

Lecture 6: Query Processing; Hurry up!

- Overview
- EXPLAIN
- Measuring Performance
- Disk Architectures
- Indexes
 - Motivation, Definition, Demonstration
 - Classification
 - Primary vs. Secondary
 - Unique
 - Clustered vs UnClustered
- Join Algorithms
 - Nested Loop
 - Simple
 - Index
- Join Algorithms (ctd.)
 - Sort-Merge
 - External Sorting
 - Costs and Complexities
- Mechanics
 - Parsing
 - Optimization

Learning objectives

LO6.1: Use SQL to declare indexes

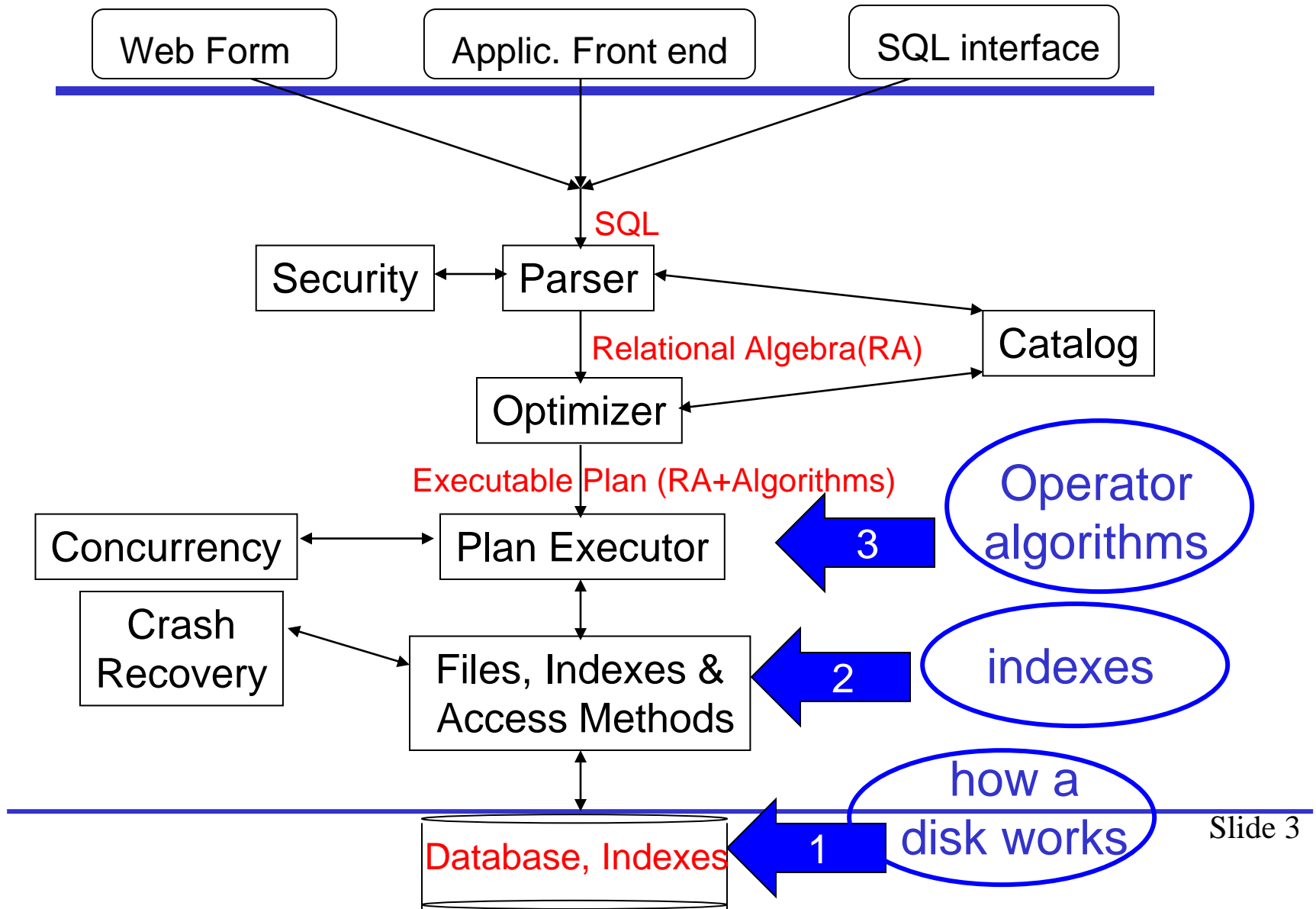
LO6.2: Determine the I/O cost of finding record(s) using a B+ tree

LO6.3: Given a join query, calculate the cost using each join algorithm: Nested loops, Index Nested Loops, Sort-Merge

LO6.4: Parse a query

LO6.5: Use VP to answer questions about optimization

Today we will start from the bottom

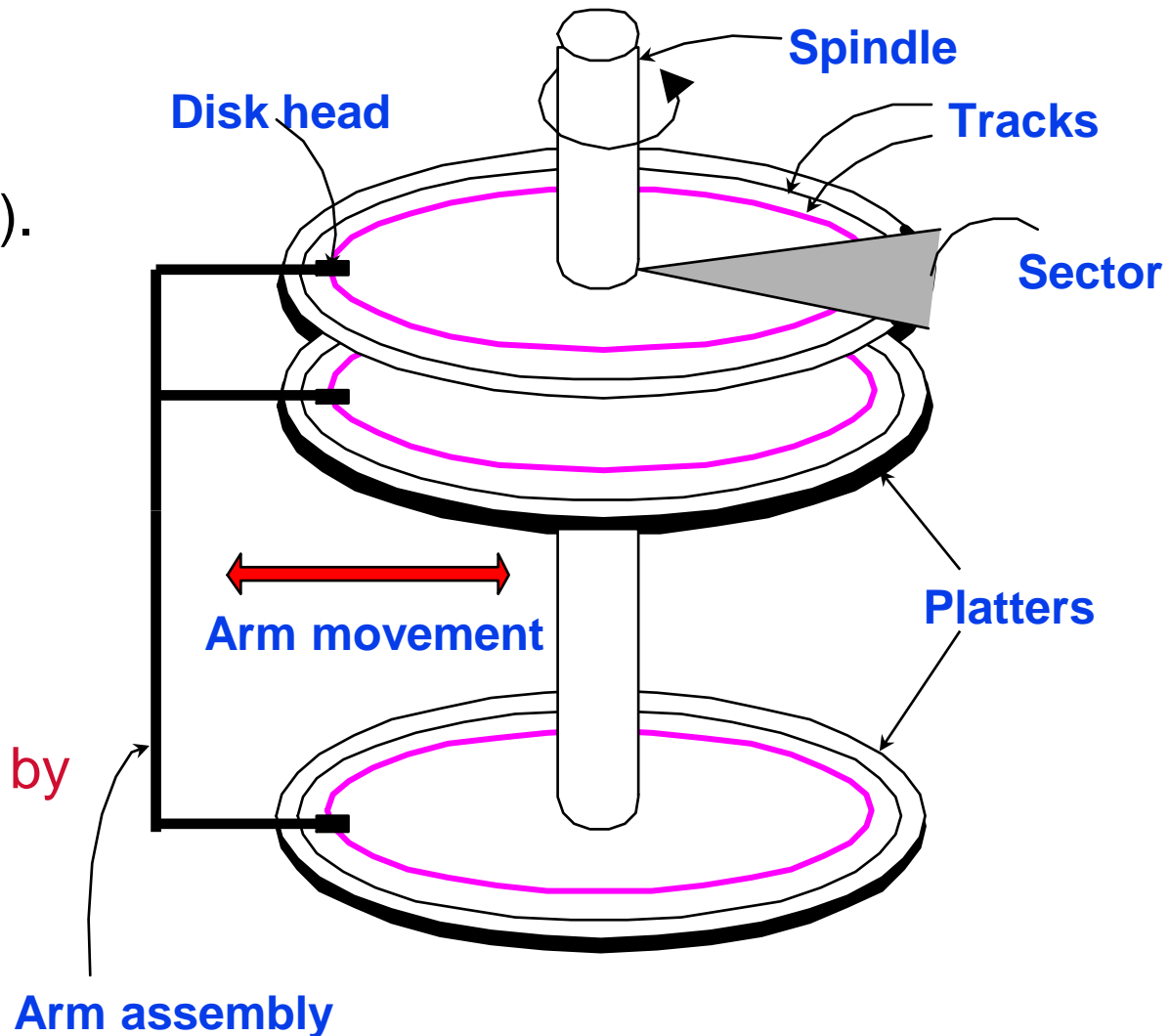


Measuring Query Speed

- Our goal this week is to figure out how to execute a query **fast**.
- But the **time** a query takes to execute is **hard** to measure or predict.
 - Depends on environment
- Simpler, easier to measure and predict: **Number of disk I/Os**.
 - Good: Very **roughly** proportional to execution time
 - Bad: Does not take into account CPU time or type of I/O
- **Therefore:** we will use number of disk I/Os to measure the time it takes a query to execute.
- Like looking under the lamppost.

