

# Lec 21 - SQL

**Statistical Programming**

**Sta 323 | Spring 2022**

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# SQL

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

- ANSI Standard but with dialect divergence ( MySql, Postgres, SQLite, etc.)
- This functionality maps very closely (but not exactly) with the data manipulation verbs present in dplyr.
- SQL is likely to be a foundational skill if you go into industry - learn it and put it on your CV

# Connecting via CLI

```
cr173@trig2 [class_2022_04_25]$ sqlite3 employees.sqlite
SQLite version 3.36.0 2021-06-18 18:36:39
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() using 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() using 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() using 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
```

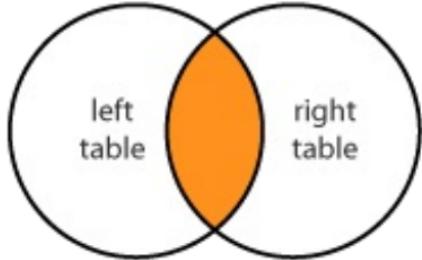
```
employees  phone
```

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

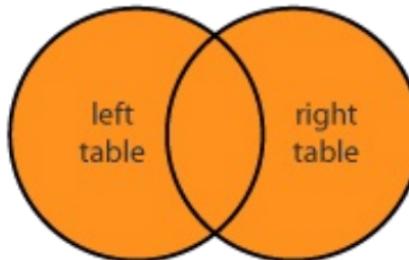
name	phone
Bob	919 555-1111
Carol	919 555-2222
Eve	919 555-3333
Frank	919 555-4444

# SQL Joins

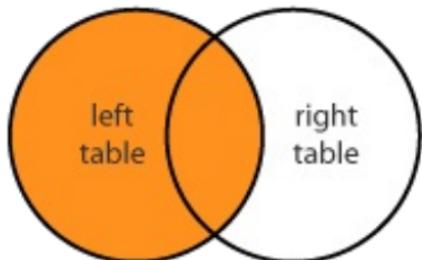
INNER JOIN



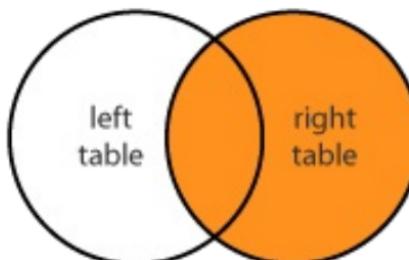
FULL JOIN



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
A
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,

```
sqlite> 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

# 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

## Exercise 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.

# Query performance

# Setup

To give us a bit more variety, we have created another SQLite database `flights.sqlite` that contains both `nycflights13::planes` and `nycflights13::flights`, the latter of which has details on the characteristics of the planes in the dataset as identified by their tail numbers.

```
db = DBI::dbConnect(RSQLite::SQLite(), "flights.sqlite")
dplyr::copy_to(db, nycflights13::flights, name = "flights", temporary = FALSE)
dplyr::copy_to(db, nycflights13::planes, name = "planes", temporary = FALSE)
DBI::dbDisconnect(db)
```

All of the following code will be run in the SQLite command line interface, to make sure you have the database make sure you've created the database and copied both the flights and planes tables into the db.

The database can then be opened from the terminal tab using,

```
sqlite3 flights.sqlite
```

As before we should set a couple of configuration options so that our output is readable, we include .timer on so that we get time our queries.

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

```
sqlite> SELECT * FROM flights LIMIT 10;  
year month day dep_time sched_dep_time dep_delay arr_time sched_arr_time arr_delay carrier flight tailnum origin dest air  
----  
2013 1 1 517 515 2.0 830 819 11.0 UA 1545 N14228 EWR IAH 227  
2013 1 1 533 529 4.0 850 830 20.0 UA 1714 N24211 LGA IAH 227  
2013 1 1 542 540 2.0 923 850 33.0 AA 1141 N619AA JFK MIA 160  
2013 1 1 544 545 -1.0 1004 1022 -18.0 B6 725 N804JB JFK BQN 183  
2013 1 1 554 600 -6.0 812 837 -25.0 DL 461 N668DN LGA ATL 116  
2013 1 1 554 558 -4.0 740 728 12.0 UA 1696 N39463 EWR ORD 150  
2013 1 1 555 600 -5.0 913 854 19.0 B6 507 N516JB EWR FLL 158  
2013 1 1 557 600 -3.0 709 723 -14.0 EV 5708 N829AS LGA IAD 53.  
2013 1 1 557 600 -3.0 838 846 -8.0 B6 79 N593JB JFK MCO 140  
2013 1 1 558 600 -2.0 753 745 8.0 AA 301 N3ALAA LGA ORD 138  
Run Time: real 0.051 user 0.000258 sys 0.000126
```

