COMPUTER SCIENCE

Database Management System

File Org. & Indexing

Lecture_1

Vijay Agarwal sir

TOPICS TO BE COVERED

01 File Structure

02 Indexing & its Type

1. FD & Normalization.
2. Transaction & Concurrency Control
3. ER MODEL & foreign key Concept
4. Query Language (RA, SQL, TRC)
5. File Org & Indexing. → Storage

File organization & Indexing.

Database

DB Files

Records.

Fields

Blocks

Q WHAT is **Block** ?

Disk :

Platter

↳ Surface

↳ Track

↳ Sector

⇓

'DATA'

File Structures & Indexing

Database

DB Files

Blocks

Records

Fields

- Database is collection of files.
- Each file is a collection of Records.
- Each record is a sequence of fields.

- DB is divided into number of blocks.
- Each block is divided into records.
- Record can be stored in a blocks.

Blocking factor [B_F] : Average Number of Records Per Block.

Blocking factor = 4

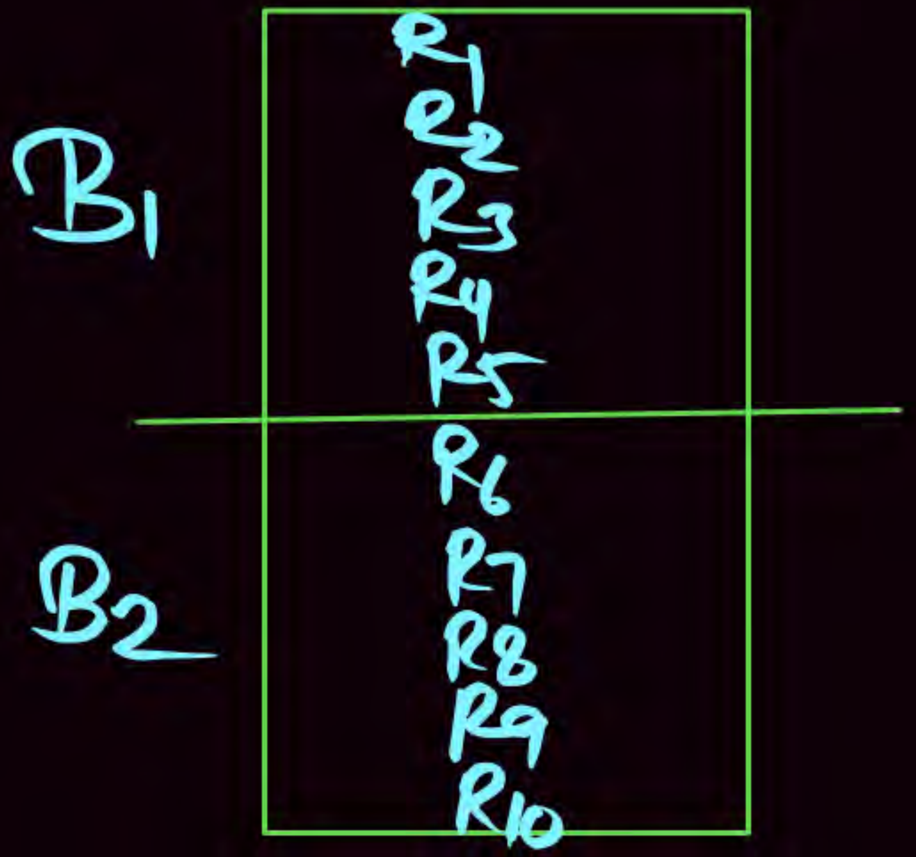
↳ 4 Records Per Block

$$\text{Block | Blocking factor } (B_F) = \frac{\text{Block Size}}{\text{Record size}}$$

Block Size = 1000 Byte

Record Size = 200 Byte

$$\text{Block factor} = \frac{1000B}{200B} = 5 \text{ Records Pr Blocks.}$$



Block Size >>>> Record Size

Floor & Ceiling Concept

Floor

$\lfloor 3.0 \rfloor = 3$

$\lfloor 2.0 \rfloor = 2$

$\lfloor 2.9 \rfloor = 2$

$\lfloor 2.8 \rfloor = 2$

$\lfloor 2.7 \rfloor = 2$

$\lfloor 2.6 \rfloor = 2$

$\lfloor 2.5 \rfloor = 2$

$\lfloor 2.4 \rfloor = 2$

$\lfloor 2.3 \rfloor = 2$

$\lfloor 2.2 \rfloor = 2$

$\lfloor 2.1 \rfloor = 2$

$\lfloor 2.0 \rfloor = 2$

Ceiling

$\lceil 2.1 \rceil = 3$

$\lceil 2.2 \rceil = 3$

$\lceil 2.3 \rceil = 3$

$\lceil 2.4 \rceil = 3$

$\lceil 2.5 \rceil = 3$

$\lceil 2.6 \rceil = 3$

$\lceil 2.7 \rceil = 3$

$\lceil 2.8 \rceil = 3$

$\lceil 2.9 \rceil = 3$

$\lceil 2.0 \rceil = 2$

$\lceil 3.0 \rceil = 3$

① SPANNED ORG.

A Record Can be Stored More than One Block.
(Partially Can be Stored)

② UNSPANNED Strategy org.

A Record Can be Stored/belongs to a Particular Block.
[Can not Stored Partially]

① SPANNED ORG.

② UNSPANNED Strategy org.

Record Blocking and Spanned Versus Unspanned Records

- Blocking factor
  - Average number of records per block for the file

(1) Spanned organization : A Particular Record Can be Stored More than One Blocks.

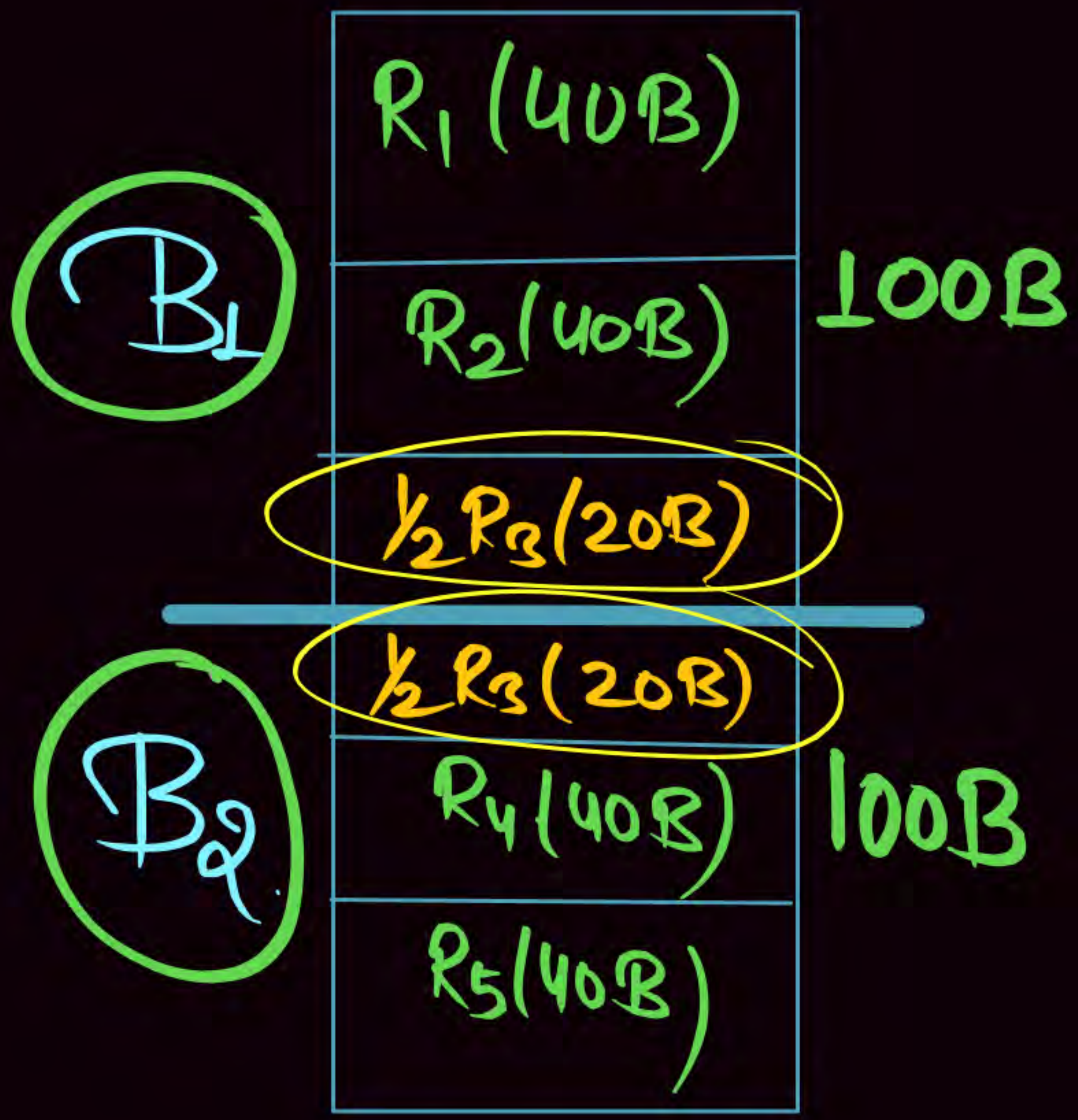
It allows Partially Part of Record Stored in a between the Block.

eg Block Size = 100 B
Record Size = 40 B

$$\text{Block factor} = \frac{\text{Block Size}}{\text{Record Size}}$$

$$\Rightarrow \frac{100B}{40B}$$

Block factor = 2.5 Records per Block.



