Module 1.4

Basic programming in R

February 2019

NOTE: this module borrows heavily from an R short course developed by a team at Colorado State University.

Load script for module #1.4

1. Click here to download the script! Save the script to a convenient folder on your laptop.

2. Load your script in RStudio. To do this, open RStudio and click on the folder icon in the toolbar at the top and load your script.

Let's get started with basic programming in R!

Functions in R

Everything in R can be boiled down to this one sentence: data are expressed as *vectors*, and vectors are managed, manipulated, and visualized via **functions**. Functions are absolutely central to R!

Let's start with a blank workspace:

```
#######
# Start with blank workspace


rm(list=ls())
```

As we have seen, base R already includes lots of functions, and thousands more functions are available in packages that you can install. Nonetheless, it's really useful to know how to write your own functions! For example, we might write our own function if we have to repeat certain sets of operations over and over in different contexts.

We use the following syntax when we are writing our own functions:

```
my.function <- function(inputs){        # function takes various arguments, or inputs

    ## Algorithm: Do something useful with the inputs

    return(output)              # optionally, return some output

}
```

First function: "Hello, world!"

Let's try to write our first function, which prints out a message: "Hello, world!"

```
####
####   Functions
####

my.function = function(){        # this function has no arguments
```

```
  message <- "Hello, world!"
  print(message)
}
```

Now we can run the function!

```
my.function()
```

```
## [1] "Hello, world!"
```

'Mean' function

Let's write a function to compute the mean of a vector. Okay fine, base R already has the "mean()" function, but let's do it anyway!

```
## We can write our own functions. Useful if we have to repeat operations over and over.
my.mean <- function(x){
    m <- sum(x)/length(x)
    return(m)
}

foo <- c(2, 4, 6, 8)
my.mean(foo)
```

```
## [1] 5
```

'Square' function

How about a function to square the arguments?

```
## A function to square the arguments.
square <- function(x){
    x^2
}

## Square a single value (scaler).
square(2)
```

```
## [1] 4
```

```
## Square a vector.
square(1:10)
```

```
##  [1]   1   4   9  16  25  36  49  64  81 100
```

'Logit' function

The logit operation (log-odds) is not included in the base R package. Let's write it ourselves!

```
## Often, we need to write functions that are not included in the base R package e.g., the logit functio
## Calculate the log-odds (logit).
logit <- function(x){
    log(x/(1-x))
}
```

```
## Calculate logit of 0.9.
logit(.9)
```

```
## [1] 2.197225
```

```
## Sequence between 0 and 1.
x <- seq(from = 0, to = 1, by = 0.01)
```

```
## Caclulate the logit of a vector.
logit.x <- logit(x)
logit.x
```

```
##   [1]        -Inf -4.59511985 -3.89182030 -3.47609869 -3.17805383
##   [6] -2.94443898 -2.75153531 -2.58668934 -2.44234704 -2.31363493
##  [11] -2.19722458 -2.09074110 -1.99243016 -1.90095876 -1.81528997
##  [16] -1.73460106 -1.65822808 -1.58562726 -1.51634749 -1.45001018
##  [21] -1.38629436 -1.32492541 -1.26566637 -1.20831121 -1.15267951
##  [26] -1.09861229 -1.04596856 -0.99462258 -0.94446161 -0.89538405
##  [31] -0.84729786 -0.80011930 -0.75377180 -0.70818506 -0.66329422
##  [36] -0.61903921 -0.57536414 -0.53221681 -0.48954823 -0.44731222
##  [41] -0.40546511 -0.36396538 -0.32277339 -0.28185115 -0.24116206
##  [46] -0.20067070 -0.16034265 -0.12014431 -0.08004271 -0.04000533
##  [51]  0.00000000  0.04000533  0.08004271  0.12014431  0.16034265
##  [56]  0.20067070  0.24116206  0.28185115  0.32277339  0.36396538
##  [61]  0.40546511  0.44731222  0.48954823  0.53221681  0.57536414
##  [66]  0.61903921  0.66329422  0.70818506  0.75377180  0.80011930
##  [71]  0.84729786  0.89538405  0.94446161  0.99462258  1.04596856
##  [76]  1.09861229  1.15267951  1.20831121  1.26566637  1.32492541
##  [81]  1.38629436  1.45001018  1.51634749  1.58562726  1.65822808
##  [86]  1.73460106  1.81528997  1.90095876  1.99243016  2.09074110
##  [91]  2.19722458  2.31363493  2.44234704  2.58668934  2.75153531
##  [96]  2.94443898  3.17805383  3.47609869  3.89182030  4.59511985
## [101]         Inf
```

```
## Plot x on x-axis, and logit(x) on y axis.
plot(x, logit.x, type = 'l')    # View the output graphically.
```
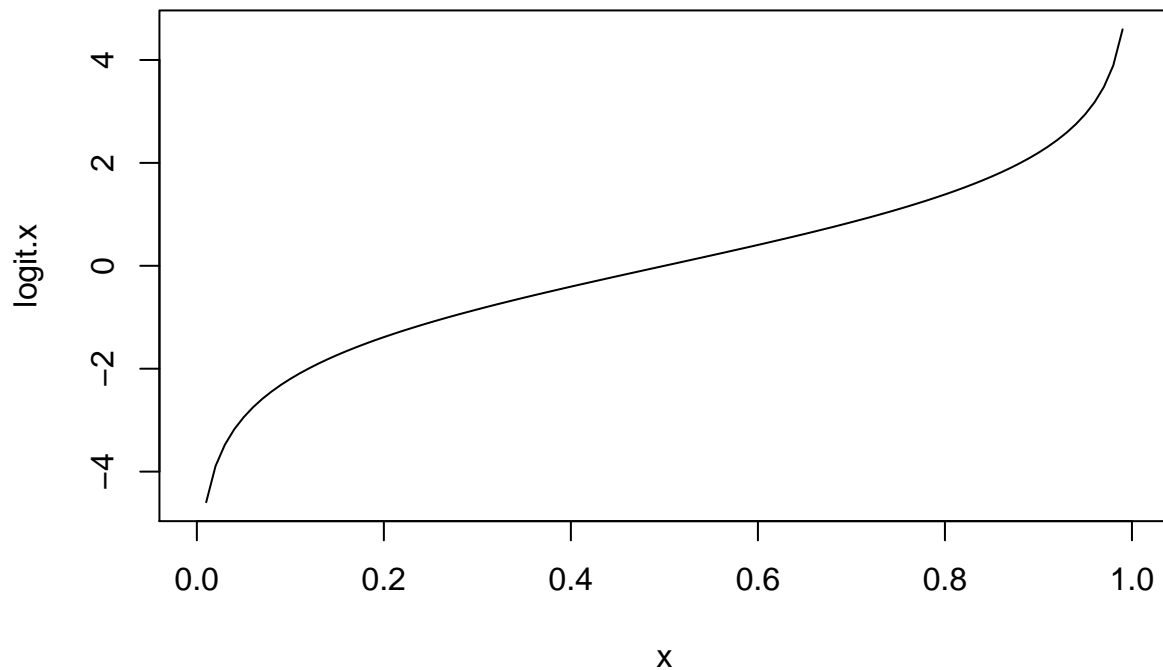
'Expit' function

