

# The why of databases

# Numbers every programmer should know

Task	Timing (ns)	Timing (μs)
L1 cache reference	0.5	
L2 cache reference	7	
Main memory reference	100	0.1
Random seek SSD	150,000	150
Read 1 MB sequentially from memory	250,000	250
Read 1 MB sequentially from SSD	1,000,000	1,000
Disk seek	10,000,000	10,000
Read 1 MB sequentially from disk	20,000,000	20,000
Send packet CA->Netherlands->CA	150,000,000	150,000

From [jboner/latency.txt](#) & [sirupsen/napkin-math](#)

Jeff Dean's original talk

# Implications for big data

Lets imagine we have a 10 GB flat data file and that we want to select certain rows based on a particular criteria. This requires a sequential read across the entire data set.

If we can store the file in memory:

- $10 \text{ } GB \times (250 \text{ } \mu\text{s}/1 \text{ } MB) = 2.5 \text{ seconds}$

If we have to access the file from SSD:

- $10 \text{ } GB \times (1 \text{ } ms/1 \text{ } MB) = 10 \text{ seconds}$

If we have to access the file from disk:

- $10 \text{ } GB \times (20 \text{ } ms/1 \text{ } MB) = 200 \text{ seconds}$

This is just for reading sequential data, if we make any modifications (writing) or the data is

# Blocks

Cost: Disk << SSD <<< Memory

Speed: Disk <<< SSD << Memory

So usually possible to grow our disk storage to accommodate our data. However, memory is usually the limiting resource, and if we can't fit everything into memory?

Create blocks - group related data (i.e. rows) and read in multiple rows at a time. Optimal size will depend on the task and the properties of the disk.

# Linear vs Binary Search

Even with blocks, any kind of querying / subsetting of rows requires a linear search, which requires  $O(N)$  accesses where  $N$  is the number of blocks.

We can do much better if we are careful about how we structure our data, specifically sorting some or all of the columns.

- Sorting is expensive,  $O(M \log N)$ , but it only needs to be done once.
- After sorting, we can use a binary search for any subsetting tasks (  $O(\log N)$  ).
- These "sorted" columns are known as indexes.
- Indexes require additional storage, but usually small enough to be kept in memory while blocks stay on disk.

# Databases

# SQL

Structures Query Language is a special purpose language for interacting with (querying and modifying) these indexed tabular data structures.

- ANSI Standard but with dialect divergence ( MySql, Postgre, sqlite, etc.)
- This functionality maps very closely (but not exactly) with the data manipulation verbs present in dplyr.
- We will see this mapping in more detail next time.
- SQL is likely to be a foundational skill if you go into industry - learn it and put it on your CV

# R & databases - the DBI package

Low level package for interfacing R with Database management systems (DBMS) that provides a common interface to achieve the following functionality:

- connect/disconnect from DB
- create and execute statements in the DB
- extract results/output from statements
- error/exception handling
- information (meta-data) from database objects
- transaction management (optional)

# RSQLite

Provides the implementation necessary to use DBI to interface with an SQLite database.

```
library(RSQLite)
```

this package also loads the necessary DBI functions as well.

Once loaded we can create a connection to our database,

```
con = dbConnect(RSQLite::SQLite(), ":memory:")
str(con)

## Formal class 'SQLiteConnection' [package "RSQLite"] with 5 slots
##  ..@ Id                  :<externalptr>
##  ..@ dbname              : chr ":memory:"
##  ..@ loadable.extensions: logi TRUE
##  ..@ flags               : int 6
##  ..@ vfs                 : chr ""
```

# Example Table

```
employees = data.frame(  
  name = c("Alice", "Bob", "Carol", "Dave", "Eve", "Frank"),  
  email = c("alice@company.com", "bob@company.com",  
           "carol@company.com", "dave@company.com",  
           "eve@company.com", "frank@comany.com"),  
  salary = c(52000, 40000, 30000, 33000, 44000, 37000),  
  dept = c("Accounting", "Accounting", "Sales",  
          "Accounting", "Sales", "Sales"),  
)
```

```
dbWriteTable(con, name = "employees", value = employees)  
## [1] TRUE  
  
dbListTables(con)  
## [1] "employees"
```

