Introduction to Database Systems
CSE 414

Lecture 25:
Basics of Data Storage and Indexes

Announcements

- HW8 and WQ7
  - Due on 5/30
- OH changes
  - Alvin will be away next Wed
  - Jonathan will give next Wed's lecture
- Final on Thurs 6/7
  - Final review on 6/3 afternoon

Recap: Transactions

- Protocols discussed:
  - Nothing 
  - 2PL → unrecoverable schedules
  - Strict 2PL → phantom problem
  - Predicate locking → expensive!

- Recall our execution model!

Isolation Levels in SQL

1. "Dirty reads"
   SET TRANSACTION ISOLATION LEVEL READ UNCOMMITTED

2. "Committed reads"
   SET TRANSACTION ISOLATION LEVEL READ COMMITTED

3. "Repeatable reads"
   SET TRANSACTION ISOLATION LEVEL REPEATABLE READ

4. Serializable transactions
   SET TRANSACTION ISOLATION LEVEL SERIALIZABLE

Try these in HW8!

Beware!

In commercial DBMSs:

- Default level is often NOT serializable
- Default level differs between DBMSs
- Some engines support subset of levels!
- Serializable may not be exactly ACID
  - Locking ensures isolation, not atomicity
- Also, some DBMSs do NOT use locking and different isolation levels can lead to different pbs
- Bottom line: RTFM for your DBMS!

Class Overview

- Unit 1: Intro
- Unit 2: Relational Data Models and Query Languages
- Unit 3: Non-relational data
- Unit 4: RDMBS internals and query optimization
- Unit 5: Parallel query processing
- Unit 6: DBMS usability, conceptual design
- Unit 7: Transactions
- Unit 8: Advanced topics: Query optimization

Query Performance

- My database application is too slow… why?
- One of the queries is very slow… why?

- To understand performance, we need to understand:
  - How is data organized on disk
  - How to estimate query costs

  - In this course we will focus on **disk-based** DBMSs

Data Storage

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

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

10	Tom	Hanks	block 1
20	Amy	Hanks	
50	…	…	block 2
200	…		
220			block 3
240			
420			
800			

In the example, we have 4 blocks with 2 tuples each

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

Data File Types

The data file can be one of:

- Heap file
  - Unsorted
- Sequential file
  - Sorted according to some attribute(s) called *key*

Student

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- Heap file
  - Unsorted
- Sequential file
  - Sorted according to some attribute(s) called *key*

Note: *key* here means something different from primary key:
it just means that we order the file according to that attribute.
In our example we ordered by **ID**. Might as well order by **fName,**
if that seems a better idea for the applications running on
our database.

Index

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  - The key = an attribute value (e.g., student ID or name)
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- The index contains (key, value) pairs:
  - The key = an attribute value (e.g., student ID or name)
  - The value = a pointer to the record
- Could have many indexes for one table

Key = means here search key

This  Is Not A Key

Different keys:

