Lecture 1: Introduction to R

CME/STATS 195

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Course Objectives & Organization

Course Logistics

CME/STATS 195 will run for 4 weeks: 09/27-10/23/2018

- Lectures: Tue, Thu 12:00 PM - 1:20 PM, Building 200 room 034
- Office hours: Mon 4PM, Huang (Basement) Student Area
- Class website: https://cme195.github.io/
- Homework submission: https://canvas.stanford.edu/
- Questions/Communication: https://canvas.stanford.edu/

Grading (Satisfactory/No Credit):

- Homework assignments (40%)
- (Group) final project (40%)
- Participation (20%)

Assignments

Homework:

- work individually
- due the 3rd week of class

Final project:

- work in groups up to 4 students
- title and abstract due the 3rd week of class
- final report and R code due one week after the last class
- details can be found on class website

Late day policy:

- no later than 5 days post due date; 10% penalty per day

Pre-requisites and expectations

No formal pre-requisites, but you should have some prior knowledge of statistics and some programming experience.

The goal of this course is for you to:

- familiarize yourself with R
- learn how to do interesting and practical things quickly in R
- start using R as a powerful tool for data science

We will NOT learn:

- computer programming
- statistics
- big data

This is a short course, so you will not learn everything about R.

Topics Covered

- R Basics: data types and structures, variable assignment etc.
- R as a programming language: syntax, flow control, iteration, functions.
- Importing and tidying data.
- Processing and transforming data with `dplyr`.
- Visualizing data with `ggplot2`.
- Exploratory data analysis (EDA)
- Elements of statics: modeling, predicting and testing.
- Some R tools for supervised & unsupervised learning.
- Generating R Markdown reports for efficient communication.

The R language

What is R?

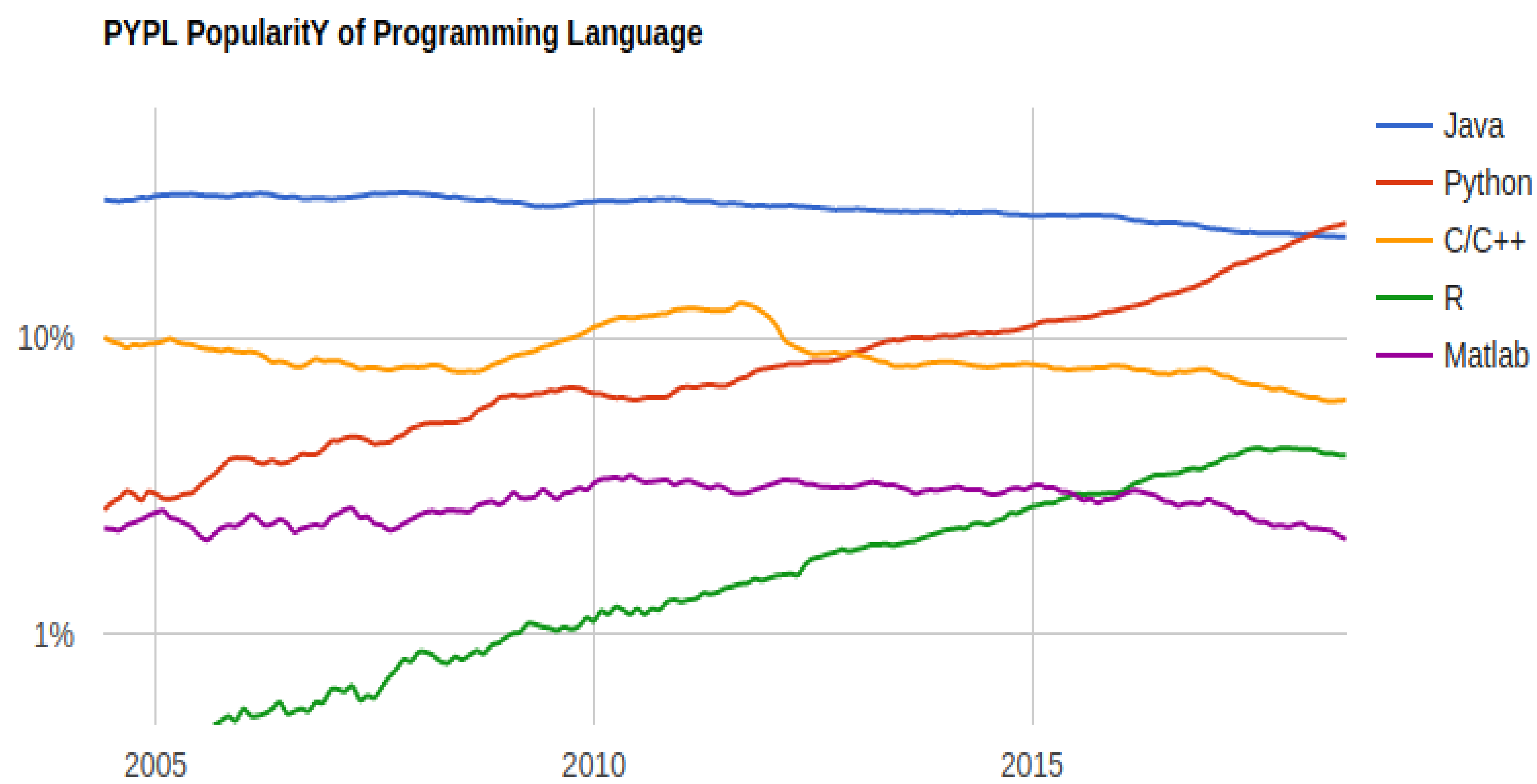
- R was created by Rob Gentleman and Ross Ihaka in 1994; it is based on the S language developed at Bell Labs by John Chambers (Stanford Statistics).
- It is **an open-source language and environment** for statistical computing and graphics.

- R offers:
  - A simple and effective programming language.
  - A data handling and storage facility.
  - A suite of libraries for matrix computations.
  - A large collection of tools for data analysis.
  - Facilities for generating high-quality graphics and data display.

- R is **highly extensible**, but remains **a fully planned and coherent system**, rather than an incremental accumulation of specific and inflexible tools.

Who uses R?

Traditionally, academics and researchers. However, recently R has expanded also to industry and enterprise market. Worldwide usage on log-scale:



Source: http://pypl.github.io/PYPL.html

The PYPL Index is created by analyzing how often language tutorials are searched on Google (generated using raw data from Google Trends).

Why should you learn R?

Pros:

- Open source and cross-platform.
- Created with statistics and data in mind; new ideas and methods in statistics usually appear in R first.
- Provides a wide range of high-quality packages for data analysis and visualization.
- Arguably, the most commonly used language by data scientists

Cons:

- Performance/Scalability: low speed, poor memory management.
- Some packages are low-quality and provide no support.
- A unconventional syntax and a few unusual features compared to other languages.