# Removing Tables

```
dbWriteTable(con, "employs", employees)
## [1] TRUE

dbListTables(con)
## [1] "employees" "employs"

dbRemoveTable(con, "employs")
## [1] TRUE

dbListTables(con)
## [1] "employees"
```

# Querying Tables

```
(res = dbSendQuery(con, "SELECT * FROM employees"))
## <SQLiteResult>
##   SQL  SELECT * FROM employees
##   ROWS Fetched: 0 [incomplete]
##           Changed: 0

dbFetch(res)
##    name          email salary      dept
## 1 Alice alice@company.com  52000 Accounting
## 2   Bob  bob@company.com  40000 Accounting
## 3 Carol carol@company.com  30000     Sales
## 4  Dave dave@company.com  33000 Accounting
## 5   Eve eve@company.com  44000     Sales
## 6 Frank frank@comany.com  37000     Sales

dbClearResult(res)
## [1] TRUE
```

# Creating empty tables

```
dbCreateTable(con, "iris", iris)

(res = dbSendQuery(con, "select * from iris"))
## <SQLiteResult>
##   SQL  select * from iris
##   ROWS Fetched: 0 [complete]
##       Changed: 0

dbFetch(res)
## [1] Sepal.Length Sepal.Width  Petal.Length Petal.Width  Species
## <0 rows> (or 0-length row.names)
```

```
dbFetch(res) %>% as_tibble()
## # A tibble: 0 × 5
## # ... with 5 variables: Sepal.Length <dbl>, Sepal.Width <dbl>, Petal.Length <dbl>,
## #   Petal.Width <dbl>, Species <chr>

dbClearResult(res)
```

# Adding to tables

```
dbAppendTable(con, name = "iris", value = iris)
## [1] 150
## Warning message:
## Factors converted to character

(res = dbSendQuery(con, "select * from iris"))
## <SQLiteResult>
##   SQL select * from iris
##   ROWS Fetched: 0 [incomplete]
##       Changed: 0

dbFetch(res) %>% as_tibble()
## # A tibble: 150 x 5
##   Sepal.Length Sepal.Width Petal.Length Petal.Width Species
##       <dbl>       <dbl>       <dbl>       <dbl>   <chr>
## 1         5.1        3.5        1.4        0.2  setosa
## 2         4.9        3.0        1.4        0.2  setosa
## 3         4.7        3.2        1.3        0.2  setosa
## 4         4.6        3.1        1.5        0.2  setosa
## 5         5.0        3.6        1.4        0.2  setosa
## 6         5.4        3.9        1.7        0.4  setosa
## 7         4.6        3.4        1.4        0.3  setosa
## 8         5.0        3.4        1.5        0.2  setosa
```

# Ephemeral results

```
res
## <SQLiteResult>
##   SQL  select * from iris
##   ROWS Fetched: 150 [complete]
##           Changed: 0

dbFetch(res) %>% as_tibble()
## # A tibble: 0 x 5
## # ... with 5 variables: Sepal.Length <dbl>, Sepal.Width <dbl>, Petal.Length <dbl>,
## #   Species <chr>

dbClearResult(res)
```

# SQL Queries

# Connecting

```
cr173@trig2 [class_2021_10_19]$ sqlite3 employees.sqlite
SQLite version 3.34.1 2021-01-20 14:10:07
Enter ".help" for usage hints.
Connected to a transient in-memory database.
Use ".open FILENAME" to reopen on a persistent database.
sqlite>
```

# Table information

The following is specific to SQLite

```
sqlite> .tables
```

```
employees
```

```
sqlite> .schema employees
```

```
CREATE TABLE `employees` (
    `name` TEXT,
    `email` TEXT,
    `salary` REAL,
    `dept` TEXT
);
```

```
sqlite> .indices employees
```

