

dplyr <-> SQL

Statistical Programming

Fall 2021

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Creating a database

```
(db = DBI::dbConnect(RSQLite::SQLite(), "flights.sqlite"))

## <SQLiteConnection>
##   Path: flights.sqlite
##   Extensions: TRUE

flight_tbl = dplyr::copy_to(db, nycflights13::flights, name = "flights", temporary = FALSE)
flight_tbl

## # Source:  table<flights> [?? x 19]
## # Database: sqlite 3.36.0 [flights.sqlite]
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>   <int>           <int>    <dbl>   <int>           <int>
## 1 2013     1     1      517             515       2     830             819
## 2 2013     1     1      533             529       4     850             830
## 3 2013     1     1      542             540       2     923             850
## 4 2013     1     1      544             545      -1    1004            1022
## 5 2013     1     1      554             600      -6     812             837
## 6 2013     1     1      554             558      -4     740             728
## 7 2013     1     1      555             600      -5     913             854
## 8 2013     1     1      557             600      -3     709             723
## 9 2013     1     1      557             600      -3     838             846
## 10 2013    1     1      558             600      -2     753             745
## # ... with more rows, and 11 more variables: arr_delay <dbl>, carrier <chr>,
```

What have we created?

All of this data now lives in the database on the filesystem not in memory,

```
pryr::object_size(db)
## 2,456 B

pryr::object_size(flight_tbl)
## 6,192 B

pryr::object_size(nycflights13::flights)
## 40,650,048 B

ls -lah *.sqlite
## -rw-r--r-- 1 root root 22M Oct 28 19:35 flights.sqlite
```

What is flight_tbl?

```
class(nycflights13::flights)

## [1] "tbl_df"     "tbl"        "data.frame"

class(flight_tbl)

## [1] "tbl_SQLiteConnection" "tbl_dbi"           "tbl_sql"
## [4] "tbl_lazy"            "tbl"

str(flight_tbl)

## List of 2
## $ src:List of 2
##   ..$ con  :Formal class 'SQLiteConnection' [package "RSQLite"] with 8 slots
##     ... .@ ptr          :<externalptr>
##     ... .@ dbname       : chr "flights.sqlite"
##     ... .@ loadable.extensions: logi TRUE
##     ... .@ flags        : int 70
##     ... .@ vfs          : chr ""
##     ... .@ ref          :<environment: 0x55fb66a28478>
##     ... .@ bigint       : chr "integer64"
##     ... .@ extended_types: logi FALSE
##   ..$ disco: NULL
##   -. attr(*, "class")= chr [1:4] "src_SQLiteConnection" "src_dbi" "src_sql" "src"
```

Accessing existing tables

```
(dplyr::tbl(db, "flights"))
```

```
## # Source:  table<flights> [?? x 19]
## # Database: sqlite 3.36.0 [flights.sqlite]
##   year month   day dep_time sched_dep_time dep_delay arr_time sched_arr_time
##   <int> <int> <int>   <int>           <int>    <dbl>   <int>       <int>
## 1 2013     1     1      517            515        2     830        819
## 2 2013     1     1      533            529        4     850        830
## 3 2013     1     1      542            540        2     923        850
## 4 2013     1     1      544            545       -1    1004       1022
## 5 2013     1     1      554            600       -6     812        837
## 6 2013     1     1      554            558       -4     740        728
## 7 2013     1     1      555            600       -5     913        854
## 8 2013     1     1      557            600       -3     709        723
## 9 2013     1     1      557            600       -3     838        846
## 10 2013    1     1      558            600       -2     753        745
## # ... with more rows, and 11 more variables: arr_delay <dbl>, carrier <chr>,
## #   flight <int>, tailnum <chr>, origin <chr>, dest <chr>, air_time <dbl>,
## #   distance <dbl>, hour <dbl>, minute <dbl>, time_hour <dbl>
```

Using dplyr with sqlite

```
(oct_21 = flight_tbl %>%
  filter(month == 10, day == 21) %>%
  select(origin, dest, tailnum)
)

## # Source:  lazy query [?? x 3]
## # Database: sqlite 3.36.0 [flights.sqlite]
##   origin dest tailnum
##   <chr>  <chr> <chr>
## 1 EWR    CLT   N152UW
## 2 EWR    IAH   N535UA
## 3 JFK    MIA   N5BSAA
## 4 JFK    SJU   N531JB
## 5 JFK    BQN   N827JB
## 6 LGA    IAH   N15710
## 7 JFK    IAD   N825AS
## 8 EWR    TPA   N802UA
## 9 LGA    ATL   N996DL
## 10 JFK   FLL   N627JB
## # ... with more rows
```

```
dplyr::collect(oct_21)
```

```
## # A tibble: 991 × 3
##   origin dest tailnum
##   <chr>  <chr> <chr>
## 1 EWR    CLT   N152UW
## 2 EWR    IAH   N535UA
## 3 JFK    MIA   N5BSAA
## 4 JFK    SJU   N531JB
## 5 JFK    BQN   N827JB
## 6 LGA    IAH   N15710
## 7 JFK    IAD   N825AS
## 8 EWR    TPA   N802UA
## 9 LGA    ATL   N996DL
## 10 JFK   FLL   N627JB
## # ... with 981 more rows
```

Laziness

`dplyr / dbplyr` uses lazy evaluation as much as possible, particularly when working with non-local backends.