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

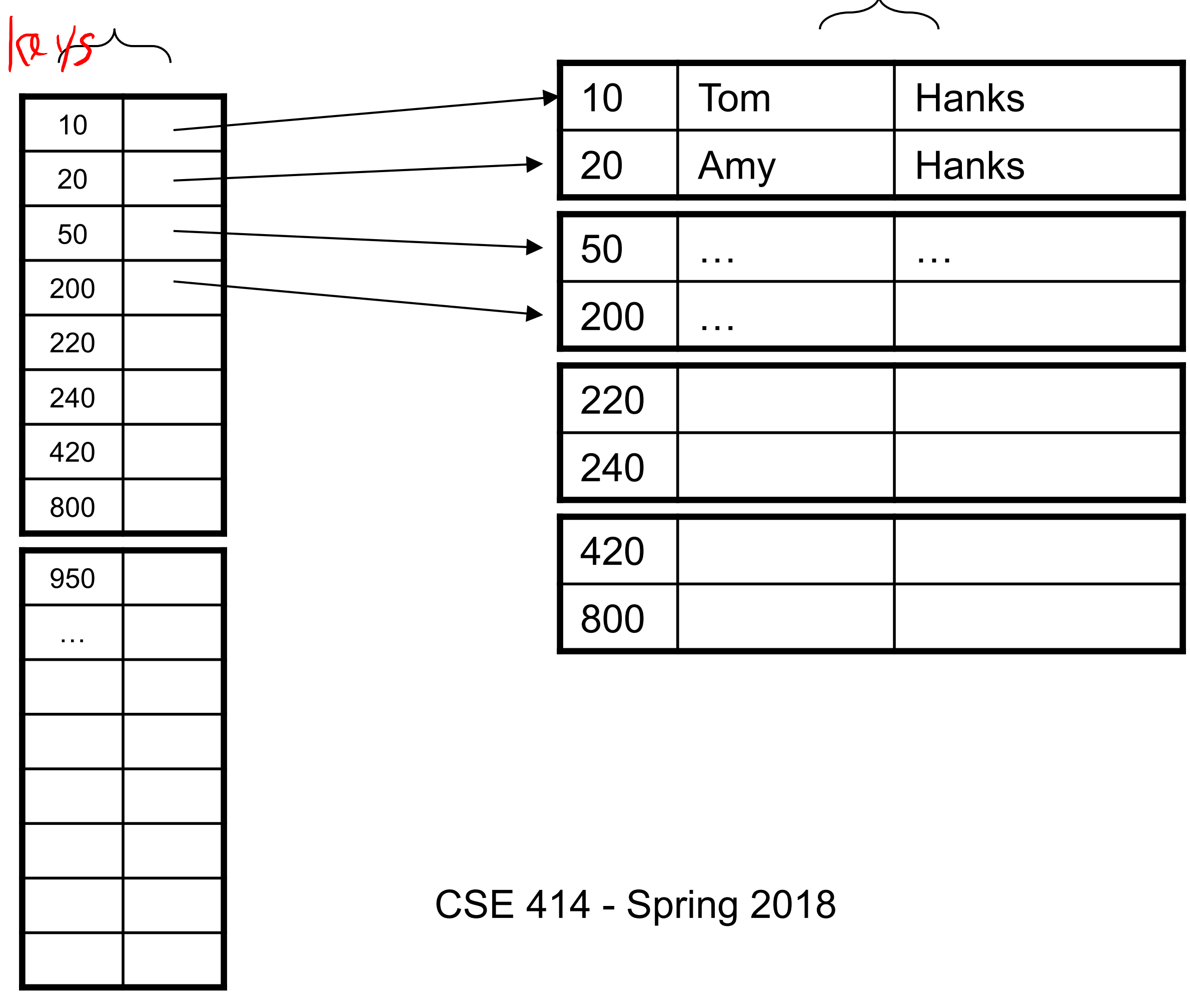
Example 1: Index on ID

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

Index **Student_ID** on **Student.ID**

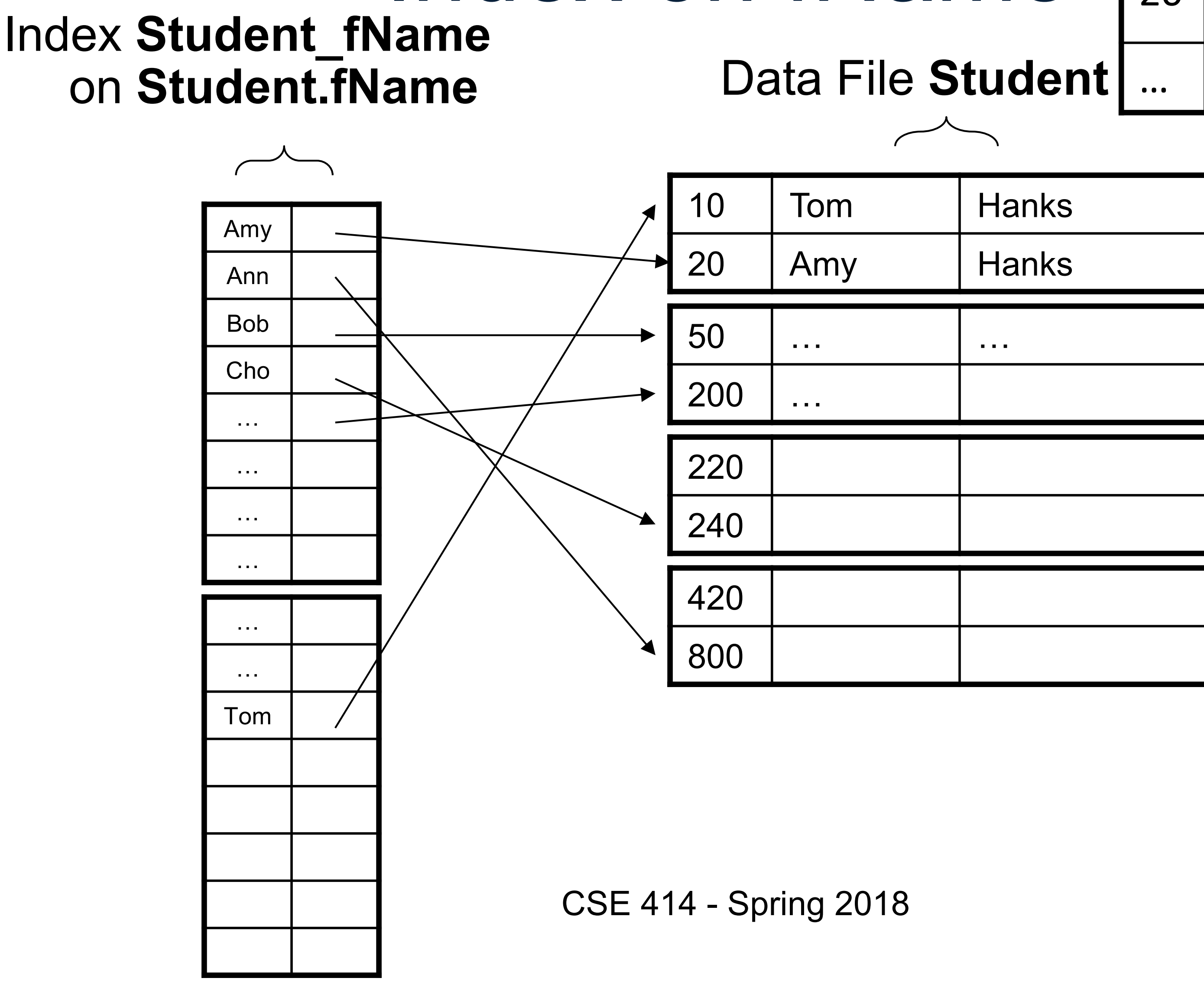
Data File **Student**



Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

Example 2: Index on fName



Index Organization

We need a way to represent indexes after loading into memory so that they can be used

Several ways to do this:

- Hash table
- B+ trees – most popular
  - They are search trees, but they are not binary instead have higher fanout
  - Will discuss them briefly next
- Specialized indexes: bit maps, R-trees, inverted index

