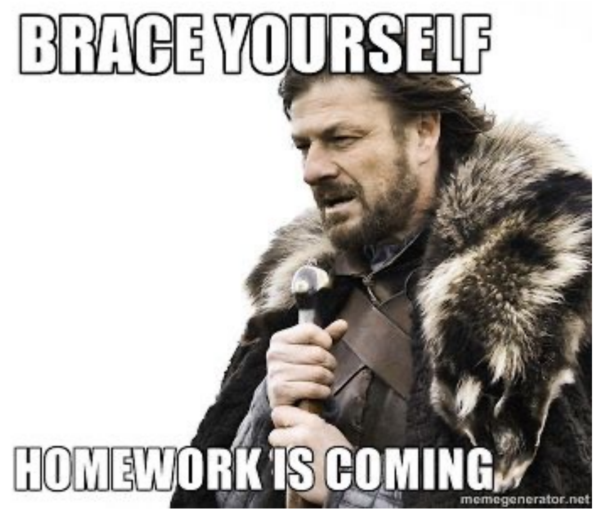
Piazza signup:
http://piazza.com/mit/spring2024/6s079

http://dsg.csail.mit.edu/6.S079/

6.S079
Lecture 3

Sam Madden



Lab 1 Due ~~Friday~~ Monday

Key ideas:
More SQL
Indexes and performance tuning

Recap: SQL Syntax and Joins

- Bands schema
  - **Bands**: bandid, name, genre
  - **Shows**: showid, show_bandid REFERENCES bands.bid, date, venue
  - **Fans**: fanid, name, birthday
  - **BandFans**: bf_bandid REFERENCES bands.bandid, bf_fanid REFERENCES fans.fanid

Dates of 'slipknot' shows

```
SELECT date
FROM shows JOIN bands ON show_bandid  = bandid
WHERE name = 'slipknot'
```

Alternately

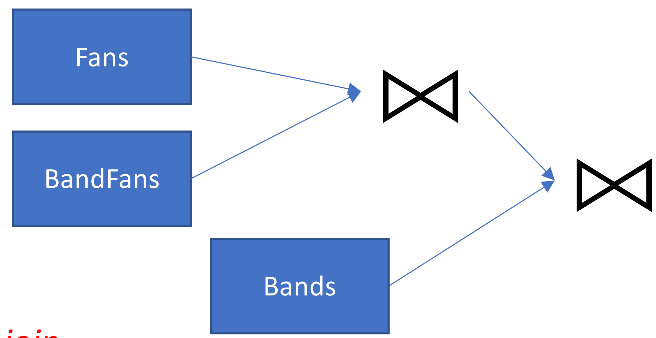
```
SELECT date
FROM shows, bands
WHERE show_bandid  = bandid
AND name = 'slipknot'
```

Bands: bandid, name, genre
Shows: showid, show_bandid, date, venue
Fans: fanid, name, birthday
BandFans: bf_bandid, bf_fanid

Aliases and Ambiguity

Bands: bandid, name, genre
Shows: showid, show_bandid, date, venue
Fans: fanid, name, birthday
BandFans: bf_bandid, bf_fanid

- Fans who like 'slipknot'




```
SELECT name
FROM fans JOIN bandfans ON bf_fanid = fanid
JOIN bands on bf_bandid = bandid
WHERE name = 'slipknot'
```

Unclear which "name" we are referring to

3 table join
(fans $\bowtie$ bandfans) $\bowtie$ bands

This doesn't work. Why?

Aliases and Ambiguity

Bands: bandid, name, genre
Shows: showid, show_bandid, date, venue
Fans: fanid, name, birthday
BandFans: bf_bandid, bf_fanid

- Fans who like 'slipknot'
- Solution: disambiguate which table we are referring to

Declare 'f' and 'b' as aliases for fans and bands

SELECT ~~name~~ f.name
FROM fans f JOIN bandfans ON bf_fanid = fanid
JOIN bands b on bf_bandid = bandid
WHERE ~~name~~ b.name = 'slipknot'

Poll: SQL Comprehension

- Fill in the blank to complete this query to "find shows by slipknot after Jan 1 2022"? (Assume syntax for dates is correct)

SELECT date, venue FROM ____________ WHERE name = 'slipknot' AND date > '1/1/2022'

A. show, bands
B. shows JOIN bands ON showid = show_bandid
C. shows JOIN bands ON bandid = show_bandid
D. shows JOIN bands ON bandid = showid

Bands: <u>bandid</u>, name, genre
Shows: <u>showid</u>, show_bandid, date, venue
Fans: <u>fanid</u>, name, birthday
BandFans: <u>bf_bandid</u>, <u>bf_fanid</u>

https://clicker.mit.edu/6.S079/

Aggregation

- Find the number of fans of each band

```
SELECT bands.name,count(*)
FROM bands JOIN bandfans ON bandid=bf_bandid
GROUP BY bands.name
```

- What about bands with 0 fans?

Left Join?

- T1 LEFT JOIN T2 ON pred produces all rows in T1 x T2 that satisfy pred, plus all rows in T1 that don't join with any row in T2
  - For those rows, fields of T2 are NULL

Example:

SELECT bands.name, MAX(bf_fanid)

FROM bands LEFT JOIN bandfans

ON bandid=bf_bandid

GROUP BY bands.name

name	bandid
slipknot	1
limp bizkit	2
mariah carey	3

bf_bandid	bf_fanid
1	1
2	2
2	3

name	MAX
slipknot	1
limp bizkit	3
mariah carey	NULL

What about COUNT?

Can also use "RIGHT JOIN" and "OUTER JOIN" to get all rows of T2 or all rows of both T1 and T2

Substituting for NULLs

```
SELECT bands.name, MAX(bf_fanid)
FROM bands LEFT JOIN bandfans
ON bandid=bf_bandid
GROUP BY bands.name
```

name	MAX
slipknot	1
limp bizkit	3
mariah carey	NULL

- What if I don’t want the NULL value?
  - Use COALESCE

```
SELECT bands.name, COALESCE(MAX(bf_fanid),-1)
FROM bands LEFT JOIN bandfans
ON bandid=bf_bandid
GROUP BY bands.name
```

name	MAX
slipknot	1
limp bizkit	3
mariah carey	-1

COUNT on NULLs

- NULLs are very confusing in SQL

Example:

SELECT bands.name, COUNT(*)

FROM bands LEFT JOIN bandfans

ON bandid=bf_bandid

GROUP BY bands.name

name	bandid
slipknot	1
limp bizkit	2
mariah carey	3

bf_bandid	bf_fanid
1	1
2	2
2	3

name	COUNT
slipknot	1
limp bizkit	2
mariah carey	1

Not what we wanted!

Solution

- NULLs are very confusing in SQL

Example:

SELECT bands.name, COUNT(bf_bandid)

FROM bands LEFT JOIN bandfans

ON bandid=bf_bandid

GROUP BY bands.name

name	bandid
slipknot	1
limp bizkit	2
mariah carey	3

bf_bandid	bf_fanid
1	1
2	2
2	3

name	COUNT
slipknot	1
limp bizkit	2
mariah carey	0

COUNT(*) counts all rows including NULLs, COUNT(col) only counts rows with non-null values in col

Self Joins

- Fans who like ‘slipknot’ and ‘limp bizkit’

```
SELECT f.name
FROM fans f JOIN bandfans ON bf_fanid = fanid
JOIN bands b on bf_bandid = bandid
WHERE b.name = 'slipknot' AND b.name = 'limp bizkit'
```

Doesn’t work!

