

**CME/STATS 195**

**Lecture 1: Introduction to R**

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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 3PM, 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 statistics: modeling, predicting and testing.
- Some R tools for supervised & unsupervised learning.
- Generating R Markdown reports for efficient communication.

# The R language



# What is R?

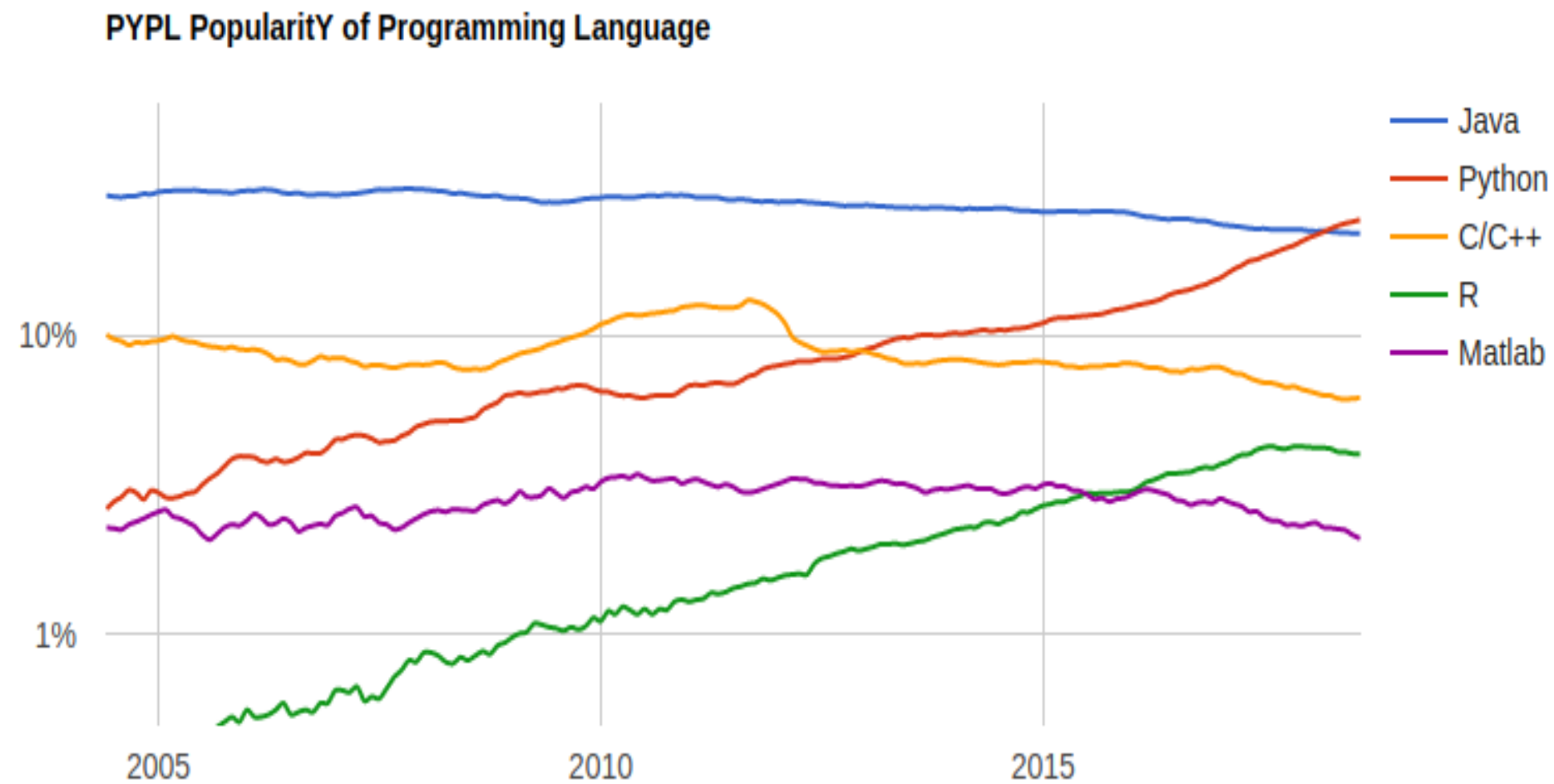
- R was created by Rob Gentleman and Ross Ihaka in 1994; it is based on the S language developed at Bell Labs by John Chambers (Stanford Statistics).
- It is an **open-source language and environment** for statistical computing and graphics.



