Introduction to Data Structure (Data Management) Lecture 13

Felipe P. Vista IV

Reminder

- Everybody, make sure that your name in ZOOM is in the following format:
  - University ID Num Name (no “(   )“)
  - Ex: 202054321 Juan Dela Cruz
  -
  - Not changing your name to this format
    - you might be marked Absent

  * → absent?

- Data Storage Basics

- Indexes

INTRO TO DATA STRUCTURE

Data Storage Basics

Motivation

- To understand performance, we need to understand a bit about how DBMS works:
  - the database application is too slow… why?
  - one of the queries is very slow… why?

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  - one of the queries is very slow… why?
- Understanding query optimization
  - we've seen SQL query ~> logical plan (RA),
    but not much about RA ~> physical plan

Motivation

- To understand performance, we need to understand a bit about how DBMS works:
  - the database application is too slow… why?
  - one of the queries is very slow… why?
- Understanding query optimization
  - we've seen SQL query ~> logical plan (RA),
    but not much about RA ~> physical plan
- Choice of indexes is often up to us

Student

Id	fName	lName
10	Matt	Burt
20	Makenna	Balvanz
…	…	…

Data Storage

- DBMSs store data in files

Student

Id	fName	lName
10	Matt	Burt
20	Makenna	Balvanz
…	…	…

Data Storage

- DBMSs store data in files
- Most common organization is row-wise storage:
  - file is split into blocks
  - Each block contains a set of tuples

10	Matt	Burt	block 01
20	Makenna	Balvanz	
50	…	…	block 02
200	…		
220			block 03
240			
420			block 04
800			

The given example has 4 blocks with 2 tuples each

Student

Id	fName	lName
10	Matt	Burt
20	Makenna	Balvanz
…	…	…

Data Storage

- DBMSs store data in files
- Most common organization is row-wise storage:
  - file is split into blocks
  - Each block contains a set of tuples
- DBMS reads the entire block

10	Matt	Burt	block 01
20	Makenna	Balvanz	
50	…	…	block 02
200	…		
220			block 03
240			
420			block 04
800			

The given example has 4 blocks with 2 tuples each

Student

Id	fName	lName
10	Soheill	Satavis
20	Nwabisa	Ngumbela
…	…	…

Data File Types

The data heap file can be one of:

- Heap file
  - unsorted

Student

Id	fName	lName
10	Soheill	Satavis
20	Nwabisa	Ngumbela
…	…	…

Data File Types

The data heap file can be one of:

- Heap file
  - unsorted
- Sequential file
  - sorted based on some attributes

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10	Soheill	Satavis
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…	…	…

Data File Types

The data heap file can be one of:

- Heap file
  - unsorted
- Sequential file
  - sorted based on some attributes

Note:
The key here is something different from primary key:
- it just means that we order the file according to that attribute.

In our example, we order by ID.
- we can also order by fName,
--- if it seems a better idea for applications using the DB.

Index

- An additional file, that allows fast access to records in the data file given a search key

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- The index contains (key, value) pairs:
  - Key:= attribute value (e.g. Student ID, name)
  - Value:= pointer to the record

Index

- An additional file, that allows fast access to records in the data file given a search key
- The index contains (key, value) pairs:
  - Key:= attribute value (e.g. Student ID, name)
  - Value:= pointer to the record
- Could have many indexes for one table
  - sorted based on some attributes

Key = it means as a search key

What Key?

Different **keys**:

- Primary key – uniquely identifies a tuple

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- Key of Sequential file – how data file is sorted, if at all

What Key?

Different **keys**:

- Primary key – uniquely identifies a tuple
- Key of Sequential file – how data file is sorted, if at all
- Index Key – how index is organized

Ex. 1: Index on ID

Student

Id	fName	lName
10	Soheill	Satavis
20	Nwabisa	Ngumbela
…	…	…

Index on Student.ID

10	
20	
50	
200	
220	
240	
420	
800	

950	
…	

Student

Id	fName	lName
10	Soheill	Satavis
20	Nwabisa	Ngumbela
...	...	...

Ex. 1: Index on ID

Index on **Student.ID**

10	
20	
50	
200	
220	
240	
420	
800	
950	
...	

