Introduction to R

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R

- An integrated suite of tools for data analysis and graphical display.
- R:
  - is an extensive and coherent collection of tools for statistics and data analysis.
  - is an interactive computing environment.
  - provides graphical facilities for data analysis and display.
  - An object-oriented programming language that is *constantly* being extended by the user community.

Language layout

- Commands are either
  - Expressions (evaluated and printed) or

```
> 2*pi
[1] 6.283185
```

  - Assignments (evaluated and pass the value to a variable)

```
> a = 2*pi
> a <- 2*pi
```

- Commands are separated by either a semi-colon ; or a newline.
- The # symbol marks the rest of the line as a comment.
- The prompt is > unless the command is syntactically incomplete, when the prompt changes to +.
- Multiple assignments are evaluated from right to left

```
> b <- a <- 6 # 6 is first passed to a and then to b.
```

- Several commands can be grouped together as an expression by placing them within braces { … }
  - Value of grouped expression is value of last command.
  - Used to specify functions.

Vectors and Matrices

- Most used objects of R users are vectors, matrices, lists and functions
- Six basic types of vectors: logical, integer, double, complex, character
  - Types cannot be mixed
- Different ways to create a vector:

```
> w <- c(1,2,9.8,7,5,pi) # concatenate the values
> w # all values coerced doubles
[1] 1.000000 2.000000 9.800000 7.000000 5.000000 3.141593
> v <- 1:10 # integers from 1 to 10
> v
 [1]  1  2  3  4  5  6  7  8  9 10
> colors <- c("red", "green", "blue", "white”) # vector of character strings; can use ‘…’ or “…”.
> colors # will always print “…”
[1] "red"   "green" "blue"  "white”
> v[4] # 4th element of vector v
[1] 4
> colors[4] # 4th element of vector colors
[1] "white”
> v > 6 # what will this do?
```

Vectors and Matrices (cont'd)

- Different ways to extract subsets of values from a vector:

```
> v > 6 # creates logical vector
 [1] FALSE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE  TRUE  TRUE
> letters #letters is built in character vector of the 26 letters of alphabet
 [1] "a" "b" "c" "d" "e" "f" "g" "h" "i" "j" "k" "l" "m" "n" "o" "p" "q" "r" "s" "t" "u" "v" "w" "x" "y" "z"
> a <- letters[1:10] # can use vectors of integers to extract a subset of values
> a
 [1] "a" "b" "c" "d" "e" "f" "g" "h" "i" "j"
> a[v > 6] # can use logical conditions in vector to extract values!  This is a very useful feature of R.
[1] "g" "h" "i" "j"
> v[v>6]
[1]  7  8  9 10
> a[c(7,8,9,10)]
[1] "g" "h" "i" "j"
> names(v) <- letters[1:10] # can name the elements of a vector
> v
 a  b  c  d  e  f  g  h  i  j
 1  2  3  4  5  6  7  8  9 10
> v["g"] # can now access the 7th value of v by using its name
g
7
> names(v) = NULL # remove the names
> a[-c(2,4,6,8,10)] # values can be omitted from a vector by using negative indices
[1] "a" "c" "e" "g" "i"
```

Vectors and Matrices (cont'd)

- Create a matrix from a vector using matrix() function:

```
> m <- matrix(1:10, nrow=2, byrow=TRUE) # specified number of rows and filled by row
> m
     [,1] [,2] [,3] [,4] [,5]
[1,]    1    2    3    4    5
[2,]    6    7    8    9   10
> ma <- matrix(a, ncol=2) # specified the number of columns and filled by column
> ma
     [,1] [,2]
[1,] "a"  "f"
[2,] "b"  "g"
[3,] "c"  "h"
[4,] "d"  "i"
[5,] "e"  "j"
```

- Accessing specific values of a matrix:

```
> m[2,3]
[1] 8
> ma[2,2]
[1] "g"
```

Vectors and Matrices (cont'd)

