An Introduction to R

ML01 - Spring 2019

This Week

- The R programming language
  - Syntax and constructs
  - Variable initializations
  - Function declarations
- Introduction to R Graphics Functionality
  - Some useful functions

The R Project

- Environment for statistical computing and graphics
  - Free software
- Associated with simple programming language
  - Similar to S and S-plus
- www.r-project.org

Compiled C vs Interpreted R

- C requires a complete program to run
  - Program is translated into machine code
  - Can then be executed repeatedly
- R can run interactively
  - Statements converted to machine instructions as they are encountered
  - This is much more flexible, but also slower

R Function Libraries

- Implement many common statistical procedures
- Provide excellent graphics functionality
- A convenient starting point for many data analysis projects

R Programming Language

- Interpreted language
- To start, we will review
  - Syntax and common constructs
  - Function definitions
  - Commonly used functions

Interactive R

- R defaults to an interactive mode
- A prompt “>” is presented to users
- Each input expression is evaluated…
- … and a result returned

R as a Calculator

```
> 1 + 1        # Simple Arithmetic
[1] 2
> 2 + 3 * 4    # Operator precedence
[1] 14
> 3 ^ 2        # Exponentiation
[1] 9
> exp(1)       # Basic mathematical functions are available
[1] 2.718282
> sqrt(10)
[1] 3.162278
> pi           # The constant pi is predefined
[1] 3.141593
> 2*pi*6378    # Circumference of earth at equator (in km)
[1] 40074.16
```

Variables in R

- Numeric
  - Store floating point values
- Boolean (T or F)
  - Values corresponding to True or False
- Strings
  - Sequences of characters
- Type determined automatically when variable is created with "<-" operator

R as a Smart Calculator

```
> x <- 1                # Can define variables
> y <- 3                # using "<-" operator to set values
> z <- 4
> x * y * z
[1] 12

> X * Y * Z             # Variable names are case sensitive
Error: Object "X" not found

> This.Year <- 2004    # Variable names can include period
> This.Year
[1] 2004
```

R does a lot more!

- Definitely not just a calculator
- R thrives on vectors
- R has many built-in statistical and graphing functions

R Vectors

- A series of numbers
- Created with
  - `c()` to concatenate elements or sub-vectors
  - `rep()` to repeat elements or patterns
  - `seq()` or `m:n` to generate sequences
- Most mathematical functions and operators can be applied to vectors
  - Without loops!

Defining Vectors

```
> rep(1,10)         # repeats the number 1, 10 times
[1] 1 1 1 1 1 1 1 1 1 1
> seq(2,6)          # sequence of integers between 2 and 6
[1] 2 3 4 5 6       # equivalent to 2:6
> seq(4,20,by=4)    # Every 4th integer between 4 and 20
[1]  4  8 12 16 20
> x <- c(2,0,0,4)   # Creates vector with elements 2,0,0,4
> y <- c(1,9,9,9)
> x + y             # Sums elements of two vectors
[1]  3  9  9 13
> x * 4             # Multiplies elements
[1]  8  0  0 16
> sqrt(x)                # Function applies to each element
[1] 1.41 0.00 0.00 2.00 # Returns vector
```

Accessing Vector Elements

- Use the `[]` operator to select elements
- To select specific elements:
  - Use index or vector of indexes to identify them
- To exclude specific elements:
  - Negate index or vector of indexes
- Alternative:
  - Use vector of T and F values to select subset of elements

Accessing Vector Elements

```
> x <- c(2,0,0,4)
> x[1]        # Select the first element, equivalent to x[c(1)]
[1] 2
> x[-1]       # Exclude the first element
[1] 0 0 4
> x[1] <- 3 ; x
[1] 3 0 0 4
> x[-1] = 5 ; x
[1] 3 5 5 5
> y < 9       # Compares each element, returns result as vector
[1]  TRUE FALSE FALSE FALSE
> y[4] = 1
> y < 9
[1]  TRUE FALSE FALSE  TRUE
> y[y<9] = 2  # Edits elements marked as TRUE in index vector
> y
[1] 2 9 9 2
```

Data Frames

- Group a collection of related vectors
- Most of the time, when data is loaded, it will be organized in a data frame
- Let’s look at an example …

Setting Up Data Sets

- Load from a text file using `read.table()`
  - Parameters `header, sep, and na.strings` control useful options
  - `read.csv()` and `read.delim()` have useful defaults for comma or tab delimited files

- Create from scratch using `data.frame()`
  - Example:

```
data.frame(height=c(150,160),
           weight=(65,72))
```

Blood Pressure Data Set

HEIGHT	WEIGHT	WAIST	HIP	BPSYS	BPDIA
172	72	87	94	127.5	80
166	91	109	107	172.5	100
174	80	95	101	123	64
176	79	93	100	117	76
166	55	70	94	100	60
163	76	96	99	160	87.5

...