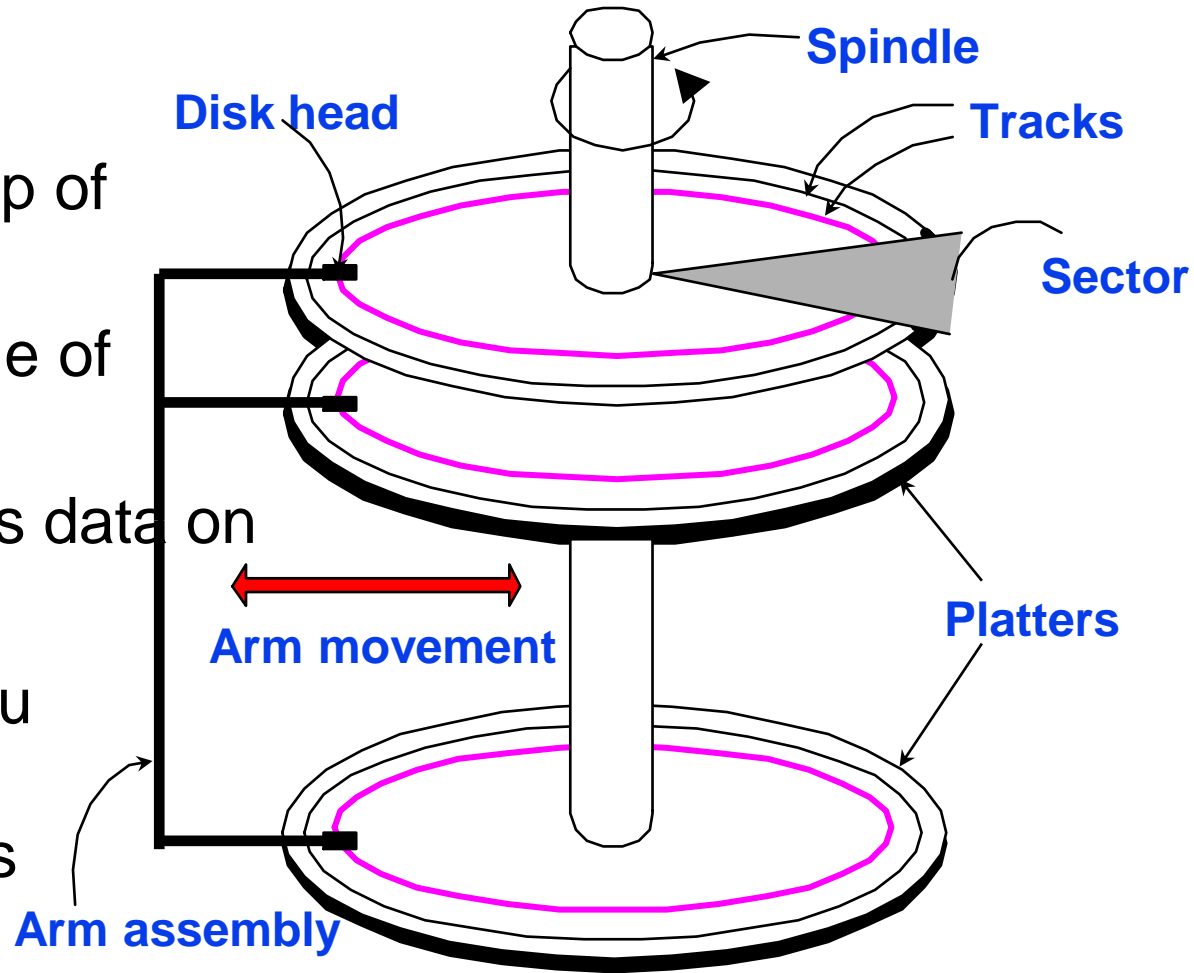
Components of a Disk *

- platters are always spinning (say, 7200rpm).
- one head reads/writes at any one time.
- to read a record:
 - position arm (seek)
 - engage head
 - wait for data to spin by
 - read (transfer data)



More terminology

- Each **track** is made up of fixed size **sectors**.
- **Page size** is a multiple of **sector size**.
- A platter typically has data on both surfaces.
- All the tracks that you can reach from one position of the arm is called a **cylinder** (imaginary!).



Cost of Accessing Data on Disk

- Time to access (read/write) a disk block:
 - *seek time* (moving arms to position disk head on track)
 - *rotational delay* (waiting for block to rotate under head)
 - **Half a rotation**, on average
 - *transfer time* (actually moving data to/from disk surface)
- Key to lower I/O cost: **reduce seek/rotation delays!**
(you have to wait for the transfer time, no matter what)
- The text measures the cost of a query by the NUMBER of page I/Os, implying that all I/Os have the same cost, and that CPU time is free. This is a common simplification.
 - Real DMBSs (in the optimizer) would consider sequential vs. random disk reads – because sequential reads are much faster – and would count CPU time.

Typical Disk Drive Statistics (2009)*

Sector size: 512 bytes

Seek time

Average 4-10 ms

Track to track .6-1.0 ms

Average Rotational Delay - 3 to 5 ms

(rotational speed 10,000 RPM to 5,400RPM)

Transfer Time - Sustained data rate

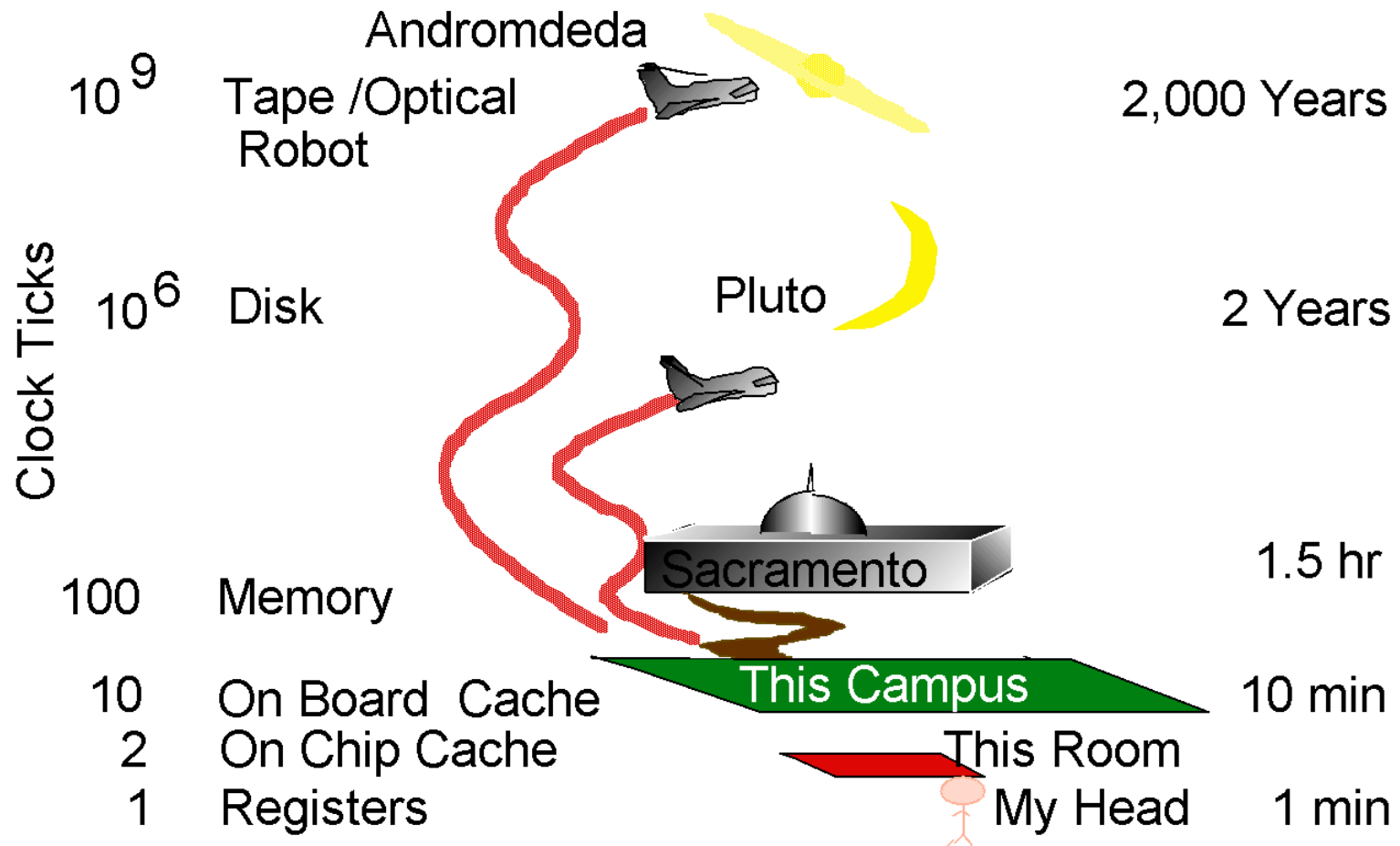
0.3- 0.1 msec per 8K
page, or 25-75 Meg/second

Density

12-18GB/in²

Rule of Thumb: 100 I-Os/second/page

How far away is the data?



