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 statisti 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?

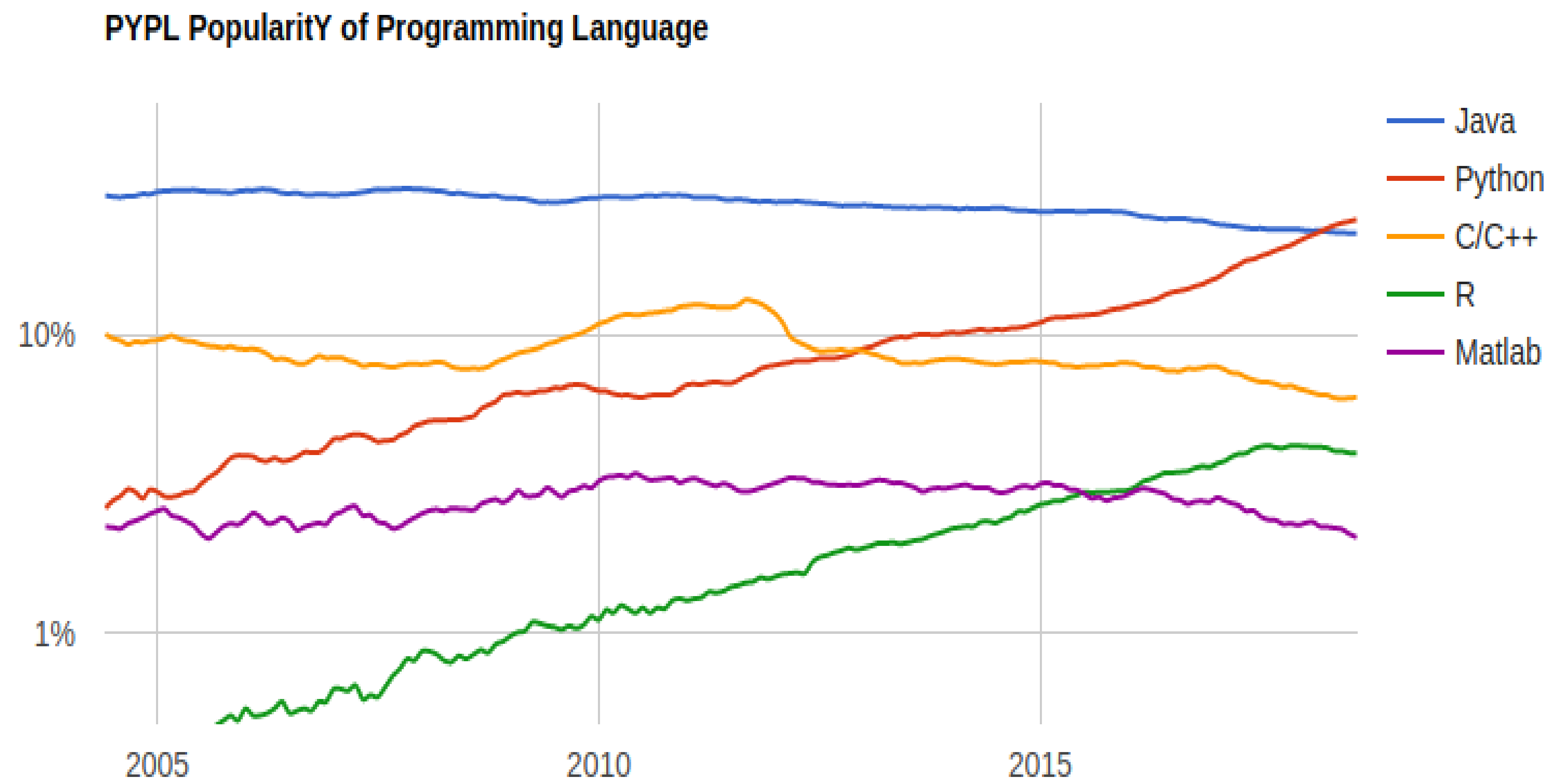
- R was created by Rob Gentleman and Ross Ihaka in 1994; it is based on the S language developed at Bell Labs by John Chambers (Stanford Statistics).
- It is **an open-source language and environment** for statistical computing and graphics.

