

# 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 are several popular database management systems (DBMS):
  - ▶ MySQL, PostgreSQL, SQLite, Oracle, Microsoft SQL Server, etc.
- ▶ Structured Query Language (SQL) is used to 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.

```
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

```
# 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.

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

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

```
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.

```
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

```
# ---- 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

```
sql <- "SELECT caldt, vwret 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) <- "vwret"
```

`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](#).

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

## An Example

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

```
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

```
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))]
```

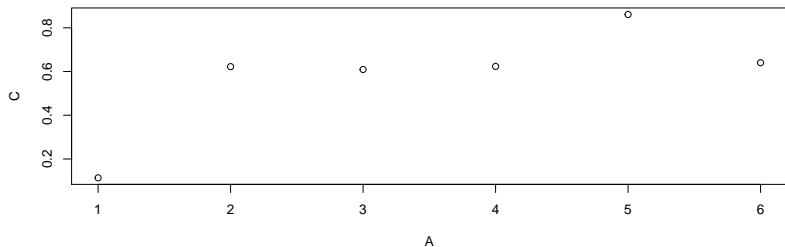
```
##      Total      Mean  
## 1:      9 0.6183179
```

```
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`

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

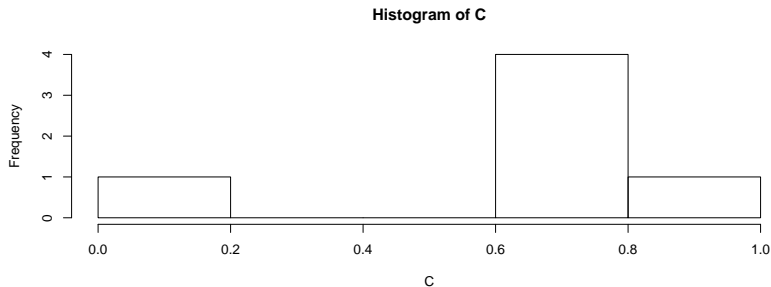


```
## NULL
```

## Multiple Expressions Go in Curly Braces

```
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

```
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
```

```
# 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 :=

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

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

```
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

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

```
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).

```
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

```
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.

```
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

```
(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
```

```
(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
```

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



## merge example

```
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
```

```
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 = 1, 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

```
(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

```
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

```
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
```

```
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

```
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
```

```
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](#).