From <http://research.microsoft.com/~gray/papers/AlphaSortSigmod.doc>

Block, page and record sizes

- **Block** – According to text, smallest unit of I/O.
- **Page** – often used in place of block.
- My notation is:
 - **Page** is smallest I/O for **operating system**
 - **Block** is smallest I/O for an **application**
 - Block is integral number of units
- “typical” record size: commonly hundreds, sometimes thousands of bytes
 - Unlike the toy records in textbooks
- “typical” page size 4K, 8K

What Block Size is **Faster**?*

- At times you can choose a block size for an application. How?
 - In some OS's, e.g., IBM's, you can **enforce** a block size
 - Or you can perform several reads at once, imitating a large block size. This is called **asynchronous readahead**.
 - This is like: **should I buy one bottle or a case?**
- What application will run **faster** with a **large** block size?
 - Goal is for the disk to **overlap** reads with the CPU's processing of records. Potentially running twice as **fast**.
- What application will run **faster** with a **small** block size?
 - Goal is not to waste memory or read time.

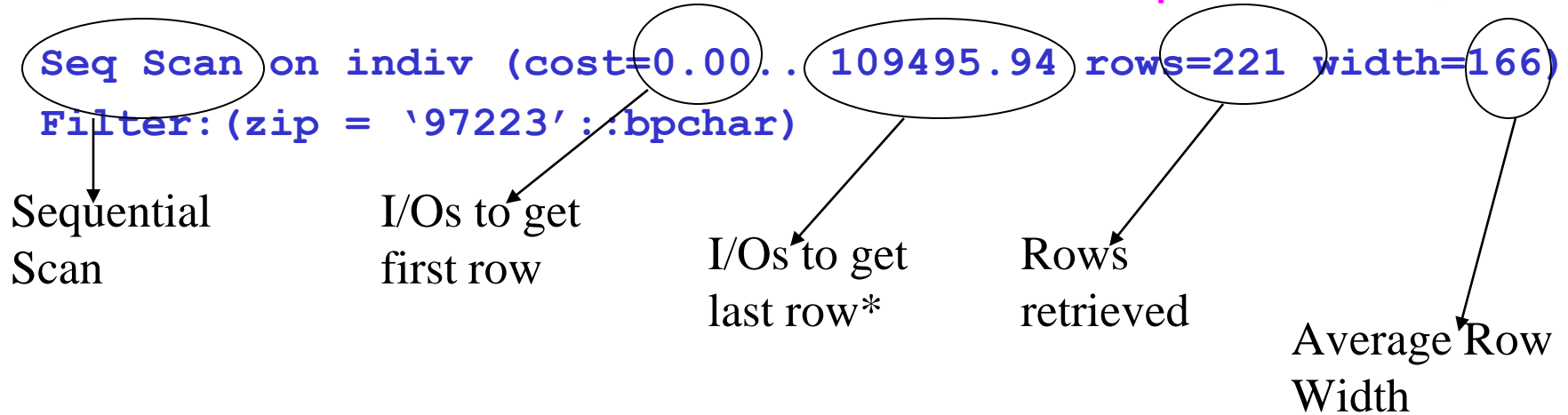
Time for some Magic

- You are in charge of a **production** DBMS for the FEC.
 - Production: an enterprise depends on the DBMS for its existence.
- Customers will ask queries like “find donations from 97223”. You must ensure a reasonable response time.
- **If** the queries run forever, customers will be unhappy and you will be **DM**.
 - The DBMS will grind to a halt. Customers will complain to congress, you will be out of a job.
- Wouldn't it be nice to know what plan the optimizer will choose, and how long that plan will take to execute?
- Rub the **magic lantern**...

Postgres' EXPLAIN

- Output for

EXPLAIN SELECT * FROM indiv WHERE zip = '97223';



- These values are **estimates** from sampling.
- Most DBMS's provide this facility.
- Also useful when a query runs longer than expected.
- If you are online, try it.

*Actually this includes CPU costs but we will call it I/O costs to simplify

You are now DM

- More than 100K I/Os!
 - Response time is 1,000 seconds, or 17 minutes.
- Unacceptable! Customers will complain!
- Is there a faster way than Seq Scan?
- You must do something or you are out of a job!!!

To the Rescue: Index

- An *Index* is a data structure that speeds up access to records based on some *search key field(s)*.
- Indexes are not part of the SQL standard
 - Because of physical data independence
- Typical SQL command to create an index:

```
CREATE INDEX indexname  
      ON tablename (searchkeyname[s]) ;
```

- For example

```
CREATE INDEX indiv_zip_idx ON indiv(zip) ;
```

Nota Bene

- “*Search key*” is *not* the same as a *key* for the table. Attributes in a “search key” need not be unique.

Index Demonstration: Input, Output

```
EXPLAIN SELECT * FROM indiv WHERE zip='97223';
```

Seq Scan on indiv (cost=0.00..109495.94 rows=221 width=166)
Filter: (zip = '97223'::bpchar)

```
CREATE INDEX indiv_zip_idx ON indiv(zip);
```

```
EXPLAIN SELECT * FROM indiv WHERE zip='97223';
```

Bitmap Heap Scan on indiv (cost=6.06..861.32 rows=221 width=166)
Recheck Cond: (zip = '97223'::bpchar)

-> Bitmap Index Scan on indiv_zip_idx (cost=0.00..6.01 rows=221
width=0)

Index Cond: (zip = '97223'::bpchar)

- With an index, the I/Os went from 109,495 to 861!
- That's 17 minutes to 9 seconds!

LO6.1: Practice with indexes*

- When you declare a primary key, most modern DBMSs (including Postgres) create a **clustered (sorted) index** on the primary key attribute (s).
- Give the SQL for creating all possible single-attribute indexes on the table `Emp(ssn PRIMARY KEY, name)`
- What are the search keys of each index?

Data Entries*

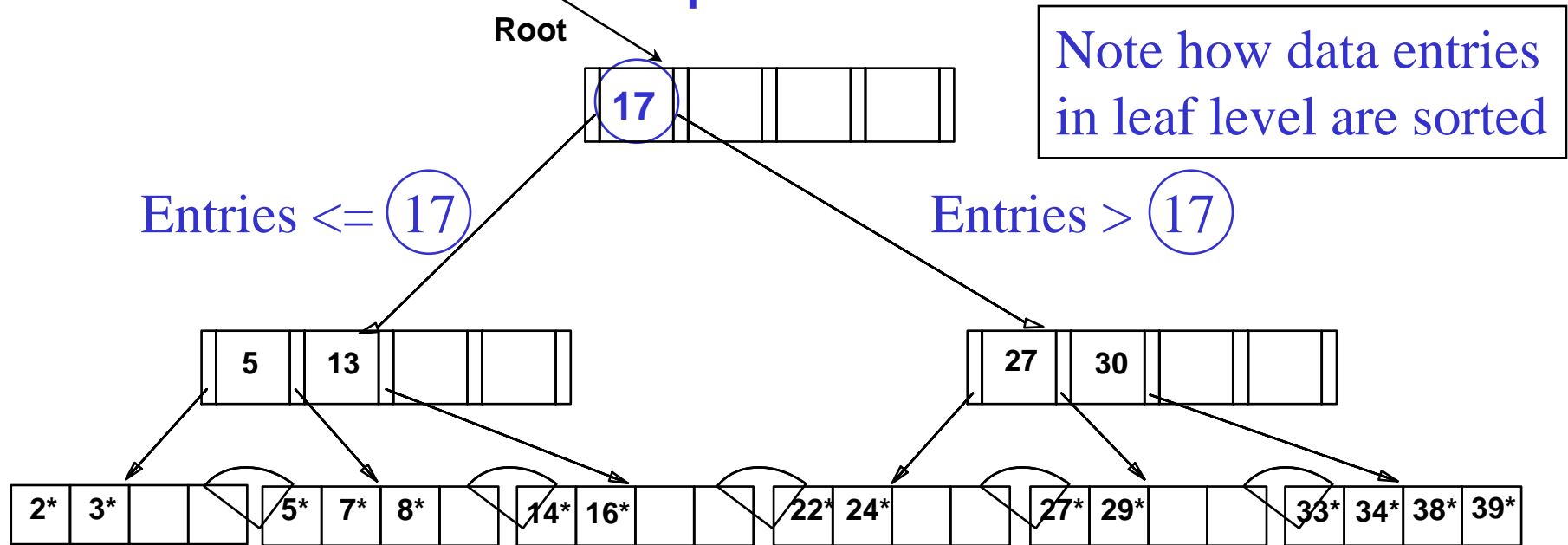
- Before we learn about how indexes are built, we must understand the concept of **data entries**.
- Given a search key value, the index produces a **data entry**, which produces the data record in one I/O.
- Other real-life indexes will help motivate this concept.
- Each of the following indexes speeds up data retrieval. What is the search key, data entry, and data record for each one?