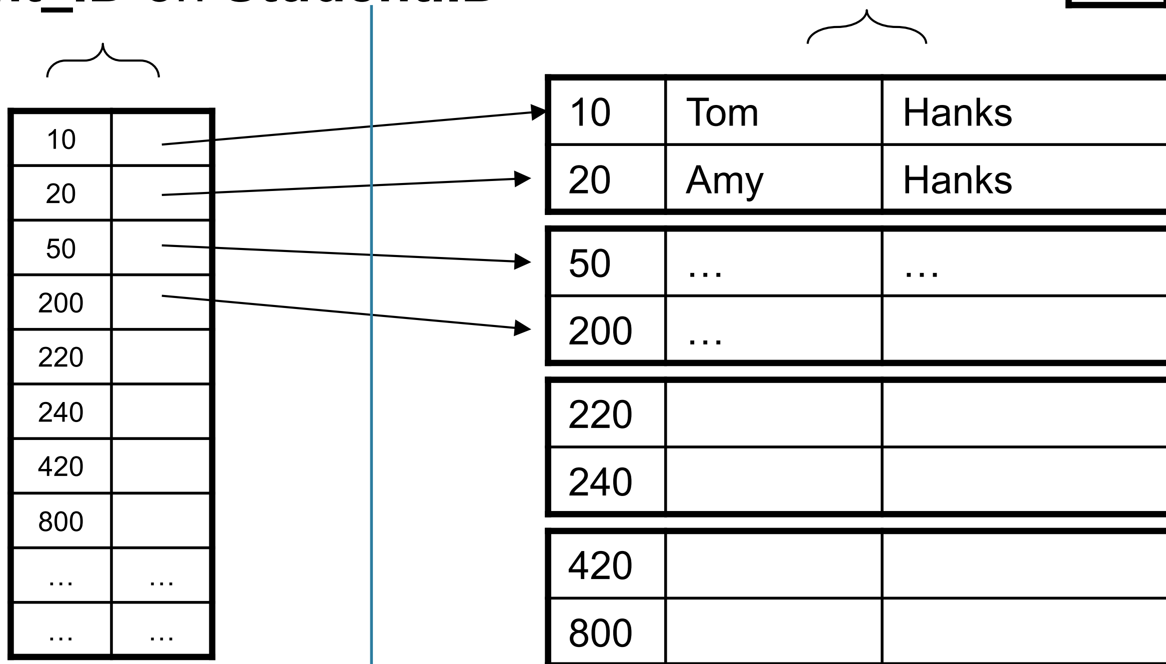
Hash table example

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

Index **Student_ID** on **Student.ID**

Data File **Student**



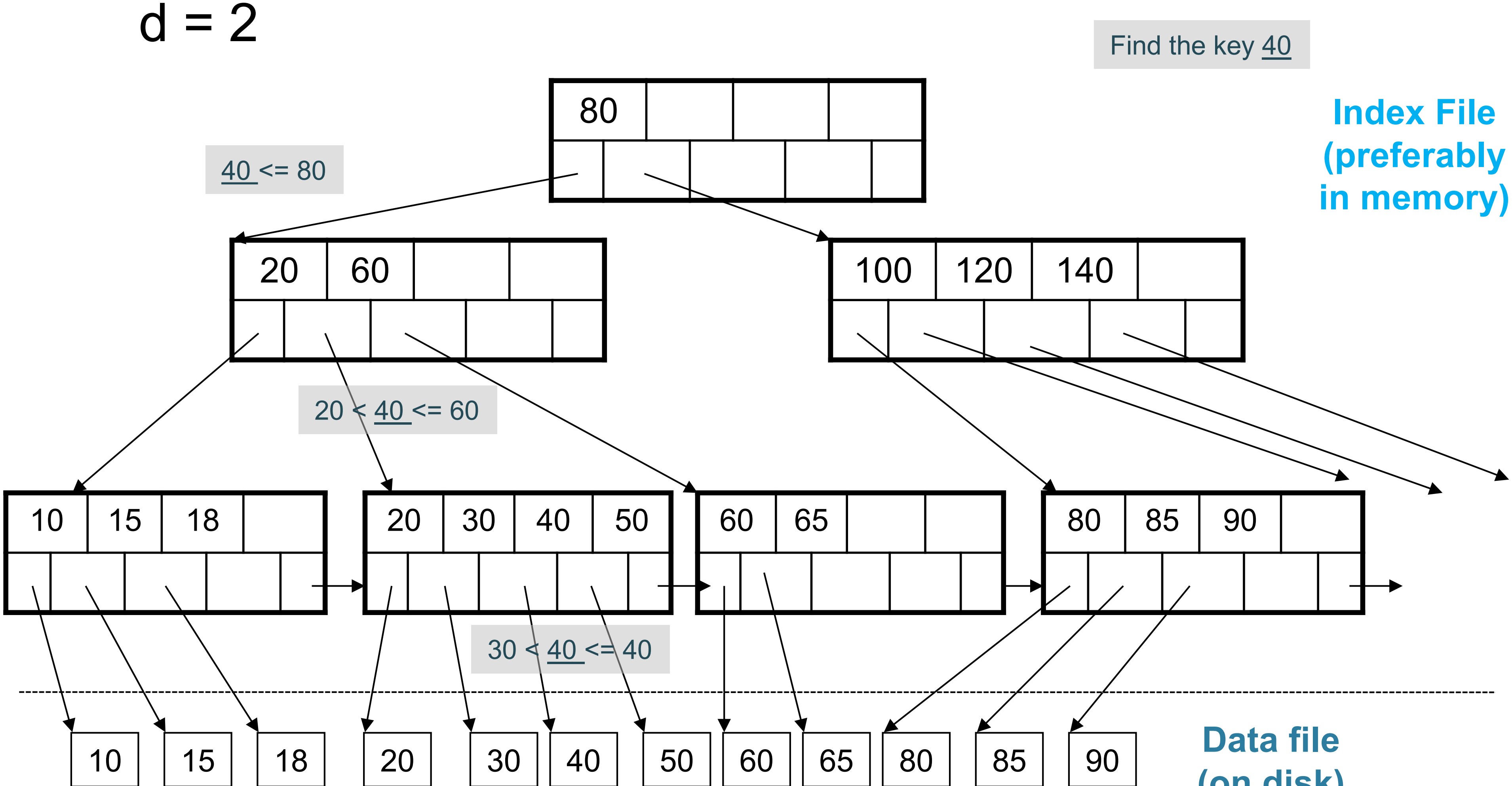
Index File (preferably in memory)