# SELECT Statements

```
sqlite> SELECT * FROM employees;
```

```
Alice|alice@company.com|52000.0|Accounting
Bob|bob@company.com|40000.0|Accounting
Carol|carol@company.com|30000.0|Sales
Dave|dave@company.com|33000.0|Accounting
Eve|eve@company.com|44000.0|Sales
Frank|frank@comany.com|37000.0|Sales
```

# Pretty Output

We can make this table output a little nicer with some additional SQLite options:

```
sqlite> .mode column  
sqlite> .headers on
```

```
sqlite> SELECT * FROM employees;
```

name	email	salary	dept
Alice	alice@company.com	52000.0	Accounting
Bob	bob@company.com	40000.0	Accounting
Carol	carol@company.com	30000.0	Sales
Dave	dave@company.com	33000.0	Accounting
Eve	eve@company.com	44000.0	Sales
Frank	frank@comany.com	37000.0	Sales

# select using SELECT

We can subset for certain columns (and rename them) using SELECT

```
sqlite> SELECT name AS first_name, salary FROM employees;
```

first_name	salary
Alice	52000.0
Bob	40000.0
Carol	30000.0
Dave	33000.0
Eve	44000.0
Frank	37000.0

# arrange using ORDER BY

We can sort our results by adding ORDER BY to our SELECT statement

```
sqlite> SELECT name AS first_name, salary FROM employees ORDER BY salary;
```

first_name	salary
Carol	30000.0
Dave	33000.0
Frank	37000.0
Bob	40000.0
Eve	44000.0
Alice	52000.0

We can sort in the opposite order by adding DESC

```
SELECT name AS first_name, salary FROM employees ORDER BY salary DESC;
```

first_name	salary
Alice	52000.0
Eve	44000.0
Bob	40000.0
Frank	37000.0
Dave	33000.0
Carol	30000.0

# filter via WHERE

We can filter rows by adding WHERE to our statements

```
sqlite> SELECT * FROM employees WHERE salary < 40000;
```

name	email	salary	dept
Carol	carol@company.com	30000.0	Sales
Dave	dave@company.com	33000.0	Accounting
Frank	frank@comany.com	37000.0	Sales

```
sqlite> SELECT * FROM employees WHERE salary < 40000 AND dept = "Sales";
```

name	email	salary	dept
Carol	carol@company.com	30000.0	Sales
Frank	frank@comany.com	37000.0	Sales

# group\_by via GROUP BY

We can create groups for the purpose of summarizing using GROUP BY. As with dplyr it is not terribly useful by itself.

```
sqlite> SELECT * FROM employees GROUP BY dept;
```

name	email	salary	dept
Dave	dave@company.com	33000.0	Accounting
Frank	frank@comany.com	37000.0	Sales

```
sqlite> SELECT dept, COUNT(*) AS n FROM employees GROUP BY dept;
```

dept	n
Accounting	3
Sales	3

# head via LIMIT

We can limit the number of rows we get by using `LIMIT` and order results with `ORDER BY` with or without `DESC`

```
sqlite> SELECT * FROM employees LIMIT 3;
```

name	email	salary	dept
Alice	alice@company.com	52000.0	Accounting
Bob	bob@company.com	40000.0	Accounting
Carol	carol@company.com	30000.0	Sales

```
sqlite> SELECT * FROM employees ORDER BY name DESC LIMIT 3;
```

name	email	salary	dept
Frank	frank@comany.com	37000.0	Sales
Eve	eve@company.com	44000.0	Sales
Dave	dave@company.com	33000.0	Accounting

# Exercise 1

Using sqlite calculate the following quantities,

1. The total costs in payroll for this company
2. The average salary within each department

# Import CSV files

```
sqlite> .mode csv  
sqlite> .import phone.csv phone  
sqlite> .tables
```

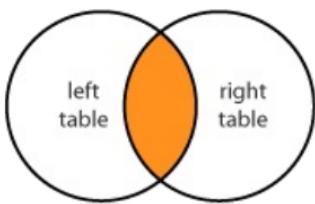
```
employees  phone
```

```
sqlite> .mode column  
sqlite> SELECT * FROM phone;
```

