

# R crash course - Introduction

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October 2, 2016

# Dependencies

- ▶ Please download and install
  - ▶ Latest version ( $\geq 3.1.2$ ) of R  
(*free* – GPL – from <https://www.r-project.org/>)
  - ▶ Latest version of Rstudio (also *free* – AGPL – from <https://www.rstudio.com/>)

## A Question

*You are given three sticks, each of a random length between 0 and 1.*

*What's the probability you can make a triangle?*

- ▶ The answer is  $1/2$
- ▶ By the end of this session, we'll confirm this with a simulation in R

# Rstudio Basics

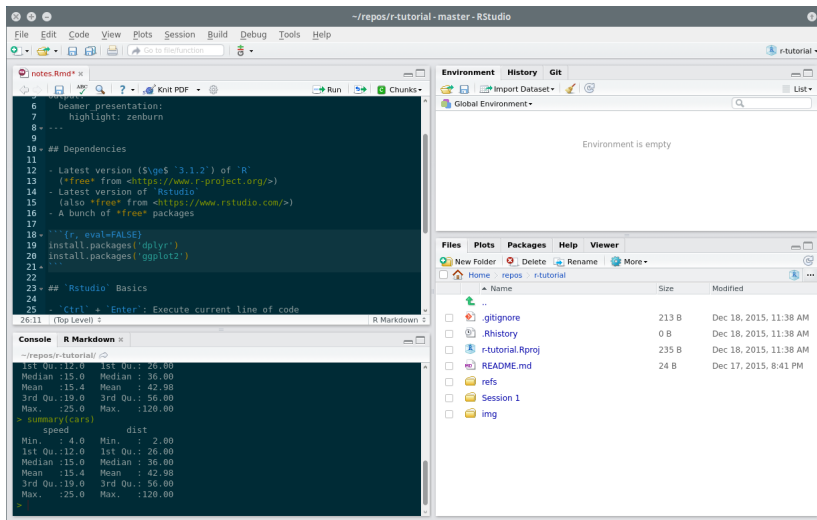


Figure 1: Screenshot of Rstudio

# Rstudio Basics

- ▶ Save/load scripts as text files named \*.R
- ▶ Save/load environment as .Rdata file
- ▶ Ctrl + L: Clear console
- ▶ Ctrl + #: Focus on panel #
- ▶ Ctrl + Enter: Execute selection
- ▶ Ctrl + Shift + C: Comment/Uncomment selection
- ▶ Many more (if you're willing to explore)

## R Basics

## R Basics: Working Directory

- ▶ Working directory (wd) is where your R session will load/save files
- ▶ To see where your current working directory is, run

```
getwd()
```

- ▶ To set the working directory to desired path, run

```
setwd("path")
```

- ▶ Note that ~ is replaced with your HOME directory, e.g. C:\Users\Username\Documents in windows
- ▶ Use forward slashes (/), even on Windows!

```
setwd("~/R")
```

# R Basics: Math Operations

- ▶ Simple math operations

```
3+11  # add stuff  
3-11  # subtract stuff  
3/11  # divide stuff  
3*11  # multiply stuff  
2^10  # raise to powers
```



## R Basics: Assignments

- ▶ Convention for assigning values to variables is `<-`
- ▶ Direction of arrow indicates direction of assignment

```
A <- 12
A # 12
A + 3 -> B
B # 15
24 -> A
A # 24
```

- ▶ The equal sign (`=`) also works, but only for assignment to the left, e.g.

```
A = 12 # good
12 = A # BAD
```

## R Basics: Strings

- ▶ A String variable can be declared in either double quotes("") or single quotes ('')

```
s <- "This is a valid string"  
s
```

```
## [1] "This is a valid string"
```

```
s <- 'and so is this'  
s
```

```
## [1] "and so is this"
```

## R Basics: Re-Assignments

- ▶ A variable can be re-assigned to anything

```
x <- 860306 # first x is assigned a number  
x
```

```
## [1] 860306
```

```
x <- 'This is a variable!'  
x # Now it is a string
```

```
## [1] "This is a variable!"
```

# Vectors

## Vectors: `c()`

- ▶ Vectors are the building blocks of R — even a single variable is actually an “atomic” vector (vector of size 1)
- ▶ Vectors in R are created by concatenating a series of elements

```
X <- c(1,2,3)
X # vector of numbers (1, 2, 3)
```

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

```
Y <- c('this', 'that', 'those')
Y # this is a vector of Strings
```

```
## [1] "this" "that" "those"
```