SPANNED org.

Advantage: No Memory Wastage.

DisAdvantage: Block Access Increase.

Suitable: For. Variable Length Record.

Record Blocking and Spanned Versus Unspanned Records

- Blocking factor
  - Average number of records per block for the file.

(2) Unspanned organization : A Record Can be Stored Not More than One Block (Stored in a paricular Block)

Record Not Stored Partially in a Block.

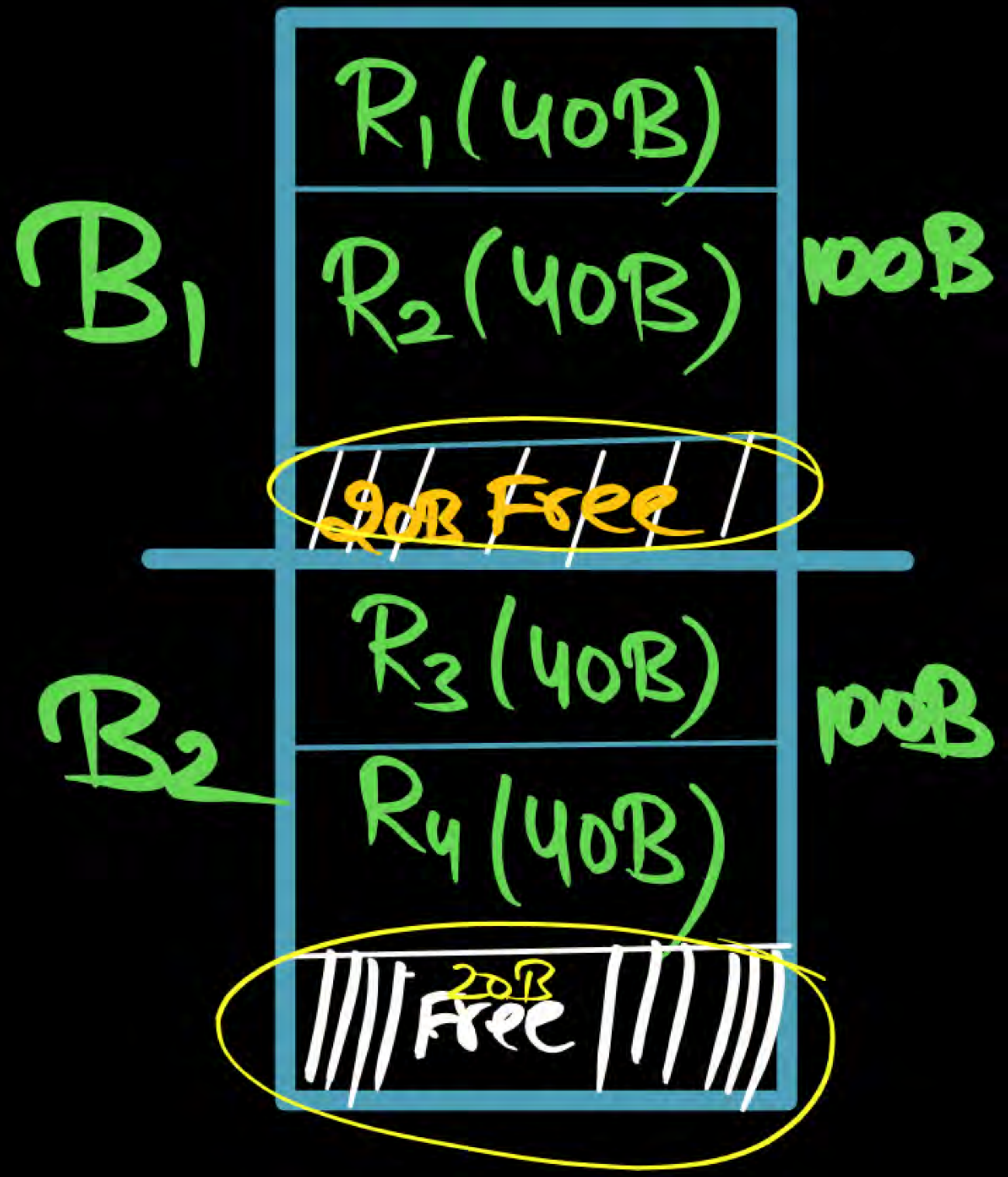
Block Size = 100B

Record Size = 40B

$$\text{Blocking factor} = \left\lfloor \frac{\text{Block Size}}{\text{Record Size}} \right\rfloor = \left\lfloor \frac{100B}{40B} \right\rfloor$$

$$= \lfloor 2.5 \rfloor$$

= 2 Records Per Block.



Unspanned Org

Advantage: Block Access Reduced.

Advantage: Wastage of Memory (Internal Fragmentation).

Suitable: For Fixed Length Record.

Note:

In spanned roganization No memory is waste but I/O cost is more (Block Access Increase).

But in unspanned organization memory is waste but input output cost is less compared to spanned organization.

Default organization is unspanned organization.

Note:

I/O Cost: Input Output cost means Number of Blocks transferred from secondary memory to Main memory in order to access some records.

Search Key: Attribute used to access the Data from DB

Organization of records in a file:
(1) ORDERED file organization
(2) Unordered file organization

1. Ordered File → ✓

2. Unordered File (Heap)

ORDERED File	Unordered (Heap) File
Searching Easy	Insertion Easy
Insertion Expensive (Reorg the file)	Searching Expensive
Binary Search	**Linear Search**
To Access a Record Avg No of Block Access = $\lceil \log_2 B \rceil$ (B: # DATA Block)	Average Case = $\frac{B}{2}$ Worst Case = B

Files of Ordered Records (Sorted Files)

- Ordered (sequential) file
  - Records sorted by ordering field
    - Called ordering key if ordering field is a key field
- Advantages
  - Reading records in order of ordering key value is extremely efficient
  - Finding next record
  - Binary search technique

NOTE:
To Access a record the average number of
Block Access = $\log_2 B$
(B: Data Blocks)

Files of Unordered Records (Heap Files)

- Heap (or pile) file
  - Records placed in file in order of insertion
- Inserting a new record is very efficient
- Searching for a record requires linear search
- Deletion techniques
  - Rewrite the block
  - Use deletion marker

NOTE:
To Access a record the average number of

Block Access = $\frac{B}{2}$

(B: Data Blocks)

Worst Case = B

Access Times for Various 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	$\log_2 b$

Average access times for a file of b blocks under basic file organizations

Indexing :

Indexing are Used to Improve the Searching Efficiency.

→ Search in a faster Ways.

→ To Reduce the I/O Cost.

One Record of Index file Contain 2 fields.

Search key	Pointer (Block Pointer)

→ Denote to a Block where key is available.

Indexing (Basic Concepts)

- Indexing mechanisms used to speed up access to desired data.
  - E.g., author catalog in library
- **Search Key** - attribute to set of attributes used to look up records in a file.
- An **index file** consists of records (called **index entries**) of the form

search-key	pointer

- Index files are typically much smaller than the original file.
- Two basic kinds of indices:
  - **Ordered indices:** search keys are stored in sorted order
  - **Hash indices:** search keys are distributed uniformly across "buckets" using a "hash function".

