Databases and SQL

Programming for Statistical Science

Shawn Santo

Supplementary materials

Full video lecture available in Zoom Cloud Recordings

Additional resources

- Introduction to `dbplyr` vignette

Databases

A **database** is a collection of data typically stored in a computer system. It is controlled by a **database management system (DBMS)**. There may be applications associated with them, such as an API.

Types of DBMS: MySQL, Microsoft Access, Microsoft SQL Server, FileMaker Pro, Oracle Database, and dBASE.

Types of databases: Relational, object-oriented, distributed, NoSQL, graph, and more.

DBMS benefits

- Lower storage and retrieval costs
- Easy data access
- Backup and recovery
- Data consistency

Relational database management system

- A system that governs a relational database, where data is identified and accessed in relation to other data in the database.

- Relational databases generally organize data into tables comprised of **fields** and **records**.

- Many relational database management systems (RDBMS) use SQL to access data. More on SQL in the next slide.

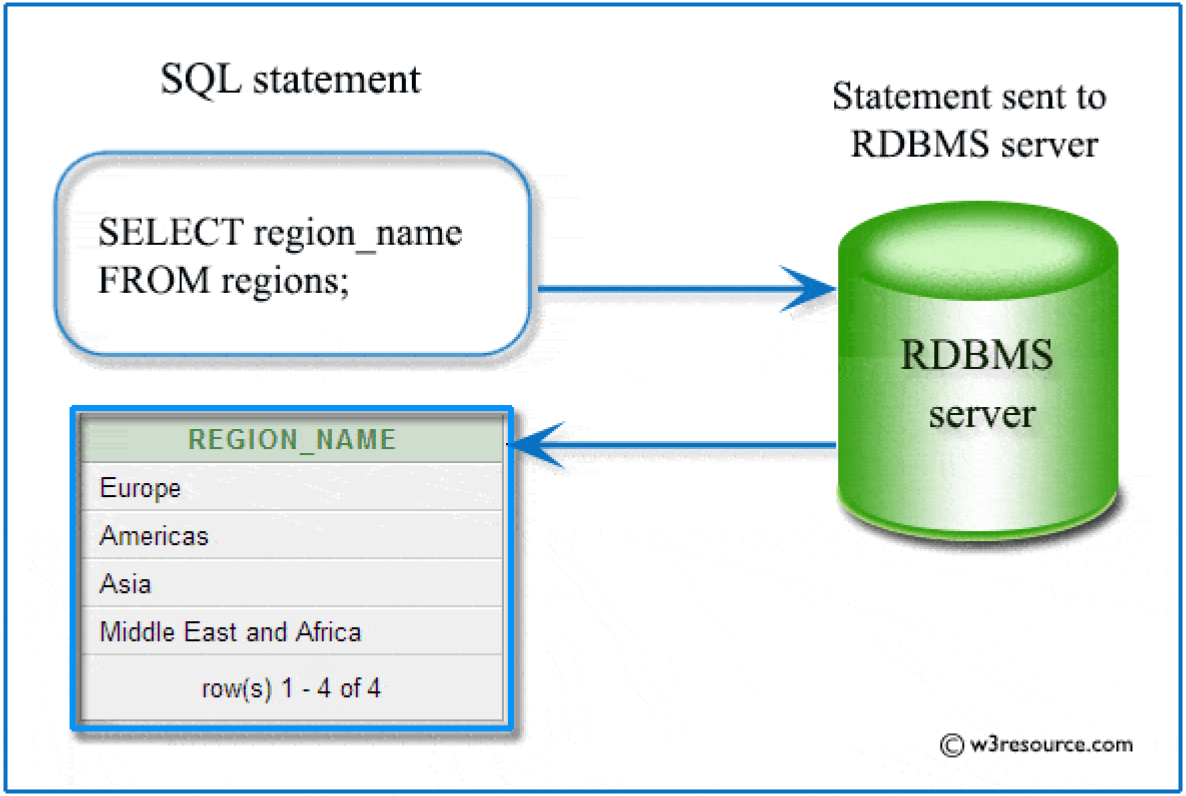
SQL

- SQL stands for Structured Query Language.

- It is an American National Standards Institute standard computer language for accessing and manipulating RDBMS.

- There are different versions of SQL, but to be compliant with the American National Standards Institute the version must support the key query verbs (functions).

Big picture



```
SELECT region_name
FROM regions;
```

REGION_NAME
Europe
Americas
Asia
Middle East and Africa
row(s) 1 - 4 of 4

Source: https://www.w3resource.com/sql/tutorials.php

Translation to SQL

Package `dbplyr`

Package `dbplyr` allows you to query a database by automatically generating SQL queries. We'll use it as a starting point to see the connection between `dplyr` verbs (functions) and `SQL` verbs before we transition using SQL.

