

Lecture 1: Introduction to R

October 3, 2017

Contents























- R language
- How to get and use R?
- R Basics
- Course Objectives & Organization

R language

What is R?

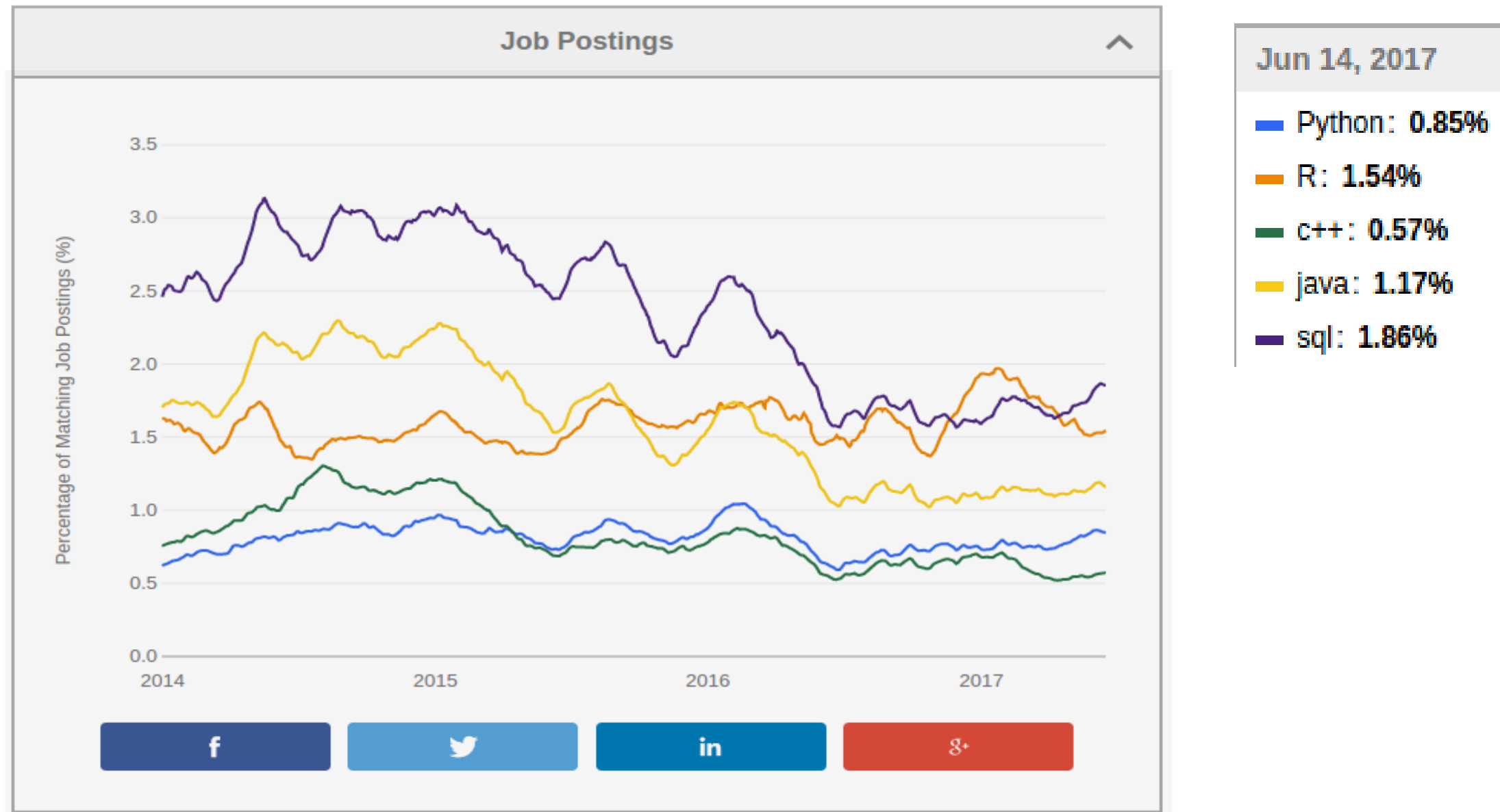
- R is a **language and environment** for statistical computing and graphics.
- It was created by Rob Gentleman and Ross Ihaka in 1994; it is based on the S language developed at Bell Labs by John Chambers (Stanford Statistics).
- R is a GNU package, which means it is **freely distributed software**.
- R is an **integrated suite of software facilities** for data manipulation, statistical calculation and graphical display, and is **highly extensible**.
- It is, however, a **fully planned and coherent system**, rather than an incremental accumulation of specific and inflexible tools.

Why should you learn R?

Language Rank	Types	Spectrum Ranking
1. Python	 	100.0
2. C	  	99.7
3. Java	  	99.5
4. C++	  	97.1
5. C#	  	87.7
6. R		87.7
7. JavaScript	 	85.6
8. PHP		81.2
9. Go	 	75.1
10. Swift	 	73.7

Source: <https://spectrum.ieee.org/>

Why should you learn R?



Source: <https://indeed.com/jobtrends>

When should you use R?