Index file block size is same as DB file Block Size

$\boxed{\text{Block Size of Index File = Block Size of DB file}}$

$\boxed{\text{One Index Record Size = Size of Search Key + Size of Block Pointer}}$

NOTE: To Access a Record Average number of block access

$$= \underbrace{\log_2 B_i}_{\text{Index Block access}} + \underbrace{1}_{\text{Data Block access}}$$

Index Block access

Data Block access

[Bi : Index Block]

Example:

- Suppose that:
  - record size $\boxed{R = 150 \text{ bytes}}$ block size $B = 512$ bytes,

    $r = 30000$ records
- Then, we get:
  - blocking factor $Bfr = \left\lfloor \frac{\text{Block size}}{\text{Record Size}} \right\rfloor = \left\lfloor \frac{512B}{150B} \right\rfloor = 3$ Record Per Block.
  - number of file blocks $b =$

$$\frac{30{,}000}{3} = 10{,}000 \text{ Data Block}$$

$$\boxed{B = 10{,}000}$$

ORERDED file

To Access a Record Avg No. of Block Access $= \lceil \log_2 B \rceil$

$2^{10} = 1024$

$2^{11} = 2048$

$2^{12} = 4096$

$2^{13} = 8192$

$\lceil 13.x \rceil$ $2^{14} =$

$\Rightarrow \lceil \log_2 10000 \rceil$

$= 14$ Ans

Unoderd file

To Access a Record Avg Number of Block Access $= B/2$.

$\Rightarrow \frac{10000}{2} = 5000$ Ans

Worst $= 10{,}000$ Ans

Example:

- Suppose that:
  - record size R = 150 bytes, block size B = 512 bytes,

    r = 30000 records
- Then, we get:
  - blocking factor Bfr = $\boxed{\text{B div R} = \text{512 div 150} = \text{3 records/block}}$
  - number of file blocks b = $\boxed{(r/\text{Bfr}) = (30000/3) = 10000 \text{ blocks}}$

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
- For an index on the SSN field, assume the field size $V_{SSN}=9$ bytes, assume the record pointer size $P_R=7$ bytes. Then:

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- For an index on the SSN field, assume the field size $V_{SSN}=9$ bytes, assume the record pointer size $P_R=7$ bytes. Then:
  - index entry size $R_1=(V_{SSN}+P_R)=$
  - index blocking factor $Bfr_1=B \text{ div } R_1=$ entries / block
  - number of index blocks $b=(r/Bfr_1)=$ = blocks
  - binary search needs $\log_2 bI=\log_2 938=$ block accesses

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
- For an index on the SSN field, assume the field size $V_{SSN}=9$ bytes, assume the record pointer size $P_R=7$ bytes. Then:
  - index entry size $R_1=(V_{SSN}+P_R)=(9+7)=16$ bytes
  - index blocking factor $Bfr_1=B \text{ div } R_1=512 \text{ div} 16=32$ entries / block
  - number of index blocks $b=(r/Bfr_1)=(30000/32)=938$ blocks
  - binary search needs $\log_2 bI=\log_2 938=10$ block accesses

Category of Index

1) Dense Index Files

Number of Index entries = Number of DB Records

2) Sparse Index Files

Number of Index entries = Number of Blocks

Dense Index Files

- Dense Index - Index record appears for every search-key values in the file.
- Example - index on *ID* attribute of *instructor* relation

10101
12121
15151
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76543
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10101	Srinivasan	Comp. Sci.	65000	
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15151	Mozart	Music	40000	
22222	Einstein	Physics	95000	
32343	El Said	History	60000	
33456	Gold	Physics	87000	
45565	Katz	Comp. Sci.	75000	
58583	Califieri	History	62000	
76543	Singh	Finance	80000	
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83821	Brandt	Comp. Sci.	92000	
98345	Kim	Elec. Eng.	80000	

Sparse Index Files

- Sparse Index: contains index records for only some search-key values.
  - Applicable when records are sequentially ordered on search-key
- To locate a record with search-key value K we:
  - Find index record with largest search-key value $< K$
  - Search file sequentially starting at the record to which the index record points

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45565	Katz	Comp. Sci.	75000	
58583	Califieri	History	62000	
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Types of Index

Single-level Ordered Indexes

- Primary indexes
- Clustering indexes
- Secondary indexes

Multilevel Indexes

Dynamic multilevel indexes Using B-Tress and B^+ Trees.

Q.1

Assume a relational database system that holds relation: C(colleges) with the following characteristics

- Records are stored as fixed length, fixed format records, length is 256 bytes.
- There are 16384 records.
- Records contains key attribute CollegeNumber (C.N), length 22 bytes and other fields.
- Unspanned organization is used to store the information or record.

Let's suppose we want to build a sparse primary index on C.N then how many numbers of 4096-byte blocks are needed to store the primary index when block pointer size is 10 bytes _____?

A. 7

B. 8

C. 9

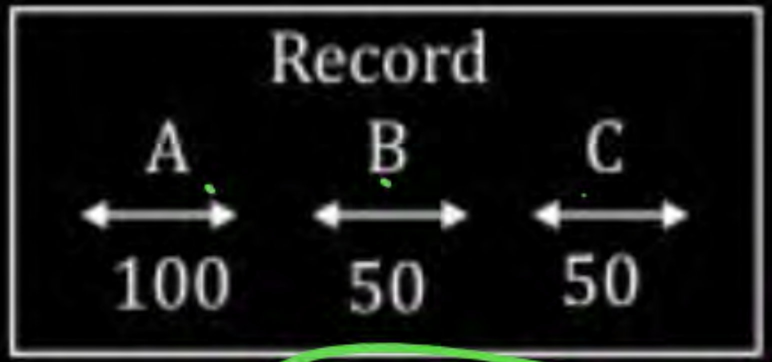
D. 10

File Organization:

- Data Records can be :

  1) Fixed Length Records

  2) Variable Length Records



200 bytes = for each Records

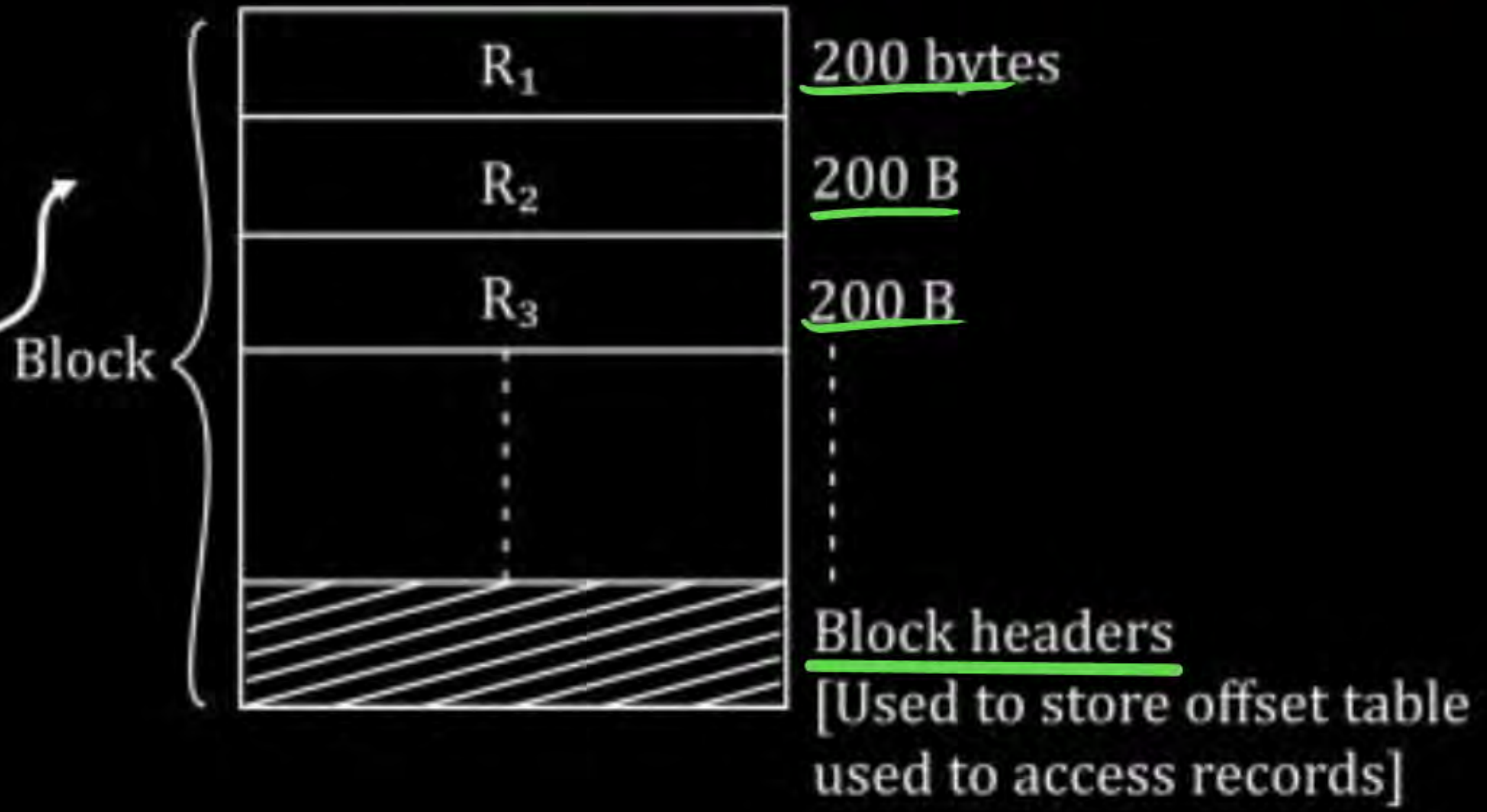
1) Fixed Length Records

Create table R

(A char (100),

B char (50),

C char (50));