Read into R using:

```
bp <-
  read.table("bp.txt",header=T,na.strings=c("x"))
```

Accessing Data Frames

- Multiple ways to retrieve columns…
- The following all retrieve weight data:
  - `bp["WEIGHT"]`
  - `bp[,2]`
  - `bp$WEIGHT`
- The following excludes weight data:
  - `bp[,-2]`

Lists

- Collections of related variables
- Similar to records in C
- Created with list function
  - `point <- list(x = 1, y = 1)`
- Access to components follows similar rules as for data frames, the following all retrieve `x`:
  - `point$x; point[“x”]; point[1]; point[-2]`

So Far …
Common Forms of Data in R

- Variables are created as needed

- Numeric values
- Vectors
- Data Frames
- Lists

- Used some simple functions:
  - `c(), seq(), read.table(), …`

Next …

- More detail on the R language, with a focus on managing code execution
  - Grouping expressions
  - Controlling loops

Programming Constructs

- Grouped Expressions
- Control statements
  - `if … else …`

  - `for` loops
  - `repeat` loops
  - `while` loops

  - `next, break` statements

Grouped Expressions

```
{expr_1; expr_2; … }
```

- Valid wherever single expression could be used
- Return the result of last expression evaluated
- Relatively similar to compound statements in C

if … else …

```
if (expr_1) expr_2 else expr_3
```

- The first expression should return a single logical value
  - Operators `&&` or `||` may be used
- Conditional execution of code

Example: if … else …

```
# Standardize observation i
if (sex[i] == "male")
  {
   z[i] <- (observed[i] -
  males.mean) / males.sd;
   }
else
   {
   z[i] <- (observed[i] -
```

for

```
for (name in expr_1) expr_2
```

- Name is the loop variable
- `expr_1` is often a sequence
  - e.g. `1:20`
  - e.g. `seq(1, 20, by = 2)`

Example: for

```
# Sample M random pairings in a set of N objects
for (i in 1:M)
   {
   # As shown, the sample function returns a
   single
    # element in the interval 1:N
   p = sample(N, 1)
   q = sample(N, 1)

   # Additional processing as needed…
   ProcessPair(p, q);
   }
```

repeat

```
repeat expr
```

- Continually evaluate expression
- Loop must be terminated with `break` statement

Example: repeat

```
# Sample with replacement from a set of N objects
# until the number 615 is sampled twice
M <- matches <- 0
repeat
   {
   # Keep track of total connections sampled
   M <- M + 1

   # Sample a new connection
   p = sample(N, 1)

   # Increment matches whenever we sample 615
   if (p == 615)
      matches <- matches + 1;

   # Stop after 2 matches
   if (matches == 2)
      break;
   }
```

while

```
while (expr_1) expr_2
```

- While `expr_1` is false, repeatedly evaluate `expr_2`
- `break` and `next` statements can be used within the loop

Example: while

```
# Sample with replacement from a set of N objects
# until 615 and 815 are sampled consecutively
match <- false
while (match == false)
    {
    # sample a new element
    p = sample(N, 1)

    # if not 615, then goto next iteration
    if (p != 615)
       next;

    # Sample another element
    q = sample(N, 1)

    # Check if we are done
    if (q != 815)
       match = true;
    }
```

Functions in R

- Easy to create your own functions in R
- As tasks become complex, it is a good idea to organize code into functions that perform defined tasks
- In R, it is good practice to give default values to function arguments

Function definitions

```
name <- function(arg1, arg2, …)
          expression
```

- Arguments can be assigned default values:

  ```
  arg_name = expression
  ```

- Return value is the last evaluated expression or can be set explicitly with `return()`

Defining Functions

```
> square <- function(x = 10) x * x
> square()
[1] 100
> square(2)
[1] 4

> intsum <- function(from=1, to=10)
    {
    sum <- 0
    for (i in from:to)
      sum <- sum + i
    sum
    }
> intsum(3)         # Evaluates sum from 3 to 10 …
[1] 52
> intsum(to = 3)    # Evaluates sum from 1 to 3 …
[1] 6
```

Some notes on functions …

- You can print the arguments for a function using `args()` command

```
> args(intsum)
function (from = 1, to = 10)
```

- You can print the contents of a function by typing only its name, without the `()`

- You can edit a function using

```
> my.func <- edit(my.old.func)
```

Debugging Functions

- Toggle debugging for a function with `debug()`/`undebug()` command

- With debugging enabled, R steps through function line by line
  - Use `print()` to inspect variables along the way
  - Press `<enter>` to proceed to next line

```
> debug(intsum)
> intsum(10)
```

So far ...

- Different types of variables
  - Numbers, Vectors, Data Frames, Lists
- Control program execution
  - Grouping expressions with `{ }`
  - Controlling loop execution
- Create functions and edit functions
  - Set argument names
  - Set default argument values

Useful R Functions

- Online Help
- Random Generation
- Input / Output
- Data Summaries
- Exiting R

Random Generation in R

- In contrast to many C implementations, R generates pretty good random numbers
- `set.seed(seed)` can be used to select a specific sequence of random numbers
- `sample(x, size, replace = FALSE)` generates a sample of size elements from `x`.
  - If `x` is a single number, sample is from `1:x`

Random Generation

- `runif(n, min = 1, max = 1)`
  - Samples from Uniform distribution
- `rbinom(n, size, prob)`
  - Samples from Binomial distribution
- `rnorm(n, mean = 0, sd = 1)`
  - Samples from Normal distribution
- `rexp(n, rate = 1)`
  - Samples from Exponential distribution
- `rt(n, df)`
  - Samples from T-distribution
- And others!