	Search Key	Data Entry	Data Record
Library Catalog			
Google			
Mapquest			

Essentially all DBMS Indexes are B+ Trees

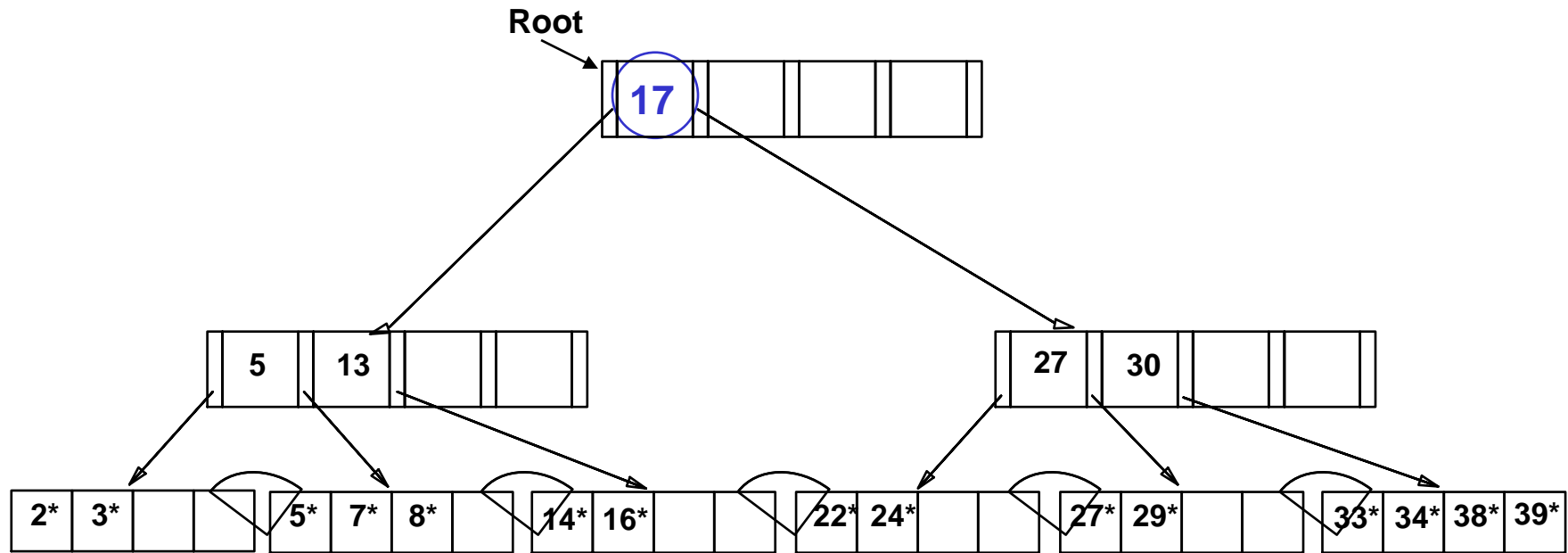
- Oracle, SQLServer and DB2 support only B+Tree indexes. Postgres supports hash indexes but does not recommend using them.
- B+ tree indexes support *range searches* (*WHERE const < attribute*) and *equality searches* (*WHERE const = attribute*).
- The next page contains a sample B+ tree index. Think of it as an *index on the first two digits of zip code*.
- *28** is a *data entry* that points to the donations from zip codes that start with 28.
- Above the data entries are *index entries* that help find the correct data entry.

Example B+ Tree



- Find 29*? 28*? All $> 15^*$ and $< 30^*$
- Insert/delete: Find data entry in leaf, then change it. Need to adjust parent sometimes.
 - And change sometimes bubbles up the tree
 - This keeps the tree *balanced*: **each data retrieval takes the same number of I/Os.**
 - Each page is always at least *half full*.

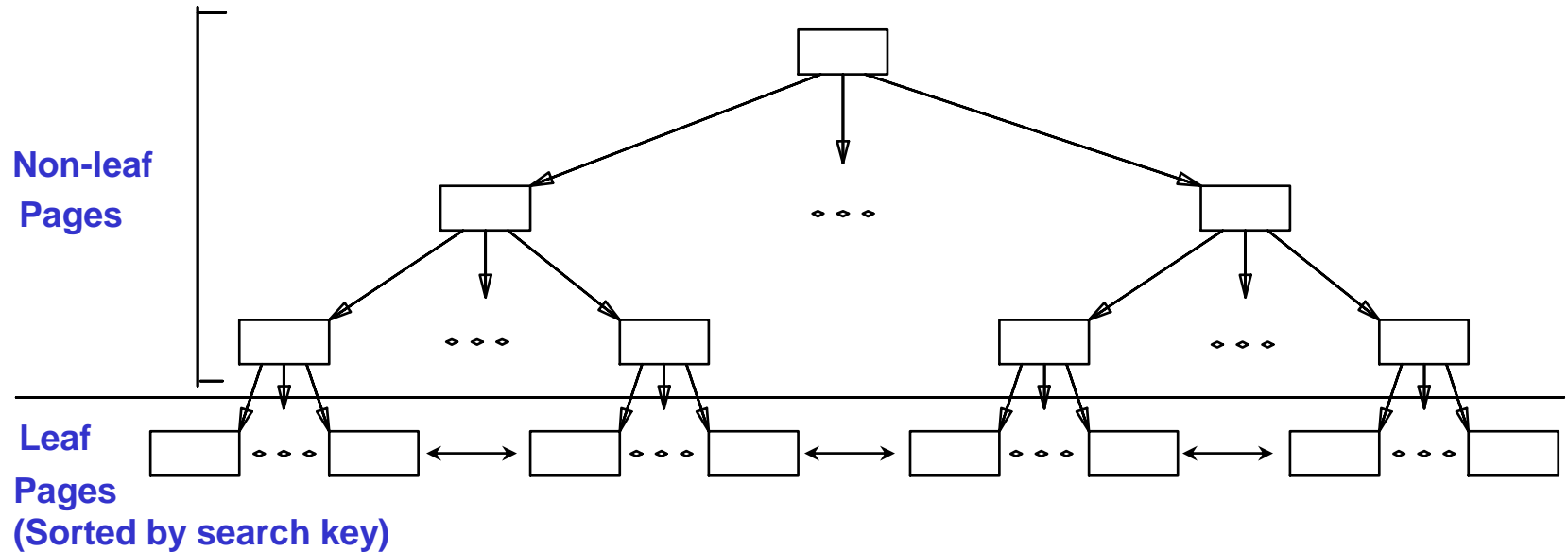
LO6.2: I/O Cost in a B+ Tree*



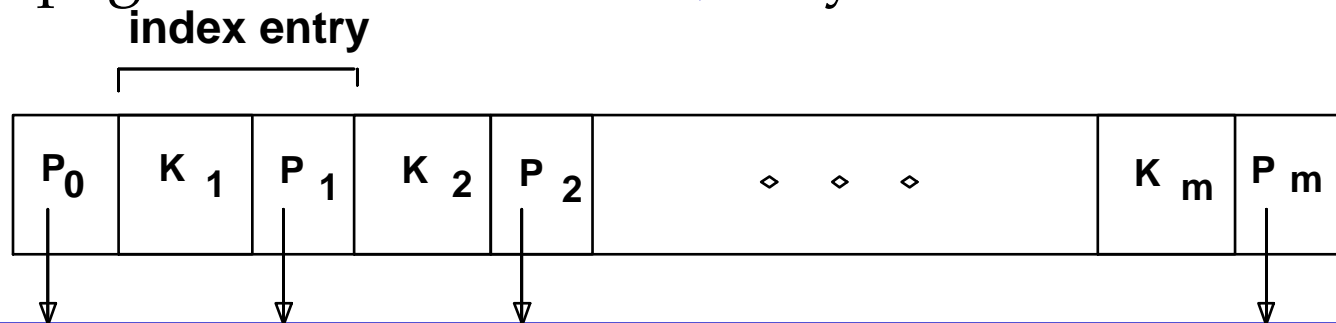
How many I/Os are required to retrieve data records with search key values x , $13 < x < 27$? Assume x is a unique key.