File Organization:

2) Variable Length Records

Create table S

(D char (100),

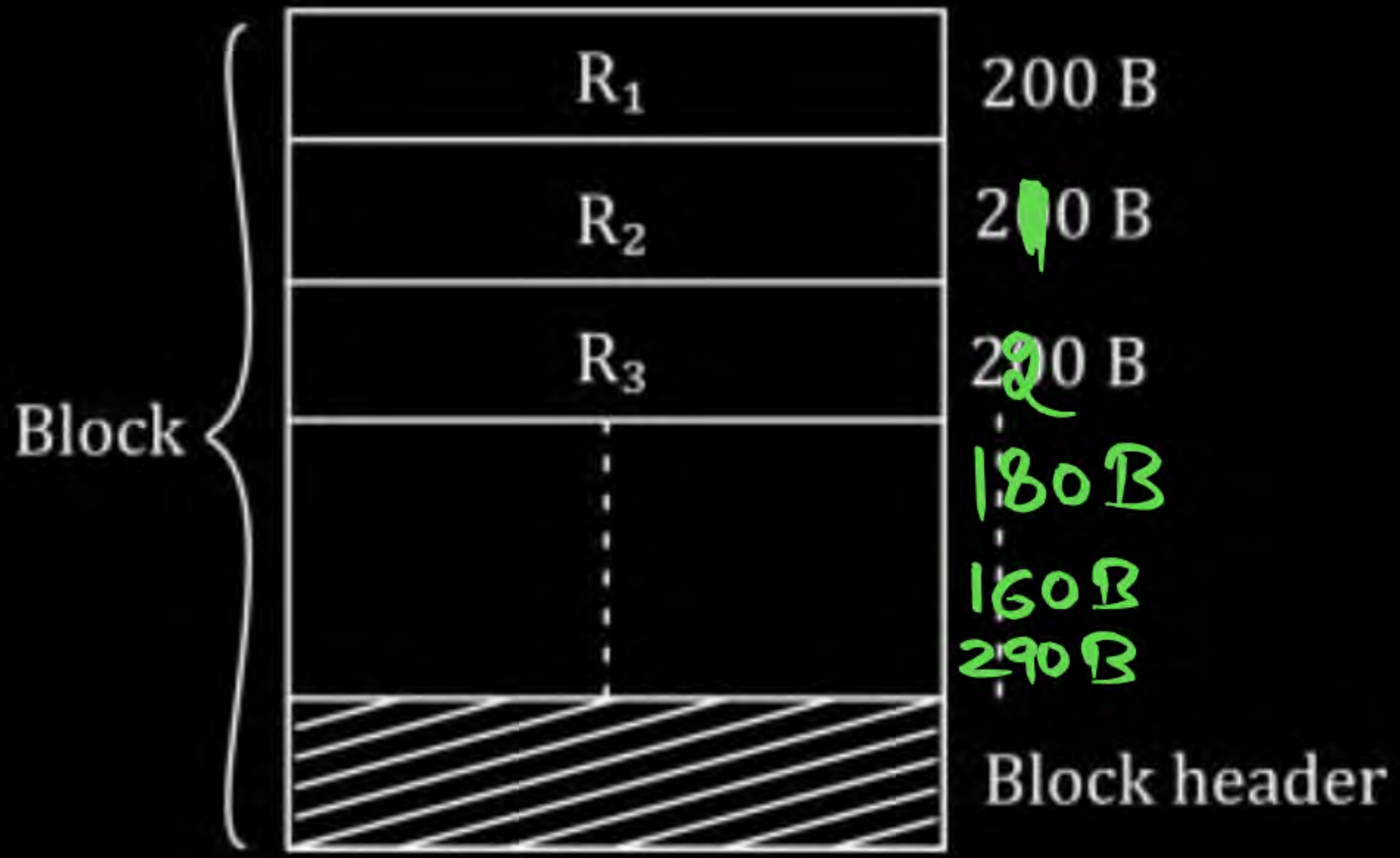
E char (50),

F text

);

$\therefore$ size (D) + Size (E) + size(F)

100   50   not fixed



File Organization:

- DB File with all records fixed length
- DB file with variable length records

$\Rightarrow$ both are possible in RDBMS

Record Organization:

(a) Spanned Organization

Record allow to span in more than one block

Example: Block size 1000B Record size 400B

Advantage:

⇒ Possible to allocate file with no internal fragmentation.

Record Organization:

$\frac{B-H}{R}$

R: Record
B: Block.

(a) Spanned Organization

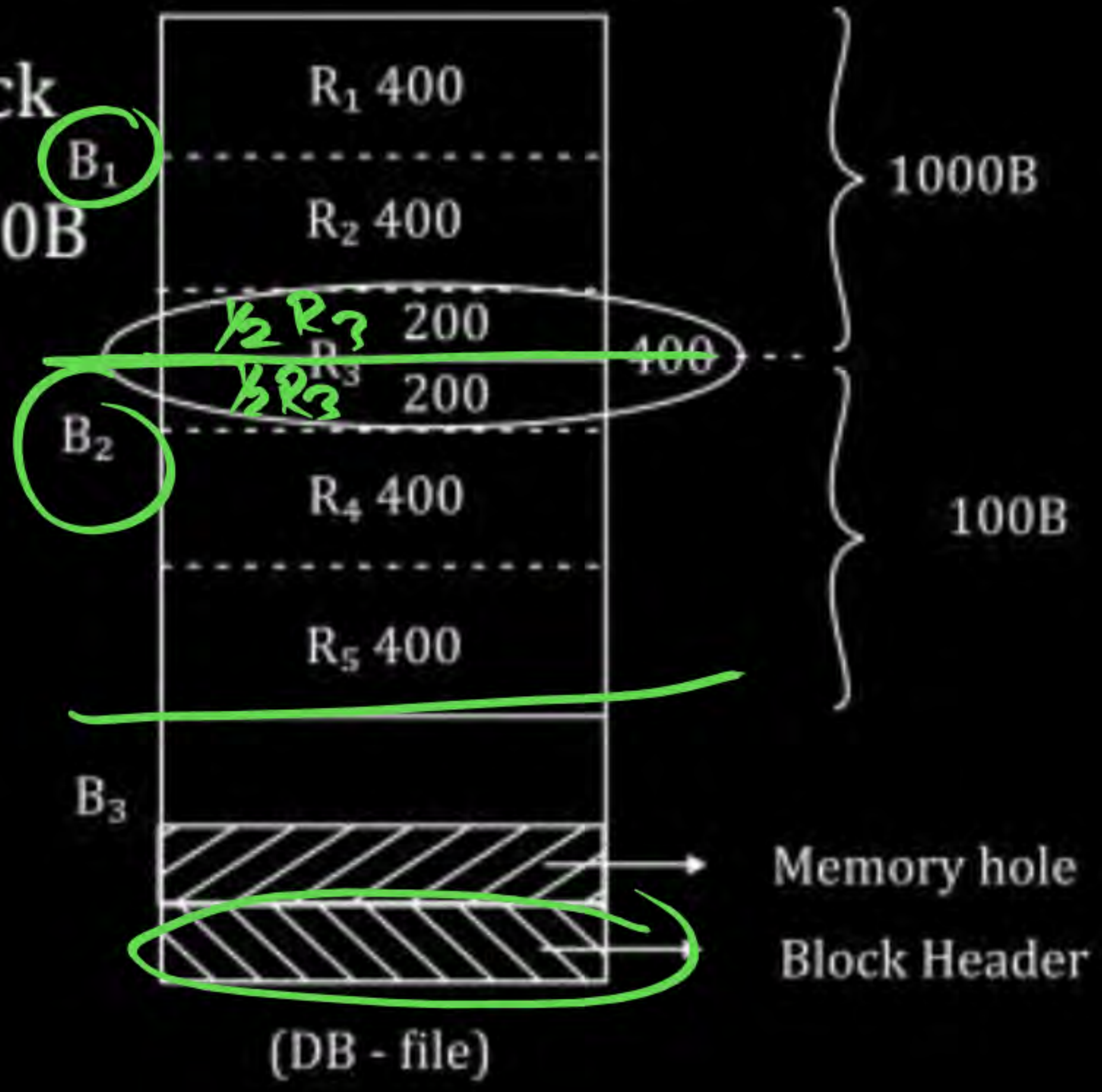
Record allow to span in more than one block

Example: Block size 1000B; Record size 400B

Block Factor $= \frac{1000-0}{400} = 2.5\ R/B$

⇒ Too complex to manage records

⇒ More access cost to access records.