A few alternatives to R:

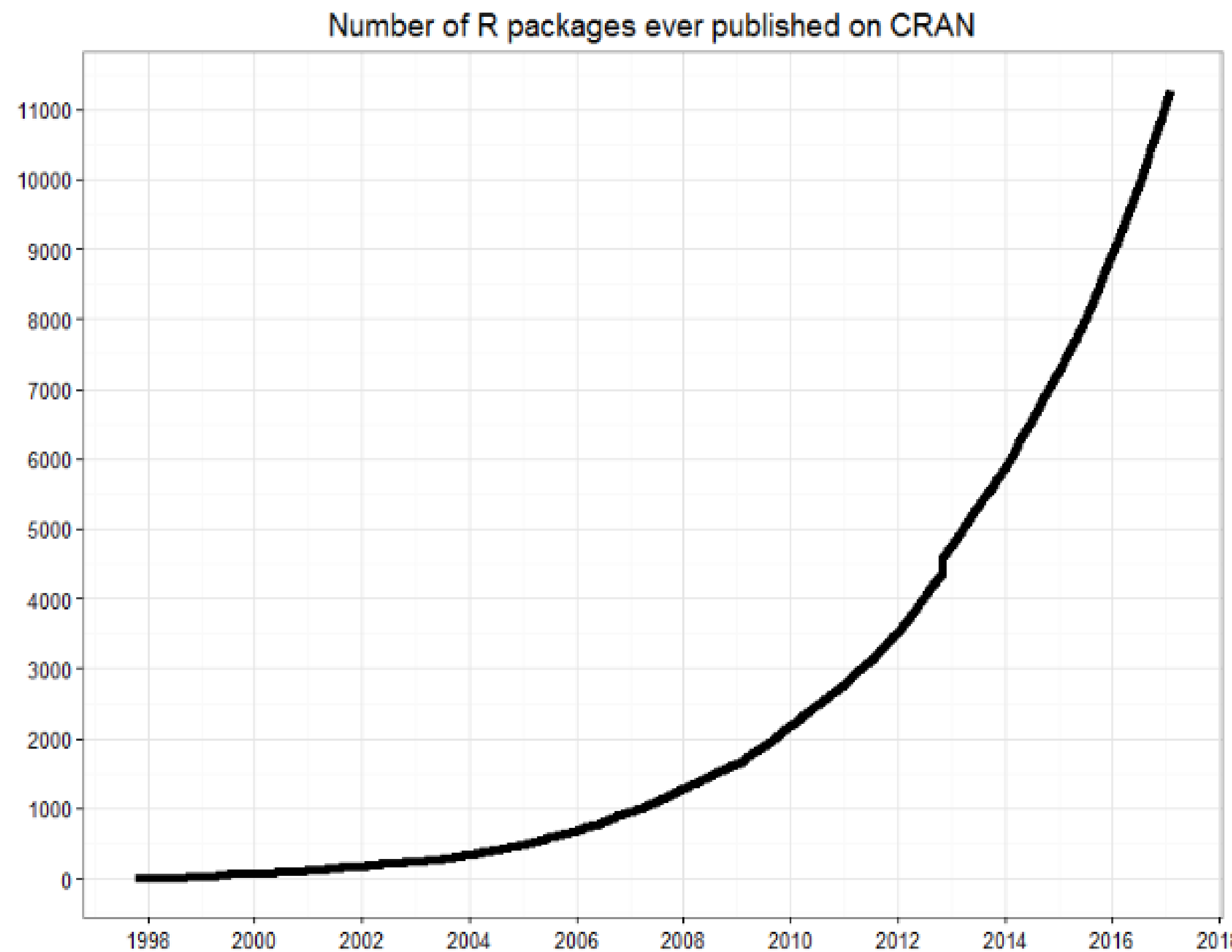
- **Python:** fastest growing, general-purpose programming, with data science libraries.
- **SAS:** used for statistical analysis; commercial and expensive, slower development.
- **SQL:** designed for managing data held in a relational database management system.
- **MATLAB:** proprietary, mostly for numerical computing, and matrix computations.

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 passe 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?

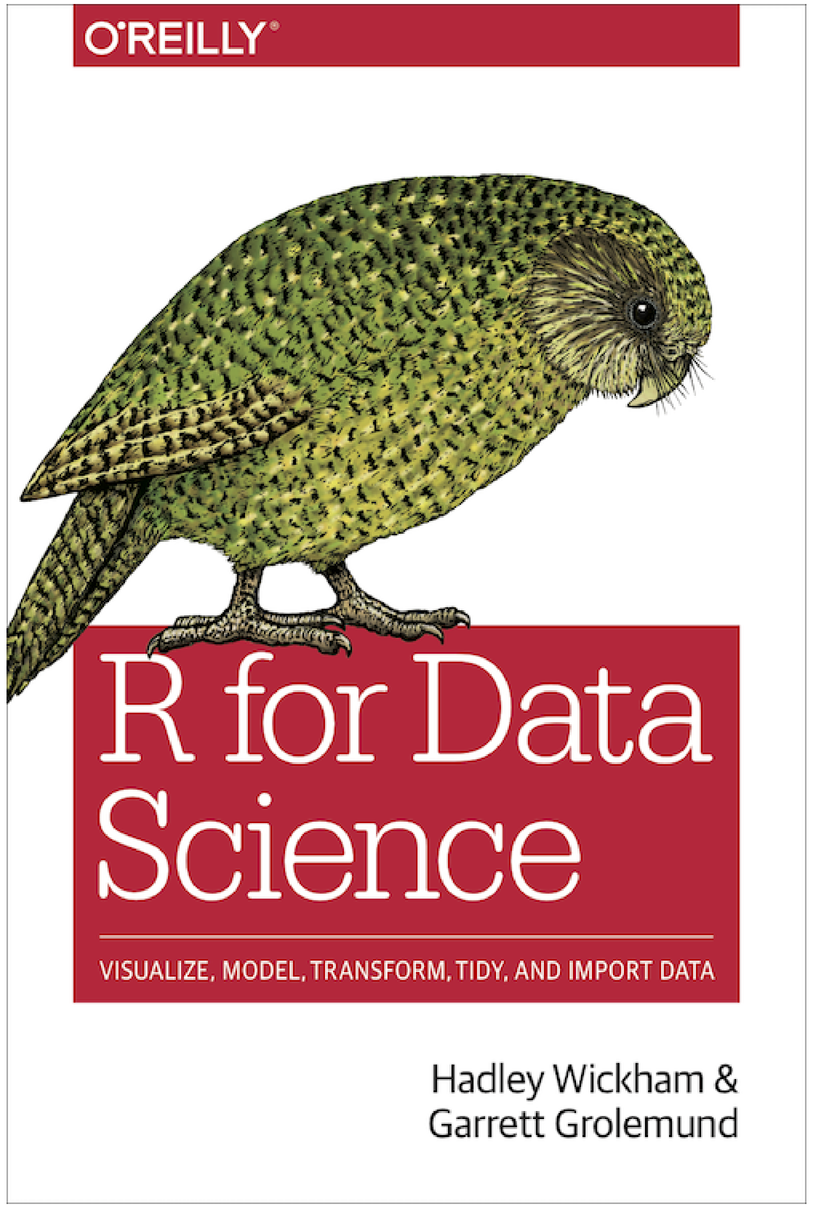
As of September 29, there are 13,083 packages on CRAN, 1,560 on Bioconductor, and many others on github)



Source: http://blog.revolutionanalytics.com/

“Textbook”

We will use *R for Data Science* as a primary reference.



Freely available at: http://r4ds.had.co.nz/

Other 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)

Setting up an R environment

Installing R

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

To download it, go to the Comprehensive R Archive Network CRAN website. Download the latest version for your OS and follow the instructions.

Each year a new version of R is available, and 2-3 minor releases. You should update your software regularly.