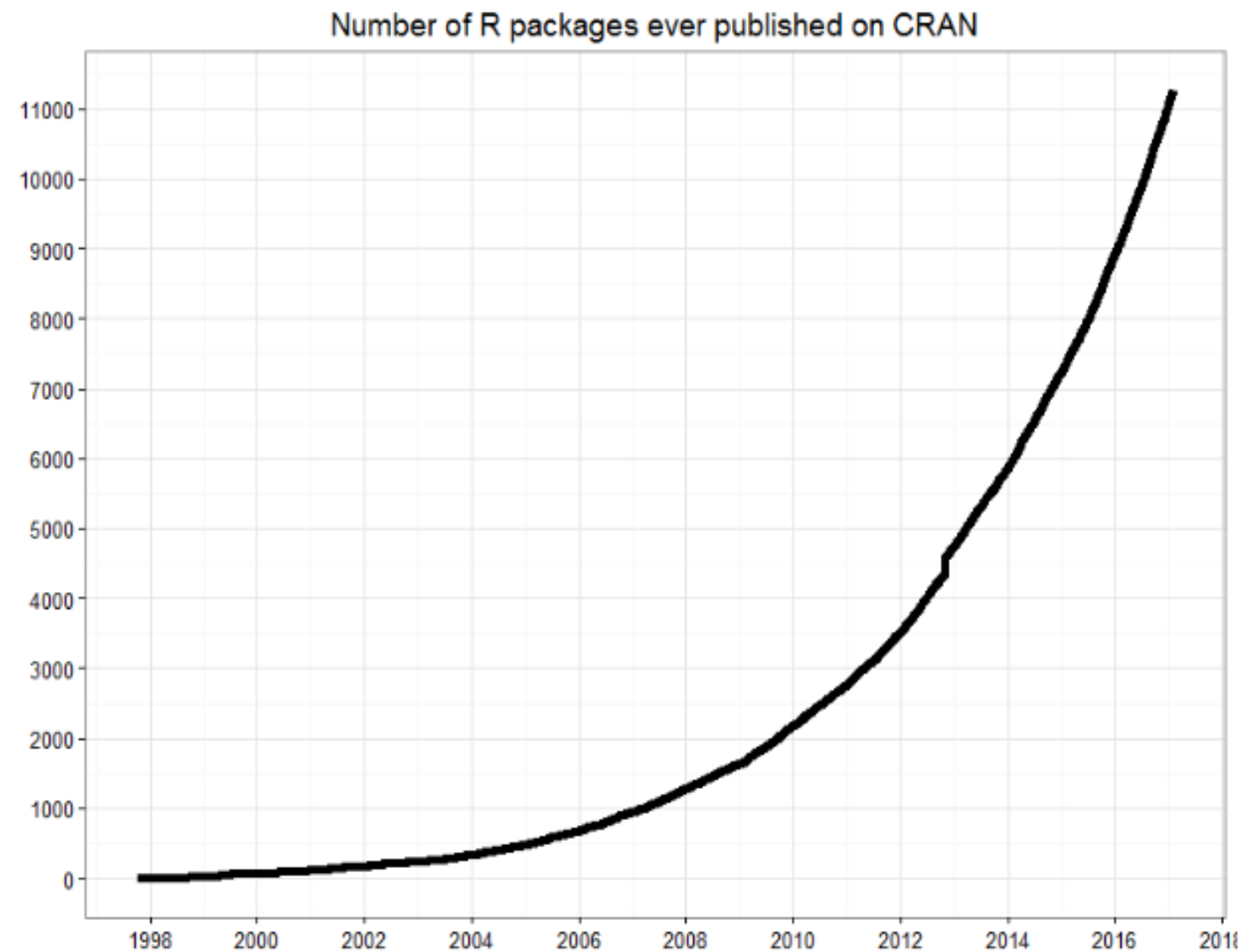
- R can be used for **data analysis and visualization**.
- It provides efficient **exploration and prototyping** tools, but also offers powerful frameworks for **building and fitting statistical models**.
- R is very good when working with **data that fits in the computer's memory**.
- It's **NOT** as good for working with massive datasets whose elements need to be continuously accessed.

What makes R good?

- R is an **interpreted language**, i.e. programs do not need to be compiled into machine-language instructions.
- R is **object oriented**, i.e. it can be extended to include non-standard data structures (**objects**). A generic function can act differently depending on what objects you pass to it.
- R supports **matrix arithmetics**.
- R packages can generate **publication-quality** plots, and **interactive graphics**.
- Many **user-created R packages** contain implementations of **cutting edge statistics methods**.

What makes R good?

As of September 29, there are 11,502 packages on [CRAN](#), 1,383 on [Bioconductor](#) and many others on [github](#))



Source:

<http://blog.revolutionanalytics.com/>

How to get and use R?

How to install R?

R is open sources and cross platform (Linux, Mac, Windows).

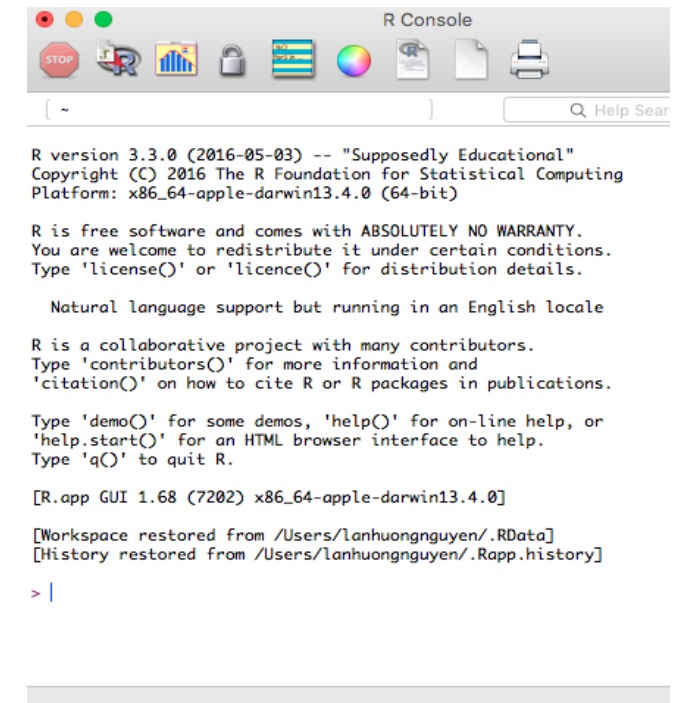
To install it just go to **the official R website** (<https://www.r-project.org/>), download the latest version for your OS and follow the instructions.

How to run R? (interpreter mode)

Start the R console:

- by launching the R graphical user interface
- by typing “R” in the command line/terminal.

Then, use the R commands interactively. To quit use `q()`.

A screenshot of the R Console graphical user interface. The window has a title bar with standard macOS window controls (red, yellow, green buttons) and a title "R Console". Below the title bar is a menu bar with icons for Stop, R logo, Help, Lock, Settings, Color, File, and Print. The main content area displays the R version 3.3.0 (2016-05-03) -- "Supposedly Educational" and copyright information. It also shows the license text, natural language support status, and a list of help commands like 'contributors()', 'citation()', 'demo()', 'help()', 'help.start()', and 'q()'. At the bottom, it shows the workspace and history restored from a previous session, followed by a prompt "> |".

```
R version 3.3.0 (2016-05-03) -- "Supposedly Educational"
Copyright (C) 2016 The R Foundation for Statistical Computing
Platform: x86_64-apple-darwin13.4.0 (64-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

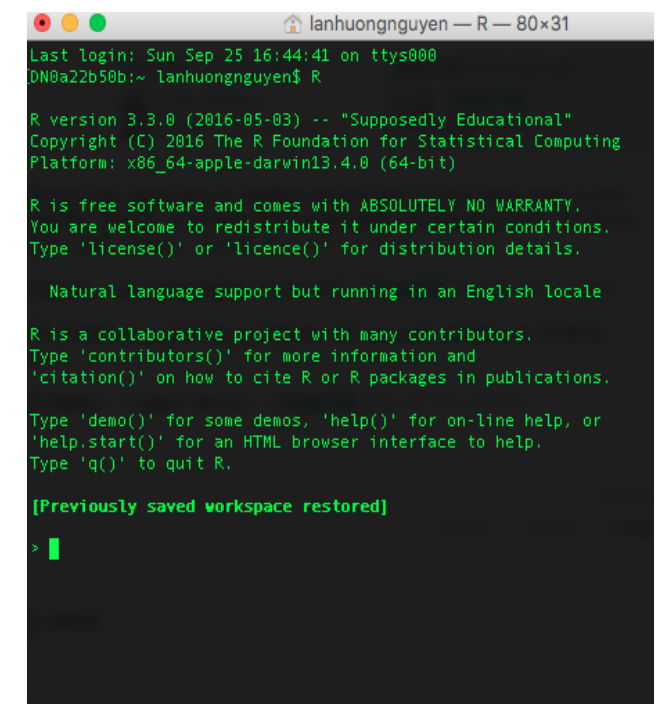
[R.app GUI 1.68 (7202) x86_64-apple-darwin13.4.0]

[Workspace restored from /Users/lanhuongnguyen/.RData]
[History restored from /Users/lanhuongnguyen/.Rapp.history]

> |
```