Advantage:

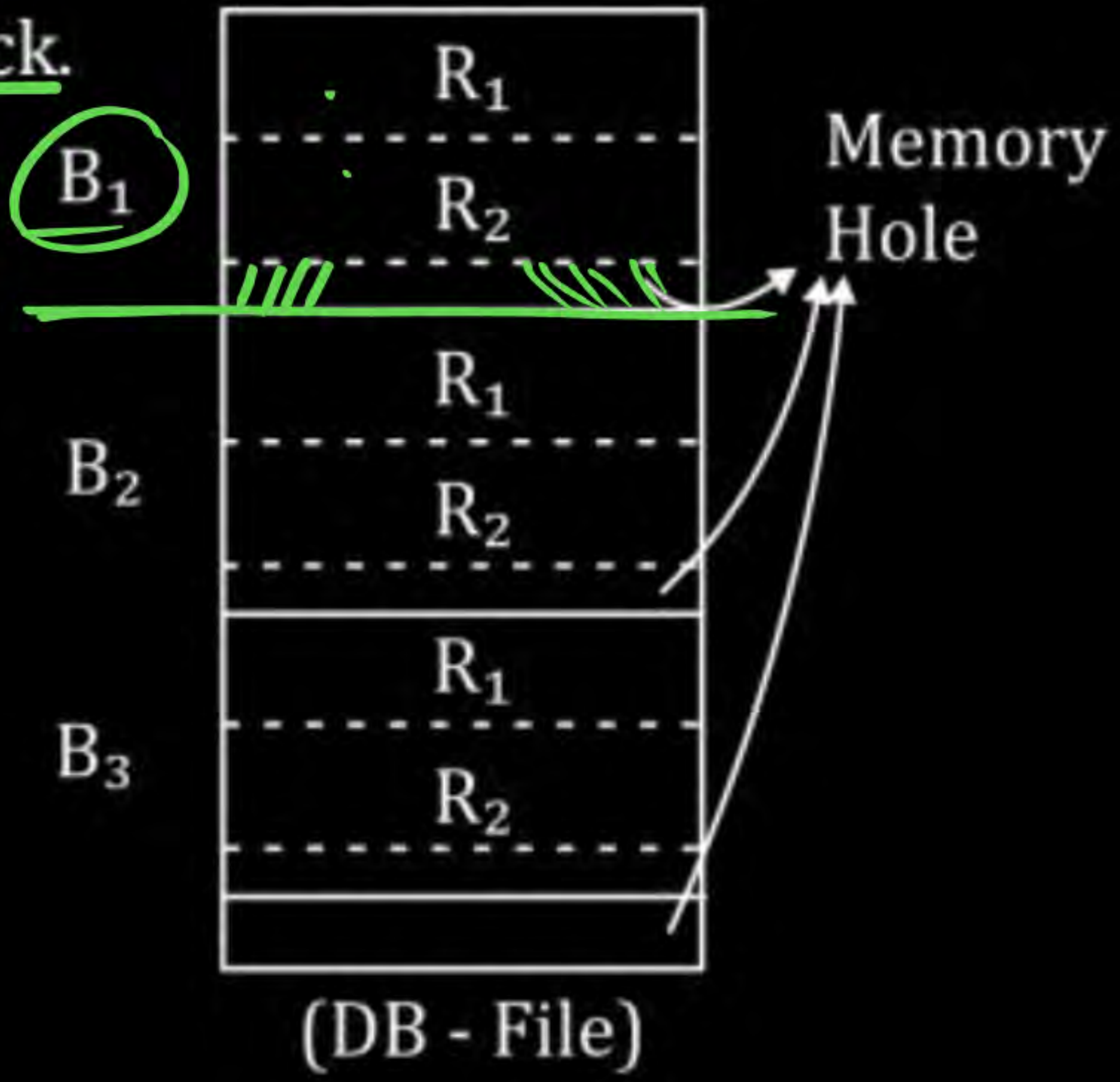
⇒ Possible to allocate file with no internal fragmentation

Record Organization:

(a) Unspanned Organization

Complete Record must be stored in one Block.

$$\text{Block Factor} = \left\lfloor \frac{1000-0}{400} \right\rfloor = 2\ R/B$$



- ⇒ Easy to Manage records
- ⇒ Access cost is also less.
- ⇒ May not possible to avoid internal fragmentation.

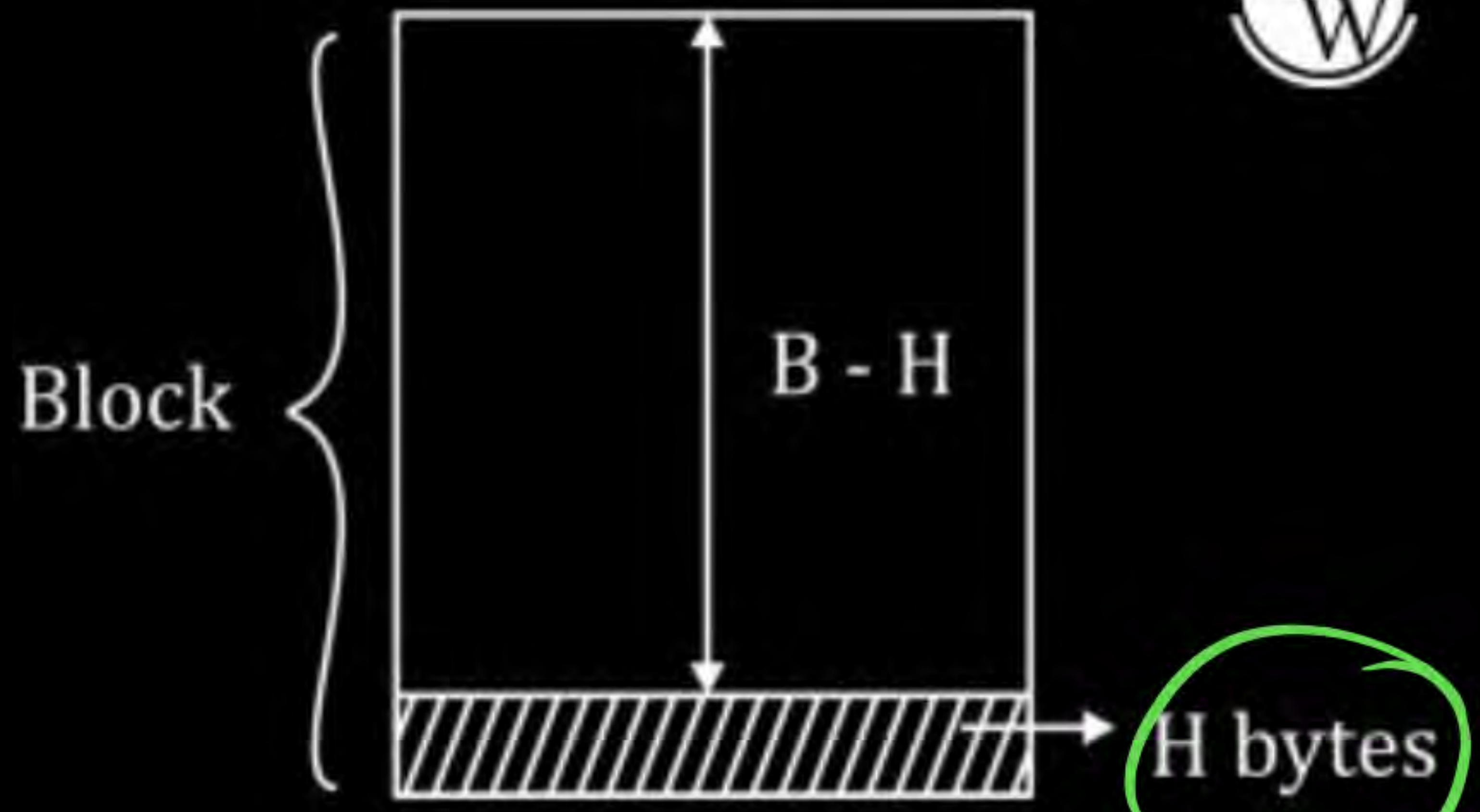
Block Factor

Maximum Possible Records per Block.

Block Size: B bytes

Block Header size: H bytes

Record size: R bytes



'0' Byte

- Block factor for unspanned: $\left\lfloor \frac{B-H}{R} \right\rfloor$ record / block

  because for fixed length record unspanned is preferred.

- Block Factor for spanned: $\frac{B-H}{R}$ record / block

  $\frac{B-H}{R}$

NOTE:

1) To organize DB file with fixed length record unspanned organization is preferred.