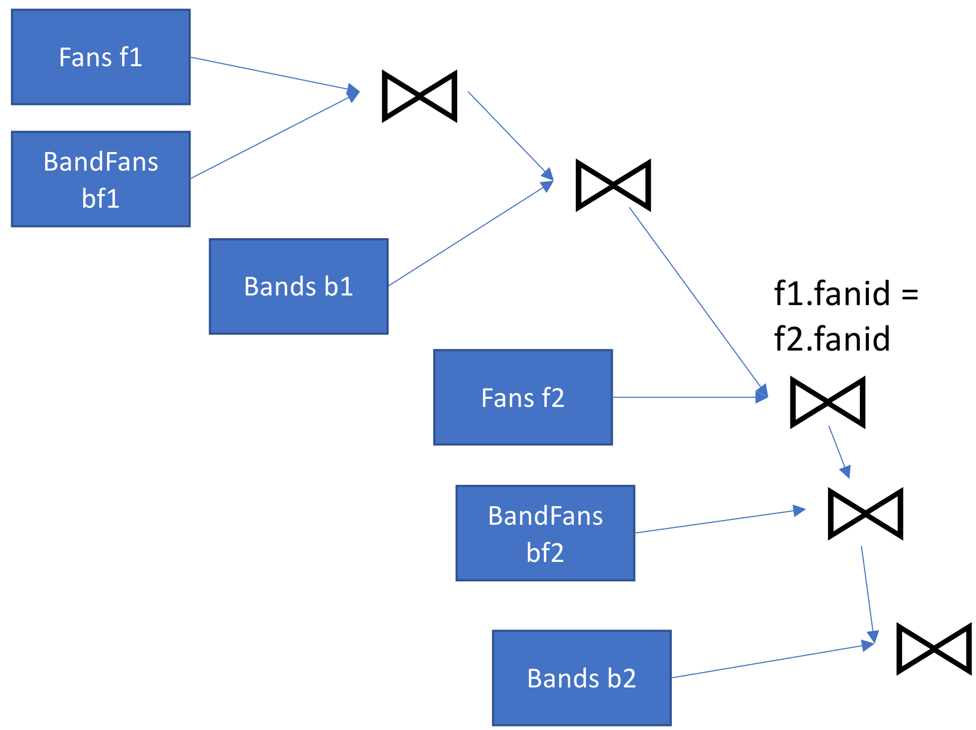
OR b.name = ‘limp bizkit’?

Also doesn’t work!

Self Joins

- Fans who like ‘slipknot’ and ‘limp bizkit’
- Need to build two tables, one of ‘slipknot’ fans and one of ‘limp bizkit’ fans, and intersect them

```
SELECT f1.name
FROM fans f1 JOIN bandfans bf1 ON bf_fanid = fanid
JOIN bands b1 on bf_bandid = bandid
JOIN fans f2 ON f1.fanid = f2.fanid
JOIN bandfans bf2 ON bf2.bf_fanid = f2.fanid
JOIN bands b2 ON b2.bandid = bf2.bf_bandid
WHERE b1.name = 'slipknot' AND b2.name = 'limp bizkit'
```



Nested Queries

```
SELECT fans1.name
FROM (
    SELECT fanid, f.name
    FROM fans f JOIN bandfans ON bf_fanid = fanid
    JOIN bands b ON bf_bandid = bandid
    WHERE b.name  = 'slipknot') AS fans1,
JOIN (
    SELECT fanid, f.name
    FROM fans f JOIN bandfans ON bf_fanid = fanid
    JOIN bands b ON bf_bandid = bandid
    WHERE b.name  = 'limp bizkit') AS fans2
 ON fans1.fanid = fans2.fanid
```

Every query is a relation (table)

Generally anywhere you can use a table, you can use a query!

Simplify with Common Table Expressions (CTEs)

```
WITH fans1 AS
    (SELECT fanid, f.name
    FROM fans f JOIN bandfans ON bf_fanid = fanid
    JOIN bands b ON bf_bandid = bandid
    WHERE b.name  = 'slipknot'),
fans2 AS
    (SELECT fanid, f.name
    FROM fans f JOIN bandfans ON bf_fanid = fanid
    JOIN bands b ON bf_bandid = bandid
    WHERE b.name  = 'limp bizkit')
SELECT fans1.name
FROM fans1 JOIN fans2 ON fans1.fanid = fans2.fanid
```

CTEs work better than nested expressions when the CTE needs to be referenced in multiple places


NOW
YOU
TRY!

Question

- Write a SQL query to find all the bands who have fans who are fans of 'limp bizkit'
  - I.e.:
    - Mary is a fan of limp bizkit and korn
    - Tim is a fan of creed and justin Bieber
    - Sam is a fan of limp bizkit and nickelback
    - Janelle is a fan of nickelback and slipknot

Should return korn and nickelback

Bands: bandid, name, genre
Shows: showid, show_bandid, date, venue
Fans: fanid, name, birthday
BandFans: bf_bandid, bf_fanid

```
WITH lb_fans AS
( SELECT bf_fanid fanid
  FROM bandfans
  JOIN bands ON bandid = bf_bandid
  WHERE bands.name = 'limp bizkit'
)
SELECT bands.name
FROM bandfans
JOIN lb_fans ON bf_fanid = fanid
JOIN bands ON bf_bandid = bandid
```

fanid	name
1	mary
2	tim
3	sam
4	janelle

fanid
1
3

lb_fans

Need to eliminate duplicates
Filter out limp bizkit

bf_bandid	bf_fanid
2	1
3	1
5	2
6	2
2	3
4	3
1	4
4	4

bands
limp bizkit
korn
limp bizkit
nickelback

bandid	name
1	slipknot
2	limp bizkit
3	korn
4	nickelback
5	creed
6	Justin bieber

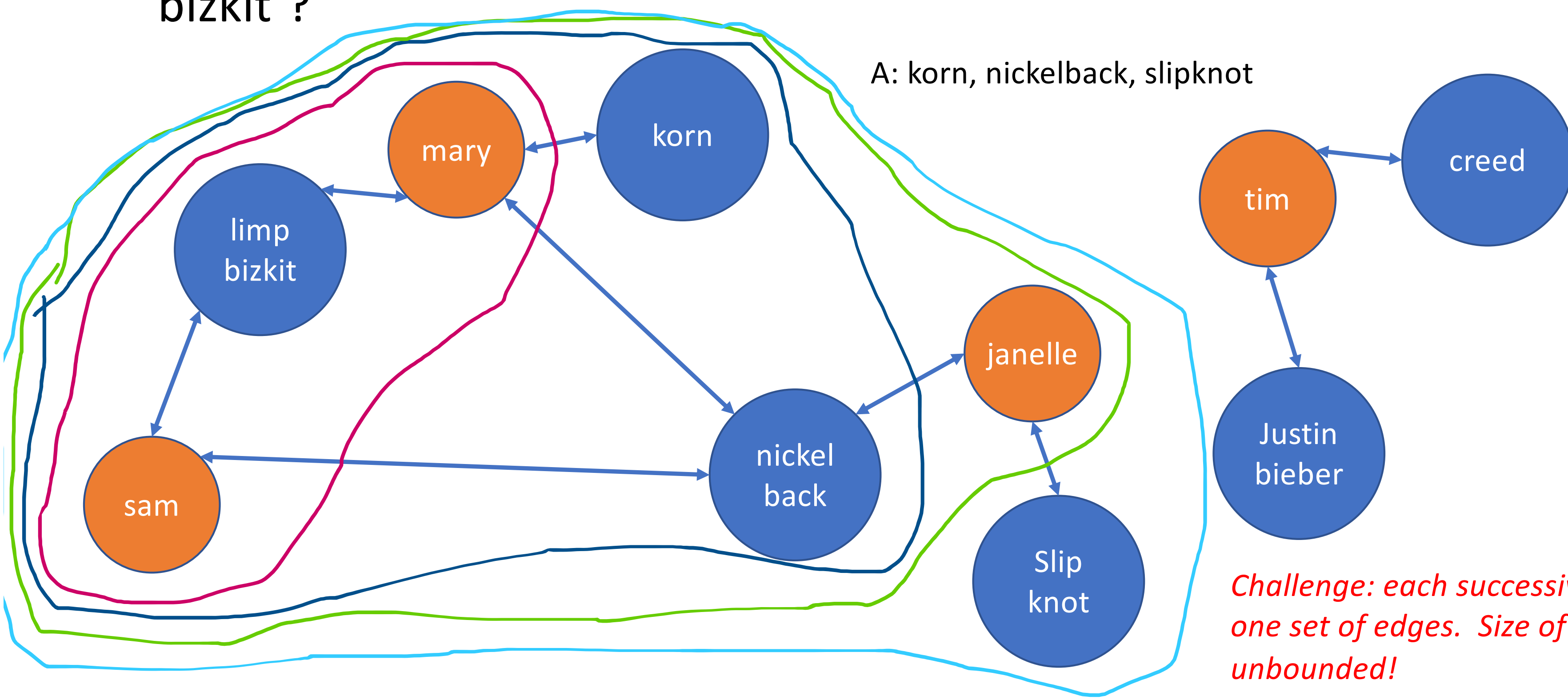
Solution

```
WITH lb_fans AS
( SELECT bf_fanid fanid
  FROM bandfans
  JOIN bands ON bandid = bf_bandid
  WHERE bands.name = 'limp bizkit'
)
SELECT DISTINCT bands.name
FROM bandfans
JOIN lb_fans ON bf_fanid = fanid
JOIN bands ON bf_bandid = bandid
WHERE bands.name != 'limp bizkit'
```

Recursive Queries

- Suppose we want to find all bands connected to a fan who likes 'limp bizkit'?