A useful, related function is the inverse-logit, or "expit" function:

```
## The expit (or inverse logit) funtion.
expit <- function(x){
    exp(x)/(1+exp(x))
}

## Calculate the inverse-logit of logit(0.9) = 2.197225.
expit(2.197225)
```
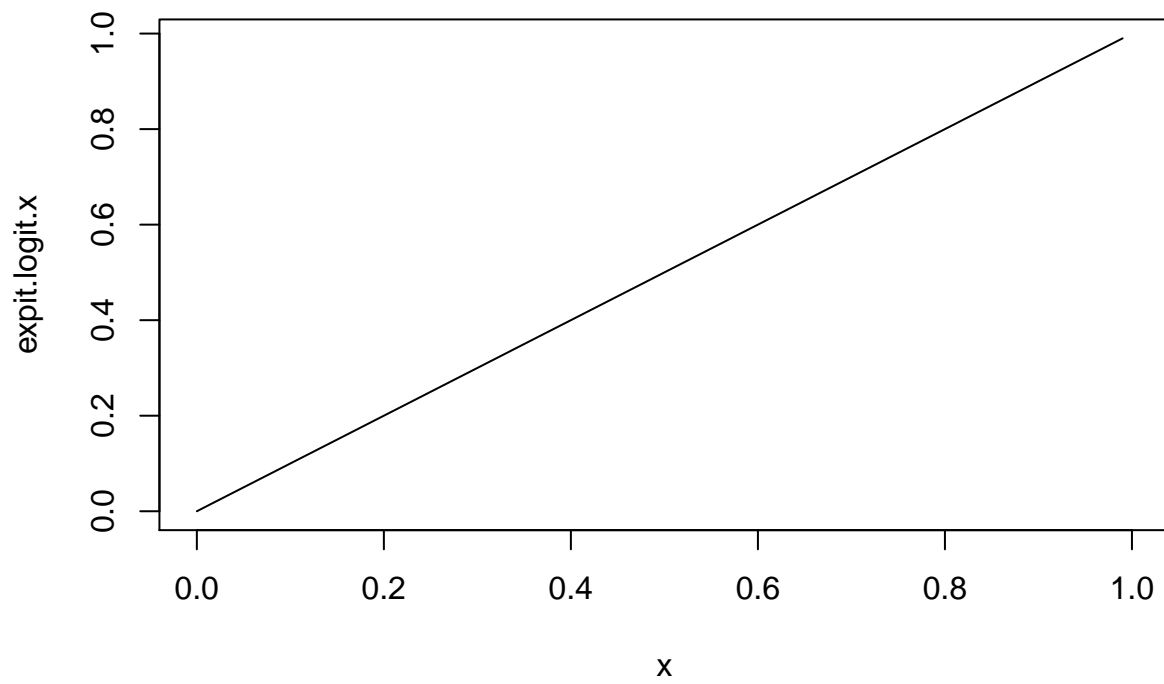
```
## [1] 0.9
```
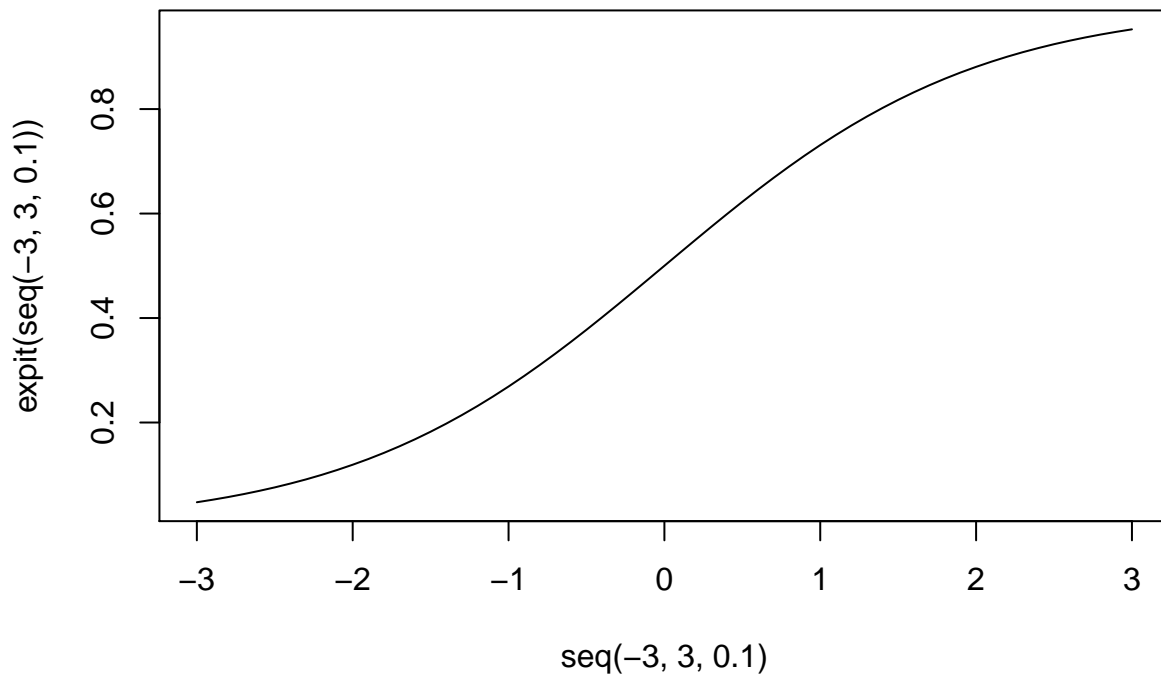
```
expit.logit.x <- expit(logit.x)    # Return to original x values.

## Plot x on x-axis, and expit(logit(x)) = x on y axis.
plot(x, expit.logit.x, type = 'l')
```

```
## Plot "logistic" curve
plot(x=seq(-3,3,0.1),y=expit(seq(-3,3,0.1)),type="l")
```