- 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 into 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:

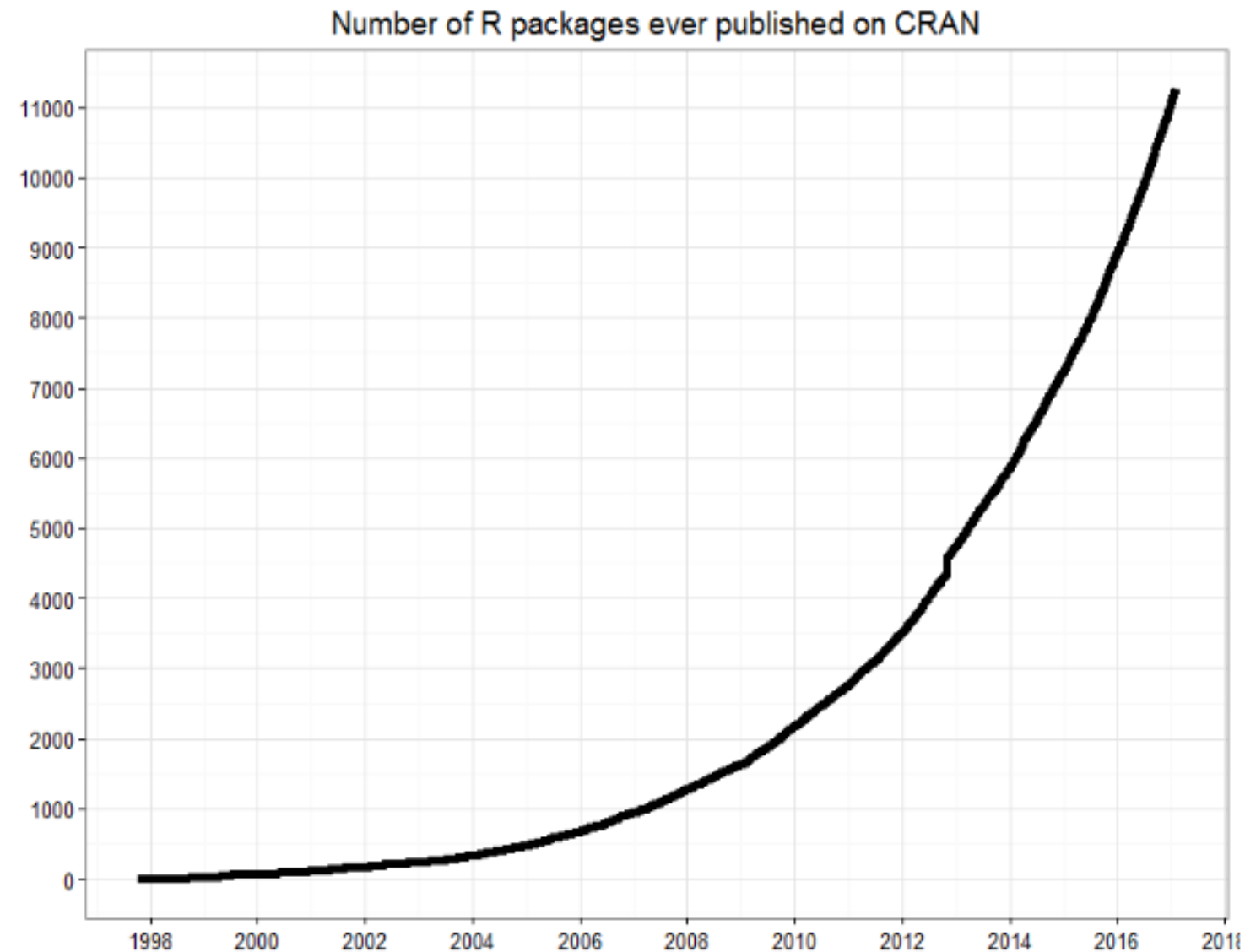
- **Python:** fastest growing, general-purpose programming, with data science libraries.
- **SAS:** used for statistical analysis; commercial and expensive, slower development.
- **SQL:** designed for managing data held in a relational database management system.
- **MATLAB:** proprietary, mostly for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