- When building a query, we don't want the entire table, often we want just enough to check if our query is working / makes sense.
- Since we would prefer to run one complex query over many simple queries, laziness allows for verbs to be strung together.
- Therefore, by default `dplyr`
 - won't connect and query the database until absolutely necessary (e.g. `show output`),
 - and unless explicitly told to, will only query a handful of rows to give a sense of what the result will look like.
 - we can force evaluation via `compute()`, `collect()`, or `collapse()`

A crude benchmark

```
system.time({
  oct_21 = flight_tbl %>%
    filter(month == 10, day == 21) %>%
    select(origin, dest, tailnum)
  )
})

##      user  system elapsed
##  0.005   0.000   0.006
```

```
system.time({
  print(oct_21) %>%
    capture.output() %>%
    invisible()
})

##      user  system elapsed
##  0.046   0.000   0.046
```

```
system.time({
  dplyr::collect(oct_21) %>%
    capture.output() %>%
    invisible()
})

##      user  system elapsed
##  0.063   0.004   0.068
```

dplyr -> SQL - dplyr::show_query()

```
class(oct_21)
```

```
## [1] "tbl_SQLiteConnection" "tbl_db"           "tbl_sql"  
## [4] "tbl_lazy"             "tbl"
```

```
show_query(oct_21)
```

```
## <SQL>  
## SELECT `origin`, `dest`, `tailnum`  
## FROM `flights`  
## WHERE ((`month` = 10.0) AND (`day` = 21.0))
```

More complex queries

```
oct_21 %>% group_by(origin, dest) %>% summarize(n=n())  
  
## `summarise()` has grouped output by 'origin'. You can override using the `.groups` argument.  
  
## # Source: lazy query [?? x 3]  
## # Database: sqlite 3.36.0 [flights.sqlite]  
## # Groups: origin  
##   origin dest     n  
##   <chr>  <chr> <int>  
## 1 EWR    ATL     15  
## 2 EWR    AUS      3  
## 3 EWR    AVL      1  
## 4 EWR    BNA      7  
## 5 EWR    BOS     17  
## 6 EWR    BTV      3  
## 7 EWR    BUF      2  
## 8 EWR    BWI      1  
## 9 EWR    CHS      4  
## 10 EWR   CLE      4  
## # ... with more rows
```

```
oct_21 %>% group_by(origin, dest) %>% summarize(n=n()) %>% show_query()
```

```
## `summarise()` has grouped output by 'origin'. You can override using the `.groups` argument.
```

```
oct_21 %>% count(origin, dest) %>% show_query()
```

```
## <SQL>
## SELECT `origin`, `dest`, COUNT(*) AS `n`
## FROM (SELECT `origin`, `dest`, `tailnum`
## FROM `flights`
## WHERE ((`month` = 10.0) AND (`day` = 21.0)))
## GROUP BY `origin`, `dest`
```

SQL Translation

In general, dplyr / dbplyr knows how to translate basic math, logical, and summary functions from R to SQL. dbplyr has a function, `translate_sql`, that lets you experiment with how R functions are translated to SQL.

```
dbplyr::translate_sql(x == 1 & (y < 2 | z > 3))  
## <SQL> `x` = 1.0 AND (`y` < 2.0 OR `z` > 3.0)  
  
dbplyr::translate_sql(x ^ 2 < 10)  
## <SQL> POWER(`x`, 2.0) < 10.0  
  
dbplyr::translate_sql(x %% 2 == 10)  
## <SQL> `x` % 2.0 = 10.0  
  
dbplyr::translate_sql(mean(x))  
## Warning: Missing values are always removed in SQL.  
## Use `AVG(x, na.rm = TRUE)` to silence this warning  
## This warning is displayed only once per session.  
## <SQL> AVG(`x`) OVER ()
```

```
dbplyr::translate_sql(sd(x))

## <SQL> sd(`x`)

dbplyr::translate_sql(paste(x,y))

## <SQL> CONCAT_WS(' ', `x`, `y`)

dbplyr::translate_sql(cumsum(x))

## Warning: Windowed expression 'SUM(`x`)' does not have explicit order.
## Please use arrange() or window_order() to make deterministic.

## <SQL> SUM(`x`) OVER (ROWS UNBOUNDED PRECEDING)

dbplyr::translate_sql(lag(x))

## <SQL> LAG(`x`, 1, NULL) OVER ()
```

Dialectic variations?