A: korn, nickelback, slipknot



Challenge: each successive join follows one set of edges. Size of graph is unbounded!

Recursive Queries

- Recursive WITH clause can join with itself
- Example: define a table t with one column n, iteratively join with with itself

```
WITH RECURSIVE t(n) AS
( VALUES (1)          ”base case”
UNION
SELECT n+1            Run repeatedly until no change
FROM t WHERE n < 100
)
SELECT sum(n) FROM t;
```

n
1

n
1
2

n
1
2
3

n
1
2
3
4

n
1
2
3
4
5

Recursive Queries

- Suppose we want to find all bands connected to a fan who likes ‘limp bizkit’?

```
WITH recursive lb_fan_bands as (
   SELECT bf_fanid, bf_bandid
   FROM bandfans
   JOIN bands on bf_bandid = bandid
   WHERE bands.name = 'limp bizkit'
UNION
   SELECT bandfans.bf_fanid, bandfans.bf_bandid
   FROM bandfans JOIN lb_fan_bands
   ON (lb_fan_bands.bf_fanid = bandfans.bf_fanid
      OR lb_fan_bands.bf_bandid = bandfans.bf_bandid)
)
SELECT distinct name FROM lb_fan_bands
JOIN bands ON bf_bandid = bandid
WHERE name != 'limp bizkit'
```

Tricky – add new fans of bands we already found and new bands liked by fans we already found

Recursion Example

- Limp bizkit is band 2

bf_bandid	bf_fanid
2	1
3	1
5	2
6	2
2	3
4	3
1	4
4	4

Base case

bf_bandid	bf_fanid
2	1
2	3

```
WITH recursive lb_fan_bands as (
SELECT bf_fanid, bf_bandid
   FROM bandfans
   JOIN bands on bf_bandid = bandid
   WHERE bands.name = 'limp bizkit'
   UNION
   SELECT bandfans.bf_fanid, bandfans.bf_bandid
   FROM bandfans JOIN lb_fan_bands
   ON (lb_fan_bands.bf_fanid = bandfans.bf_fanid
      OR lb_fan_bands.bf_bandid = bandfans.bf_bandid))
```

Recursion Example

- Limp bizkit is band 2

```
WITH recursive lb_fan_bands as (
SELECT bf_fanid, bf_bandid
   FROM bandfans
   JOIN bands on bf_bandid = bandid
   WHERE bands.name = 'limp bizkit'
   UNION
   SELECT bandfans.bf_fanid, bandfans.bf_bandid
   FROM bandfans JOIN lb_fan_bands
   ON (lb_fan_bands.bf_fanid = bandfans.bf_fanid
      OR lb_fan_bands.bf_bandid = bandfans.bf_bandid))
```

bf_bandid	bf_fanid
2	1
3	1
5	2
6	2
2	3
4	3
1	4
4	4

Base case

bf_bandid	bf_fanid
2	1
2	3

Iter 1

bf_bandid	bf_fanid
2	1
2	3

Recursion Example

- Limp bizkit is band 2

```
WITH recursive lb_fan_bands as (
SELECT bf_fanid, bf_bandid
   FROM bandfans
   JOIN bands on bf_bandid = bandid
   WHERE bands.name = 'limp bizkit'
   UNION
   SELECT bandfans.bf_fanid, bandfans.bf_bandid
   FROM bandfans JOIN lb_fan_bands
   ON (lb_fan_bands.bf_fanid = bandfans.bf_fanid
      OR lb_fan_bands.bf_bandid = bandfans.bf_bandid))
```

bf_bandid	bf_fanid
2	1
3	1
5	2
6	2
2	3
4	3
1	4
4	4

Base case

bf_bandid	bf_fanid
2	1
2	3

Iter 1

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3

Recursion Example

- Limp bizkit is band 2

```
WITH recursive lb_fan_bands as (
SELECT bf_fanid, bf_bandid
   FROM bandfans
   JOIN bands on bf_bandid = bandid
   WHERE bands.name = 'limp bizkit'
   UNION
   SELECT bandfans.bf_fanid, bandfans.bf_bandid
   FROM bandfans JOIN lb_fan_bands
   ON (lb_fan_bands.bf_fanid = bandfans.bf_fanid
      OR lb_fan_bands.bf_bandid = bandfans.bf_bandid))
```

bf_bandid	bf_fanid
2	1
3	1
5	2
6	2
2	3
4	3
1	4
4	4

Base case already got these rows

Base case

bf_bandid	bf_fanid
2	1
2	3

Iter 1

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3

Recursion Example

- Limp bizkit is band 2

```
WITH recursive lb_fan_bands as (
SELECT bf_fanid, bf_bandid
   FROM bandfans
   JOIN bands on bf_bandid = bandid
   WHERE bands.name = 'limp bizkit'
   UNION
   SELECT bandfans.bf_fanid, bandfans.bf_bandid
   FROM bandfans JOIN lb_fan_bands
   ON (lb_fan_bands.bf_fanid = bandfans.bf_fanid
      OR lb_fan_bands.bf_bandid = bandfans.bf_bandid))
```

bf_bandid	bf_fanid
2	1
3	1
5	2
6	2
2	3
4	3
1	4
4	4

Iter 1 already got these fans

Base case

bf_bandid	bf_fanid
2	1
2	3

Iter 1

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3

Iter 2

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3

Recursion Example

- Limp bizkit is band 2

```
WITH recursive lb_fan_bands as (
SELECT bf_fanid, bf_bandid
   FROM bandfans
   JOIN bands on bf_bandid = bandid
   WHERE bands.name = 'limp bizkit'
   UNION
   SELECT bandfans.bf_fanid, bandfans.bf_bandid
   FROM bandfans JOIN lb_fan_bands
   ON (lb_fan_bands.bf_fanid = bandfans.bf_fanid
      OR lb_fan_bands.bf_bandid = bandfans.bf_bandid))
```

bf_bandid	bf_fanid
2	1
3	1
5	2
6	2
2	3
4	3
1	4
4	4

Base case

bf_bandid	bf_fanid
2	1
2	3

Iter 1

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3

Iter 2

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3

One new fan found

Recursion Example

- Limp bizkit is band 2

```
WITH recursive lb_fan_bands as (
SELECT bf_fanid, bf_bandid
   FROM bandfans
   JOIN bands on bf_bandid = bandid
   WHERE bands.name = 'limp bizkit'
   UNION
   SELECT bandfans.bf_fanid, bandfans.bf_bandid
   FROM bandfans JOIN lb_fan_bands
   ON (lb_fan_bands.bf_fanid = bandfans.bf_fanid
      OR lb_fan_bands.bf_bandid = bandfans.bf_bandid))
```

bf_bandid	bf_fanid
2	1
3	1
5	2
6	2
2	3
4	3
1	4
4	4

Base case

bf_bandid	bf_fanid
2	1
2	3

Iter 1

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3

Iter 2

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3
4	4

Recursion Example

- Limp bizkit is band 2

```
WITH recursive lb_fan_bands as (
SELECT bf_fanid, bf_bandid
   FROM bandfans
   JOIN bands on bf_bandid = bandid
   WHERE bands.name = 'limp bizkit'
   UNION
   SELECT bandfans.bf_fanid, bandfans.bf_bandid
   FROM bandfans JOIN lb_fan_bands
   ON (lb_fan_bands.bf_fanid = bandfans.bf_fanid
      OR lb_fan_bands.bf_bandid = bandfans.bf_bandid))
```

bf_bandid	bf_fanid
2	1
3	1
5	2
6	2
2	3
4	3
1	4
4	4

Base case

bf_bandid	bf_fanid
2	1
2	3

Iter 2

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3
4	4

One new band found

Iter 3

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3
4	4

Recursion Example

- Limp bizkit is band 2

```
WITH recursive lb_fan_bands as (
SELECT bf_fanid, bf_bandid
   FROM bandfans
   JOIN bands on bf_bandid = bandid
   WHERE bands.name = 'limp bizkit'
   UNION
   SELECT bandfans.bf_fanid, bandfans.bf_bandid
   FROM bandfans JOIN lb_fan_bands
   ON (lb_fan_bands.bf_fanid = bandfans.bf_fanid
      OR lb_fan_bands.bf_bandid = bandfans.bf_bandid))
```

bf_bandid	bf_fanid
2	1
3	1
5	2
6	2
2	3
4	3
1	4
4	4

At this point all bands have been found!
Recursion stops when no new records found.

