Introduction to Database Systems
CSE 344

Lecture 10:
Basics of Data Storage and Indexes

Reminder

- Webquiz 3 is due next Tuesday
- HW3 is due next Wednesday

Review

- Logical plans
- Physical plans
- Overview of query optimization and execution

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			4
800			

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

Data File Types

Student

ID	fName	lName
10	Tom	Hanks
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…		

The data file can be one of:

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

Data File Types

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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)
  - The value = a pointer to the record

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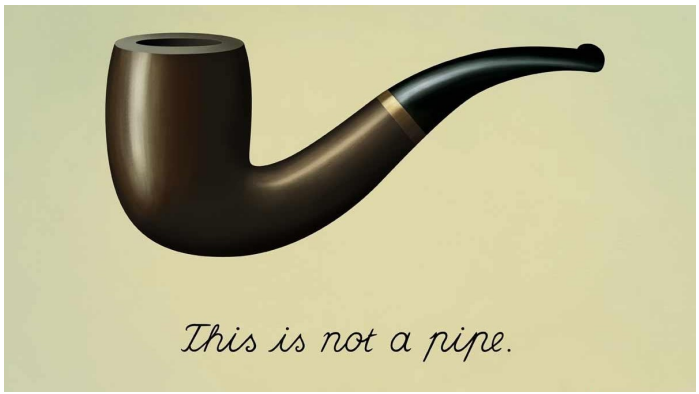
- The index contains (key, value) pairs:
  - The key = an attribute value (e.g., student ID or name)
  - The value = a pointer to the record
- Could have many indexes for one table