- Different ways to extract subsets of values from a matrix:

```
> m > 3 # creates a logical matrix
     [,1]  [,2]  [,3] [,4] [,5]
[1,] FALSE FALSE FALSE TRUE TRUE
[2,]  TRUE  TRUE  TRUE TRUE TRUE
> m[m > 3] # creates a vector of values
[1]  6  7  8  4  9  5 10
> m[2,2:4] # vector from 2nd row and columns 2 to 4.
[1] 7 8 9
> m[2,] # vector from 2nd row
[1]  6  7  8  9 10
> m[,5] # vector from 5th column
[1]  5 10
> m[,2:4] # matrix comprised all rows and columns 2 to 4
     [,1] [,2] [,3]
[1,]    2    3    4
[2,]    7    8    9
> m[1,]>3 # logical vector based on 1st row values > 3
[1] FALSE FALSE FALSE  TRUE  TRUE
> m[,m[1,]>3] # subset columns based on 1st row values > 3
     [,1] [,2]
[1,]    4    5
[2,]    9   10
```

Lists

- List collects together items of different types.

```
> Empl <- list(employee=c("Fred", "Barney"), spouse=c("Wilma", "Betty"), age=c(35,32), wage=c(10.5,8.7))
> Empl # Components and elements of the list are displayed
$employee # Component
[1] "Fred"   "Barney" # Elements
$spouse
[1] "Wilma" "Betty"
$age
[1] 35 32
$wage
[1] 10.5  8.7
```

- Accessing elements of a list using $ or [[index]]:

```
> Empl$spouse # Can access elements of 2nd component by name
[1] "Wilma" "Betty"
> Empl$spouse[1] # Element 1 of 2nd component can be accessed using index
[1] "Wilma"
> Empl[[2]] # Can access elements of 2nd component by index
[1] "Wilma" "Betty"
> Empl[[2]][2] # 2nd element of 2nd component can be accessed using index
[1] "Betty"
```

Lists (cont'd)

```
> Empl[3:4] # Access multiple components using [3:5].
$age
[1] 35 32
$wage
[1] 10.5  8.7
> Empl[[3:4]] # Don't use [[3:4]] to try to access multiple components!
Error in Empl[[3:4]] : recursive indexing failed at level 2
> Empl <- c(Empl, new = "Jetson") # Add new elements using c(); Elements don't have to be the same length.
> unlist(Empl) # Function unlist converts a list to a vector with names.
emplyee1 emplyee2  spouse1  spouse2    age1    age2   wage1   wage2     new
  "Fred" "Barney"  "Wilma"  "Betty"    "35"    "32"   "10.5"   "8.7" "Jetson" # Character string vector
> unlist(Empl, use.names=F) # We can remove names using use.names=F option.
[1] "Fred"   "Barney" "Wilma"  "Betty"  "35"    "32"    "10.5"   "8.7"    "Jetson"
> fourcomp <- c(list(x=1:3, a=3:5), list(y=7:8, b=c(3, 39))) # one list with four components
> onecomp <- c(list(x=1:3, a=3:5), list(y=7:8, b=c(3, 39)), recursive=T) # if recursive = T, list arguments are
      unlisted before being joined
> onecomp # vector of length 10
x1 x2 x3 a1 a2 a3 y1 y2 b1 b2
 1  2  3  3  4  5  7  8  3 39
```

Factors and Data Frames

- Factor is a special type of vector that holds categorical variable.
  - Gene expression data from wild type (wt), mutant (mt) and mutants treated with TNFα (mut-tnf)
  - Factor with three levels corresponding to three treatments: wt, mut, mut-tnf

```
> exp <- factor(c("wt", "wt", "wt", "mut", "mut", "mut", "mut-tnf", "mut-tnf", "mut-tnf"))
> Exp # three replicates per treatment
[1] wt     wt     wt     mut    mut    mut    mut-tnf mut-tnf mut-tnf
Levels: mut mut-tnf wt
```

- Data frame is a matrix-like object whose columns may be of differing type (i.e., numerical, logical, character).

```
> GeneExp <- c(2.1, 5.5, 14.2) # Numerical vector
> RespTNF <- c(F, T, T) # Logical vector
> GeneName <- c("p53", "NFkB", "cMyc") # Character string vector
> AffyId <- c("affyid1", "affyid2", "affyid3") # Character string vector
> ExpData <- data.frame(GeneExp, RespTNF, GeneName, row.names=AffyId, stringsAsFactors=F)
> ExpData # Must set stringsAsFactors variable False or will convert all characters vectors to factors
        GeneExp RespTNF GeneName
affyid1     2.1   FALSE      p53
affyid2     5.5    TRUE     NFkB
affyid3    14.2    TRUE     cMyc
```