To open a terminal window use:

- For linux: `Ctrl + Alt + T`
- For Mac: `Command + space`. Type “Terminal” and press Enter.
- For Windows: `WinKey + R`. Type “cmd” and press Enter.

A screenshot of a terminal window. The title bar shows the user "lanhuongnguyen" and the window size "80x31". The terminal shows the last login time and the command "R" being executed. The output is the same R version and license information as seen in the R Console screenshot. At the bottom, it shows "[Previously saved workspace restored]" and a prompt "> |".

```
Last login: Sun Sep 25 16:44:41 on ttys000
DN0a22b50b:~ lanhuongnguyen$ R

R version 3.3.0 (2016-05-03) -- "Supposedly Educational"
Copyright (C) 2016 The R Foundation for Statistical Computing
Platform: x86_64-apple-darwin13.4.0 (64-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
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Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

[Previously saved workspace restored]

> |
```

How to run R? (scripting mode)

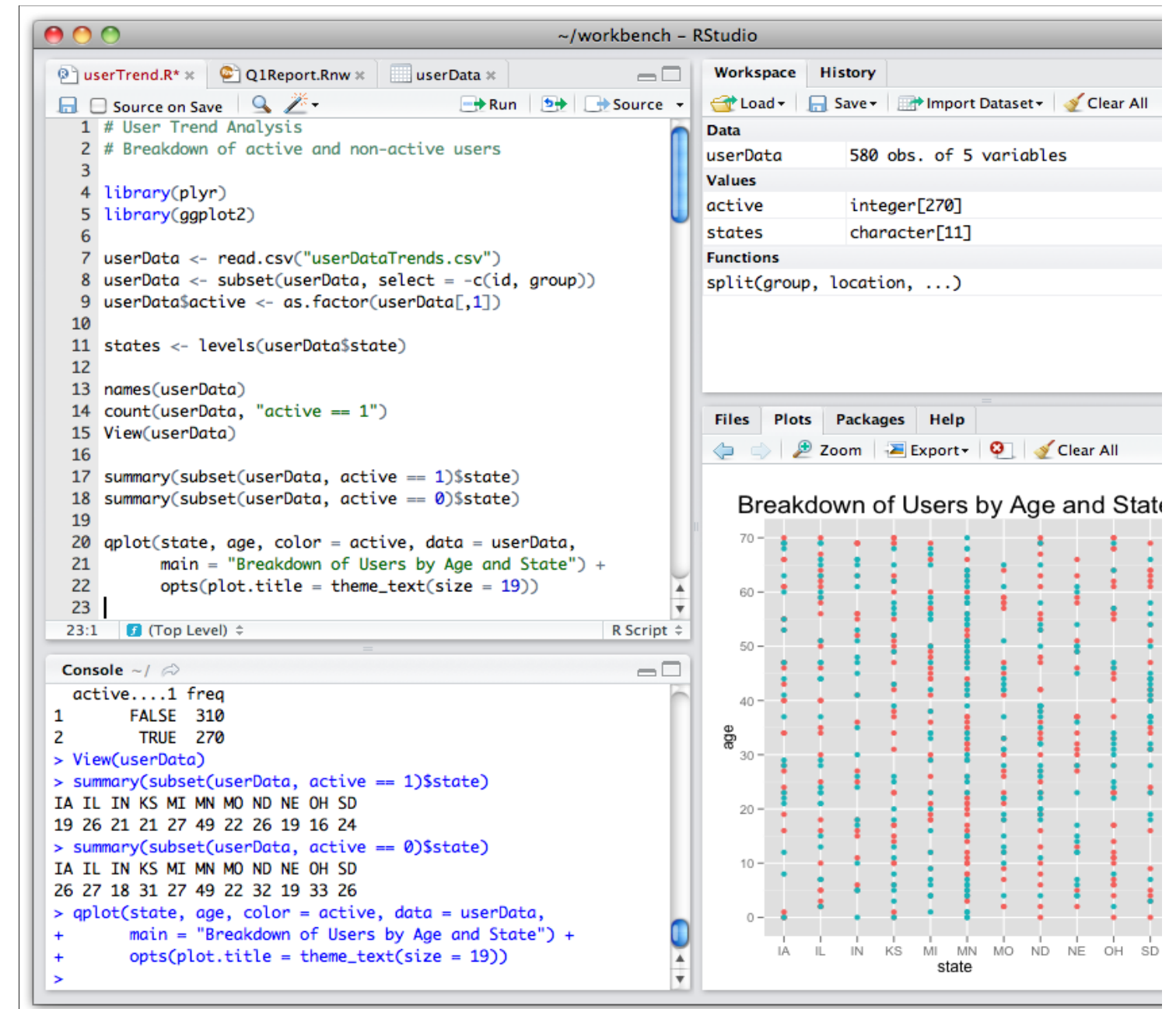
- A more convenient way to interact with R is **to write a script**.
- A script should contains all code that you want to execute.
- You should write your R code in a **suitable editor** (NOT in e.g. Microsoft Word).
- After you finish writing your code, save is as an R script file, e.g. `script.R`.
- Then, you can run/execute the code from the terminal by calling `Rscript script.R`