- 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 al
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 searcl
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:

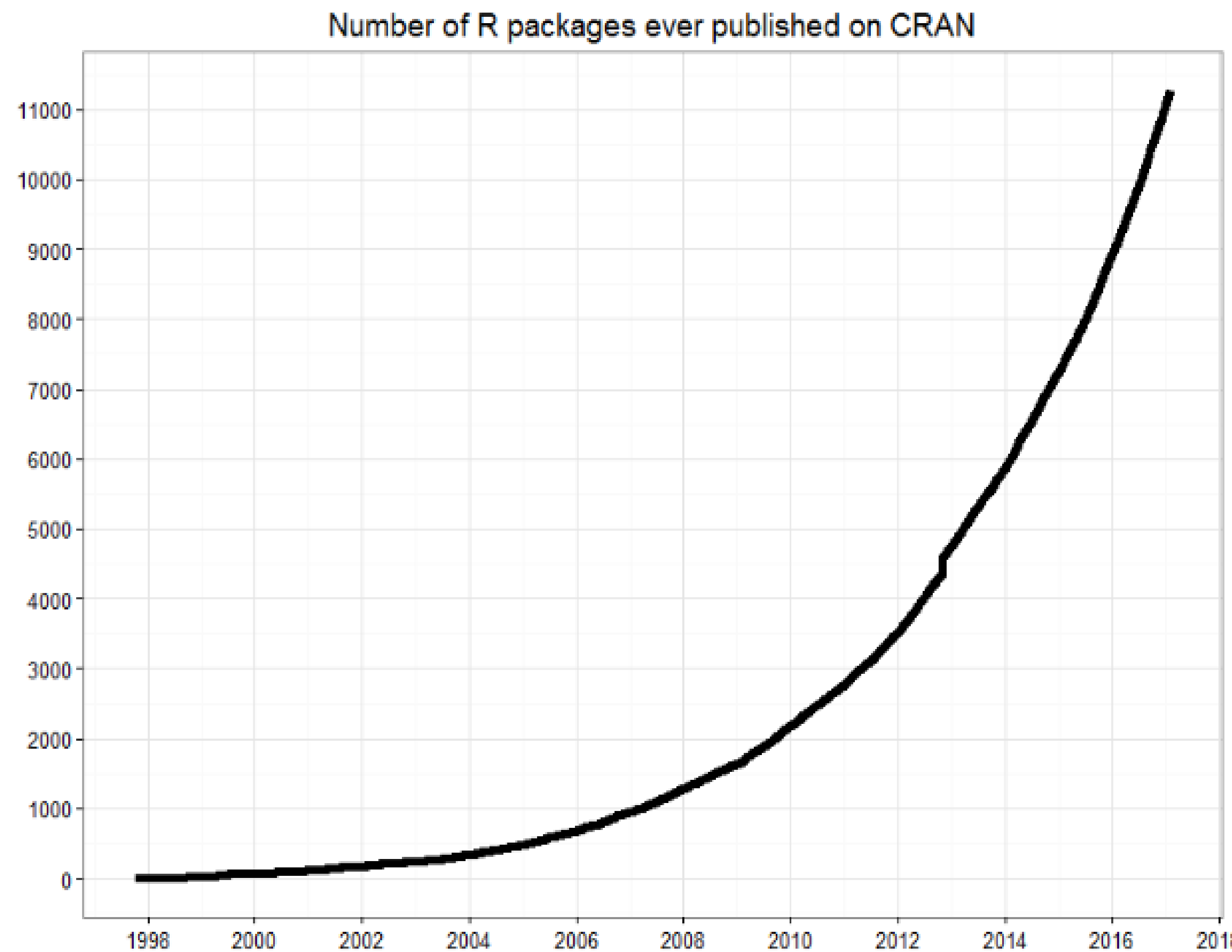
- **Python:** fastest growing, general-purpose programming, with data science libraries.
- **SAS:** used for statistical analysis; commercial and expensive, slower development.
- **SQL:** designed for managing data held in a relational database management system.
- **MATLAB:** proprietary, mostly for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