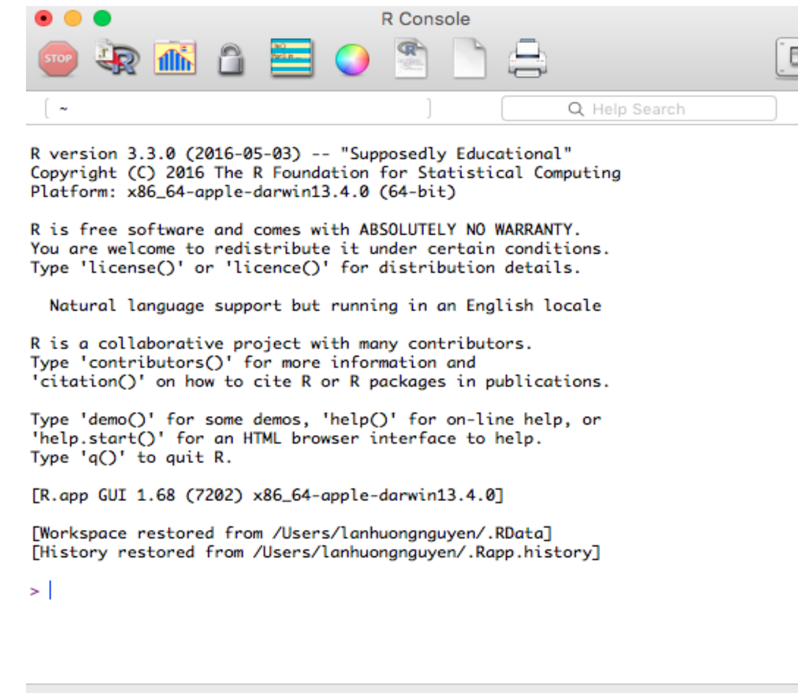
Running R code

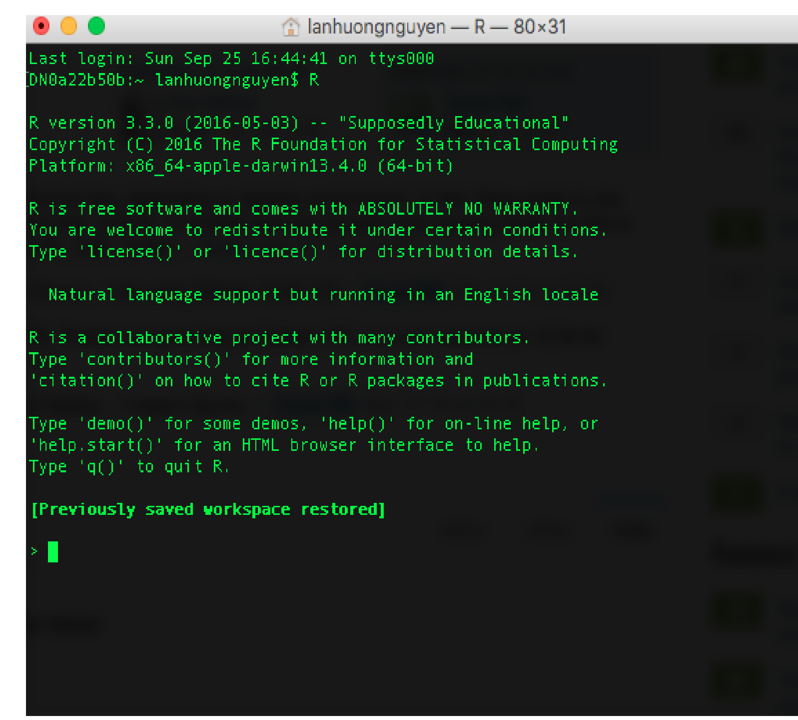
Interpreter mode:

- open a terminal and launch R by calling “R” (or open an R console).
- type R commands interactively in the command line, pressing `Enter` to execute.
- use `q()` to quit R.

Scripting mode:

- write a text file containing all commands you want to run
- save your script as an R script file (e.g. “myscript.R”)
- execute your code from the terminal by calling “Rscript myscript.R”





R editors

The most popular **R editors** are:

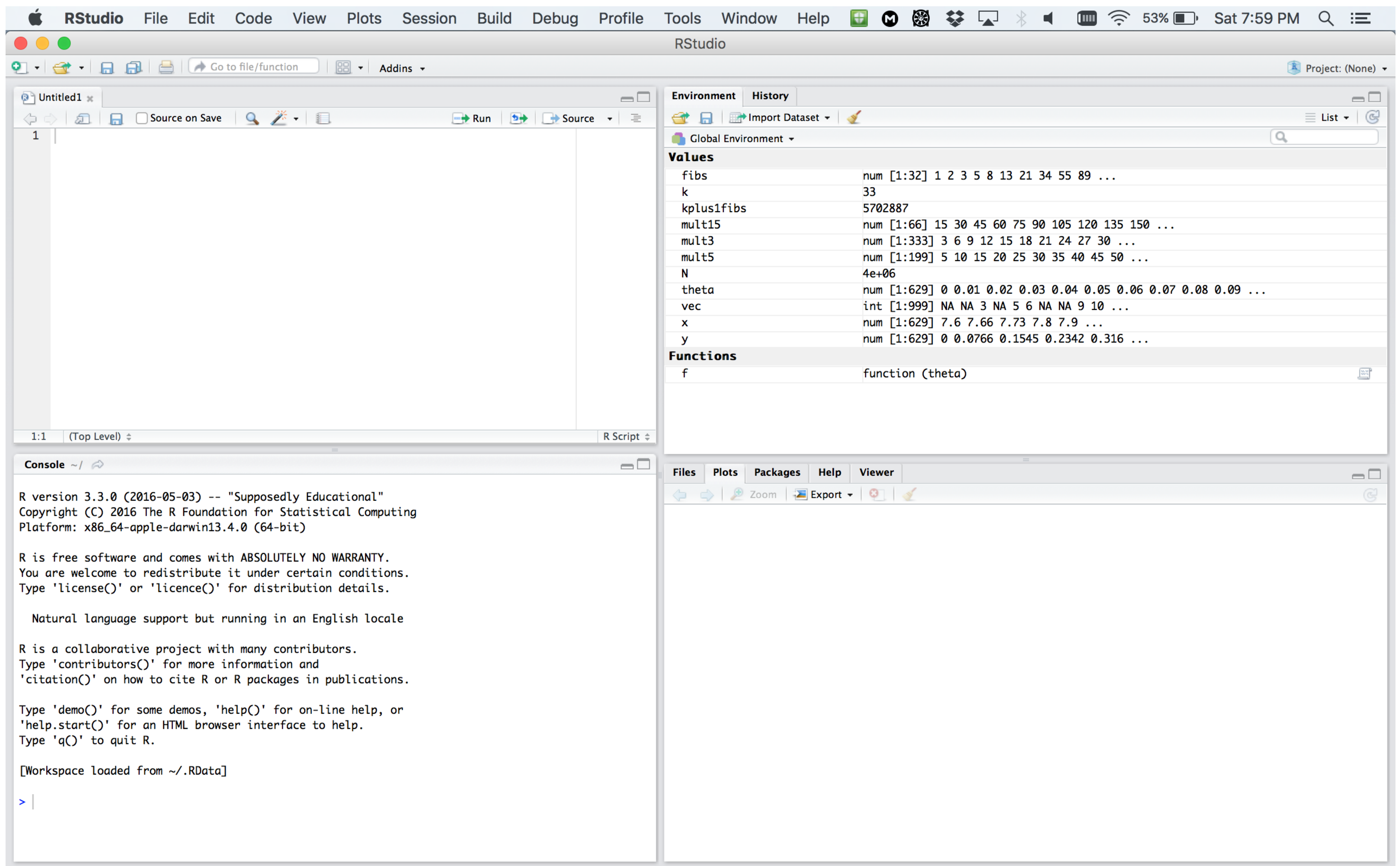
- **Rstudio**, an integrated development environment (IDE) for R.
- **Emacs**, a free, powerful, customizable editor for many languages.