R Help System

- R has a built-in help system with useful information and examples

- `help()` provides general help
- `help(plot)` will explain the plot function
- `help.search("histogram")` will search for topics that include the word histogram

- `example(plot)` will provide examples for the plot function

Input / Output

- Use `sink(file)` to redirect output to a file
- Use `sink()` to restore screen output
- Use `print()` or `cat()` to generate output inside functions
- Use `source(file)` to read input from a file

Basic Utility Functions

- `length()` returns the number of elements
- `mean()` returns the sample mean
- `median()` returns the sample mean
- `range()` returns the largest and smallest values
- `unique()` removes duplicate elements
- `summary()` calculates descriptive statistics
- `diff()` takes difference between consecutive elements
- `rev()` reverses elements

Managing Workspaces

- As you generate functions and variables, these are added to your current workspace
- Use `ls()` to list workspace contents and `rm()` to delete variables or functions
- When you quit, with the `q()` function, you can save the current workspace for later use

Graphics in R

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Computer Graphics

- Graphics are important for conveying important features of the data
- They can be used to examine
  - Marginal distributions
  - Relationships between variables
  - Summary of very large data
- Important complement to many statistical and computational techniques

Example Data

- The examples in this lecture will be based on a dataset with six variables:
  - Height (in cm)
  - Weight (in kg)
  - Waist Circumference (in cm)
  - Hip Circumference (in cm)
  - Systolic Blood Pressure
  - Diastolic Blood Pressure

The Data File

Height	Weight	Waist	Hip	bp.sys	bp.dia
172	72	87	94	127.5	80
166	91	109	107	172.5	100
174	80	95	101	123	64
176	79	93	100	117	76
166	55	70	94	100	60
163	76	96	99	160	87.5
154	84	98	118	130	80
165	90	108	101	139	80
155	66	80	96	120	70
146	59	77	96	112.5	75
164	62	76	93	130	47.5
159	59	76	96	109	69
163	69	96	99	155	100
143	73	97	117	137.5	85

. . .

Reading in the Data

```
> dataset <- read.table("815data.txt", header = T)
> summary(dataset)

     Height          Weight            Waist
 Min.   :131.0   Min.   :  0.00   Min.   :  0.0
 1st Qu.:153.0   1st Qu.: 55.00   1st Qu.: 74.0
 Median :159.0   Median : 63.00   Median : 84.0
 Mean   :159.6   Mean   : 64.78   Mean   : 84.6
 3rd Qu.:166.0   3rd Qu.: 74.00   3rd Qu.: 94.0
 Max.   :196.0   Max.   :135.00   Max.   :134.0

. . .
```

Graphics in R

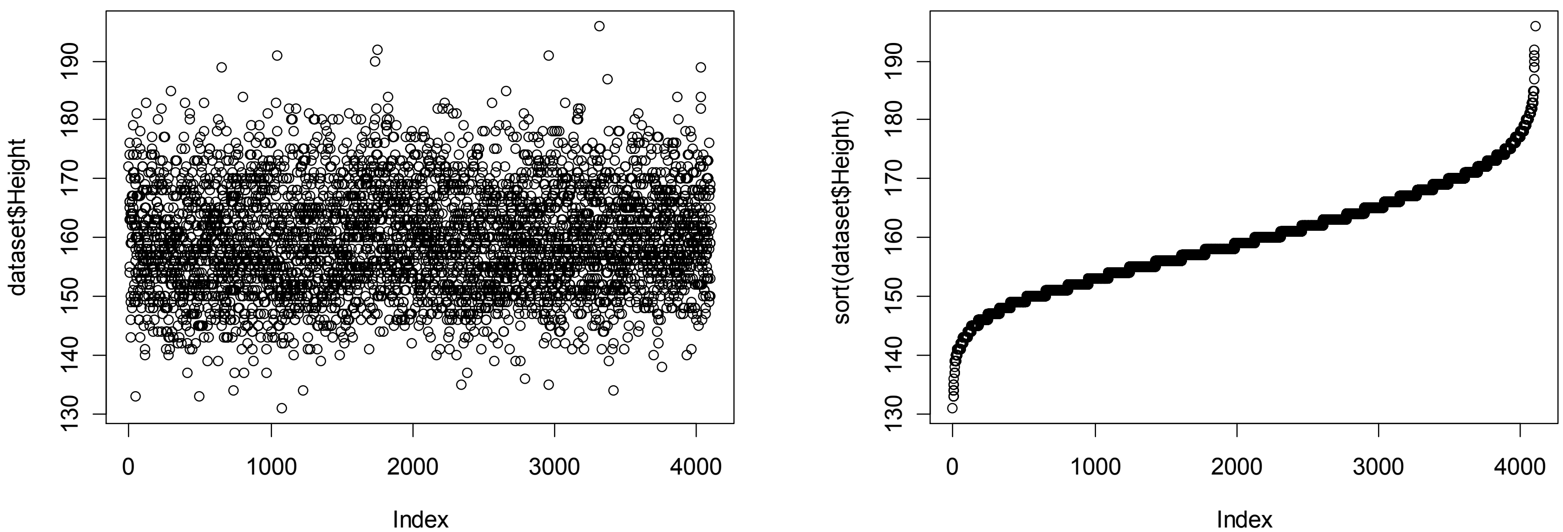
- `plot()` is the main graphing function
- Automatically produces simple plots for vectors, functions or data frames
- Many useful customization options

Plotting a Vector

- `plot(v)` will print the elements of the vector v according to their index

```
# Plot height for each observation
> plot(dataset$Height)
# Plot values against their ranks
> plot(sort(dataset$Height))
```