Base case

bf_bandid	bf_fanid
2	1
2	3

Iter 2

bf_bandid	bf_fanid
2	1
2	3
3	1
4	3
4	4

Iter 3

bf_bandid	bf_fanid	
2	1	*limp bizkit*
2	3	
3	1	*korn*
4	3	*nickelback*
4	4	
1	4	*slipknot*

Take a Break

Database Tuning Primer

- Sometimes queries don't run as fast as you would like
- Need to "tune" the database to run faster

- Unlike SQL, most tuning is very specific to the database you are using
  - Many different databases out there, e.g., MySQL, Postgres, Oracle, SQLite, SQLServer (aka AzureDB), Redshift, Snowflake, etc

- Before we explore some of the most common ways to tune, let's understand why a query may be slow

If you want to understand this in more detail, take 6.814/6.830!

Analytics vs Transactions

- **Analytics** is more typical of data science
  - E.g., dashboards or ad-hoc queries looking at trends and aggregates
  - Queries often read a significant amount of data (> 1% of DB?)
  - Updates are infrequent / batch
  - Focus is on minimizing the amount of data we need to read, and ensuring sufficient memory/resources for expensive operations like sorts & joins

Focus in this class

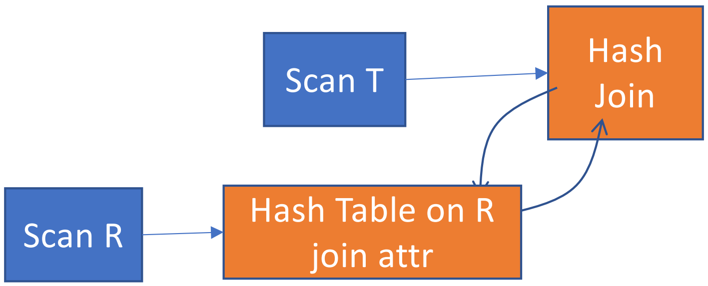
- **Transactions** are common in websites, other online applications
  - Create, Read, Update, Delete (CRUD) workload
  - Less complex queries (often "key/value" is sufficient)
  - Requires mechanisms to prevent concurrent updates to same data
  - Focus is on eliminating contention in these mechanisms, ensuring queries are indexed

Where Does Time Go?

- In analytics applications, CPU + I/O dominate
- CPU: instructions to compute results
  - Most typically the time to join tables
- I/O: transferring data from disk
  - Most typically reading data from tables or moving data to / from memory when results don't fit into RAM

Example

- Joining a 1 GB table T to a 100 MB table R
- 10 Bytes / record (so T = 100M records, R = 10M records)
- System can process 100M records / sec
- Disk can read 100 MB/sec
- 200 MB of memory



- Executing join:
  - Load R into a hash table (1 sec I/O + 0.1 sec to process 10M records)
  - Scan through T, looking up each record in hash table (10 sec I/O, + 1 sec to process 100M records)
  - Total time 12.1 sec

Tuning Goal

- Reduce the number of and size of records read and processed
- Ensure that we have sufficient memory for joins and other operations
  - If neither join result can fit into memory system falls back on much slower implementations that shuffle data to / from disk
  - Surprisingly, database systems still answer queries when tables are larger than memory!
    - Fall back on “external” implementations

Bandfans example

- Created a larger fake version of bandfans
  - 1M likes
  - 800 fans
  - 100K bands

Understanding Database Plans

- Most database systems provide an "explain" command that shows how it executes a query

  EXPLAIN SELECT count(*)
  FROM bandfans JOIN bands ON bf_bandid = bandid
  WHERE name = 'limp bizkit'

This query takes 80ms to execute
Not slow, but this isn't a large DB, and could be painful if we have to run many times

Example: POSTGRES

```
Aggregate  (cost=18210.82..18210.83 rows=1 width=8)
   ->  Hash Join  (cost=4.60..18204.60 rows=2489 width=0)
         Hash Cond: (bandfans.bf_bandid = bands.bandid)
         ->  Seq Scan on bandfans  (cost=0.00..14425.08 rows=1000008 width=4)
         ->  Hash  (cost=4.59..4.59 rows=1 width=4)
               ->  Seq Scan on bands  (cost=0.00..4.59 rows=1 width=4)
                     Filter: ((name)::text = 'limp bizkit'::text)
```

Parse tree
Read bottom up

Understanding Database Plans

- Most database systems provide an "explain" command that shows how it executes a query

  EXPLAIN SELECT count(*)
  FROM bandfans JOIN bands ON bf_bandid = bandid
  WHERE name = 'limp bizkit'

Scan Bands (name = 'limp bizkit')

Example: POSTGRES

```
Aggregate  (cost=18210.82..18210.83 rows=1 width=8)
   ->  Hash Join  (cost=4.60..18204.60 rows=2489 width=0)
         Hash Cond: (bandfans.bf_bandid = bands.bandid)
         ->  Seq Scan on bandfans  (cost=0.00..14425.08 rows=1000008 width=4)
         ->  Hash  (cost=4.59..4.59 rows=1 width=4)
               ->  Seq Scan on bands  (cost=0.00..4.59 rows=1 width=4)
                     Filter: ((name)::text = 'limp bizkit'::text)
```

Understanding Database Plans

- Most database systems provide an "explain" command that shows how it executes a query

  EXPLAIN SELECT count(*)
  FROM bandfans JOIN bands ON bf_bandid = bandid
  WHERE name = 'limp bizkit'

Example: POSTGRES

Scan Bands (name = 'limp bizkit')

Estimated time and number of rows
Time units are arbitrary
Two numbers: time to produce 1st record .. time to produce last record

Here time is a combination of CPU + I/O

```
Aggregate  (cost=18210.82..18210.83 rows=1 width=8)
   ->  Hash Join  (cost=4.60..18204.60 rows=2489 width=0)
         Hash Cond: (bandfans.bf_bandid = bands.bandid)
         ->  Seq Scan on bandfans  (cost=0.00..14425.08 rows=1000008 width=4)
         ->  Hash  (cost=4.59..4.59 rows=1 width=4)
               ->  Seq Scan on bands  (cost=0.00..4.59 rows=1 width=4)
                     Filter: ((name)::text = 'limp bizkit'::text)
```

Understanding Database Plans

- Most database systems provide an "explain" command that shows how it executes a query

  EXPLAIN SELECT count(*)

  FROM bandfans JOIN bands ON bf_bandid = bandid

  WHERE name = 'limp bizkit'

Example: POSTGRES

Scan Bands (name = 'limp bizkit')

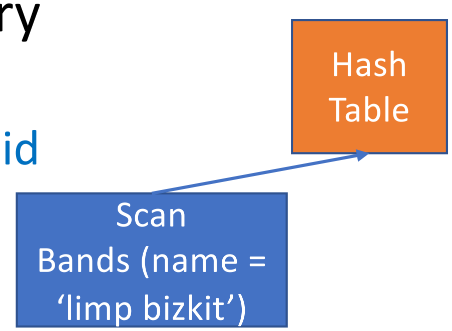
```
Aggregate  (cost=18210.82..18210.83 rows=1 width=8)
   ->  Hash Join  (cost=4.60..18204.60 rows=2489 width=0)
         Hash Cond: (bandfans.bf_bandid = bands.bandid)
         ->  Seq Scan on bandfans  (cost=0.00..14425.08 rows=1000008 width=4)
         ->  Hash  (cost=4.59..4.59 rows=1 width=4)
               ->  Seq Scan on bands  (cost=0.00..4.59 rows=1 width=4)
                     Filter: ((name)::text = 'limp bizkit'::text)
```

Most expensive steps

Understanding Database Plans

- Most database systems provide an "explain" command that shows how it executes a query