R Editors

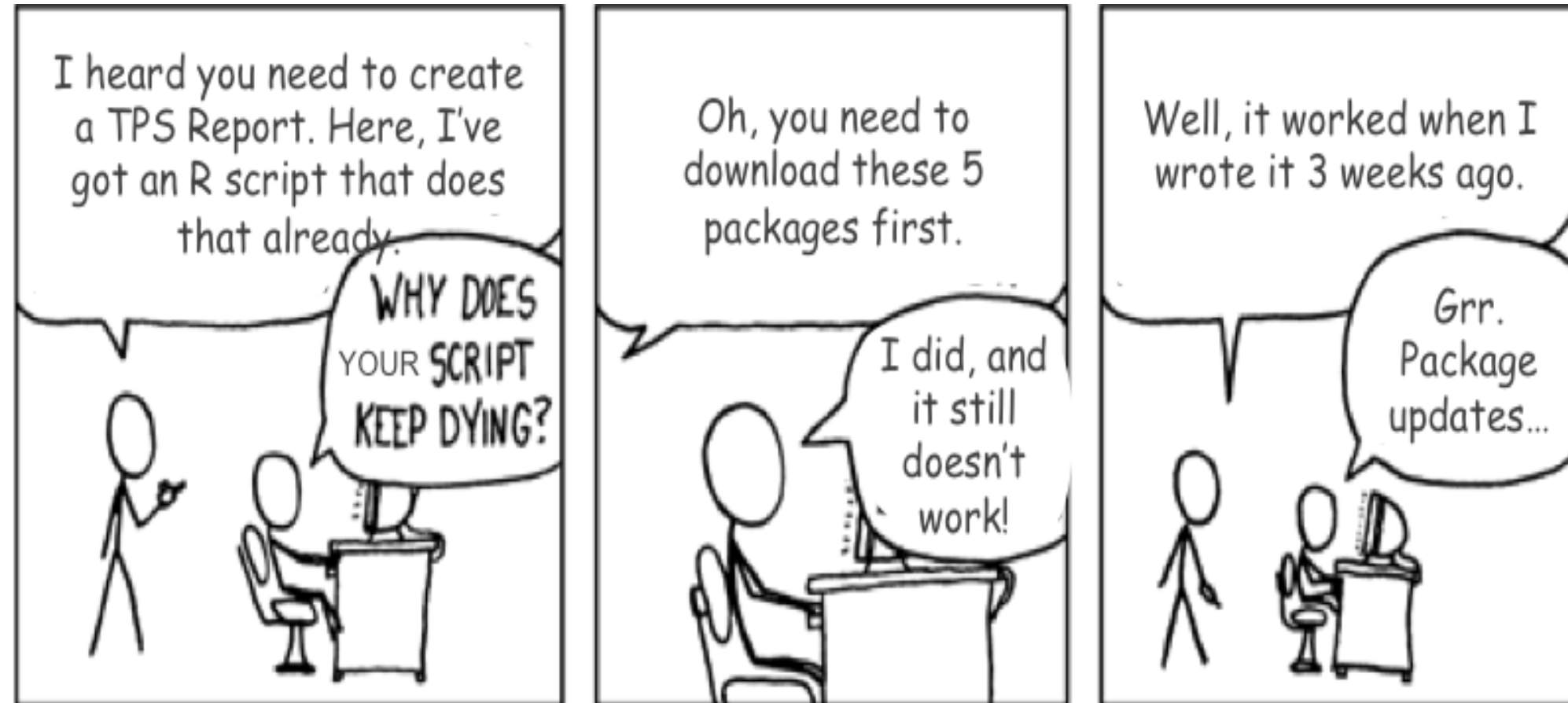
The most popular R editors are:

- **Rstudio**, an integrated development environment (IDE) for R.
- **Emacs** (a free, powerful, customizable editor for many languages).

In this class, we will use **RStudio**, as it is more user-friendly.



R packages



R packages

- R packages are a **collection of R functions, complied code and sample data**.
- They are stored under a directory called **library** in the R environment.
- Some packages are **installed by default** during R installation and are always automatically loaded at the beginning of an R session.
- Additional packages by the user from:
 - **CRAN** The first and biggest R repository.
 - **Bioconductor**: Bioinformatics packages for the analysis of biological data.
 - **github**: packages under development

Available R packages

```
# Get library locations containing R packages  
.libPaths()
```

```
## [1] "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "/usr/local/lib/R/site-
```

```
# Get the info on all the packages installed  
installed.packages()[1:5, 1:3]
```

```
##      Package      LibPath      Versi  
## abind      "abind"      "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "1.4.  
## acepack    "acepack"    "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "1.4.  
## ade4       "ade4"       "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "1.7.  
## ADGofTest  "ADGofTest"  "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "0.3'  
## affy       "affy"       "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "1.54
```

```
# Get all packages currently loaded in the R environment  
search()
```

```
## [1] ".GlobalEnv"      "package:stats"    "package:graphics" "package:grDev"
```

Installing R packages

- From CRAN:

```
# install.packages("Package Name"), e.g.  
install.packages("glmnet")
```

- From Bioconductor:

```
# First, load Bioconductor script. You need to have an R version >=3.3.0.  
source("https://bioconductor.org/biocLite.R" )  
  
# Then you can install packages with: biocLite("Package Name"), e.g.  
biocLite("limma")
```

- From github:

```
# You need to first install a package "devtools" from CRAN  
install.packages("devtools")  
  
# Load the "devtools" package  
library(devtools)  
  
# Then you can install a package from some user's repository, e.g.  
install_github("twitter/AnomalyDetection" )  
  
# or using install_git("url"), e.g.  
install_git("https://github.com/twitter/AnomalyDetection" )
```

Useful resources for learning R

- *R in a nutshell* and introductory book by Joseph Adler - *R tutorial*
(https://www.tutorialspoint.com/r/r_packages.htm)
- *Advanced R* book by Hadley Wickham for intermediate programmers
(<http://adv-r.had.co.nz/Introduction.html>)
- `swirl` R-package for interactive learning for beginners
(<http://swirlstats.com/>)
- Data Camp courses for data science, R, python and more
(<https://www.datacamp.com/courses>)

R Basics

R as an extensible calculator

- R allows you to intuitively input and easily compute elementary mathematical expressions , e.g.

```
23 + 8
```

```
## [1] 31
```

```
abs(-10)
```

```
## [1] 10
```

```
4 * exp(10) + sqrt(2)
```

```
## [1] 88107.28
```

- Intuitive arithmetic operators: addition (+), subtraction (-), multiplication (*), division: (/), exponentiation: (^), modulus: (%%)

