CSE 344

JULY 18TH

INDEXING

ADMINISTRIVIA

- **HW4 due today**

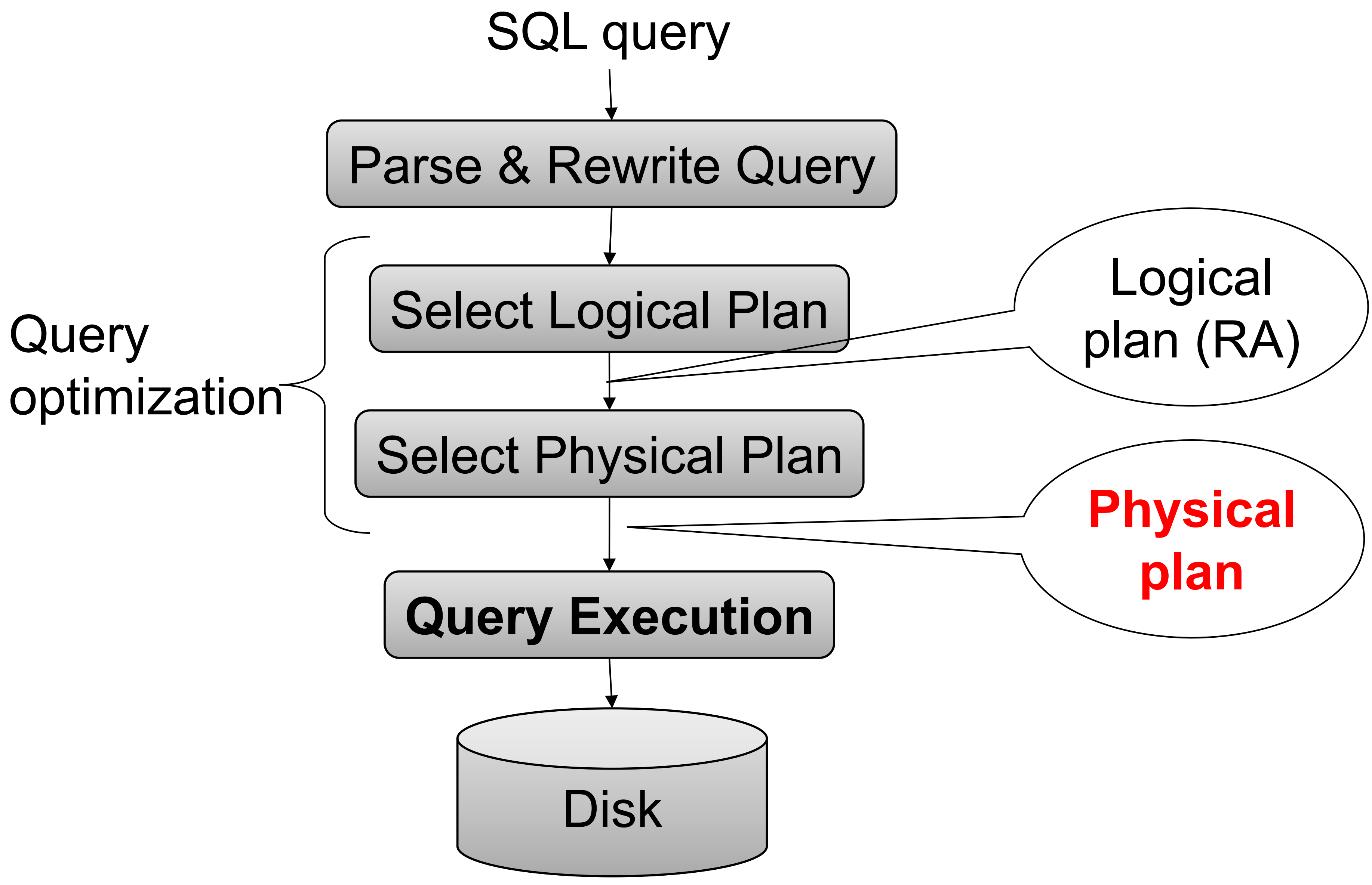
- **HW5 out already**
  - Asterix and SQL++

- **Section tomorrow on Asterix + review**
  - bring laptop
  - install Asterix (see HW5 instructions)

REVIEW (PT 1)

- **Query evaluation**
  - process
  - logical and physical query plans
  - pipelining (using iterator interface)

QUERY EVALUATION STEPS



LOGICAL VS PHYSICAL PLANS

Logical plans:

- Created by the parser from the input SQL text
- Expressed as a relational algebra tree
- Each SQL query has many possible logical plans

Physical plans:

- Goal is to choose an efficient implementation for each operator in the RA tree
- Each logical plan has many possible physical plans

REVIEW (PT 2)

- **Physical plan details**
  - join algorithms
    - nested loop, hash join, sorted merge join
  - file organization
    - heap or sequential
  - indexes (today)

- **Eventual Goal: estimate cost of a query plan**

```
Supplier(sid, sname, scity, sstate)
Supply(sid, pno, quantity)
```

JOIN ALGORITHMS

Logical operator: Supplier $\bowtie_{sid=sid}$ Supply

Potential physical operators (more shortly...):

1. **Nested Loop Join**
   - two nested loops to iterate through both sets of tuples
2. **Sorted Merge join**
   - sort the tuples from each (on disk)
   - pass through both sorted lists in order to find matches
3. **Hash join**
   - put tuples from second into a hash table with key sid
   - for each tuple from first, lookup sid in hash to get matches

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

DATA FILE TYPES

The data file can be one of:

Heap file

- Unsorted

Sequential file

- Sorted according to some attribute(s) called *key*

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

INDEX

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

The index contains (key, value) pairs:

- The key = an attribute value (e.g., student ID or name)
- The value = a pointer to the record