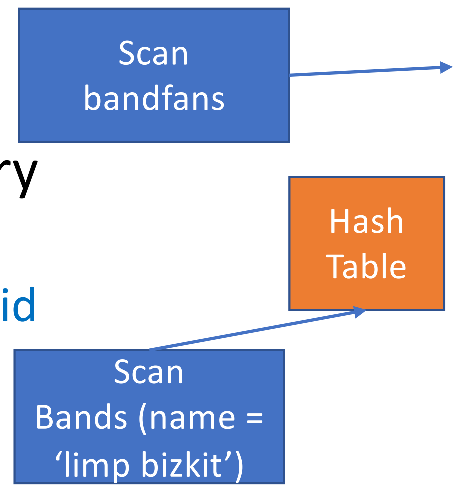
  EXPLAIN SELECT count(*)
  FROM bandfans JOIN bands ON bf_bandid = bandid
  WHERE name = 'limp bizkit'



Example: POSTGRES

```
Aggregate  (cost=18210.82..18210.83 rows=1 width=8)
   ->  Hash Join  (cost=4.60..18204.60 rows=2489 width=0)
         Hash Cond: (bandfans.bf_bandid = bands.bandid)
         ->  Seq Scan on bandfans  (cost=0.00..14425.08 rows=1000008 width=4)
         ->  Hash  (cost=4.59..4.59 rows=1 width=4)
               ->  Seq Scan on bands  (cost=0.00..4.59 rows=1 width=4)
                     Filter: ((name)::text = 'limp bizkit'::text)
```

Understanding Database Plans



- Most database systems provide an "explain" command that shows how it executes a query

  EXPLAIN SELECT count(*)

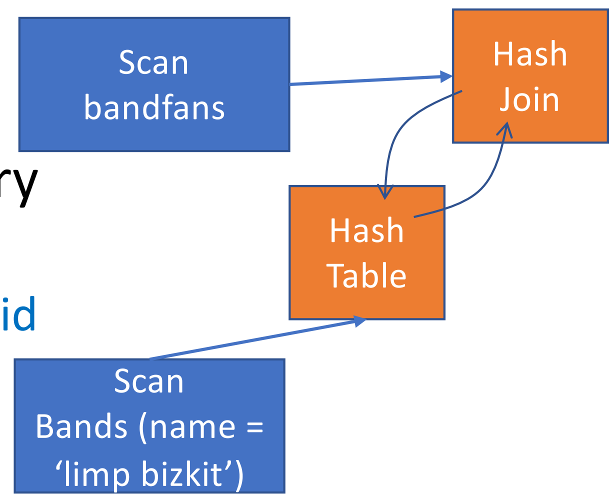
  FROM bandfans JOIN bands ON bf_bandid = bandid

  WHERE name = 'limp bizkit'

Example: POSTGRES

```
Aggregate  (cost=18210.82..18210.83 rows=1 width=8)
   ->  Hash Join  (cost=4.60..18204.60 rows=2489 width=0)
         Hash Cond: (bandfans.bf_bandid = bands.bandid)
         ->  Seq Scan on bandfans  (cost=0.00..14425.08 rows=1000008 width=4)
         ->  Hash  (cost=4.59..4.59 rows=1 width=4)
               ->  Seq Scan on bands  (cost=0.00..4.59 rows=1 width=4)
                     Filter: ((name)::text = 'limp bizkit'::text)
```

Understanding Database Plans



- Most database systems provide an "explain" command that shows how it executes a query

  EXPLAIN SELECT count(*)

  FROM bandfans JOIN bands ON bf_bandid = bandid

  WHERE name = 'limp bizkit'

Example: POSTGRES

```
Aggregate  (cost=18210.82..18210.83 rows=1 width=8)
   ->  Hash Join  (cost=4.60..18204.60 rows=2489 width=0)
         Hash Cond: (bandfans.bf_bandid = bands.bandid)
         ->  Seq Scan on bandfans  (cost=0.00..14425.08 rows=1000008 width=4)
         ->  Hash  (cost=4.59..4.59 rows=1 width=4)
               ->  Seq Scan on bands  (cost=0.00..4.59 rows=1 width=4)
                     Filter: ((name)::text = 'limp bizkit'::text)
```

How Can We Make This Faster?

- Goal: Reduce amount of data read
- What about just scanning bands rows that correspond to ‘limp bizkit’?
  - Index on bands.name
- Could we just scan the bandfans rows that correspond to ‘limp bizkit’?
  - Index on bandfans.bandid

Creating An Index

- CREATE INDEX band_name ON bands(name);
- CREATE INDEX bf_index ON bandfans(bf_bandid);

B-Tree Index Example (B=2)

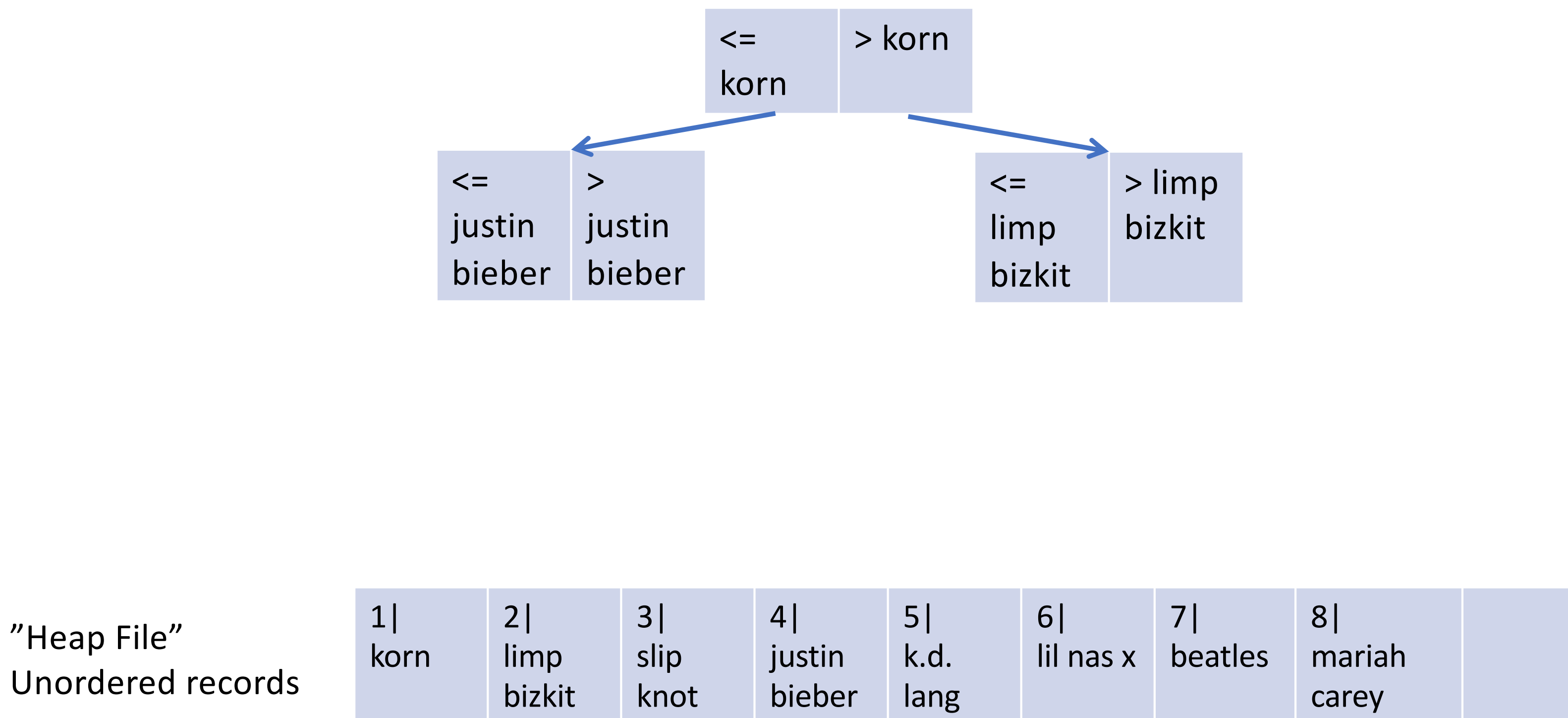
"Heap File" Unordered records	1| korn	2| limp bizkit	3| slip knot	4| justin bieber	5| k.d. lang	6| lil nas x	7| beatles	8| mariah carey	