How many I/Os are required to retrieve data records with search key values x , $3 < x < 15$? Assume x is a unique key.

B+ Tree Indexes



- ❖ Leaf pages contain *data entries*, and are chained (prev & next)
- ❖ Non-leaf pages have *index entries*; only used to direct searches:



Don't get carried away!*

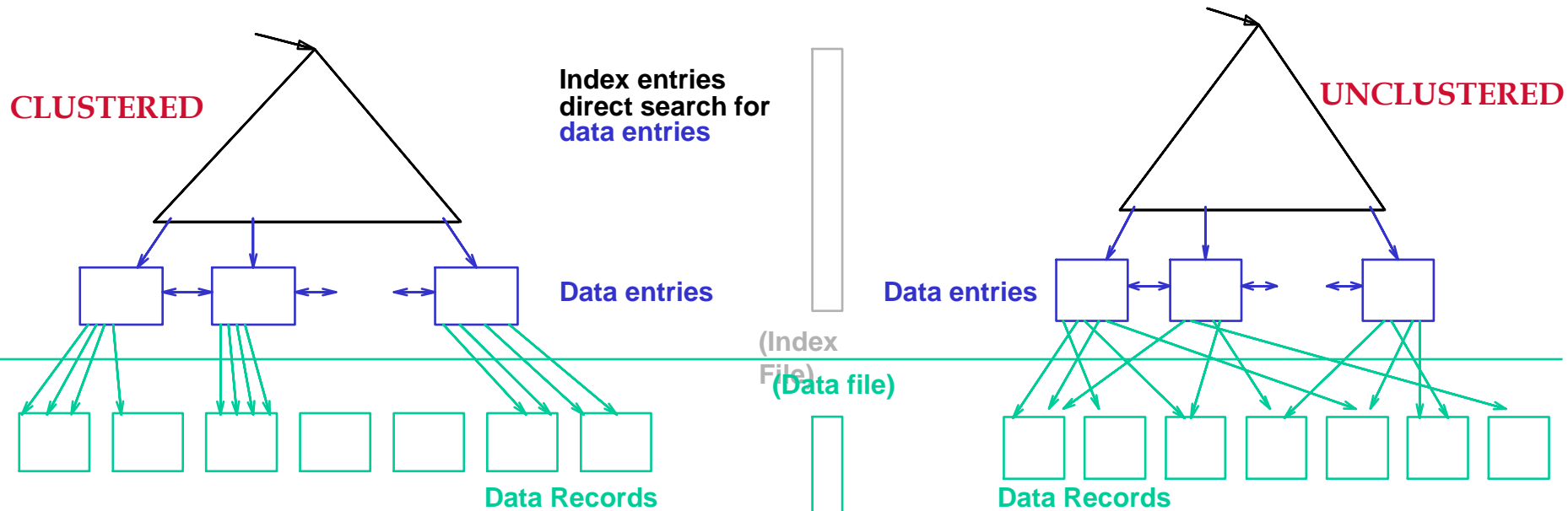
- Now I don't want you to run out and index every attribute and set of attributes in all your tables!
- If you define an index, you will incur three **costs**
 - Space to store the index
 - Updates to the search key will be slower – why?
 - The optimizer will take longer to choose the best plan because it has more plans to choose from.
 - We will see that sometimes it is better not to use an index
- There is one **advantage** to having an index
 - Some queries run faster (better be sure about this).

Index Classification

- *Primary vs. secondary*: If the index's search key contains the relation's primary key, then the index is called a **primary** index, otherwise a **secondary** index.
 - The index created by the DBMS for the primary key is usually called **the primary index**.
- *Unique* index: Search key contains a candidate key, i.e. no duplicate values of the search key.

Clustered vs. Unclustered indexes

- If the order of the data records is the same as, or 'close to', the order of the search key, then the index is called **clustered**.



Comments on Clustered Indexes

- If you are retrieving only **one** record, **any** index will do.
 - Retrieve one record in each index and count the I/Os.
 - Assume the height of the index entry tree is 2.
- If you are retrieving **many** records with the same search key value, a **clustered** index is almost always **faster**.
 - Retrieve 10 records from each index and count the I/Os.
 - Clustered:
 - Unclustered:
- Lest you get carried away: a table can have only one clustered index. Why?
- DBMSs make their primary indexes clustered.
- PS: DB2, Postgres and MySQL construct clustered indexes as we have described on the previous slide. Oracle and SQLServer put the data records in place of the data entries.

Where Are We?

- We've now learned two ways to perform a 1-table SELECT query: Sequential Scan and Index Scan.
- EXPLAIN tells you which plan/algorithm the optimizer will choose; which one it thinks is the fastest.
- Now we study possible plans/algorithms for multi-table join SELECT queries.

Join Algorithms: Motivation (apocryphal)

- When I was young I was asked to help with a charity art auction. At the start I got a big stack of **bidder cards** with bidder IDs and bidder information.
- At the end I got a much bigger stack of **bought cards**, each one containing a bidder ID and the cost of a painting that a bidder bought.
- Suddenly there was a long line of bidders who wanted to go home. For each bidder, I had to give the cashier the **bidder's card** with the bidder's matching **bought cards**.
- What would you do if you were in this situation?

Computer Science Algorithms

- Answers to the previous question will be investigated on the following pages. They fall into three categories, the three basic algorithms of computer science: **iteration, sorting and hashing**.
- **Nested Loop Join** (iteration) comes in two versions:
 - Simple Nested Loop
 - Index Nested Loop
- **Sort Merge Join**
- **Hash Join** (Will not be covered in this course)

Join Algorithms – an Introduction

- The text discusses algorithms for every relational operator. We study only join algorithms since join is so expensive.
- $L \bowtie R$ is very common!
- Notation: M pages in L , p_L rows per page, N pages in R , p_R rows per page.
- In our examples, L is indiv and R is comm.
- Our algorithms work for any equijoins.

A simple join

```
SELECT *  
FROM   indiv L, comm R  
WHERE  
L.commid=R.commid
```

Review how to compute this join by hand, with the cl versions of the tables.

$M = 23,224$ pages in L, $p_L = 39$ rows per page,
 $N = 414$ pages in R, $p_R = 24$ rows per page.

These (estimated) statistics are stored in the system catalog.

In PostgreSQL, retrieve number of pages with the function

```
SELECT pg_relation_size('tablename')/8192;
```

Retrieve rows per page using

```
SELECT COUNT(*)/(pages in L or R) FROM L or R;
```

The simplest algorithm: Nested Loops

Join on commid in L and commid in R

```
foreach row l in L do
  foreach row r in R do
    if rcommid == lcommid then add <r, s> to result
```

- For each **row** in the *outer* table L, we scan the entire *inner* table R, row by row.
 - Cost: $M + (p_L * M) * N = 23,224 + (39 * 23,224) * 414$ I/Os
= 374,997,928 I/Os $\approx 3,749,979$ seconds ≈ 43 days

Assuming approximately 100 I/Os per second
(86,400 secs/day)

Nested Loops Join

Table L
on disk

2	...
12	...
6	...

1	...
5	...
27	...

Memory Buffers:

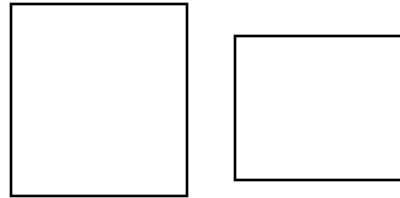


Table R
on disk

...	2
...	13

...	12
...	27

...	1
...	5

Nested Loops Join

Table L
on disk

2	...
12	...
6	...
1	...
5	...
27	...



Memory Buffers:

2	...
12	...
6	...

...	2
...	13



Table R
on disk

...	2
...	13
...	12
...	27
...	1
...	5



Query Answer
2 2

Nested Loops Join

Table L
on disk

2	...
12	...
6	...