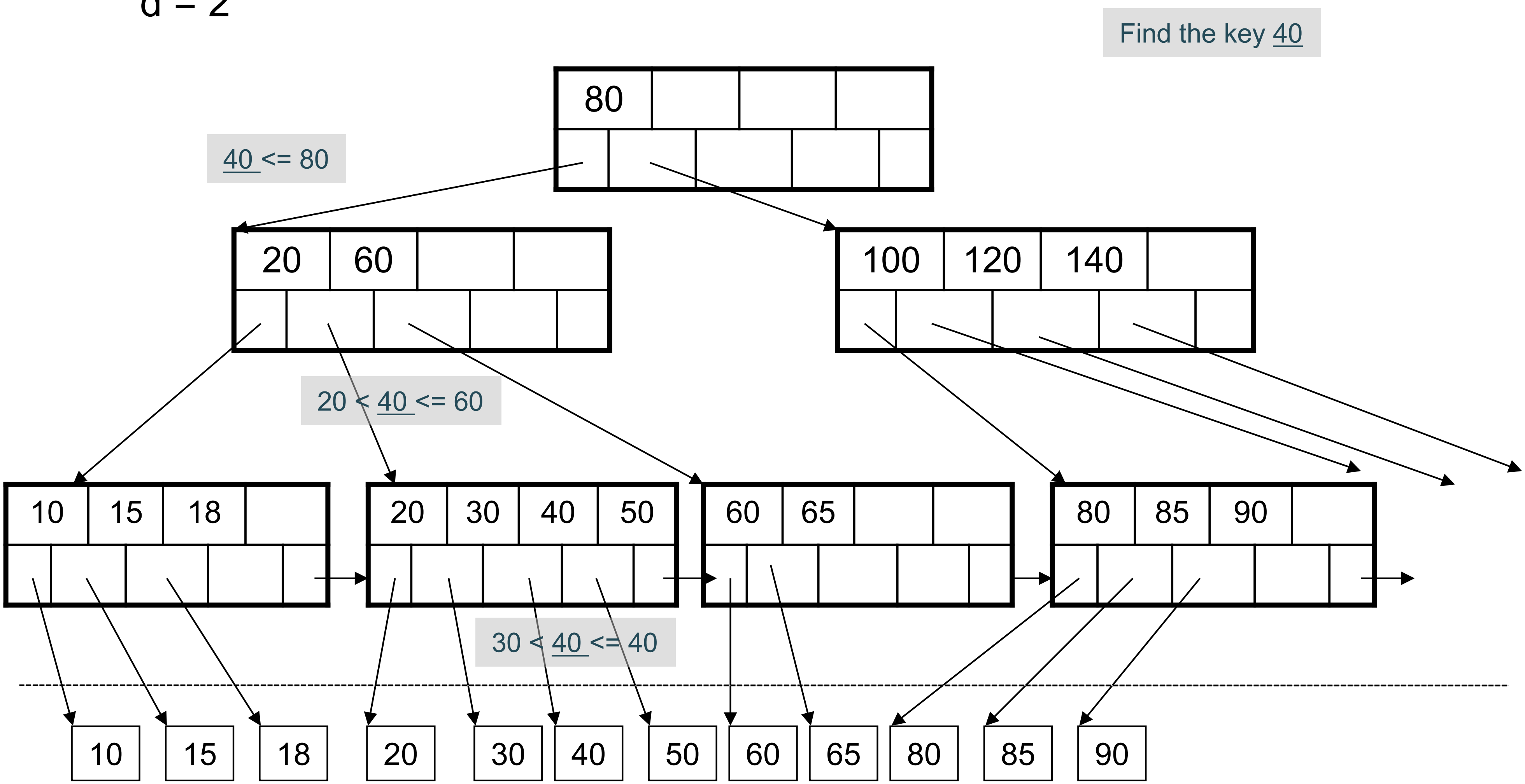
Could have many indexes for one table

Most common types:

- hash index
- B+ tree index

B+ TREE INDEX BY EXAMPLE

d = 2



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

<u>Hard</u> 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): more expensive, but becoming less so

SUMMARY SO FAR

Index = enables direct access to records in another data file

- B+ tree / Hash table
- Clustered / unclustered

Data resides on (hard) disk

- Organized in blocks
- Sequential reads are efficient
- Random access less efficient
- Random read 1-2% of data worse than sequential

RECALL: PHYSICAL DATA INDEPENDENCE

Applications are insulated from changes in physical storage details

SQL and relational algebra facilitate physical data independence

- Both languages input and output relations
- Can choose different implementations for operators

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

```
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:

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

Student(<u>ID</u>, fname, lname)
Takes(studentID, courseID)

```
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:

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

Index selection

```
for y' in Takes_courseID where y'.courseID > 300
  y = fetch the Takes record pointed to by y'
  for x' in Student_ID where x'.ID = y.studentID
      x = fetch the Student record pointed to by x'
      output *
```

Index join

Student(<u>ID</u>, fname, lname)
Takes(studentID, courseID)

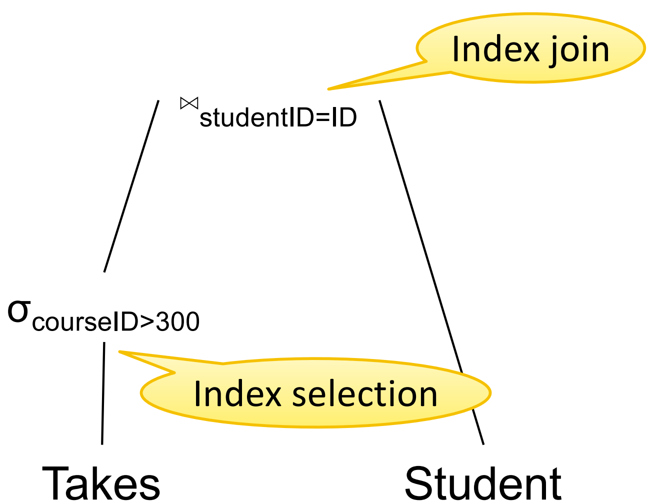
```
SELECT *
FROM  Student x, Takes y
WHERE x.ID=y.studentID AND y.courseID > 300
```

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:

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



Index selection

```
for y' in Takes_courseID where y'.courseID > 300
  y = fetch the Takes record pointed to by y'
  for x' in Student_ID where x'.ID = y.studentID
        x = fetch the Student record pointed to by x'
        output *
```

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)
```

GETTING PRACTICAL: CREATING INDEXES IN SQL

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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)
```

```
select *
from V
where P=55 and M=77
```

```
select *
from V
where P=55
```

```
select *
from V
where M=77
```

GETTING PRACTICAL: CREATING INDEXES IN SQL

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

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