B-Tree Index Example (B=2)

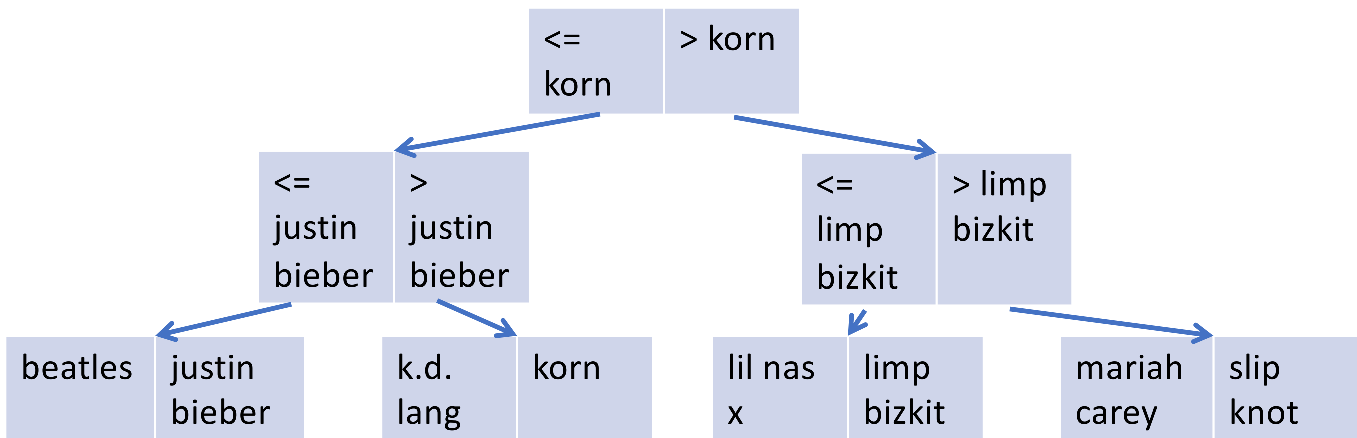
<= korn	> korn

”Heap File” Unordered records	1| korn	2| limp bizkit	3| slip knot	4| justin bieber	5| k.d. lang	6| lil nas x	7| beatles	8| mariah carey	

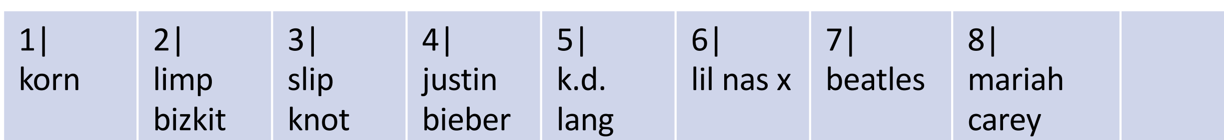
B-Tree Index Example (B=2)



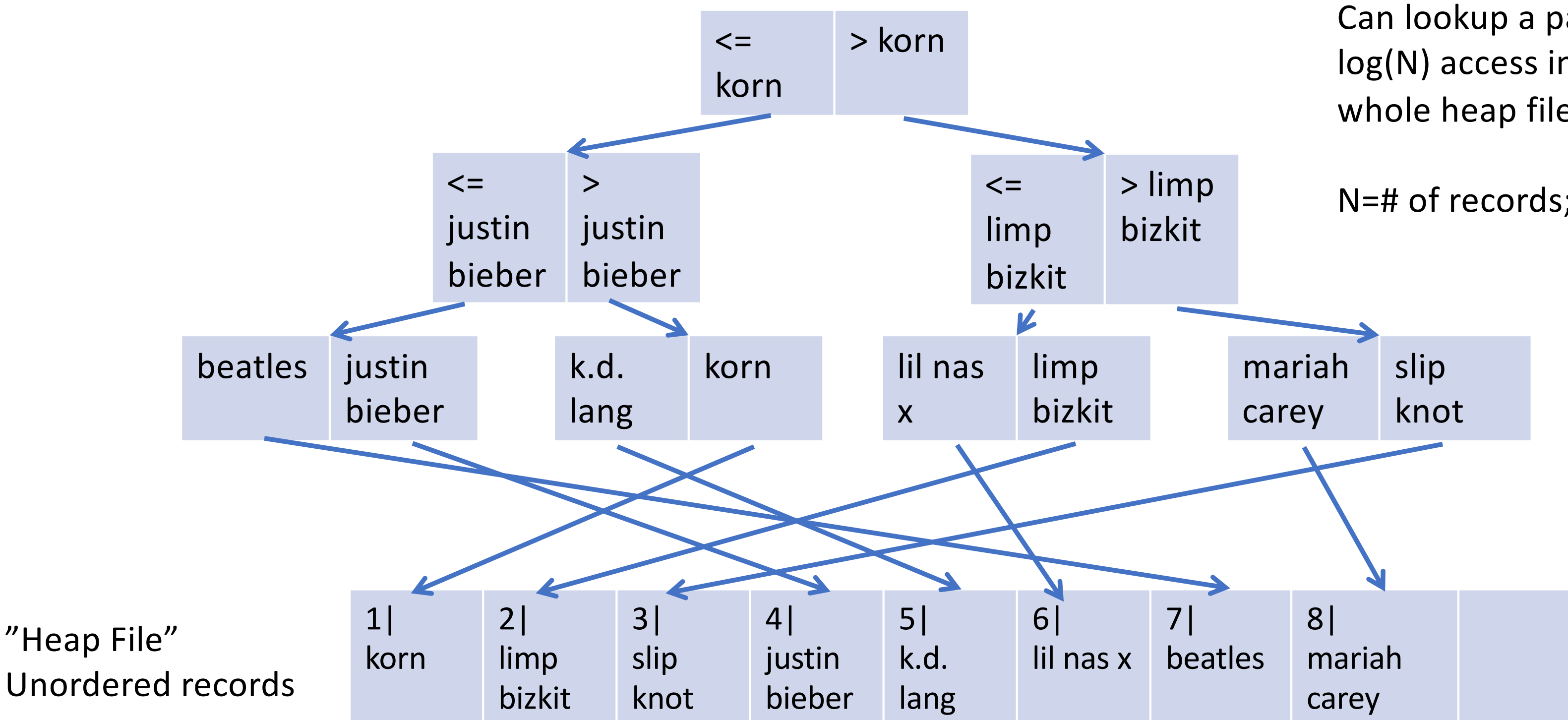
B-Tree Index Example (B=2)



”Heap File”
Unordered records



B-Tree Index Example (B=2)

