# MFE R Programming Workshop

## Week 5

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## Introduction

## Questions

Any questions before we start?

## Overview

- Importing Data from Databases
- Importing Data from the Web
- Importing Data from WRDS
- `data.table`

## Importing Data from Databases

## Databases

- A database stores data in table format.
- There a several popular database management systems (DMS):
  - MySQL, PostgreSQL, SQLite, Oracle, Microsoft SQL Server, etc.
- Structured Query Language (SQL) is used maintain and query the database.

## Databases in R

- There are different R packages for each DMS:
  - MySQL = RMySQL
  - PostgreSQL = RPostgreSQL
  - SQLite = RSQLite
  - Oracle = ROracle
  - SQL Server = RSQLServer
- The functions we use to interact with the database are specified in the R package `DBI`.

## A MySQL Example: Establish a Connection

- First, we need to establish a connection to the database.

```r
library(DBI)
con <- dbConnect(RMySQL::MySQL(), # the MySQL driver
                 dbname = "dbname", # database name
                 host = "IP_or_WebAddress",
                 port = 3306, # port is 3306 by default
                 user = "username",
                 password = "password")
```

## List and Import Tables

```r
# lists the tables in the database
dbListTables(con)
# returns a dataframe
dbReadTable(con, "tablename")
# import all the tables
table_names <- dbListTables(con)
tables <- lapply(table_names, dbReadTable, conn = con)
# close the connection when you are done
dbDisconnect(con)
```

## Importing Data From the Web

## JSON

- JSON object: an unordered collection of name-value pairs.
- JSON array: an ordered sequence of zero or more values.
- JSON objects and arrays can be nested in each other.
- R handles JSON with the `jsonlite` package.

## An Example with `jsonlite`

- Let's get the current wind and temperature status at LAX.

```r
library(jsonlite)
airportCode <- "LAX"
url <- paste0("http://services.faa.gov/airport/status/",
              airportCode)
LAX <- fromJSON(url)
LAX$weather$wind
```

```
## [1] "West at 13.8mph"
```

```r
LAX$weather$temp
```

```
## [1] "68.0 F (20.0 C)"
```

## Quandl

- Quandl is a useful source of financial data and there is an R package `Quandl` to import the data into R.
- See https://www.quandl.com/tools/r.
- Data can be downloaded as `xts` objects, datatables, etc.

```r
library(Quandl)
# download GDP % growth as an xts object
gdp <- Quandl("FRED/GDP", type="xts")
last(gdp, 4)
```

```
##                [,1]
## 2016 Q4 18905.54
## 2017 Q1 19057.71
## 2017 Q2 19250.01
## 2017 Q3 19495.48
```

## Importing Data from WRDS

## WRDS, CRSP, and R

- Wharton Research Data Services (wrds) has over 250 terabytes of data.
- One data provider is The Center for Research in Security Prices (CRSP).
  - You will use CRSP data throughout the MFE program.
- I will show you how to access WRDS from R.
- Documentation: Using R with WRDS

## Setup

- First, you need to encode your wrds password: instructions here.
- We also need to obtain access to WRDS and download the SAS drivers for JDBC from here.
- The two files should be saved locally.
- Take note of the path to the files; we need the path to establish the connection to WRDS.

## Establish the Connection

```r
# ---- INPUTS ---- #
username <- "myUserName"
password <- "myPassword"
# local path to the sas files
sasPath <- "C:/Users/myUser/Documents/wrds-drivers"
# ---- CODE ---- #
library(rJava)
options(java.parameters = '-Xmx4g')
library(RJDBC)
sasCore <- paste0(sasPath, "/sas.core.jar")
sasDriver <- paste0(sasPath, "/sas.intrnet.javatools.jar")
.jaddClassPath(c(sasCore, sasDriver))
driver <- RJDBC::JDBC(
         "com.sas.net.sharenet.ShareNetDriver",
          sasDriver, identifier.quote = "`")
wrds <- RJDBC::dbConnect(driver,
"jdbc:sharenet://wrds-cloud.wharton.upenn.edu:8551/",
 username, password)
```

## Accessing Data

- On the previous slide, we created the connection `wrds`.

```
res <- dbSendQuery(wrds, "select * from DATASET")
data <- fetch(res, n = -1)
data
```

- **`dbSendQuery()`** uses `wrds` to submit the SQL query string to WRDS, which then returns the result `res`.
- **`select * from DATASET`** is a SAS SQL query.
  - See the SAS SQL Documentation for more information.
- **`fetch()`** fetches the actual data based on the result `res`.
- **`n = -1`** is a parameter that determines how many observations to download.
  - `n = -1` specifies that we'd like unlimited observations returned.
  - `n = 10` would limit the number of observations returned to 10.