Plotting a Vector



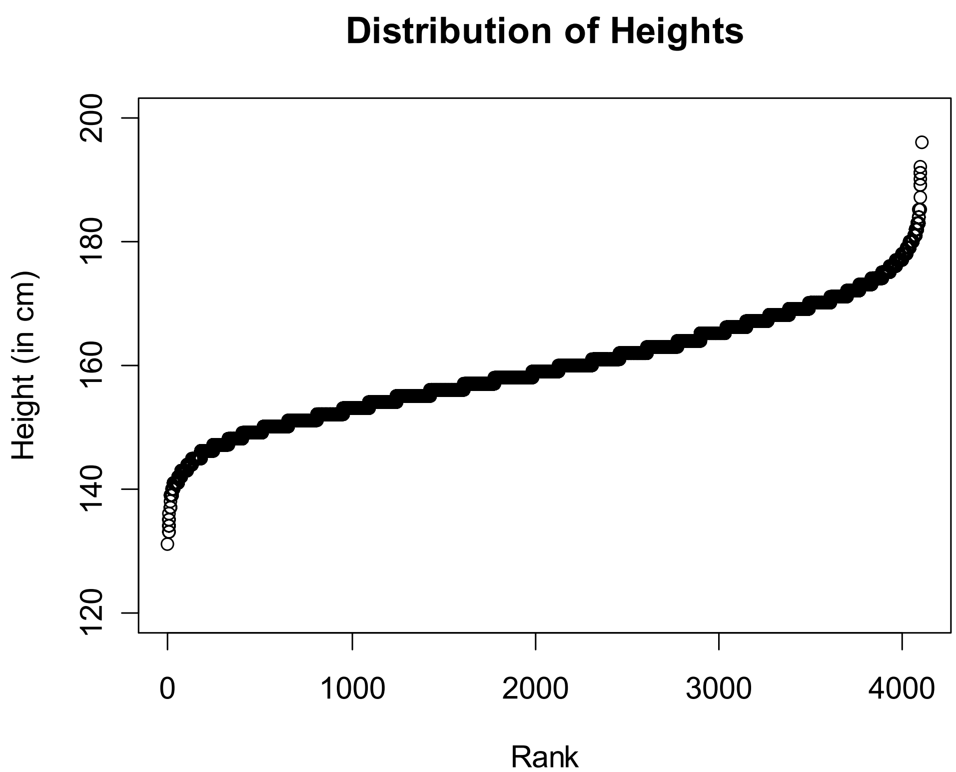
`plot(dataset$Height)` `plot(sort(dataset$Height))`

Common Parameters for `plot()`

- Specifying labels:
  - `main` – provides a title
  - `xlab` – label for the x axis
  - `ylab` – label for the y axis

- Specifying range limits
  - `ylim` – 2-element vector gives range for x axis
  - `xlim` – 2-element vector gives range for y axis

A Properly Labeled Plot

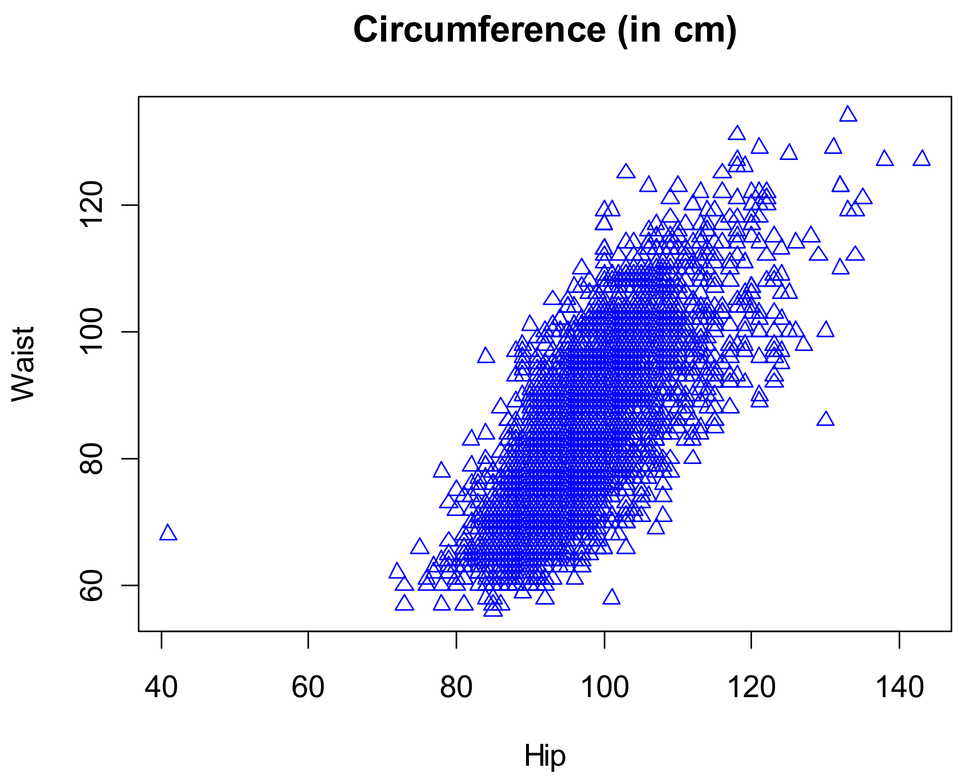



```
plot(sort(dataset$Height), ylim = c(120,200),
ylab = "Height (in cm)", xlab = "Rank", main = "Distribution of Heights")
```