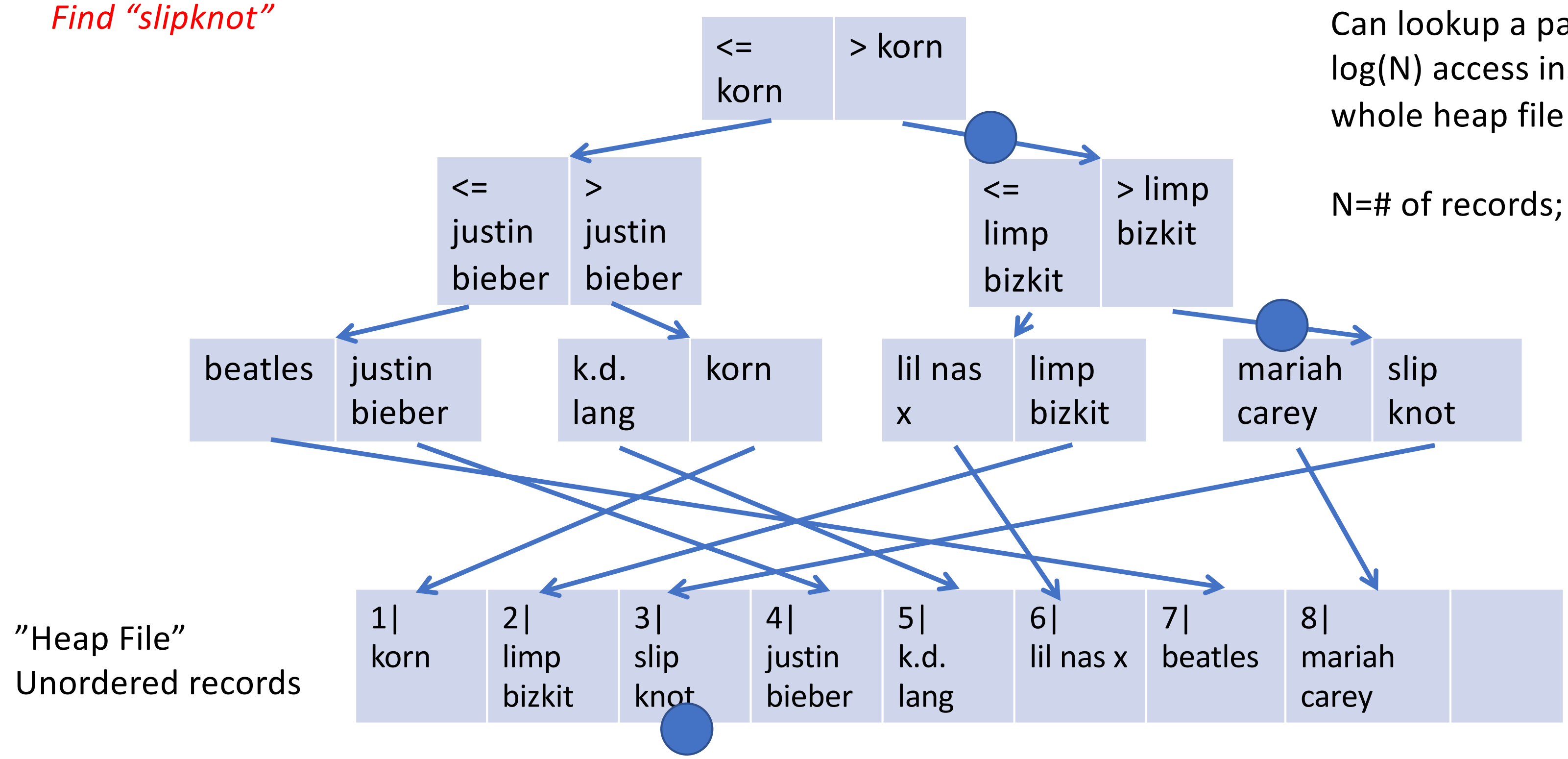


Can lookup a particular record in log(N) access instead of scanning whole heap file

N=# of records; base of log is B

B-Tree Index Example (B=2)

Find "slipknot"



Can lookup a particular record in log(N) access instead of scanning whole heap file

N=# of records; base of log is B

Pros and Cons of Indexing

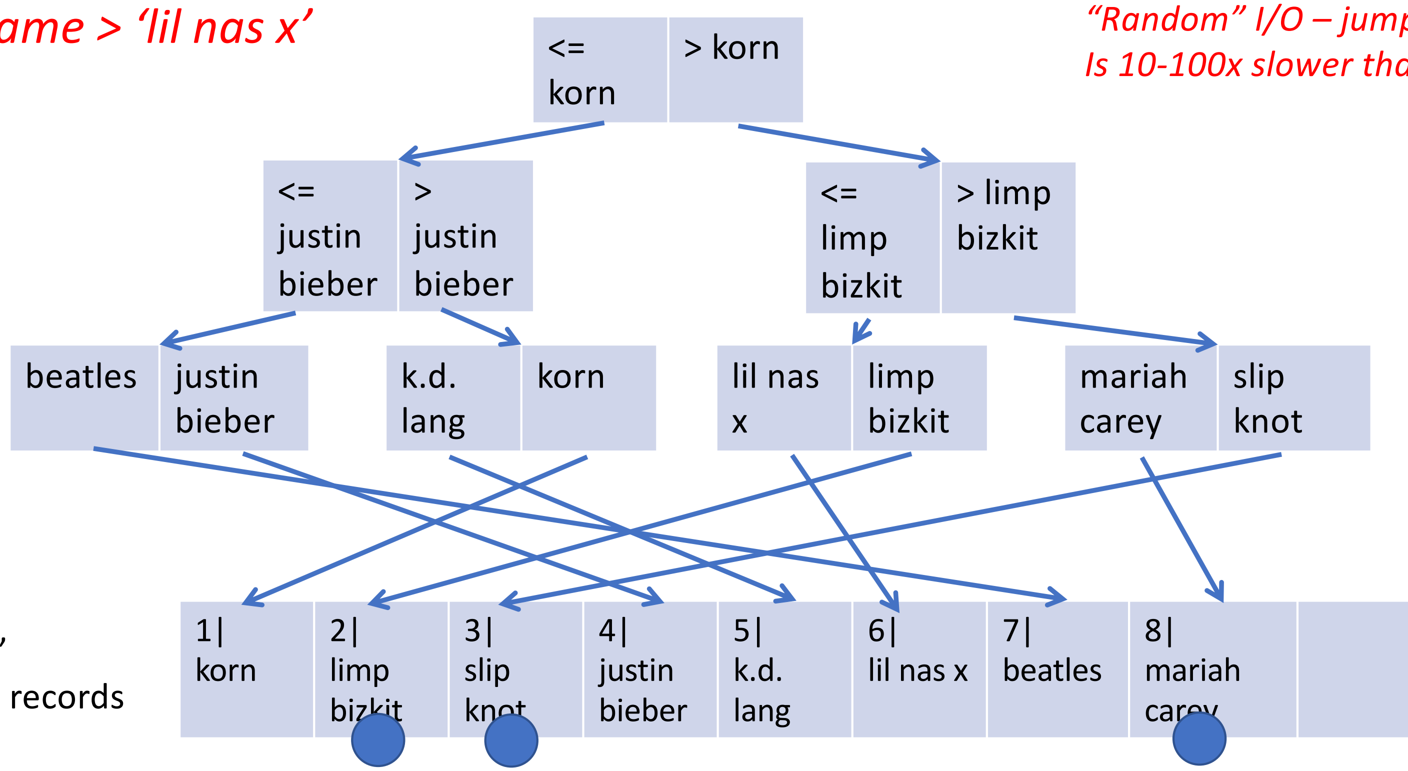
- Pros:
  - Reduces time to lookup specific records

- Cons:
  - Uses space
  - Increases insert time
  - If heap file isn't ordered on index, may not speed up I/O

B-Tree Index Example (B=2)

Find name > 'lil nas x'