```
select *
from V
where P=55 and M=77
```

yes

```
select *
from V
where P=55
```

yes

```
select *
from V
where M=77
```

no

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)
```

Not supported in SQLite

```
select *
from V
where P=55 and M=77
```

yes

```
select *
from V
where P=55
```

yes

```
select *
from V
where M=77
```

no

Student

ID	fName	lName
10	Tom	Hanks
20	Amy	Hanks
…		

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 does index selection:

- The 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
- 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=?
```

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=?
```

What indexes ?

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=?
```

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
WHERE N>? and N<?
```

100 queries:

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

100000 queries:

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

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

THE INDEX SELECTION PROBLEM 3

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

Your workload is this

100000 queries:

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

1000000 queries:

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

100000 queries:

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

What indexes ?

THE INDEX SELECTION PROBLEM 3

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

Your workload is this

100000 queries:

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

1000000 queries:

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

100000 queries:

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

A: V(N, P)

How does this index differ from:

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

THE INDEX SELECTION PROBLEM 4

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

Your workload is this

1000 queries:

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

100000 queries:

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

What indexes ?

THE INDEX SELECTION PROBLEM 4

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

Your workload is this

1000 queries:

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

100000 queries:

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

A: V(N) secondary,   V(P) primary index

TWO TYPICAL KINDS OF QUERIES

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

- Point queries
- What data structure should be used for index?