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

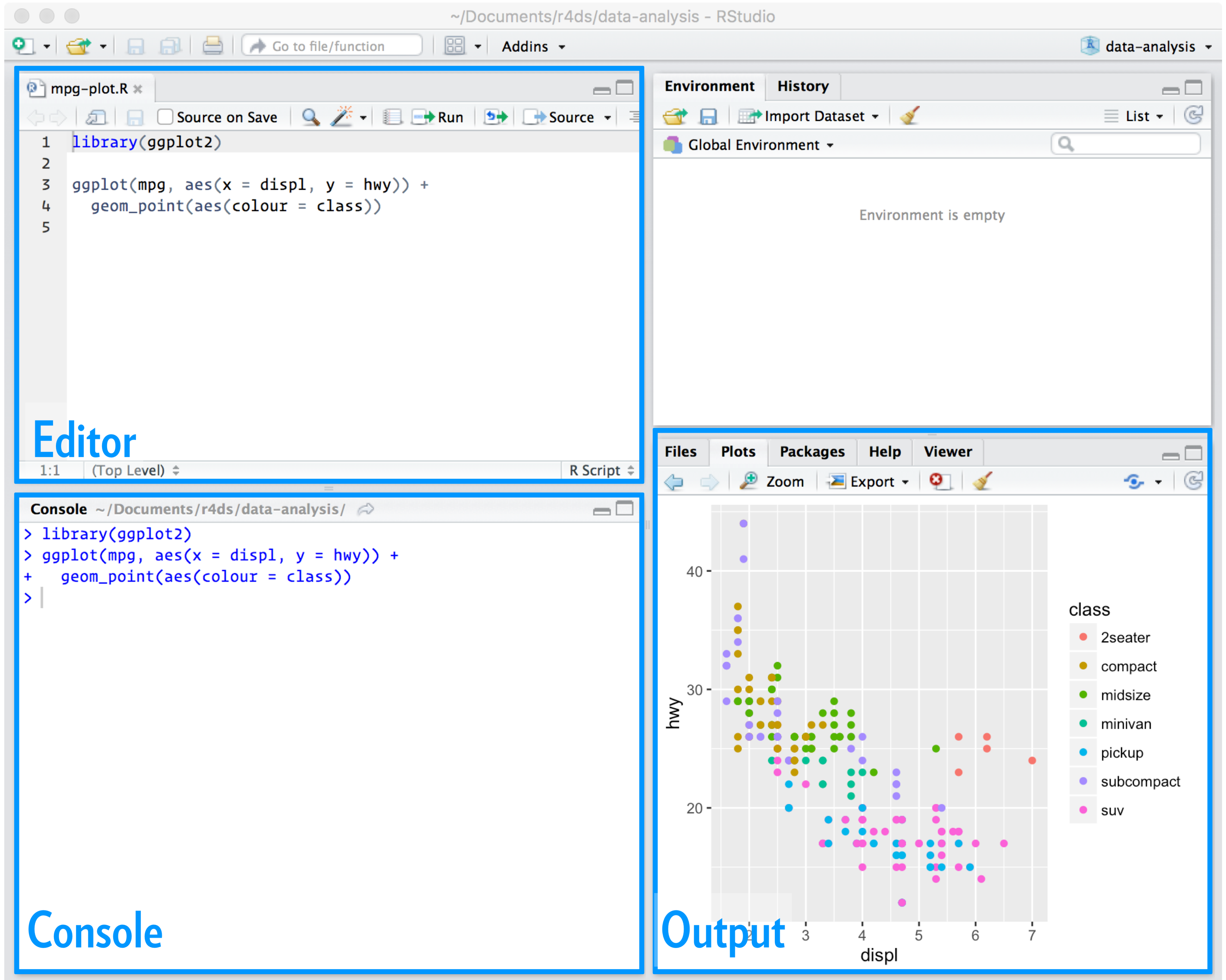
Installing RStudio

RStudio is open-source and cross-platform (Linux, Mac, Windows).

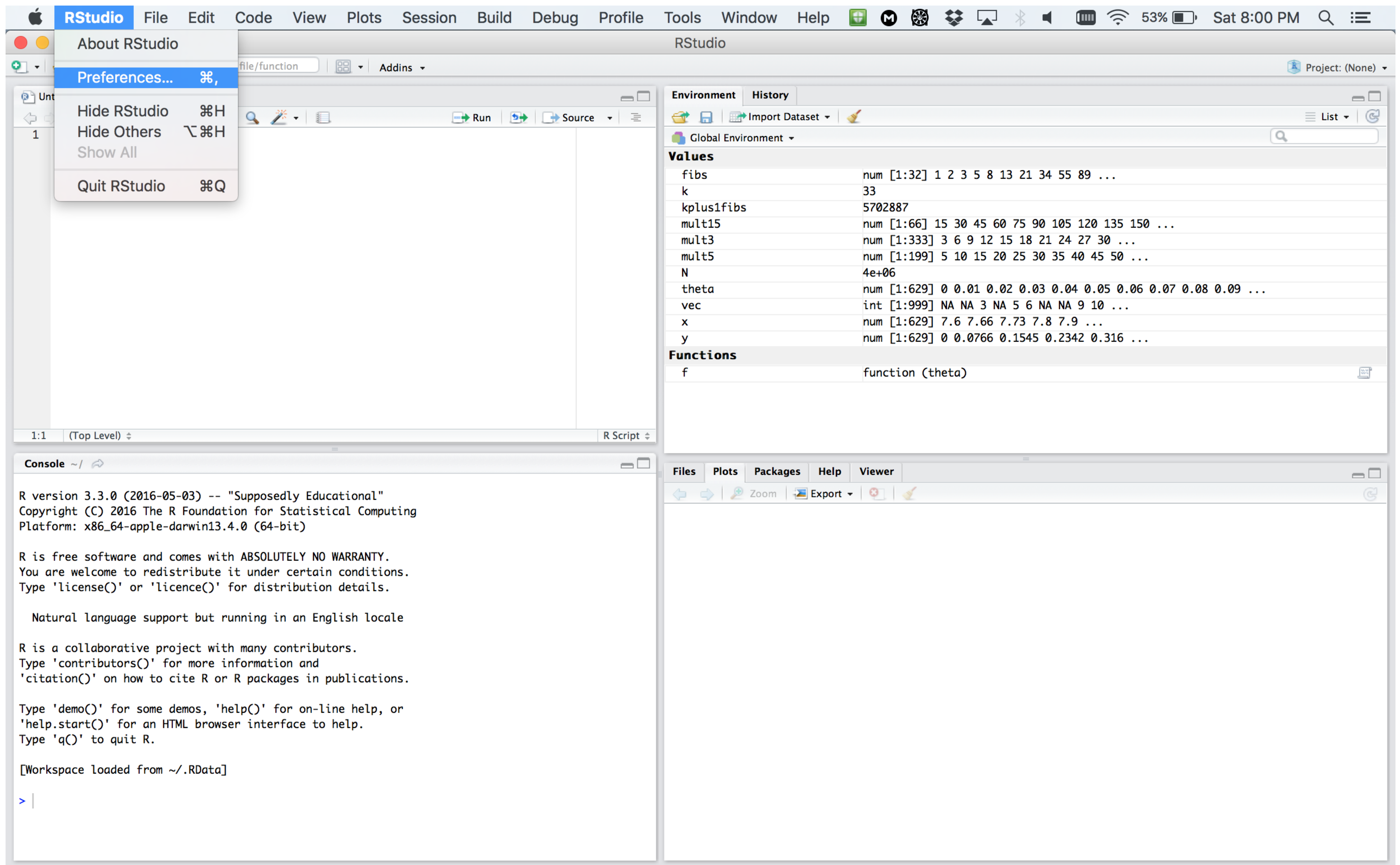
Download and install the latest version for your OS from the official website.