"Random" I/O – jumping around on disk
Is 10-100x slower than reading in order

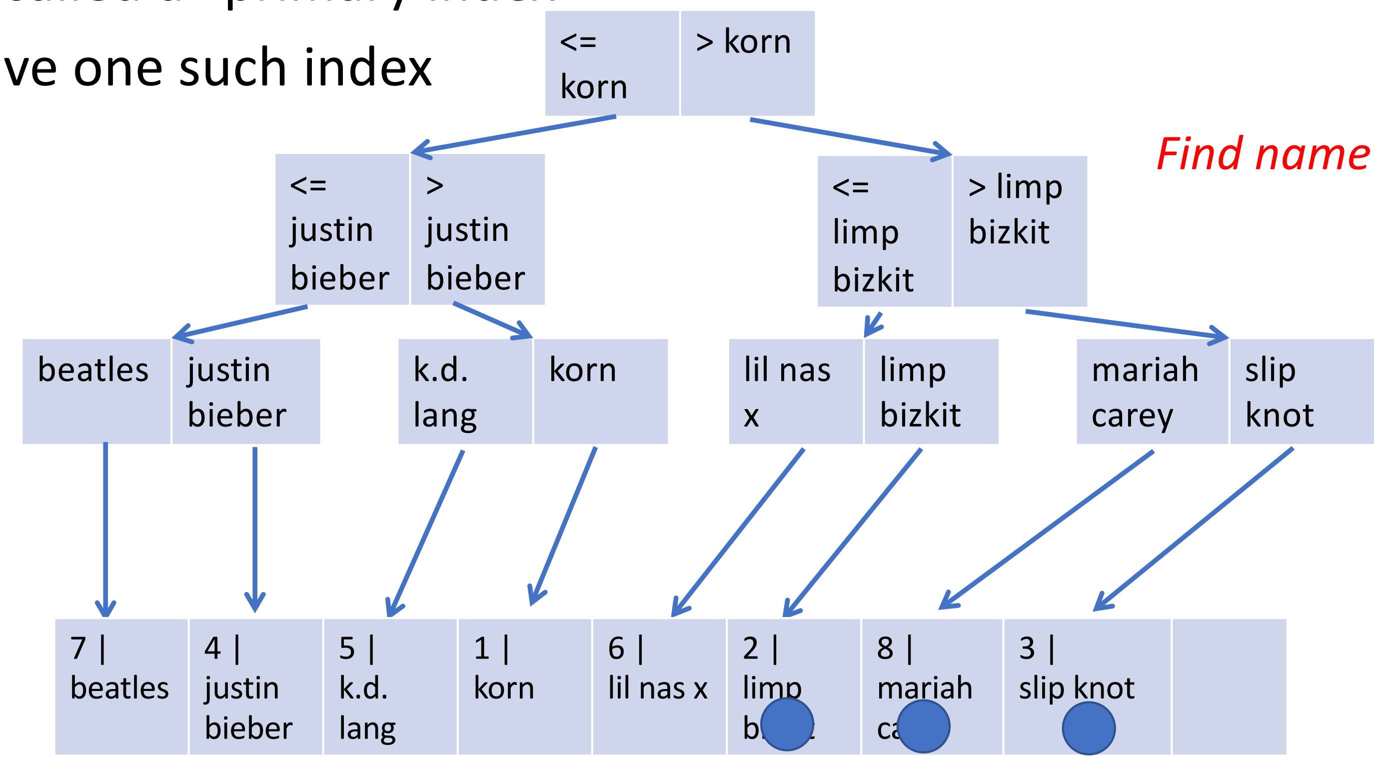


"Heap File"
Unordered records

“Clustering” a B-Tree

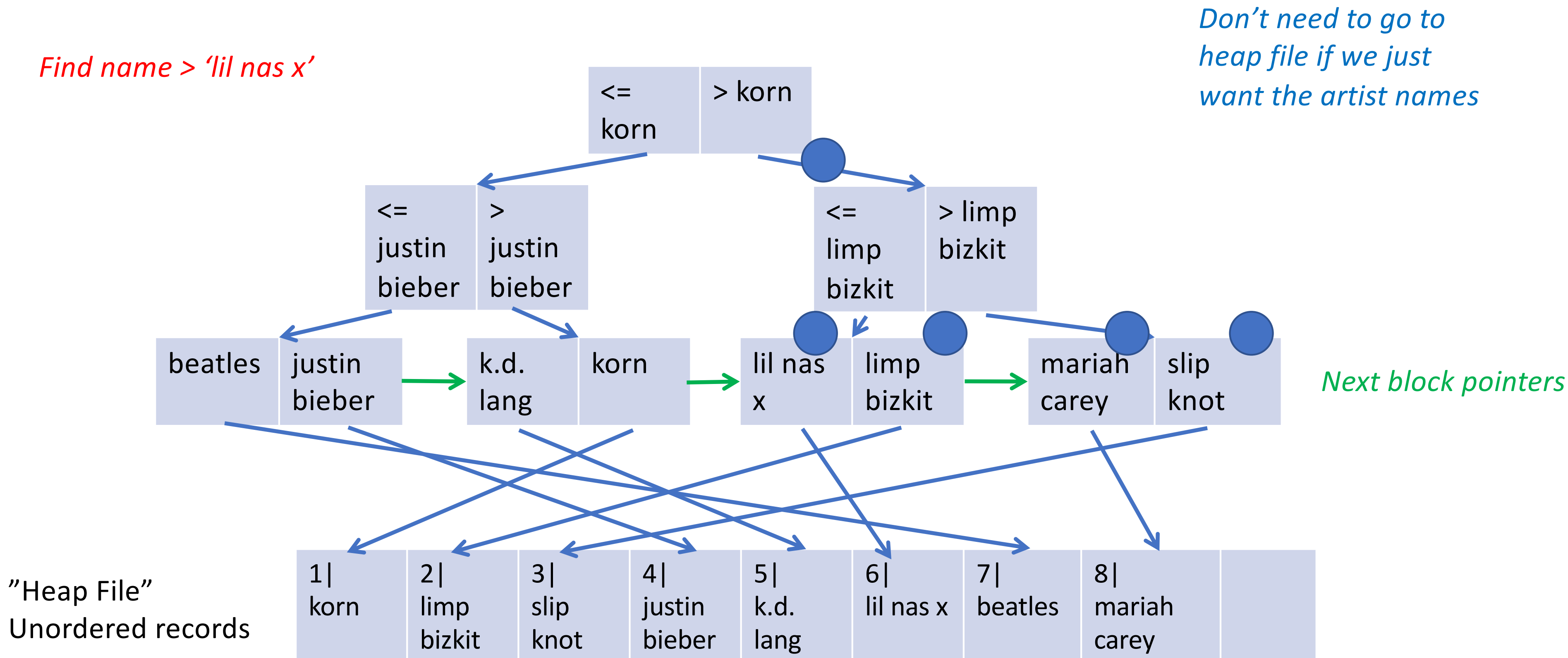
- Records are in order of index
- Alternately called a “primary index”
- Can only have one such index

How this is done is DB specific.



Find name > ‘lil nas x’

Index-Only Scans



Postgres

create index bf_index on bandfans(bf_bandid);

EXPLAIN SELECT count(*)
FROM bandfans JOIN bands ON bf_bandid = bandid
WHERE name = 'limp bizkit’

```
Aggregate  (cost=2162.44..2162.45 rows=1 width=8)
  ->  Nested Loop  (cost=0.42..2162.36 rows=30 width=0)
        ->  Seq Scan on bands  (cost=0.00..1918.84 rows=3 width=4)
              Filter: ((name)::text = 'limp bizkit'::text)
        ->  Index Only Scan using bf_index on bandfans  (cost=0.42..56.17 rows=2500 width=4)
              Index Cond: (bf_bandid = bands.bandid)
```

Find limp bizkit record by scanning bands

Postgres

create index bf_index on bandfans(bf_bandid);

Estimated cost 2000 vs 12000
Actual 8ms vs 80ms

EXPLAIN SELECT count(*)
FROM bandfans JOIN bands ON bf_bandid = bandid
WHERE name = 'limp bizkit’

```
Aggregate  (cost=2162.44..2162.45 rows=1 width=8)
  ->  Nested Loop  (cost=0.42..2162.36 rows=30 width=0)
        ->  Seq Scan on bands  (cost=0.00..1918.84 rows=3 width=4)
              Filter: ((name)::text = 'limp bizkit'::text)
        ->  Index Only Scan using bf_index on bandfans  (cost=0.42..56.17 rows=2500 width=4)
              Index Cond: (bf_bandid = bands.bandid)
```

For each limp bizkit record (3 estimated)

Do an index only scan to count the number of fans

Don’t need to go to records at all since index keys have bandid

Postgres

create index bf_index on bandfans(bf_bandid);
create index band_name on bands(name);

EXPLAIN SELECT count(*)
FROM bandfans JOIN bands ON bf_bandid = bandid
WHERE name = 'limp bizkit'

Estimated cost 260 vs 2000 vs 12000
Actual .5 ms vs 8 ms vs 80 ms

160x speedup!

Use index to directly lookup 'limp bizket'

```
Aggregate  (cost=259.94..259.95 rows=1 width=8)
  ->  Nested Loop  (cost=0.72..259.87 rows=30 width=0)
        ->  Index Scan using band_name on bands  (cost=0.29..16.34 rows=3 width=4)
              Index Cond: ((name)::text = 'limp bizkit'::text)
        ->  Index Only Scan using bf_index on bandfans  (cost=0.42..56.17 rows=2500 width=4)
              Index Cond: (bf_bandid = bands.bandid)
```

Today's Reading

- Critique of SQL
- Some specific complaints about, e.g.,
  - json and windowing support
  - Verbose join syntax
  - Pitfalls around, e.g., subqueries
- More generally:
  - Lack of standards for extensions, e.g., new types or procedural support
  - New features, e.g., json and windows, are added via new syntax, rather than libraries as in most languages
    - Massive spec, very complex to support, huge burden on developers

Against SQL

Published 2021-07-09

Recap: Some Common Data Access Themes

- SQL provides a powerful set-oriented way to get the data you want
- Joins are the crux of data access and primary performance concern
- To speed up queries, “read what you need”
  - Indexing & Index-only Scans
  - Predicate pushdown
    - E.g., using an index to find ‘limp bizkit’ records
  - Column-orientation
    - More on this later – we can physically organize data to avoid reading parts of records we don’t need

Next Time

- Pandas / Python
- When to use SQL vs Python