## Example: S&P 500 Returns

```r
sql <- "SELECT caldt, vwretd FROM CRSPQ.MSP500"
res <- dbSendQuery(wrds, sql)
dbHasCompleted(res) #check that this is true
msp500 <- fetch(res, n = -1)
dbClearResult(res) # free up memory
msp500$caldt <- as.Date(msp500$caldt)
library(xts)
msp500 <- xts::xts(msp500[, -1],
                   order.by = msp500$caldt)
colnames(msp500) <- "vwretd"
```

## `data.table`

## What is a data.table?

- Think of data.table as an advanced version of data.frame.
    - Every column is the same length, but may have a different type
- It inherits from data.frame and works perfectly even when data.frame syntax is applied on data.table.
- data.table is very fast.
- The syntax of data.table is very concise.
    - Lowers programmer time. . .
    - . . . but it can be hard to understand
    - Make sure you comment your code!
- Highly recommend going through data.table Cheat Sheet.

```r
library(data.table)
```

## An Example

- Syntax is `DT[i, j, by]`
- Take DT, subset rows using **i**, then calculate **j** grouped by **by**.

```r
data("mtcars")
mtcarsDT <- data.table(mtcars)
mtcarsDT[
  mpg > 20,
  .(AvgHP = mean(hp),
    "MinWT(kg)" = min(wt*453.6)),
  by = .(cyl, under5gears = gear < 5)]
```

```
##     cyl under5gears     AvgHP MinWT(kg)
## 1:   6        TRUE 110.00000 1188.4320
## 2:   4        TRUE  78.33333  732.5640
## 3:   4       FALSE 102.00000  686.2968
```

## Creating a `data.table`

```r
set.seed(1234)
DT <- data.table(A=1:6, B=c("a", "b", "c"),
                 C=runif(6), D=FALSE)
DT
```

```
##    A B         C     D
## 1: 1 a 0.1137034 FALSE
## 2: 2 b 0.6222994 FALSE
## 3: 3 c 0.6092747 FALSE
## 4: 4 a 0.6233794 FALSE
## 5: 5 b 0.8609154 FALSE
## 6: 6 c 0.6403106 FALSE
```

## Selecting Rows by Number in **i**

- The comma is optional.

```
DT[2:4, ]
```

```
##     A B         C     D
## 1: 2 b 0.6222994 FALSE
## 2: 3 c 0.6092747 FALSE
## 3: 4 a 0.6233794 FALSE
```

```
DT[2:4]
```

```
##     A B         C     D
## 1: 2 b 0.6222994 FALSE
## 2: 3 c 0.6092747 FALSE
## 3: 4 a 0.6233794 FALSE
```

## Selecting Rows: other methods

- The comma is optional.

```
DT[ A %in% 2:3,]
```

```
##    A B         C     D
## 1: 2 b 0.6222994 FALSE
## 2: 3 c 0.6092747 FALSE
```

```
DT[ B == "a", ]
```

```
##    A B         C     D
## 1: 1 a 0.1137034 FALSE
## 2: 4 a 0.6233794 FALSE
```

## Selecting Columns in **j**

- Columns are specified as a list with the actual names, not as character vectors.
- `.()` is an alias to `list()` in data.tables.

```
DT[2:3, list(A, C)]
```

```
##    A         C
## 1: 2 0.6222994
## 2: 3 0.6092747
```

```
DT[2:3, .(A, C)]
```

```
##    A         C
## 1: 2 0.6222994
## 2: 3 0.6092747
```

## Selecting Columns in **j** with character vectors

- To select columns with a character vector, use the `with = FALSE`.

```
DT[2:3, c("A", "C"), with = FALSE]
```

```
##    A         C
## 1: 2 0.6222994
## 2: 3 0.6092747
```

## Computing on Columns

- If the lengths of the results are not equal, the shorter one will be recycled.

```
DT[A %in% 2:4, .(Total = sum(A), Mean = mean(C))]
```