## Vectors: seq()

- ▶ Create a vector from a sequence with `seq(from, to, by=1)`

```
seq(1, 10)
```

```
## [1] 1 2 3 4 5 6 7 8 9 10
```

```
seq(1, 10, 2)
```

```
## [1] 1 3 5 7 9
```

- ▶ Use short-hand `from:to` if you're incrementing by one

```
1:10
```

```
## [1] 1 2 3 4 5 6 7 8 9 10
```

## Vectors: rep()

- Use rep() to repeat values

```
rep(13, 4)
```

```
## [1] 13 13 13 13
```

```
rep('Yes!', 3)
```

```
## [1] "Yes!" "Yes!" "Yes!"
```

```
rep(c('Sat.', 'Sun.'), 2)
```

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

## Vectors: `rdist()`

- Generate vector of  $n$  samples from a specified distribution

```
runif(n = 10)  # 10 samples from Unif(0, 1)
rnorm(n = 10)  # 10 samples from Norm(0, 1)
rpois(n = 10)  # 10 samples from Poisson(1)
rexp(n = 10)   # 10 samples from Exp(1)
```

- Distribution parameters can be specified as arguments, e.g.

```
# 100 samples from a Norm(20, 5) distribution
rnorm(n = 100, mean = 20, sd = 5)
```

- Read documentation for available distributions

```
?Distributions
```



## Vectors: Indexing

- ▶ Use square braces ([]) to index a vector (base 1)

```
X <- c(10, 11, 12, 13)  
X[1]
```

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

```
X[4]
```

```
## [1] 13
```

```
X[5]
```

```
## [1] NA
```

## Vectors: Indexing (cont'd)

- ▶ Negative indexing is used to exclude elements

```
X[-1]
```

```
## [1] 11 12 13
```

- ▶ Index multiple objects by indexing with a vector

```
ind <- c(2, 4)  
X[ind]
```

```
## [1] 11 13
```

## Vectors: Re-assignment with Indices

- ▶ Replace elements by re-assigning with index

```
X[1] <- 101  
X
```

```
## [1] 101 11 12 13
```

- ▶ Replace multiple elements as well

```
X[2:3] <- c(22, 33)  
X
```

```
## [1] 101 22 33 13
```

## Vectors: Add Elements by Index

- Add new elements to a vector by assigning

```
X[5]
```

```
## [1] NA
```

```
X[5] <- 555  
X
```

```
## [1] 101 22 33 13 555
```

## Vectors: Advanced Indexing

- ▶ Vectors can be indexed by a binary vector (TRUE/FALSE) of equal length
- ▶ i.e., you can index vectors by a specified condition, e.g.,

```
X <- 1:100  
# create a binary vector with the same length of X  
# where the element is TRUE if the element of X  
# in the corresponding position satisfies condition  
ind <- X > 95  
tail(ind) # take a peek at the last few entries
```

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

```
X[ind]
```

```
## [1] 96 97 98 99 100
```

# Matrices

# Creating Matrices

- ▶ A matrix is created from a vector, using `matrix()`, e.g.

```
X <- c(1:12)
# syntax: matrix(vector, # of rows, # of columns)
A <- matrix(X, 3, 4)
A
```

```
##      [,1] [,2] [,3] [,4]
## [1,]    1    4    7   10
## [2,]    2    5    8   11
## [3,]    3    6    9   12
```

- ▶ Notice that the matrix is created column-first

## Matrix Indexing

- ▶ Similar to vectors, a matrix can be indexed with square braces, with the syntax [row #, col #], e.g.
- ▶ Leaving an entry empty will result in the full row/column

```
A[3,2]  # third row, second column
```

```
## [1] 6
```

```
A[2,]   # entire second row
```

```
## [1]  2  5  8 11
```

```
A[,4]   # entire fourth column
```

```
## [1] 10 11 12
```



## Vector/Matrix Operations

# Vector Operations

```
X = c(1:4)
```

```
t(X) # transpose (column) vector X to row vector
```

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

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

```
X + X # element-wise summation
```

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

```
X - X # element-wise subtraction
```

```
## [1] 0 0 0 0
```

## Vector Operations (cont'd)

```
X^3    # element-wise exponentiation
```

```
## [1]  1  8 27 64
```

```
X * X  # element-wise multiplication
```

```
## [1]  1  4  9 16
```

```
X %*% X  # dot (inner) product
```

```
##      [,1]
```

```
## [1,]  30
```

# Matrix Operations

```
A = matrix(1:4, 2, 2) # create 2x2 matrix  
t(A) # transpose (column) vector A to row vector
```

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

```
A + A # element-wise summation
```

