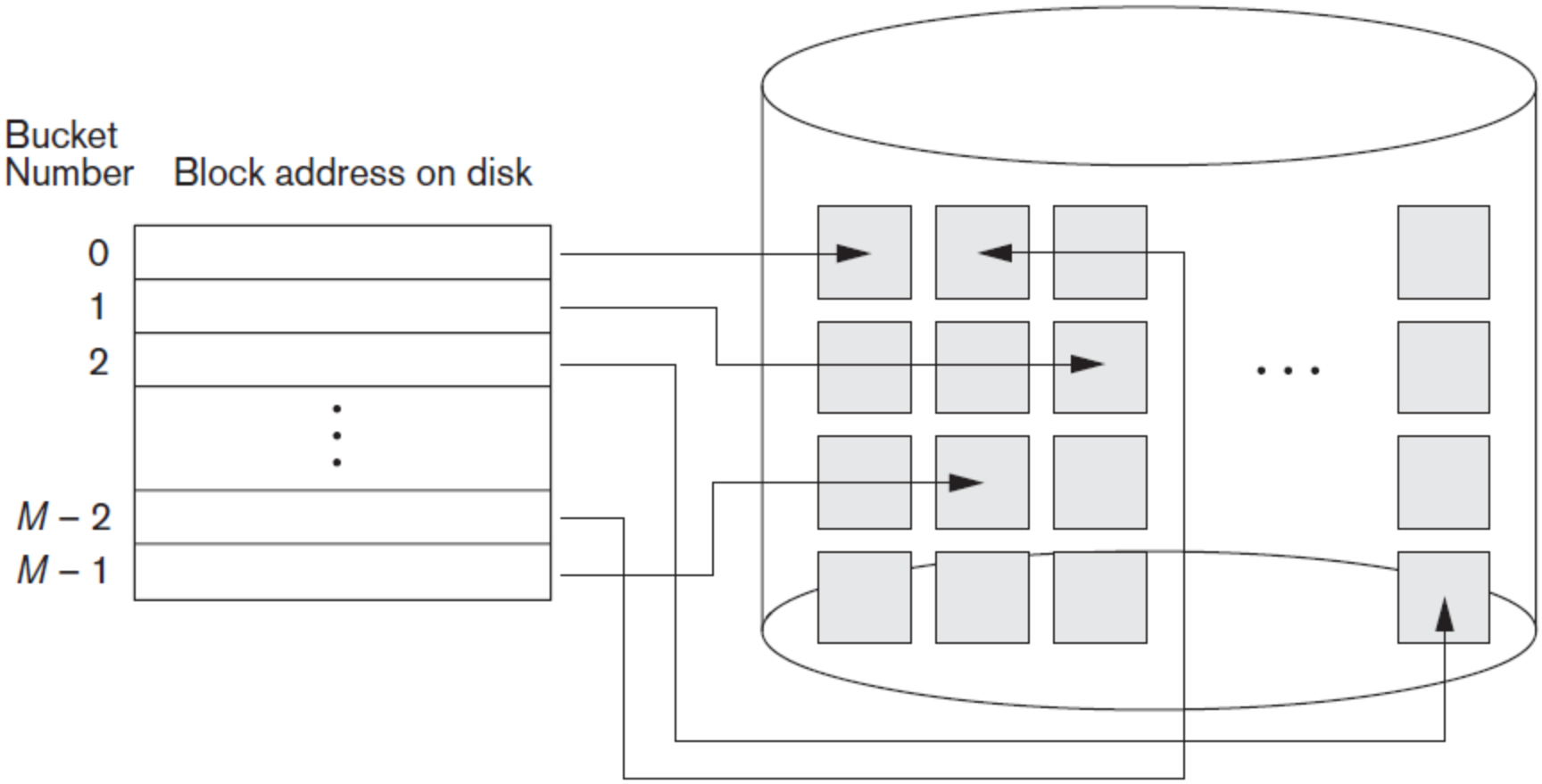
Table 17.2 Average Access Times for a File of *b* Blocks under Basic File Organizations

Type of Organization	Access/Search Method	Average Blocks to Access a Specific Record
Heap (unordered)	Sequential scan (linear search)	$b/2$
Ordered	Sequential scan	$b/2$
Ordered	Binary search	$\log_2 b$

Hashed Files

- Hashing for disk files is called **External Hashing.**
- The file blocks are divided into M equal-sized **buckets**, numbered $bucket_0$, $bucket_1$, ..., $bucket_{M-1}$.
  - Typically, a bucket corresponds to one (or a fixed number of) disk block.
- One of the file fields is designated to be the **hash key** of the file.
- The record with hash key value K is stored in bucket i, where i=h(K), and h is the **hashing function**.
- Search is very efficient on the hash key.
- Collisions occur when a new record hashes to a bucket that is already full.
  - An overflow file is kept for storing such records.
  - Overflow records that hash to each bucket can be linked together

Hashed Files (cont.)



Hashed Files (cont.)

- There are numerous methods for collision resolution, including the following:
  - ***Open addressing:*** Proceeding from the occupied position specified by the hash address, the program **checks the subsequent positions in order until an unused** (empty) position is found.

- h(K) = K mod 7

0	1	2	3	4	5	6
	1		3	11		6

- Insert 8

	1	8	3	11		6

- Insert 15

	1	8	3	11	15	6

- Insert 13

13	1	8	3	11	15	6

Hashed Files (cont.)

- There are numerous methods for collision resolution, including the following:
  - ***Chaining:***
    - Various overflow locations are kept: extending the array with a number of overflow positions.
    - A pointer field is added to each record location.
    - A collision is resolved by placing the new record in an unused overflow location and setting the pointer of the occupied hash address location to the address of that overflow location.
  - ***Multiple hashing:***
    - The program applies a second hash function if the first results in a collision.
    - If another collision results, the program uses open addressing or applies a third hash function and then uses open addressing if necessary.

Hashed Files (cont.) - Overflow handling

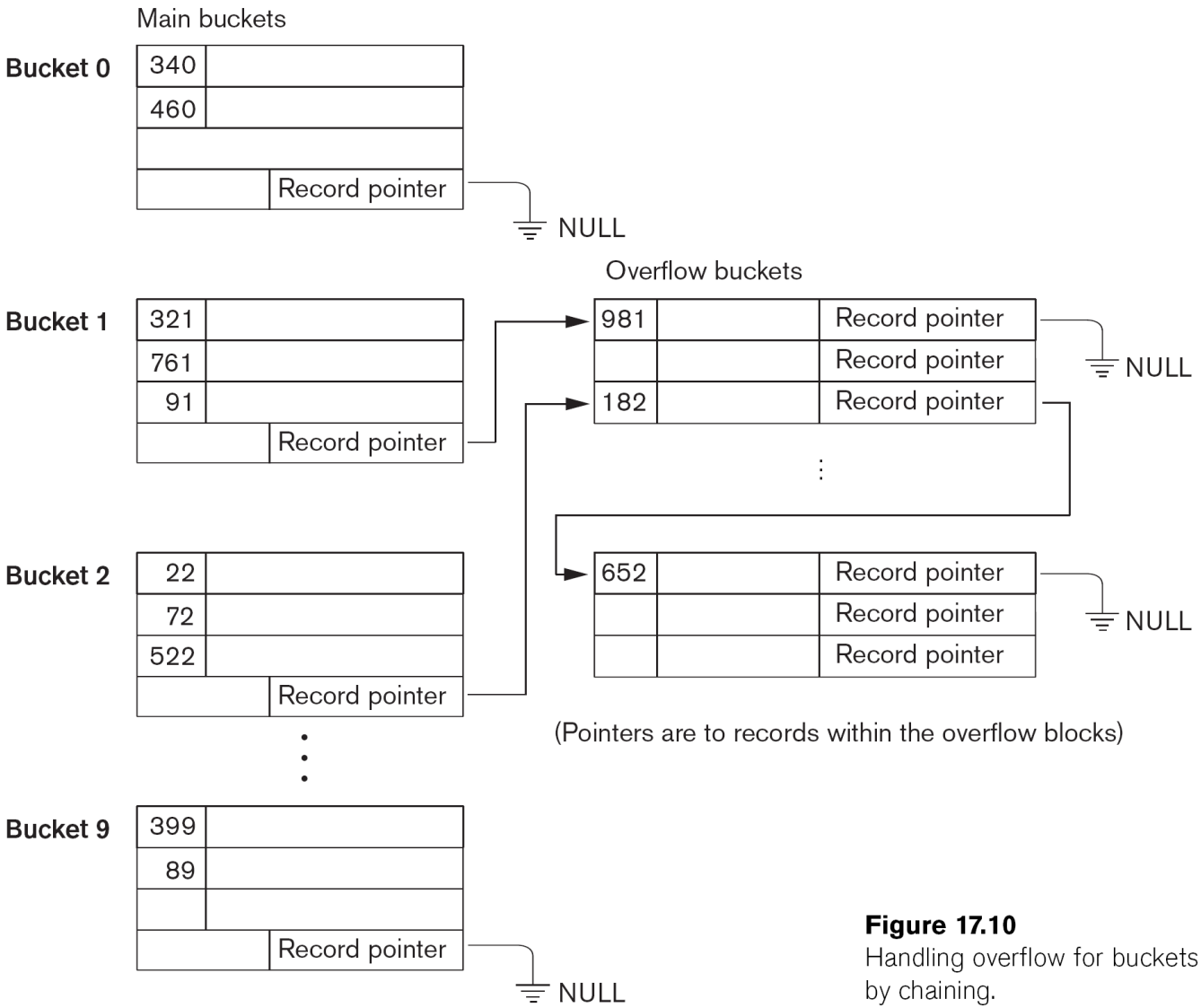


Figure 17.10
Handling overflow for buckets by chaining.

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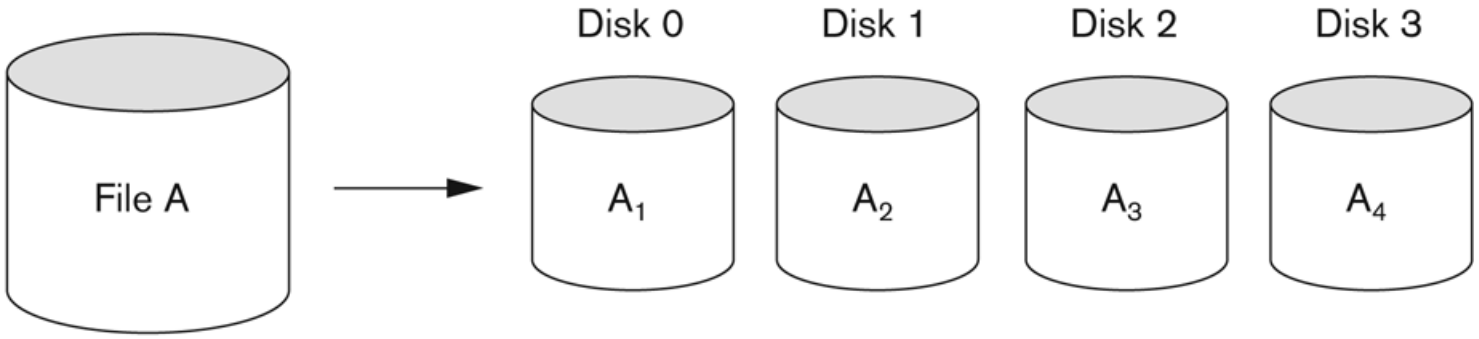
Parallelizing Disk Access using RAID Technology

- Secondary storage technology must take steps to keep up in performance and reliability with processor technology.
- A major advance in secondary storage technology is represented by the development of **RAID**, which originally stood for **Redundant Arrays of Inexpensive Disks.**
- The main goal of RAID is to even out the widely different rates of performance improvement of disks against those in memory and microprocessors.