```
SELECT *
FROM Movie
WHERE year >= ? AND
          year <= ?
```

- Range queries
- What data structure should be used for index?

TWO TYPICAL KINDS OF QUERIES

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

- Point queries
- What data structure should be used for index?

Hash tables

```
SELECT *
FROM Movie
WHERE year >= ? AND
         year <= ?
```

- Range queries
- What data structure should be used for index?

B+ Trees

BASIC INDEX SELECTION GUIDELINES

Consider queries in workload in order of importance

Consider relations accessed by query

- No point indexing other relations

Look at WHERE clause for possible search key

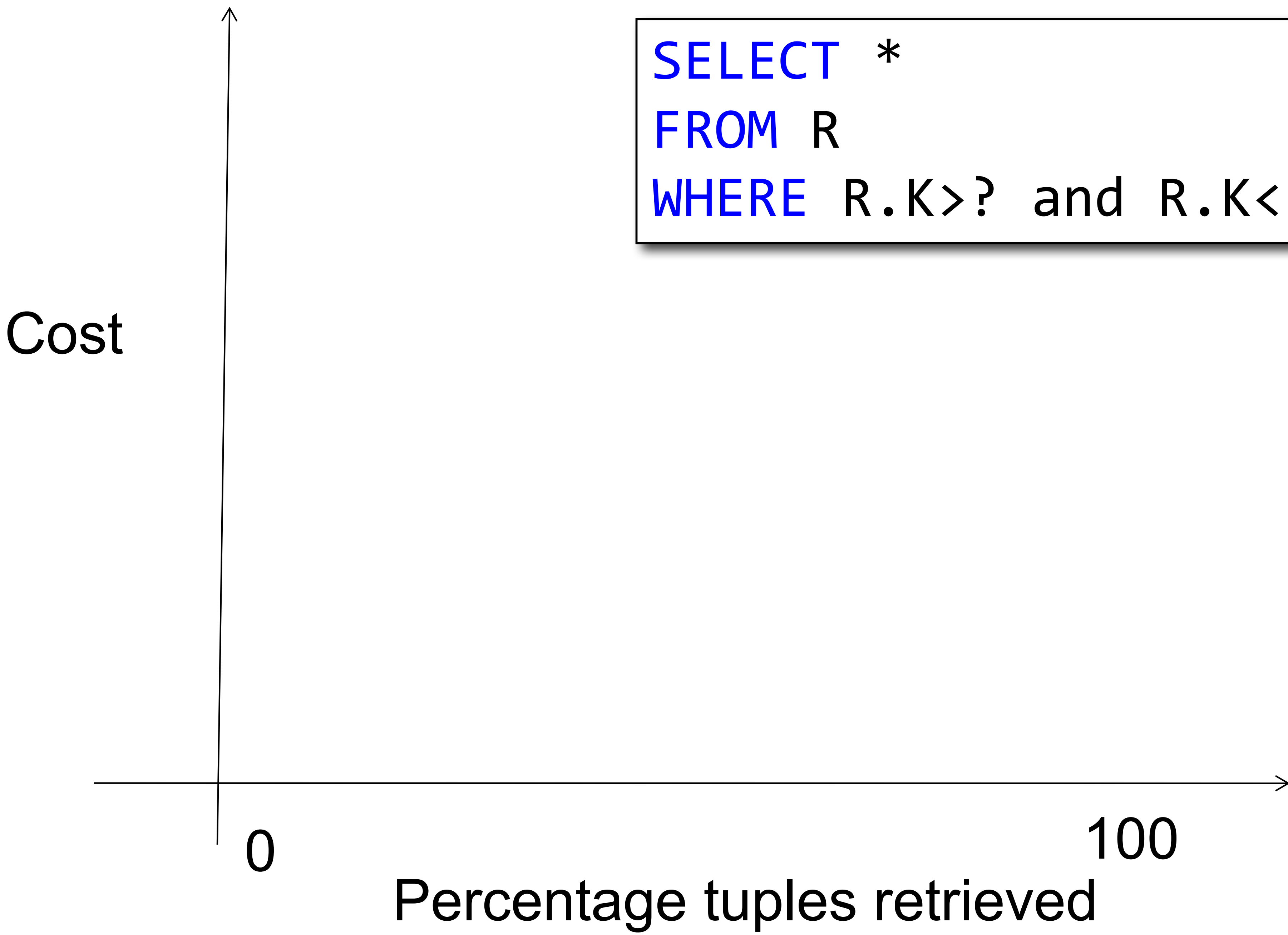
Try to choose indexes that speed-up multiple queries

TO CLUSTER OR NOT

Range queries benefit mostly from clustering

Covering indexes do *not* need to be clustered: they work equally well unclustered