To get started, load the packages.

```r
library(dplyr)
library(dbplyr)
```

We'll use data from `nycflights13::airports` to create a table in a temporary in-memory database.

Creating an in-memory database

We'll create an in-memory SQLite database and copy the airports tibble as a table into the database.

```
con <- DBI::dbConnect(RSQLite::SQLite(), dbname = ":memory:")
```

```
copy_to(con, df = nycflights13::airports, name = "airports")
db_list_tables(con)
```

```
#> [1] "airports"     "sqlite_stat1" "sqlite_stat4"
```

Retrieve a single table from our in-memory database.

```
airports_db <- tbl(con, "airports")
```

```
airports_db
```

```
#> # Source:   table<airports> [?? x 8]
#> # Database: sqlite 3.33.0 [:memory:]
#>    faa   name                            lat    lon   alt    tz dst   tzone       
#>    <chr> <chr>                         <dbl>  <dbl> <dbl> <dbl> <chr> <chr>       
#>  1 04G   Lansdowne Airport              41.1  -80.6  1044    -5 A     America/New_Yo…
#>  2 06A   Moton Field Municipal A…       32.5  -85.7   264    -6 A     America/Chicago
#>  3 06C   Schaumburg Regional            42.0  -88.1   801    -6 A     America/Chicago
#>  4 06N   Randall Airport                41.4  -74.4   523    -5 A     America/New_Yo…
#>  5 09J   Jekyll Island Airport          31.1  -81.4    11    -5 A     America/New_Yo…
#>  6 0A9   Elizabethton Municipal …       36.4  -82.2  1593    -5 A     America/New_Yo…
#>  7 0G6   Williams County Airport        41.5  -84.5   730    -5 A     America/New_Yo…
#>  8 0G7   Finger Lakes Regional A…       42.9  -76.8   492    -5 A     America/New_Yo…
#>  9 0P2   Shoestring Aviation Air…       39.8  -76.6  1000    -5 U     America/New_Yo…
#> 10 0S9   Jefferson County Intl          48.1 -123.    108    -8 A     America/Los_An…
#> # … with more rows
```

What is different when compared to a tibble object?

Example

NYC flights to airports by time zone.

```
airport_timezone <- airports_db %>%
  group_by(tzone) %>%
  summarise(count = n())
```

```
airport_timezone
```

```
#> # Source:   lazy query [?? x 2]
#> # Database: sqlite 3.33.0 [:memory:]
#>    tzone               count
#>    <chr>               <int>
#>  1 <NA>                    3
#>  2 America/Anchorage     239
#>  3 America/Chicago       342
#>  4 America/Denver        119
#>  5 America/Los_Angeles   176
#>  6 America/New_York      519
#>  7 America/Phoenix        38
#>  8 America/Vancouver       2
#>  9 Asia/Chongqing          2
#> 10 Pacific/Honolulu       18
```

Translation to SQL

```
airport_timezone %>%
  show_query()
```

```
#> <SQL>
#> SELECT `tzone`, COUNT() AS `count`
#> FROM `airports`
#> GROUP BY `tzone`
```

```
airports_db %>%
  group_by(tzone) %>%
  summarise(count = n())
```

```
#> # Source:   lazy query [?? x 2]
#> # Database: sqlite 3.33.0 [:memory:]
#>    tzone               count
#>    <chr>               <int>
#>  1 <NA>                    3
#>  2 America/Anchorage     239
#>  3 America/Chicago       342
#>  4 America/Denver        119
#>  5 America/Los_Angeles   176
#>  6 America/New_York      519
#>  7 America/Phoenix        38
#>  8 America/Vancouver       2
#>  9 Asia/Chongqing          2
#> 10 Pacific/Honolulu       18
```

What are the `dplyr` translations to SQL?

Exercise

What are the corresponding SQL verbs based on the `dplyr` structure below?

```
airports_db %>%
  filter(lat >= 33.7666, lat <= 36.588,
         lon >= -84.3201, lon <= -75.4129) %>%
  arrange(desc(alt)) %>%
  select(name, alt)
```

Limitations

```
tail(airport_car)

Error: tail() is not supported by sql sources
```

```
airports_db %>%
  filter(lat >=  33.7666, lat <=  36.588,
         lon >= -84.3201, lon <= -75.4129) %>%
  arrange(desc(alt)) %>%
  select(name, alt) %>%
  slice(1:3)

Error in UseMethod("slice_") :
  no applicable method for 'slice_' applied to an object of class
  "c('tbl_SQLiteConnection', 'tbl_dbi', 'tbl_sql', 'tbl_lazy', 'tbl')"
```

```
airports_db %>%
  filter(lat >= 33.7666, lat <= 36.588, lon >= -84.3201, lon <= -75.4129)
  select(name, alt) %>%
  filter(stringr::str_detect(name, pattern="Raleigh"))

Error in stri_detect_regex(string, pattern, negate = negate, opts_regex =
  object 'name' not found
```