Data file (on disk)

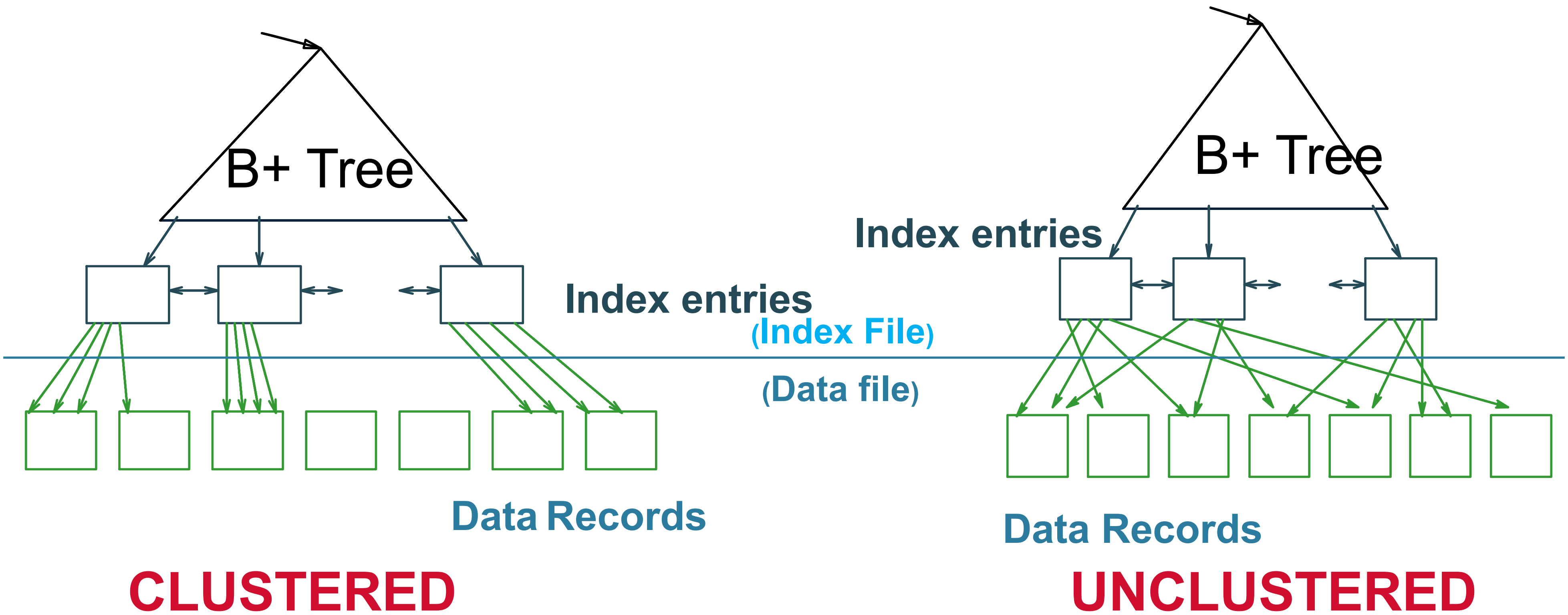
B+ Tree Index by Example

Recall binary trees from CSE 143!