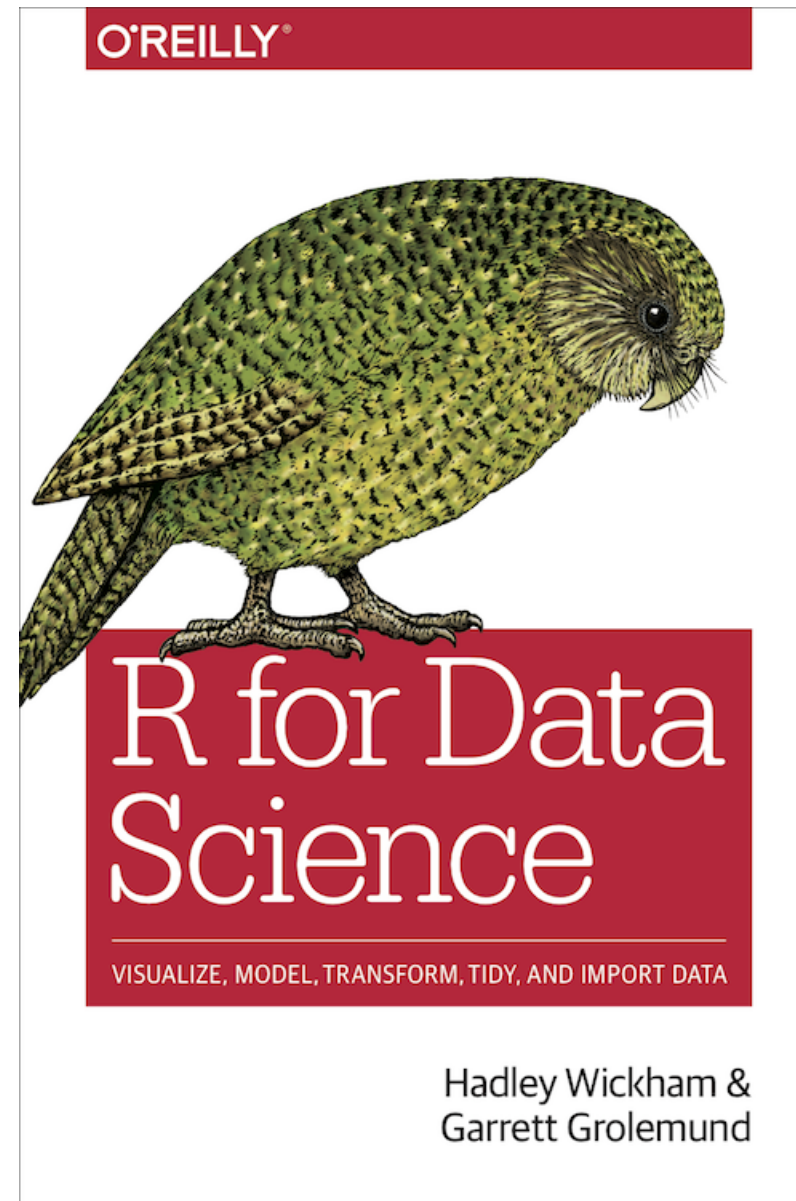
As of September 29, there are 13,083 packages on [CRAN](#), 1,560 on [Bioconductor](#) and many others on [github](#))



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](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/>)
- DataCamp 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.