Data Frames (cont'd)

- Accessing subsets of values from data frames:

```
> ExpData[1,] # 1st row, like a matrix
      GeneExp RespTNF GeneName
affyid1     2.1   FALSE      p53
> ExpData[,2] # 2nd column, like a matrix
[1] FALSE  TRUE  TRUE
> ExpData$GeneExp # 1st column name, like a list
[1]  2.1  5.5 14.2
> row.names(ExpData) # creates a vector or row names
[1] "affyid1" "affyid2" "affyid3"
> ExpData[row.names(ExpData)=="affyid2",] # use a logical condition, like a matrix
      GeneExp RespTNF GeneName
affyid2     5.5    TRUE     NFkB
> ExpData[ExpData$RespTNF,] # use the logical vector in the data frame
      GeneExp RespTNF GeneName
affyid2     5.5    TRUE     NFkB
affyid3    14.2    TRUE     cMyc
```

Object Attributes

- All objects have two attributes: mode and length

```
> mode(v)
[1] "numeric"
> length(v) # Number of elements in vector
[1] 10
> mode(ma)
[1] "character"
> length(ma) # Number of elements in matrix
[1] 10
> mode(Empl) # Mode is list because of mixed types
[1] "list"
> length(Empl) # Number of components in list
[1] 4
> mode(ExpData) # Data frame is a list because of mixed types
[1] "list"
> length(ExpData) # Number of columns (like components of a list) in data frame
[1] 3
> mode(RespTNF)
[1] "logical”
> length(RespTNF)
[1] 3
```

Object Attributes (cont'd)

- Can access the names of vector elements, lists, and data frame columns using names():

```
> names(Empl)
[1] "employee" "spouse"   "age"      "wage"
> names(ExpData)
[1] "GeneExp"  "RespTNF"  "GeneName"
> names(ma)
NULL
```

- Can access the dimensions of a matrix or data frame using dim():

```
> dim(ma)
[1] 5 2
> dim(ExpData)
[1] 3 3
> dim(v)
NULL
> dim(Empl)
NULL
> nrow(ma)
[1] 5
> ncol(ma)
[1] 2
```

Calling Conventions for Functions

- Functions may have arguments specified or unspecified when the function is defined
  - There may be an arbitrary number of unspecified arguments
  - Unspecified arguments denoted by …
  - Specified arguments may be supplied in the same order in which they occurred in the function definition
  - Specified arguments may be supplied as name=value in which case their order is not important

```
> help(t.test) # if you know the name of the R built in function, you can use help() to get usage information
t.test(x, y = NULL,      alternative = c("two.sided", "less", "greater"),      mu = 0, paired = FALSE, var.equal =
      FALSE,      conf.level = 0.95, ...)
> x <- rnorm(10) # 10 numbers randomly drawn from a normal distribution; x ~ N(0, 1)
> y <- rnorm(10) # 10 numbers randomly drawn from a normal distribution; y ~ N(0, 1)
> t.test(x, y, "greater") # arguments in same order in which they are defined in function
> t.test(x=x, alternative="greater", y=y) # argument names specified but in wrong order
      Welch Two Sample t-test
data:  x and y
t = 1.1862, df = 16.896, p-value = 0.1260
alternative hypothesis: true difference in means is greater than 0
95 percent confidence interval:
 -0.2838161       Inf
sample estimates:
  mean of x   mean of y
 0.02149336 -0.58618035
> t.test(x, "greater", y) # argument names not specified and in wrong order
Error in match.arg(alternative) :
  'arg' must be NULL or a character vector
```

R Functions and Packages

- The R Base Package (so many functions; indexed by alphabet!)
  - http://stat.ethz.ch/R-manual/R-patched/library/base/html/00Index.html
  - Basic functions that come with your installation of R
  - mean(); sum(); median(); quantile(); max(); min(); range();
  - abs(); sign(); log(); log10(), sqrt(); exp(); sin(); cos(); tan(); sinh(); tanh()
  - sort(); order(); rev();
  - duplicated(); unique();
  - seq(); rep();
  - round(); trunc(), floor(); ceiling()
  - cat(); paste(); substring(); grep()
  - merge(); cbind(); rbind()
- Contributed Packages: Currently, the CRAN package repository features 15515 packages:
  - http://cran.r-project.org/web/packages/
  - Specialized packages implementing the latest methods developed in computational statistics.
- Use help() for assistance on usage!