Plotting Two Vectors

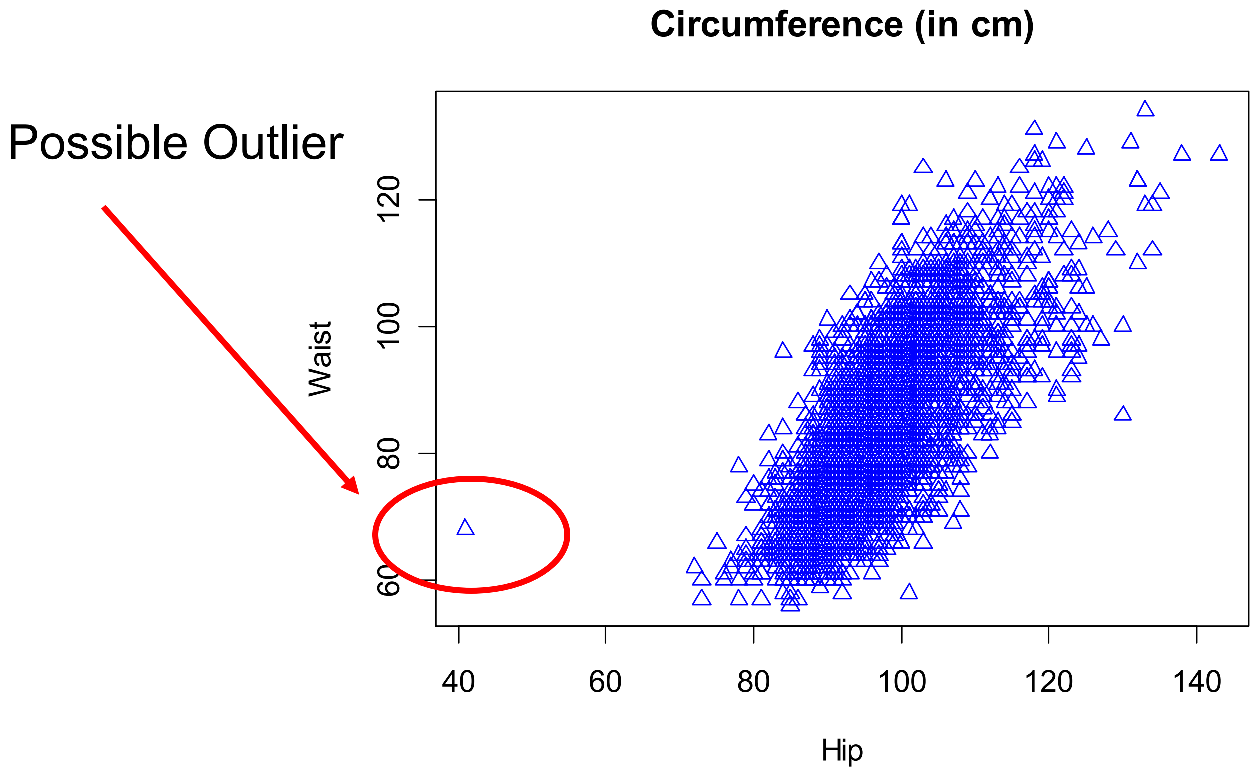
- `plot()` can pair elements from 2 vectors to produce x-y coordinates
- `plot()` and `pairs()` can also produce composite plots that pair all the variables in a data frame.

Plotting Two Vectors




```
plot(dataset$Hip, dataset$Waist,
  xlab = "Hip", ylab = "Waist",
main = "Circumference (in cm)", pch = 2, col = "blue")
```

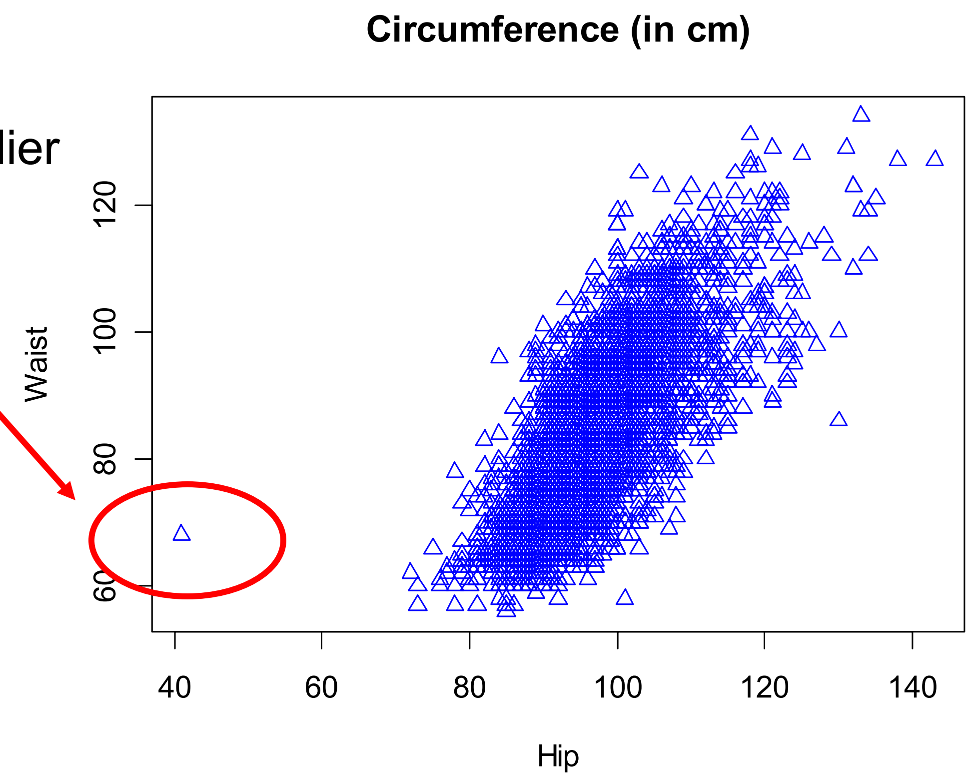
Plotting Two Vectors




```
plot(dataset$Hip, dataset$Waist,
 xlab = "Hip", ylab = "Waist",
main = "Circumference (in cm)", pch = 2, col = "blue")
```