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



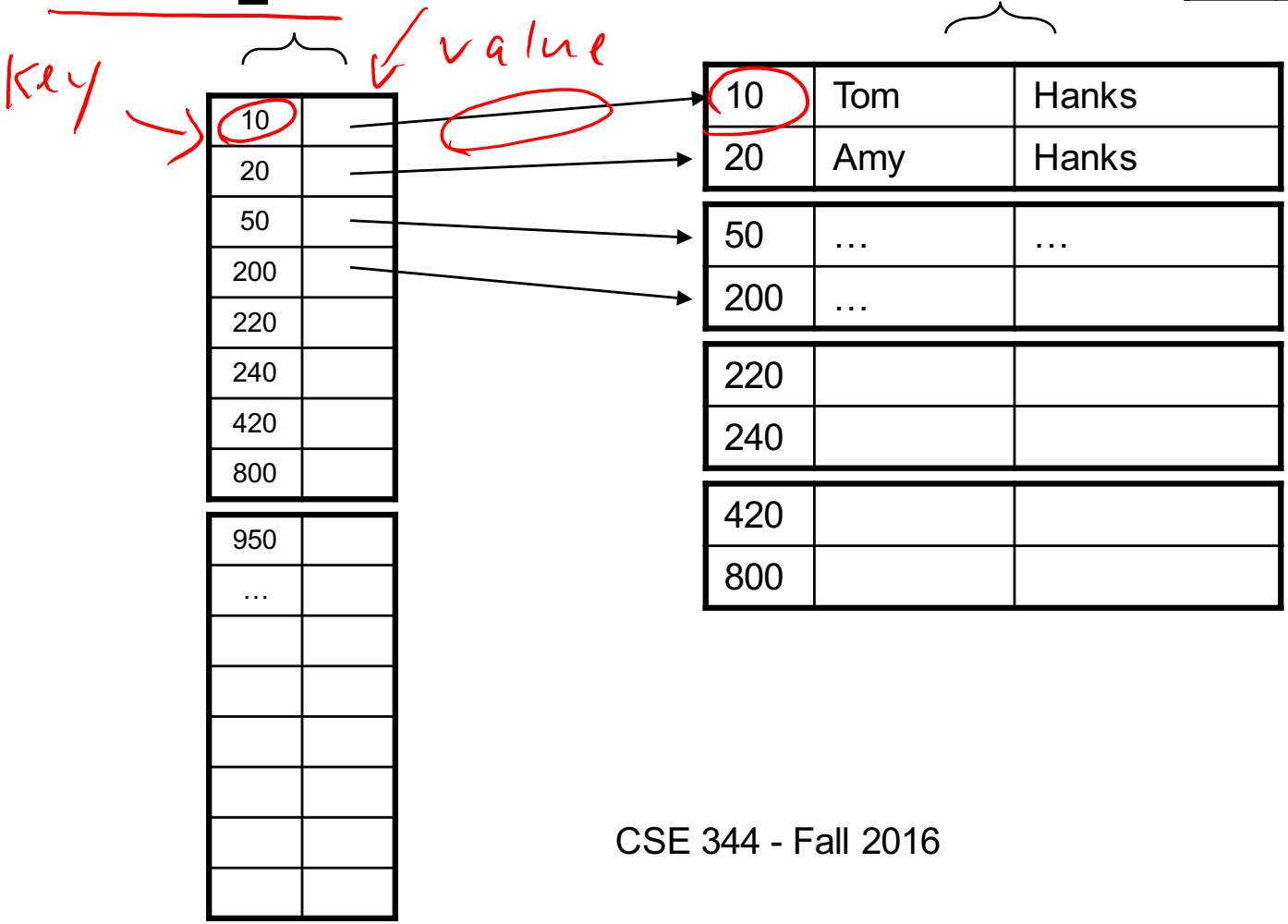
Example 1: Index on ID

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

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

Data File **Student**