2) To organize DB file with variable length record spanned organization preferred.

Indexing (Basic Concepts)

- Indexing mechanisms used to speed up access to desired data.
  - E.g., author catalog in library
- **Search Key** - attribute to set of attributes used to look up records in a file.
- An **index file** consists of records (called **index entries**) of the form

search-key	pointer

- Index files are typically much smaller than the original file.
- Two basic kinds of indices:
  - **Ordered indices:** search keys are stored in sorted order
  - **Hash indices:** search keys are distributed uniformly across "buckets" using a "hash function".

Index file block size is same as DB file Block Size

Block Size of Index File = Block Size of DB file

One Index Record Size = Size of Search Key + Size of Block Pointer

NOTE: To Access a Record Average number of block access
$= \log_2 B_i + 1$

Index Block access

Data Block access

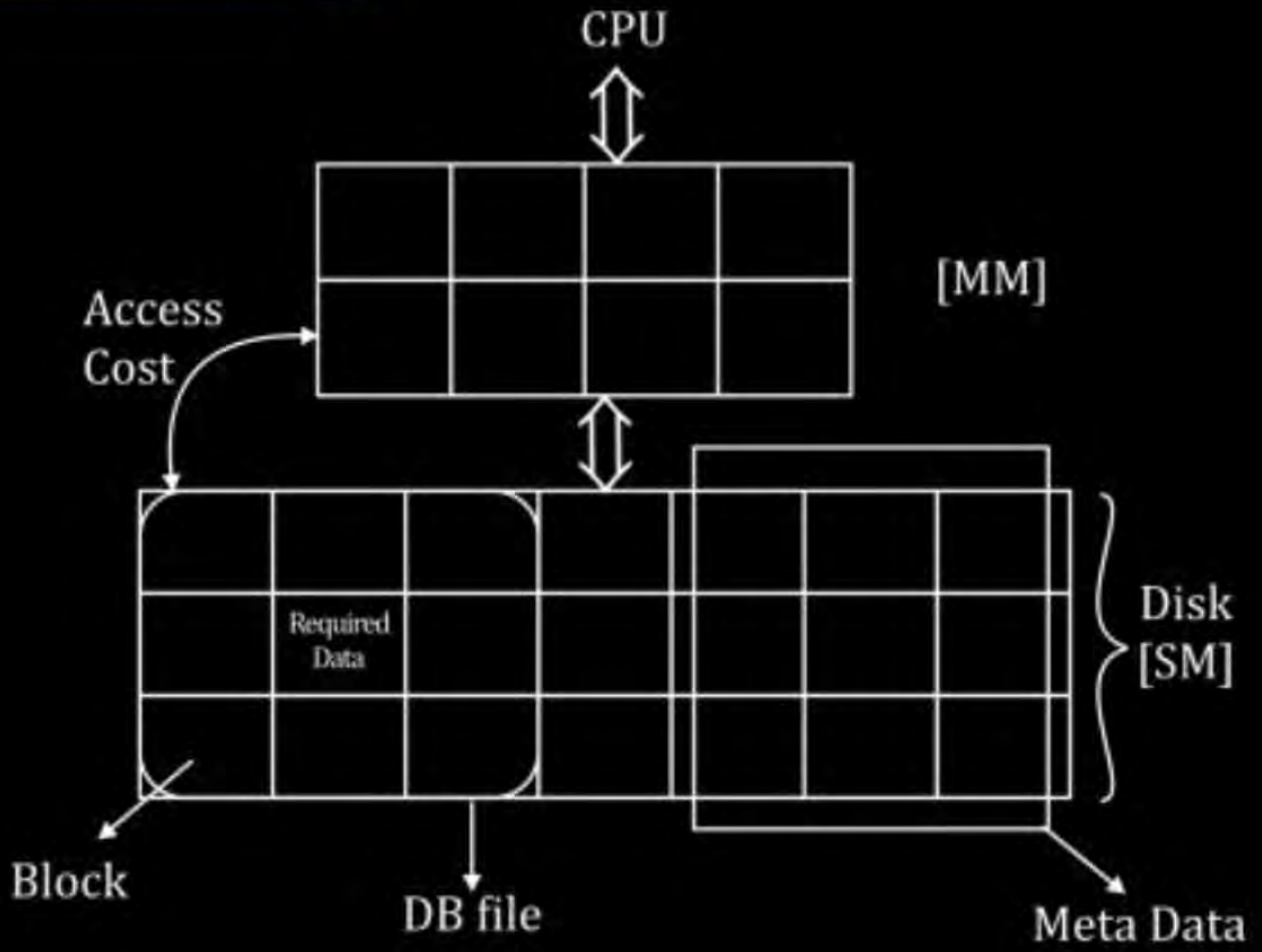
[Bi : Index Block]

Indexing

Used to reduce access cost or I/O cost.

Access Cost: Number of SM(secondary Memory) Blocks (Disk blocks) to transfer from SM to MM in order to access required data.

Indexing



CPU
[MM]
Access
Cost
Required
Data
Disk
[SM]
Block
DB file
Meta Data

Meta Data [Data Dictionary]