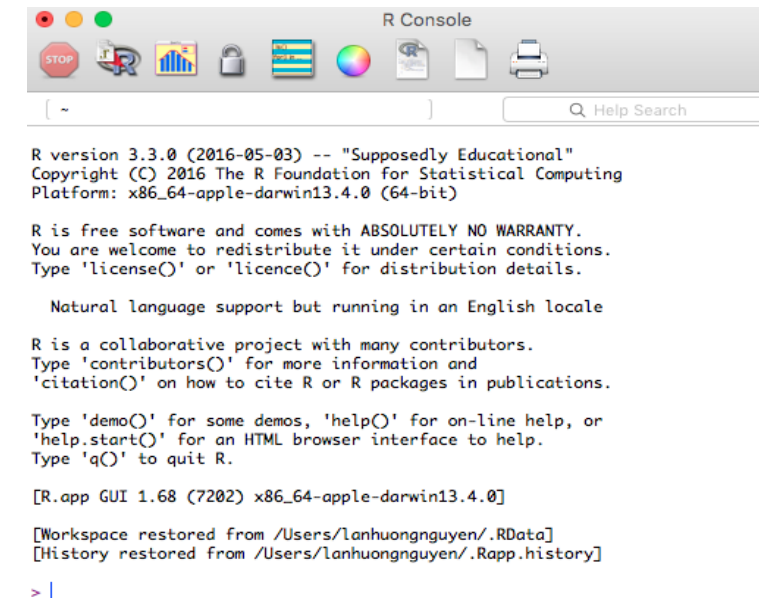
# Running R code

## 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”

A screenshot of the R Console window on a macOS system. The window title is "R Console". The menu bar includes "STOP", "R", "Help", "File", "Edit", "View", "Window", and "Help Search". The main text area displays the R version 3.3.0 (2016-05-03) -- "Supposedly Educational" startup message, including copyright information and a license notice. It also shows the workspace restored from a previous session.

```
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.

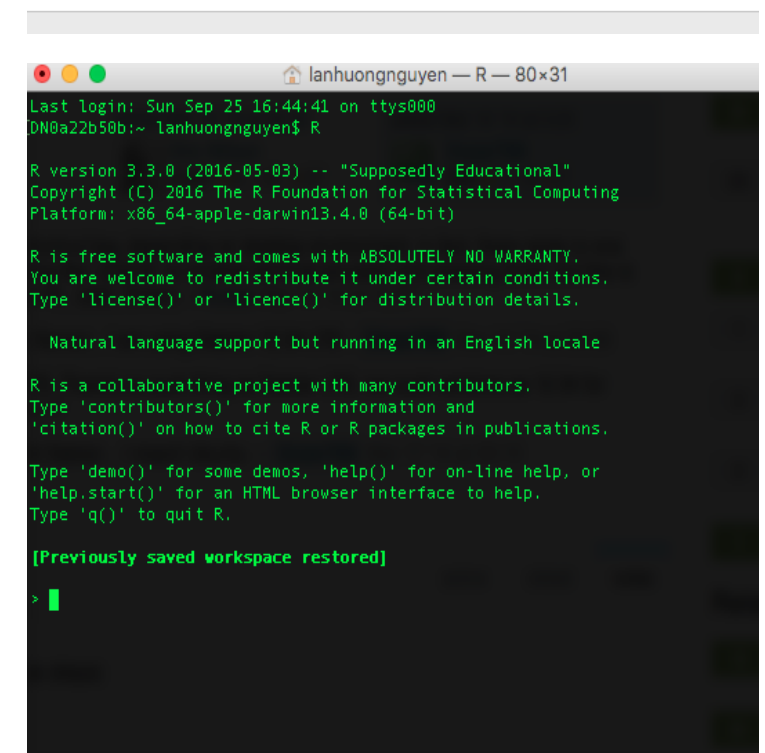
Natural language support but running in an English locale

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]

> |
```

A screenshot of a terminal window titled "lanhuongnguyen — R — 80x31". The terminal shows the command "R" being executed, which launches the R interpreter. The output is identical to the R Console window, showing the version and license information. The prompt is now ">".

```
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 '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]

> █
```

# R editors

The most popular **R editors** are:

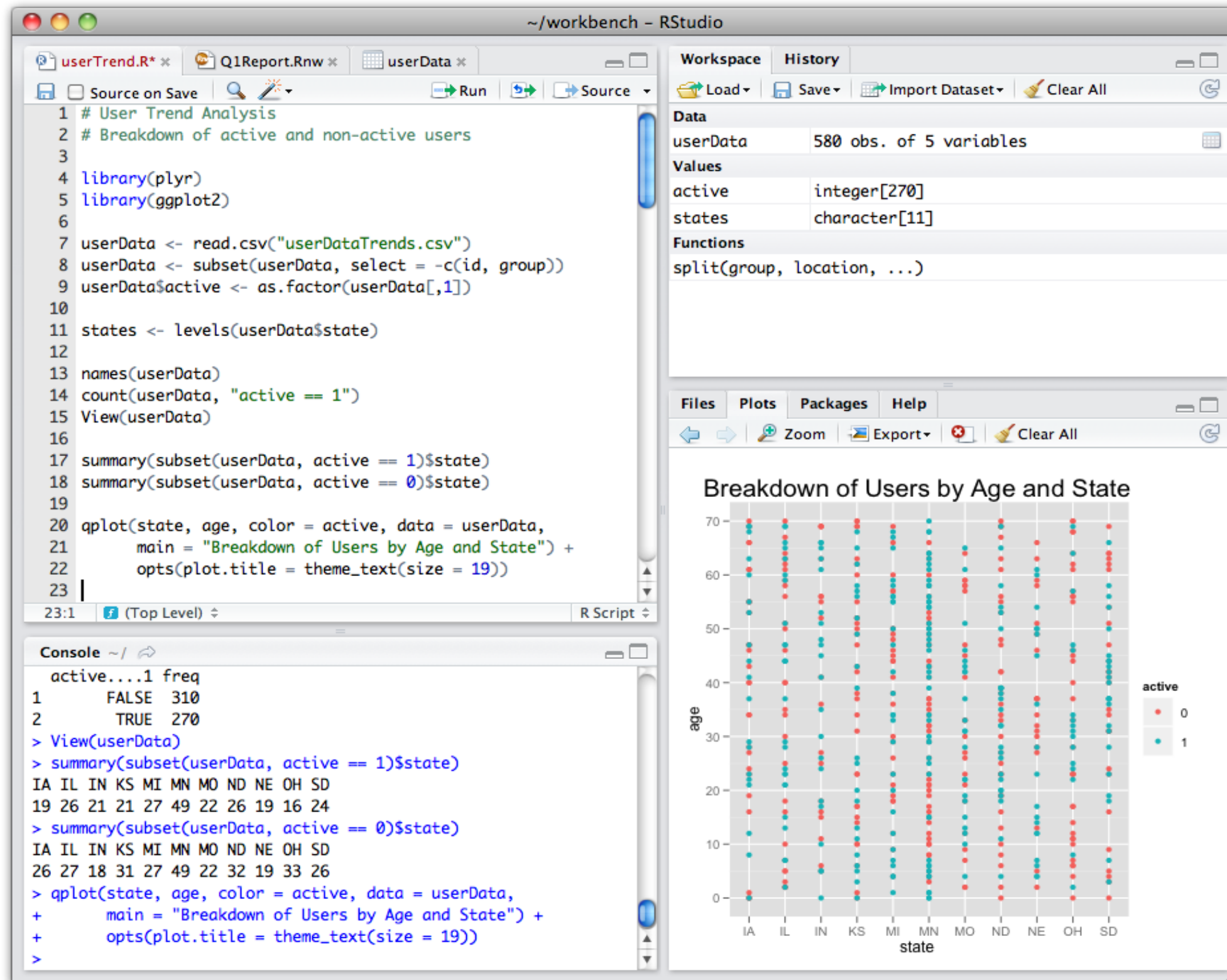
- **Rstudio**, an integrated development environment (IDE) for R.
- **Emacs**, a free, powerful, customizable editor for many languages.

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](#).



# 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:

```
# 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")
```

# Where are R packages stored?

```
# 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"
```

```
# 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"

```
# 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.

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

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

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

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

```
a <- 27L  
cat(" Next the class of var_x becomes ", class(a), "\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] "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", "Sat")  
(today <- days[5])
```

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

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

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

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

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

```
# Accessing vector elements using logical indexing.  
(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 0.27
```

```
# 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 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 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 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", "col5")
(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 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
```

```
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  $A \times B$ , with  $A \in \mathbb{R}^{m \times n}$  and  $B \in \mathbb{R}^{n \times p}$ :

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

```
# 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

- 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.

```
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 another list. List is created using `list()` function.

```
# 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
```

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

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

```
# 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
```

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

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

```
# 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

```
# 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" ...
```

```
# 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
```

```
# 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" 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
```

- 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", "2013-07-30", "2014-06-17")),
  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] Tue Fri Wed Sun Mon  
## Levels: Fri Mon Sat Sun Thu Tue Wed
```

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

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

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

```
## [1] Tue Fri Wed Sun Mon  
## 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] "2018-09-23"
```

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

```
## [1] "2018-09-23 14:38:34 PDT"
```

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

```
## Time difference of 100 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" "Au
```

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