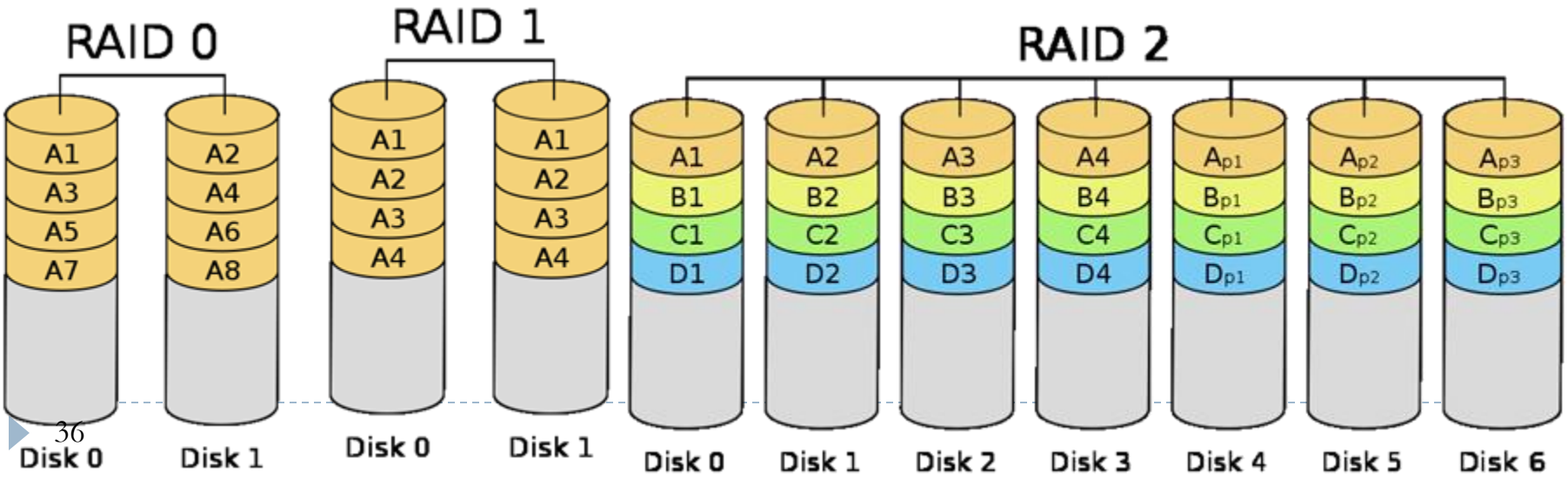
RAID Technology (cont.)

- A natural solution is a large array of small independent disks acting as a single higher-performance logical disk.
- A concept called **data striping** is used, which utilizes *parallelism* to improve disk performance.
- Data striping distributes data transparently over multiple disks to make them appear as a single large, fast disk.



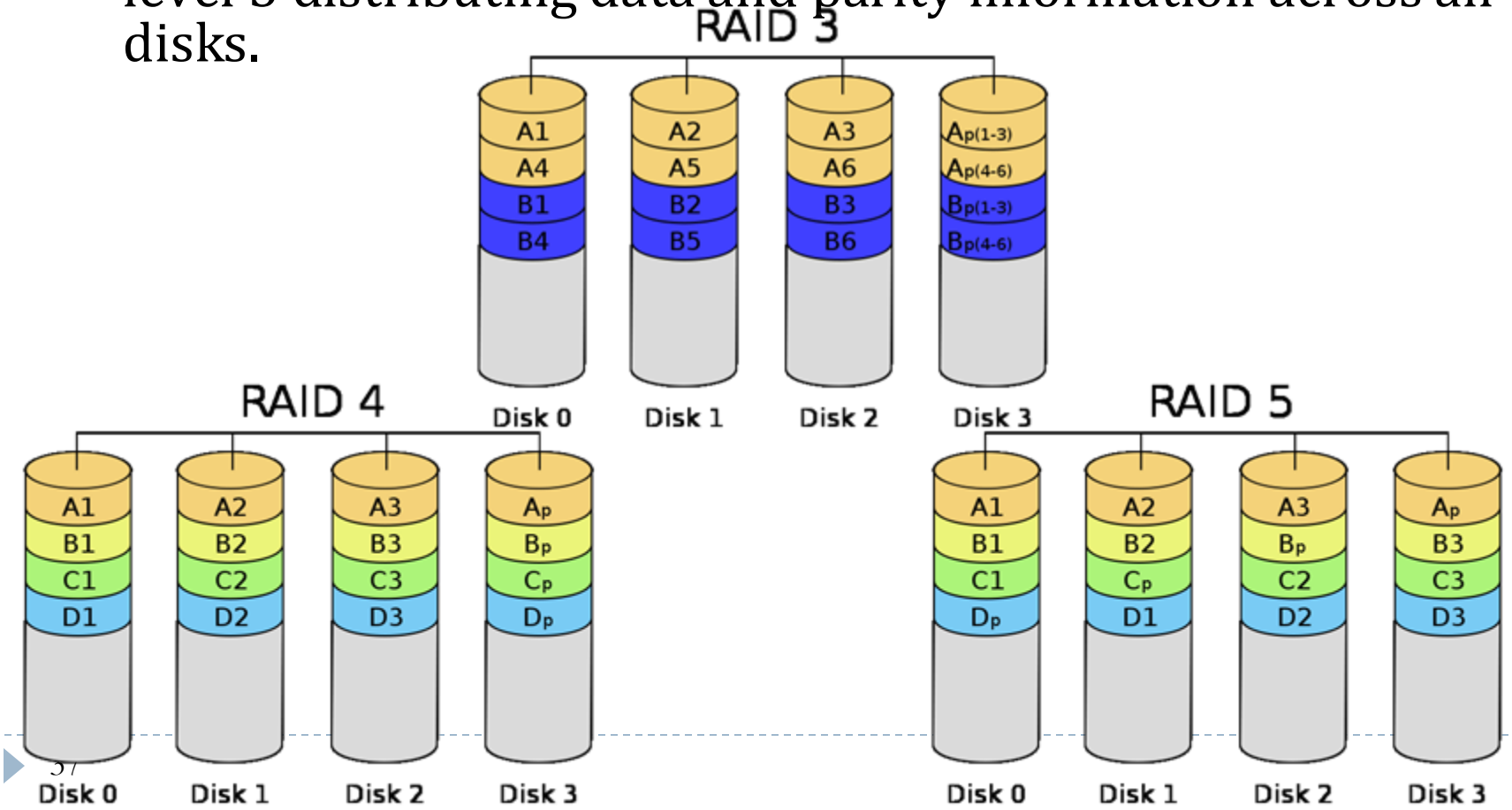
RAID Technology (cont.)

- Different raid organizations were defined based on different combinations of the two factors of granularity of data interleaving (striping) and pattern used to compute redundant information.
  - **Raid level 0** has no redundant data and hence has the best write performance.
  - **Raid level 1** uses mirrored disks.
  - **Raid level 2** uses memory-style redundancy by using Hamming codes, which contain parity bits for distinct overlapping subsets of components. Level 2 includes both error detection and correction.



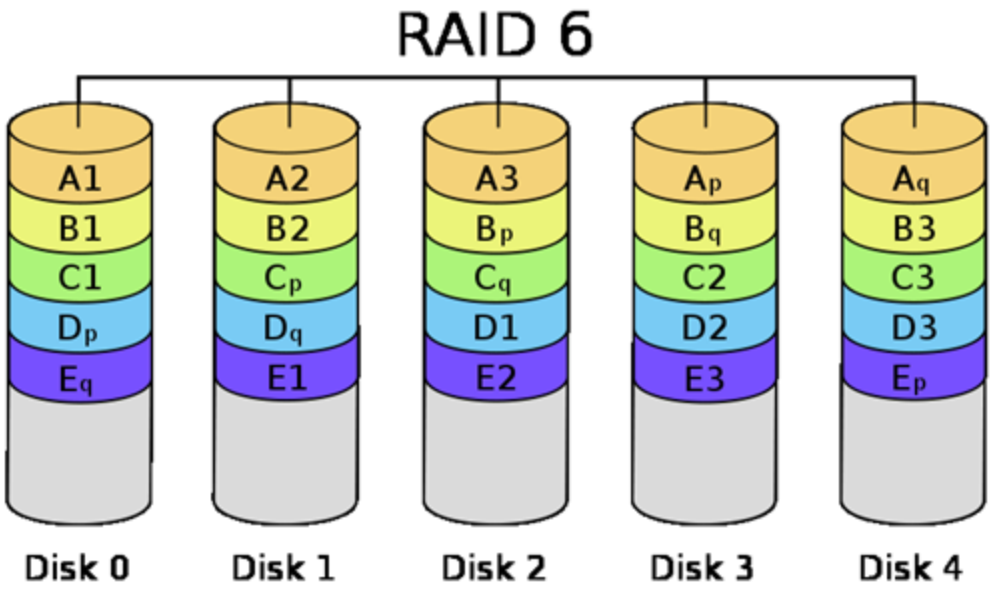
RAID Technology (cont.)

- **Raid level 3** uses a single parity disk relying on the disk controller to figure out which disk has failed.
- **Raid levels 4 and 5** use block-level data striping, with level 5 distributing data and parity information across all disks.



RAID Technology (cont.)

- **Raid level 6** applies the so-called $P + Q$ redundancy scheme using Reed-Soloman codes to protect against up to two disk failures by using just two redundant disks.



Use of RAID Technology (cont.)

- Different raid organizations are being used under different situations:
  - Raid level 1 (mirrored disks)is the easiest for rebuild of a disk from other disks
    - It is used for critical applications like logs.
  - Raid level 2 uses memory-style redundancy by using Hamming codes, which contain parity bits for distinct overlapping subsets of components. Level 2 includes both error detection and correction.
  - Raid level 3 (single parity disks relying on the disk controller to figure out which disk has failed) and level 5 (block-level data striping) are preferred for large volume storage, with level 3 giving higher transfer rates.
  - Most popular uses of the RAID technology currently are: Level 0 (with striping), Level 1 (with mirroring) and Level 5 with an extra drive for parity.
  - Design decisions for RAID include – level of RAID, number of disks, choice of parity schemes, and grouping of disks for block-level striping.

Storage Area Networks

- The demand for higher storage has risen considerably in recent times.
- Organizations have a need to move from a static fixed data center oriented operation to a more flexible and dynamic infrastructure for information processing.
- Thus they are moving to a concept of Storage Area Networks (SANs).
  - In a SAN, online storage peripherals are configured as nodes on a high-speed network and can be attached and detached from servers in a very flexible manner.
- This allows storage systems to be placed at longer distances from the servers and provide different performance and connectivity options.

Storage Area Networks (cont.)

- **Advantages of SANs are:**
  - Flexible many-to-many connectivity among servers and storage devices using fiber channel hubs and switches.
  - Up to 10km separation between a server and a storage system using appropriate fiber optic cables.
  - Better isolation capabilities allowing nondisruptive addition of new peripherals and servers.
- SANs face the problem of combining storage options from multiple vendors and dealing with evolving standards of storage management software and hardware.

Contents

Indexes as Access Paths

- A single-level 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 (although it could be specified on several fields)
- One form of an index is a file of entries <**field value, pointer to record>**, which is ordered by field value
- The index is called an access path on the field.

Indexes as Access Paths (cont.)

- The index file usually occupies considerably less disk blocks than the data file because its entries are much smaller.
- A *binary search* on the index yields a pointer to the file record.
- Indexes can also be characterized as dense or sparse:
  - 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**, on the other hand, has index entries for only some of the search values

Example

Given the following data file: EMPLOYEE(NAME, SSN, ADDRESS, JOB, SAL, ...)