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

```
A - A # element-wise subtraction
```

```
##      [,1] [,2]  
## [1,]    0    0  
## [2,]    0    0
```

## Matrix Operations (cont'd)

```
A^3 # element-wise exponentiation
```

```
##      [,1] [,2]  
## [1,]    1  27  
## [2,]    8  64
```

```
A * A # element-wise multiplication
```

```
##      [,1] [,2]  
## [1,]    1    9  
## [2,]    4   16
```

```
A %*% A # dot (inner) product
```

```
##      [,1] [,2]  
## [1,]    7   15  
## [2,]   10   22
```

## Matrix Operations: Warning

- Dimensions must make sense!

```
A <- matrix(1:6, 2, 3)
B <- matrix(1:6, 3, 2)
A %*% B # 2x3 times 3x2: OK
```

```
##      [,1] [,2]
## [1,]   22   49
## [2,]   28   64
```

```
A %*% A # 2x3 times 2x3: Nope
```

```
## Error in A %*% A: non-conformable arguments
```

## Vector/Matrix Comparisons

- Comparisons are all done element-wise

```
c(1, 2, 3) == c(1, 2, 4)
```

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

```
c(1, 2, 3) < c(1, 2, 4)
```

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

```
c(1, 2, 3) >= c(1, 2, 4)
```

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

- Note the double equal sign for comparing equality (one would be assignment!)

# Helpful Vector Functions

- If possible, avoid loops by operating over the Vector/Matrix as a whole

```
mean(X)           # mean
sd(X)             # standard deviation
var(X)            # variance
max(X)            # maximum
min(X)            # minimum
median(X)         # median
sum(X)            # sum
prod(X)           # product
quantile(X,probs=0.5) # quantile for specified probs
length(X)         # length of the vector
range(X)          # range
```



# Helpful Matrix Functions

- If possible, avoid loops by operating over the Vector/Matrix as a whole

```
rowSums(A)    # Row sums
colSums(A)    # Column sums
rowMeans(A)   # Row means
colMeans(A)   # Columns means
diag(A)       # Diagonal of a matrix
solve(A)      # Inverse of a matrix
cov(A)        # Variance covariance matrix
cor(A)        # Correlation matrix
```

# Functions

## Some more built-in functions

- ▶ We've already seen many built-in functions, but here are some more!

```
log(X)    # element-wise log
exp(X)    # element-wise exponential
sqrt(X)   # element-wise square root
```

## Functions for Strings

```
# concatenate two (or more) strings  
paste('one plus one equals', 1+1, '!')
```

```
## [1] "one plus one equals 2 !"
```

```
# specify a separator  
paste('one plus one', 1+1, sep='=')
```

```
## [1] "one plus one=2"
```

```
# if you're into C-style formatting ...  
sprintf('one plus one = %d', 1+1)
```

```
## [1] "one plus one = 2"
```

## Functions for Strings (cont'd)

- ▶ Often, we want to concatenate strings with no spaces (e.g., when constructing filenames/paths in run-time)

```
# short-hand for concatenation w/o spaces  
filename = 'some_file_name.csv'  
paste0('path/to/', filename)
```

```
## [1] "path/to/some_file_name.csv"
```

```
# function specifically for constructing file paths  
file.path('path', 'to', filename)
```

```
## [1] "path/to/some_file_name.csv"
```

## Functions for Strings (cont'd)

- ▶ To enforce upper/lower cases

```
s <- 'SoMe CraZY STRING'  
tolower(s)
```

```
## [1] "some crazy string"
```

```
toupper(s)
```

```
## [1] "SOME CRAZY STRING"
```

# Generic Functions

- Some functions for exploring objects

```
obj <- 1:100  
head(obj, n=5) # display first n rows of obj
```

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

```
tail(obj, n=5) # display last n rows of obj
```

```
## [1] 96 97 98 99 100
```

## Generic Functions (cont'd)

```
str(obj) # display structure of obj
```

```
## int [1:100] 1 2 3 4 5 6 7 8 9 10 ...
```

```
summary(obj) # display summary of obj
```

##	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
##	1.0	25.8	50.5	50.5	75.2	100.0



# Control Flow

- ▶ if statements

```
if (condition) {  
    # stuff to do when condition is TRUE  
} else if(other_condition) { # (OPTIONAL)  
    # stuff to do if other_condition is TRUE  
} else { # (OPTIONAL)  
    # stuff to do if all other conditions are FALSE  
}
```

- ▶ Some consider the catch-all else clause to be dangerous
  - ▶ Some style guides even recommend avoiding the use of else for better readability
- ▶ Best practice is to make conditions explicit whenever possible