Data file **Student**

10	Soheil	Satavis
20	Nwabisa	Ngumbela
50	...	...
200	...	
220		
240		
420		
800		

Ex. 1: Index on ID

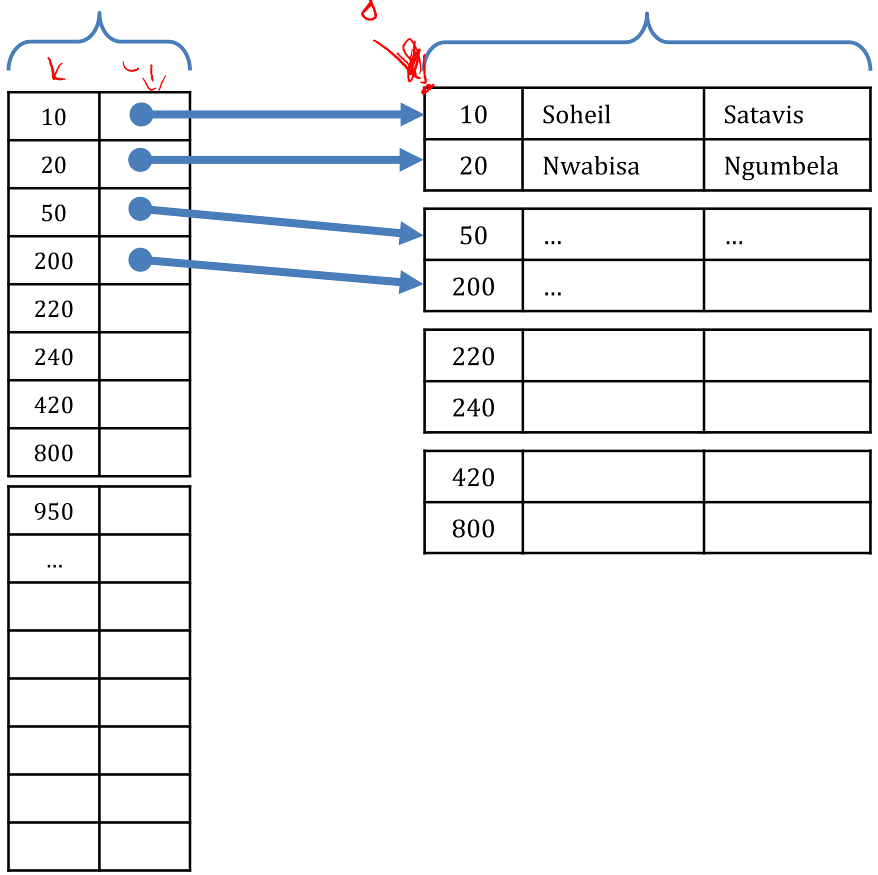
Student

Id	fName	lName
10	Soheill	Satavis
20	Nwabisa	Ngumbela
…	…	…

File

Index on Student.ID

Data file Student



Ex. 2: Index on fName

Student

Id	fName	lName
10	Soheill	Satavis
20	Nwabisa	Ngumbela
…	…	…

Index on Student.fName

Nwabisa	
Pat	
Janin	
Mikki	
…	
…	
…	
…	

…	
…	
Soheil	

Student

Id	fName	lName
10	Soheill	Satavis
20	Nwabisa	Ngumbela
…	…	…

Ex. 2: Index on fName

Index on Student.fName

Nwabisa	
Pat	
Janin	
Mikki	
…	
…	
…	
…	

…	
…	
Soheil	

Data file Student

8 Nwabisa

10	Soheil	Satavis
20	Nwabisa	Ngumbela

50	…	…
200	…	

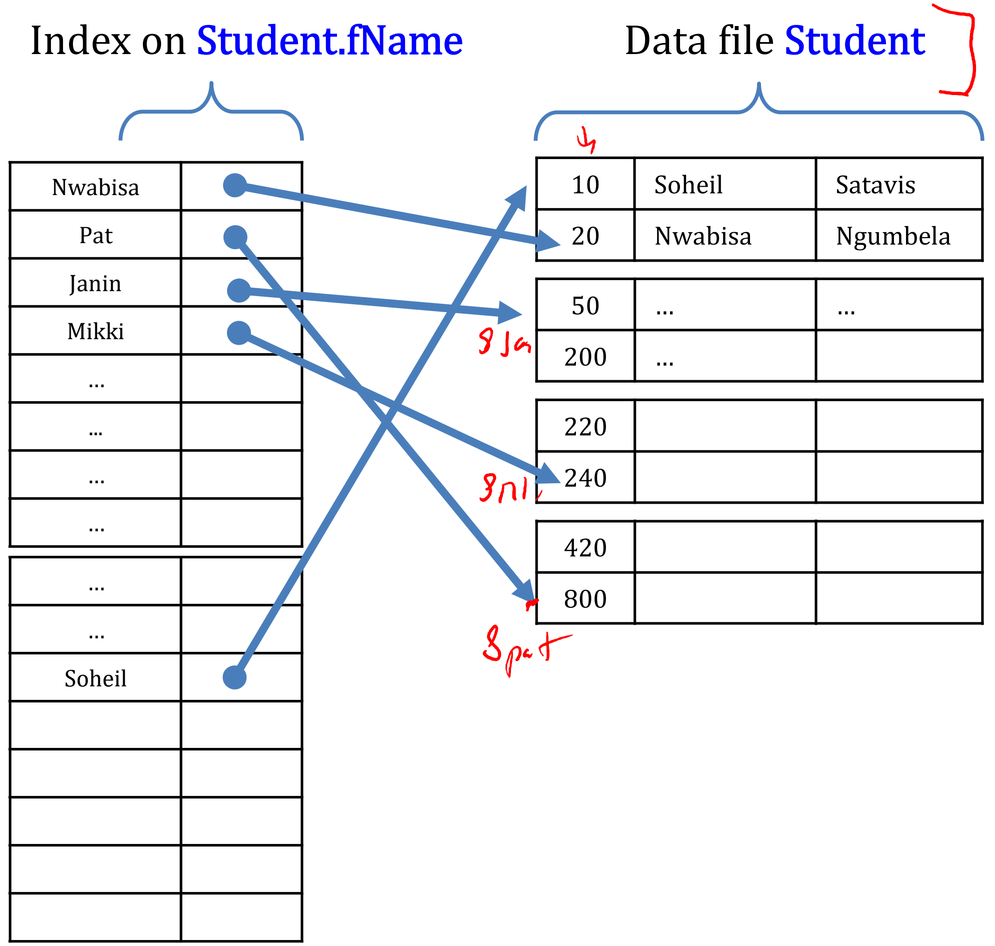
220		
240		

420		
800		

Ex. 2: Index on fName

Student

Id	fName	lName
10	Soheill	Satavis
20	Nwabisa	Ngumbela
…	…	…



Index on lName

Pelyo	8 Pat
Gates	8 Sdan
Balvant	8 Mic

Index on Organization

Several index organizations:

- B+ trees – most popular
  - They are search trees,
  - but they are not binary, instead have higher fan-out

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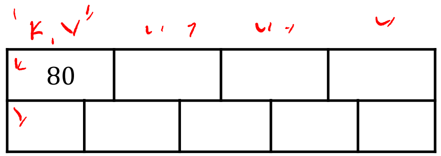
Index on Organization

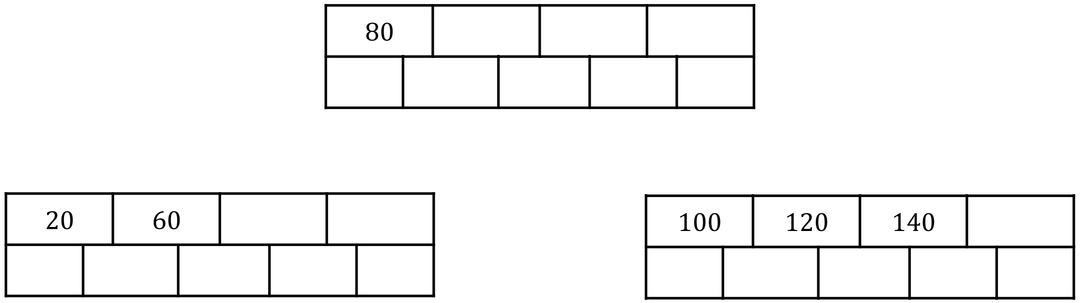
Several index organizations:

- B+ trees – most popular
  - They are search trees,
  - but they are not binary, instead have higher fan-out
- Hash table
- Specialized indexes – bit maps, R-trees, inverted index

Recap: B+ Tree



Recap: B+ Tree



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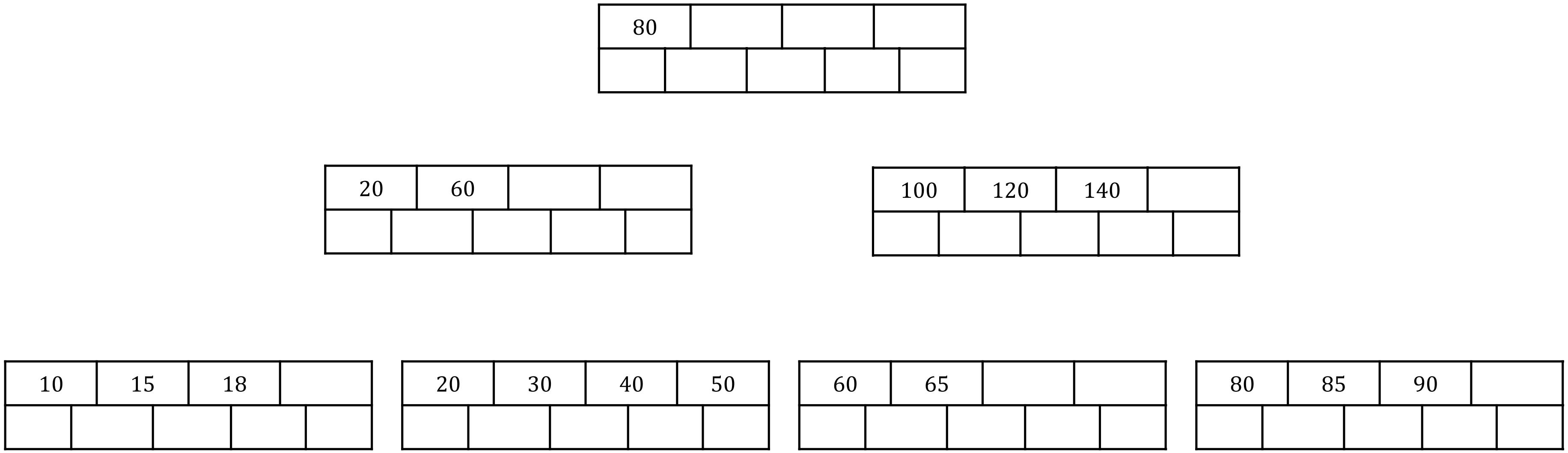