Suppose that:

- record size R=150 bytes, block size B=512 bytes, r=30000 records
- SSN Field size V_{SSN}=9 bytes, record pointer size P_R=7 bytes

Then, we get:

- blocking factor: $bfr = \lfloor B/R \rfloor = \lfloor 512/150 \rfloor = 3$ records/block
- number of blocks needed for the file: $b = \lceil r/bfr \rceil = \lceil 30000/3 \rceil = 10000$ blocks

For an dense index on the SSN field:

- index entry size: $R_i = (V_{SSN} + P_R) = (9+7) = 16$ bytes
- index blocking factor $bfr_i = \lfloor B/R_I \rfloor = \lfloor 512/16 \rfloor = 32$ entries/block
- number of blocks for index file: $b_i = \lceil r/bfr_i \rceil = (30000/32) = 938$ blocks
- search for and retrieve a record needs: $\lceil \log_2 b_i \rceil + 1 = \lceil \log_2 938 \rceil + 1 = 11$ block accesses

- This is compared to an average linear search cost of:

$$(b/2) = 10000/2 = 5000 \text{ block accesses}$$

- If the file records are ordered, the binary search cost would be:

$$\lceil \log_2 b \rceil = \lceil \log_2 10000 \rceil = 14 \text{ block accesses}$$

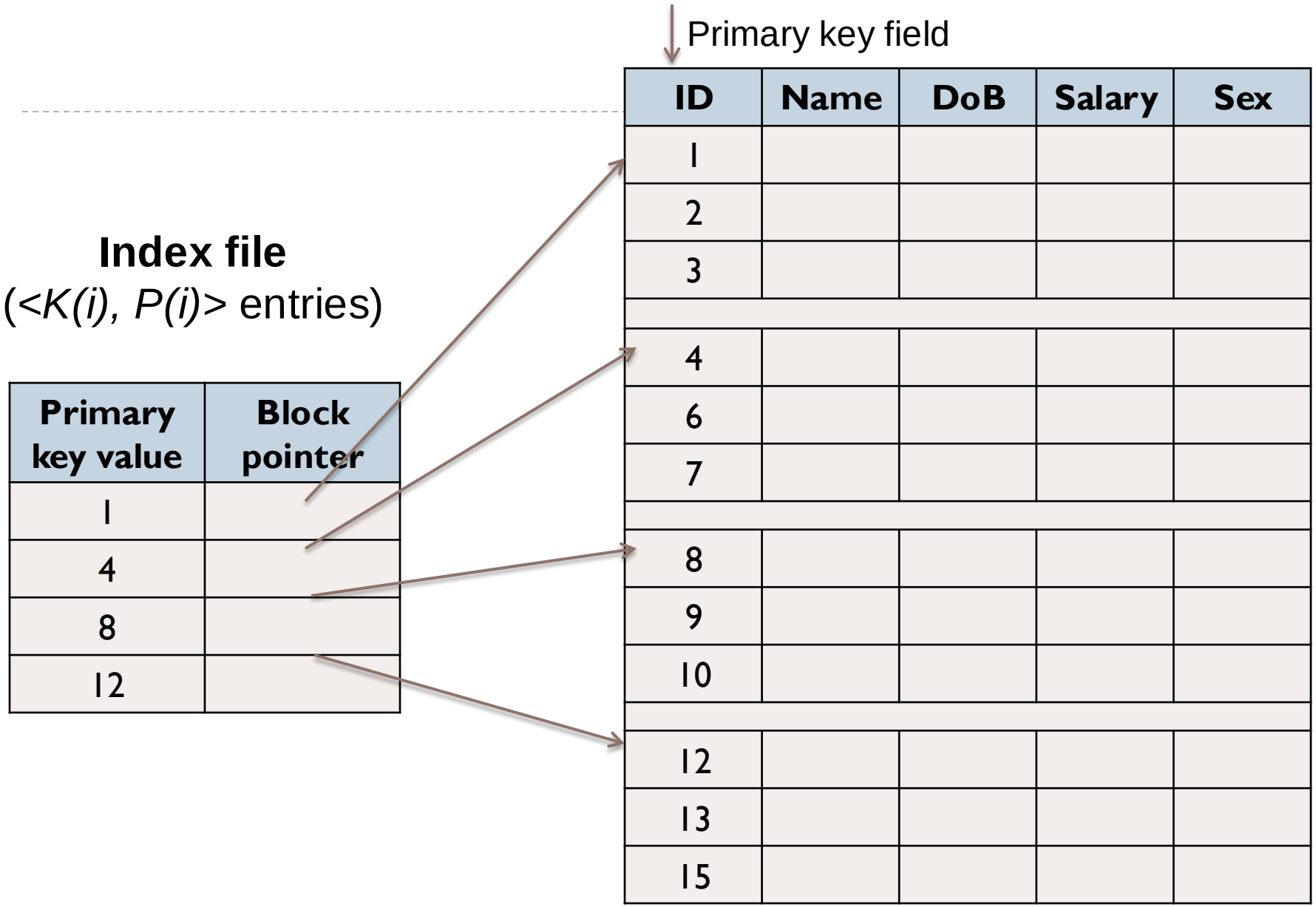
Contents

Types of Single-level Ordered Indexes

- Primary Indexes
- Clustering Indexes
- Secondary Indexes

Primary Index

- Defined on an **ordered data file.**
  - The data file is ordered on a ***key field***.
- One index entry *for each block* in the data file
  - *First record* in the block, which is called the *block anchor*
- A similar scheme can use the *last record* in a block.


Primary key field
Index file
(<K(i), P(i)> entries)
Primary key value
Block pointer
1
4
8
12
ID
Name
DoB
Salary
Sex
1
2
3
4
6
7
8
9
10
12
13
15

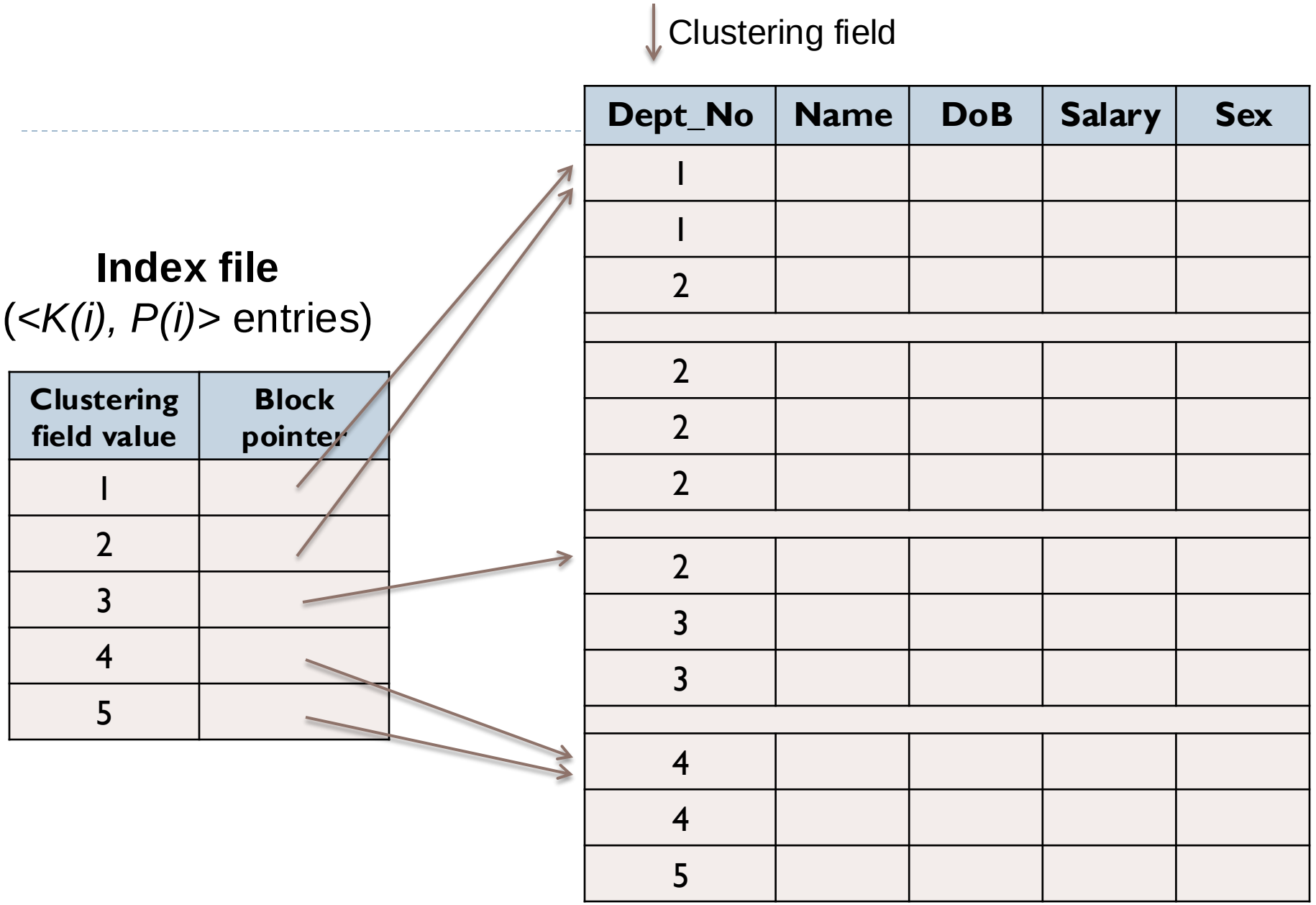
Primary Index

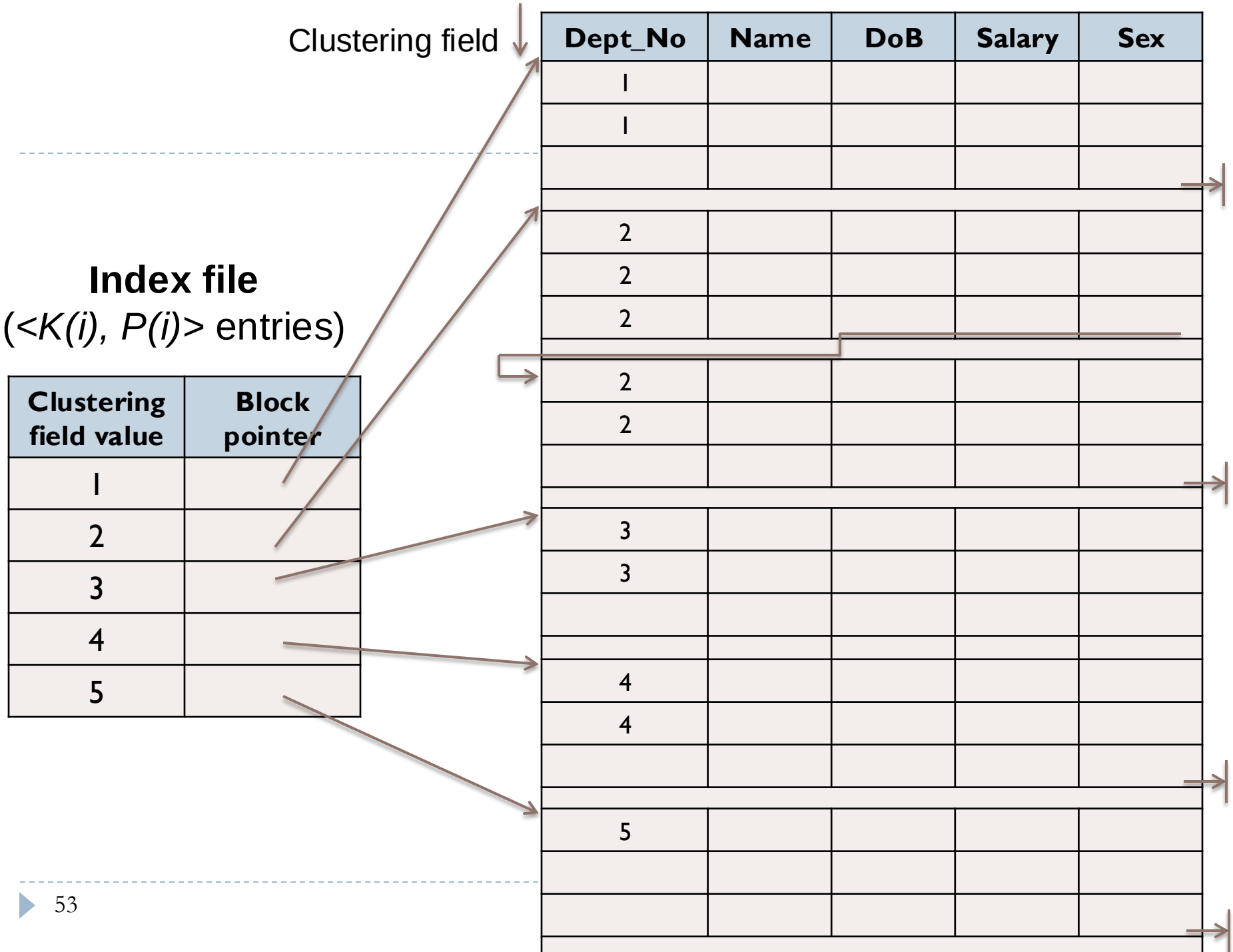
- Number of index entries?
  - Number of blocks in data file.
- Dense or Nondense?
  - Nondense
- Search/ Insert/ Update/ Delete?