By default `dbplyr::translate_sql()` will translate R / dplyr code into ANSI SQL, if we want to see results specific to a certain database we can pass in a connection object,

```
dbplyr::translate_sql(sd(x), con = db)

## Warning: Missing values are always removed in SQL.
## Use `STDEV(x, na.rm = TRUE)` to silence this warning
## This warning is displayed only once per session.

## <SQL> STDEV(`x`) OVER ()

dbplyr::translate_sql(paste(x,y), con = db)

## <SQL> `x` || ' ' || `y`

dbplyr::translate_sql(cumsum(x), con = db)

## Warning: Windowed expression 'SUM(`x`)' does not have explicit order.
## Please use arrange() or window_order() to make deterministic.

## <SQL> SUM(`x`) OVER (ROWS UNBOUNDED PRECEDING)

dbplyr::translate_sql(lag(x), con = db)
```

Complications?

```
oct_21 %>% mutate(tailnum_n_prefix = grepl("^N", tailnum))

## Error: no such function: grepl

oct_21 %>% mutate(tailnum_n_prefix = grepl("^N", tailnum)) %>% show_query()

## <SQL>
## SELECT `origin`, `dest`, `tailnum`, grepl('^N', `tailnum`) AS `tailnum_n_prefix`
## FROM `flights`
## WHERE ((`month` = 10.0) AND (`day` = 21.0))
```

SQL -> R / dplyr

Running SQL queries against R objects

There are two packages that implement this in R which take very different approaches,

- `tidyquery` - this package parses your SQL code using the `quereyparser` package and then translates the result into R / `dplyr` code.
- `sqldf` - transparently creates a database with teh data and then runs the query using that database. Defaults to SQLite but other backends are available.

tidyquery

```
data(flights, package = "nycflights13")

tidyquery::query(
  "SELECT origin, dest, COUNT(*) AS n
   FROM flights
  WHERE month = 10 AND day = 21
 GROUP BY origin, dest"
)
```

```
## # A tibble: 181 × 3
##   origin dest     n
##   <chr>  <chr> <int>
## 1 EWR    ATL     15
## 2 EWR    AUS      3
## 3 EWR    AVL      1
## 4 EWR    BNA      7
## 5 EWR    BOS     17
## 6 EWR    BTV      3
## 7 EWR    BUF      2
## 8 EWR    BWI      1
## 9 EWR    CHS      4
## 10 EWR   CLE      4
## # ... with 171 more rows
```

```
flights %>%
  tidyquery::query(
    "SELECT origin, dest, COUNT(*) AS n
     WHERE month = 10 AND day = 21
     GROUP BY origin, dest"
  ) %>%
  arrange(desc(n))
```

```
## # A tibble: 181 × 3
##   origin dest     n
##   <chr>  <chr> <int>
## 1 JFK    LAX     32
## 2 LGA    ORD     31
## 3 LGA    ATL     30
## 4 JFK    SFO     24
## 5 LGA    CLT     22
## 6 EWR    ORD     18
## 7 EWR    SFO     18
## 8 EWR    BOS     17
## 9 LGA    MIA     17
## 10 EWR   LAX     16
## # ... with 171 more rows
```

Translating to dplyr

```
tidyquery::show_dplyr(  
  "SELECT origin, dest, COUNT(*) AS n  
   FROM flights  
 WHERE month = 10 AND day = 21  
 GROUP BY origin, dest"  
)
```

```
## flights %>%  
##   filter(month == 10 & day == 21) %>%  
##   group_by(origin, dest) %>%  
##   summarise(n = dplyr::n()) %>%  
##   ungroup()
```

sqldf

```
sqldf::sqldf(  
  "SELECT origin, dest, COUNT(*) AS n  
   FROM flights  
  WHERE month = 10 AND day = 21  
 GROUP BY origin, dest"  
)  
  
## Warning: no DISPLAY variable so Tk is not avail
```

```
##      origin dest  n  
## 1      EWR    ATL 15  
## 2      EWR    AUS  3  
## 3      EWR    AVL  1  
## 4      EWR    BNA  7  
## 5      EWR    BOS 17  
## 6      EWR    BTV  3  
## 7      EWR    BUF  2  
## 8      EWR    BWI  1  
## 9      EWR    CHS  4  
## 10     EWR    CLE  4  
## 11     EWR    CLT 15  
## 12     EWR    CMH  3  
## 13     EWR    CVG  9  
## 14     EWR    DAY  4
```

```
sqldf::sqldf(  
  "SELECT origin, dest, COUNT(*) AS n  
   FROM flights  
  WHERE month = 10 AND day = 21  
 GROUP BY origin, dest"  
) %>%  
  as_tibble() %>%  
  arrange(desc(n))
```

```
## # A tibble: 181 × 3  
##      origin dest  n  
##      <chr>  <chr> <int>  
## 1      JFK    LAX  32  
## 2      LGA    ORD  31  
## 3      LGA    ATL  30  
## 4      JFK    SFO  24  
## 5      LGA    CLT  22  
## 6      EWR    ORD  18  
## 7      EWR    SFO  18  
## 8      EWR    BOS  17  
## 9      LGA    MIA  17  
## 10     EWR    LAX  16  
## # ... with 171 more rows
```

Query performance

Setup

To give us a bit more variety, I am going to add one more table to our SQLite database - nycflights13::planes which has details on the characteristics of the planes in the dataset as identified by their tail numbers.

```
dplyr::copy_to(db, nycflights13::planes, name = "planes", temporary = FALSE)
```

All of the following code will be run in the SQLite commandline 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 1

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

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) left 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 (c
```

```
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.