Element wise and Scalar Operators and their Precedence

- $ (list extraction)
- [[[(vector and list element extraction)
- ^ ** (exponentiation)

```
> m^2
 [,1] [,2] [,3] [,4] [,5]
[1,]   1   4   9   16   25
[2,]  36  49  64  81  100
```

- - (unary minus; negative values)
- : (sequence generation)
- %% %/% %*% (special/matrix operators)
- * / (multiply, divide)

```
> m/m
    [,1] [,2] [,3] [,4] [,5]
[1,]   1   1   1   1   1
[2,]   1   1   1   1   1
```

- + - (addition, subtraction)

```
> m+m
    [,1] [,2] [,3] [,4] [,5]
[1,]   2   4   6   8   10
[2,]  12  14  16  18  20
```

- < > <= >= == != (comparison operators)
- ! (logical negation)
- & | && || (element wise and scalar logical operators)
- ~ (formula)
- <- -> = (assignment)

Reading Data Into R

- Set working directory

```
> setwd("~/courses/BIOC_8145/intro_R/example")
> list.files()
[1] "data_frame.txt" "matrix.txt"     "vector.txt"
```

- Read In Data
  - Reading in tables of mixed types: numeric, character and logical

```
> df <- read.table("data_frame.txt", header=T, as.is=T, sep="\t") # as data.frame
> df
  Data   Class Logic
1   7.5   Plant  TRUE
2   6.0  Animal FALSE
3 100.0 Microbe  TRUE
```

  - Reading in a vector

```
> v <- scan("vector.txt") # reading in a vector
Read 3 items
> v
[1] 3.0 2.2 7.0
```

Reading Data into R (cont'd)

- Reading in a matrix

```
> m <- scan("matrix.txt")
Read 9 items
> m # Not what I want!
[1]  3.0  9.1  1.7  2.2  4.0 11.0  7.0  3.2  7.8
```

- Let's try read.table()

```
> m <- read.table("matrix.txt", header=F, sep="\t")
> m # This will work, but I get row indexes and column names.  What about a simple matrix?
  V1  V2   V3
1 3.0 9.1  1.7
2 2.2 4.0 11.0
3 7.0 3.2  7.8
> m <- matrix(scan("matrix.txt"), byrow=T, ncol=3)
Read 9 items
> m # A simple numerical matrix.
     [,1] [,2] [,3]
[1,]  3.0  9.1  1.7
[2,]  2.2  4.0 11.0
[3,]  7.0  3.2  7.8
```