Clustering Index

- Defined on an **ordered data file.**
  - The data file is ordered on a *non-key field*.

- One index entry *each distinct value* of the field.
  - The index entry points to the *first data block* that contains records with that field value


Clustering field
Index file
(<K(i), P(i)> entries)
Clustering field value
Block pointer
1
2
3
4
5
Dept_No
Name
DoB
Salary
Sex
1
1
2
2
2
2
2
3
3
3
4
4
5


Clustering field
Dept_No
Name
DoB
Salary
Sex
Index file
(<K(i), P(i)> entries)
Clustering field value
Block pointer
1
2
3
4
5

Clustering Index

- Number of index entries?
  - Number of distinct indexing field values in data file.
- Dense or Nondense?
  - Nondense
- Search/ Insert/ Update/ Delete?
- At most **one primary index or one clustering index but not both.**

Secondary index

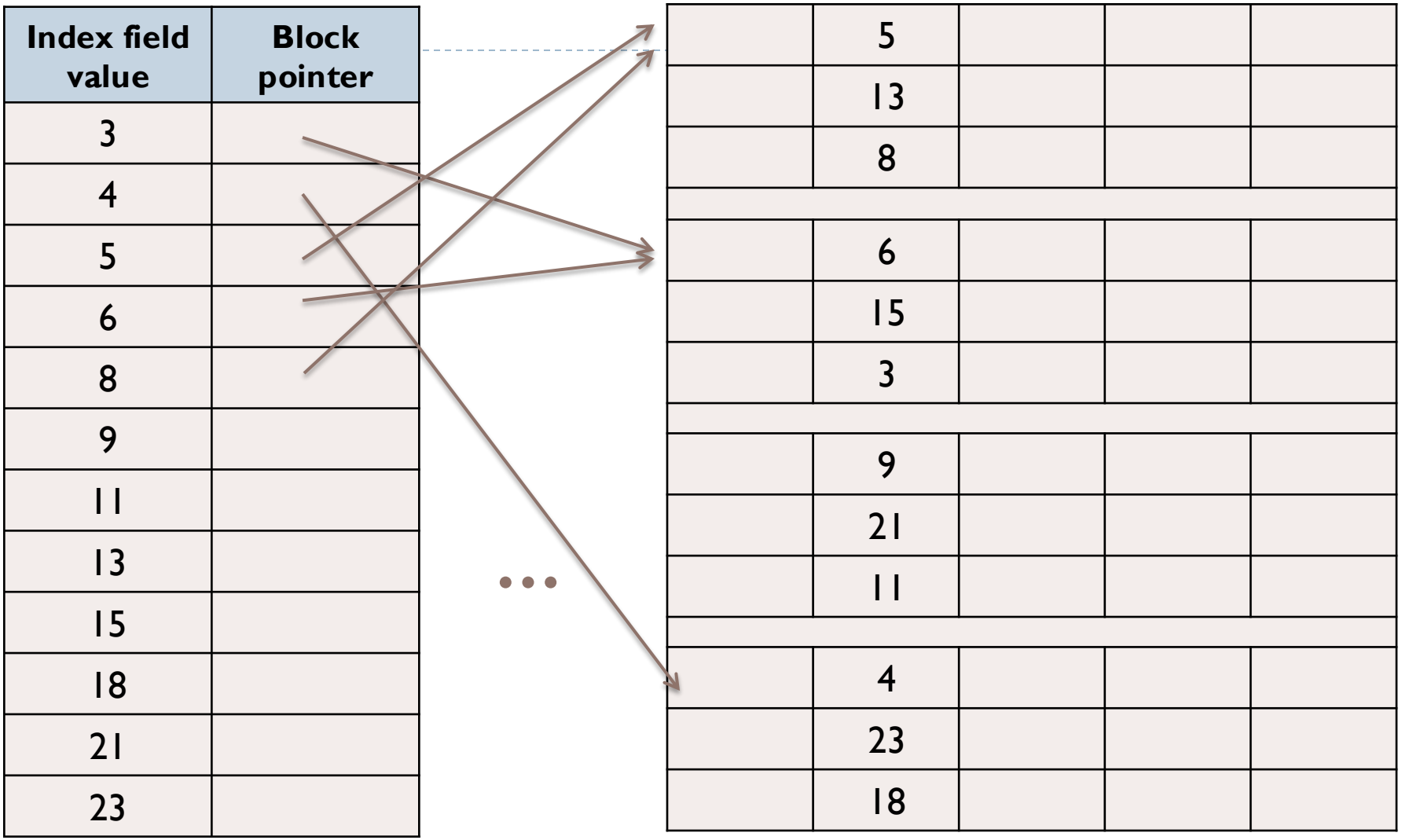
- A secondary index provides a secondary means of accessing a file.
  - The data file is unordered on indexing field.
- Indexing field:
  - secondary key (unique value)
  - nonkey (duplicate values)
- The index is an ordered file with two fields.
  - The first field: *indexing field.*
  - The second field: *block* pointer or *record* pointer.
- There can be ***many*** secondary indexes for the same file.

Index file
(<*K(i)*, *P(i)*> entries)

Index field value	Block pointer
3	
4	
5	
6	
8	
9	
11	
13	
15	
18	
21	
23	

Secondary key field

	5			
	13			
	8			
	6			
	15			
	3			
	9			
	21			
	11			
	4			
	23			
	18			



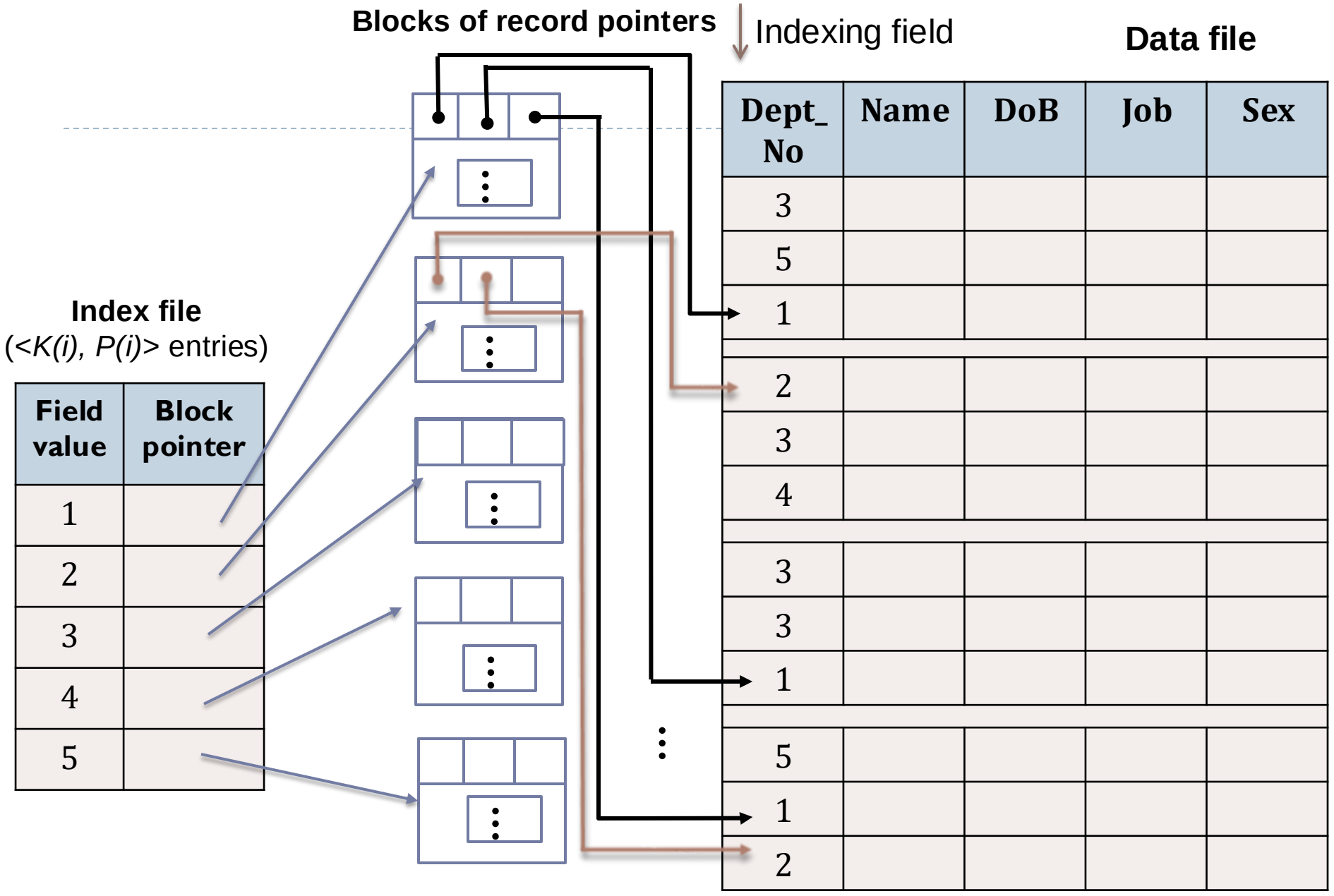
Secondary index on key field

Secondary index on key field

- Number of index entries?
  - Number of record in data file
- Dense or Nondense?
  - Dense
- Search/ Insert/ Update/ Delete?

Secondary index on non-key field

- **Discussion:** Structure of Secondary index on non-key field?
- Option 1: include **duplicate index entries** with the same $K(i)$ value - one for each record.
- Option 2: keep a **list of pointers** $<P(i, 1), ..., P(i, k)>$ in the index entry for $K(i)$.
- Option 3:
  - more commonly used.
  - one entry for each *distinct index field value* + *an* **extra level of indirection** to handle the multiple pointers.



Secondary Index on non-key field: option 3

Secondary index on nonkey field

- Number of index entries?
  - Number of records in data file
  - Number of distinct index field values
- Dense or Nondense?
  - Dense/ nondense
- Search/ Insert/ Update/ Delete?

Summary of Single-level indexes

- Ordered file on indexing field?
  - Primary index
  - Clustering index
- Indexing field is Key?
  - Primary index
  - Secondary index
- Indexing field is not Key?
  - Clustering index
  - Secondary index

Summary of Single-level indexes

- Dense index?
  - Secondary index
- Nondense index?
  - Primary index
  - Clustering index
  - Secondary index

Summary of Single-level indexes

Table 18.2 Properties of Index Types

Type of Index	Number of (First-level) Index Entries	Dense or Nondense (Sparse)	Block Anchoring on the Data File
Primary	Number of blocks in data file	Nondense	Yes
Clustering	Number of distinct index field values	Nondense	Yes/no[a]
Secondary (key)	Number of records in data file	Dense	No
Secondary (nonkey)	Number of records[b] or number of distinct index field values[c]	Dense or Nondense	No

[a]Yes if every distinct value of the ordering field starts a new block; no otherwise.
[b]For option 1.
[c]For options 2 and 3.

Example

Given the following data file: EMPLOYEE(NAME, SSN, ADDRESS, JOB, SAL, ...)