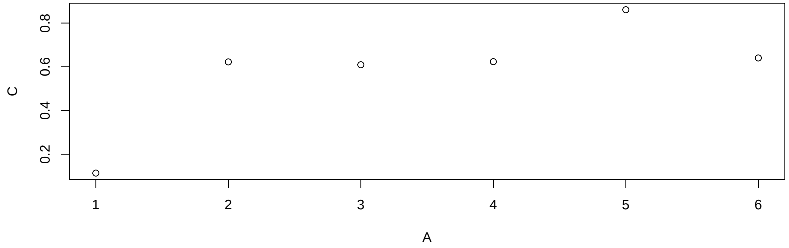
```
##    Total      Mean
## 1:     9 0.6183179
```

```
DT[A %in% 2:4, .(B, Mean = mean(C))]
```

```
##    B      Mean
## 1: b 0.6183179
## 2: c 0.6183179
## 3: a 0.6183179
```

## You can put almost anything into **j**

```r
DT[, plot(A, C)]
```

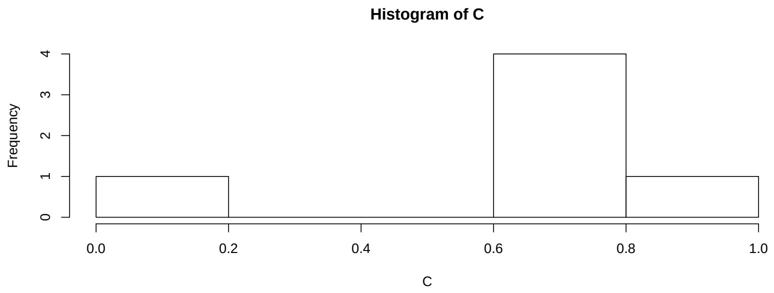


```
## NULL
```

## Multiple Expressions Go in Curly Braces

```r
DT[, {print(A)
      hist(C)
      NULL}] # set return value to NULL
```

```
## [1] 1 2 3 4 5 6
```



```
## NULL
```

## Returning a Vector.

```
DT[, .(A)]  # a data.table
```

```
##    A
## 1: 1
## 2: 2
## 3: 3
## 4: 4
## 5: 5
## 6: 6
```

```
DT[, A]  # a vector
```

```
## [1] 1 2 3 4 5 6
```

## Doing **j** by Group

```r
DT[, .(Total = sum(A),
       Mean = mean(C)),
       by = "B"] # returned in the order they appear
```

```
##    B Total      Mean
## 1: a     5 0.3685414
## 2: b     7 0.7416074
## 3: c     9 0.6247927
```

```r
# functions work as well
DT[, .(Total = sum(C)), by = .(Group = A%%2)]
```

```
##    Group    Total
## 1:     1 1.583894
## 2:     0 1.885989
```

## .N

- .N, when used inside square brackets, contains the number of rows.
- When put in **j**, .N counts the observations in each group.

```
DT[.N] # the last row, the same as DT[nrow(DT)]
```

```
##    A B         C     D
## 1: 6 c 0.6403106 FALSE
```

```
DT[, .(Total = sum(C), Count = .N), by = .(Group = A%%2)]
```

```
##    Group    Total Count
## 1:     1 1.583894     3
## 2:     0 1.885989     3
```

## Subset of Data - .SD

- .SD is a data.table.
- .SD holds all the columns except for the one specified in **by**, and .SD is only accessible in **j**.
- This is very useful if you have a very wide data.table.
- .SDcols allows you to apply a function to a subset of the columns.

```
DT <- as.data.table(mtcars)
DT[, lapply(.SD, median), by = cyl,
   .SDcols = c("mpg","gear","wt")]
```

```
##    cyl  mpg gear    wt
## 1:   6 19.7    4 3.215
## 2:   4 26.0    4 2.200
## 3:   8 15.2    3 3.755
```

- Since lapply returns a list, we don't need to wrap it in .().