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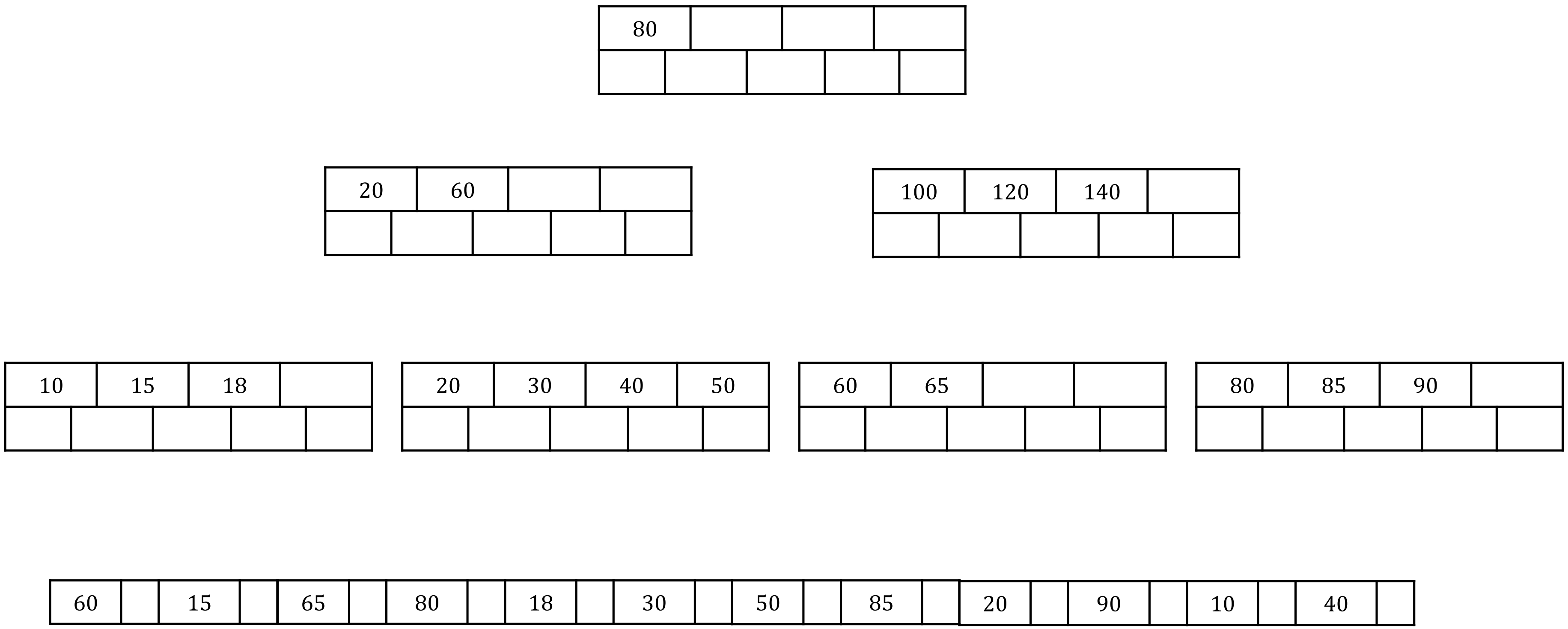
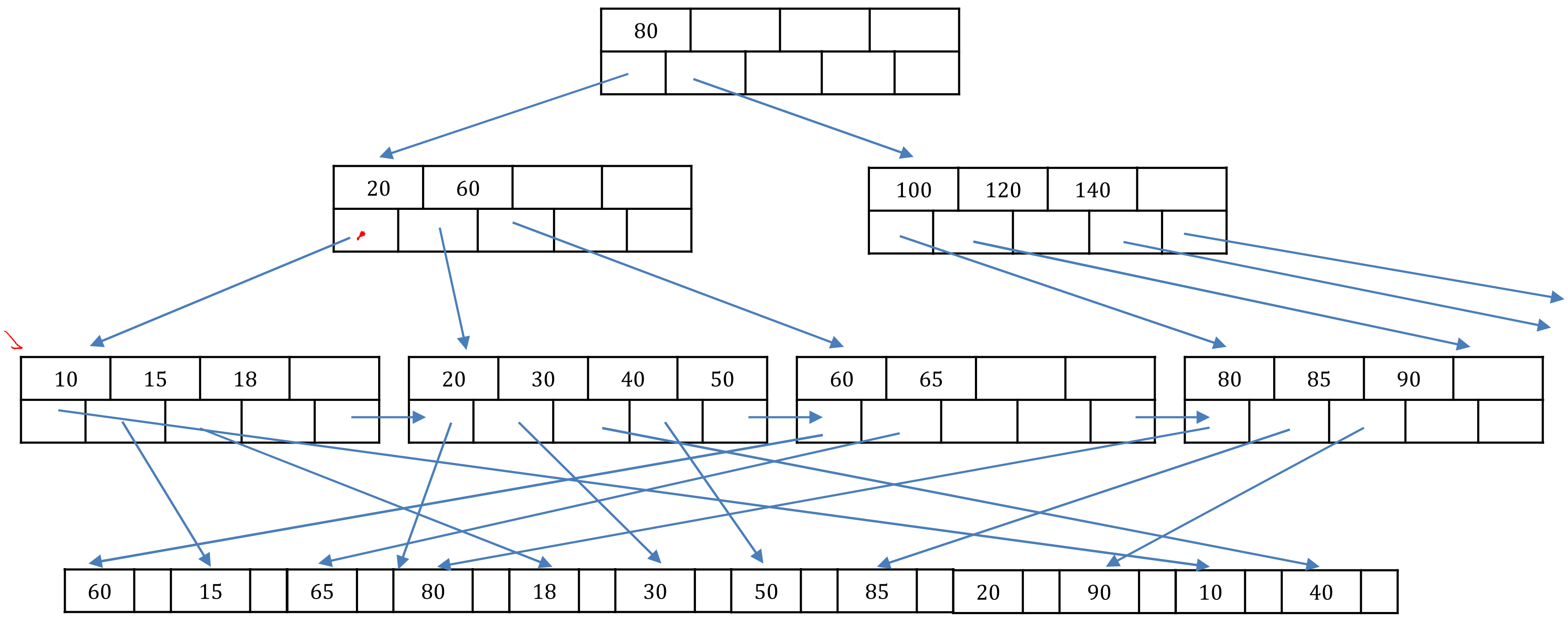

80
20 60
100 120 140
10 15 18
20 30 40 50
60 65
80 85 90
60 15 65 80 18 30 50 85 20 90 10 40

Recap: B+ Tree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30
50
85
20
90
10
40

www.jbnu.ac.kr

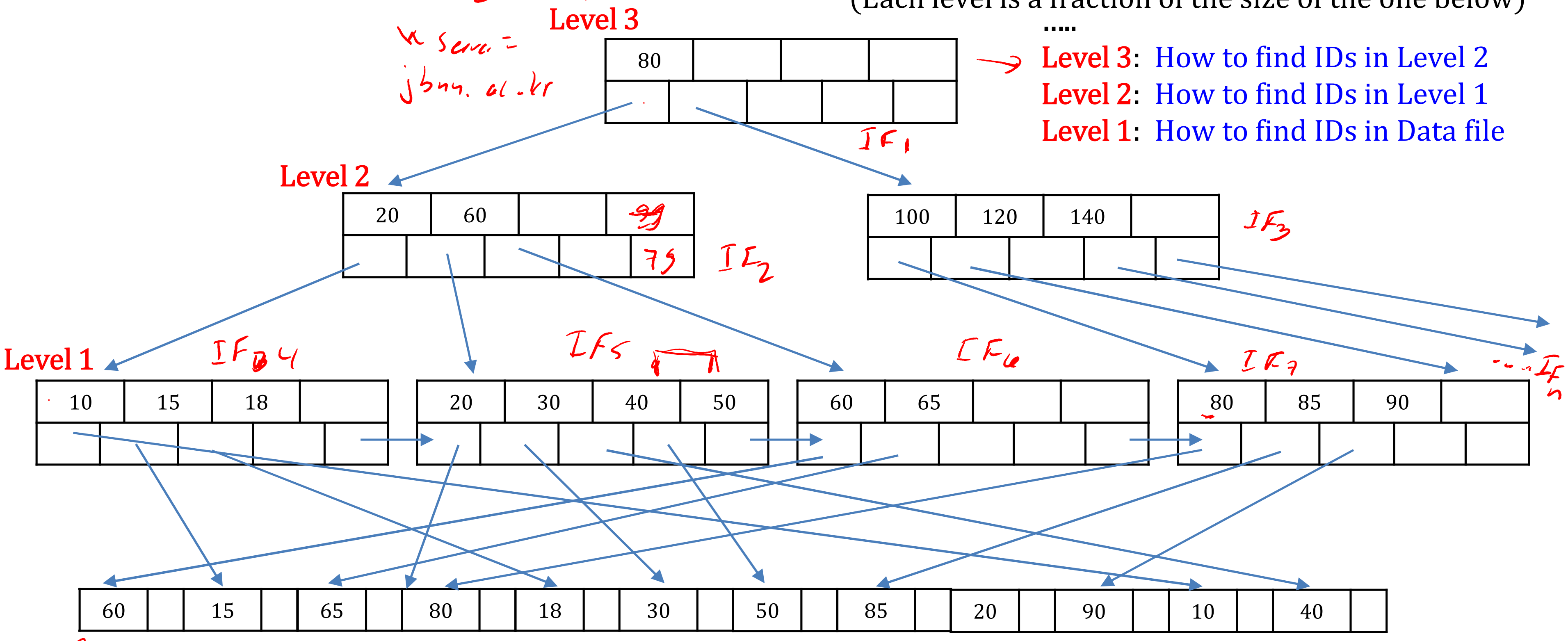
DNS 1 = .kr
DNS 2 = .ac.kr
ac server = jbnu.ac.kr

Recap: B+ Tree

(Each level is a fraction of the size of the one below)

.....