1	...
5	...
27	...

Memory Buffers:

2	...
12	...
6	...

...	2
...	13

No match:
Discard!

Table R
on disk

...	2
...	13

...	12
...	27

...	1
...	5

Query Answer

2 2

Nested Loops Join

Table L
on disk

2	...
12	...
6	...

1	...
5	...
27	...

Memory Buffers:

2	...
12	...
6	...

...	12
...	27

Table R
on disk

...	2
...	13

...	12
...	27

...	1
...	5



No match:
Discard!

Query Answer

2 2

Nested Loops Join

Table L
on disk

2	...
12	...
6	...

1	...
5	...
27	...

Memory Buffers:

2	...
12	...
6	...

...	12
...	27

No match:
Discard!

Table R
on disk

...	2
...	13

...	12
...	27

...	1
...	5

Query Answer

2 2

Nested Loops Join

Table L
on disk

2	...
12	...
6	...

1	...
5	...
27	...

Memory Buffers:

2	...
12	...
6	...

...	1
...	5

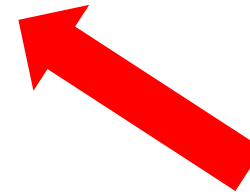
No match:
Discard!

Table R
on disk

...	2
...	13

...	12
...	27

...	1
...	5



Query Answer
2 2

Nested Loops Join

Table L
on disk

2	...
12	...
6	...

1	...
5	...
27	...

Memory Buffers:

2	...
12	...
6	...

...	1
...	5

No match:
Discard!

Table R
on disk

...	2
...	13

...	12
...	27

...	1
...	5

Query Answer

2 2

Nested Loops Join

Table L
on disk

2	...
12	...
6	...

1	...
5	...
27	...

Memory Buffers:

2	...
12	...
6	...

...	2
...	13

No match:
Discard!

Table R
on disk

...	2
...	13

...	12
...	27

...	1
...	5



Query Answer
2 2

Nested Loops Join

Table L
on disk

2	...
12	...
6	...

1	...
5	...
27	...

Memory Buffers:

2	...
12	...
6	...

...	2
...	13

No match:
Discard!

Table R
on disk

...	2
...	13

...	12
...	27

...	1
...	5

Query Answer

2 2

Nested Loops Join

Table L
on disk

2	...
12	...
6	...

1	...
5	...
27	...

Memory Buffers:

2	...
12	...
6	...

...	12
...	27

Match!

Table R
on disk

...	2
...	13

...	12
...	27

...	1
...	5



Query Answer

2 2
12 12

And so forth ...

Index Nested Loops Join

IF THERE IS AN INDEX ON $r.commid$

foreach row l in L do

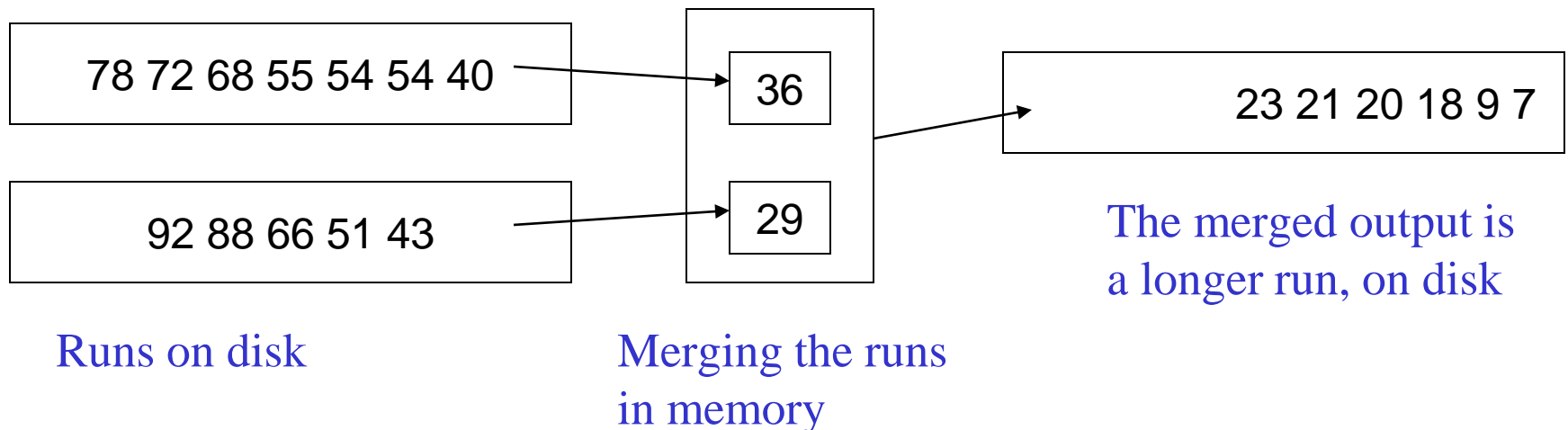
use the index to find all rows r in R where $l_{commid} = r_{commid}$
for all such r : add $\langle l, r \rangle$ to result

Cost: $M + (M * p_L) * \text{cost of finding matching } R \text{ rows}$
 $= 23224 + ((23224 * 39) * 3) = 2,740,432 \text{ I/Os} \approx 27,404 \text{ secs} \approx 8 \text{ hours}$

Cost of finding the rows in R using
the index on $commid$ – much
cheaper than scanning all of $comm$!

External Sorting

- Many relational operator algorithms require **sorting a table**
- Often the table **won't fit in memory**
- How do we sort a dataset that won't fit in memory?
- Answer: **External Sort-Merge** algorithm
 - **First pass**: Read and write a memoryfull of (sorted) runs at a time.
 - **Second and later passes**: Merge runs to make longer runs
 - Here's a picture of merging two runs:



External Sorting – Cost

- Number of passes depends on how many pages of memory are devoted to sorting
 - Can sort M pages of data using B pages of memory in **2 passes** if $\sqrt{M} \leq B$
 - Can sort big files M with not much memory B
 - If page size is 4K:
 - Can sort 4Gig of data in 4Meg of memory
 - Can sort 256Gig of data in 32Meg of memory
 - Each pass is a read and a write, so if $\sqrt{M} \leq B$ then sort costs $(M+M)+(M+M)$ so can be done in **$4 \cdot M$ I/Os**
 - So it's reasonable to assume that sorting M pages costs **$4 \cdot M$** .

Sort-Merge Join

- This join algorithm is the one many people think of when asked how they would join two tables. It is also the simplest to visualize. It involves three steps.
 1. Sort L on l_{commid}
 2. Sort R on r_{commid}
 3. Merge the sorted L and R on l_{commid} and r_{commid} .
- We've covered the algorithm and cost of steps 1 and 2 on the previous pages

The Merge Step

- What is the algorithm for step 3, the merge?
 - Advance scan of L until current L-row's $l_{commid} \geq$ current R row's r_{commid} , then advance scan of R until current R-row's $r_{commid} \geq$ current L row's l_{commid} ; do this until current L row's $l_{commid} =$ current R row's r_{commid} .
 - At this point, all L rows with same l_{commid} and all R rows with same r_{commid} match; output $\langle l, r \rangle$ for all pairs of such rows.
 - Then resume scanning L and R.
- What is the cost of the merge step?
 - Normally, $M+N$
- What if there are many duplicate values of l_{commid} and r_{commid} ?
 - What if all values of l_{commid} are the same and equal to all values of r_{commid} ?
 - Then $L \bowtie R = L \times R$ and the cost of the merge step is $L * R$.
- BUT, almost every real life join is a foreign key join. One of the joining attributes is a key, so the duplicate value problem does not occur.