Suppose that:

- record size R=150 bytes, block size B=512 bytes, r=30000 records
- SSN Field size V_{SSN}=9 bytes, block pointer size P=6 bytes

Then, we get:

- blocking factor: $bfr = \lfloor B/R \rfloor = \lfloor 512/150 \rfloor = 3$ records/block
- number of blocks needed for the file: $b = \lceil r/bfr \rceil = \lceil 30000/3 \rceil = 10000$ blocks

For a primary index on the ordering key field SSN:

- index entry size: $R_i = (V_{SSN} + P) = (9+6) = 15$ bytes
- index blocking factor $bfr_i = \lfloor B/R_i \rfloor = \lfloor 512/15 \rfloor = 34$ entries/block
- number of blocks for index file: $b_i = \lceil b/bfr_i \rceil = \lceil 10000/34 \rceil = 295$ blocks
- search for and retrieve a record needs: $\lceil \log_2 b_i \rceil + 1 = \lceil \log_2 295 \rceil + 1 = 10$ block accesses

- This is compared to a dense index cost of: 11 block accesses

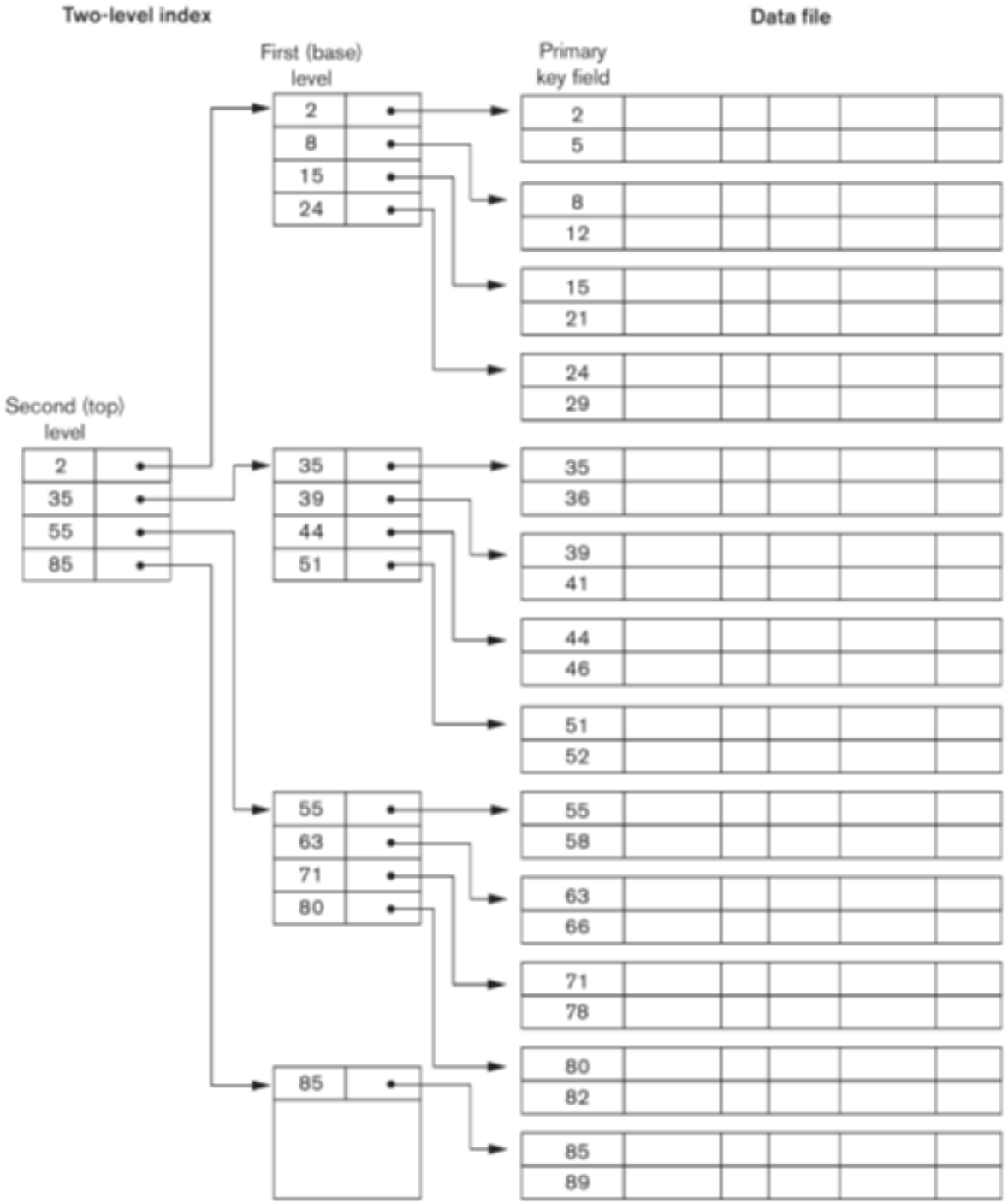
Contents

Multi-Level Indexes

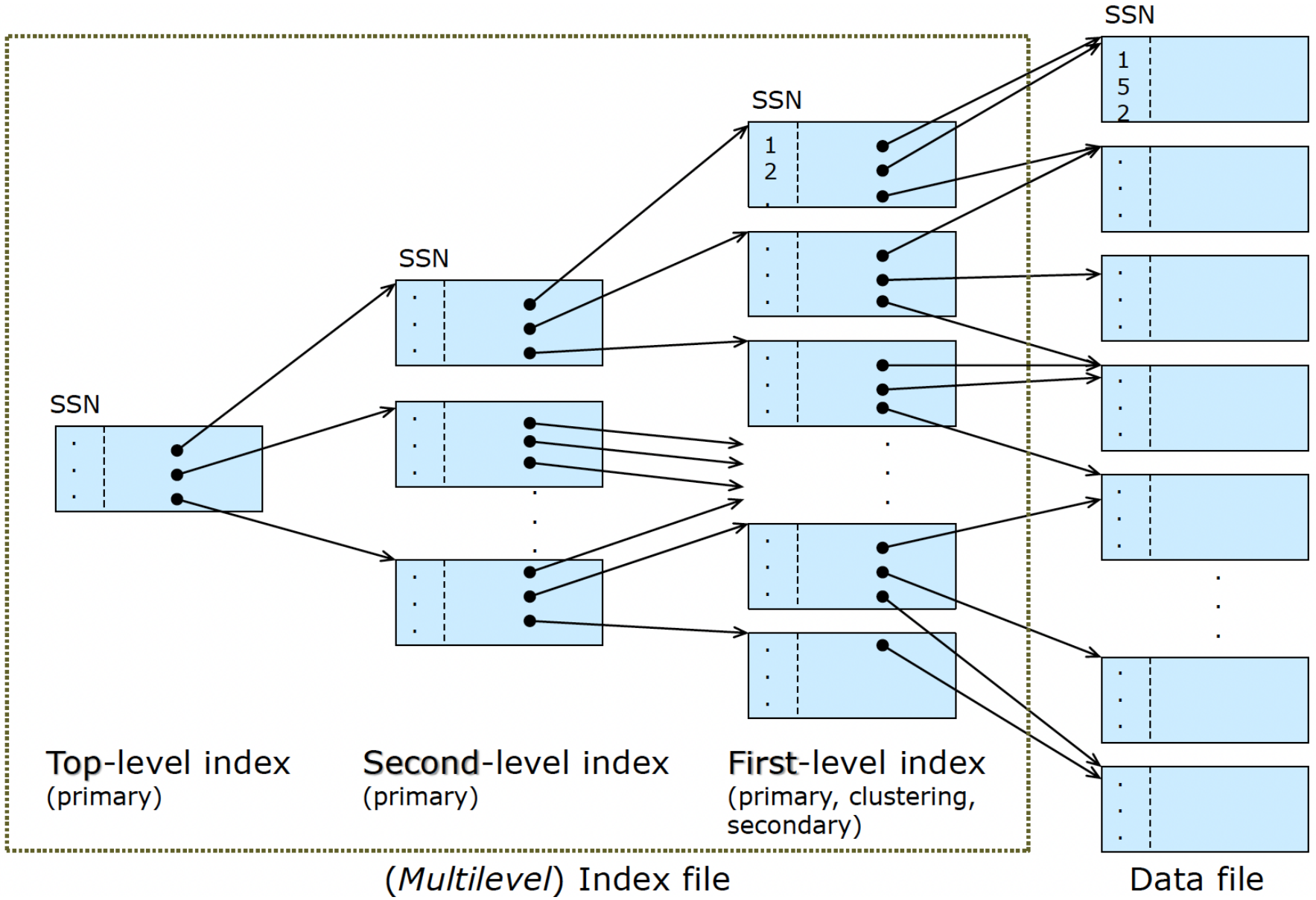
- Because a single-level index is an ordered file, we can **create a primary index *to the index itself*.**
  - The original index file is called the *first-level index* and the index to the index is called the *second-level index.*
- We can repeat the process, creating a third, fourth, ..., top level **until all entries of the *top level* fit in one disk block.**
- A multi-level index can be created for any type of first-level index (primary, secondary, clustering) as long as the first-level index consists of *more than one* disk block.

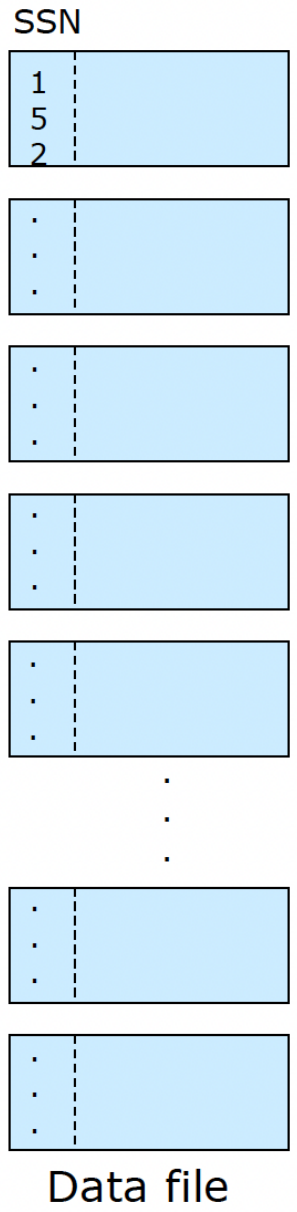
Multi-Level Indexes

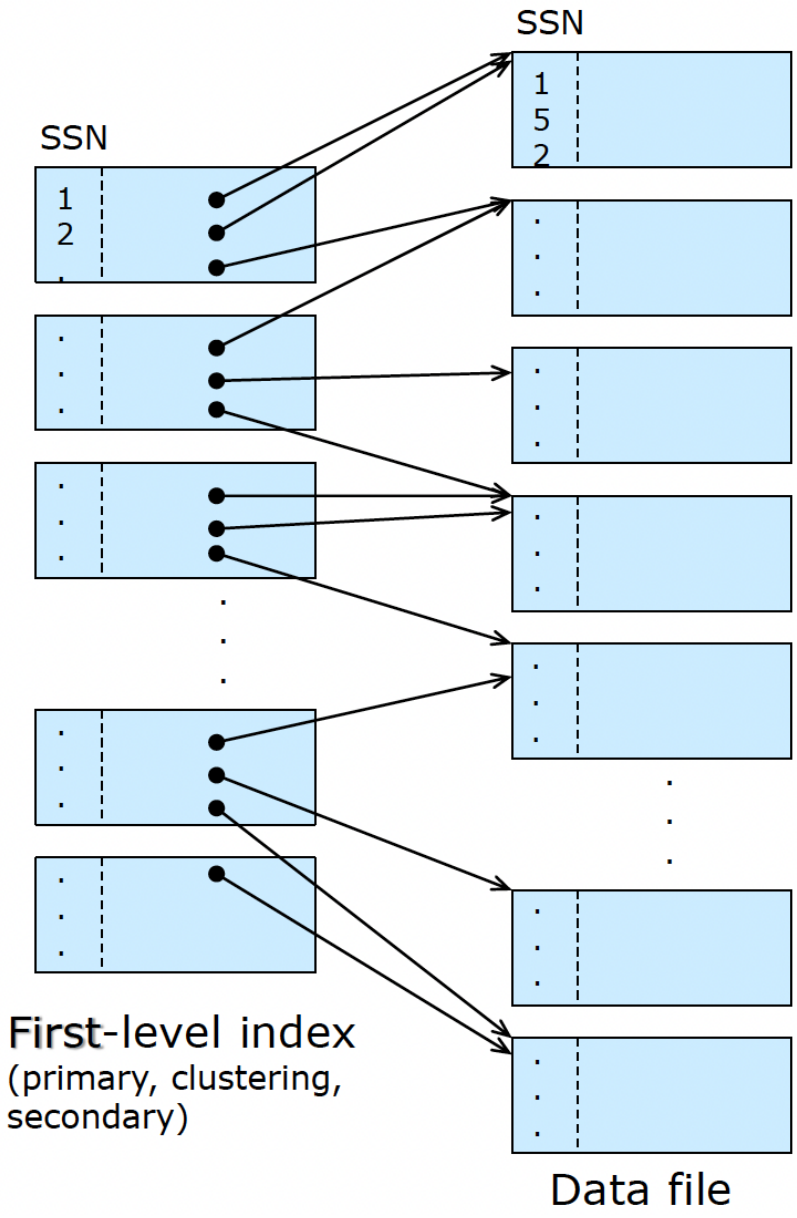
- Such a multi-level index is a form of *search tree*.
- However, insertion and deletion of new index entries is a severe problem because every level of the index is an *ordered file.*