Level 3: How to find IDs in Level 2
Level 2: How to find IDs in Level 1
Level 1: How to find IDs in Data file



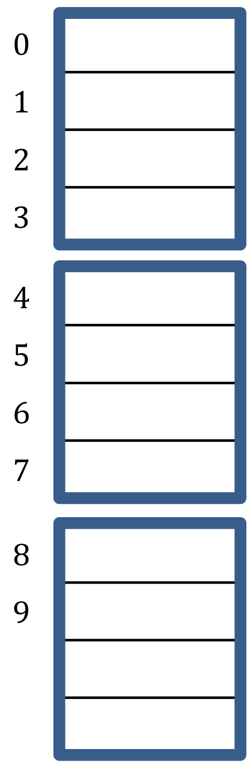
id dB File

Hash Index

A (naïve) hash function:

$$\boxed{H(x) = x \bmod 10}$$

 = disk block



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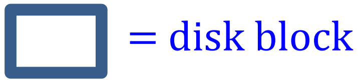
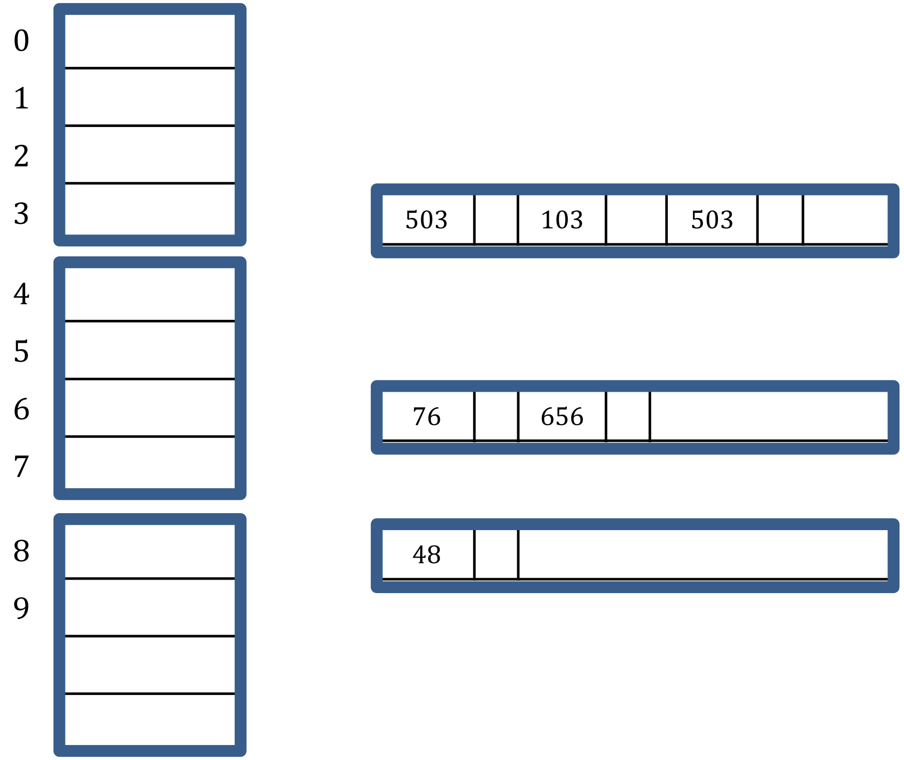




Hash Index

A (naïve) hash function:

$H(x)=x \bmod 10$

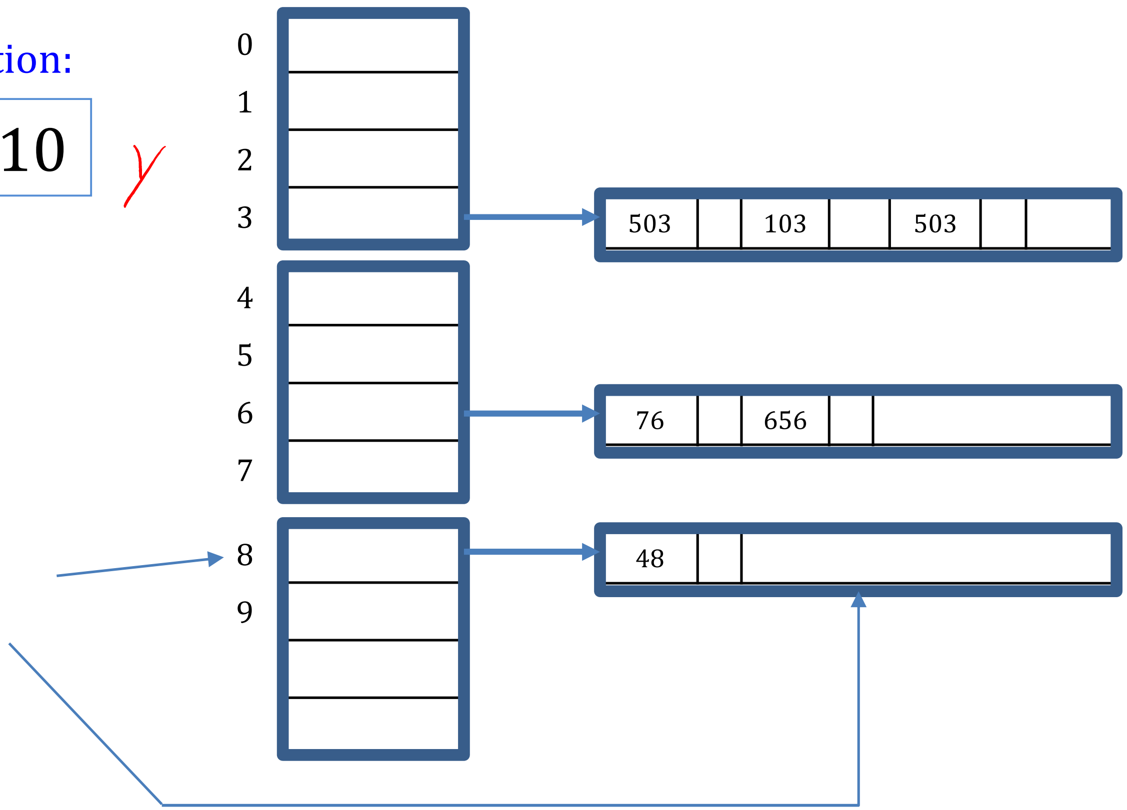
y

= disk block

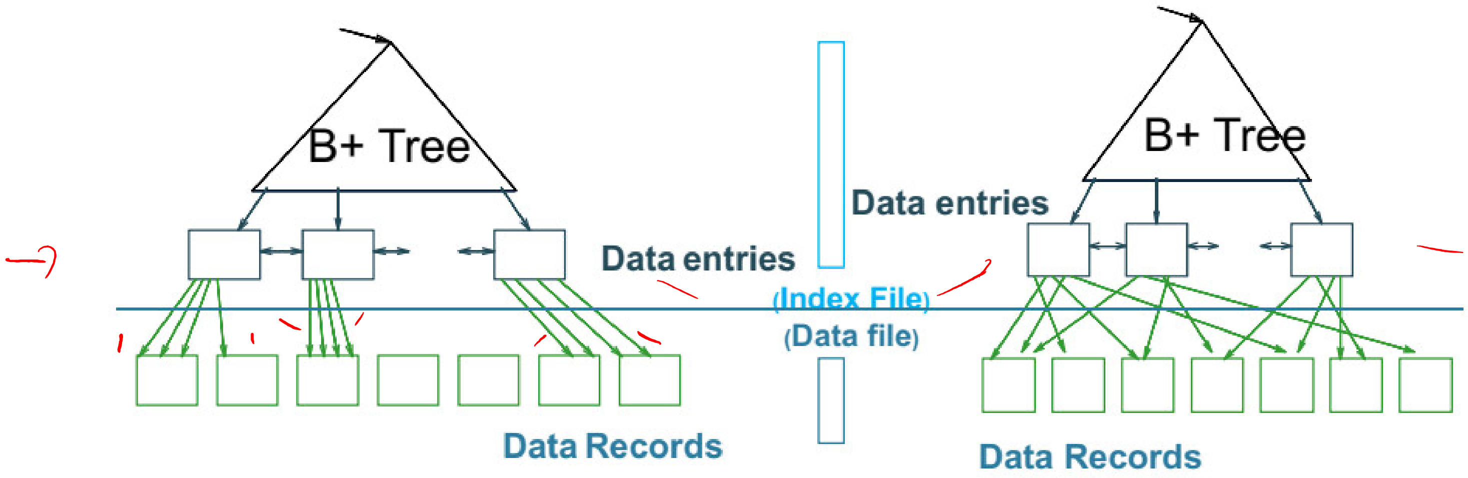
Cost per lookup:

- One access in array
- One access in list

No range queries!