Writing Data to a File

- write() writes vector or matrix to a file

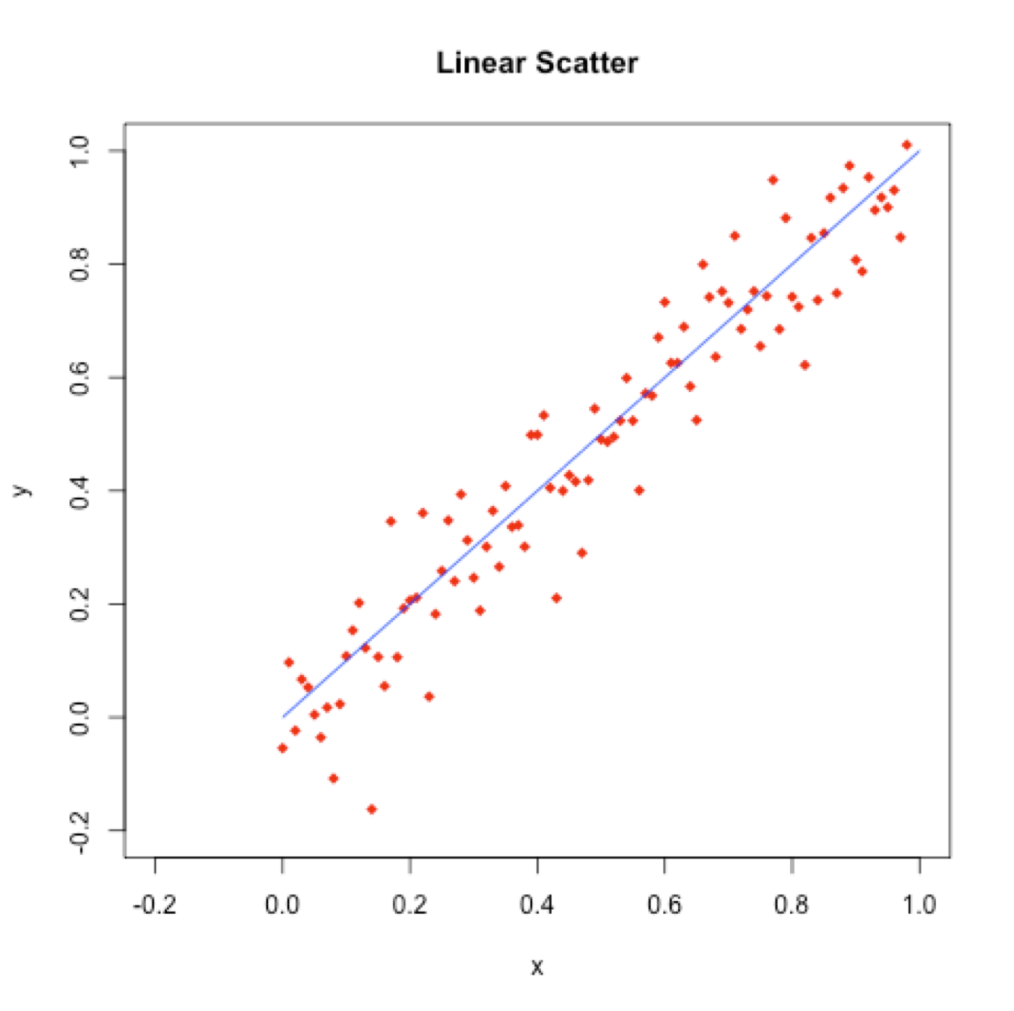
```
> t(m) # transpose of matrix m: rows -> columns and columns -> rows
     [,1] [,2]
[1,]    1    6
[2,]    2    7
[3,]    3    8
[4,]    4    9
[5,]    5   10
> tm <- t(m)
> write(tm, file="matrix.txt", ncol=5, sep="\t") # must transpose matrix m to preserve order of values in file
```

- write.table() writes a data frame to a file

```
> write.table(ExpData, file="ExpData.txt", quote=F, sep="\t", row.names=T, col.names=T) # row.names=T and
      col.names=T are the default; it's useful to show you they can be omitted.
```

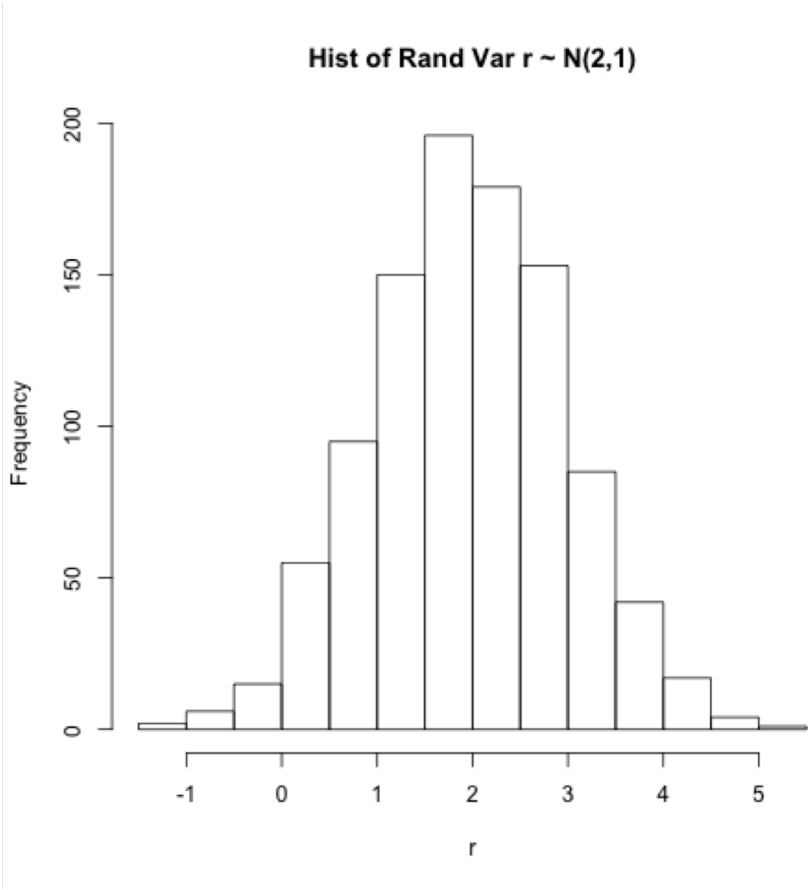
Graphics

```
> x <- seq(0,1,by=0.01)
> y <- x + rnorm(length(x), mean=0, sd=0.1)
> png(filename="linear_scatter.png")
> plot(x, y, xlab="x", ylab="y", main="Linear Scatter", xlim=c(-.2,1), ylim=c(-.2,1), pch=18, col="red")
> lines(x,x,col="blue")
> graphics.off()
```