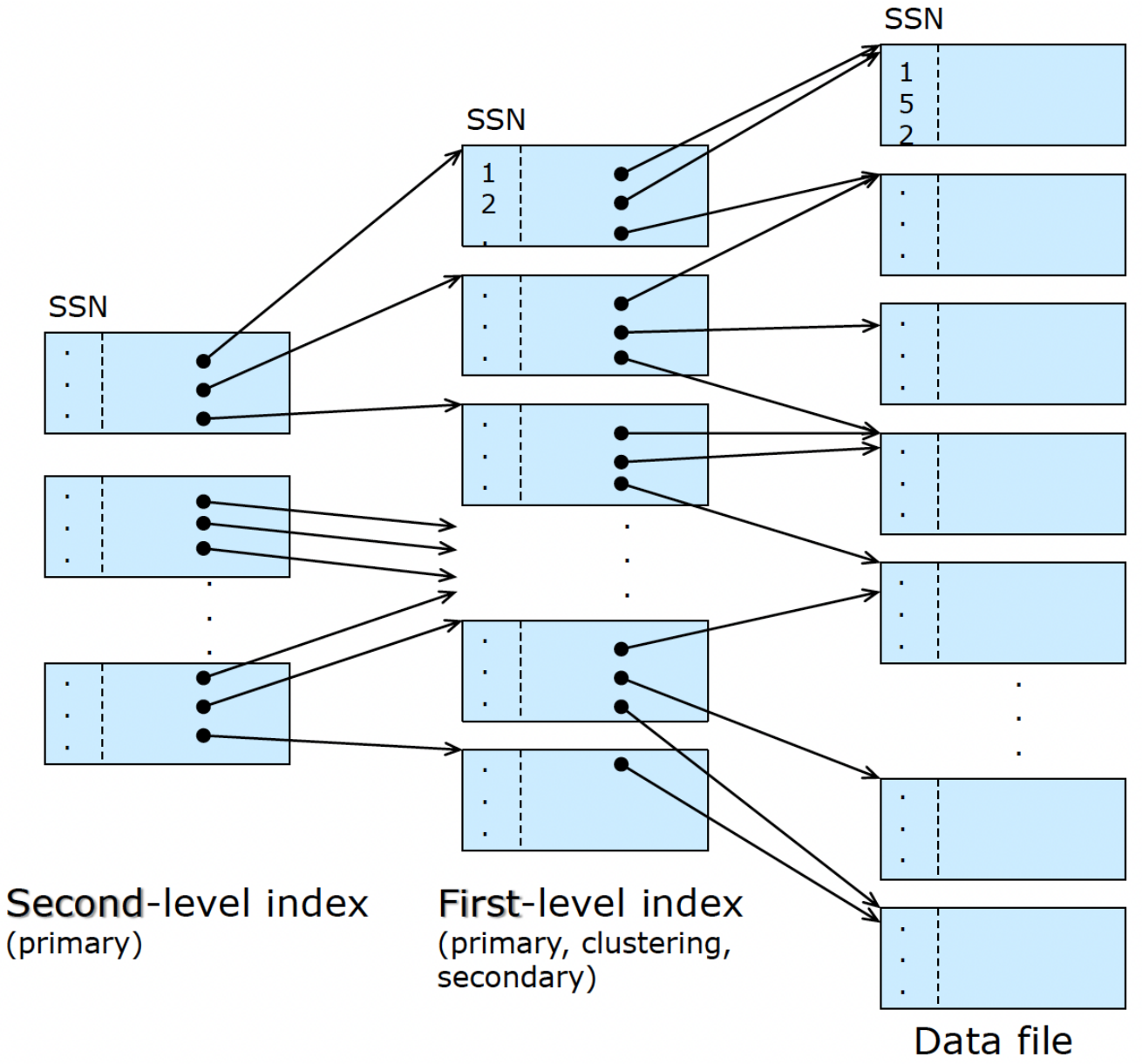


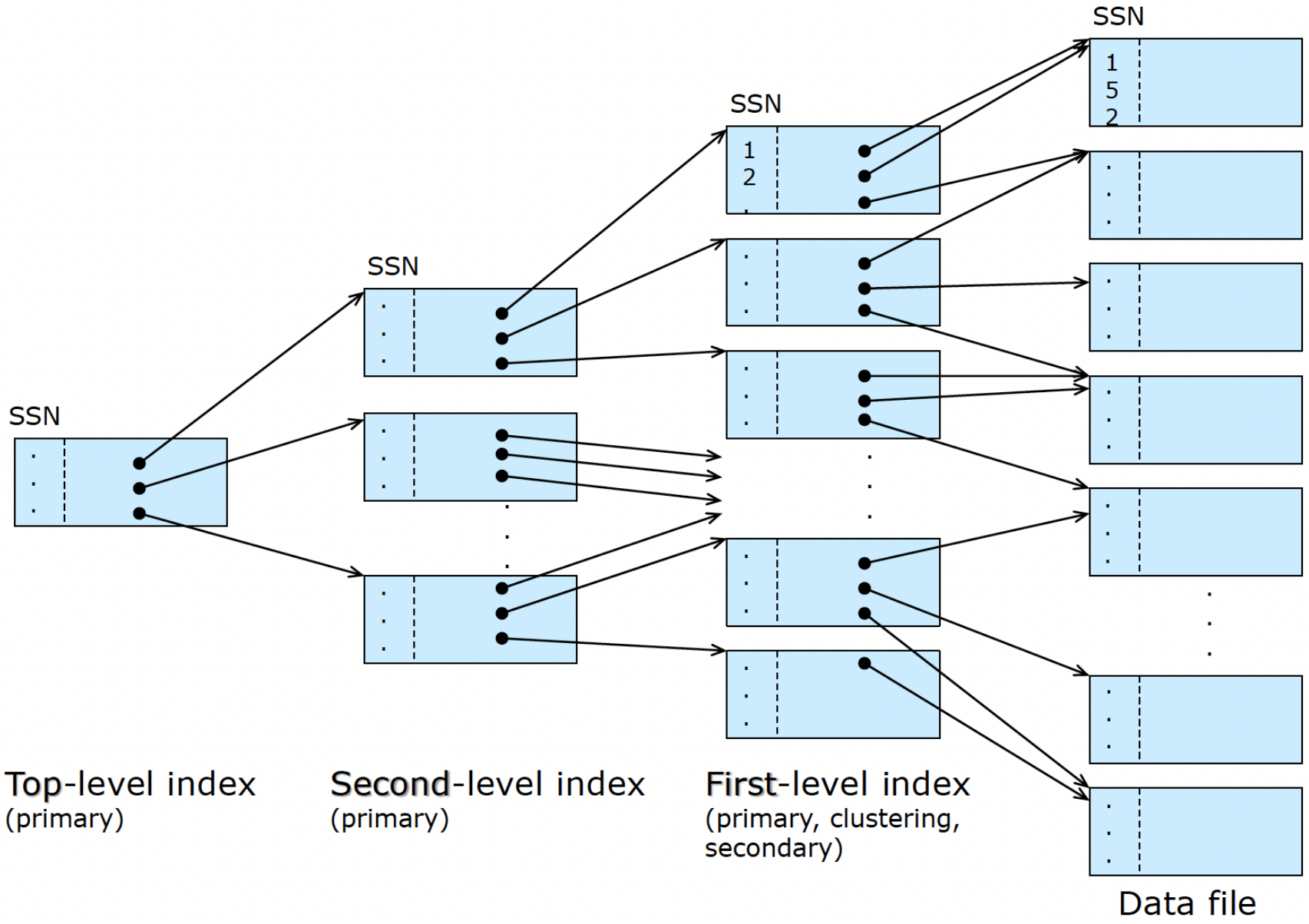
A two-level primary index resembling ISAM (Indexed Sequential Access Method) organization.

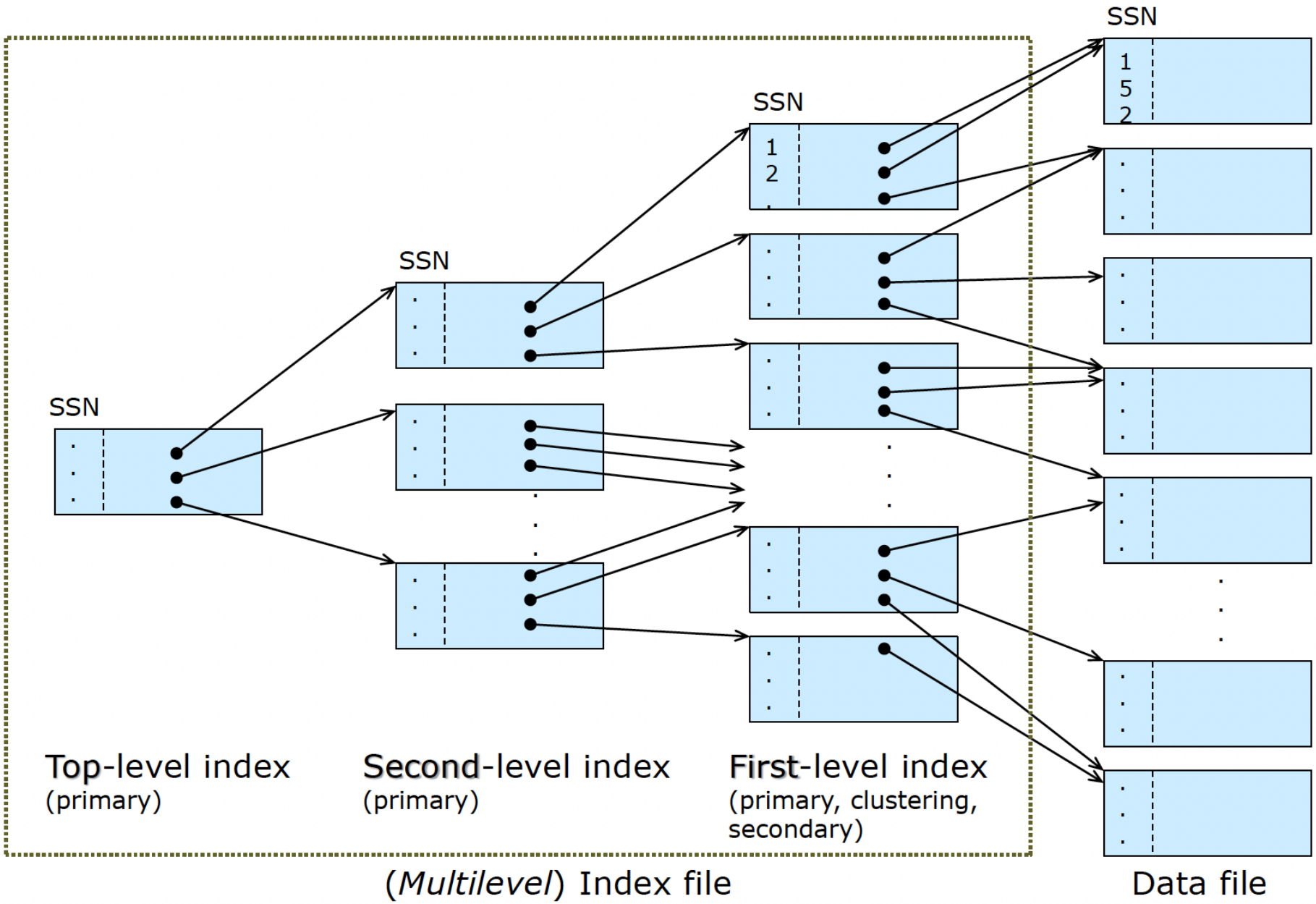

SSN
SSN
SSN
SSN
1
5
2
1
2
Top-level index
(primary)
Second-level index
(primary)
First-level index
(primary, clustering,
secondary)
(Multilevel) Index file
Data file