→ record format

→ Field format

→ Number of blocks allocated for file

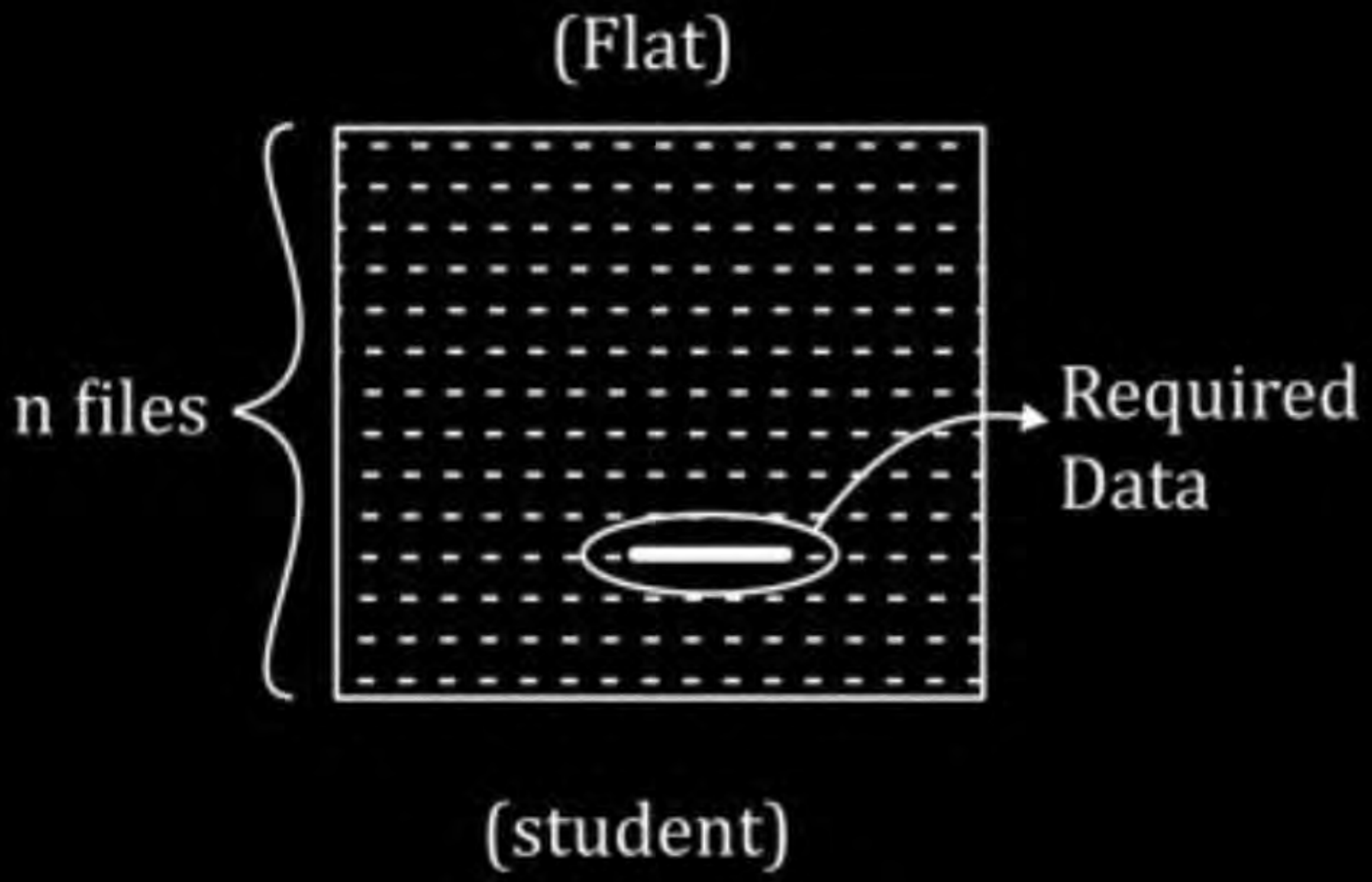
→ Number of record in file

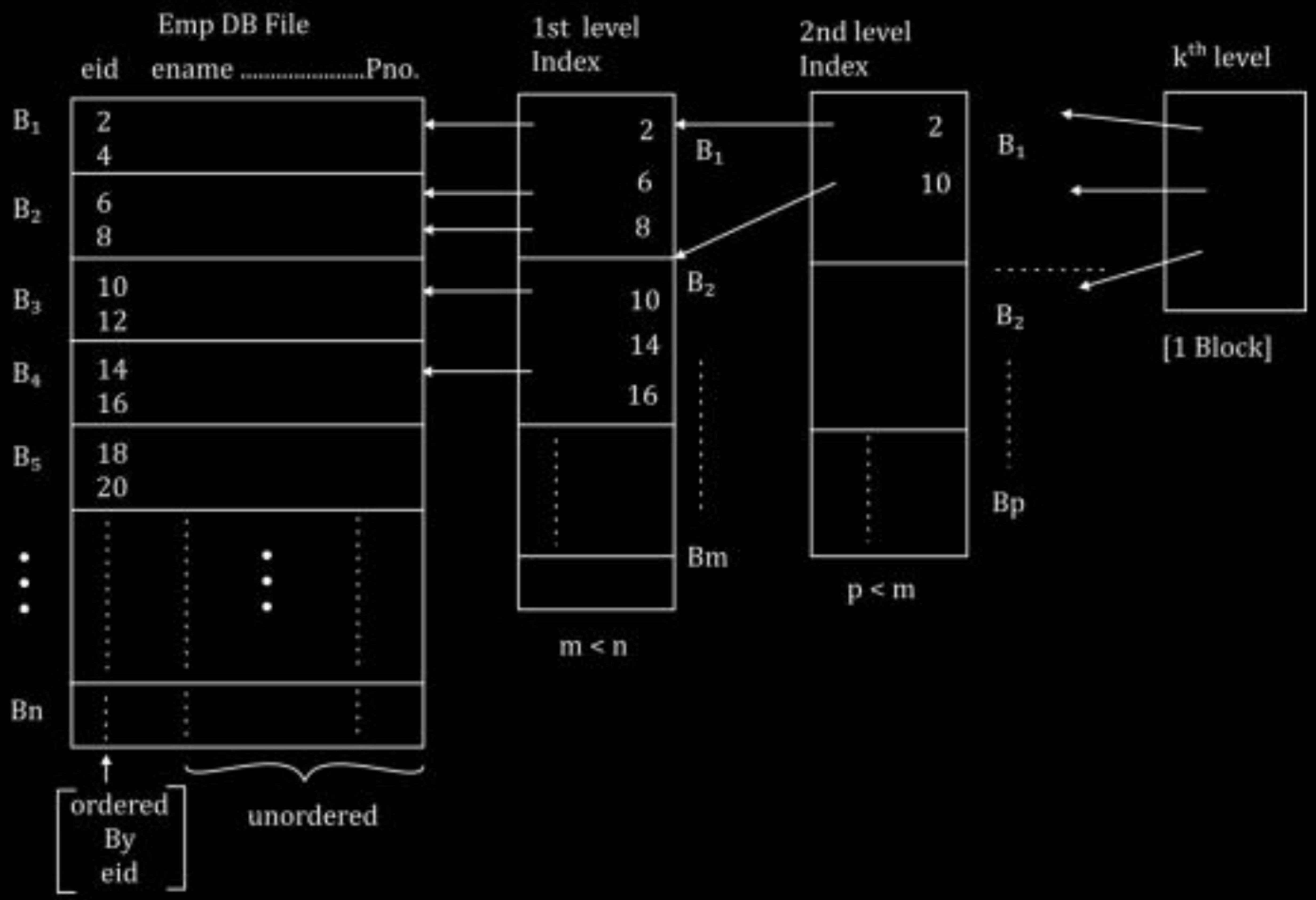
→ Ordered field of file, etc

Indexing

Huge access cost to access data from flat file system.

[complete file should transfer to mm to locate required data]





Emp DB File
eid ename ....Pno.
B1
2
4
B2
6
8
B3
10
12
B4
14
16
B5
18
20
Bn
ordered By eid
unordered
1st level Index
2
6
8
10
14
16
B1
B2
Bm
m < n
2nd level Index
2
10
B1
B2
Bp
p < m
k^th level
[1 Block]

Index File:

$$\boxed{\text{BF (Block Factor) of Index} = \left\lfloor \frac{B-H}{K+P} \right\rfloor \text{ entries / block}}$$

$$\text{Index File}\left\{\boxed{\begin{array}{cc} k_1 & p_1 \\ k_2 & p_2 \\ \vdots & \vdots \end{array}}\right. \quad \therefore \ \mathrm{BF} = \left\lfloor \frac{\mathrm{B-H}}{\mathrm{k-p}} \right\rfloor$$

$$\boxed{\left\lfloor \frac{B-H}{R} \right\rfloor \text{ record / block} < \left\lfloor \frac{B-H}{K+P} \right\rfloor \text{ entries / block}}$$

$$\left\{\begin{array}{l} \text{\# of DB} \\ \text{File block} \end{array}\right\} > \left\{\begin{array}{l} \text{\# of Index} \\ \text{blocks} \end{array}\right\}$$

Multilevel Index:

1) 1st level index is index to DB file and 2nd level onward Index to index file until 1 block index at last level.
2) Idle access cost to access record using multi level index is $(n + 1)$ blocks, n is number of level in index.

Categories of Index:

1) Dense Index [More entries in Index File]
2) Sparse Index [Less entries in Index File]

Category of Index

1) Dense Index Files

Number of Index entries = Number of DB Records

2) Sparse Index Files

Number of Index entries = Number of Blocks

Dense Index Files

- Dense Index - Index record appears for every search-key values in the file.
- Example - index on *ID* attribute of *instructor* relation

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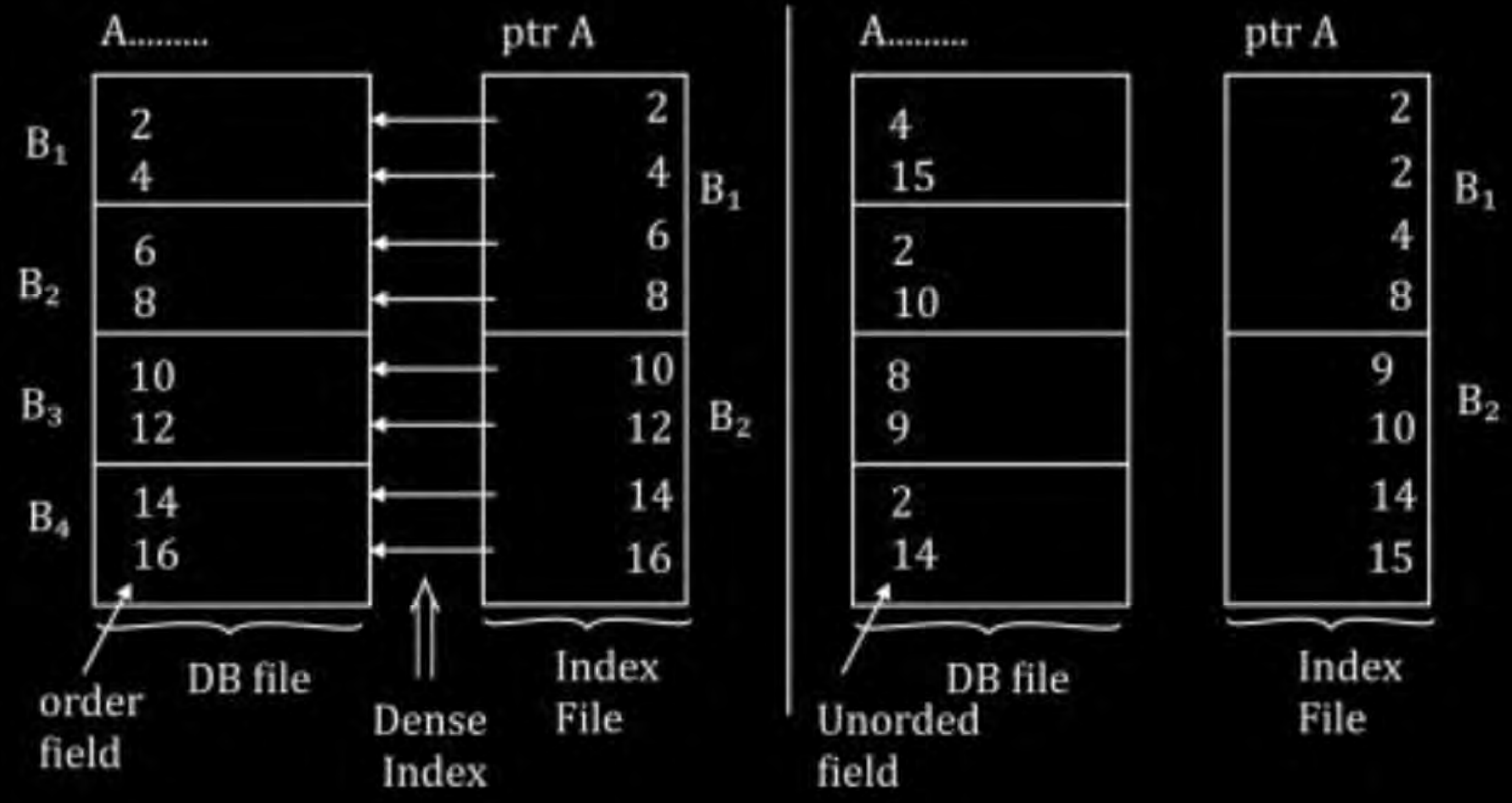
Dense Index [More entries in Index File]