Plotting Two Vectors

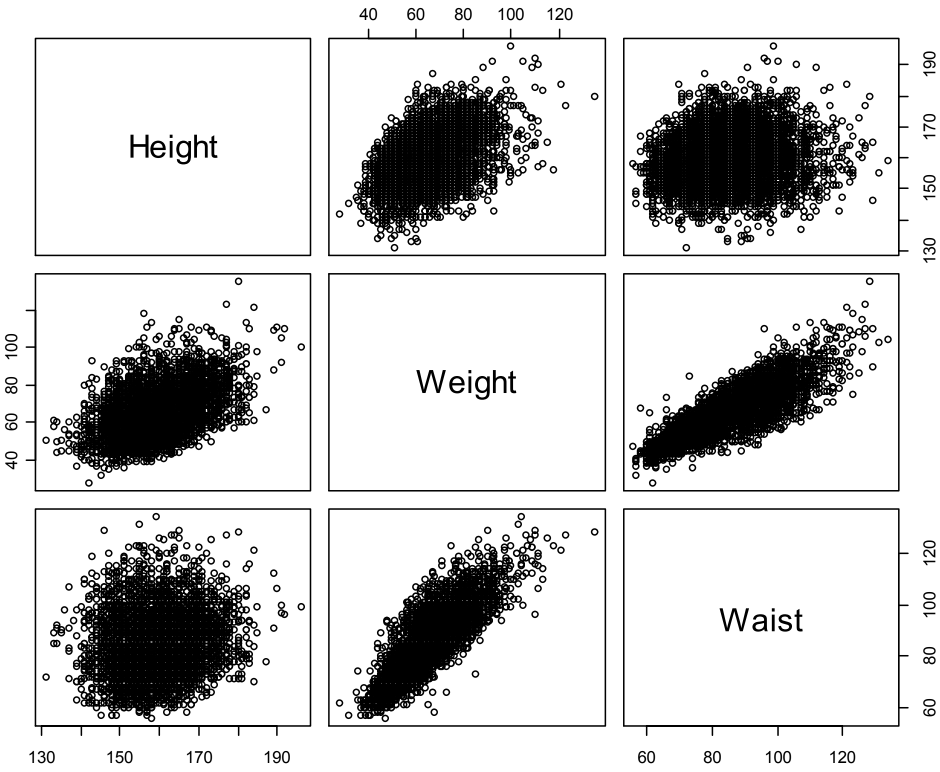
Possible Outlier



These options set the plotting symbol (pch) and line color (col)

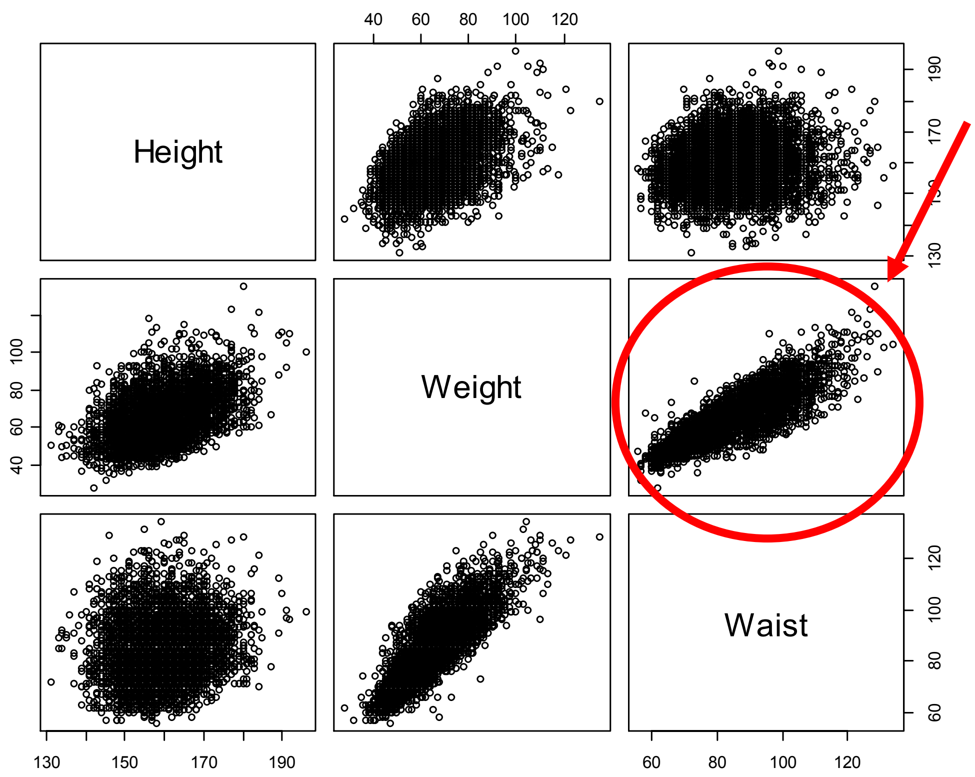
```
plot(dataset$Hip, dataset$Waist,
xlab = "Hip", ylab = "Waist",
main = "Circumference (in cm)", pch = 2, col = "blue")
```

Plotting Contents of a Dataset




```
plot(dataset[-c(4,5,6)])
```

Plotting Contents of a Dataset



Weight and Waist Circumference Appear Strongly Correlated

You could check this with the `cor()` function.