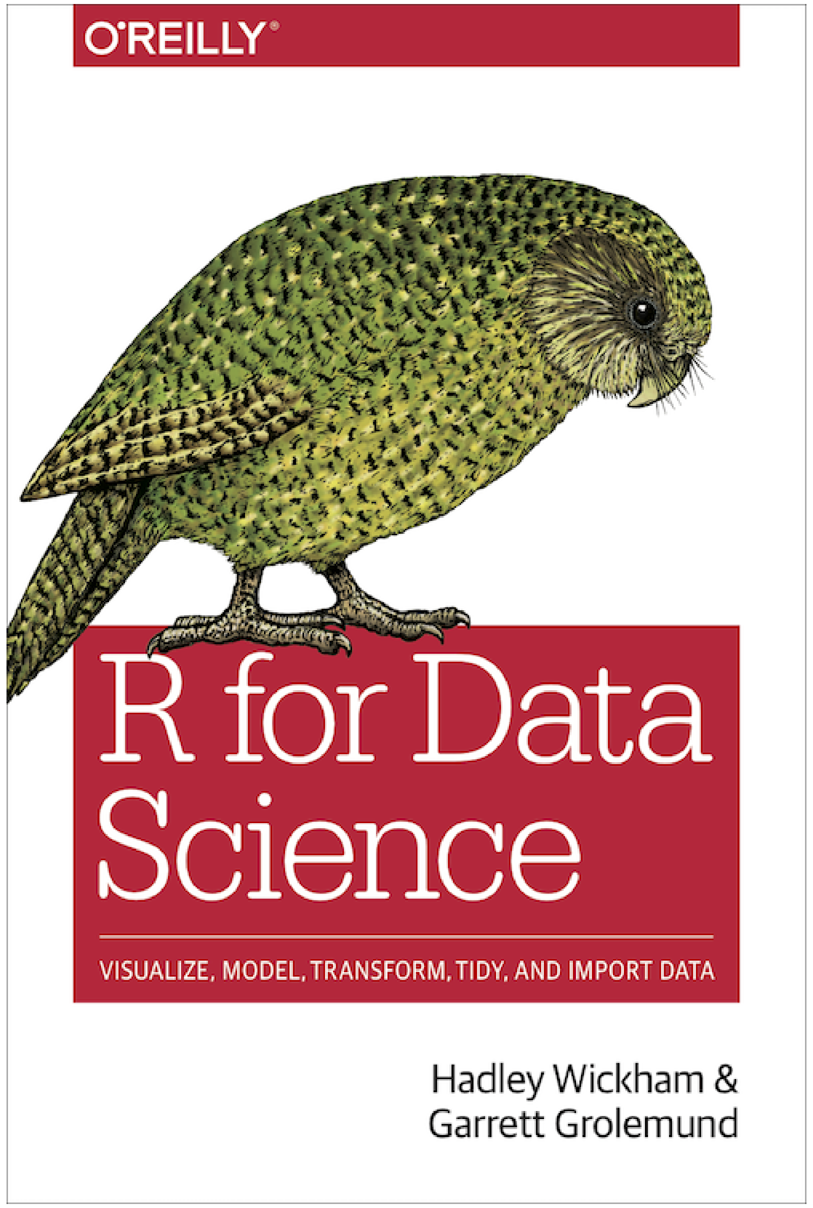
As of September 29, there are 13,083 packages on CRAN, 1,560 on Bioconduc
and many others on github)



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.