Wildlife survival function

Finally, let's develop a function to compute the survival rate from data collected on wild individuals tracked over time:

```
## n is the number of animals being monitored.
## d is the number of animals that died.
survival <- function(n, d){
    (n-d)/n
}

## One year of data.
survival(n = 10, d = 5)
```
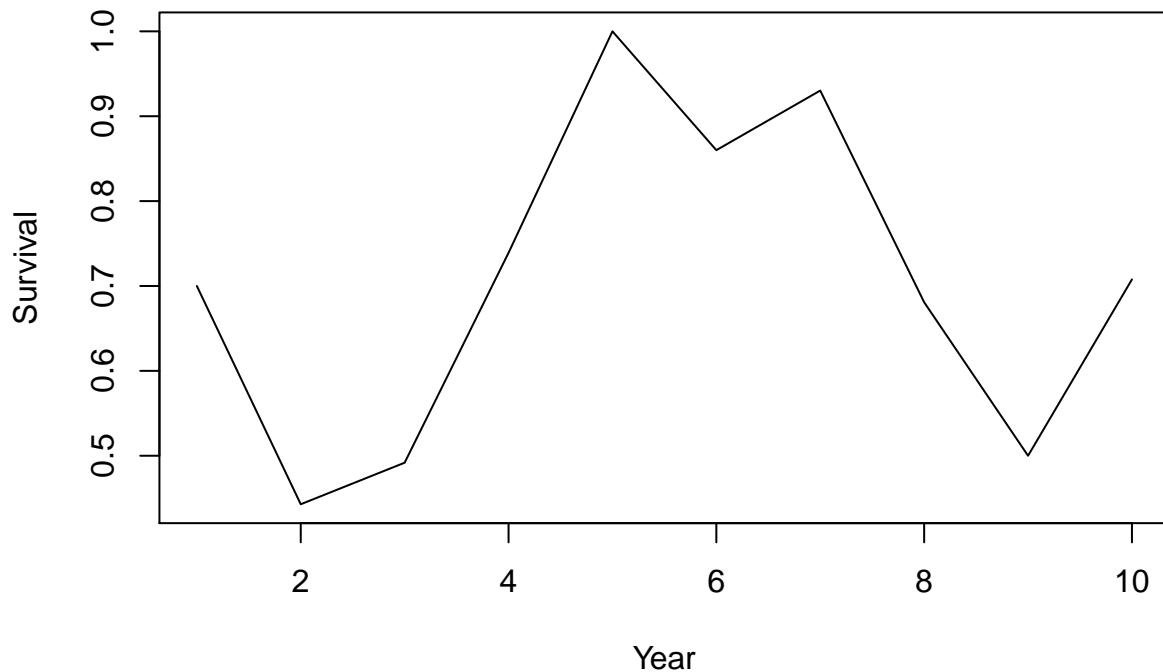
```
## [1] 0.5
```

```
## Simulate many years of data.
d <- sample(0:50, 10, replace = TRUE)   # note use of "sample()" function
n <- c(100, 100-d)
(surv <- survival(n = n[1:10], d = d))
```

```
##   [1] 0.7000000 0.4428571 0.4918033 0.7391304 1.0000000 0.8600000 0.9302326
##   [8] 0.6808511 0.5000000 0.7076923
```

```
## Plot year-specific survival rate.
plot(1:10, surv, type = 'l',xlab="Year",ylab="Survival")
```

Conditional statements

Conditional, or logical, operations (IF [condition] THEN [do something] ELSE [do something]) are a basic building block of computer programming.

if. . . else statements in R

The basic syntax for if. . . else statements in R is as follows:

```
if([some condition]){            ## if some condition is met
  [execute some commands]
}else if ([some other condition]){   ## if some other condition is met (often not necessary)
  [execute some other commands]
}else{                           ## if none of the above conditions are met (otherwise...)
  [execute some other commands]
}
```

NOTE: you can include any number of "else if(. . .)" statements- and most of the time you can omit these entirely!

Let's try it!

```
####
####  if...else statements
####
```

```
########
# Draw a sample from a Binomial distribution with p = 0.7 (here, p is detection probability).
n.samples <- 1
p <- 0.7
x <- rbinom(n = n.samples, size = 1, prob = p)

if (x > 0) {
    print("Detected")
} else {
    print("Not detected")
}
```

```
## [1] "Detected"
```

ifelse() function

Note that "if. . . else" only works for testing one condition at a time. If we have a spreadsheet with lots of data, we need something else – somethign "vectorized" – like the "ifelse()" function:

```
####
####  ifelse()
####

## Note if...else only works for testing one value. If we have a spreadsheet with lots of data, need sor
n.samples <- 100
set.seed(2017)

## 100 samples from a binomial disribution with detection probability = p = 0.7.
y <- rbinom(n = n.samples, size = 1, prob = p)
y
```

```
##    [1] 0 1 1 1 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 0 0 1 0 1 1 1 1 0 1 1 1 0
##   [36] 1 1 1 1 1 1 1 1 1 1 0 1 1 1 0 0 1 0 1 1 0 1 1 0 1 0 1 1 1 0 0 1 1 1 1 1
##   [71] 0 1 1 0 0 1 1 1 1 0 1 0 1 0 1 1 1 1 1 1 0 1 1 1 0 1 0 1 0 1
```

```
## incorrect usage
if (y == 1) {
    print("Detected")
} else {
    print("Not detected")
}   # PRINTS A WARNING MESSAGE!
```

```
## Warning in if (y == 1) {: the condition has length > 1 and only the first
## element will be used
```

```
## [1] "Not detected"
```

```
## Use ifelse instead.
detection.history <- ifelse(y == 1, print("Detected"), print("Not detected"))
```

```
## [1] "Detected"
## [1] "Not detected"
```

```
detection.history
```

```
##    [1] "Not detected" "Detected"     "Detected"     "Detected"
##    [5] "Not detected" "Not detected" "Detected"     "Detected"
```

```
##    [9] "Detected"     "Detected"     "Detected"     "Detected"
##   [13] "Detected"     "Detected"     "Detected"     "Detected"
##   [17] "Detected"     "Not detected" "Not detected" "Not detected"
##   [21] "Detected"     "Detected"     "Not detected" "Not detected"
##   [25] "Detected"     "Not detected" "Detected"     "Detected"
##   [29] "Detected"     "Detected"     "Not detected" "Detected"
##   [33] "Detected"     "Detected"     "Not detected" "Detected"
##   [37] "Detected"     "Detected"     "Detected"     "Detected"
##   [41] "Detected"     "Detected"     "Detected"     "Detected"
##   [45] "Not detected" "Detected"     "Detected"     "Detected"
##   [49] "Not detected" "Not detected" "Detected"     "Not detected"
##   [53] "Detected"     "Detected"     "Not detected" "Detected"
##   [57] "Detected"     "Not detected" "Detected"     "Not detected"
##   [61] "Detected"     "Detected"     "Detected"     "Not detected"
##   [65] "Not detected" "Detected"     "Detected"     "Detected"
##   [69] "Detected"     "Detected"     "Not detected" "Detected"
##   [73] "Detected"     "Not detected" "Not detected" "Detected"
##   [77] "Detected"     "Detected"     "Detected"     "Not detected"
##   [81] "Detected"     "Not detected" "Detected"     "Not detected"
##   [85] "Detected"     "Detected"     "Detected"     "Detected"
##   [89] "Detected"     "Detected"     "Not detected" "Detected"
##   [93] "Detected"     "Detected"     "Not detected" "Detected"
##   [97] "Not detected" "Detected"     "Not detected" "Detected"
```

```
## Going the other direction.
ifelse(detection.history == "Detected", 1, 0)
```

```
##   [1] 0 1 1 1 0 0 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 0 0 1 0 1 1 1 1 0 1 1 1 0
##  [36] 1 1 1 1 1 1 1 1 1 1 0 1 1 1 0 0 1 0 1 1 0 1 1 0 1 0 1 1 1 0 0 1 1 1 1 1
##  [71] 0 1 1 0 0 1 1 1 1 0 1 0 1 0 1 1 1 1 1 1 0 1 1 0 1 0 1 0 1 0 1
```

```
xt  <-  cbind(rbinom(10, 1, .5), rbinom(10, 1, .6))
xt
```

```
##       [,1] [,2]
##  [1,]    1    1
##  [2,]    1    1
##  [3,]    0    0
##  [4,]    0    1
##  [5,]    1    0
##  [6,]    0    0
##  [7,]    0    1
##  [8,]    1    1
##  [9,]    0    1
## [10,]    0    1
```

```
ifelse(xt[, 1] > 0 & xt[, 2] > 0, print("Detected twice"),
       print("Not detected twice"))
```

```
## [1] "Detected twice"
## [1] "Not detected twice"
```

```
##  [1] "Detected twice"     "Detected twice"     "Not detected twice"
##  [4] "Not detected twice" "Not detected twice" "Not detected twice"
##  [7] "Not detected twice" "Detected twice"     "Not detected twice"
## [10] "Not detected twice"
```