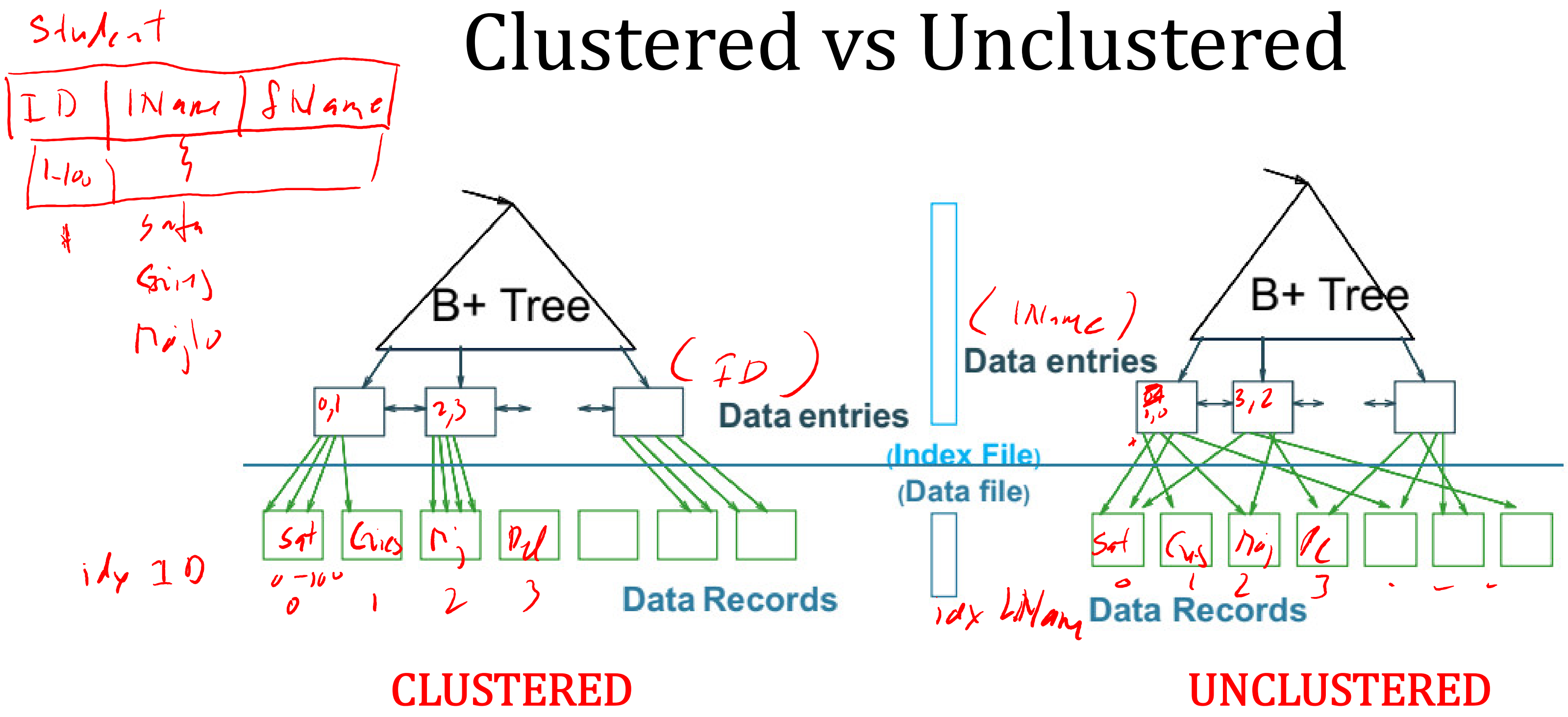
Clustered vs Unclustered



CLUSTERED

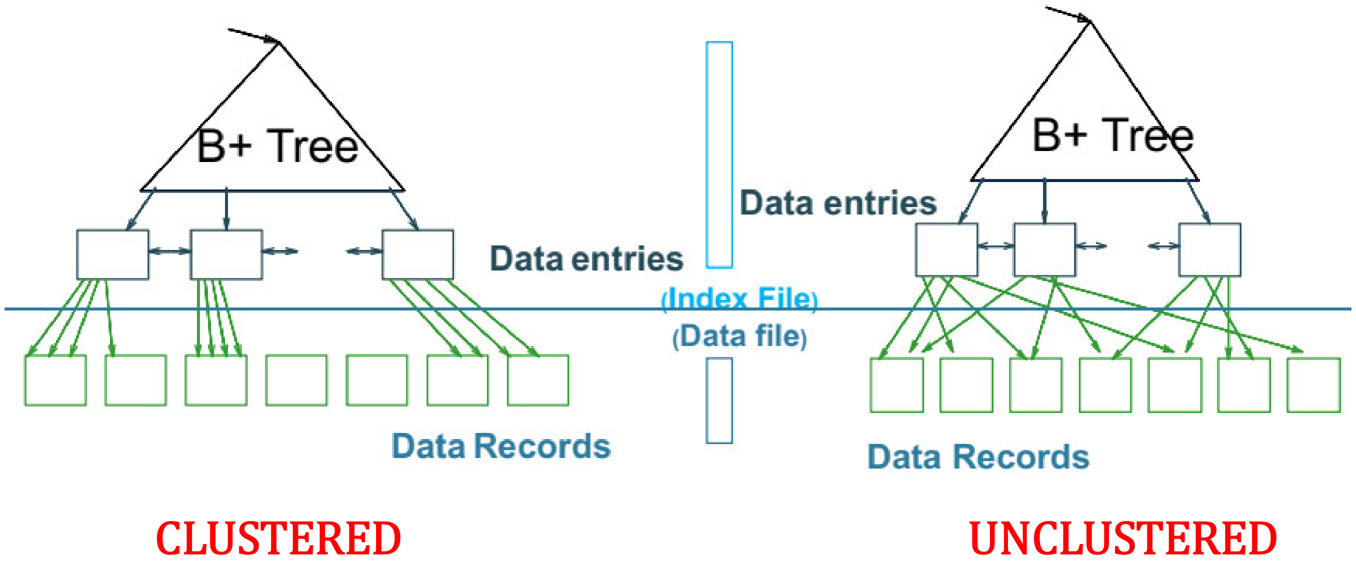
UNCLUSTERED

Clustered vs Unclustered



Every table can have **only one** clustered and **many** unclustered indexes

Clustered vs Unclustered

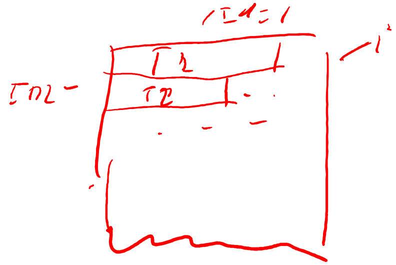


Every table can have **only one** clustered and **many** unclustered indexes

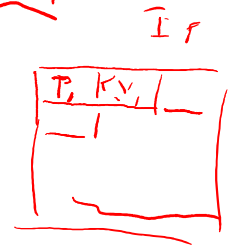
SQL server defaults to cluster by **primary key**

I 1)

Index Classification



- Clustered/unclustered
  - *Clustered records* = records close in index are close in data
    - Option 1: Data inside data file is sorted on disk
    - Option 2: Store data directly inside the index (no separate files)
  - *Unclustered* = records close in index maybe far in data



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- Primary/ secondary
  - Meaning 1:
    - Primary: is over attributes that include Primary Key
    - Secondary: otherwise
  - Meaning 2: means the same as clustered/unclustered

DB ind

Primary secondary → Physical Logical

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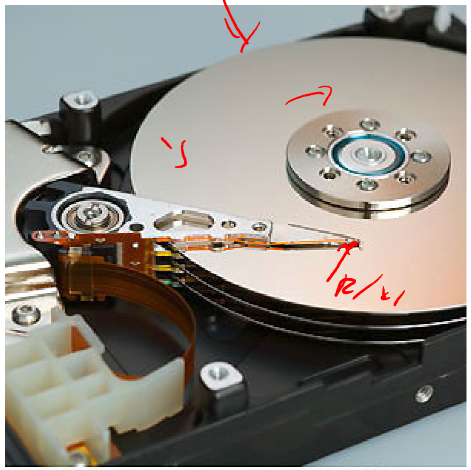
- Organization
  - B+ tree or Hash table

Floppy disk 2.88 MB

Scanning a Data File

TB HD

- Hard disks are mechanical devices!
  - 60's technology, much higher density now
  - Read only as fast as the rotation speed!