`plot(dataset[-c(4,5,6)])`

Histograms

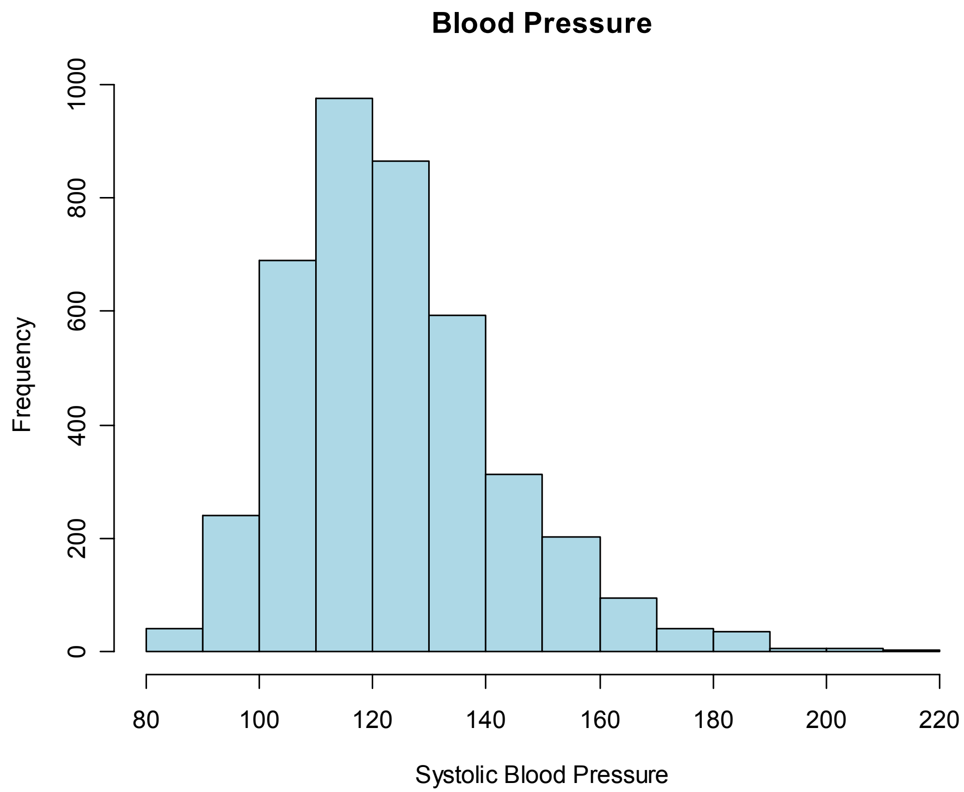
- Generated by the `hist()` function

- The parameter `breaks` is key
  - Specifies the number of categories to plot

  or
  - Specifies the breakpoints for each category

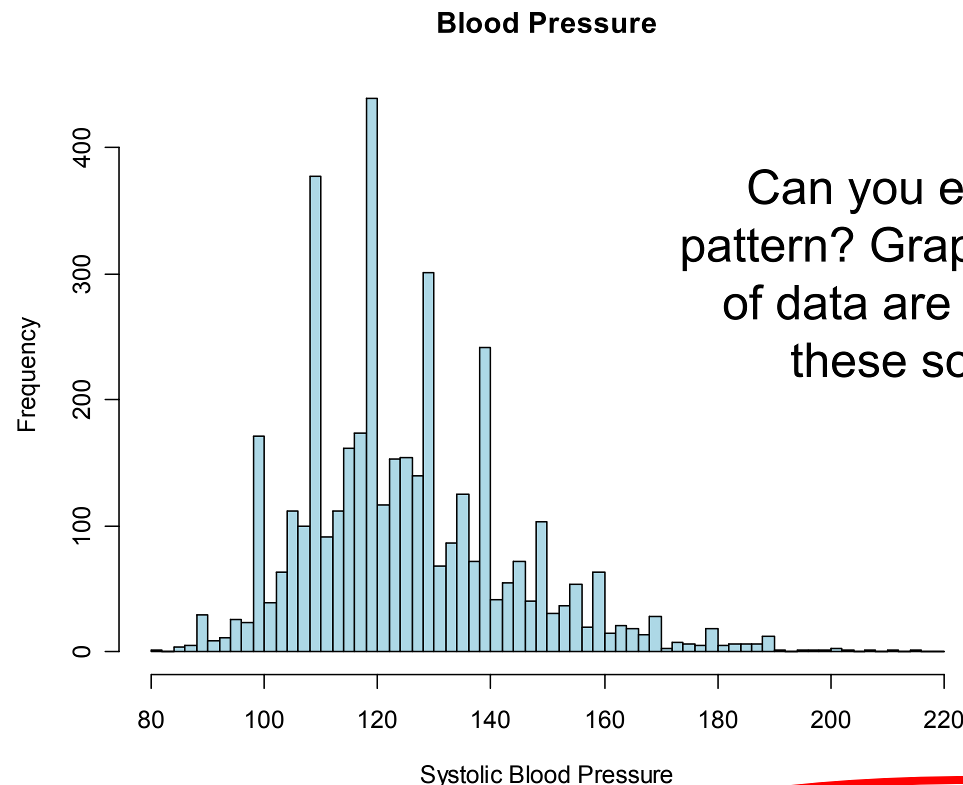
- The `xlab, ylab, xlim, ylim` options work as expected

Histogram




```
hist(dataset$bp.sys, col = "lightblue",
xlab = "Systolic Blood Pressure", main = "Blood Pressure")
```