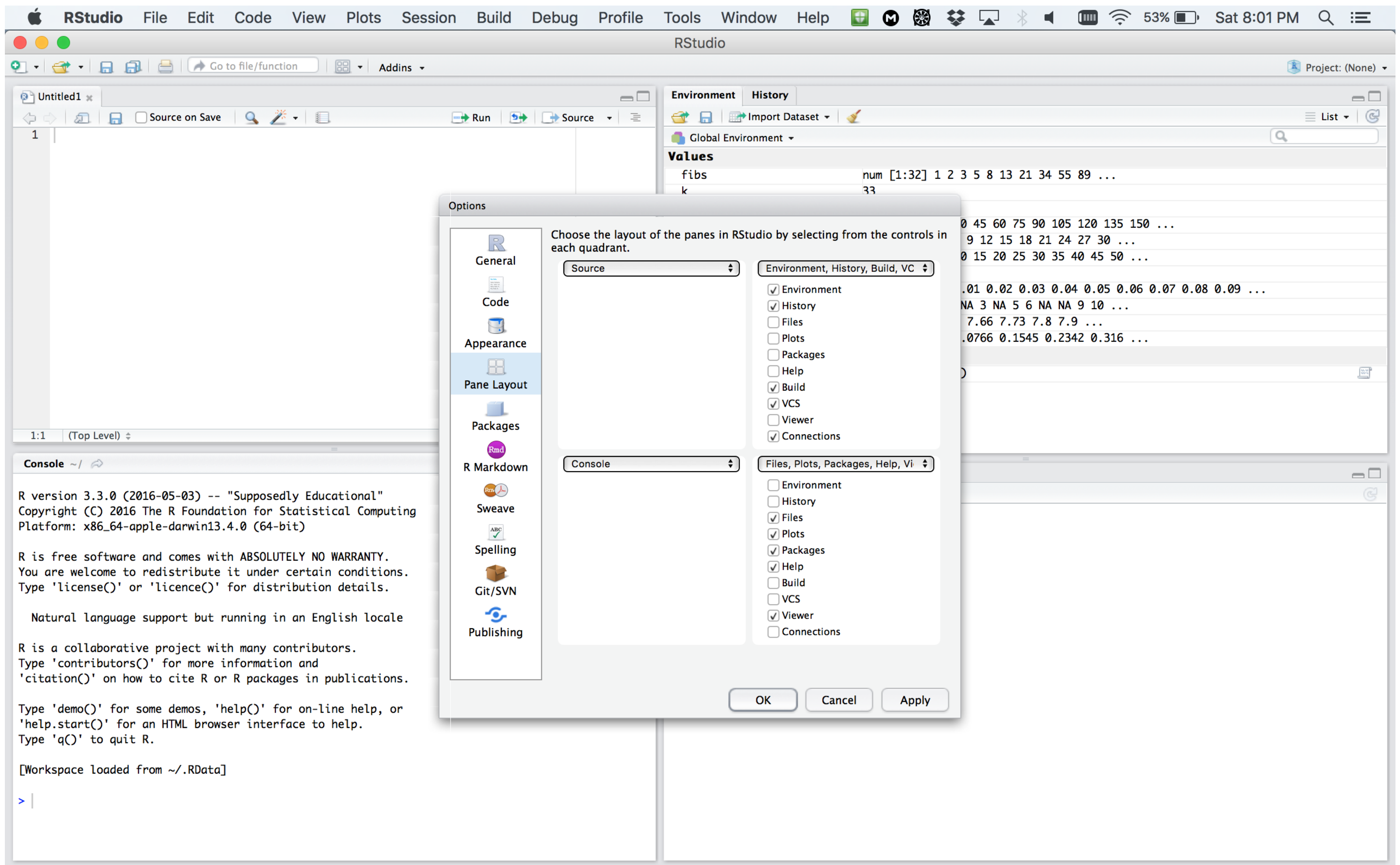
RStudio window



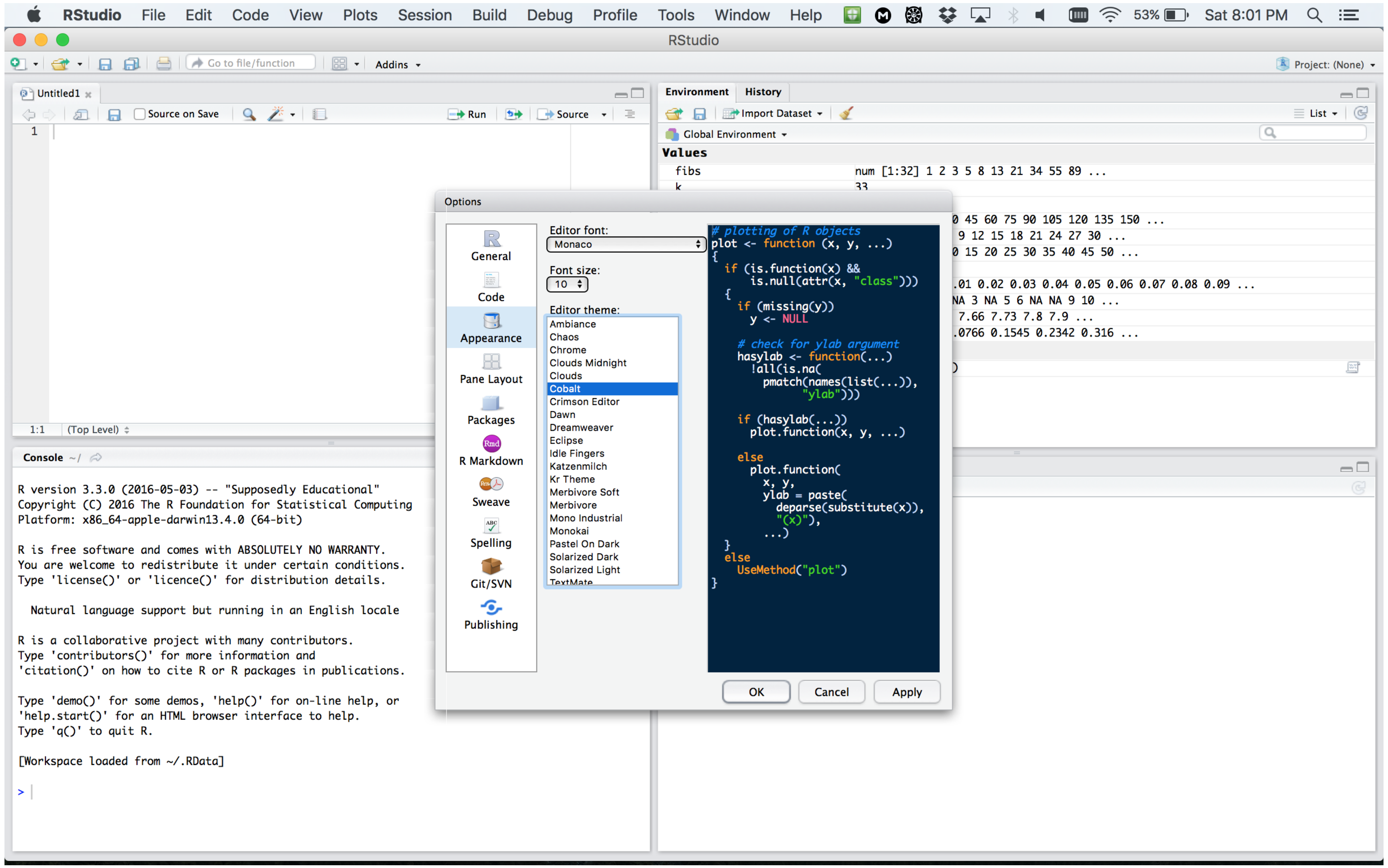
RStudio preferences



RStudio layout

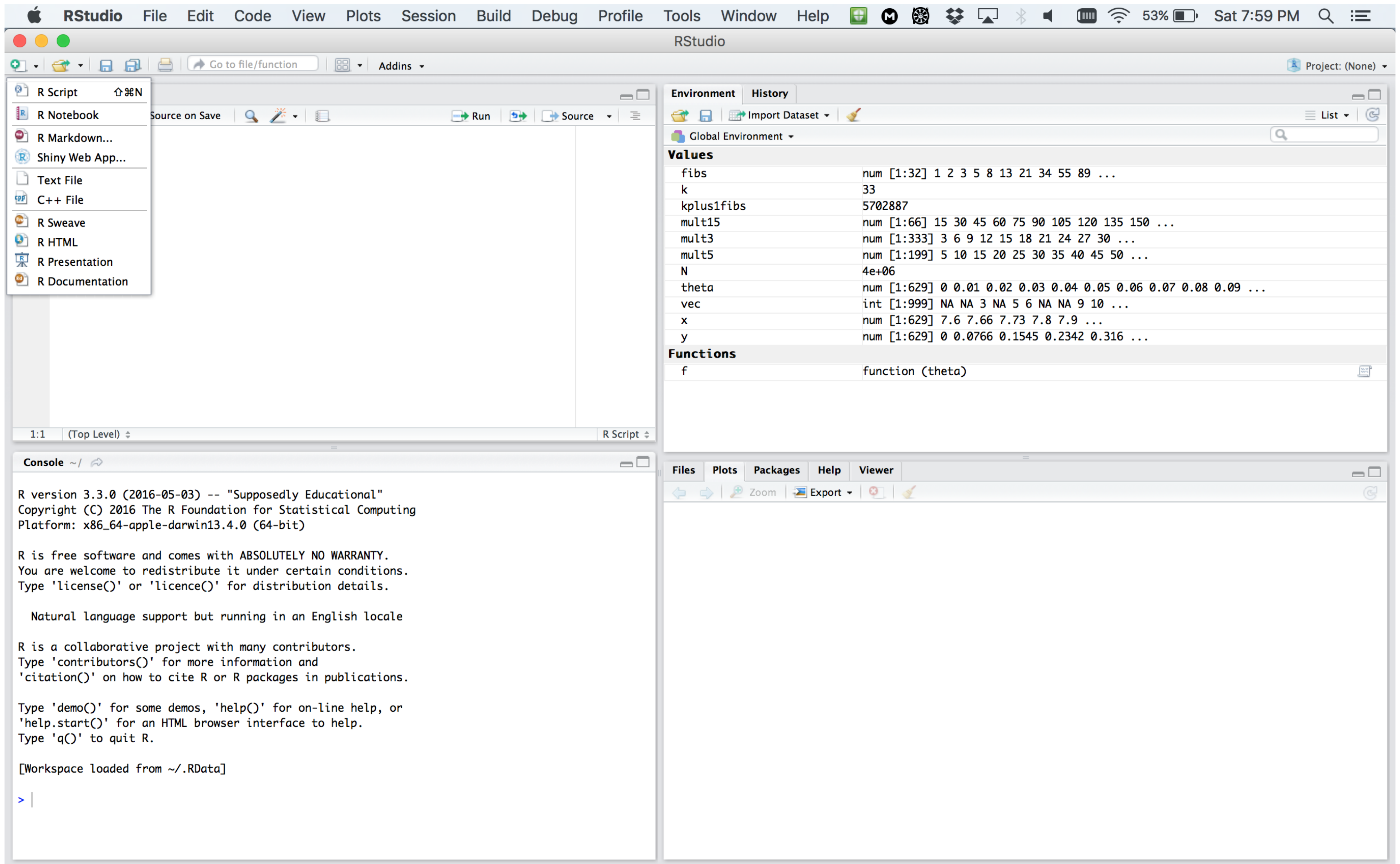


RStudio apprearance



More on RStudio cuztomization can be found here

R document types



R document types

- R Script **a text file** containing R commands stored together.
- R Markdown files can generate high quality reports contatining notes, code and code outputs. **Python and bash code** can also be executed.
- R Notebook is an R Markdown document with **chunks that can be executed independently and interactively**, with output visible immediately beneath the input.
- R presentation let’s you author **slides** that make use of R code and LaTeX equations as **straightforward** as possible.
- R Sweave enables the embedding of **R code within LaTeX documents**.
- Other documents

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

Installing R packages from different repositories:

- From CRAN:

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

- From Bioconductor:

```r
# 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:

```r
# 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 reporsitory, e.g.
install_github("twitter/AnomalyDetection")

# or using install_git("url"), e.g.
install_git("https://github.com/twitter/AnomalyDetection")
```

Where are R packages stored?

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

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

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

```
##              Package       LibPath                                            Version
## abind        "abind"       "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "1.4-5"
## acepack      "acepack"     "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "1.4.1"
## adaptiveGPCA "adaptiveGPCA" "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "0.1.1"
## ade4         "ade4"        "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "1.7-11"
## ADGofTest    "ADGofTest"   "/home/lanhuong/R/x86_64-pc-linux-gnu-library/3.4" "0.3"
```

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

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

Basics of coding in R

R as a calculator

- R can be used as a calculator, e.g.

```
23 + sin(pi/2)
```

```
## [1] 24
```

```
abs(-10) + (17-3)^4
```

```
## [1] 38426
```

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

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

- Intuitive arithmetic operators: addition (+), subtraction (-), multiplication (*), division: (/), exponentiation: (^), modulus: (%%)
- Built-in constants: `pi, LETTERS, letters, month.abb, month.name`

Variables

- **Variables** are objects 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**.

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
```

Naming variables

Variable names must start with a letter, and can only contain:

- letters
- numbers
- the character _
- the character .

```
a <- 0
first.variable <- 1
SecondVariable <- 2
variable_2 <- 1 + first.variable
very_long_name.3 <- 4
```

Some words are reserved in R and cannot be used as object names:

- `Inf` and `-Inf` which respectively stand for positive and negative infinity, R will return this when the value is too big, e.g. `2^1024`
- `NULL` denotes a null object. Often used as undeclared function argument.