Built-in constants

```
pi
```

```
## [1] 3.141593
```

```
LETTERS
```

```
## [1] "A" "B" "C" "D" "E" "F" "G" "H" "I" "J" "K" "L" "M" "N" "O" "P" "Q" "R" "
```

```
letters
```

```
## [1] "a" "b" "c" "d" "e" "f" "g" "h" "i" "j" "k" "l" "m" "n" "o" "p" "q" "r" "
```

```
month.abb
```

```
## [1] "Jan" "Feb" "Mar" "Apr" "May" "Jun" "Jul" "Aug" "Sep" "Oct" "Nov" "Dec"
```

```
month.name
```

```
## [1] "January" "February" "March" "April" "May" "June" "
```

Special values in R

Some words are **reserved** in R and cannot be used as object/variable/function names:

- Inf and -Inf which respectively stand for positive and negative infinity. R will return this value if results are numbers that are too big.

```
2^1024
```

```
## [1] Inf
```

```
-1/0
```

```
## [1] -Inf
```

- NULL denotes a null object and is often used as a default value of an argument in a function definition, e.g.:

```
f1 <- function(arg1, arg2 = NULL) {  
  print(paste("Argument 1 is:", arg1))  
  if(!is.null(arg2))  
    print(paste("Argument 2 is:", arg2))  
}
```

Special values in R

- NA represents a missing value (“not available”).

```
v <- c(1, 2, 3)
length(v) <- 4

# R automatically fills a NA into the end of `v` as no value is provided.
v
```

```
## [1] 1 2 3 NA
```

- NaN means ‘Not a Number’, and can result from a computation that is undefined:

```
0/0
```

```
## [1] NaN
```

```
1/0 - 1/0
```

```
## [1] NaN
```


Values

In computer science a value is an **expression which cannot be evaluated any further**.

For example, an expression $2 + 3$ is not a value as it can be reduced to expression 5.

Examples of values:

2, 1057, "Hello world!", "01/20/2016", Inf, TRUE

Values have types ...

Data types

The values in R are limited to **only 6 types**:

- **Logical:** TRUE/FALSE
- **Numeric:** 12.4, 30, 2, 1009, 3.141593
- **Integer:** 2L, 34L, -21L, 0L
- **Complex:** 3 + 2i, -10 - 4i
- **Character:** 'a', '23.5', "good", "Hello world!", "TRUE"
- **Raw** (used to hold raw bytes):
as.raw(TRUE), as.raw(2), charToRaw("Hello")

An atomic vector (one-element vector) is the simplest object in R, and it must belong to one of these 6 types.

Fortunately, R supports more complicated, R-objects which are **built upon these atomic vectors**.

Variables

- In computer programs, **variables** are used to store various information.
- Variables are nothing but **reserved memory locations** for storing values.
- In contrast to other programming languages like C or java, **in R the variables are NOT declared as some data type/class** (e.g. vectors, lists, data-frames).
- When variables are assigned with R-Objects, **the data type of the R-object becomes the data type of the variable.**

Naming variables

- A valid variable name consists of letters, numbers and a dot or underline characters.
- The variable name must start with a letter or a dot not followed by a number.

Examples of:

- valid variable names:

`var_name`, `_var2_name`, `.var_name` , `var.name3`.

- invalid variable names:

`var_name%`, `var.name!`, `2var_name`, `.2var_name`

Variable assignment

Variable assignment can be done using the following operators: =, <- , ->:

```
# Assignment using equal operator.  
var.1 = 34759  
  
# Assignment using leftward operator.  
var.2 <- "learn R"  
  
# Assignment using rightward operator.  
TRUE -> var.3
```

The values of the variables can be printed with `print()` function, or `cat()`.

```
print(var.1)
```

```
## [1] 34759
```

```
cat("var.2 is ", var.2)
```

```
## var.2 is learn R
```

```
cat("var.3 is ", var.3 , "\n")
```

```
## var.3 is TRUE
```

Variable class

R is a **dynamically typed language**, which means that we can change a variable data type of the same variable again and again when using it in a program.

```
var_x <- "Hello"  
cat("The class of var_x is", class(var_x), "\n")
```

```
## The class of var_x is character
```

```
var_x <- 34.5  
cat(" Now the class of var_x is ", class(var_x), "\n")
```

```
## Now the class of var_x is numeric
```

```
var_x <- 27L  
cat(" Next the class of var_x becomes ", class(var_x), "\n")
```

```
## Next the class of var_x becomes integer
```

You can see what variables are **currently available in the workspace** by calling

```
print(ls())
```

```
## [1] "f1" "v" "var.1" "var.2" "var.3" "var_x"
```

Data structures

There are many types/classes of R-objects, but **the most frequently used data structures are:**

- Vectors
- Matrices
- Arrays
- List
- Data frames
- Factors

Vectors

- Vectors are the most basic R data objects. There is no simpler object, e.g. no scalars.
- Even when you write **just one value in R**, it becomes a **vector of length 1** and belongs to one of the vector types: logical, integer, double, complex, character and raw.
- Vectors can be defined using a combine, `c()` function:

```
# Create a vector  
(vec1 <- c(1, 3, 7:12))
```

```
## [1] 1 3 7 8 9 10 11 12
```

```
(vec2 <- c('apple', 'banana', 'tangerine', 'watermelon'))
```

```
## [1] "apple" "banana" "tangerine" "watermelon"
```

```
# Non-character values are coerced to character  
(s <- c('apple', 123.56, 5, TRUE))
```

```
## [1] "apple" "123.56" "5" "TRUE"
```


Numerical sequences

- Can be generated with a `seq()` function:

```
# Create vector with elements from 5 to 9 incrementing by 0.4.  
(v <- seq(5, 9, by = 0.4))
```

```
## [1] 5.0 5.4 5.8 6.2 6.6 7.0 7.4 7.8 8.2 8.6 9.0
```

- or using a colon operator:

```
# Creating a sequence from 5 to 13.  
(v <- 5:13)
```

```
## [1] 5 6 7 8 9 10 11 12 13
```

```
# Colon can be used also for non-integers (still increments of 1)  
(v <- 6.6:12.6)
```

```
## [1] 6.6 7.6 8.6 9.6 10.6 11.6 12.6
```

```
# If the final element specified does not belong to the sequence then it is discarded  
(v <- 3.8:11.4)
```

```
## [1] 3.8 4.8 5.8 6.8 7.8 8.8 9.8 10.8
```