```sql
SELECT *
FROM R
WHERE R.K>? and R.K<?
```



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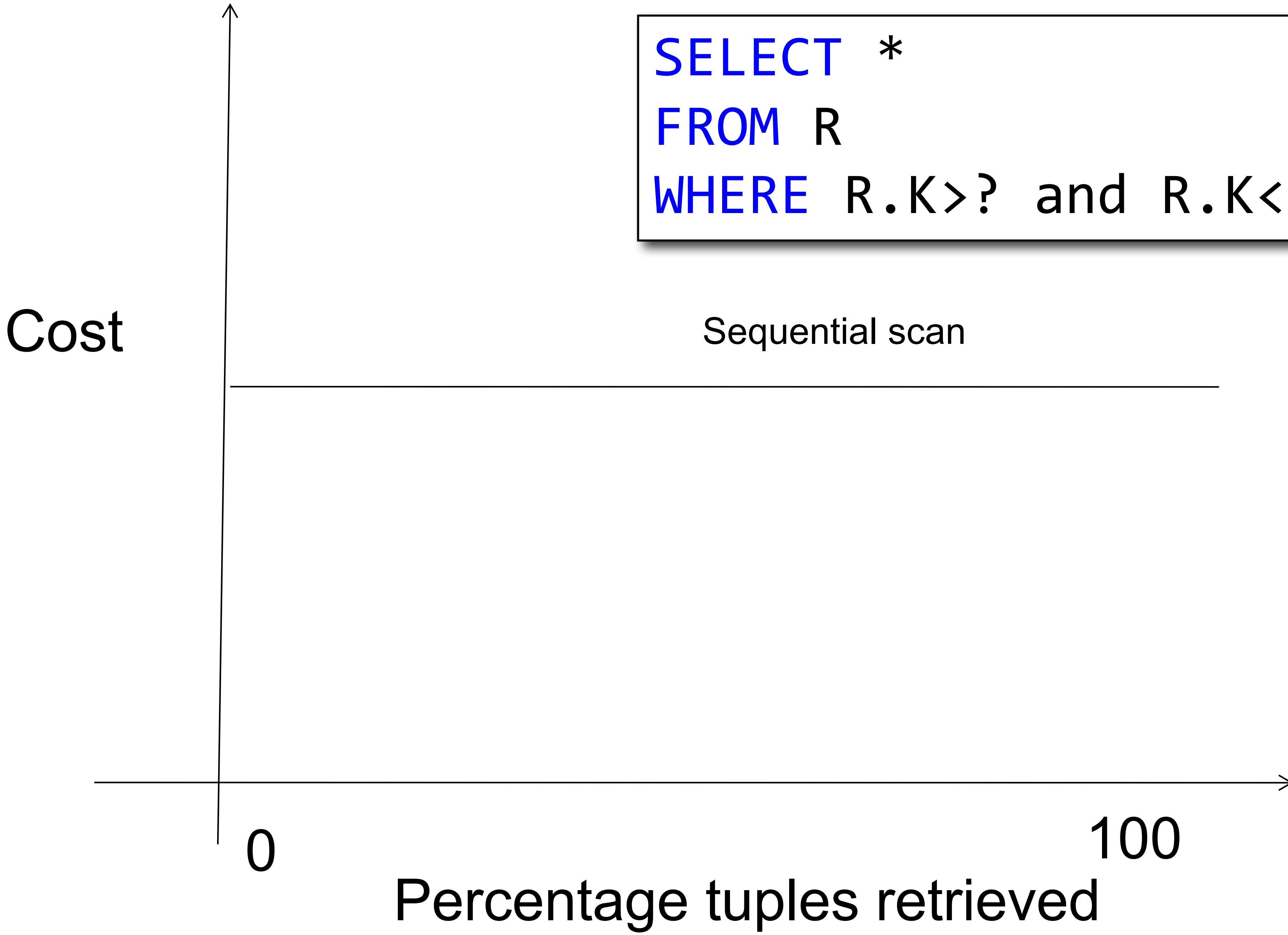

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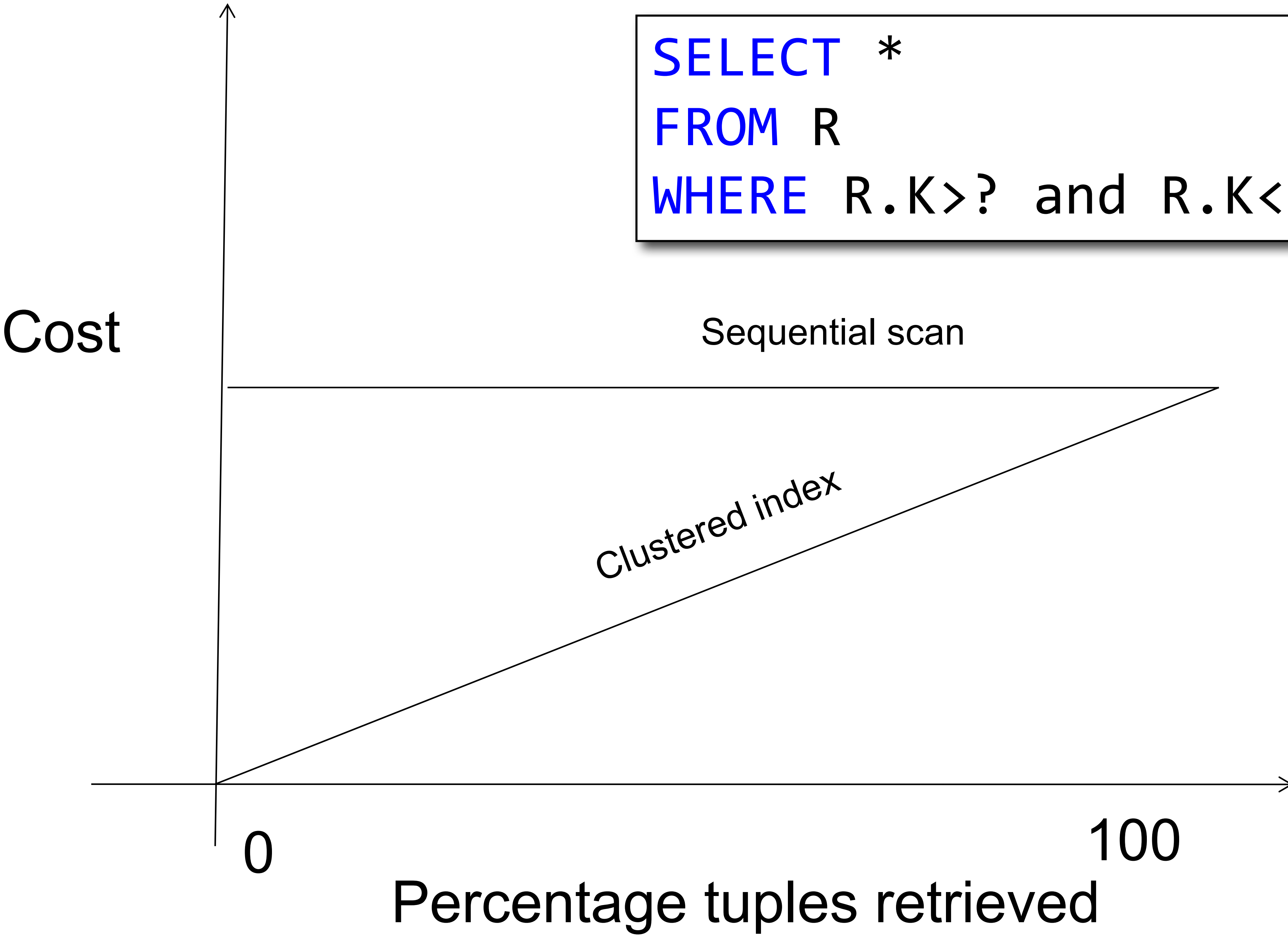

```sql
SELECT *
FROM R
WHERE R.K>? and R.K<?
```