## Add or Update Columns by Reference Using :=

```r
(DT <- data.table(A=1:3, B=4:6))
```

```
##    A B
## 1: 1 4
## 2: 2 5
## 3: 3 6
```

```r
DT[,C := A + B]
DT
```

```
##    A B C
## 1: 1 4 5
## 2: 2 5 7
## 3: 3 6 9
```

## Create Multiple Columns with := in One Statement

```r
DT_cars <- data.table(mtcars)[, .(mpg, cyl)]
DT_cars[, `:=`(avg = mean(mpg), med = median(mpg)), by = cy
head(DT_cars)
```

```
##      mpg cyl      avg  med
## 1: 21.0   6 19.74286 19.7
## 2: 21.0   6 19.74286 19.7
## 3: 22.8   4 26.66364 26.0
## 4: 21.4   6 19.74286 19.7
## 5: 18.7   8 15.10000 15.2
## 6: 18.1   6 19.74286 19.7
```

## Remove Columns Using :=

- We use NULL to remove columns.

```
DT[, D := 10:12]
DT
```

```
##    A B C  D
## 1: 1 4 5 10
## 2: 2 5 7 11
## 3: 3 6 9 12
```

```
DT[,`:=`(B = NULL, C = NULL)]
# DT[, c("B", "C") := NULL] # also works
DT
```

```
##    A  D
## 1: 1 10
## 2: 2 11
## 3: 3 12
```

## Combining := with **i** and **by**

```r
DT <- data.table(A=1:6, B=c("a", "b", "c"), C=runif(6))
DT[, D := sum(C), by = B]
DT
```

```
##    A B           C         D
## 1: 1 a 0.009495756 0.5237469
## 2: 2 b 0.232550506 0.9261418
## 3: 3 c 0.666083758 1.2110586
## 4: 4 a 0.514251141 0.5237469
## 5: 5 b 0.693591292 0.9261418
## 6: 6 c 0.544974836 1.2110586
```

## Use set() in Loops.

- `set()` is a loopable, low-overhead version, of the `:=` operator, but it cannot handle grouping.
- Syntax: `set(DT, i, j, value)`.
- Instead of `for (i in 1:6) DT[i, C := i+1]` we can

```
DT <- data.table(A = 7:12, B = 10:15)
for (i in 1:6) set(DT, i, "B", i+1)
# for (i in 1:6) set(DT, i, 2L, i+1) # would work too
DT
```

```
##     A B
## 1:  7 2
## 2:  8 3
## 3:  9 4
## 4: 10 5
## 5: 11 6
## 6: 12 7
```

## `setnames()` to Change the Column Names

- `setnames(DT, "old", "new")` changes the column names by reference (no copies are being made).

```r
setnames(DT,c("A", "B"),c("X", "Y"))
DT
```

```
##      X Y
## 1:   7 2
## 2:   8 3
## 3:   9 4
## 4:  10 5
## 5:  11 6
## 6:  12 7
```

## setcolorder() Reorders the Columns by Reference

```r
setcolorder(DT,c("Y", "X"))
DT
```

```
##    Y  X
## 1: 2  7
## 2: 3  8
## 3: 4  9
## 4: 5 10
## 5: 6 11
## 6: 7 12
```

## Regular Expressions

- Metacharacters allow you to match certain types of characters.
  - For example, "." means any single character, "^" means "begins with", and "$" means "ends with".
- If you want to use any of the metacharacters as actual text, you need to use the \ escape sequence.
- See ?gsub() and ?grep().

```
iris_dt <- as.data.table(iris)
# Change column names
setnames(iris_dt, names(iris_dt),
         gsub("^Sepal\\.", "", names(iris_dt)))
# Remove columns
iris_dt[, grep("^Petal", names(iris_dt)) := NULL]
head(iris_dt, n = 2)
```

```
##    Length Width Species
## 1:    5.1   3.5  setosa
## 2:    4.9   3.0  setosa
```

## Keys

- Setting a key sorts the table by the column specified.

```r
DT <- data.table(A=c("c", "b", "a"),B=1:6)
setkey(DT, A)
DT
```

```
##    A B
## 1: a 3
## 2: a 6
## 3: b 2
## 4: b 5
## 5: c 1
## 6: c 4
```

## Keys as Row Names

- Keys can be used like row names.

```
DT["a"]
```

```
##      A B
## 1: a 3
## 2: a 6
```

```
DT["a", mult = "first"]
```

```
##      A B
## 1: a 3
```

```
DT["a", mult = "last"]
```

```
##      A B
## 1: a 6
```

## nomatch

- Keys can be used like row names.

```
DT[c("a","d")]
```

```
##    A  B
## 1: a  3
## 2: a  6
## 3: d NA
```

```
DT[c("a","d"), nomatch = 0]
```

```
##    A B
## 1: a 3
## 2: a 6
```