ComputerHope.com

* disk density or areal density - measurement of the amount of data a disk can hold
- measured by the TPI (tracks per inch) or bits per inch

defrag → defragment

Scanning a Data File

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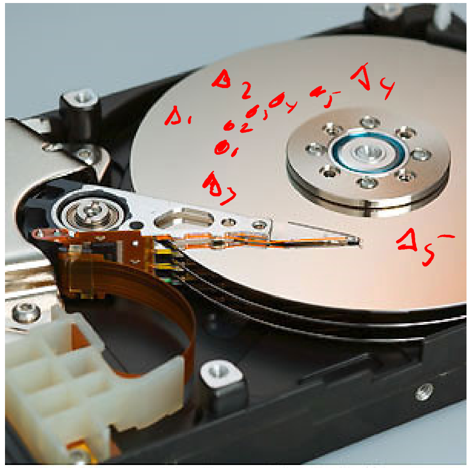
  - Read only as fast as the rotation speed!
- Result?
  - sequential scan is MUCH FASTER than random reads
  - Good: read blocks 1, 2, 3, 4, 5,...
  - Bad: read blocks 2342, 11, 321, 9, ...



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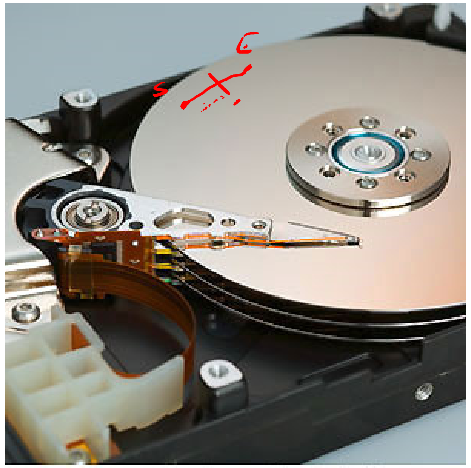
Say, A = 8 FTE2,

Scanning a Data File



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- Rule of thumb:
  - Random reading 1-2% of the file ≈ entire file sequentially scanned
  - this decrease over time (due to increased density of disks)

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Scanning a Data File

HDD

- Hard disks are mechanical devices!
  - 60's technology, much higher density now
  - Read only as fast as the rotation speed!
- Result?
  - sequential scan is MUCH FASTER than random reads
  - Good: read blocks 1, 2, 3, 4, 5,...
  - Bad: read blocks 2342, 11, 321, 9, ...
- Rule of thumb:
  - Random reading 1-2% of the file ≈ entire file sequentially scanned
  - this decrease over time (due to increased density of disks)
- HDD ~> Solid State (SSD)
  - Entirely different performance characteristics

ComputerHope.com

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- measured by the TPI (tracks per inch) or bits per inch

Takes(studentID, courseID)
Student(**ID**, name, …)

Example

```
for y in Takes
  if courseID = 200 then
    for x in Student
      if x.ID=y.studentID
        output *
```

```
Takes(studentID, courseID)
Student(ID, name, …)
```

Example

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for y in Takes
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        output *
```

```
SELECT name
FROM Student x, Takes y
WHERE x.ID=y.studentID
      AND y.courseID=300
```

```
Takes(studentID, courseID)
Student(ID, name, …)
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Example

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SELECT name
FROM Student x, Takes y
WHERE x.ID=y.studentID
      AND y.courseID=300
```

Assume the database has indexes on these attributes:

- **index_takes_course** = index on Takes.courseID
- **index_studentID** = index on Student.ID

```
Takes(studentID, courseID)
Student(ID, name, …)
```

(ID is underlined in Student.)

Example

(Frontend)

Proj

```
for y in Takes
  if courseID = 200 then
    for x in Student
      if x.ID=y.studentID
        output *
```

Sel

(back end)

```
SELECT name
FROM Student x, Takes y
WHERE x.ID=y.studentID
      AND y.courseID=300
```

Assume the database has indexes on these attributes:

- index_takes_course = index on Takes.courseID
- index_studentID = index on Student.ID

Base File

(dBfile idx

key

```
for y1 in index_takes_course where y1.courseID = 300
  for y in y1.Takes
    for x1 in index_studentID where x.ID = y.studentID
      for x in x1.Student
        output x.*, y.*
```

```
Takes(studentID, courseID)
Student(ID, name, …)
```

Example

π

```
for y in Takes
  if courseID = 200 then
    for x in Student
      if x.ID=y.studentID
        output *
```

σ

$\bowtie$

```
SELECT name
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```

Assume the database has indexes on these attributes:

- **index_takes_course** = index on Takes.courseID
- **index_studentID** = index on Student.ID

Index selection — σ

Index join — $\bowtie_1$

```
for y1 in index_takes_course where y1.courseID = 300
  for y in y1.Takes
    for x1 in index_studentID where x.ID = y.studentID
      for x in x1.Student
        output x.*, y.*
```

π

Getting Practical:
Creating Indexes in SQL

```
CREATE TABLE V(M int, N varchar(20), P int);
```

```
CREATE INDEX V1 ON V(N);
```

```
CREATE INDEX V2 ON V(P, M);
```

```
CREATE INDEX V3 ON V(M, N);
```

```
CREATE UNIQUE INDEX V4 ON V(N);
```

```
CREATE CLUSTERED INDEX V5 ON V(N);
```

Getting Practical:
Creating Indexes in SQL

```
CREATE TABLE V(M int, N varchar(20), P int);
```

```
CREATE INDEX V1 ON V(N);
```

```
CREATE INDEX V2 ON V(P, M);
```

What does this mean?

```
CREATE INDEX V3 ON V(M, N);
```

```
CREATE UNIQUE INDEX V4 ON V(N);
```

```
CREATE CLUSTERED INDEX V5 ON V(N);
```

Not supported in SQLite

Student

Id	fName	lName
10	Divan	Mahlooji
20	Jenny	Rhee
…	…	…

Which Indexes?

- How many indexes **could** we create?

Student

Id	fName	lName
10	Divan	Mahlooji
20	Jenny	Rhee
…	…	…

Which Indexes?

- How many indexes **could** we create?

15, namely: (ID), (fName), (lName), (ID, fName), (fName, ID), …

(ID, lM) (LM, ID) (f, LN) (LN, FN), ~~(FD, LN, FN)~~

Student

Id	fName	lName
10	Divan	Mahlooji
20	Jenny	Rhee
…	…	…

Which Indexes?

- How many indexes **could** we create?

15, namely: (ID), (fName), (lName), (ID, fName), (fName, ID), …

- Which indexes **should** we create?

5? 10? 15; 20?

Student

Id	fName	lName
10	Divan	Mahlooji
20	Jenny	Rhee
…	…	…

Which Indexes?

- How many indexes **could** we create?

15, namely: (ID), (fName), (lName), (ID, fName), (fName, ID), …

- Which indexes **should** we create?

Few! Each new index slows down updates to Student

Index selection is a hard problem

Student

Id	fName	lName
10	Divan	Mahlooji
20	Jenny	Rhee
…	…	…

Which Indexes?

- The index selection problem
  - given a Studn table, and a "workload" (big Java application with lots of SQL queries),
  - decide which indexes to create (and which ones NOT to create!)

Student

Id	fName	lName
10	Divan	Mahlooji
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…	…	…

Which Indexes?

- The index selection problem
  - given a table, and a "workload" (big Java application with lots of SQL queries),
  - decide which indexes to create (and which ones NOT to create!)

- Who will do index selection?
  - database administrator DBA
  - semi-automatically, using a database administration tool

Index Selection: Which Search Key?