Cost of Sort-Merge Join

- Assuming that sorting can be done in two passes and that the join is a foreign key join
- Cost: (cost to sort L) + (cost to sort R) + (cost of merge)

$$= 4M + 4N + (M+N) = 5(M+N)$$

- For our running example the cost is:

$$5(M+N) = 5(23224+414) = 118,190 \text{ I/Os} \approx 1,181 \text{ seconds} \approx 20 \text{ minutes}$$

- In reality the cost is much less because of optimizations, indexes, and the use of hash join
 - Cf. CS587/410

Costs for Join Algorithms

Join Algorithm	I/O Cost	O()	Time for our example
Nested Loop	$M + P_L * M * N$	$M * N$	43 Days
Index Nested Loop	$M + P_L * M * (\text{cost of index access}^*)$	M	8 Hours
Sort-merge, with 2-pass sort for both inputs	$5(M+N)$	$M+N$	20 minutes

*For homework and exercises you may assume this is 3 times the number of rows retrieved

LO6.3: Costs of Join Algorithms*

- Consider this join query:

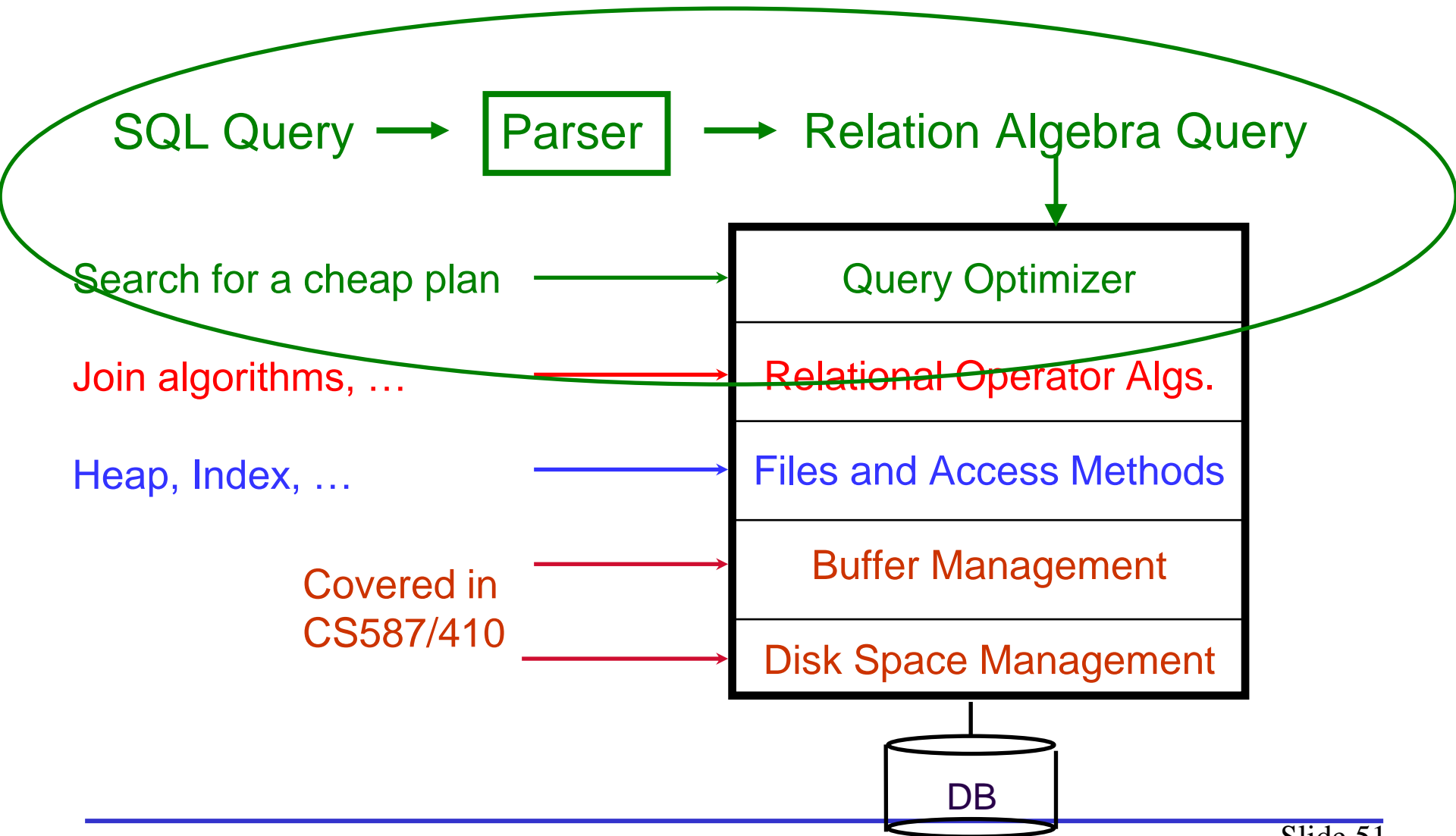
SELECT *

FROM pas L, comm R

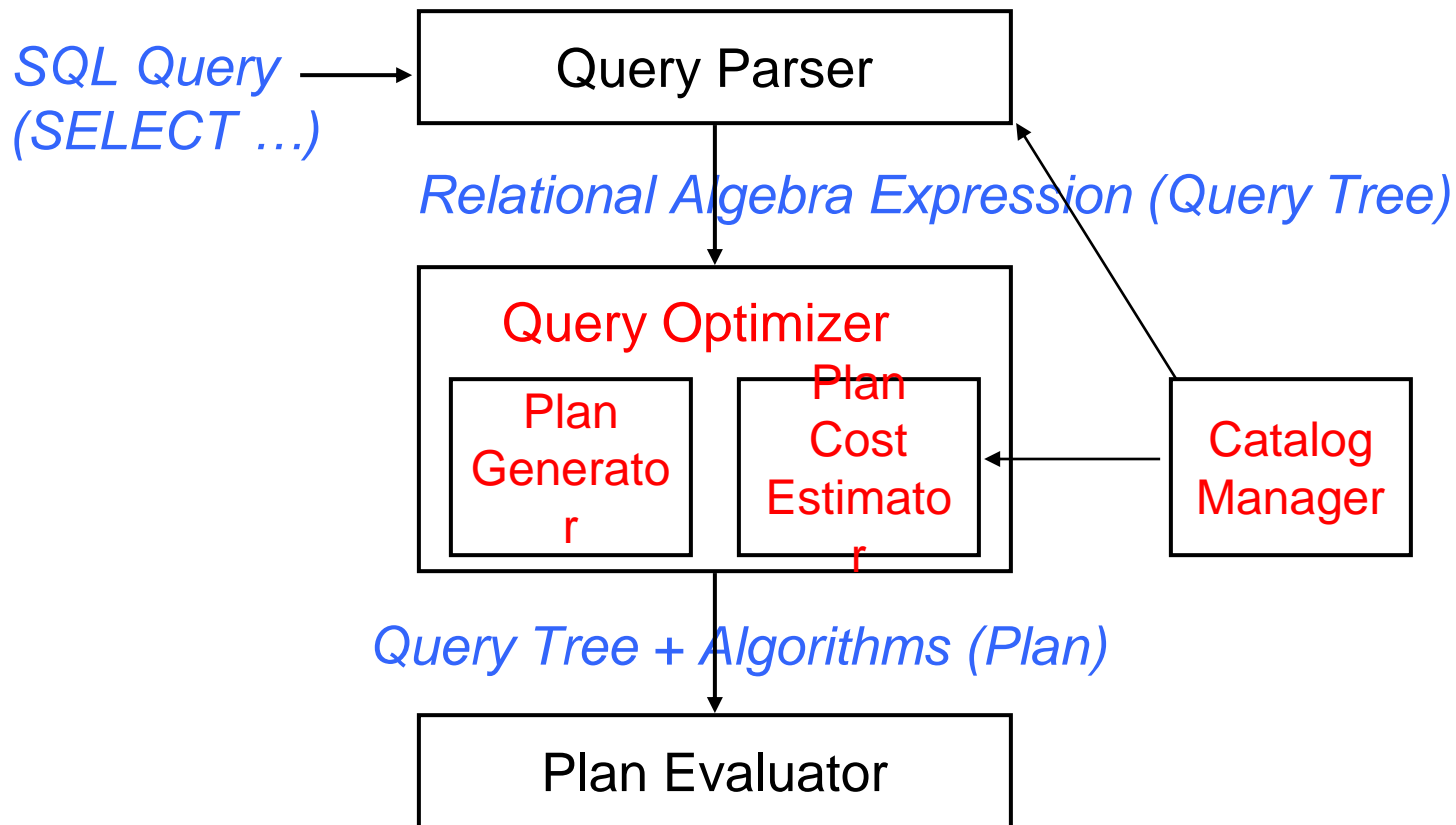
WHERE L.commid = R.commid;

- Calculate the cost (in time) of a nested loop, index nested loop and sort-merge join.