```
## [1] "July" "November" "March" "February" "October" "January" "December" "No
```

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

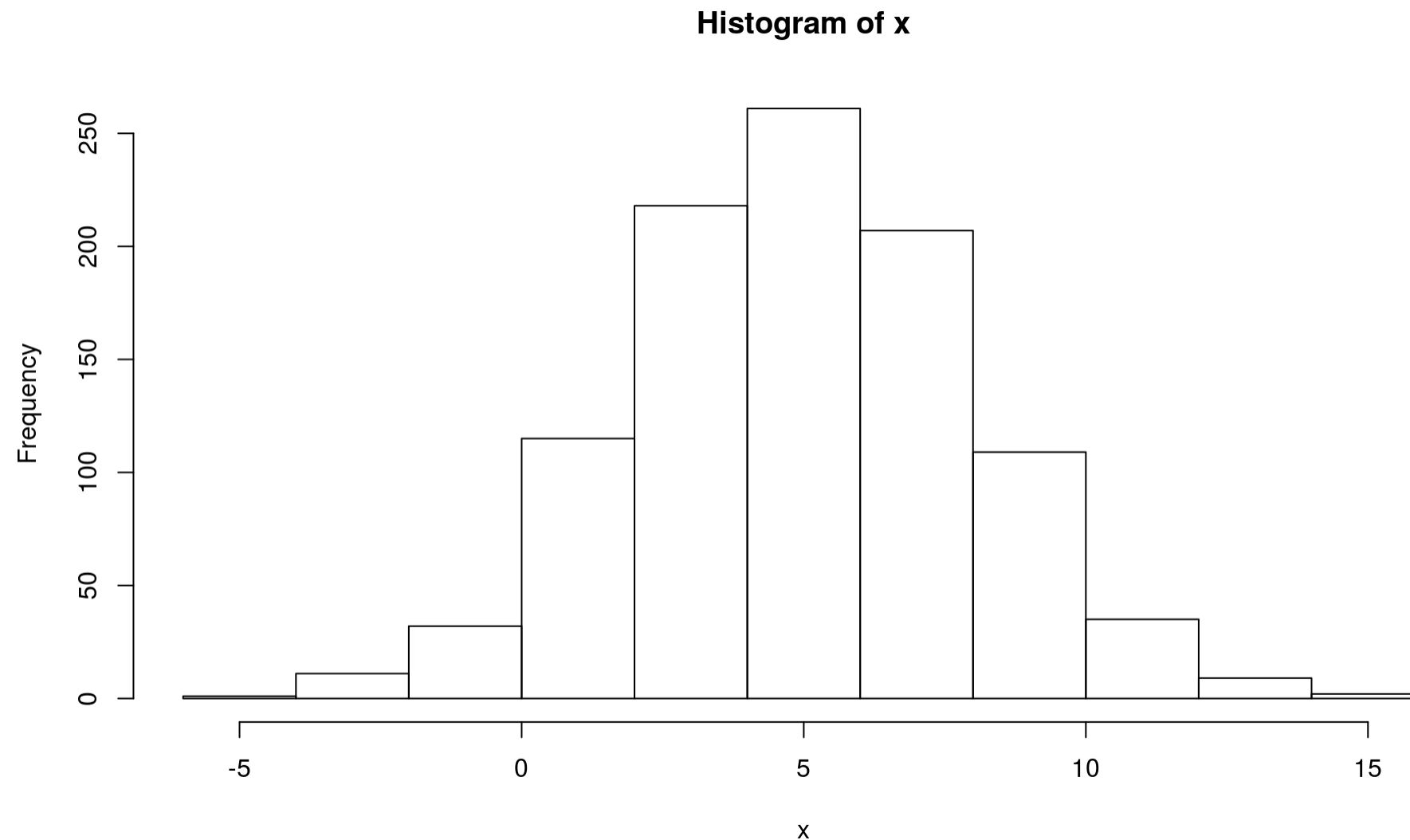
```
x <- sample(v, 1000, replace=TRUE) # Random sample
table(x)
```

```
## 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] [,6]
## [1,]    1    6   11   16   21   26
## [2,]    2    7   12   17   22   27
## [3,]    3    8   13   18   23   28
## [4,]    4    9   14   19   24   29
## [5,]    5   10   15   20   25   30
```

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 frames

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

```
##      student score letter  late
## 1    Alice    98      A FALSE
## 2    Sarah    99      A  TRUE
## 3    Harry    97      A FALSE
## 4      Ron    91      A  TRUE
## 5     Kate    96      A FALSE
```

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()`.