Iterating!

Iterating, or running the same operation over and over sequentially, is another fundamental computer programming tool. Computers are great at performing multiple computations really, really fast! **Loops** are a good way to take advantage of computers!

The basic syntax for iterating in R is called a "FOR loop", and looks like this:

```
for([placeholder variable] in [iteration vector of length x]){
   [perform specified operation(s) x times, with the placeholder variable alternately set at each value
}
```

For example...

```
####
####  for loops
####

n.iter <- 10
count <- 0
for(i in 1:n.iter){
  count <- count+1            # assign a new value of count equal to the old value of count + 1
  print(count)
}
```

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

Here, "i" is the *placeholder variable* and "1:n.iter" is the *iteration vector*:

```
   # closer look at iteration vector:
1:n.iter
```

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

Essentially, R starts this FOR loop by setting the value of the *placeholder variable* "i" to the first value of the *iteration vector* (i.e., the value 1). It then runs the two commands in the body of the for loop [count <- count+1; print(count)]. Then, it sets the placeholder variable "i" to the next value in the *iteration vector* (i.e., the value 2) and runs the commands again. It keeps doing this until it reaches the end of the iteration vector, at which point it stops!

Often, we use the placeholder variable directly within the FOR loop. Here are some examples:

```
## Using the placeholder variable "i" within the for loop:

count <- 0
for(i in 1:n.iter){
    count <- count+i              # assign a new value of count equal to the old value of count + i
    print(count)
}
```

```
## [1] 1
## [1] 3
## [1] 6
## [1] 10
## [1] 15
## [1] 21
## [1] 28
## [1] 36
## [1] 45
## [1] 55
```

```
## A for-loop for dependent sequence (here, the Fibonacci sequence)
n.iter <- 10
x <- rep(0, n.iter)            # set up vector of all zeros
x[1] <- 1                      # assign x_1  <-  1
x[2] <- 1                      # assign x_2 = 0
x
```

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

```
for(i in 3:n.iter){
    x[i] <- x[i-1]+x[i-2]      # x_i = x_(i-1) + x_(i-2)
}
x
```

```
##  [1]  1  1  2  3  5  8 13 21 34 55
```

Iterating using the "apply() family of functions in R"

```
###
### apply (A more efficient, vectorized way to iterate)
###

W <- matrix(rpois(4, 10), nrow = 2, ncol = 2)  # Create a 2X2 matrix using a Poisson distribution with
W
```

```
##      [,1] [,2]
## [1,]   12    5
## [2,]   10    8
```

```
## Calculate the row means.
apply(W, 1, mean)
```

```
## [1] 8.5 9.0
```

```
## Calculate the column means.
apply(W, 2, mean)
```

```
## [1] 11.0  6.5
```

```
## Identify the column that has the largest value.
apply(W, 1, which.max)
```

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

```
## Apply your own functions to each row in a matrix.
MyFunc <- function(x){
    2+sum(x/5)-3/2*mean(x)^2
```

```
}
apply(W, 1, MyFunc)
```

```
## [1] -102.975 -115.900
```

Practice exercises

Using conditional statements

Reject null hypothesis

In traditional statistics, one of the primary goals is to compare a test statistic with a "critical value": if the test statistic exceeds the critical value, you can reject a null hypothesis with a reasonable degree of certainty (such that the rate at which you incorrectly reject the null hypothesis remains at or below a pre-specified value, called the "alpha-level").

In the example below, we simulate data (n=100) from a normal distribution with mean of 1, and we use a Student's t-test to assess whether or not we can reject the null hypothesis that the data were derived from a distribution with mean of zero. Here, the *test statistic* is the t-statistic (representing the standardized difference of the sample mean from zero), and the *critical value* is determined as a pre-specified quantile of the "t" distribution (here, we use a two-tailed test holding alpha=0.05).

The act of rejecting or failing to reject a null hypothesis is an instance of conditional logic (if. . . then. . . else). Let's see how we might implement this test in R:

```
####################
####  Practice exercises ####
####################


###
### Perform hypothesis test using if...then...else
###

n.samples <- 100
x <- rnorm(n = n.samples, mean = 1, sd = 1)  # Generate fake data from a normal distribution (using rand
mu <- mean(x)                                # Compute the sample mean.
s <- sd(x)                                   # Compute the sample standard deviation.
t <- mu/(s/sqrt(n.samples))                  # Calculate t-statistic (here, standardized difference of t
t.crit <- qt(p = 0.975, df = 99)             # Calculate critical value for test (above which we can rej
if (t > t.crit) {
    print("reject")                          # Reject if condition holds.
} else {
    print("fail to reject")                  # Fail to reject otherwise.
}
```

```
## [1] "reject"
```

Did you successfully reject the null hypothesis? What if you set the mean to zero when you simulate the data?