- Make some attribute **K** a search key if the WHERE clause contains:
  - an exact match on **K**   K = '20200512'
  - a range predicate on **K**   K = '20200512 — 20200612'
  - a join on **K**

Index Selection Problem

```
V(M, N, P);
```

```
SELECT *
FROM V
WHERE V.M = 33;
```

Scan V
For each record:
  if M=33 **then** output

Lookup key 33 in I1
For each record: output

INDEX I1 **ON** V(M)

```
SELECT *
FROM V
WHERE V.M = 33
      AND V.P = 55;
```

Scan V
For each record:
  if M=33 and P=55 **then** output

Lookup key 33 in I1
For each record
  if P=55 **then** output

Index Selection Problem 1

```
V(M, N, P);
```

The workload is just as given and nothing else:

100,000 queries:

```
SELECT *
FROM V
WHERE N = ?
```

10K

100 queries:

```
SELECT *
FROM V
WHERE P = ?
```

Which indexes?

Index Selection Problem 1

```
V(M, N, P);
```

The workload is just as given and nothing else:

100,000 queries:

```sql
SELECT *
FROM V
WHERE N = ?
```

100 queries:

```sql
SELECT *
FROM V
WHERE P = ?
```

A: **V(N)** and **V(P)** (hash tables or B-trees)

Index Selection Problem 2

```
V(M, N, P);
```

The workload is just as given and nothing else:

100,000 queries:

```
SELECT *
FROM V
WHERE N > ?
  AND N < ?
```

100 queries:

```
SELECT *
FROM V
WHERE P = ?
```

100,000 queries:

```
INSERT INTO V
VALUES(?, ?, ?)
```

Which indexes?

Index Selection Problem 2

```
V(M, N, P);
```

The workload is just as given and nothing else:

100,000 queries:

```
SELECT *
FROM V
WHERE N > ?
  AND N < ?
```

v(N)

100 queries:

```
SELECT *
FROM V
WHERE P = ?
```

v(P)

100,000 queries:

```
INSERT INTO V
VALUES(?, ?, ?)
```

↳ v(M), v(N), v(P)

A: definitely **V(N)** (must B-tree); unsure about **V(P)**

Index Selection Problem 3

```
V(M, N, P);
```

The workload is just as given and nothing else:

100,000 queries:

```
SELECT *
FROM V
WHERE N = ?
```

V(N)

1,000,000 queries:

```
SELECT *
FROM V
WHERE N = ?
  AND P > ?
```

V(N), V(P) ⇒ V(N,P)

100,000 queries:

```
INSERT INTO V
VALUES(?, ?, ?)
```

V(N,P) = 8

n = ?

P = ?

Which indexes?

V(N), V(N,P) ⇒ V(N,P)

Index Selection Problem 3

```
V(M, N, P);
```

The workload is just as given and nothing else:

100,000 queries:

```
SELECT *
FROM V
WHERE N = ?
```

1,000,000 queries:

```
SELECT *
FROM V
WHERE N = ?
  AND P > ?
```

100,000 queries:

```
INSERT INTO V
VALUES(?, ?, ?)
```

A: **V(N, P)** (B-tree)

Index Selection Problem 3

```
V(M, N, P);
```

The workload is just as given and nothing else:

100,000 queries:

```
SELECT *
FROM V
WHERE N = ?
```

1,000,000 queries:

```
SELECT *
FROM V
WHERE N = ?
  AND P > ?
```

H.W.

100,000 queries:

```
INSERT INTO V
VALUES(?, ?, ?)
```

A: **V(N, P)** (B-tree)

How does this index differ from:

1. Two indexes **V(N)** and **V(P)**?
2. An index **V(P, N)**?

Index Selection Problem 4

```
V(M, N, P);
```

The workload is just as given and nothing else:

~~1,000~~ 100 queries:

```
SELECT *
FROM V
WHERE N > ?
  AND N < ?
```

100,000 queries:

```
SELECT *
FROM V
WHERE P > ?
  AND P < ?
```

V(N) → S.I.

Which indexes?

V(P) → P I

Index Selection Problem 4

```
V(M, N, P);
```

The workload is just as given and nothing else:

1,000 queries:

```
SELECT *
FROM V
WHERE N > ?
  AND N < ?
```

100,000 queries:

```
SELECT *
FROM V
WHERE P > ?
  AND P < ?
```

A: **V(N)** secondary, **V(P)** primary index (both B-tree)

Index Selection Problem 5

```
V(M, N, P);
```

Q1 ✓

```
SELECT *
FROM V
WHERE V.M = 33
```

Q2 ✓

```
SELECT *
FROM V
WHERE V.M = 33
  AND V.P = 55
```

Suppose the database has these indexes. Which ones can the optimizer use?

Yes

Yes

```
INDEX I1 ON V(M);
INDEX I2 ON V(M, P);
INDEX I3 ON V(P, M);
```

A

B

C

Index Selection Problem 5 – Recap Indexes

```
V(M, N, P);
```

Suppose the database has these indexes. Which ones can the optimizer use?

Q1

```
SELECT *
FROM V
WHERE V.M = 33
```

Q2

```
SELECT *
FROM V
WHERE V.M = 33
  AND V.P = 55
```

Yes!

```
INDEX I1 ON V(M);

INDEX I2 ON V(M, P);

INDEX I3 ON V(P, M);
```

	Q1	Q2
I1	✓	✓
I2		

Index Selection Problem 5 – Recap Indexes

```
V(M, N, P);
```

I_1 P_I

Q1

```
SELECT *
FROM V
WHERE V.M = 33
```

Q2

```
SELECT *
FROM V
WHERE V.M = 33
  AND V.P = 55
```

Yes! But why?

Yes!

Suppose the database has these indexes. Which ones can the optimizer use?

```
INDEX I1 ON V(M);

INDEX I2 ON V(M, P);

INDEX I3 ON V(P, M);
```

P

P S

Q1 Q2

I3

Index Selection Problem 5 – Recap Indexes

```
V(M, N, P);
```

```
SELECT * 
FROM V
WHERE V.M = 33
```

```
SELECT *
FROM V
WHERE V.M = 33
  AND V.P = 55
```

Suppose the database has these indexes. Which ones can the optimizer use?

```
INDEX I1 ON V(M);

INDEX I2 ON V(M, P);

INDEX I3 ON V(P, M);
```

No! But why?

Yes!

Recap Indexes

```
Movie(mid, title, year)
```

CLUSTERED INDEX I ON Movie(id)
INDEX J ON Movie(year)

```
SELECT *
FROM Movie
WHERE year = 2010
```

'J' ✓

```
SELECT *
FROM Movie
WHERE (year = 1910)
```

'J' X

title = 'RATATOUILLE';

The system used the index **J** for one of the queries, but not for the other.

Which and why?

Basic Index Selection Guidelines

- Consider queries in workload in order of importance
  - ignore infrequent queries if you also have many writes

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- Consider relations accessed by query
  - No point indexing other relations

Basic Index Selection Guidelines

- Consider queries in workload in order of importance
  - ignore infrequent queries if you also have many writes
- Consider relations accessed by query
  - No point indexing other relations
- Look at WHERE clause for possible search key

S ~
F ~
W year = '2010'

S * ST
F
W SID = "xxx"

Basic Index Selection Guidelines

- Consider queries in workload in order of importance
  - ignore infrequent queries if you also have many writes
- Consider relations accessed by query
  - No point indexing other relations
- Look at WHERE clause for possible search key
- Try to choose indexes that speed-up multiple queries