- `NA` represents a missing value ("Not Available").
- `NaN` means "Not a Number". R will return this when a computation is undefined, e.g. `0/0`.

Data types

Values in R are limited to **only 6 atomic classes**:

- **Logical**: `TRUE/FALSE` or `T/F`
- **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** (holding raw bytes): `as.raw(2), charToRaw("Hello")`

Objects can have different structures based on atomic class and dimensions:

Dimensions	Homogeneous	Heterogeneous
1d	vector	list
2d	matrix	data.frame
nd	array	

R also supports more complicated objects built upon these.

Variable class

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

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

```
## The class of x is character
```

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

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

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

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

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

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

```
## [1] "a"                "first.variable"   "SecondVariable"   "var.1"            "var.2"
```

Vectors

Vectors are the simplest R data objects; there are no scalars in R.

```
# Create a vector with "combine"
x1 <- c(1, 3, 7:12)
x2 <- c('apple', 'banana', 'watermelon')
# Look at content of a variable:
x1
```

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

```
print(x2)
```

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

```
# Including in () also prints content
(x3 <- 1:5)
```

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

```
# If mixed, on-character values are coerced
# to character type
(s <- c('apple', 123.56, 5, TRUE))
```

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

```
# Generate numerical sequence, e.g. sequence
# from 5 to 7 with 0.4 increment.
(v <- seq(5, 7, by = 0.4))
```

```
## [1] 5.0 5.4 5.8 6.2 6.6 7.0
```

Vector indexing

- Elements of a vector can be accessed using indexing, with square 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",
(today <- days[5])
```

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

```
# Accessing vector elements using position.
(weekend.days <- days[c(1, 7)])
```

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

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

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

```
# Accessing vector elements using logical index
(birthday <- days[c(F, F, F, F, T, F, F)])
```

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

Logical operations

```
# Comparisons (==,!=,>,>=,<,<=)
1 == 2
```

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

```
# Check whether number is even
# (%% is the modulus)
(5 %% 2) == 0
```

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

```
# Logical indexing
x <- seq(1,10)
x[(x%%2) == 0]
```

```
## [1]  2  4  6  8 10
```

```
# Element-wise comparison
c(1,2,3) > c(3,2,1)
```

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

```
# Check whether numbers are even,
# one by one
(seq(1,4) %% 2) == 0
```

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

```
# Logical indexing
x <- seq(1,10)
x[x>=5]
```

```
## [1]  5  6  7  8  9 10
```

Vector arithmetics

Two vectors of same length can be added, subtracted, multiplied or divided. Vectors can be concatenated with combine function `c()`.