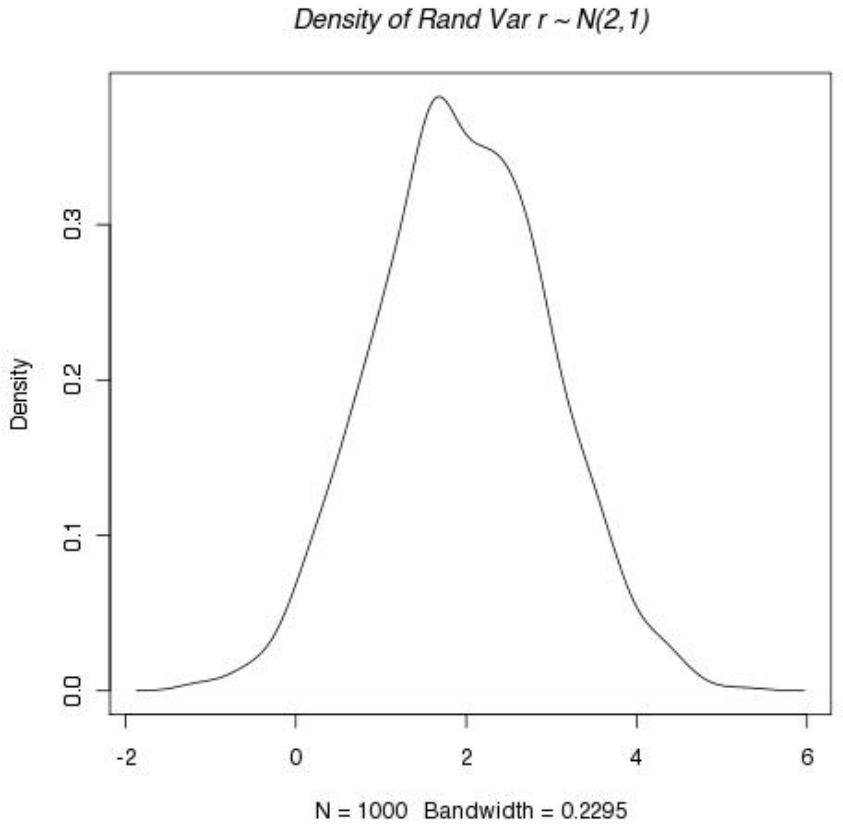


Graphics (cont'd)

```
>r <- rnorm(1000, mean=2, sd=1)
> bmp(filename="hist.bmp")
> hist(r, main="Hist of Rand Var r ~ N(2,1)")
> graphics.off()
```