To Cluster or Not to Cluster

- Range queries benefit mostly from clustering

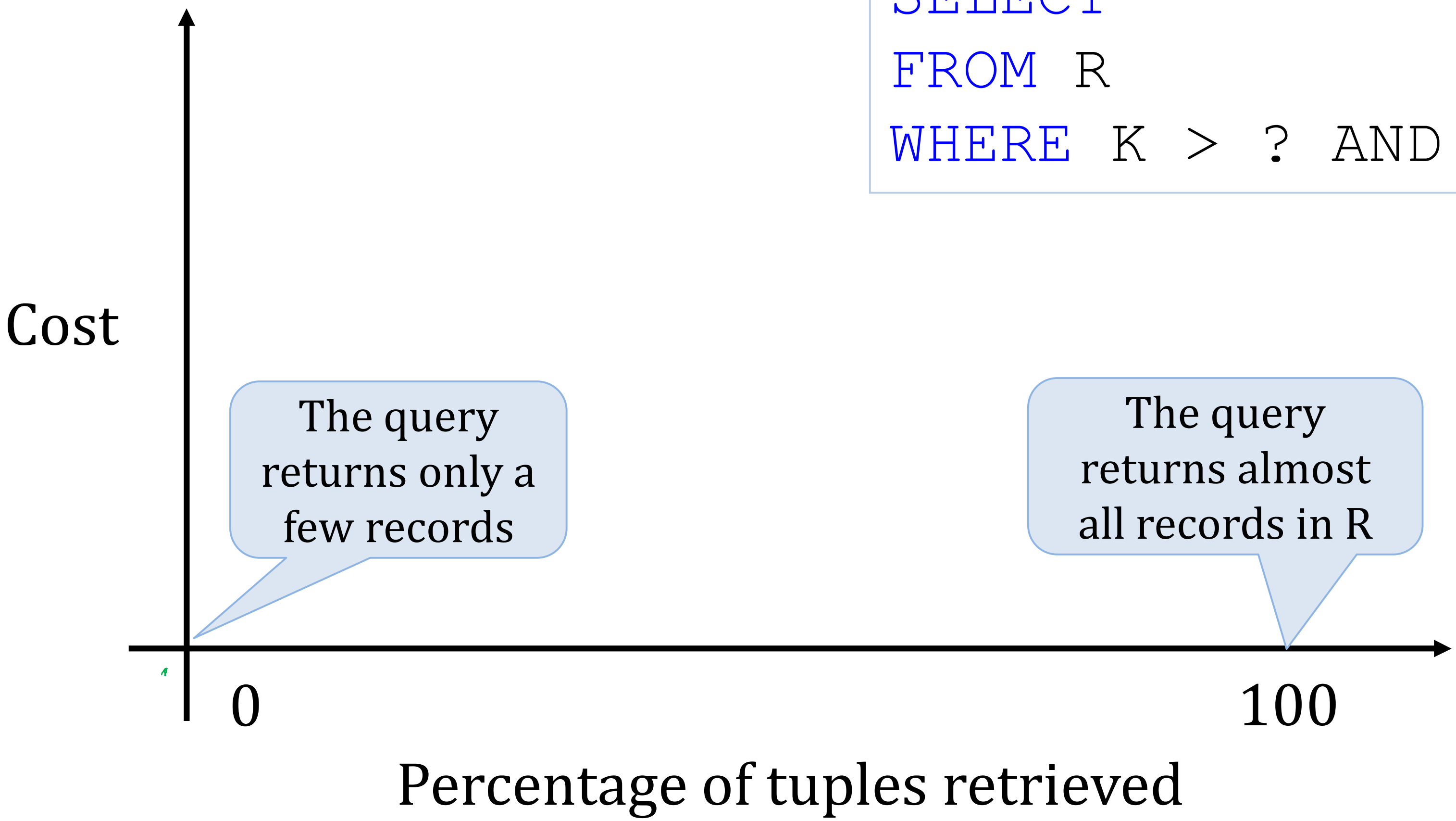
To Cluster or Not to Cluster

- Range queries benefit mostly from clustering

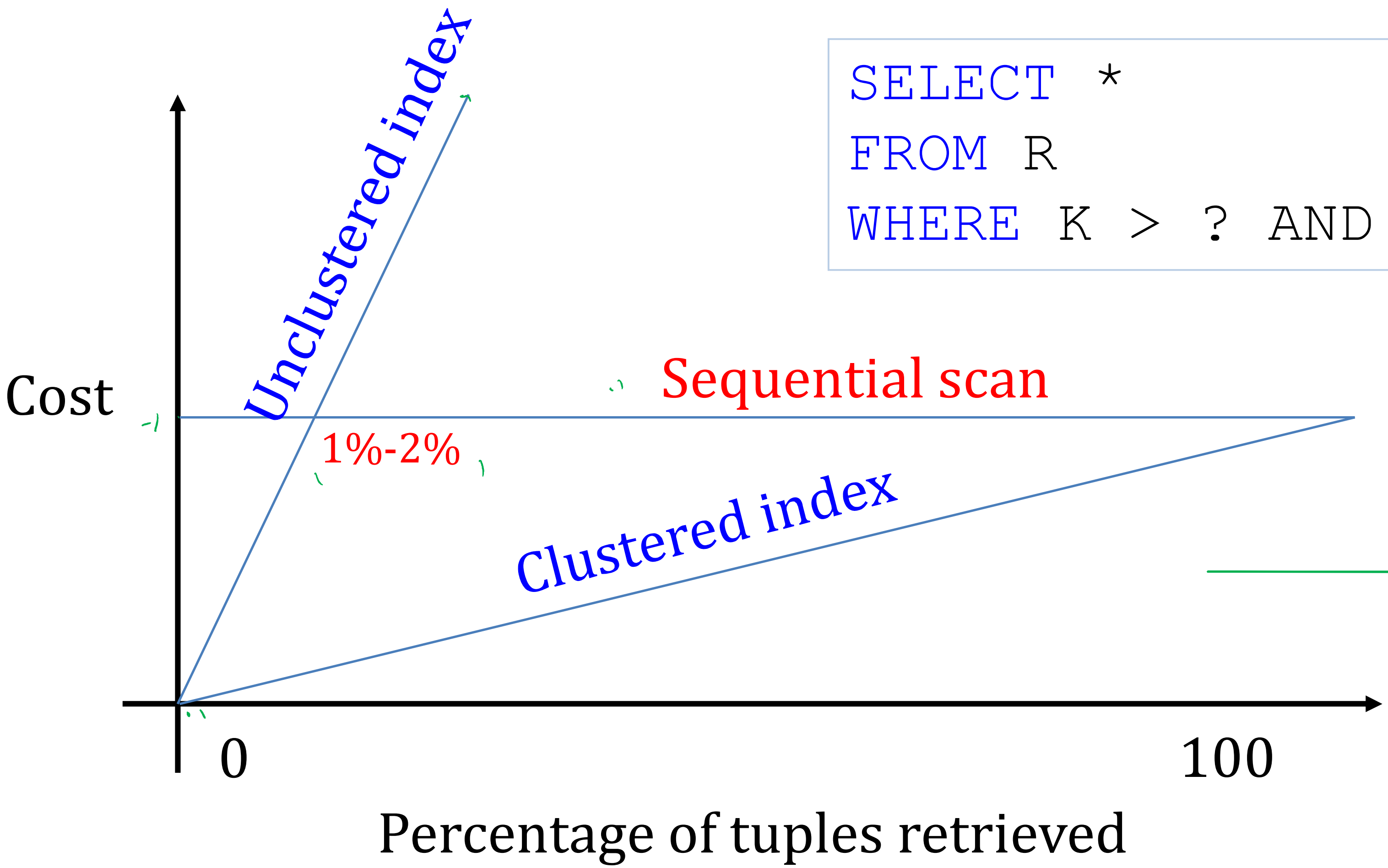
- Covering indexes do not need to be clustered: they work equally well unclustered
  - a covering index for a query is one where every attribute mentioned in the query is part of the index's search key
  - in that case, index has all the info you need anyway

To Cluster or Not to Cluster

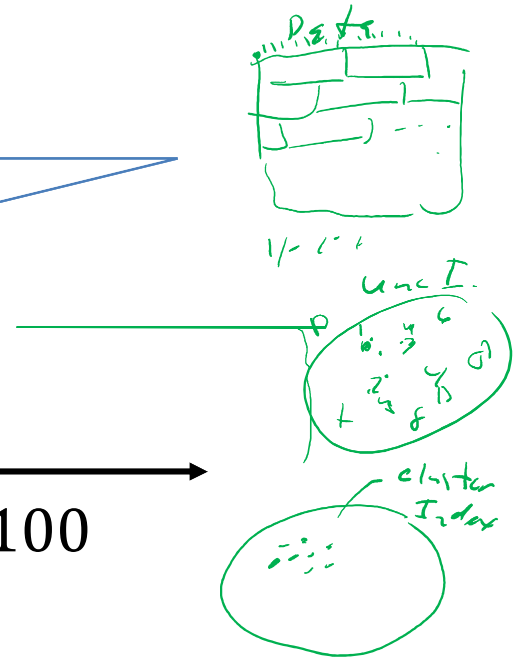
```
SELECT *
FROM R
WHERE K > ? AND K < ?
```



To Cluster or Not to Cluster




```
SELECT *
FROM R
WHERE K > ? AND K < ?
```



Thank you.