Now we focus on the top of this diagram



Detail of the top



Parsing and Optimization

- The Parser

- Verifies that the SQL query is **syntactically correct**, that the **tables and attributes exist**, and that the user has the appropriate **permissions**.
- **Translates the SQL query into a simple query tree** (operators: relational algebra plus a few other ones)

- The Optimizer:

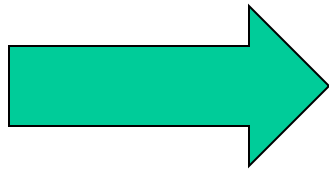
- **Generates other, equivalent query trees** (Actually builds these trees bottom up)
- **For each** query tree generated:
 - Selects algorithms for each operator (producing a query *plan*)
 - estimates the cost of the plan
- **Chooses the plan with lowest cost** (of the plans considered, which is not necessarily all possible plans)

Here's what the parser does

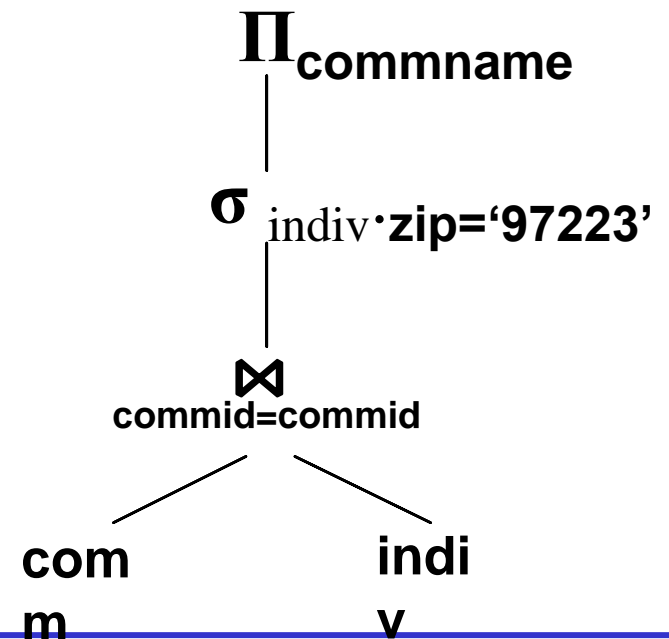
SQL

Query:

```
SELECT commname
FROM   comm JOIN indiv
USING  commid
WHERE  indiv.zip='97223';
```



Relational Algebra
Tree:



LO6.4: Parse a Query*

- Describe the parser's output when the input is

```
SELECT candname  
FROM   cand JOIN pas  
USING  candid  
WHERE  amount > 3000;
```

What does the optimizer do?

- Fortunately, a Master's student at PSU, **Tom Raney**, has just added a patch to PostgreSQL (PG) that allows anyone to look **inside the optimizer** (PG calls it the **planner**).
- One of the lead PG developers says “it’s like finding Sasquatch”.
- We’ll use Tom’s patch to see what the PG planner does.
- The theory behind the PG planner [668] is shared by **all DBMS optimizers***.

*Except SQL Server, though I won't keep saying this.

Overview of DBMS Optimizers

- "Optimizing a query" consists of these 4 tasks
 1. Generate all trees equivalent to the parser-generated tree
 2. Assign algorithms to each node of each tree
 - A tree with algorithms is called a **plan**.
 3. Calculate the cost of each generated plan
 - Using the join cost formulas we learned in previous slides*
 4. Choose the cheapest plan

*Statistics for calculating these costs are kept in the **system catalog**.

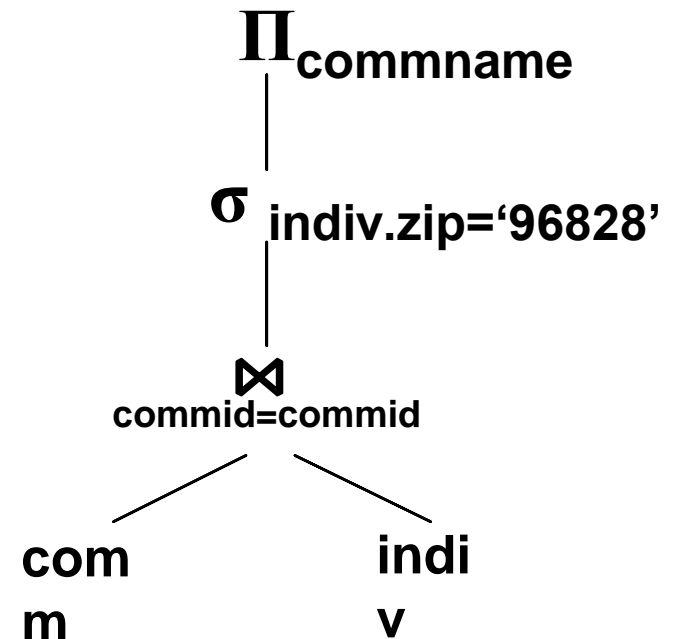
Dynamic Programming

- A **no-brainer** approach to these 4 tasks could take **forever**. For medium-large queries there are millions of plans and it can take a millisecond to compute each plan cost, resulting in **hours** to optimize a query.
- This problem was solved in 1979 [668] by Patsy Selinger's IBM team using **Dynamic Programming**.
- The trick is to solve the problem bottom-up:
 - First optimize all **one**-table subqueries
 - Then use those optimal plans to optimize all **two**-table subqueries
 - Use those results to optimize all **three**-table subqueries, etc.

Consider A Query and its Parsed Form

SELECT commname
FROM indiv JOIN comm USING (commid)
WHERE indiv.zip = '96828';

I chose 96828 because it
is in Hawaii. Wishful
thinking.



What Will a Selinger-type Optimizer Do?

1. Optimize **one table** subqueries
 - **indiv WHERE zip=96828** , then **comm**
2. Optimize **two-table** queries
 - **The entire query**
 - Let's use Raney's patch, the **Visual Planner**, to see what PG's Planner does.
 - We'll watch PG's Planner in **two** cases
 - **noindex.pln**: no index on indiv.zip
 - **index.pln**: a nonclustered index on indiv.zip

How to Set Up Your Visual Planner

- Download, then unzip, in Windows or *NIX:
 - `cs.pdx.edu/~len/386/VP1.7.zip`
- Read README.TXT, don't worry about details
- Be sure your machine has a Java VM
 - <http://www.java.com/en/download/index.jsp>
- Click on Visual_Planner.jar
 - If that does not work, use this at the command line:
 - `java -jar Visual_Planner.jar`
- In the resulting window
 - File/Open
 - Navigate to the directory where you put VP1.7
 - Navigating to C: may take a while
 - Choose noindex.pln

Windows in the Visual Planner *

- The **SQL** window holds the (canned) query
- The **Plan Tree** window holds the **optimal** plan for the query.
- The **Statistics** window holds statistics about the highlighted node of the Plan Tree's plan
- Click a Plan Tree node to see its statistics
 - Why is the Seq Scan on the right input, indiv, almost the same cost as the Sort?
 - Why is there an index scan on the joining attribute of comm?
- Why is a merge join the optimal plan?
 - Almost no cost to sort the right input
 - No cost to sort the left input because the index is clustered

Visualize Dynamic Programming*

- Recall the first steps of Dynamic Programming: Optimize indiv, then comm.
- Postgres calls these the ROI steps and they are displayed in the **ROI** window of VP.
- In the ROI window, **click on indiv** to see how the PG Planner optimized indiv. What happened?
- In the ROI window, **click on comm**. What happened?
 - The Planner saved the index scan even though it was slower than the Seq Scan, because it had an *interesting order*.
 - The index scan is ordered on commid, which is a joining attribute, so it is an interesting order.

The Last Act

- The last step of Dynamic Programming is to optimize the entire query, the two-table join.
- Click on **indiv/comm** in the ROI Window.
 - **Blue** plans are those that have the fastest total cost or the fastest startup cost, either overall or for some interesting order.
 - **Red** plans are dominated by another plan.
 - Dominated means there is a faster plan with the same order.
 - To see a plan in a separate window, Shift-click it.
 - Plans are listed in alphabetical order, then in order of total cost, then in order of startup cost.

What Happened in the Last Act?*

- The first blue plan is the optimal plan we've been looking at.
- Why is the second blue plan there?
- Look at the other Merge Join plans. Why are they red?
- Find and describe the most expensive plan. What makes it so expensive?

Index to the Rescue*

- File/Open, navigate to index.pln
- Without the index the optimal plan cost 35,471
- What is the cost of the optimal plan now?
- Why?

LO6.2 EXERCISE*

- Consider the B+-tree index on slide 21. Assume none of the tree is in memory and the index is unique. Assume that in the data file, every data record is on a different page. How many disk I/Os are needed to retrieve all records with search key values x , $7 < x < 16$?

LO6.3: EXERCISE

- Consider the join query:

SELECT *

FROM comm L, cand R JOIN ON (assoccand = candid)

Calculate the cost of a nested loop, index nested loop and sort-merge join.

LO6.4: EXERCISE

- Follow the instructions on slide 61 to set up the Visual Planner. Open the file noindex.pln
 - What is the startup cost and the total cost of the left input?
- Open the file index.pln
 - Click on the "Bitmap Index Scan". What index is being used?
 - What is the order of the left input?