

Session 1 - R Basics

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January 9-10, 2016

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

Dependencies

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

Rstudio Basics

The screenshot displays the RStudio IDE interface with the following components:

- Menu Bar:** File, Edit, Code, View, Plots, Session, Build, Debug, Tools, Help.
- Toolbar:** Includes icons for file operations, running code, and viewing plots.
- Script Editor (notes.Rmd):** Contains R Markdown code for a presentation, including dependencies and package installation instructions.
- Environment:** Shows the Global Environment, which is currently empty.
- Files Panel:** Displays the file structure of the project, including folders like .gignore, .Rhistory, .Rtutorial.Rproj, README.md, refs, Session 1, and img.
- Console:** Shows the output of the R code, including summary statistics for the 'cars' dataset.

```
6 beamer_presentation:
7   highlight: zenburn
8 ---
9
10 ## Dependencies
11
12 - Latest version ( $\$ge\$`3.1.2`$ ) of 'R'
13   (*free* from <https://www.r-project.org/>)
14 - Latest version of 'Rstudio'
15   (also *free* from <https://www.rstudio.com/>)
16 - A bunch of *free* packages
17
18 ```{r, eval=FALSE}
19 install.packages('dplyr')
20 install.packages('ggplot2')
21 ```
22
23 ## 'Rstudio' Basics
24
25 - 'Ctrl' + 'Enter': Execute current line of code
```

```
26:11 (Top Level) >
~/repos/r-tutorial/ >
list()
1st Qu.:12.0 1st Qu.: 26.00
Median :15.0 Median : 36.00
Mean :15.4 Mean : 42.98
3rd Qu.:19.0 3rd Qu.: 56.00
Max. :25.0 Max. :120.00
> summary(cars)
      speed          dist
Min.   : 4.0   Min.   : 2.00
1st Qu.:12.0   1st Qu.: 26.00
Median :15.0   Median : 36.00
Mean   :15.4   Mean   : 42.98
3rd Qu.:19.0   3rd Qu.: 56.00
Max.   :25.0   Max.   :120.00
> |
```

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("~/Documents/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 ('')

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

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

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

```
## [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 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'  
paste0('path/to/', filename, '.csv')
```

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

```
paste0(getwd(), '/', filename, '.csv')
```

```
## [1] "/home/jongbin/repos/r-tutorial/1-intro/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.
##      1.00   25.75   50.50   50.50   75.25   100.00
```


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 conditions are TRUE  
}
```

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

```
N <- 1e5;
ptm <- proc.time() # measure execution time
m <- 0
for (i in 1:N) {
  X <- runif(3)
  if (is_good(X)) {
    m <- m + 1
  }
}
m / N
```

```
## [1] 0.49981
```

```
proc.time() - ptm
```

```
##      user  system elapsed
##    1.053    0.004    1.061
```

Answer 2: An Okay Way

```
N <- 1e5;
ptm <- proc.time() # measure execution time
X <- matrix(runif(N*3), nrow=3, ncol=N)
m <- 0
for (i in 1:N) {
  if (is_good(X[,i])) {
    m <- m + 1
  }
}
m / N
```

```
## [1] 0.49894
```

```
proc.time() - ptm
```

```
##      user  system elapsed
##    0.768    0.004    0.773
```

Answer 3: A Better Way

```
N <- 1e5;  
ptm <- proc.time() # measure execution time  
X <- matrix(runif(N*3), nrow=3, ncol=N)  
m <- apply(X, 2, is_good)  
sum(m) / N
```

```
## [1] 0.5001
```

```
proc.time() - ptm
```

```
##      user  system elapsed  
##    0.824    0.008    0.833
```

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 `dplyr` package, run

```
install.packages("dplyr")
```

- ▶ 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 `dplyr` package, first load it with

```
library("dplyr")
```