Lazy remote queries

```
airport_car <- airports_db %>%
  filter(lat >=  33.7666, lat <=  36.588,
         lon >= -84.3201, lon <= -75.4129) %>%
  arrange(desc(alt)) %>%
  select(name, alt) %>%
  collect()
```

- Data is never pulled into R unless you explicitly ask for it with `collect()`.
- Work is delayed until the moment it is required. Until I ask for `airport_car`, nothing is communicated to the database.

Close connection

```
DBI::dbDisconnect(con)
```

SQL and R

Create a database

Set up a relational database management system and include some baseball data from package `Lahman`.

```r
library(RSQLite)
library(DBI)
library(Lahman)
```

```r
con <- dbConnect(RSQLite::SQLite(), ":memory:")
dbWriteTable(con, name = "batting", value = Batting)
dbWriteTable(con, name = "pitching", value = Pitching)
dbWriteTable(con, name = "teams", value = Teams)
```

Seeing tables and fields

```r
dbListTables(con)
```

```
#> [1] "batting"  "pitching" "teams"
```

```r
dbListFields(con, name = "teams") %>% head()
```

```
#> [1] "yearID"   "lgID"     "teamID"   "franchID" "divID"    "Rank"
```

```r
dbListFields(con, name = "pitching")
```

```
#>  [1] "playerID" "yearID"   "stint"    "teamID"   "lgID"     "W"
#>  [7] "L"        "G"        "GS"       "CG"       "SHO"      "SV"
#> [13] "IPouts"   "H"        "ER"       "HR"       "BB"       "SO"
#> [19] "BAOpp"    "ERA"      "IBB"      "WP"       "HBP"      "BK"
#> [25] "BFP"      "GF"       "R"        "SH"       "SF"       "GIDP"
```

Common SQL query structure

Main verbs to query data tables:

```
SELECT columns or computations
  FROM table
  WHERE condition
  GROUP BY columns
  HAVING condition
  ORDER BY column [ASC | DESC]
  LIMIT offset, count
```

`WHERE`, `GROUP BY`, `HAVING`, `ORDER BY`, `LIMIT` are all optional. Primary computations: `MIN`, `MAX`, `COUNT`, `SUM`, `AVG`.

We can perform these queries with `dbGetQuery()` and `paste()`.

Verb connections

SQL	`dplyr`
SELECT	`select()`
FROM	Pipe in data frame
WHERE	`filter()` pre-aggregation/calculation
GROUP_BY	`group_by()`
HAVING	`filter()` post-aggregation/calculation
ORDER BY	`arrange()` with possibly a `desc()`
LIMIT	`slice(1:n)`

Examples

Pull some attendance numbers

```
dbGetQuery(con, paste("SELECT yearID, franchID, attendance",
                      "FROM teams",
                      "LIMIT 5"))
```

```
#>   yearID franchID attendance
#> 1   1871      BNA         NA
#> 2   1871      CNA         NA
#> 3   1871      CFC         NA
#> 4   1871      KEK         NA
#> 5   1871      NNA         NA
```

```
dbGetQuery(con, paste("SELECT yearID, franchID, attendance",
                      "FROM teams",
                      "WHERE yearID >= 2000",
                      "LIMIT 5"))
```

```
#>   yearID franchID attendance
#> 1   2000      ANA    2066982
#> 2   2000      ARI    2942251
#> 3   2000      ATL    3234304
#> 4   2000      BAL    3297031
#> 5   2000      BOS    2585895
```

What happens if we change the order or query structure?

```
dbGetQuery(con, paste("FROM teams",
                      "SELECT yearID, franchID, attendance",
                      "WHERE yearID >= 2000",
                      "LIMIT 5"))
```

```
#> Error: near "FROM": syntax error
```

Get the average yearly attendance for each franchise since 2010 and show the top 10.

```
dbGetQuery(con, paste("SELECT franchID, AVG(attendance)",
                      "FROM teams",
                      "WHERE yearID >= 2010",
                      "ORDER BY AVG(attendance) DESC",
                      "LIMIT 10"))
```

```
#>   franchID AVG(attendance)
#> 1      ARI         2422734
```

What went wrong?