Cleaning up messy data

Sometimes (like all the time) your data will be "messy" - that is, it will have some errors (e.g., incorrect data entry) that need to be fixed prior to running an analysis. Take this example of "messy" data from a simulated occupancy study:

```
###
### Clean up messy matrix using ifelse
###

## Simulate data.
observations <- matrix(sample(c("Detected", "NotDetected", 1, 0), 20*3, replace = TRUE), 20, 3)     # si

habitat <- rnorm(20, 0, 2)     # simulate environmental covariate
Data <- cbind(observations, habitat)     # bind into single matrix.
Data

##                                           habitat
##  [1,] "NotDetected" "Detected"    "Detected"    "1.1651537695756"
##  [2,] "0"           "NotDetected" "1"           "-0.613816554750075"
##  [3,] "0"           "NotDetected" "0"           "2.21824770751705"
##  [4,] "NotDetected" "1"           "NotDetected" "-1.41476041128591"
##  [5,] "NotDetected" "NotDetected" "0"           "1.67620138721813"
##  [6,] "0"           "Detected"    "1"           "2.91765526282092"
##  [7,] "NotDetected" "NotDetected" "NotDetected" "4.86943597273634"
##  [8,] "NotDetected" "0"           "NotDetected" "3.13166254497207"
##  [9,] "NotDetected" "1"           "Detected"    "1.17810663231691"
## [10,] "Detected"    "1"           "0"           "1.40889464651772"
## [11,] "NotDetected" "Detected"    "NotDetected" "-1.31838013069218"
## [12,] "Detected"    "NotDetected" "1"           "-0.959218095366536"
## [13,] "1"           "1"           "Detected"    "2.31665529967448"
## [14,] "0"           "Detected"    "1"           "-0.600024626226216"
## [15,] "0"           "0"           "1"           "-1.19162607148504"
## [16,] "Detected"    "0"           "NotDetected" "0.952650163756112"
## [17,] "Detected"    "Detected"    "Detected"    "3.31960806917777"
## [18,] "1"           "1"           "NotDetected" "-2.82432188658575"
## [19,] "0"           "NotDetected" "NotDetected" "2.00889649628675"
## [20,] "0"           "0"           "1"           "3.37380275696964"
```

As you can see, non-detections are coded here as both "NotDetected" and "0", and likewise, detection events also have two alternative codes. To clean up this data set, let's do the following:

- Make sure that detections and non-detections are coded in a consistent manner!

- Reduce the significant digits of the environmental covariate "Habitat".

- Finally, we probably want to add column names to our matrix.

Note the use of the "ifelse()" function here, which is a convenient and efficient way to perform a test consecutively on an entire vector using a single line of code!

```
## Clean-up data using "ifelse()" function
NewObs <- ifelse( (Data[, 1:3] == "Detected") | (Data[, 1:3] == "1"), 1, 0) #  The "|" means "or." Simi
NewHabitat <- as.numeric(Data[, 4])   # as.numeric gets rid of quotes around habitat data.
NewHabitat <- round(NewHabitat, 2)    # round rounds to number of decimals specified.
NewData <- cbind(NewObs, NewHabitat) # bind the columns to form a matrix.
colnames(NewData) <- c("obs1", "obs2", "obs3", "Habitat")  # provide column names
NewData

##       obs1 obs2 obs3 Habitat
##  [1,]    0    1    1    1.17
##  [2,]    0    0    1   -0.61
```

```
## [3,]     0    0    0     2.22
## [4,]     0    1    0    -1.41
## [5,]     0    0    0     1.68
## [6,]     0    1    1     2.92
## [7,]     0    0    0     4.87
## [8,]     0    0    0     3.13
## [9,]     0    1    1     1.18
## [10,]    1    1    0     1.41
## [11,]    0    1    0    -1.32
## [12,]    1    0    1    -0.96
## [13,]    1    1    1     2.32
## [14,]    0    1    1    -0.60
## [15,]    0    0    1    -1.19
## [16,]    1    0    0     0.95
## [17,]    1    1    1     3.32
## [18,]    1    1    0    -2.82
## [19,]    0    0    0     2.01
## [20,]    0    0    1     3.37
```

Looks a lot better now, right!

Using FOR loops

Iteration is one of the things computers do best, and harnessing this ability is endlessly useful! Here are some examples:

View a landscape from multiple angles

In this example, we use a FOR loop to view the topography of a rugged landscape (using the built-in "volcano" dataset in R) from multiple perspectives.

```
###
### FOR loop examples
###


#############
## EXAMPLE 1: Plot a 3D surface using data already stored in R.

Z <- 2 * volcano          # Exaggerate the relief (multiply the elevation by 2)

X <- 10 * (1:nrow(Z))    # set horizontal coordinates -- 10 meter spacing (S to N)

Y <- 10 * (1:ncol(Z))    # set vertical coordinates -- 10 meter spacing (E to W)

# Z    # make sure the elevation matrix looks right

par(bg = "white")
layout(matrix(c(1,1),nrow=1))
persp(X,  Y, Z, theta = 135, phi = 30, col = "green3",    # "persp()" produces a 3D "perspective plot"
      scale = FALSE, ltheta = -120, shade = 0.75,
      border = NA, box = FALSE)
```
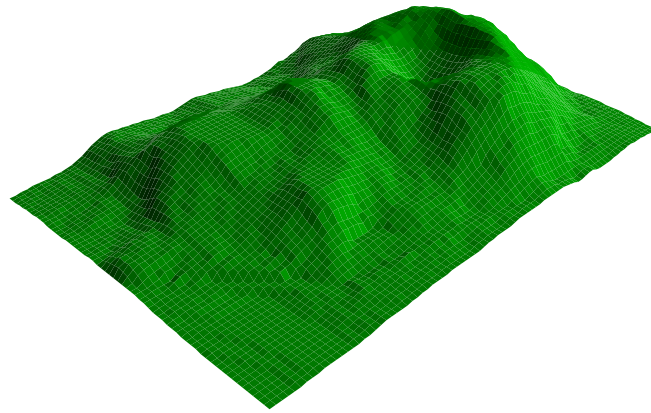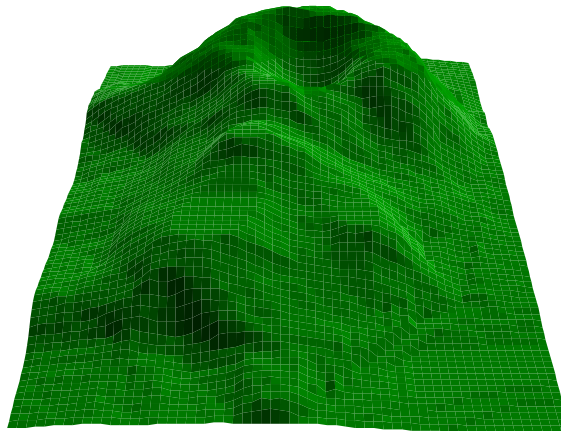
Now let's view from an alternative angle!

```
## change the value of theta from 135 to 90 to change the viewing angle
persp(X, Y, Z, theta = 90, phi = 30, col = "green3",
      scale = FALSE,  ltheta = -120, shade = 0.75,
      border = NA, box = FALSE)
```

Now we can use a FOR loop to view this landscape from many angles. Try it!

```
## Use a for-loop to help view many angles.
for(i in 1:18){
    persp(X, Y, Z, theta = i*20, phi = 30, col = "green3",
          scale = FALSE,  ltheta = -120, shade = 0.75,
          border = NA, box = FALSE)
    print(i*20)
    readline()                              # Pauses the for-loop until [enter] is pushed
}
```

Challenge problems!