Accessing vector elements

- Elements of a vector can be accessed using indexing, with `[]` brackets.
- Unlike in many languages, in R indexing starts with **1**.
- Using negative integer value indices drops corresponding element of the vector.
- Logical indexing (TRUE/FALSE) is allowed.

```
days <- c("Sun", "Mon", "Tue", "Wed", "Thurs", "Fri")  
  
# Accessing vector elements using position.  
(weekend.days <- days[c(1, 7)])
```

```
## [1] "Sun" "Sat"
```

```
# Accessing vector elements using negative index  
(week.days <- days[c(-1, -7)])
```

```
## [1] "Mon" "Tue" "Wed" "Thurs" "Fri"
```

```
# Accessing vector elements using logical indexing  
(my.birthday <- days[c(FALSE, FALSE, FALSE, FALSE, TRUE)])
```

```
## [1] "Thurs"
```

Vector arithmetics

Two vectors of same length can be added, subtracted, multiplied or divided giving an output vector of the same length.

```
# Create two vectors.  
v1 <- c(1,4,7,3,8,15)  
v2 <- c(12,9,4,11,0,8)
```

```
# Vector addition.  
(vec.sum <- v1+v2)
```

```
## [1] 13 13 11 14 8 23
```

```
# Vector subtraction.  
(vec.difference <- v1-v2)
```

```
## [1] -11 -5 3 -8 8 7
```

```
# Vector multiplication.  
(vec.product <- v1*v2)
```

```
## [1] 12 36 28 33 0 120
```

```
# Vector division.  
(vec.ratio <- v1/v2)
```

```
## [1] 0.08333333 0.44444444 1.75000000 0.27272727      Inf 1.87500000
```

Recycling

- **Recycling** is an automatic lengthening of vectors in certain settings.
- If an operator (such as +, -, or ^) is applied to two vectors of different lengths, R will repeat the shorter vector until the length of the longer vector is reached.

```
# The number '3' can be thought of as a vector of length one.  
3 + 1:6
```

```
## [1] 4 5 6 7 8 9
```

```
# Add 1 to every other number from 1 to 6.  
0:1 + 1:6
```

```
## [1] 1 3 3 5 5 7
```

```
# Multiply two vectors of unequal lengths.  
1:3 * 1:5
```

```
## Warning in 1:3 * 1:5: longer object length is not a multiple of shorter object
```

```
## [1] 1 4 9 4 10
```

Note: a warning is not an error. It only informs you that your code continued to but perhaps it did not work as you intended.

Matrices

- Matrices in R are objects whose elements are arranged in a **two-dimensional rectangular layout**.
- **All elements must be of the same type** (numeric, logical, character, etc.).
The most frequently used are **numeric matrices**.

Matrices

A matrix can be created with a function

```
matrix(data, nrow, ncol, byrow, dimnames)
```

where:

- data is the input vector with elements of the matrix.
- nrow is the number of rows to be created
- byrow is a logical value. If FALSE (the default) the matrix is filled by columns, otherwise the matrix is filled by rows.
- dimnames is NULL or a list of length 2 giving the row and column names

```
# Elements are arranged sequentially by  
(M <- matrix(c(5:19), nrow = 3, byrow
```

```
##      [,1] [,2] [,3] [,4] [,5]  
## [1,]    5    6    7    8    9  
## [2,]   10   11   12   13   14  
## [3,]   15   16   17   18   19
```

```
# Elements are arranged sequentially by  
(N <- matrix(c(5:19), nrow = 3, byrow
```

```
##      [,1] [,2] [,3] [,4] [,5]  
## [1,]    5    8   11   14   17  
## [2,]    6    9   12   15   18  
## [3,]    7   10   13   16   19
```

```
# Define the column and row names.  
rownames <- c("row1", "row2", "row3")  
colnames <- c("col1", "col2", "col3",  
(P <- matrix(c(5:19), nrow = 3, byrow  
              dimnames = list(rownames,
```

```
##      col1 col2 col3 col4 col5  
## row1     5     6     7     8     9  
## row2    10    11    12    13    14  
## row3    15    16    17    18    19
```


respectively

a Matrix

```
P
```

```
##      col1 col2 col3 col4 col5
## row1     5     6     7     8     9
## row2    10    11    12    13    14
## row3    15    16    17    18    19
```

```
P[2, 5] # the element in 2nd column and 5th row
```

```
## [1] 14
```

```
P[2, ] # the 2nd row.
```

```
## col1 col2 col3 col4 col5
##    10    11    12    13    14
```

```
P[, 3] # the 3rd column.
```

```
## row1 row2 row3
##     7    12    17
```

Accessing Elements

```
P[c(3,2), ] # the 3rd and 2nd row.
```

```
##      col1 col2 col3 col4 col5
## row3    15    16    17    18    19
## row2    10    11    12    13    14
```

```
P[, c(3, 1)] # the 3rd and 1st column.
```

```
##      col3 col1
## row1     7     5
## row2    12    10
## row3    17    15
```

```
P[1:2, 3:5] # Subset 1:2 row 3:5 column
```

```
##      col3 col4 col5
## row1     7     8     9
## row2    12    13    14
```

Matrix Computations

Matrix addition and subtraction needs matrices of same dimensions:

```
# Create two 2x3 matrices.  
(A <- matrix(c(3, 9, -1, 4, 2, 6), nrow =
```

```
##      [,1] [,2] [,3]  
## [1,]  3  -1   2  
## [2,]  9   4   6
```

```
(B <- matrix(c(5, 2, 0, 9, 3, 4), nrow =
```

```
##      [,1] [,2] [,3]  
## [1,]  5   0   3  
## [2,]  2   9   4
```

```
# Add the matrices.  
A + B
```

```
##      [,1] [,2] [,3]  
## [1,]  8  -1   5  
## [2,] 11  13  10
```

```
# Subtract the matrices  
A - B
```

```
##      [,1] [,2] [,3]  
## [1,] -2  -1  -1  
## [2,]  7  -5   2
```

Matrix Computations

Matrix **elementwise multiplication** and **division** needs matrices of same dimensions:

```
# Add the matrices.  
A * B
```

```
##      [,1] [,2] [,3]  
## [1, ]  15   0   6  
## [2, ]  18  36  24
```

```
# Subtract the matrices  
A / B
```

```
##      [,1]      [,2]      [,3]  
## [1, ]  0.6      -Inf  0.6666667  
## [2, ]  4.5  0.4444444  1.5000000
```

Matrix Algebra

Linear algebra: *true matrix multiplication* $A \times B$, with A ($m \times p$) and B ($p \times n$):

$(AB)_{ij} = \sum_{k=1}^p A_{ik}B_{kj}$ can be done using the `%*%` operator:

```
# A (2 x 3) matrix X
(X <- matrix(c(3, 9, -1, 4, 2, 6), nrow
```

```
##      [,1] [,2] [,3]
## [1,]    3   -1    2
## [2,]    9    4    6
```

```
# A (3 x 4) matrix Y
(Y <- matrix(c(5, 2, 0, 9, 3, 4, 5, 6, 7
```

```
##      [,1] [,2] [,3] [,4]
## [1,]    5    9    5   11
## [2,]    2    3    6    3
## [3,]    0    4    7    4
```

```
# a matrix product is a (2 x 4) matrix
X %*% Y
```

```
##      [,1] [,2] [,3] [,4]
## [1,]   13   32   23   38
## [2,]   53  117  111  135
```