Get the average yearly attendance for each franchise since 2010 and show the top 10.

```
dbGetQuery(con, paste("SELECT franchID, AVG(attendance)",
                      "FROM teams",
                      "WHERE yearID >= 2010",
                      "GROUP BY franchID",
                      "ORDER BY AVG(attendance) DESC",
                      "LIMIT 10"))
```

```
#>    franchID AVG(attendance)
#> 1       LAD         3641336
#> 2       STL         3386500
#> 3       NYY         3383453
#> 4       SFG         3240634
#> 5       ANA         3068207
#> 6       CHC         2988555
#> 7       BOS         2950688
#> 8       COL         2796172
#> 9       MIL         2726686
#> 10      PHI         2686706
```

Note that we do not need `yearID` and `attendance` in our `SELECT` line. When do you think the `SELECT` clause is evaluated?

SQL order of execution

Order	Verb
1	`FROM`
2	`WHERE`
3	`GROUP BY`
4	`HAVING`
5	`SELECT`
6	`ORDER BY`
7	`LIMIT`

How is this different from `dplyr`?

Which players had at least 300 strikeouts (SO) in a season between 1960 and 1990?

```
dbGetQuery(con, paste("SELECT playerID, yearID, MAX(SO) as maxK",
                      "FROM pitching",
                      "WHERE yearID >= 1960 AND yearID <= 1990",
                      "GROUP BY playerID, yearID",
                      "HAVING maxK > 300",
                      "ORDER BY maxK DESC"))
```

```
#>      playerID yearID maxK
#> 1    ryanno01   1973  383
#> 2   koufasa01   1965  382
#> 3    ryanno01   1974  367
#> 4    ryanno01   1977  341
#> 5    ryanno01   1972  329
#> 6    ryanno01   1976  327
#> 7   mcdowsa01   1965  325
#> 8   koufasa01   1966  317
#> 9   richajr01   1979  313
#> 10 carltst01   1972  310
#> 11 lolicmi01   1971  308
#> 12 koufasa01   1963  306
#> 13 scottmi03   1986  306
#> 14 mcdowsa01   1970  304
#> 15 richajr01   1978  303
#> 16  bluevi01   1971  301
#> 17  ryanno01   1989  301
```

Can we restructure the query?

Which players had at least 300 strikeouts (SO) in a season between 1960 and 1990?

```
dbGetQuery(con, paste("SELECT playerID, yearID, MAX(SO) as maxK",
                      "FROM pitching",
                      "HAVING maxK > 300",
                      "GROUP BY playerID, yearID",
                      "WHERE yearID >= 1960 AND yearID <= 1990",
                      "ORDER BY maxK DESC"))
```

```
#> Error: near "GROUP": syntax error
```

```
dbGetQuery(con, paste("SELECT yearID, franchID, attendance",
                      "FROM teams",
                      "HAVING yearID >= 2000",
                      "LIMIT 5"))
```

```
#> Error: a GROUP BY clause is required before HAVING
```

SQL arithmetic and comparison operators

SQL supports the standard `+`, `-`, `*`, `/`, and `%` (modulo) arithmetic operators and the following comparison operators.

Operator	Description
=	Equal to
>	Greater than
<	Less than
>=	Greater than or equal to
<=	Less than or equal to
<>	Not equal to

SQL logical operators

Operator	Description
`ALL`	TRUE if all of the subquery values meet the condition
`AND`	TRUE if all the conditions separated by AND is TRUE
`ANY`	TRUE if any of the subquery values meet the condition
`BETWEEN`	TRUE if the operand is within the range of comparisons
`EXISTS`	TRUE if the subquery returns one or more records
`IN`	TRUE if the operand is equal to one of a list of expressions
`LIKE`	TRUE if the operand matches a pattern
`NOT`	Displays a record if the condition(s) is NOT TRUE
`OR`	TRUE if any of the conditions separated by OR is TRUE
`SOME`	TRUE if any of the subquery values meet the condition

Exercises

1. Add `Salaries` from package `Lahman` as a table to your in-memory database.

2. Compute the team salaries for each team in 2016 and display the 5 teams with the highest payroll. Which team had the lowest payroll in that year?

3. Who were the top 10 teams according to win percentage since 1990? *Hint*: https://www.w3schools.com/sql/func_sqlserver_cast.asp

4. How would you combine the batting and salaries tables to match up the players and years? Take a look at `?dplyr::join`. Try to combine the R data frame objects `Batting` and `Salaries`.

References

1. Introduction to dbplyr. (2020). https://cran.r-project.org/web/packages/dbplyr/vignettes/dbplyr.html

2. SQL Tutorial - w3resource. (2020). https://www.w3resource.com/sql/tutorials.php.