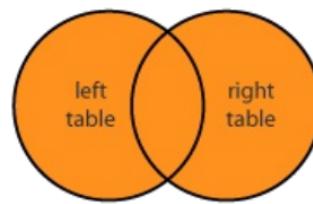
name	phone
Bob	919 555-1111
Carol	919 555-2222
Eve	919 555-3333
Frank	919 555-4444

# SQL Joins

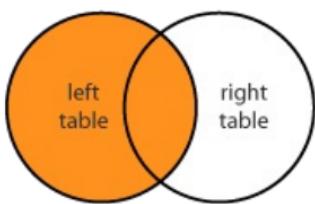
INNER JOIN



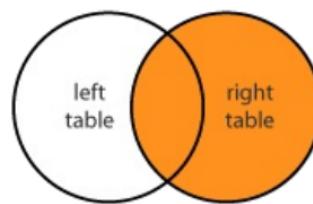
FULL JOIN



LEFT JOIN



RIGHT JOIN



1
2
3

INNER  
JOIN

A
B
C

=

2
3
B

A

1
2
3

LEFT  
JOIN

A
B
C

=

1
2
3

A

B
---

1
2
3

RIGHT  
JOIN

A
B
C

=

2
3
B
C

A

B

C

1
2
3

«FULL»  
JOIN

A
B
C

=

1
2
3

A

B

C

1
2
3

CROSS  
JOIN

A
B
C

=

1	A
1	B
1	C
2	A
2	B
2	C
3	A
3	B
3	C

# Joins - Default

By default SQLite uses a `CROSS JOIN` which is not terribly useful most of the time (similar to R's `expand.grid()`)

```
sqlite> SELECT * FROM employees JOIN phone;
```

name	email	salary	dept	name	phone
Alice	alice@company.com	52000.0	Accounting	Bob	919 555-1111
Alice	alice@company.com	52000.0	Accounting	Carol	919 555-2222
Alice	alice@company.com	52000.0	Accounting	Eve	919 555-3333
Alice	alice@company.com	52000.0	Accounting	Frank	919 555-4444
Bob	bob@company.com	40000.0	Accounting	Bob	919 555-1111
Bob	bob@company.com	40000.0	Accounting	Carol	919 555-2222
Bob	bob@company.com	40000.0	Accounting	Eve	919 555-3333
Bob	bob@company.com	40000.0	Accounting	Frank	919 555-4444
Carol	carol@company.com	30000.0	Sales	Bob	919 555-1111
Carol	carol@company.com	30000.0	Sales	Carol	919 555-2222
Carol	carol@company.com	30000.0	Sales	Eve	919 555-3333
Carol	carol@company.com	30000.0	Sales	Frank	919 555-4444
Dave	dave@company.com	33000.0	Accounting	Bob	919 555-1111
Dave	dave@company.com	33000.0	Accounting	Carol	919 555-2222
Dave	dave@company.com	33000.0	Accounting	Eve	919 555-3333
Dave	dave@company.com	33000.0	Accounting	Frank	919 555-4444

# Inner Join

If you want SQLite to find the columns to merge on automatically then we prefix the join with NATURAL.

```
sqlite> SELECT * FROM employees NATURAL JOIN phone;
```

name	email	salary	dept	phone
Bob	bob@company.com	40000.0	Accounting	919 555-1111
Carol	carol@company.c	30000.0	Sales	919 555-2222
Eve	eve@company.com	44000.0	Sales	919 555-3333
Frank	frank@comany.co	37000.0	Sales	919 555-4444