## Loops: Note!

- ▶ Loops in R are inefficient
- ▶ For most cases, there will be a much faster, *vectorized* alternative to looping
- ▶ We cover loops because there are some *rare* cases in which a loop might make more sense, but in general, loops should be avoided when writing R

# Loops

- ▶ for statements

```
for (ind in sequence/set) {  
    # iterate over sequence or elements of a set  
    # do stuff  
}
```

- ▶ while statements

```
while (condition) {  
    # stuff to do while the condition is TRUE  
    # the condition must become FALSE at some point!  
}
```

## Loops: Example

```
for (i in 1:3) {  
  print(paste('iteration', i))  
}
```

```
## [1] "iteration 1"  
## [1] "iteration 2"  
## [1] "iteration 3"
```

```
while (i >= 0) {  
  print(paste('de-iteration', i))  
  i <- i - 1 # beware of infinite loops!  
}
```

```
## [1] "de-iteration 3"  
## [1] "de-iteration 2"  
## [1] "de-iteration 1"  
## [1] "de-iteration 0"
```

# User Defined Functions

- ▶ Write your own functions in the form

```
name_of_function <- function(arguments) {  
  # do some stuff with arguments  
  return(result)  
}
```

- ▶ You can use your functions like any other function, e.g.,

```
name_of_function(arguments) # gives you the 'result'
```

## User Defined Functions: Example

- Write a function that will take a vector in  $\mathbb{R}^3$  and tell you if you can make a triangle or not

```
is_good <- function(vec) {  
  if (length(vec) != 3) {  
    # it's always a good idea to make sure your  
    # function gets what it expects to get  
    stop('is_good requires a vector of length 3')  
  }  
  for (i in 1:3) {  
    if (vec[i] > sum(vec[-i])) {  
      return(FALSE)  
    }  
  }  
  return(TRUE)  
}
```

## apply

- ▶ Loops in R are inefficient, and best avoided if possible
- ▶ Vectorize operations whenever possible.
- ▶ Using `apply` to *loop* over rows/columns of matrix/table is considered best practice (in terms of clarity)

```
apply(DATA, MARGIN, FUNCTION)
# MARGIN = 1 applies FUNCTION to each row of DATA
# MARGIN = 2 applies FUNCTION to each column of DATA
# MARGIN = c(1,2) applies FUNCTION to both
#     rows and columns of DATA
```

- ▶ e.g., to get the variance of each row/column of a matrix  $X$ ,

```
apply(X, 1, var) # variance of rows
apply(X, 2, var) # variance of columns
```

## Exercise



# The Question

*You are given three sticks, each of a random length between 0 and 1.*

*What's the probability you can make a triangle?*

- ▶ The answer is  $1/2$
- ▶ Use R to simulate 100,000 times and estimate the answer by
  1. generate 100,000 triplets of uniform (0, 1) random variables
  2. find the portion that can be made into a triangle (hint: use the `is_good` function)

## Answer 1: A (not too good) Way

```
system.time({ # measure execution time
N <- 1e5;
m <- 0
for (i in 1:N) {
  X <- runif(3)
  if (is_good(X)) {
    m <- m + 1
  }
}
cat(sprintf('%.2f%%\n', m / N * 100))
})
```

## 50.41%

```
##      user  system elapsed
##    0.656    0.001    0.660
```

## Answer 2: Preferred R Way

```
system.time({ # measure execution time
  N <- 1e5;
  X <- matrix(runif(N*3), nrow=3, ncol=N)
  m <- apply(X, 2, is_good)
  cat(sprintf('%.2f%%\n', mean(m) * 100 ))
})
```

```
## 49.81%
```

```
##      user  system elapsed
##    0.523    0.003    0.527
```

## Packages

## Installing R Packages

- ▶ R has many (*MANY*) packages created by other users that implement state-of-the-art tools (e.g., data manipulation, statistical models)
- ▶ These packages can be downloaded from the Comprehensive R Archive Network (CRAN)
- ▶ This is as simple as running a single line of code:

```
install.packages("package name")
```

- ▶ You will have to select one of many CRAN mirrors (copies across different servers) from which to download the package from
- ▶ For example, to install the tidyverse package, run

```
install.packages("tidyverse")
```

- ▶ You only need to do this *once* for each machine

# Loading Packages

- ▶ Once you've installed a package on a machine, you can load the package into your current workspace with the `library()` command
- ▶ For example, to use the `tidyverse` package, first load it with

```
library("tidyverse")
```

- ▶ Note: If you ever need to use the two packages `plyr` and `tidyverse` within the same workspace (which you will), ALWAYS (!!!) load `plyr` first!