⇒ For each DB record of DB file there exist entry in index file

[Dense Index]



⇒ (# of Index Entries in Index File) ≡ (# of DB records in DB file)

Sparse Index Files

- Sparse Index: contains index records for only some search-key values.
  - Applicable when records are sequentially ordered on search-key
- To locate a record with search-key value K we:
  - Find index record with largest search-key value $< K$
  - Search file sequentially starting at the record to which the index record points

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Sparse Index [Less entries in Index File]

⇒ For set of DB records there exist entry in Index file such a Index is called Sparse Index.

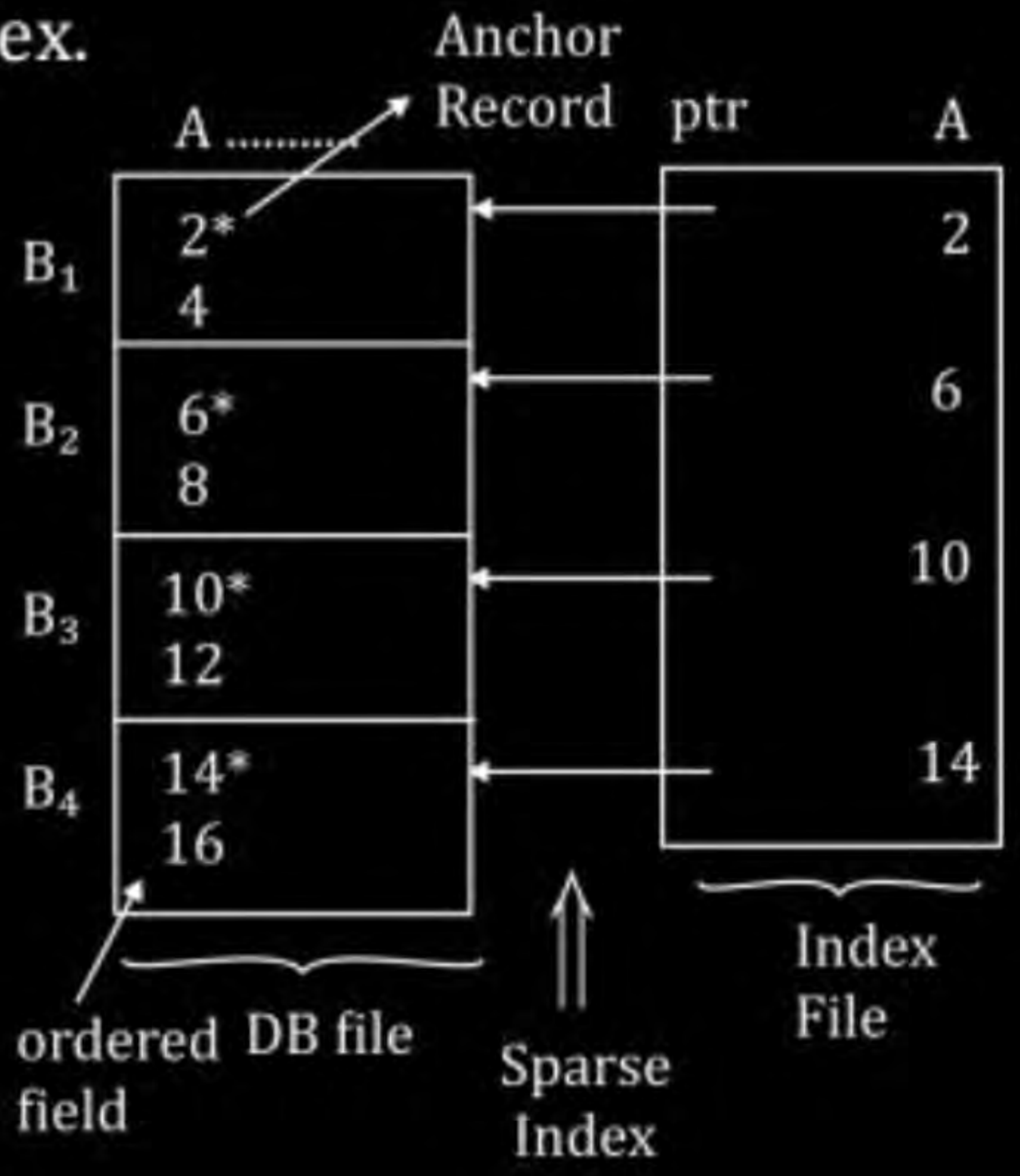
⇒ Sparse Index can build only over ordered field of file.

Anchor Record: First record of Block

[Sparse Index]

⇒ [# of entries in Index] < [# of DB records]

$$\left\{\begin{matrix}\text{\# of Index} \\ \text{entries}\end{matrix}\right\} \equiv \left\{\begin{matrix}\text{\# of DB} \\ \text{blocks}\end{matrix}\right\}$$



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$$\boxed{\left\lfloor \frac{B-H}{R} \right\rfloor \text{ record / block} < \left\lfloor \frac{B-H}{K+P} \right\rfloor \text{ entries / block}}$$

$$\left\{ \begin{matrix} \text{\# of DB} \\ \text{File block} \end{matrix} \right\} > \left\{ \begin{matrix} \text{\# of Index} \\ \text{blocks} \end{matrix} \right\}$$

Example:

- Suppose that:
  - record size $R = 150$ bytes, block size $B = 512$ bytes, $r = 30000$ records
- Then, we get:
  - blocking factor $Bfr = B \text{ div } R = 512 \text{ div } 150 = 3$ records/block
  - number of file blocks $b = (r/\text{Bfr}) = (30000/3) = 10000$ blocks

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
- For an index on the SSN field, assume the field size V_{SSN} =9 bytes, assume the record pointer size P_R=7 bytes. Then:

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- For an index on the SSN field, assume the field size $V_{SSN}=9$ bytes, assume the record pointer size $P_R=7$ bytes. Then:
  - index entry size $R_1=(V_{SSN}+P_R)=(9+7)=16$ bytes
  - index blocking factor $Bfr_1=B \text{ div } R_1=512 \text{ div} 16=32$ entries / block
  - number of index blocks $b=(r/Bfr_1)=(30000/32)=938$ blocks
  - binary search needs $\log_2 bI=\log_2 938=10$ block accesses

Q.

# of records of file: 16384

Block size: 4096 Bytes

Record size: 256 Bytes

Search key size: 22 Bytes

Pointer : 10 Bytes

⇒ I/O cost to access record without index based on ____

(a) Ordered field =

(b) Unordered Filed =

⇒ Index Dense [Using]

(a) # of index blocks at 1st level =

(b) I/O cost to access record: [Using 1st level] =

⇒ By using sparse Index:

(a) # of Index blocks at 1st level =

(b) I/O cost to access record: [Using 1st level] =

Types of Index

Single-level Ordered Indexes

- Primary indexes
- Clustering indexes
- Secondary indexes

Multilevel Indexes

Dynamic multilevel indexes Using B-Tress and B^+ Trees.

Types of Index

Type of Index
(X: search key)

- X is ordered field of DB file
  - X is primary key Alternative key of DB file ⇓ Primary Index
  - X is non key of OB file ⇓ Clustering Index
- X is Unordered field of DB file
  - X is primary key Alternative key of DB file ⇓ Secondary Index (over key)
  - X is non key of OB file ⇓ Secondary Index (Over Non-key)

THANK YOU!