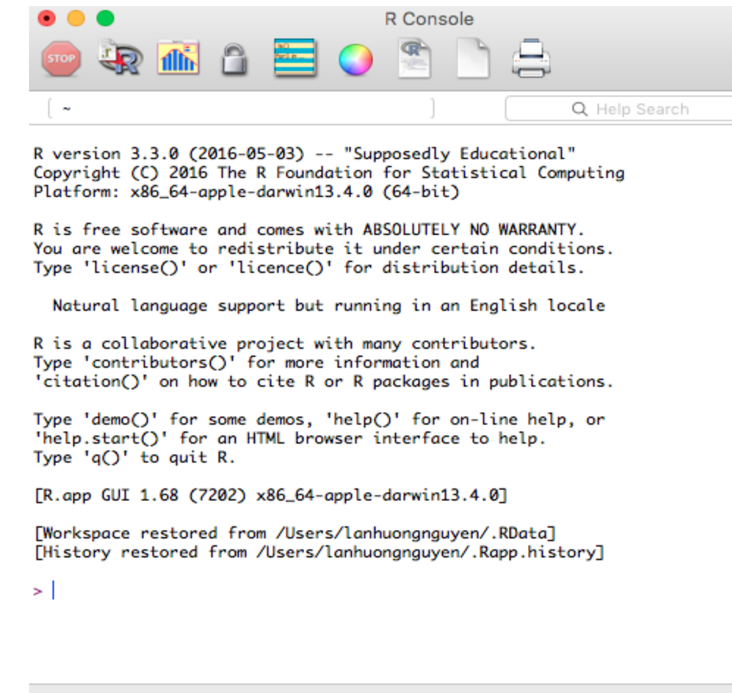
Running R code

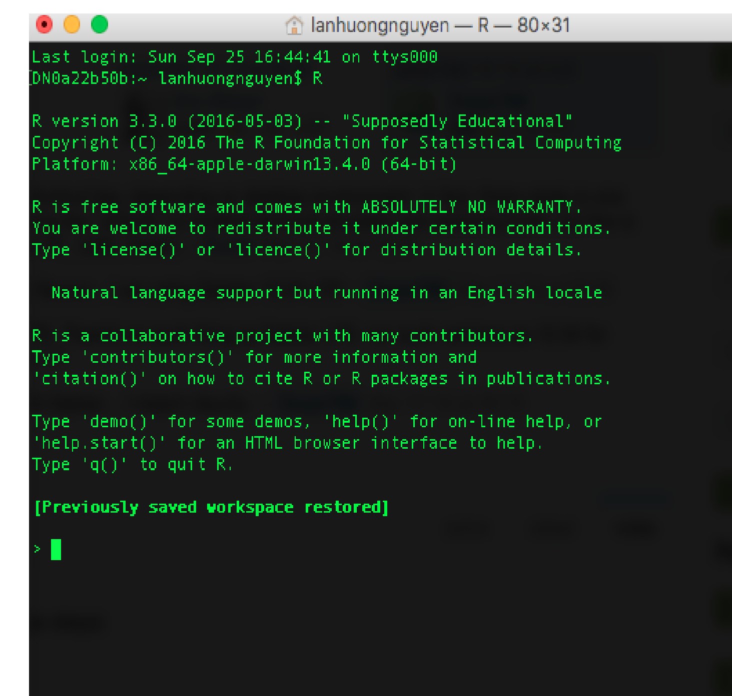
Interpreter mode:

- 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:

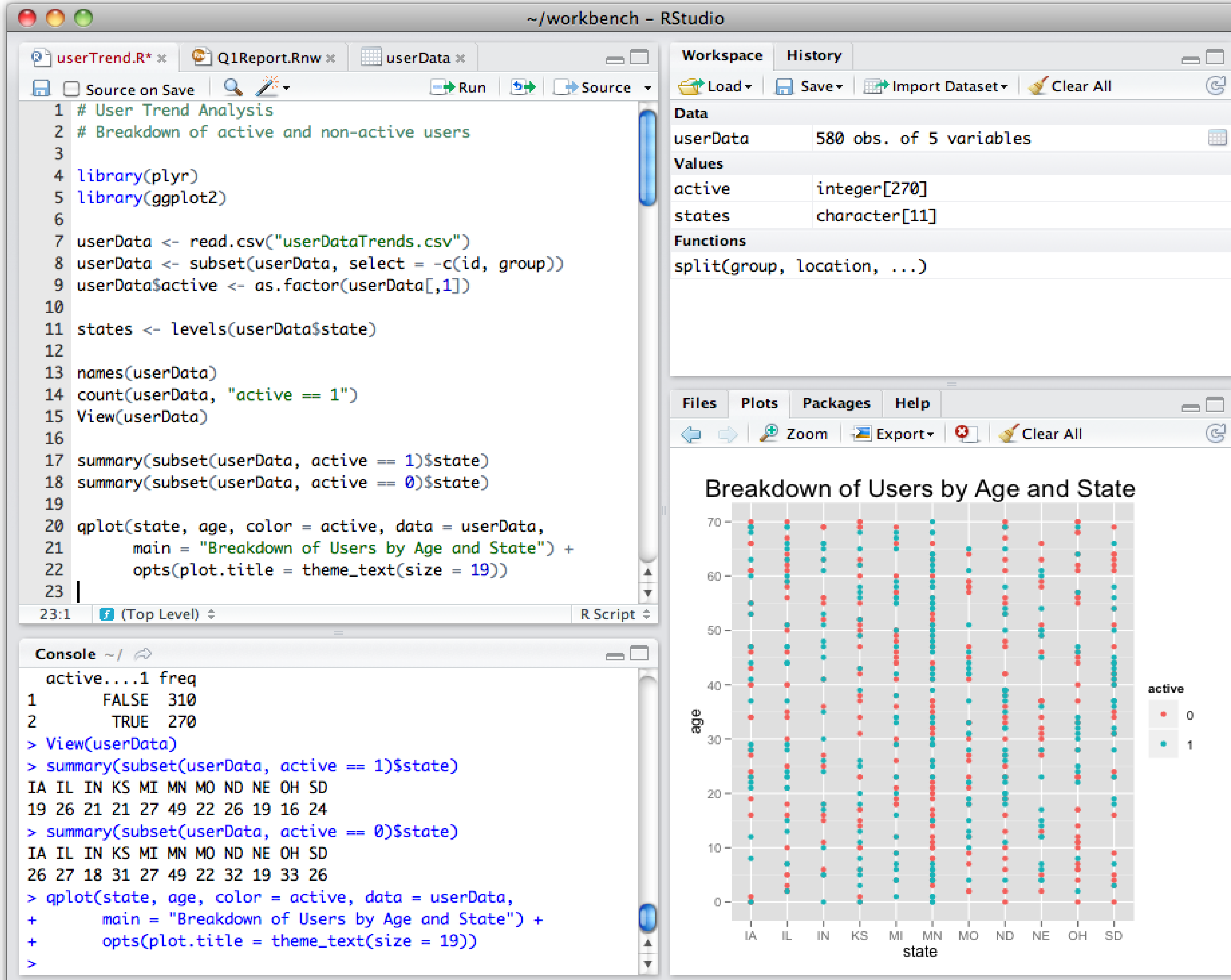
- **Rstudio**, an integrated development environment (IDE) for R.
- **Emacs**, a free, powerful, customizable editor for many languages.