1. Create a function to calculate the value of y for the equation $y = \beta_0 + \beta_1 * x$ for any value of β_0, β_1 and x.

2. Using the function in part 1, with $\beta_0 = 2$, and $\beta_1 = -1$ use a FOR loop to calculate y for the values of $x = 1,\ldots,10$. Plot the results.

3. Write a function that conducts a two-sided t test for a given null hypothesis. Here is a code skeleton to get you started!!

```
##########
# Challenge problem 3: code skeleton to get you started!

get.t.test <- function(data, mu0, alpha = 0.05) {
    n <- length(data)
```

```
    mu <- mean(____)
    s <- ____(data)
    t <- (mu-mu0)/(s/sqrt(n))
    t.crit <- qt(p = (1-alpha/2), df = n-1)         # get the critical value
    if (abs(t)>t.crit) {
        answer = "_____"
    } ____ {
        answer = "Fail to reject"
    }
    print(answer)
}
```

4. Calculate the standard deviation as an index of ruggedness from the rows of the volcano elevation data "Z", using the "apply()" function. Which row has the most rugged terrain?

5: Wrap the code below in a FOR loop to simulate the sun rising and setting over the volcano data by looping over values of "lphi" (the light angle). Try replacing "readline()" with "Sys.sleep(.5)" from the example above.

```
#######
# Example code to get you started with challenge problem 5...

persp(X, Y, Z, theta = 30, phi = 30, col = "green3",  lphi = ?,
                                        scale = FALSE,  ltheta = -120, shade = 0.75,
        border = NA, box = FALSE)
print(?)
readline()
```

–go to next module–

More practice with programming in R

Test the Central Limit Theorem!

In this example, we test the famous Central Limit Theorem (CLT) using repeated simulations.

Specifically, as we collect more samples from an arbitrary distribution, the sample mean (e.g., the mean of all the sample means) should converge on the true mean (here, equal to 5).

To test this, let's first write some *pseudocode* for how to perform this operation:

1. Specify the number of hypothetical repeat samples to draw

2. Specify the sample size for each hypothetical repeat sample

3. Specify the mean and variance of the "true" population from which we will sample
4. For each hypothetical sampling experiment:
   a. Draw a random sample from the known distribution

   b. Compute and store the sample mean

5. Visualize the distribution of sample means. Evaluate whether the sample means tend toward the true mean...

Here we translate the pseudocode into real R code!

```
##################
## EXAMPLE 2: Use a FOR loop to create a simulation to test the central limit theorem (CLT).
```

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```
n.iter <- 1000                            # large number of hypothetical "repeat samples."
sample.size <- 30                         # Sample size of 30 from each repeat sample.
mu <- 5                                   # True population mean of 5.
sd <- 2                                   # True standard deviation of 2.
means <- numeric(n.iter)                  # Initialize empty vector to store the sample means.
for(i in 1:n.iter){                       # For each of the repeat samples...
    sample <- rnorm(sample.size, mean = mu, sd = sd)     # draw a random sample from the true populatio
    means[i] <- mean(sample)                 # and store the sample mean.
}
hist(means)                               # Histogram of all the means.
abline(v = mean(means), col = 2, lwd = 4)       # The mean of the means is close to the true mean of
```

Histogram of means
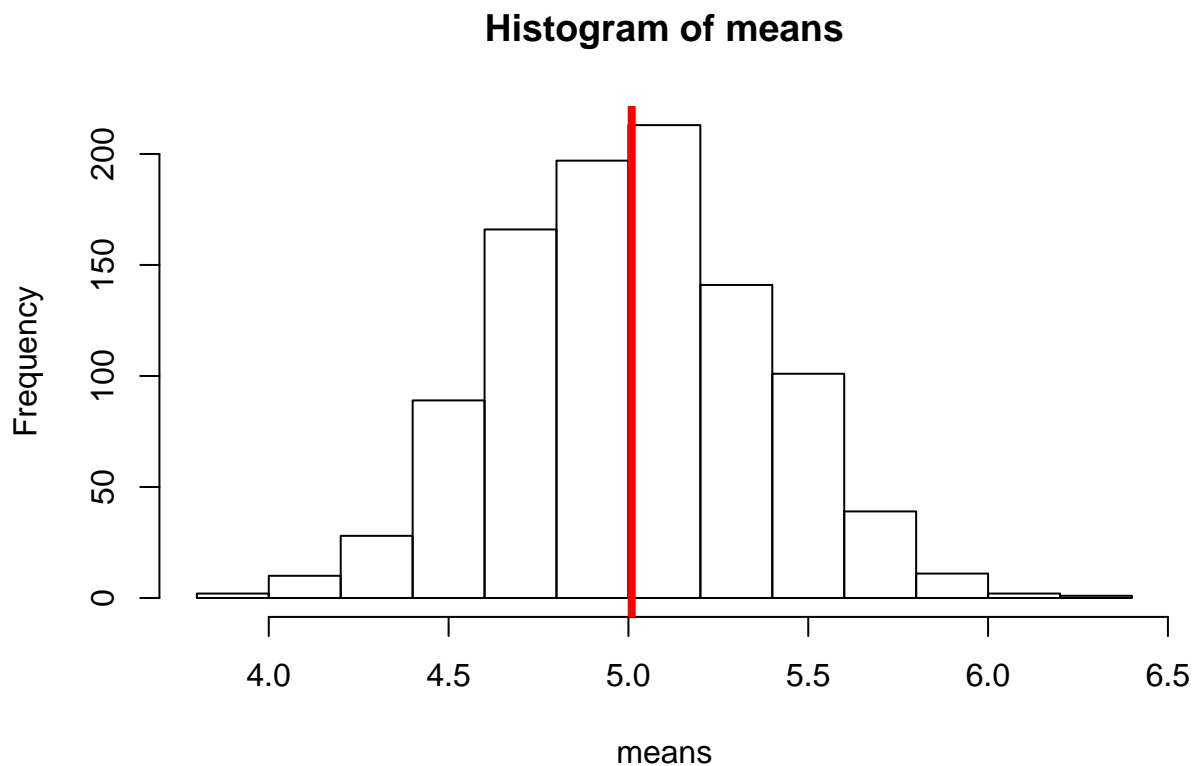