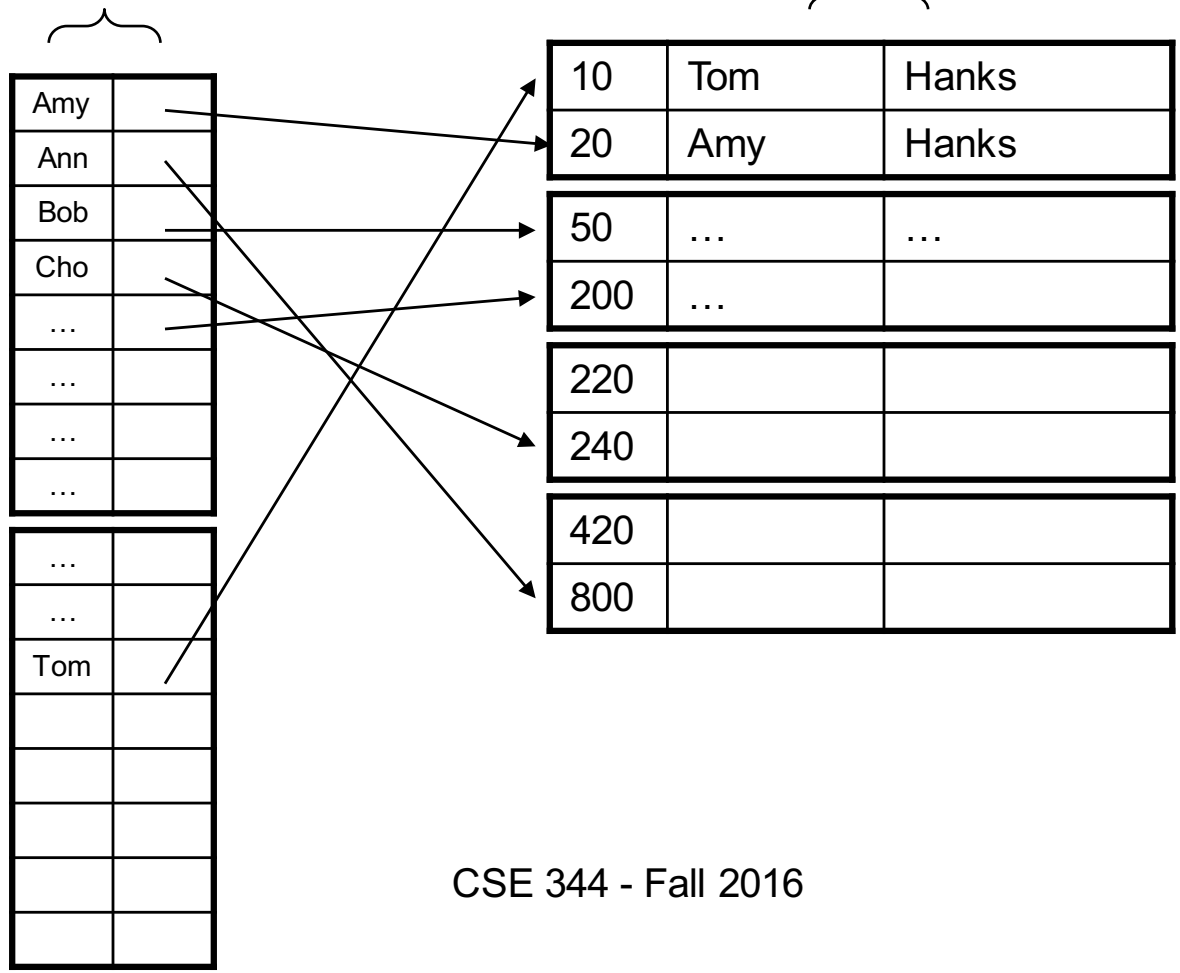
Example 2: Index on fName

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

Index **Student_fName** on **Student.fName**

Data File **Student**



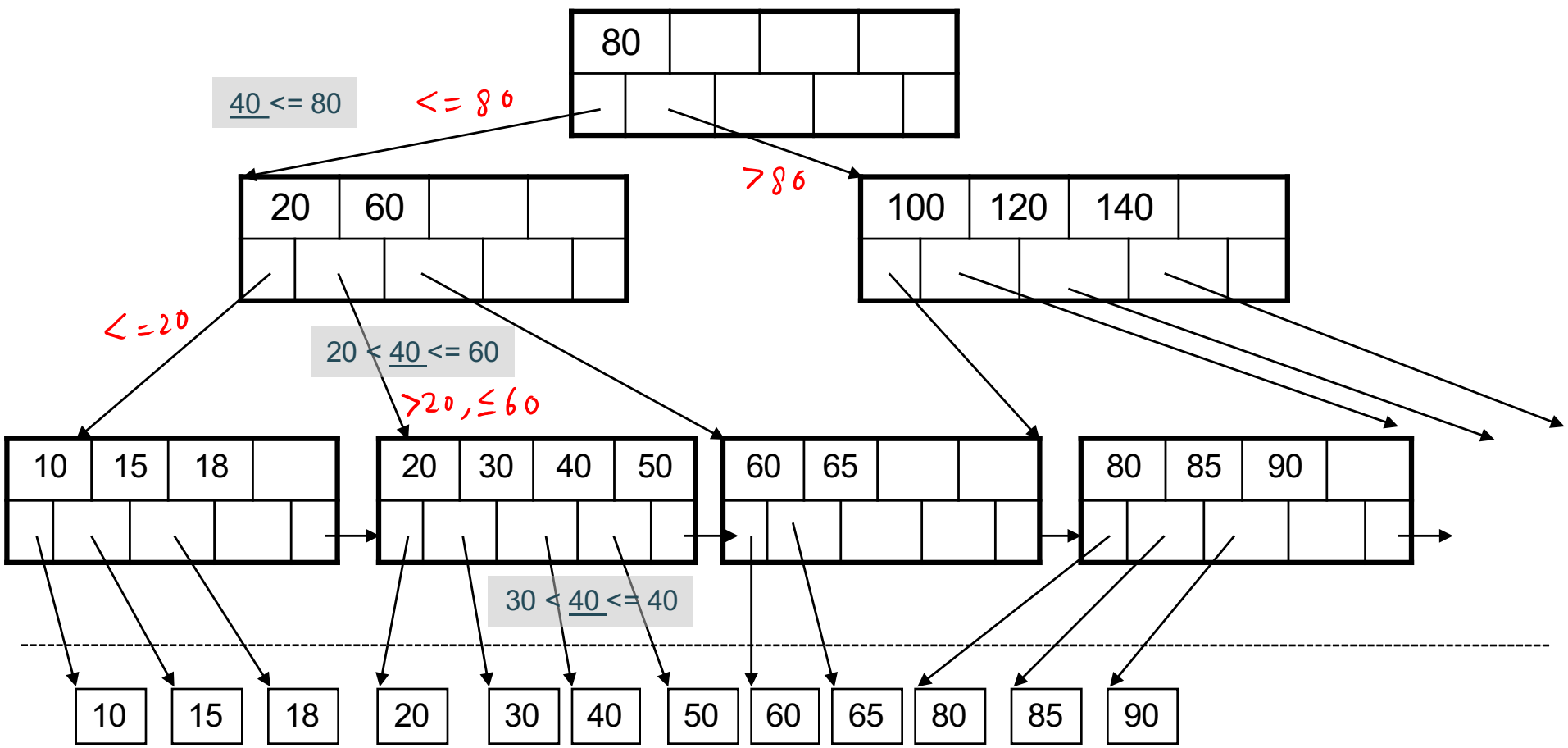
Index Organization

Several index organizations:

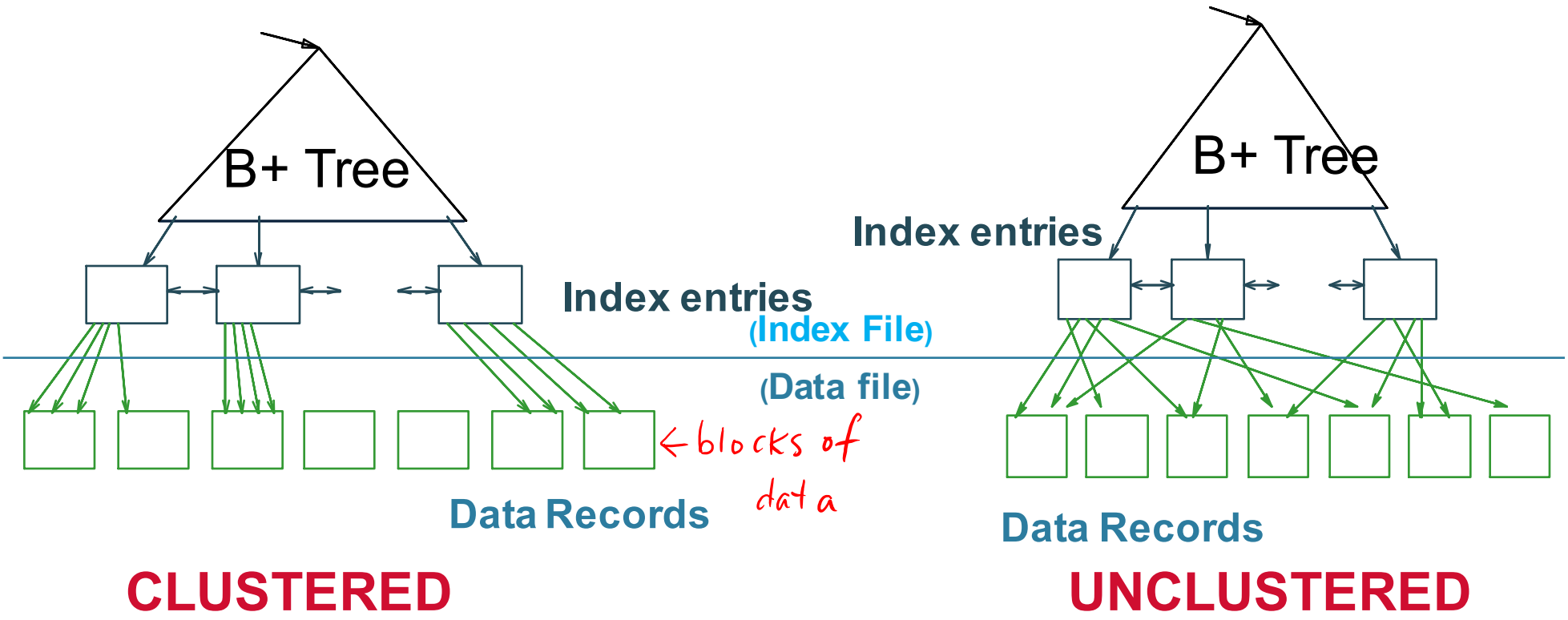
- Hash table
- B+ trees – most popular
  - They are search trees, but they are not binary instead have higher fanout
  - Will discuss them briefly next
- Specialized indexes: bit maps, R-trees, inverted index

B+ Tree Index by Example

d = 2



Clustered vs Unclustered



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

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

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- **Primary/secondary**
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- **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, not enough room for everything (NO LONGER TRUE)

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

Example

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

Assume the database has indexes on these attributes:

- **index_takes_courseID** = index on Takes.courseID
- **index_student_ID** = index on Student.ID

```
for y in index_Takes_courseID  where y.courseID > 300
  for x in Student where x.ID = y.studentID
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Index join

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)
```

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Not supported in SQLite

Which Indexes?

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- How many indexes could we create?
- Which indexes should we create?

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- Which indexes should we create?

In general this is a very hard problem

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ID	fName	lName
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- 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 does index selection:
  - The database administrator DBA
  - Semi-automatically, using a database administration tool

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Index Selection: Which Search Key

- Make some attribute K a search key if the WHERE clause contains:
  - An exact match on K
  - A range predicate on K
  - A join on K

The Index Selection Problem 1

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

Your workload is this

100000 queries:

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

100 queries:

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

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

The Index Selection Problem 2

V(M, N, P);

Your workload is this

100000 queries:

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

100 queries:

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

100000 queries:

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

What indexes ?

The Index Selection Problem 2

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

Your workload is this

100000 queries:

```
SELECT *
FROM V
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100 queries:

```
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100000 queries:

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