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.


~/workbench – RStudio
userTrend.R*
Q1Report.Rnw
userData
Source on Save
Run
Source
# User Trend Analysis
# Breakdown of active and non-active users
library(plyr)
library(ggplot2)
userData <- read.csv("userDataTrends.csv")
userData <- subset(userData, select = -c(id, group))
userData$active <- as.factor(userData[,1])
states <- levels(userData$state)
names(userData)
count(userData, "active == 1")
View(userData)
summary(subset(userData, active == 1)$state)
summary(subset(userData, active == 0)$state)
qplot(state, age, color = active, data = userData,
main = "Breakdown of Users by Age and State") +
opts(plot.title = theme_text(size = 19))
23:1
(Top Level)
R Script
Console ~/
active....1 freq
1 FALSE 310
2 TRUE 270
> View(userData)
> summary(subset(userData, active == 1)$state)
IA IL IN KS MI MN MO ND NE OH SD
19 26 21 21 27 49 22 26 19 16 24
> summary(subset(userData, active == 0)$state)
IA IL IN KS MI MN MO ND NE OH SD
26 27 18 31 27 49 22 32 19 33 26
> qplot(state, age, color = active, data = userData,
+ main = "Breakdown of Users by Age and State") +
+ opts(plot.title = theme_text(size = 19))
>
Workspace
History
Load
Save
Import Dataset
Clear All
Data
userData
580 obs. of 5 variables
Values
active
integer[270]
states
character[11]
Functions
split(group, location, ...)
Files
Plots
Packages
Help
Zoom
Export
Clear All
Breakdown of Users by Age and State
70
60
50
40
30
20
10
0
age
IA IL IN KS MI MN MO ND NE OH SD
state
active
0
1

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?

```
# 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.

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

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

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

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

```r
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'
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.

```r
days <- c("Sun","Mon","Tue","Wed","Thurs","Fri","Sat")
(today <- days[5])
```

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

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

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

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

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

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

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

Logical operations

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

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

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

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

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

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

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

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

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

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

```r
# 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 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 = TR
```

```
##      [,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

```r
# 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
```

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

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

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

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

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

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

```r
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
```

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

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

```r
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:

```r
# 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
```

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

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

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

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

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

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

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

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

```r
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 $B \in \mathbb{R}^{m \times n}$:

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

```r
# 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
```

```r
# 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 anc 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.

```r
# 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-
  dept = c("IT","Operations","Fianance"),
  stringsAsFactors = FALSE )

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

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

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

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

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

```
## [1] Thu Sat Mon Tue Fri
## 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] "2018-09-24"
```

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

```
## [1] "2018-09-24 10:09:37 PDT"
```

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

```
## Time difference of 99 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.