d = 2



Clustered vs Unclustered

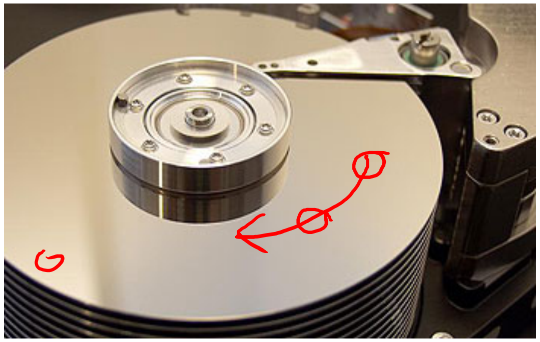


Every table can have **only one** clustered and **many** unclustered indexes
Why?

Index Classification

- **Clustered/unclustered**
  - Clustered = 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 may be far in data
- **Primary/secondary**
  - Meaning 1:
    - Primary = is over attributes that include the primary key
    - Secondary = otherwise
  - Meaning 2: means the same as clustered/unclustered
- **Organization** B+ tree or Hash table

Scanning a Data File



- Disks are mechanical devices!
  – Technology from the 60s; density much higher now
- Read only at the rotation speed!
- Consequence:
  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 ≈ sequential scanning the entire file; this is decreasing over time (because of increased density of disks)
- Solid state (SSD): $$$ expensive; put indexes, other "hot" data there, still too expensive for everything

Student(ID, fname, lname)
Takes(studentID, courseID)

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

Example

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Example

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for y in Takes
   if courseID > 300 then
     for x in Student
          if x.ID=y.studentID
            output *
```

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Assume the database has indexes on these attributes:

- **Takes_courseID** = index on Takes.courseID
- **Student_ID** = index on Student.ID

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  y = fetch the Takes record pointed to by y'
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Index join

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  for x' in Student_ID where x'.ID = y.studentID
        x = fetch the Student record pointed to by x'
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Takes(studentID, courseID)

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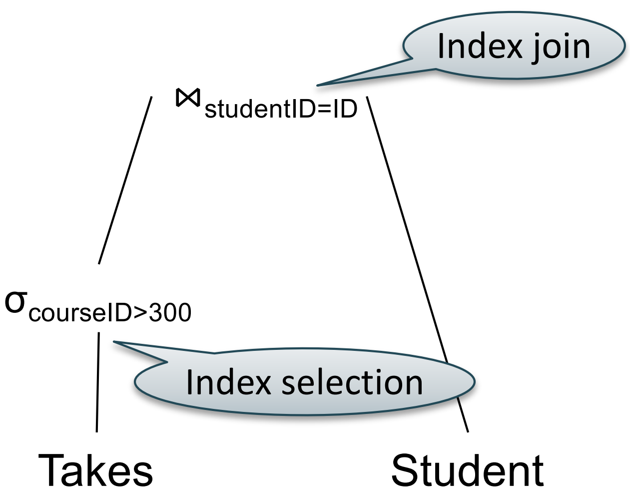

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Getting Practical: Creating Indexes in SQL

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CREATE  TABLE    V(M int,   N varchar(20),    P int);
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```
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)
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CREATE CLUSTERED INDEX V5 ON V(N)
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select *
from V
where P=55 and M=77

yes

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yes

```
select *
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Getting Practical: Creating Indexes in SQL

index

p	M	values
1	10	→
1	20	→
2	10	
3	50	

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Not supported in SQLite

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where P=55
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from V
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no