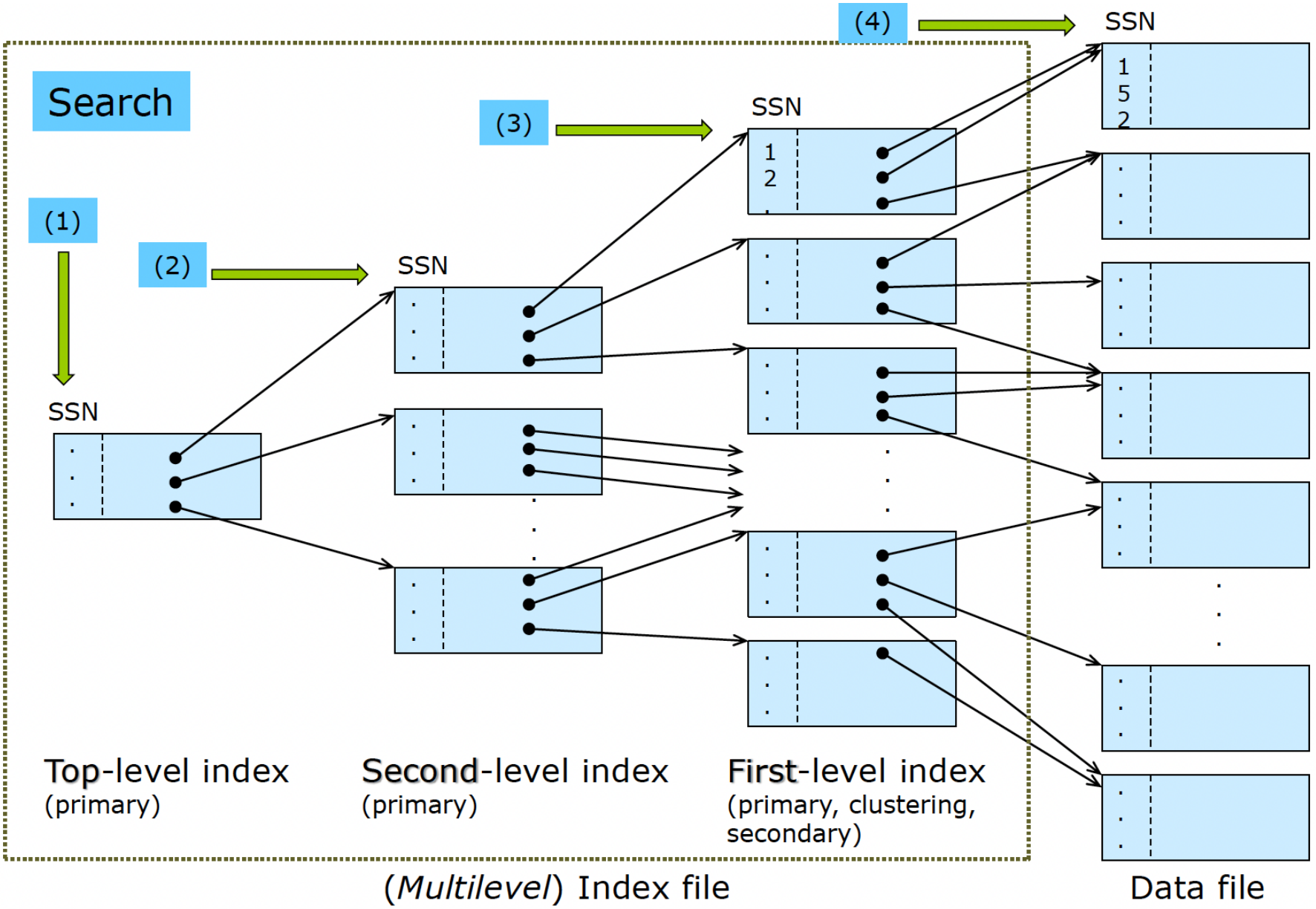

SSN
1
5
2
Data file


SSN
1
5
2
SSN
1
2
First-level index
(primary, clustering,
secondary)
Data file

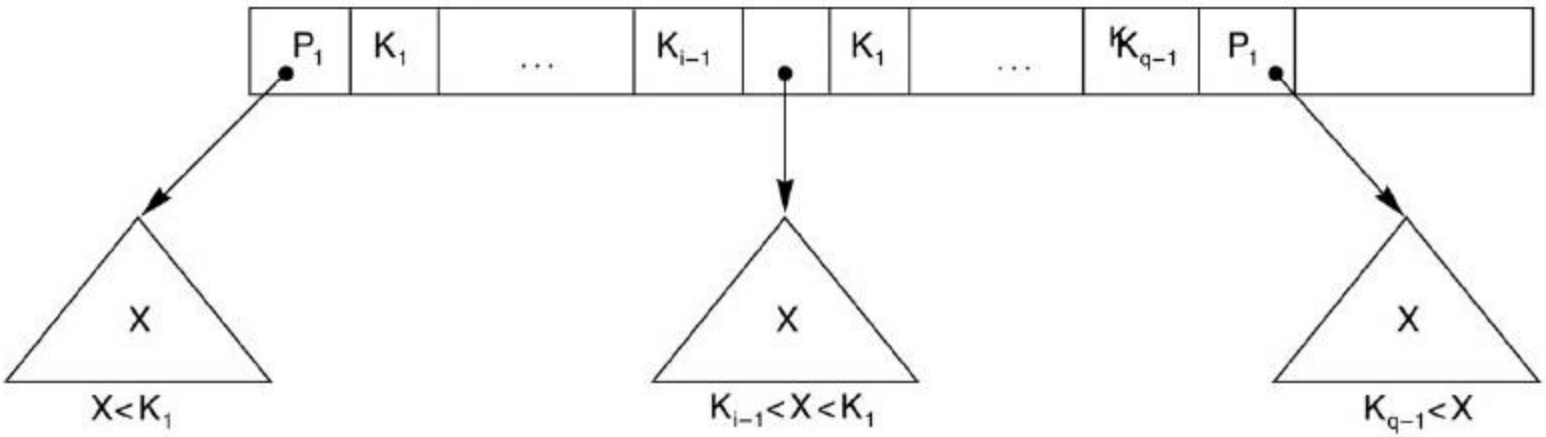

SSN
SSN
SSN
1
2
1
5
2
Second-level index
(primary)
First-level index
(primary, clustering,
secondary)
Data file


SSN
SSN
SSN
SSN
1
2
1
5
2
Top-level index
(primary)
Second-level index
(primary)
First-level index
(primary, clustering,
secondary)
Data file

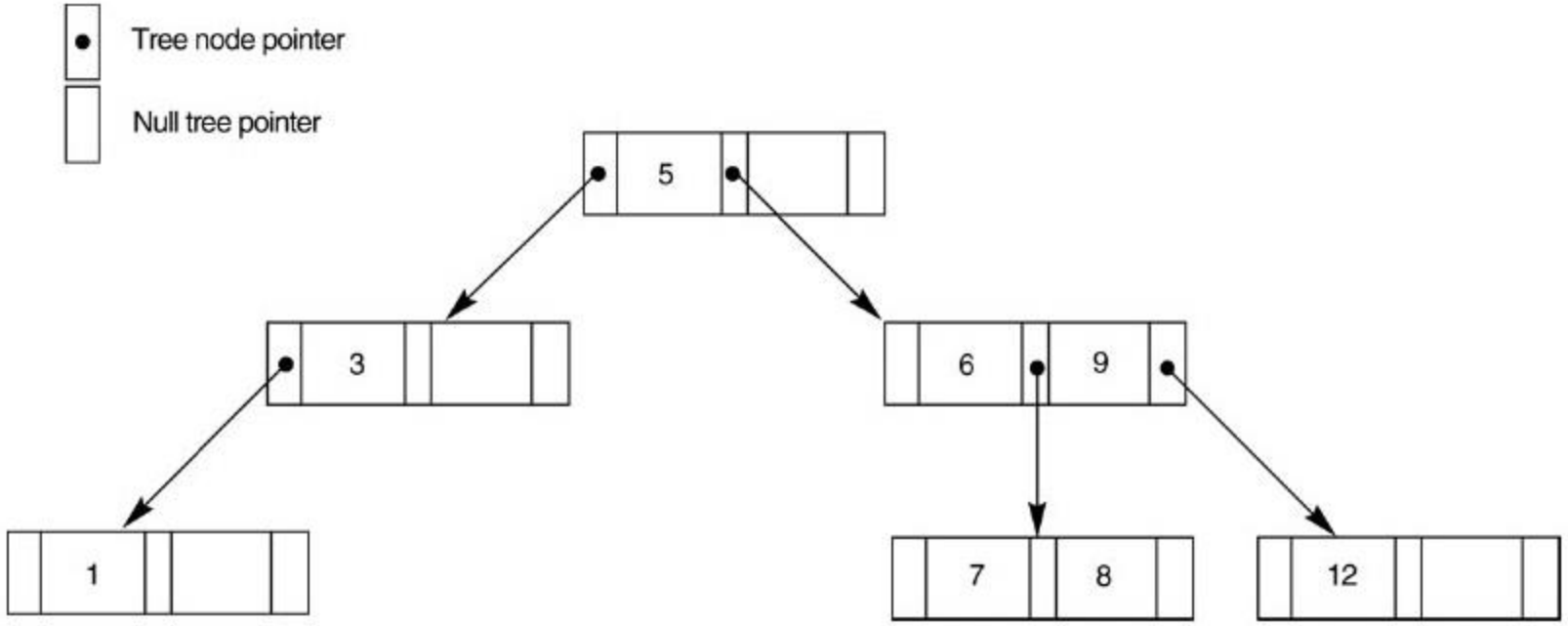

SSN
SSN
SSN
SSN
1
2
1
5
2
Top-level index
(primary)
Second-level index
(primary)
First-level index
(primary, clustering,
secondary)
(Multilevel) Index file
Data file


Search
(1)
(2)
(3)
(4)
SSN
SSN
SSN
SSN
1
2
1
5
2
Top-level index
(primary)
Second-level index
(primary)
First-level index
(primary, clustering,
secondary)
(Multilevel) Index file
Data file

A Node in a Search Tree with Pointers to Subtrees below It



A search tree of order p = 3



Contents

Dynamic Multilevel Indexes Using B-Trees and B+-Trees

- Most multi-level indexes use B-tree or B+-tree data structures because of the insertion and deletion problem.
  - This leaves space in each tree node (disk block) to allow for new index entries
- These data structures are variations of search trees that allow efficient insertion and deletion of new search values.
- In B-Tree and B+-Tree data structures, each node corresponds to a disk block.
- Each node is kept between half-full and completely full.

Dynamic Multilevel Indexes Using B-Trees and B+-Trees (cont.)

- An insertion into a node that is not full is quite efficient.
  - If a node is full, the insertion causes a split into two nodes.
- Splitting may propagate to other tree levels.
- A deletion is quite efficient if a node does not become less than half full.
- If a deletion causes a node to become less than half full, it must be merged with neighboring nodes.

Difference between B-tree and B+-tree

- In a B-Tree, pointers to data records exist at all levels of the tree.
- In a B^+-Tree, all pointers to data records exist at the leaf-level nodes.
- A B^+-Tree can have less levels (or higher capacity of search values) than the corresponding B-tree.