# Inner Join - Explicit

```
sqlite> SELECT * FROM employees JOIN phone ON employees.name = phone.name;
```

name	email	salary	dept	name	phone
Bob	bob@company.com	40000.0	Accounting	Bob	919 555-1111
Carol	carol@company.c	30000.0	Sales	Carol	919 555-2222
Eve	eve@company.com	44000.0	Sales	Eve	919 555-3333
Frank	frank@comany.co	37000.0	Sales	Frank	919 555-4444

to avoid the duplicate name column we can use USING instead of ON

```
sqlite> SELECT * FROM employees JOIN phone USING(name);
```

name	email	salary	dept	phone
Bob	bob@company.com	40000.0	Accounting	919 555-1111
Carol	carol@company.com	30000.0	Sales	919 555-2222
Eve	eve@company.com	44000.0	Sales	919 555-3333
Frank	frank@comany.com	37000.0	Sales	919 555-4444

# Left Join - Natural

```
sqlite> SELECT * FROM employees NATURAL LEFT JOIN phone;
```

name	email	salary	dept	phone
Alice	alice@company.com	52000.0	Accounting	
Bob	bob@company.com	40000.0	Accounting	919 555-11
Carol	carol@company.com	30000.0	Sales	919 555-22
Dave	dave@company.com	33000.0	Accounting	
Eve	eve@company.com	44000.0	Sales	919 555-33
Frank	frank@comany.com	37000.0	Sales	919 555-44

# Left Join - Explicit

```
sqlite> SELECT * FROM employees LEFT JOIN phone ON employees.name = phone.name;
```

name	email	salary	dept	name	phone
Alice	alice@company.com	52000.0	Accounting		
Bob	bob@company.com	40000.0	Accounting	Bob	919 555-11
Carol	carol@company.com	30000.0	Sales	Carol	919 555-22
Dave	dave@company.com	33000.0	Accounting		
Eve	eve@company.com	44000.0	Sales	Eve	919 555-33
Frank	frank@comany.com	37000.0	Sales	Frank	919 555-44

As above to avoid the duplicate `name` column we can use `USING`, or can be more selective about our returned columns,

```
SELECT employees.* , phone FROM employees LEFT JOIN phone ON employees.name = phone.name;
```

name	email	salary	dept	phone
Alice	alice@company.com	52000.0	Accounting	
Bob	bob@company.com	40000.0	Accounting	919 555-1111
Carol	carol@company.com	30000.0	Sales	919 555-2222
Dave	dave@company.com	33000.0	Accounting	

# Other Joins

Note that SQLite does not support directly support an OUTER JOIN (e.g a full join in dplyr) or a RIGHT JOIN.

- A RIGHT JOIN can be achieved by switch the two tables (i.e. A right join B is equivalent to B left join A)
- An OUTER JOIN can be achieved via using UNION ALL with both left joins (A on B and B on A)

# Creating an index

```
sqlite> CREATE INDEX index_name ON employees (name);
sqlite> .indices

index_name

sqlite> CREATE INDEX index_name_email ON employees (name,email);
sqlite> .indices

index_name
index_name_email
```

# Subqueries

We can nest tables within tables for the purpose of queries.

```
SELECT * FROM (SELECT * FROM employees NATURAL LEFT JOIN phone) WHERE phone IS NULL;
```

name	email	salary	dept	phone
Alice	alice@company.com	52000.0	Accounting	
Dave	dave@company.com	33000.0	Accounting	

```
sqlite> SELECT * FROM (SELECT * FROM employees NATURAL LEFT JOIN phone) WHERE phone IS NOT NULL;
```

name	email	salary	dept	phone
Bob	bob@company.com	40000.0	Accounting	919 555-1111
Carol	carol@company.c	30000.0	Sales	919 555-2222
Eve	eve@company.com	44000.0	Sales	919 555-3333
Frank	frank@comany.co	37000.0	Sales	919 555-4444

## Excercise 2

Lets try to create a table that has a new column - abv\_avg which contains how much more (or less) than the average, for their department, each person is paid.

Hint - This will require joining a subquery.

`employees.sqlite` is available in the exercises repo.