```
# 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 0.272727
```

```
# Vector concatenation
vec.concat <- c(v1, v2)
# Size of vector
length(vec.concat)
```

```
## [1] 12
```

Recycling

- **Recycling** is an automatic lengthening of vectors in certain settings.

```
# Element-wise multiplication
v1 <- c(1,2,3,4,5,6,7,8,9,10)
v1 * 2
```

```
##  [1]  2  4  6  8 10 12 14 16 18 20
```

- When two vectors of different lengths, R will repeat the shorter vector until the length of the longer vector is reached.

```
# Element-wise multiplication
v1 * c(1,2)
```

```
##  [1]  1  4  3  8  5 12  7 16  9 20
```

```
v1 + c(3, 7, 10)
```

```
##  [1]  4  9 13  7 12 16 10 15 19 13
```

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

Matrices

Matrices in R are objects with **homogeneous elements** (of the same type), **arranged in a 2D rectangular layout**. 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 crated
- `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 respectively

```
# Elements are arranged sequentially by column.
(N <- matrix(seq(1,20), nrow = 4, byrow = FALSE))
```

```
##      [,1] [,2] [,3] [,4] [,5]
## [1,]    1    5    9   13   17
## [2,]    2    6   10   14   18
## [3,]    3    7   11   15   19
## [4,]    4    8   12   16   20
```

```
# Elements are arranged sequentially by row.
(M <- matrix(seq(1,20), nrow = 5, byrow = TRUE))
```

```
##      [,1] [,2] [,3] [,4]
## [1,]    1    2    3    4
## [2,]    5    6    7    8
## [3,]    9   10   11   12
## [4,]   13   14   15   16
## [5,]   17   18   19   20
```

Accessing Elements of a Matrix

```
# Define the column and row names.
rownames <- c("row1", "row2", "row3")
colnames <- c("col1", "col2", "col3", "col4", "c
(P <- matrix(c(5:19), nrow = 3, byrow = TRUE,
             dimnames = list(rownames, colnames)
```

```
##      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 row and 5th column.
```

```
## [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
```

```
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 = 2))
```

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

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

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

```
A + B  # Element-wise sum; (A - B) difference
```

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

```
A * B  # Element-wise multiplication
```

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

```
A / B  # Element-wise division
```

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

```
t(A)   # Matrix transpose
```

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

Matrix Algebra

True matrix multiplication A x B, with $A \in \mathbb{R}^{m \times n}$ and $B \in \mathbb{R}^{m \times n}$:

$$(AB)_{ij} = \sum_{k=1}^{p} A_{ik} B_{kj}$$

```
# A is (2 x 3) and t(B) is (3 x 2)
A %*% t(B)     # (2 x 2)-matrix
```

```
##      [,1] [,2]
## [1,]   21    5
## [2,]   63   78
```

```
# t(A) is (3 x 2) and B is (2 x 3)
t(A) %*% B    # (3 x 3)-matrix
```

```
##      [,1] [,2] [,3]
## [1,]   33   81   45
## [2,]    3   36   13
## [3,]   22   54   30
```

More on matrix algebra here

Arrays

- In R, arrays are data objects with more than two dimensions, e.g. a (4x3x2)-array has 2 tables of size 4 rows by 3 columns.
- Arrays can store **only one data type** and are created using `array()`.
- Accessing and subsetting elements of an arrays is similar to accessing elements of a matrix.

```
row.names <- c("ROW1","ROW2","ROW3", "ROW4")
column.names <- c("COL1","COL2","COL3")
matrix.names <- c("Matrix1","Matrix2")

(arr <- array(
  seq(1, 24), dim = c(4,3,2),
  dimnames = list(row.names, column.names,
matrix.names)))
```

```
## , , Matrix1
##
##      COL1 COL2 COL3
## ROW1    1    5    9
## ROW2    2    6   10
## ROW3    3    7   11
## ROW4    4    8   12
##
## , , Matrix2
##
##      COL1 COL2 COL3
## ROW1   13   17   21
## ROW2   14   18   22
## ROW3   15   19   23
## ROW4   16   20   24
```

Lists

Lists can **contain elements of different types** e.g. numbers, strings, vectors and/or another list. List is created using `list()` function.

```r
# Unnamed list
v <- c("Jan","Feb","Mar")
M <- matrix(c(1,2,3,4),nrow=2)
lst <- list("green", 12.3)
(u.list <- list(v, M, lst))
```

```
## [[1]]
## [1] "Jan" "Feb" "Mar"
##
## [[2]]
##      [,1] [,2]
## [1,]    1    3
## [2,]    2    4
##
## [[3]]
## [[3]][[1]]
## [1] "green"
##
## [[3]][[2]]
## [1] 12.3
```

```r
# Access 2nd element
u.list[[2]]
```

```
##      [,1] [,2]
## [1,]    1    3
## [2,]    2    4
```

```r
# Named list
(n.list <- list(
  first = "Jane", last = "Doe",
  gender = "Female", yearOfBirth = 1990))
```

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

```r
# Access 3rd element
n.list[[3]]
```

```
## [1] "Female"
```

```r
# Access "yearOfBirth" element
n.list$yearOfBirth
```

```
## [1] 1990
```

Data-frames

A data frame is a table or a **2D array-like structure**, whose:

- Columns can store data of different types e.g. numeric, character etc.
- 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
```

Useful functions for data-frames

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

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

```r
# Print first few rows of the data frame.
head(employees, 2)
```

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

```r
# Print statistical summary of the data frame.
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  
```

Subsetting data-frames

- We can extract specific columns:

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

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

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

```
##        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 rows:

```
# 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

- Add a new column using assignment operator:

```
# Add the "dept" coulmn.
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
```

- Adding a new row using `rbind()` function:

```
# Create the second data frame
new.employees <- data.frame(
  row.names = paste0("E", 6:8),
  name = c("Rasmi","Pranab","Tusar"),
  salary = c(578.0,722.5,632.8),
  start_date = as.Date(c("2013-05-21","2013-07-3
  dept = c("IT","Operations","Fianance"),
  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   Fianance
```

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.

```
days <- c("Mon", "Tue", "Wed", "Thu", "Fri", "Sat", "Sun")
is.factor(month.name)
```

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

```
class(days) # Indeed these are strings of characters
```

```
## [1] "character"
```

If not specified, R will order character type by alphabetical order.

```
( days <- factor(days) ) # Convert to factors
```

```
## [1] Mon Tue Wed Thu Fri Sat Sun
## Levels: Fri Mon Sat Sun Thu Tue Wed
```

```
is.factor(days)
```

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

Factors ordering

```
days.sample <- sample(days, 5)
days.sample
```

```
## [1] Sun Sat Wed Mon Tue
## Levels: Fri Mon Sat Sun Thu Tue Wed
```

```
# Create factor with given levels
(days.sample <- factor(days.sample, levels = days))
```

```
## [1] Sun Sat Wed Mon Tue
## Levels: Mon Tue Wed Thu Fri Sat Sun
```

```
# Create factor with ordered levels
(days.sample <- factor(days.sample, levels = days, ordered = TRUE))
```

```
## [1] Sun Sat Wed Mon Tue
## Levels: Mon < Tue < Wed < Thu < Fri < Sat < Sun
```

Note that factor **labels are not the same as levels.**

```
day_names <- c("Monday", "Tuesday", "Wednesday", "Thursday", "Friday", "Saturday", "Sunday")
(days <- factor(days, levels = days, labels = day_names))
```

```
## [1] Monday    Tuesday   Wednesday Thursday  Friday    Saturday  Sunday
## Levels: Monday Tuesday Wednesday Thursday Friday Saturday Sunday
```

Dates

R makes it easy to work with dates.

```
# Define a sequence of dates
x <- seq(from=as.Date("2018-01-01"),to=as.Date("2018-05-31"), by=1)
table(months(x))
```

```
##
##    April February  January    March      May
##       30       28       31       31       31
```

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

```
## [1] "2018-09-27"
```

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

```
## [1] "2018-09-27 13:57:46 PDT"
```

```
# Number of days until the New Year.
as.Date('2019-01-01') - Sys.Date()
```

```
## Time difference of 96 days
```

Type `?strptime` for a list of possible date formats.