```
plot(density(means), main = "")
abline(v = mean(means), col = 2, lwd = 4)
```
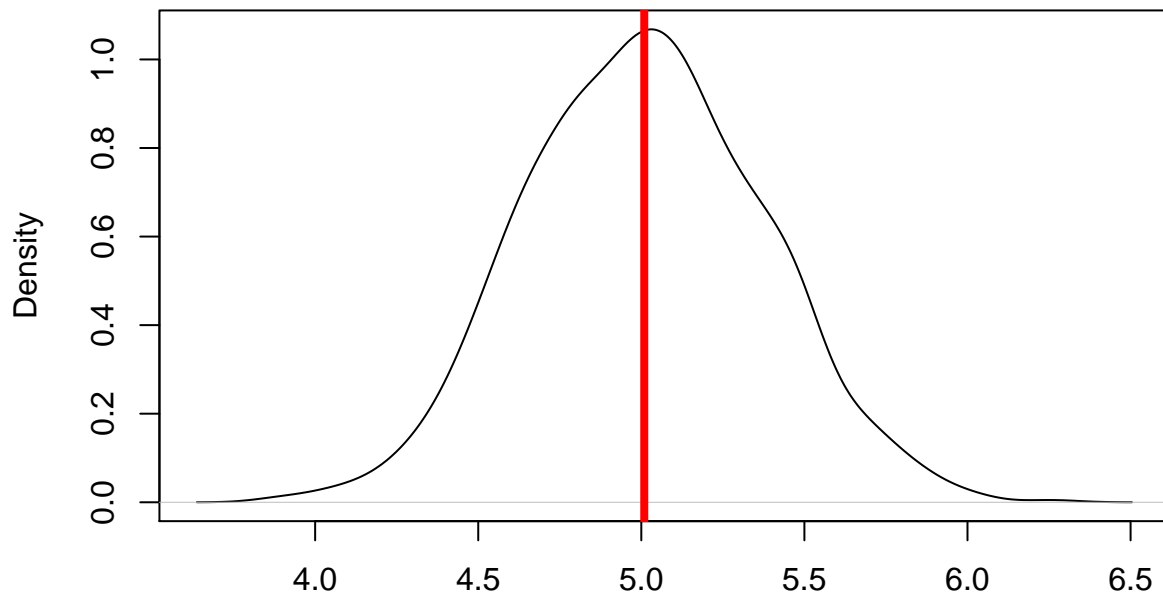
N = 1000   Bandwidth = 0.08186

```r
mean(means)                                    # Close to true mean of 5
```

```
## [1] 5.009089
```

```r
sd(means)*sqrt(30)                             # Close to true sd of 2
```

```
## [1] 1.983313
```

Practice putting it all together!

To make sure we can apply the fundamental components of programming (iterative loops and functions), let's work out an example that uses both!

Logistic population growth example

Here we model the growth/dynamics of a wild population using a classical *logistic* (S-shaped) population growth model:

To get some more practice with functions, let's first write a function to compute the expected rate of population growth on the basis of r (intrinsic rate of population growth), K (carrying capacity), and P_0 (current population size). The logistic growth equation can be written mathematically as:

$P_{t+1} = P_t + r \cdot P0 \cdot (1 - \frac{P0}{K})$

Let's implement this equation as a function in R:

```
##############
##  Logistic population growth example (uses function and for loop)
```

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```
## Logistic growth function: calculate population size using logistic growth model.
  # K = carrying capacity.
  # r = intrinsic growth rate
  # P0 = initial population size

logistic.growth <- function(r, P0, K){
    dpdt <- r*P0*(1-P0/K)                    # implement logistic growth equation
    P0+dpdt
}
logistic.growth(r = .5, P0 = 10, K = 100)    # try out the new function!
```

```
## [1] 14.5
```