```
sqlite> SELECT * FROM planes LIMIT 10;  
tailnum year type manufacturer model engines seats speed engine  
----  
N10156 2004 Fixed wing multi engine Embraer EMB-145XR 2 55 Turbo-fan  
N102UW 1998 Fixed wing multi engine AIRBUS INDUSTRIE A320-214 2 182 Turbo-fan  
N103US 1999 Fixed wing multi engine AIRBUS INDUSTRIE A320-214 2 182 Turbo-fan  
N104UW 1999 Fixed wing multi engine AIRBUS INDUSTRIE A320-214 2 182 Turbo-fan  
N10575 2002 Fixed wing multi engine Embraer EMB-145LR 2 55 Turbo-fan
```

## Exercise 3

Write a query that determines the total number of seats available on all of the planes that flew out of New York in 2013.

# Options

Incorrect:

```
sqlite> SELECT sum(seats) FROM flights NATURAL LEFT JOIN planes;  
sum(seats)  
-----  
614366  
Run Time: real 0.148 user 0.139176 sys 0.007804
```

Join and select:

```
sqlite> SELECT sum(seats) FROM flights LEFT JOIN planes USING (tailnum);  
sum(seats)  
-----  
38851317  
Run Time: real 0.176 user 0.167993 sys 0.007354
```

Select then join:

```
sqlite> SELECT sum(seats) FROM (SELECT tailnum FROM flights) LEFT JOIN (SELECT tailnum, seats FROM planes  
sum(seats)
```

# EXPLAIN QUERY PLAN

```
sqlite> EXPLAIN QUERY PLAN SELECT sum(seats) FROM flights LEFT JOIN planes USING (tailnum);
```

QUERY PLAN

```
|--SCAN flights  
`--SEARCH planes USING AUTOMATIC COVERING INDEX (tailnum=?)
```

```
sqlite> EXPLAIN QUERY PLAN SELECT sum(seats) FROM (SELECT tailnum FROM flights) LFET JOIN (SELECT tailnum
```

QUERY PLAN

```
|--MATERIALIZE SUBQUERY 2  
|   '--SCAN planes  
|--SCAN flights  
`--SEARCH SUBQUERY 2 USING AUTOMATIC COVERING INDEX (tailnum=?)
```

Key things to look for:

- SCAN - indicates that a full table scan is occurring
- SEARCH - indicates that only a subset of the table rows are visited
- AUTOMATIC COVERING INDEX - indicates that a temporary index has been created for this query

# Adding indexes

```
sqlite> CREATE INDEX flight_tailnum ON flights (tailnum);
Run Time: real 0.241 user 0.210099 sys 0.027611
```

```
sqlite> CREATE INDEX plane_tailnum ON planes (tailnum);
Run Time: real 0.003 user 0.001407 sys 0.001442
```

```
sqlite> .indexes
flight_tailnum  plane_tailnum
```

# Improvements?

```
sqlite> SELECT sum(seats) FROM flights LEFT JOIN planes USING (tailnum);
sum(seats)
-----
38851317
Run Time: real 0.118 user 0.115899 sys 0.001952
```

```
sqlite> SELECT sum(seats) FROM (SELECT tailnum FROM flights) LEFT JOIN (SELECT tailnum, seats FROM planes
sum(seats)
-----
38851317
Run Time: real 0.131 user 0.129165 sys 0.001214
```

```
sqlite> EXPLAIN QUERY PLAN SELECT sum(seats) FROM flights LEFT JOIN planes USING (tailnum);
QUERY PLAN
|--SCAN flights USING COVERING INDEX flight_tailnum
`--SEARCH planes USING INDEX plane_tailnum (tailnum=?)
```

```
sqlite> EXPLAIN QUERY PLAN SELECT sum(seats) FROM (SELECT tailnum FROM flights) LEFT JOIN (SELECT tailnum
QUERY PLAN
|--MATERIALIZE SUBQUERY 2
| `--SCAN planes
|--SCAN flights USING COVERING INDEX flight_tailnum
```

# Filtering

```
sqlite> SELECT origin, count(*) FROM flights WHERE origin = "EWR";
origin  count(*)
-----
EWR      120835
Run Time: real 0.034 user 0.028124 sys 0.005847
```

```
sqlite> EXPLAIN QUERY PLAN  SELECT origin, count(*) FROM flights WHERE origin = "EWR";
QUERY PLAN
`--SCAN flights
```

```
sqlite> SELECT origin, count(*) FROM flights WHERE origin != "EWR";
origin  count(*)
-----
LGA      215941
Run Time: real 0.036 user 0.029798 sys 0.006171
```