## Multi-Column Keys

- Use `.()` to select rows.

```
DT <- data.table(A=c("c", "b", "a"),B=1:6,C=7:12)
setkey(DT, A, B)
DT[.("b")]
```

```
##    A B  C
## 1: b 2  8
## 2: b 5 11
```

```
DT[.("b", 5)]
```

```
##    A B  C
## 1: b 5 11
```

## `merging data.tables`

- Fast merge of two `data.tables`. It behaves very similarly to that of `data.frames` except that, by default, it attempts to merge
  - at first based on the shared **key** columns, and if there are none,
  - then based on key columns of the first argument `x`, and if there are none,
  - then based on the common columns between the two `data.tables`.
- Set the `by`, or `by.x` and `by.y` arguments explicitly to override this default.
- Set the `all.x` (for left joins), `all.y` (for right joins), and `all` (for outer joins) logical arguments to override the default (inner joins).

## merge example

```r
(x <- data.table( foo = 1:4, a=20:23, zoo = 5:2 ))
```

```
##     foo  a zoo
## 1:    1 20   5
## 2:    2 21   4
## 3:    3 22   3
## 4:    4 23   2
```

```r
(y <- data.table( foo = 2:4, b=30:32, boo = 10:12))
```

```
##     foo  b boo
## 1:    2 30  10
## 2:    3 31  11
## 3:    4 32  12
```

```r
setkey(x, foo)
setkey(y, foo)
```

## merge example

```r
merge(x,y)
```

```
##    foo  a zoo  b boo
## 1:   2 21   4 30  10
## 2:   3 22   3 31  11
## 3:   4 23   2 32  12
```

```r
merge(x,y, all.x = TRUE)
```

```
##    foo  a zoo  b boo
## 1:   1 20   5 NA  NA
## 2:   2 21   4 30  10
## 3:   3 22   3 31  11
## 4:   4 23   2 32  12
```

## Using shift for to lead/lag vectors and lists

```
DT <- data.table(mtcars)[,.(mpg)]
DT[,mpg_lag1:=shift(mpg, n = 1)]
DT[,mpg_forward1:=shift(mpg, n = [illegible]type='lead')]
head(DT)
```

```
##      mpg mpg_lag1 mpg_forward1
## 1: 21.0       NA         21.0
## 2: 21.0     21.0         22.8
## 3: 22.8     21.0         21.4
## 4: 21.4     22.8         18.7
## 5: 18.7     21.4         18.1
## 6: 18.1     18.7         14.3
```

## Reshaping data.tables

- The `melt` and `dcast` functions for `data.tables` are extensions of the corresponding functions from the `reshape2` package.
- See the `data.table` reshape vignette.

```
DT <- readRDS("melt_example.RDS")
DT
```

```
##    fam_id age_mom dob_child1 dob_child2 dob_child3
## 1:      1      30 11/26/1998  1/29/2000         NA
## 2:      2      27   6/2/1996         NA         NA
## 3:      3      26  7/11/2002   4/5/2004  7/20/2007
## 4:      4      32 10/10/2004  8/27/2009   2/1/2012
## 5:      5      29  12/5/2000  2/28/2005         NA
```

## melting data.tables (wide to long)

```
(DT.m1 <- melt(DT,
  id.vars = c("fam_id", "age_mom"),
  measure.vars = c("dob_child1", "dob_child2", "dob_child3'
```

```
##     fam_id age_mom   variable      value
##  1:      1      30 dob_child1 11/26/1998
##  2:      2      27 dob_child1   6/2/1996
##  3:      3      26 dob_child1  7/11/2002
##  4:      4      32 dob_child1 10/10/2004
##  5:      5      29 dob_child1  12/5/2000
##  6:      1      30 dob_child2  1/29/2000
##  7:      2      27 dob_child2         NA
##  8:      3      26 dob_child2   4/5/2004
##  9:      4      32 dob_child2  8/27/2009
## 10:      5      29 dob_child2  2/28/2005
## 11:      1      30 dob_child3         NA
## 12:      2      27 dob_child3         NA
## 13:      3      26 dob_child3  7/20/2007
```