Now, we can use a FOR loop simulate population growth over many years:

```
## Logistic growth function within a for-loop

years <- 20                                  # How many years we want to calc population size.
pop.size <- numeric(years)                    # Empty vector to store population size.
pop.size[1] <- 5                              # Starting population size (P0).
for(i in 1:(years-1)){                        # Function within a FOR loop!
    pop.size[i+1] <- logistic.growth(r = 0.5, P0 = pop.size[i], K = 100)
}
plot(1:years, pop.size, type = 'l',
     xlab = "Years", ylab = "Population Size")
```
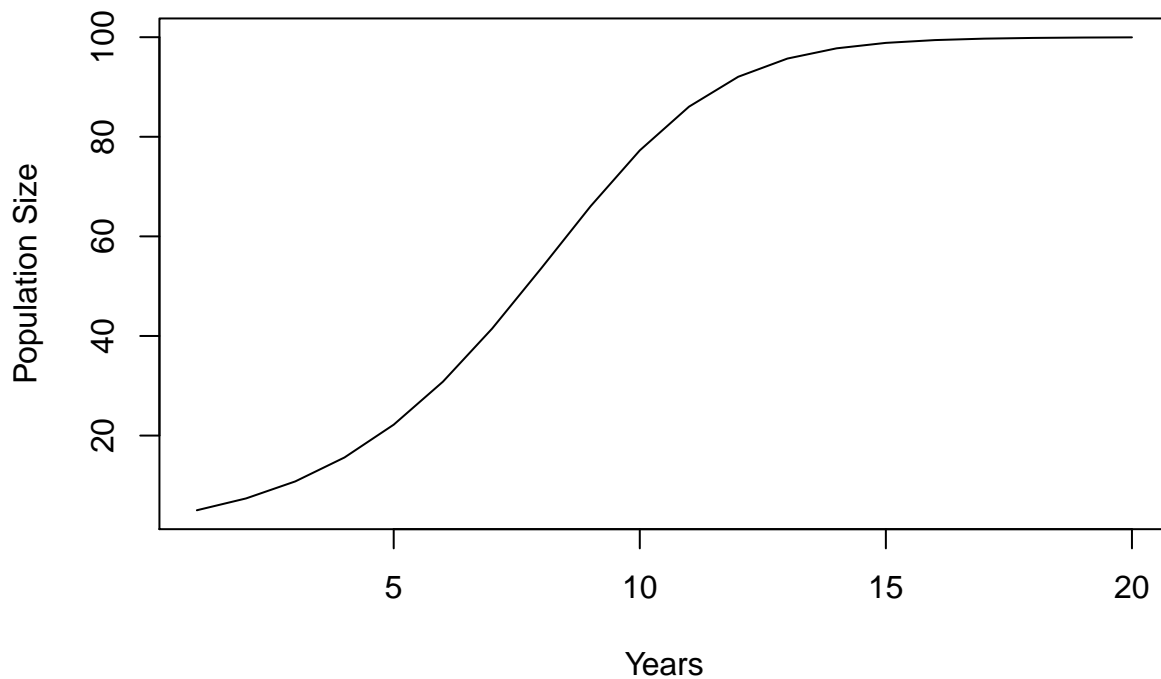
And finally, we could wrap this all up in a more complex function that simulates across years and produces a plot! That way, we could run an entire population simulation with a single line of code. Let's try it!

```
## A more complex function that ouputs a plot.
plot.logistic.growth <- function(r, P, K, years){
    pop.size[1] <- P
    for(i in 1:(years-1)){
        pop.size[i+1] <- P+r*P*(1-P/K)
        P <- pop.size[i+1]
    }
    plot(1:years, pop.size, type = 'l', xlab = "Years",
         ylab = "Population Size",
         main = paste("r = ", r, "K = ", K))
}

plot.logistic.growth(r = 0.5, P = 10, K = 100, years = 20)
```
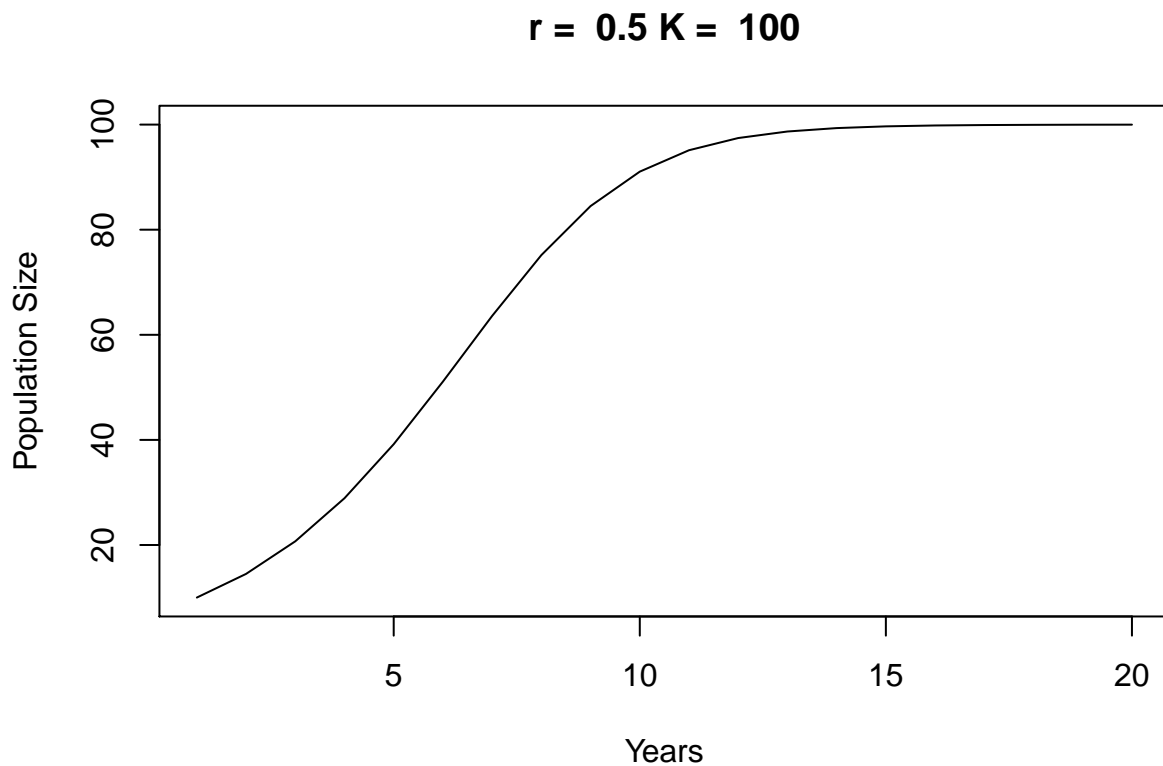


```
par(mfrow = c(2, 2), mar = c(4, 4, 1, 1))                    # Multi-figure (mf) plot with 2 rows and 2 c
plot.logistic.growth(r = 0.1, P = 10, K = 100, years = 20)    # Change the values of r and quickly print
plot.logistic.growth(r = 0.2, P = 10, K = 100, years = 20)
plot.logistic.growth(r = 0.3, P = 10, K = 100, years = 20)
plot.logistic.growth(r = 0.5, P = 10, K = 100, years = 20)
```
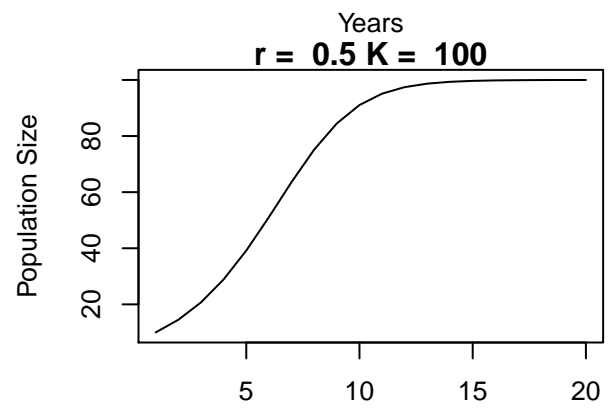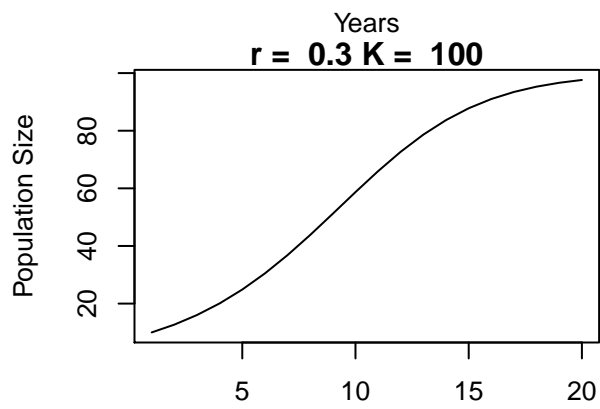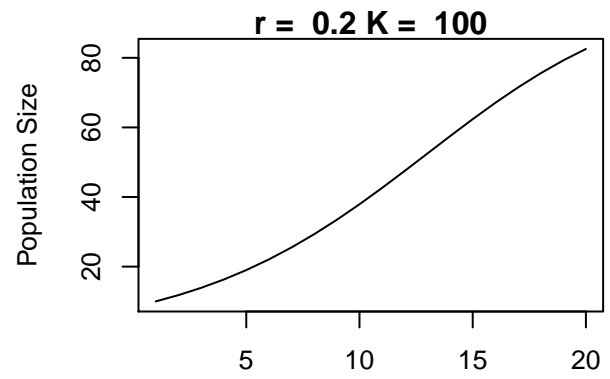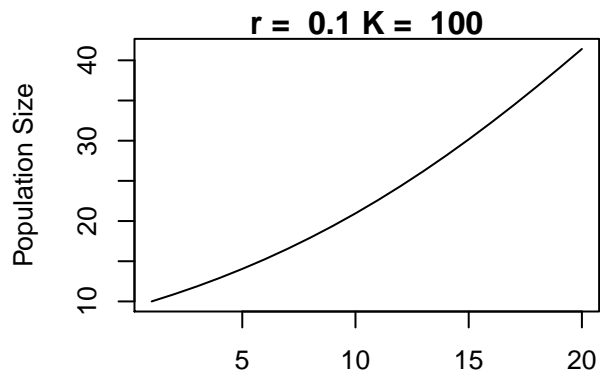
```
par(mfrow = c(1, 1))                                    # Return to a 1X1 plot.
```