Random numbers

You can generate vectors of random numbers from different distributions.

To make your results reproducible, provide a seed for the generator.

```
set.seed(123456)

sample(x = 20:100, size = 10) # Random integers
```

```
##  [1] 84 80 50 46 47 35 60 27 92 32
```

```
runif(5, min = 0, max = 1)    # Uniform distribution
```

```
## [1] 0.7979891 0.5937940 0.9053100 0.8808486 0.9938366
```

```
rnorm(5, mean = 0, sd = 1)    # Normal distribution
```

```
## [1]  1.2588422 -0.8502043  0.7627921 -1.4007445 -0.9466625
```

Random sampling

You can generate a random sample from the elements of a vector using the function sample.

```
v <- seq(1, 10)
sample(v, 5)                                # Sampling without replacement
```

```
## [1]  8 10  9  6  1
```

```
month.name
```

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

```
sample(month.name, 10, replace = TRUE)    # Sampling with replacement
```

```
##  [1] "July"      "November"  "March"     "February"  "October"   "January"   "December"  "Nov
```

Tables – the contents of a discrete vector can be easily summarized in a table.

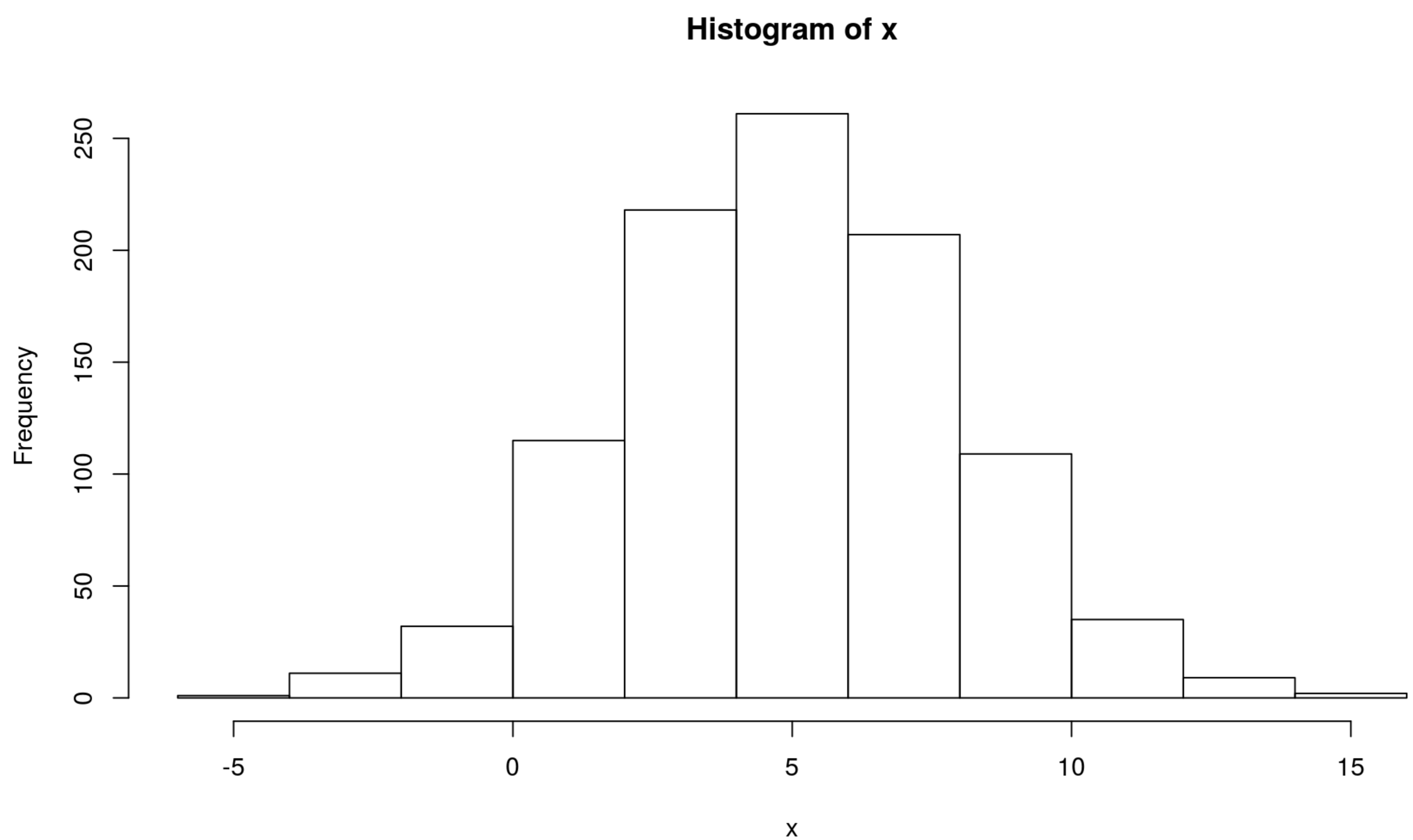
```
x <- sample(v, 1000, replace=TRUE)          # Random sample
table(x)
```

```
## x
##   1   2   3   4   5   6   7   8   9  10
## 107  97  92 105  94 113 101  97 110  84
```

Histograms

The contents of a discrete or continuous vector can be easily summarized in a histogram.

```
x <- rnorm(1000, mean = 5, sd = 3)
hist(x)
```



Exercises

Vectors

1. Generate and print a vector of 10 random numbers between 5 and 500.
2. Generate a random vector Z of 1000 letters (from “a” to “z”). Hint: the variable `letters` is already defined in R.
3. Print a summary of Z in the form of a frequency table.
4. Print the list of letters that appear an even number of times in Z.

Matrices

1. Create the following 5 by 5 matrix and store it as variable X.

```
##      [,1] [,2] [,3] [,4] [,5]
## [1,]    1    6   11   16   21
## [2,]    2    7   12   17   22
## [3,]    3    8   13   18   23
## [4,]    4    9   14   19   24
## [5,]    5   10   15   20   25
```

2. Create a matrix Y by adding an independent Gaussian noise (random numbers) with mean 0 and standard deviation 1 to each entry of X. e.g.

3. Find the inverse of Y.

4. Show numerically that the matrix product of Y and its inverse is the identity matrix.

Data fames

1. Create the following data frame and name it “exams”.

```
##   student score letter  late
## 1   Alice    86      A FALSE
## 2   Sarah    95      B  TRUE
## 3   Harry    87      B FALSE
## 4     Ron    99      B FALSE
## 5    Kate    97      A  TRUE
```

2. Compute the mean score for this exam and print it.
3. Find the student with the highest score and print the corresponding row of “exams”. Hint: use the function `which.max()`.