B-tree Structures

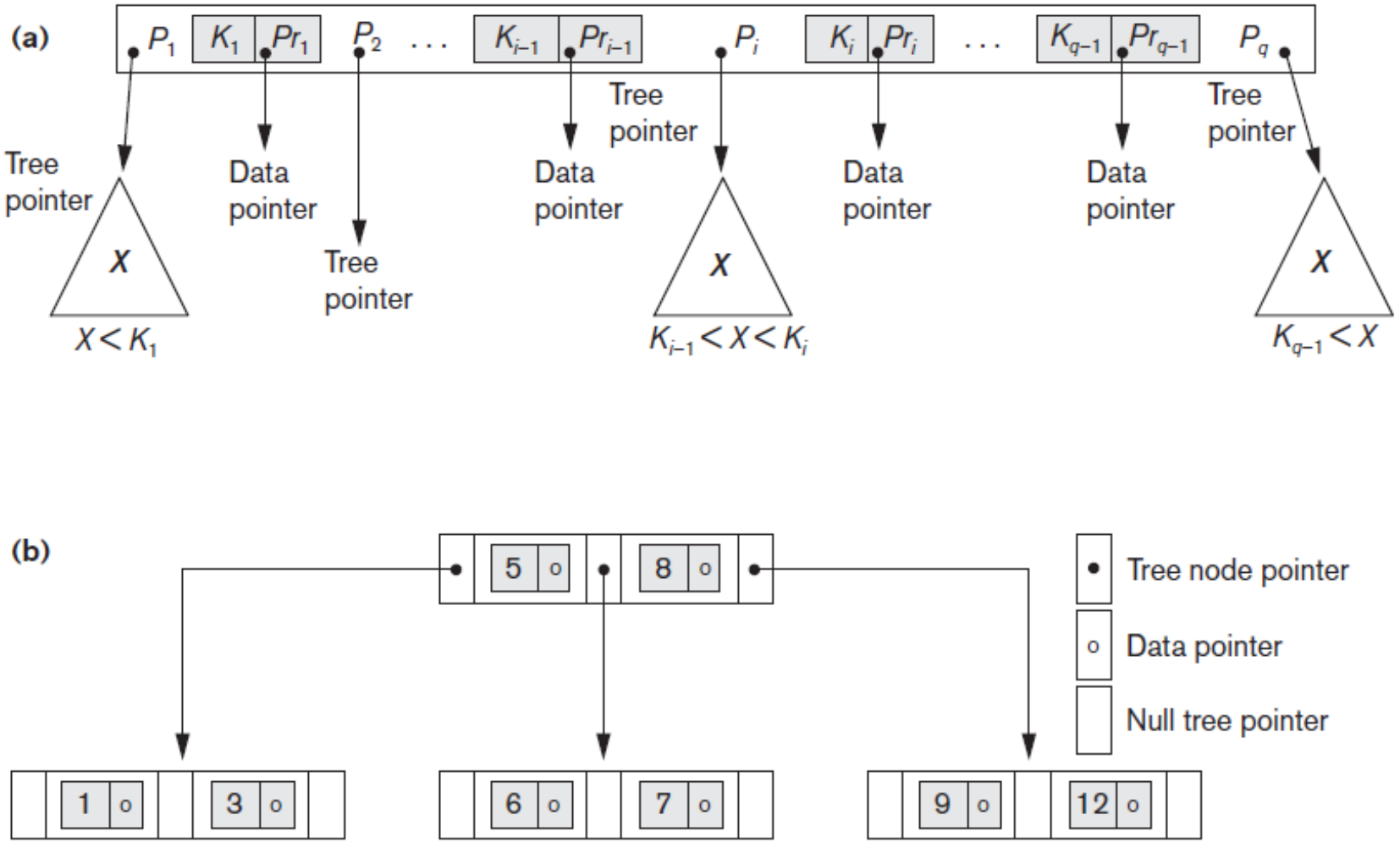


Figure 18.10
B-tree structures. (a) A node in a B-tree with $q - 1$ search values. (b) A B-tree of order $p = 3$.The values were inserted in the order 8, 5, 1, 7, 3, 12, 9, 6.

The Nodes of a B+-Tree

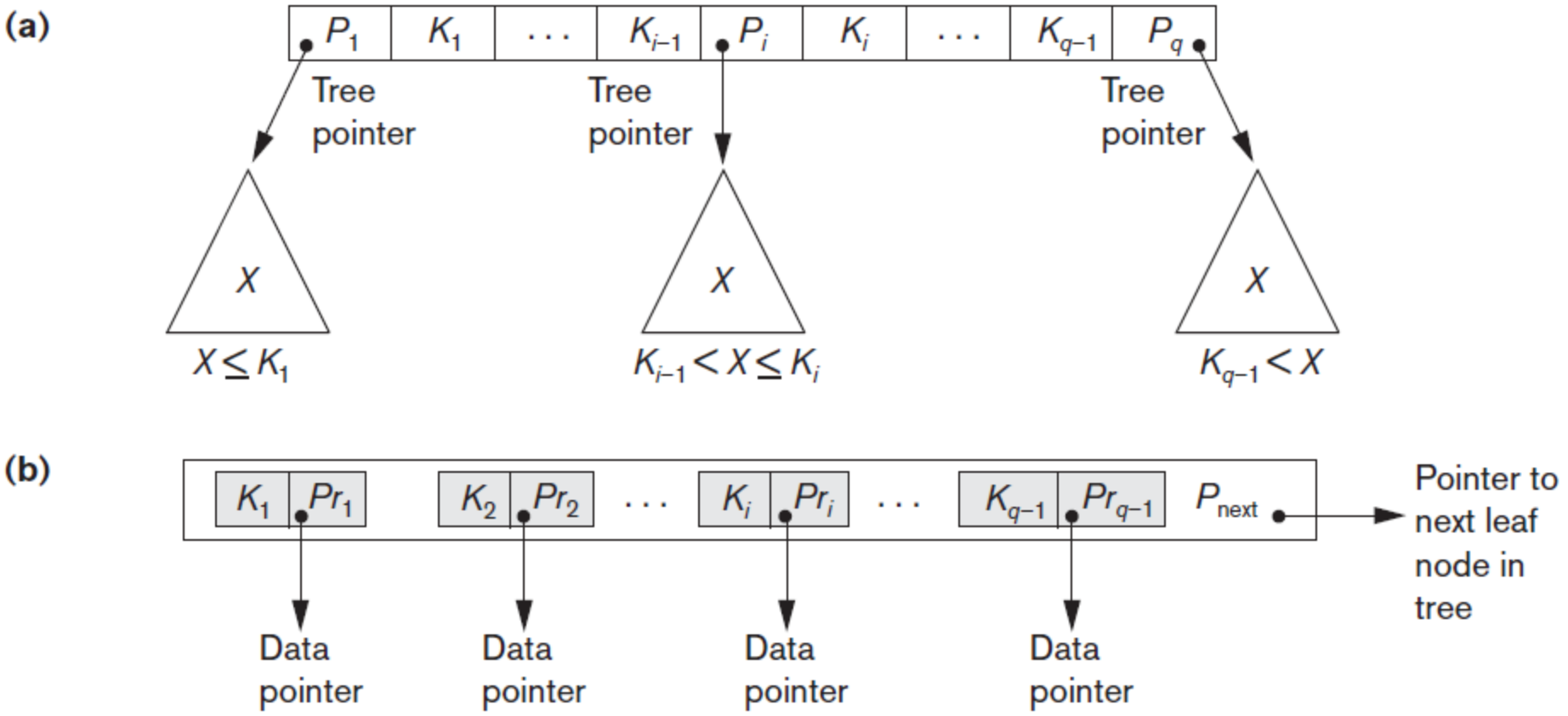


Figure 18.11

The nodes of a B+-tree. (a) Internal node of a B+-tree with $q - 1$ search values. (b) Leaf node of a B+-tree with $q - 1$ search values and $q - 1$ data pointers.

Contents


Q
A

Exercise

- *A file has r = 30,000 EMPLOYEE records of fixed length.*
- *Each record has the following fields: Name (30 bytes), SSN (9 bytes), Department_code (9 bytes), Address (40 bytes), Phone (10 bytes), Birth_date (8 bytes), Sex (1 byte), Job_code (4 bytes), and Salary (4 bytes). An additional byte is used as a deletion marker*.
- *Block size B = 512 bytes, block pointer P = 6 bytes, record pointer PR = 7 bytes.*

1. Calculate the ***record size*** R in bytes.
2. Calculate the ***blocking factor bfr*** and the ***number of file blocks b***, assuming an unspanned organization.

Solution

1. Calculate the ***record size*** R in bytes.
   - R = 30 + 9 + 9 + 40 + 10 + 8 + 1 + 4 + 4 + 1 = 116 bytes.

2. Calculate the ***blocking factor bfr*** and the ***number of file blocks b***, assuming an unspanned organization.
   - $bfr = \lfloor B/R \rfloor = \lfloor 512/116 \rfloor = 4$ (records/blocks)
   - $b = \lceil r/bfr \rceil = \lceil 30000/4 \rceil = 7500$ (blocks)

Exercise (cont.)

- *A file has r = 30,000 EMPLOYEE records of fixed length.*
- *Each record has the following fields: Name (30 bytes), SSN (9 bytes), Department_code (9 bytes), Address (40 bytes), Phone (10 bytes), Birth_date (8 bytes), Sex (1 byte), Job_code (4 bytes), and Salary (4 bytes). An additional byte is used as a deletion marker*.
- *Block size B = 512 bytes, block pointer P = 6 bytes, record pointer PR = 7 bytes.*

3. This file is *ordered by* the key field SSN. Calculate the ***number of block accesses*** needed to search for and retrieve a record from the file - given its SSN value.

Solution

3. This file is *ordered by* the key field SSN. Calculate the ***number of block accesses*** needed to search for and retrieve a record from the file - given its SSN value.

   - Binary search
   - Number of blocks accesses: $\lceil \log_2 b \rceil = \lceil \log_2 7500 \rceil = 13$

Exercise (cont.)

- *A file has r = 30,000 EMPLOYEE records of fixed length.*
- *Each record has the following fields: Name (30 bytes), SSN (9 bytes), Department_code (9 bytes), Address (40 bytes), Phone (10 bytes), Birth_date (8 bytes), Sex (1 byte), Job_code (4 bytes), and Salary (4 bytes). An additional byte is used as a deletion marker*.
- *Block size B = 512 bytes, block pointer P = 6 bytes, record pointer PR = 7 bytes.*

4. This file is *ordered by* the key field SSN and we want to construct a primary index on SSN. Calculate:
   a) the ***index blocking factor*** $\boldsymbol{bfr_i}$
   b) the ***number of index entries*** and the ***number of index blocks***

Solution

4. This file is *ordered by* the key field SSN and we want to construct a primary index on SSN. Calculate:
   a) the ***index blocking factor*** bfr_i
   - Index entry size: $R_i = 9 + 6 = 15$ (bytes)
   - Index blocking factor $bfr_i = \lfloor B/ R_i \rfloor = \lfloor 512/15 \rfloor = 34$

   b) the ***number of index entries*** and the ***number of index blocks***
   - Number of index entries: $r_i = 7500$
   - Number of index blocks: $b_i = \lceil 7500/34 \rceil = 221$

Exercise (cont.)

- *A file has r = 30,000 EMPLOYEE records of fixed length.*
- *Each record has the following fields: Name (30 bytes), SSN (9 bytes), Department_code (9 bytes), Address (40 bytes), Phone (10 bytes), Birth_date (8 bytes), Sex (1 byte), Job_code (4 bytes), and Salary (4 bytes). An additional byte is used as a deletion marker*.
- *Block size B = 512 bytes, block pointer P = 6 bytes, record pointer PR = 7 bytes.*

4. This file is ordered by the key field SSN and we want to construct a primary index on SSN. Calculate:
   c) the ***number of block accesses*** needed to search for and retrieve a record from the file - given its SSN value

Solution

4. This file is ordered by the key field SSN and we want to construct a primary index on SSN. Calculate:
   c) the ***number of block accesses*** needed to search for and retrieve a record from the file - given its SSN value.
   - Binary search on index file and 1 more blocks access to data file
   - $\lceil \log_2 b_i \rceil + 1 = \lceil \log_2 221 \rceil + 1 = 9$ blocks

Exercise (cont.)

- *A file has r = 30,000 EMPLOYEE records of fixed length.*
- *Each record has the following fields: Name (30 bytes), SSN (9 bytes), Department_code (9 bytes), Address (40 bytes), Phone (10 bytes), Birth_date (8 bytes), Sex (1 byte), Job_code (4 bytes), and Salary (4 bytes). An additional byte is used as a deletion marker*.
- *Block size B = 512 bytes, block pointer P = 6 bytes, record pointer PR = 7 bytes.*

5. If we make it into a multilevel index (two levels).
   a) Calculate the ***total number of blocks*** required by the second index
   b) the ***number of block accesses*** needed to search for and retrieve a record from the file - given its SSN value

Solution

5. If we make it into a multilevel index (two levels).

a) Calculate the ***total number of blocks*** required by the second index

- Number of 1st level index entries: $r_{i_1} = 7500$
- Number of 1st level index blocks: $b_{i_1} = 221$
- Number of 2nd level index entries: $r_{i_2} = 221$
- Number of 2nd level index blocks: $b_{i_2} = \lceil 221/34 \rceil = 7$

b) the ***number of block accesses*** needed to search for and retrieve a record from the file - given its SSN value

- $\lceil \log_2 b_{i_2} \rceil + 1 + 1 = \lceil \log_2 7 \rceil + 1 + 1 = 5$ blocks