More on matrix algebra operations
(<http://www.statmethods.net/advsta>)

Arrays

- Arrays are the R data objects which can store **data in more than two dimensions**.
- For example, an array of dimension (4, 3, 2) i.e. 4 rows and 3 columns and 2 tables.
- Arrays can store **only one data type**.
- An array is created using the `array()` function.
- Accessing and subsetting elements of an arrays is similar to accessing elements of a matrix.

```
vec <- sample(1:10000, 2*3*4)
row.names <- c("ROW1", "ROW2", "ROW3", "ROW4")
column.names <- c("COL1", "COL2", "COL3")
matrix.names <- c("Matrix1", "Matrix2")

(arr <- array(vec, dim = c(4, 3, 2), dimnames = list(row.names, column.names, matrix.names)))
```

```
##      , , Matrix1
##
##      COL1 COL2 COL3
## ROW1  7399 6382  156
## ROW2  3524 5290 1612
## ROW3   855 3544 8393
## ROW4  2683 8579 6874
##
##      , , Matrix2
##
##      COL1 COL2 COL3
## ROW1  9231 5100  570
## ROW2  5015  768 1837
## ROW3  1411 1347 9157
## ROW4  1424 6063  248
```

Lists

- In R lists can **contain elements of different types**
e.g. numbers, strings, vectors and/or another list.
- A list can also contain matrices or functions as its elements.
- List is created using `list()` function.

```
# Create a list containing heterogeneous elements
(my.list <- list(c("Jan", "Feb", "Mar"), TRUE,
                matrix(c(3, 9, 5, 1, -2, 8), nrow = 2),
                list("green", 12.3)))
```

```
## [[1]]
## [1] "Jan" "Feb" "Mar"
##
## [[2]]
## [1] TRUE
##
## [[3]]
##      [,1] [,2] [,3]
## [1,]    3    5   -2
## [2,]    9    1    8
##
## [[4]]
## [[4]][[1]]
## [1] "green"
##
## [[4]][[2]]
## [1] 12.3
```

Lists

```
# Create named list
(named.list <- list(first = "Jane",
                    last = "Doe",
                    gender = "Female",
                    yearOfBirth = 1990))
```

```
## $first
## [1] "Jane"
##
## $last
## [1] "Doe"
##
## $gender
## [1] "Female"
##
## $yearOfBirth
## [1] 1990
```

```
student <- list("John", "Smith", "Bioengineering",
               2019, TRUE)
```

```
# Name elements of grades
names(student) <- c("first", "last", "major",
                  "grad_year", "enrolled")
student
```

```
## $first
## [1] "John"
##
## $last
## [1] "Smith"
##
## $major
## [1] "Bioengineering"
##
## $grad_year
## [1] 2019
##
## $enrolled
## [1] TRUE
```

Accessing elements of a list

- Elements of the list can be accessed **by the index** of the element in the list.
- In case of named lists it can also be accessed **using the names**.

```
# Get the third element of the list  
student[[3]]
```

```
## [1] "Bioengineering"
```

```
# Get the same information using named element  
student$major
```

```
## [1] "Bioengineering"
```

```
# Get the first and the third element of the list  
student[c(1, 3)]
```

```
## $first  
## [1] "John"  
##  
## $major  
## [1] "Bioengineering"
```


Data-frames

A data frame is a table or a **2D array-like structure**. In data-frames:

- Columns can be store data of different types e.g. logical, numeric, character.
- Each column must contain the same number of data items.
- The column names should be non-empty.
- The row names should be unique.

```
# Create the data frame.
employees <- data.frame(row.names = c("E1", "E2", "E3", "E4", "E5"),
  name = c("Rick", "Dan", "Michelle", "Ryan", "Gary"),
  salary = c(623.3, 515.2, 611.0, 729.0, 843.25),
  start_date = as.Date(c("2012-01-01", "2013-09-23", "2014-11-15", "2014-05-11", "2015-03-27"),
    stringsAsFactors = FALSE)
```

```
# Print the data frame.
employees
```

```
##      name salary start_date
## E1    Rick 623.30 2012-01-01
## E2     Dan 515.20 2013-09-23
## E3 Michelle 611.00 2014-11-15
## E4     Ryan 729.00 2014-05-11
## E5     Gary 843.25 2015-03-27
```

```
# Get the structure of the data frame.
str(employees)
```

```
## 'data.frame':    5 obs. of  3 variables:
## $ name          : chr  "Rick" "Dan" "Michelle" "Ryan" "Gary"
## $ salary         : num  623 515 611 729 843
## $ start_date     : Date, format: "2012-01-01" "2013-09-23" "2014-11-15" "2014-05-11" "2015-03-27"
```

Data-frames

We can print the first few rows of a data matrix using a function `head ()`

```
# Print first 2 rows of employees  
head(employees, 2)
```

```
##      name salary start_date  
## E1 Rick   623.3 2012-01-01  
## E2  Dan   515.2 2013-09-23
```

A very useful function `summary ()` gives a statistical summary of the data stored in the data.frame objects

```
# Print the summary.  
summary(employees)
```

```
##      name      salary      start_date  
## Length:5      Min.      :515.2      Min.      :2012-01-01  
## Class :character 1st Qu.:611.0      1st Qu.:2013-09-23  
## Mode  :character Median :623.3      Median :2014-05-11  
##          Mean      :664.4      Mean      :2014-01-14  
##          3rd Qu.:729.0      3rd Qu.:2014-11-15  
##          Max.      :843.2      Max.      :2015-03-27
```

The elements of a data frame can be accessed by indexing just like the elements of a matrix

matrix.