```
sqlite> EXPLAIN QUERY PLAN  SELECT origin, count(*) FROM flights WHERE origin != "EWR";
QUERY PLAN
`--SCAN flights
```

```
sqlite> CREATE INDEX flights_orig_dest ON flights (origin, dest);
Run Time: real 0.267 user 0.232886 sys 0.030270
```

# Filtering w/ indexes

```
sqlite> SELECT origin, count(*) FROM flights WHERE origin = "EWR";  
origin  count(*)  
-----  
EWR      120835
```

Run Time: real 0.007 user 0.006419 sys 0.000159

```
sqlite> SELECT origin, count(*) FROM flights WHERE origin != "EWR";  
origin  count(*)  
-----  
JFK      215941
```

Run Time: real 0.020 user 0.019203 sys 0.000497

```
sqlite> EXPLAIN QUERY PLAN  SELECT origin, count(*) FROM flights WHERE origin = "EWR";  
QUERY PLAN  
`--SEARCH flights USING COVERING INDEX flights_orig_dest (origin=?)
```

```
sqlite> EXPLAIN QUERY PLAN  SELECT origin, count(*) FROM flights WHERE origin != "EWR";  
QUERY PLAN  
`--SCAN flights USING COVERING INDEX flights_orig_dest
```

# != alternative

```
sqlite> SELECT origin, count(*) FROM flights WHERE origin > "EWR" OR origin < "EWR";
origin  count(*)
-----
JFK      215941
Run Time: real 0.022 user 0.021148 sys 0.001290
```

```
sqlite> EXPLAIN QUERY PLAN SELECT origin, count(*) FROM flights WHERE origin > "EWR" OR origin < "EWR";
QUERY PLAN
`--MULTI-INDEX OR
  |--INDEX 1
  |   '--SEARCH flights USING COVERING INDEX flights_orig_dest (origin>?)
  '--INDEX 2
    '--SEARCH flights USING COVERING INDEX flights_orig_dest (origin<?)
```

# What about dest?

```
sqlite> SELECT dest, count(*) FROM flights WHERE dest = "LAX";
dest  count(*)
-----
LAX    16174
Run Time: real 0.017 user 0.016513 sys 0.000237
```

```
sqlite> EXPLAIN QUERY PLAN SELECT dest, count(*) FROM flights WHERE dest = "LAX";
QUERY PLAN
`--SCAN flights USING COVERING INDEX flights_orig_dest
```

```
sqlite> SELECT dest, count(*) FROM flights WHERE dest = "LAX" AND origin = "EWR";
dest  count(*)
-----
LAX    4912
Run Time: real 0.003 user 0.000729 sys 0.000778
```

```
sqlite> EXPLAIN QUERY PLAN  SELECT dest, count(*) FROM flights WHERE dest = "LAX" AND origin = "EWR";
QUERY PLAN
`--SEARCH flights USING COVERING INDEX flights_orig_dest (origin=? AND dest=?)
```

# Group bys

```
sqlite> SELECT carrier, count(*) FROM flights GROUP BY carrier;
```

carrier	count(*)
---------	----------

9E	18460
AA	32729
AS	714
B6	54635
DL	48110
EV	54173
F9	685
FL	3260
HA	342
MQ	26397
OO	32
UA	58665
US	20536
VX	5162
WN	12275
YV	601

```
Run Time: real 0.172 user 0.114274 sys 0.018946
```

```
sqlite> EXPLAIN QUERY PLAN SELECT carrier, count(*) FROM flight
QUERY PLAN
```

```
|--SCAN flights
`--USE TEMP B-TREE FOR GROUP BY
```

```
sqlite> CREATE INDEX flight_carrier ON flights (carrier);
```

```
Run Time: real 0.131 user 0.113260 sys 0.014691
```

```
sqlite> SELECT carrier, count(*) FROM flights GROUP BY carrier;
carrier  count(*)
```

9E	18460
AA	32729
AS	714
B6	54635
DL	48110
EV	54173
F9	685
FL	3260
HA	342
MQ	26397
OO	32
UA	58665
US	20536
VX	5162
WN	12275
YV	601

```
Run Time: real 0.023 user 0.022521 sys 0.000411
```

```
sqlite> EXPLAIN QUERY PLAN SELECT carrier, count(*) FROM flight
QUERY PLAN
```

```
|--SCAN flights USING COVERING INDEX flight_carrier
```

# Why not index all the things?

- As mentioned before, creating an index requires additional storage (memory or disk)
- Additionally, when adding or updating data - indexes also need to be updated, making these processes slower (read vs. write tradeoffs)
- Index order matters - flights (origin, dest), flights (dest, origin) are not the same and similarly are not the same as separate indexes on dest and origin.