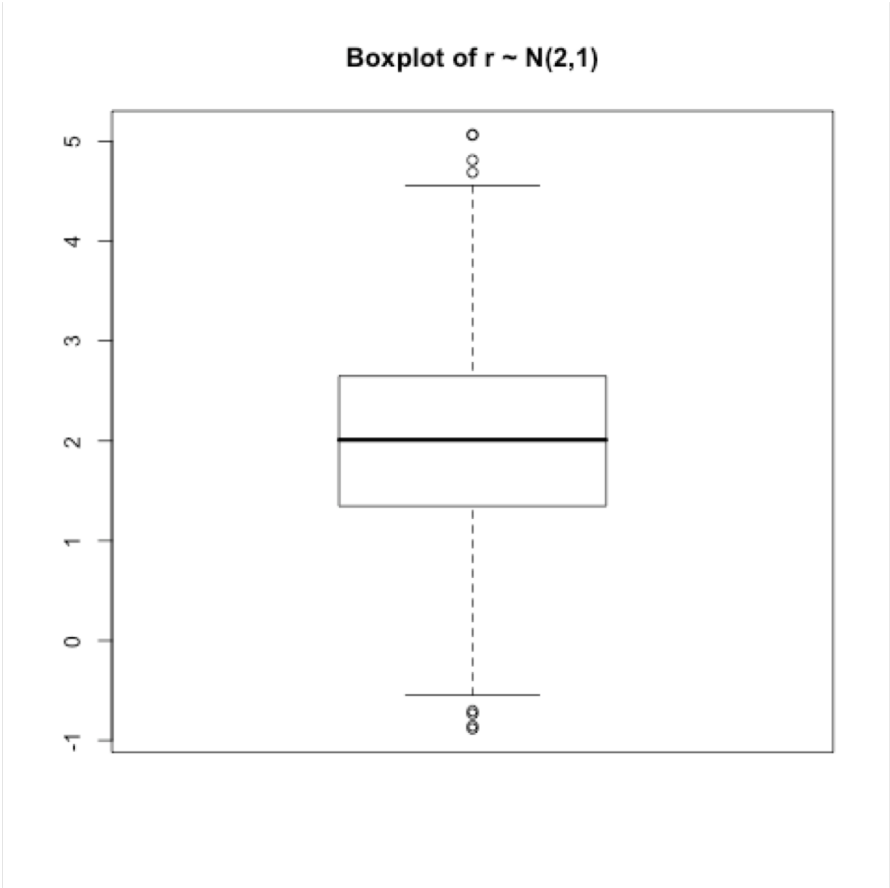



```
> jpeg(filename="density.jpeg")
> plot(density(r), main="Density of Rand Var r ~ N(2,1)")
> graphics.off()
```