## melting data.tables (wide to long)

- Can name the variable and value columns

```r
(DT.m2 <- melt(DT,
  measure.vars = c("dob_child1", "dob_child2", "dob_child3'
  variable.name = "child", value.name = "dob"))
```

```
##     fam_id age_mom      child        dob
##  1:      1      30 dob_child1 11/26/1998
##  2:      2      27 dob_child1   6/2/1996
##  3:      3      26 dob_child1  7/11/2002
##  4:      4      32 dob_child1 10/10/2004
##  5:      5      29 dob_child1  12/5/2000
##  6:      1      30 dob_child2  1/29/2000
##  7:      2      27 dob_child2         NA
##  8:      3      26 dob_child2   4/5/2004
##  9:      4      32 dob_child2  8/27/2009
## 10:      5      29 dob_child2  2/28/2005
## 11:      1      30 dob_child3         NA
```

## Casting data.tables (long to wide)

- We can get back to the original data.table DT from DT.m1 or DT.m2
  - collect all child observations corresponding to each fam_id, age_mom together under the same row.

```
dcast(DT.m2, fam_id + age_mom ~ child, value.var = "dob")
```

```
##    fam_id age_mom dob_child1 dob_child2 dob_child3
## 1:      1      30 11/26/1998  1/29/2000         NA
## 2:      2      27   6/2/1996         NA         NA
## 3:      3      26  7/11/2002   4/5/2004  7/20/2007
## 4:      4      32 10/10/2004  8/27/2009   2/1/2012
## 5:      5      29  12/5/2000  2/28/2005         NA
```

```
# using DT.m1
# dcast(DT.m1, fam_id + age_mom ~ variable,
#       value.var = "value")
```

## Pass a function to aggregate by in dcast

- Can do that with the argument `fun.aggregate`.
    - get the number of children in each family

```r
dcast(DT.m2, fam_id ~ .,
      fun.agg = function(x) sum(!is.na(x)),
      value.var = "dob")
```

```
##    fam_id .
## 1:      1 2
## 2:      2 1
## 3:      3 3
## 4:      4 3
## 5:      5 2
```

- Check `?dcast` for other useful arguments.

## `fread` and `fwrite`

- `fread` is similar to `read.csv()` but a lot faster! It reads a csv file into a `data.table`.
- `fwrite` is to write a data.table into a csv file similar to `write.csv()`.

## Converting xts objects to data.tables

```r
library(xts)
x <- matrix(1:4, nrow=2, ncol=2)
idx <- seq(as.Date("2016-10-31"), length=2, by="months")
x_xts <- xts(x, order.by = idx)
x_xts
```

```
##            [,1] [,2]
## 2016-10-31    1    3
## 2016-12-01    2    4
```

```r
colnames(x_xts) <- c("a", "b")
DT <- as.data.table(x_xts)
setkey(DT,index)
DT
```

```
##         index a b
## 1: 2016-10-31 1 3
## 2: 2016-12-01 2 4
```

## Rolling Joins

- Suppose you have a table of product sales and a table of commercials.
- You might want to associate each product sale with the most recent commercial that aired prior to the sale.

```
sales <- data.table(saleID=c("S1","S2","S3","S4","S5"),
          saleDate=as.Date(c("2014-2-20","2014-5-1",
                "2014-6-15","2014-7-1","2014-12-31")))
sales
```

```
##    saleID   saleDate
## 1:     S1 2014-02-20
## 2:     S2 2014-05-01
## 3:     S3 2014-06-15
## 4:     S4 2014-07-01
## 5:     S5 2014-12-31
```

## Rolling Joins

```r
commercials <- data.table(commID=c("C1","C2","C3","C4"),
                 commDate=as.Date(c("2014-1-1","2014-4-1",
                                    "2014-7-1","2014-9-15")))
commercials
```

```
##    commID   commDate
## 1:     C1 2014-01-01
## 2:     C2 2014-04-01
## 3:     C3 2014-07-01
## 4:     C4 2014-09-15
```

```r
setkey(sales,saleDate)
setkey(commercials,commDate)
```

## Rolling Joins

```
sales[commercials, roll=TRUE]
```

```
##    saleID   saleDate commID
## 1:     NA 2014-01-01     C1
## 2:     S1 2014-04-01     C2
## 3:     S4 2014-07-01     C3
## 4:     S4 2014-09-15     C4
```

- `data.table` is associating each commercial with the most recent sale prior to the commercial date (and including the commercial date).
- The most recent sale prior to each commercial is said to roll forwards, and the saleDate is mapped to the `commDate`.
- Notice that sale `S4` was the most recent sale prior to commercials `C3` and `C4`, so `S4` appears twice in the resultant table.
- Can do *backward* rolling joins by setting the `roll = -Inf`.

## Lab 3

Let’s work on Lab 3.