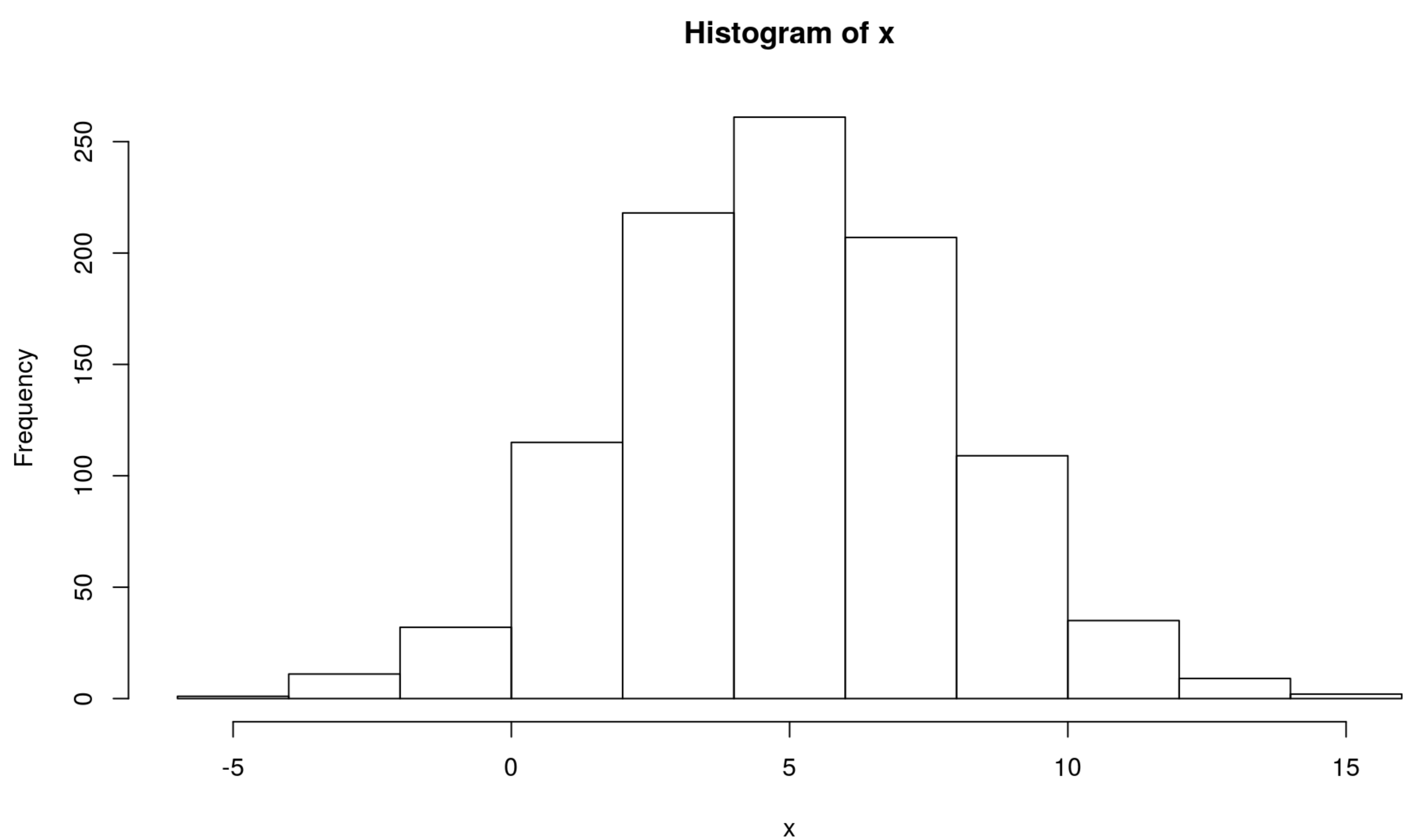
```
x <- sample(v, 1000, replace=TRUE)          # Random sample
table(x)
```

```
## 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 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()`.