Subsetting data-frames

- We can extract specific columns:

```
# using column names.
employees$name
employees[, c("name", "salary")]

# using integer indexing
employees[, 1]
employees[, c(1, 2)]
```

```
## [1] "Rick"      "Dan"      "Michelle" ' '
```

```
##      name salary
## E1    Rick  623.30
## E2     Dan  515.20
## E3 Michelle 611.00
## E4     Ryan  729.00
## E5      Gary  843.25
```

- We can extract specific row:

```
# using row names.
employees["E1", ]
employees[c("E2", "E3"), ]

# using integer indexing
employees[1, ]
employees[c(2, 3), ]
```

```
##      name salary start_date
## E1 Rick    623.3 2012-01-01
```

```
##      name salary start_date
## E2     Dan  515.2 2013-09-23
## E3 Michelle 611.0 2014-11-15
```

Adding data to data-frames

- We can add a column to a data matrix simply by assignment
- Adding a row to a data frame can be done with `rbind()` function

```
# Add the "dept" column.
employees$dept <-
  c("IT", "Operations", "IT", "HR", "Finance")
employees
```

```
##      name salary start_date dept
## E1    Rick 623.30 2012-01-01  IT
## E2     Dan 515.20 2013-09-23 Operations
## E3 Michelle 611.00 2014-11-15  IT
## E4    Ryan 729.00 2014-05-11  HR
## E5     Gary 843.25 2015-03-27  Finance
```

```
# Create the second data frame
new.employees <-
  data.frame(row.names = paste0("E", 6:11),
             name = c("Rasmi", "Pranab", "Tusar", "Rasmi", "Pranab", "Tusar"),
             salary = c(578.0, 722.5, 632.8, 578.0, 722.5, 632.8),
             start_date = as.Date(c("2013-05-21", "2013-07-30", "2014-06-17",
                                     "2013-05-21", "2013-07-30", "2014-06-17")),
             dept = c("IT", "Operations", "IT", "Operations", "IT", "Operations"),
             stringsAsFactors = FALSE)

# Concatenate two data frames.
(all.employees <- rbind(employees, new.employees))
```

```
##      name salary start_date dept
## E1    Rick 623.30 2012-01-01  IT
## E2     Dan 515.20 2013-09-23 Operations
## E3 Michelle 611.00 2014-11-15  IT
## E4    Ryan 729.00 2014-05-11  HR
## E5     Gary 843.25 2015-03-27  Finance
## E6     Rasmi 578.00 2013-05-21  IT
## E7    Pranab 722.50 2013-07-30 Operations
## E8     Tusar 632.80 2014-06-17  IT
```

Factors

- Factors are used to **categorize the data and store it as levels.**
- They are useful for variables which take on a limited number of unique values, e.g
`c("bad", "average", "good")`
`c("Male", "Female")`,
`c("yes", "no")` etc.
- Factors are created using the `factor()` function.

```
month.name
```

```
## [1] "January" "February" "March"
```

```
is.factor(month.name)
```

```
## [1] FALSE
```

```
# Apply a factor() function.  
(months.factor <- factor(month.name))
```

```
## [1] January February March April  
## Levels: April August December February J
```

```
is.factor(months.factor)
```

```
## [1] TRUE
```

Factors ordering

- If not specified R will order character type by alphabetical order.
- Note that factor **labels** are not the same as **levels**.

```
months <- sample(month.name, 6)  
months
```

```
## [1] "July"      "May"      "April"    "November" "September" "February"
```

```
(months <- factor(months, levels = month.name))
```

```
## [1] July      May      April    November September February  
## Levels: January February March April May June July August September October November
```

```
(months <- factor(months, levels = month.name, ordered = TRUE))
```

```
## [1] July      May      April    November September February  
## Levels: January < February < March < April < May < June < July < August < September
```

```
(months <- factor(months, levels = month.name, labels = month.abb))
```

```
## [1] Jul May Apr Nov Sep Feb  
## Levels: Jan < Feb < Mar < Apr < May < Jun < Jul < Aug < Sep < Oct < Nov < Dec
```

Dates

- R makes it easy to work with dates.

```
x <- seq(from = as.Date('Jan 01, 2004'),  
         to   = as.Date('2004-12-31'), by =  
         table(months(x)))
```

```
##  
##      April      August    December    Februar  
##          30          31          31          2
```

```
which(x == '2004-09-01')
```

```
## [1] 245
```

```
length(x)
```

```
## [1] 366
```

```
# Leap year!
```

- You can check the presentdate/time by calling:

```
# What day is it?  
Sys.Date()
```

```
## [1] "2017-10-23"
```

```
Sys.time() # What time is it?
```

```
## [1] "2017-10-23 17:07:45 PDT"
```

```
# Number of days until the end of the year  
as.Date('2017-12-31') - Sys.Date()
```

```
## Time difference of 69 days
```

- Look up `strptime()` function with `?strptime` command to see a list of possible date formatting.

Course Objectives & Organization

Course Logistics

- Lectures: Tue, Thu 12:00 PM - 1:20 PM, 300-300
- Office hours: Thu 3PM, Huang 304
- Class website: <https://cme195.github.io/>
- Homework submission: <https://canvas.stanford.edu/>
- Questions/Communication: <https://canvas.stanford.edu/>

Topics Covered

- Data types (e.g. logical, numeric, character)
- Data structures (e.g. vector, matrix, lists, data frames)
- Variable assignment and manipulations
- File input/output (reading and writing files).
- Functions (function calling and definition)
- `apply`, `lapply`, `sapply`, `mapply` functions
- Data processing using `dplyr`, `tidyr`
- 2D, 3D plotting
- interactive plotting
- Supervised learning methods
- Unsupervised learning methods

Course Expectations

There are no formal pre-requisites, but some prior **knowledge of statistics and programming experience** is strongly encouraged.

During the course you will learn about some statistical methods. They will be briefly explained, but the mathematics or the technical details on the algorithm won't be discussed.

Instead, I will show you how to perform the tasks using the R implementation of these methods. You will learn how to input the data, set parameters, and interpret the output of the methods.

Work Load

- two homework assignments (due a week after posted)
- a final group (up to 3 people) project

Final Project

- Choose a project that is interesting and allows you to practice your R skills.
- You are welcome to choose a project related to your own research.
- Your project should incorporate methods learnt from the course, but you are encouraged to use tools and packages not covered in class.
- Proposal (title and one-paragraph abstract) due **(10/24)** by the end of class.
- Final write-up due a week after the last class **(11/03)**.

Final Project

Final project should involve **an extensive use of R**. Focus on the programming part, not on answering the research question. Project Ideas:

- **Sports data.** e.g. decide which basketball player would you want on your team?
- **Financial data.** Perform time-series analysis of stock returns, or construct optimal portfolios for a set of equities.
- **Credit card data.** Detect fraudulent transactions.
- **Twitter data.** Use the content of the posts to perform activity and sentiment analysis.
- **User preference data.** e.g. develop a movie recommender system.
- **Cities/States data.** e.g. identify the best and worst neighborhoods to live in, or predict when/where crimes occur.

- **Biological data.** Tons of possibilities including differential gene expression, single cell, flow cytometry, mass spectrometry, image data analysis.