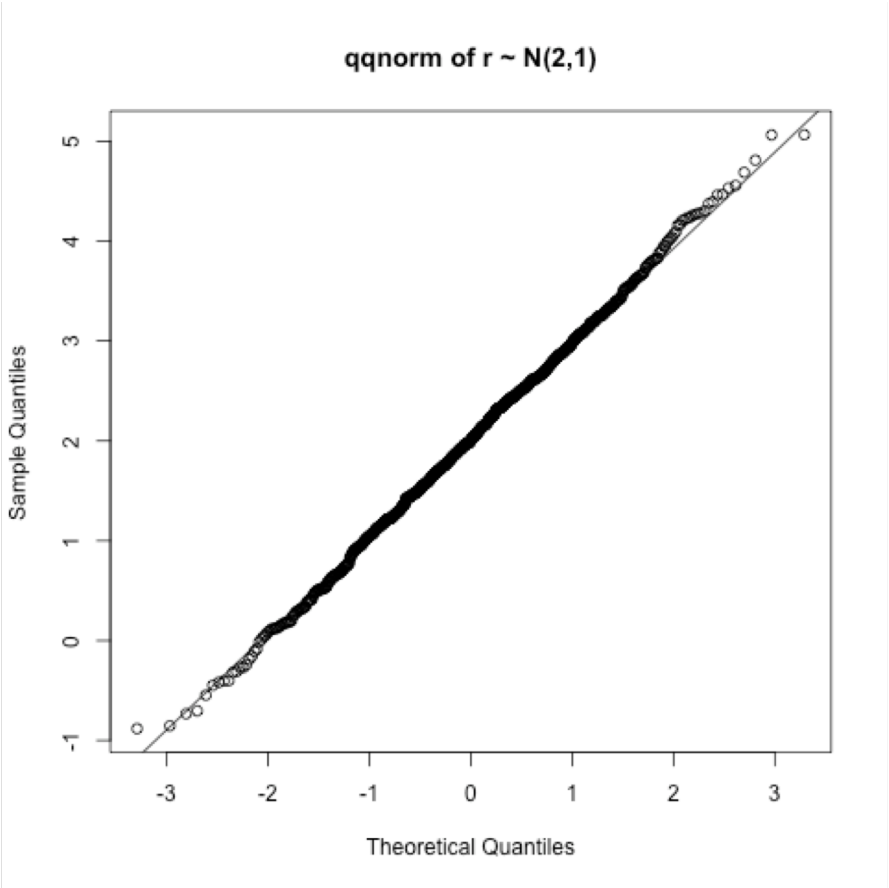


Graphics (cont'd)

```
> png("boxplot.png")
> boxplot(r, main="Boxplot of r ~ N(2,1)")
> graphics.off()
```




```
> png("qqplot.png")
> qqnorm(r, main="qqnorm of r ~ N(2,1)")
> qqline(r)
> graphics.off()
```



Control Structures

- if (condition) true.branch else false.branch

```
> if (length(v) > 10) {
+ long <- TRUE
+ variance <- var(v)
+ } else {
+ long <- FALSE
+ variance <- NA
+ }
> long
[1] FALSE
> variance
[1] NA
```

- for (variable in sequence) statement
  - Poor performance (memory and speed!) for large sequences!

```
> square_root <- numeric()
> for (i in 1:length(v)) {
+ square_root <- c(square_root, sqrt(v[i]))
+ }
> square_root
 [1] 1.000000 1.414214 1.732051 2.000000 2.236068 2.449490 2.645751 2.828427 3.000000 3.162278
```

- while (condition) statement

```
> x<-1; i<-1; sum_sqrt<-0; while (square_root[i] <= 2) {sum_sqrt <- sum_sqrt + square_root[i]; i<-i+1}
> sum_sqrt
[1] 6.146264
```

User Defined Functions

- function.name <- function(x, y, z, …) { statement }

```
> med_mean <- function(x) {if (length(x) > 10) { mean(x) } else { median(x) }}
> data1 <- c(rnorm(6), 10) # one outlier among 6 data points drawn from a N(0,1)
> med_mean(data1) # mean would have been badly skewed
[1] 0.8537254
> data1 <- c(rnorm(1000), 10) # one outlier among 1000 points drawn from a N(0,1)
> med_mean(data1) # outlier does not severely impact estimate
[1] 0.06433641
> gt1 <- function(x) (sum(x>1)) # counts the number of elements that are greater than 1
>data1 <- data.frame()
> for (i in 1:100) {data1 = rbind(data1, rnorm(10))} # creates a 100 x 10 random matrix
> dim(data1)
[1] 100  10
> rows <- apply(data1, 1, gt1) # apply the gt1 function over rows of data; treating each row as a vector
> columns <- apply(data1, 2, gt1) # apply gt1 over columns of data; treating each column as a vector
> length(rows) # rows should be a vector of length 100
[1] 100
> length(columns) # columns should be a vector of length 10
[1] 10
> names(columns) <- NULL; columns
 [1] 42 32 29 42 30 30 33 22 24 27
```

Working in R

- Use manuals, tutorials, books and web pages (that I provided and others you can find) to familiarize yourself with built in functions.
- Use help() function for usage
  - Complete but not anything like a tutorial
  - Written by and for statisticians and knowledgeable users of R
  - Helpful examples of usage listed at bottom of page (cut and paste into session)
- Common workflow: output of function1 -> input to function2 …
  - Issues: output of function1 incompatible with input requirements of function 2
    - funtion1 outputs a data frame and function2 only takes a matrix as input
  - Get comfortable with all the major R objects: lists, vectors, matrices, data frames, and functions
  - Coercion: series of functions as.xxx:
    - as.matrix: numerical data frame to numerical matrix
    - as.vector: attempts to coerce an object into a vector of specified length and mode
    - as.character: attempts to coerce an object into a character type
    - unlist: converts a list to a vector of its elements
- Avoid for loops over large sequences!