Histogram , Changed `breaks`



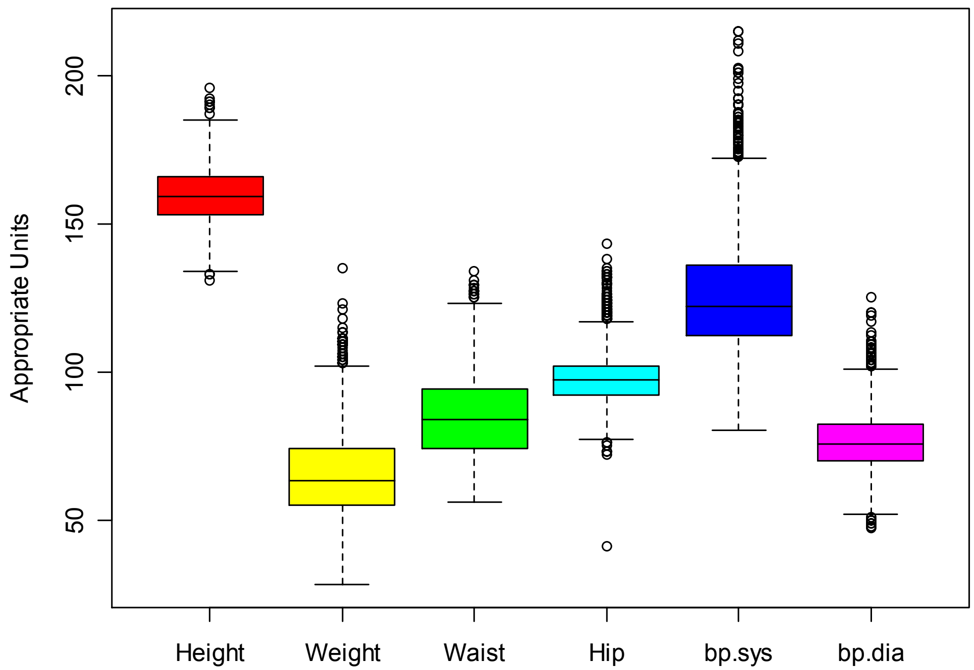
Can you explain the peculiar pattern? Graphical representations of data are useful at identifying these sorts of artifacts

```
hist(dataset$bp.sys, col = "lightblue", breaks = seq(80,220,by=2),
    xlab = "Systolic Blood Pressure", main = "Blood Pressure")
```

Boxplots

- Generated by the boxplot() function
- Draws plot summarizing
  - Median
  - Quartiles (Q1, Q3)
  - Outliers – by default, observations more than 1.5 * (Q1 – Q3) distant from nearest quartile

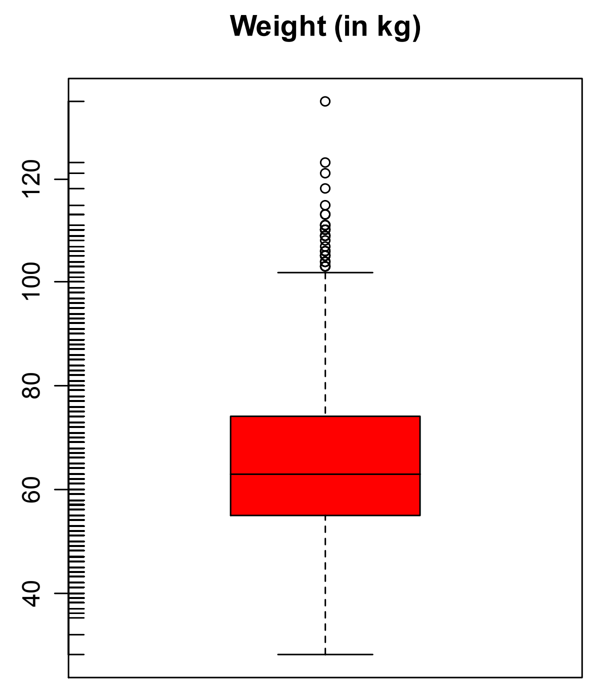
A Simple Boxplot




```
boxplot(dataset, col = rainbow(6), ylab = "Appropriate Units")
```

Adding Individual Observations

- `rug()` can add a tick for each observation to the side of a boxplot() and other plots.
- The `side` parameter specifies where tickmarks are drawn




```
> boxplot(dataset$Weight,
          main = "Weight (in kg)",
          col = "red")
> rug(dataset$Weight, side = 2)
```

Customizing Plots

- R provides a series of functions for adding text, lines and points to a plot
- We will illustrate some useful ones, but look at `demo(graphics)` for more examples

Drawing on a plot

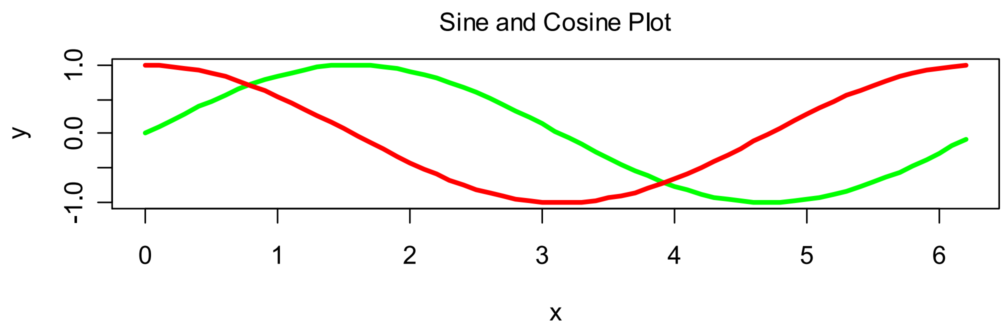
- To add additional data use
  - `points(x,y)`
  - `lines(x,y)`
- For freehand drawing use
  - `polygon()`
  - `rect()`

Text Drawing

- Two commonly used functions:
  - `text()` – writes inside the plot region, could be used to label datapoints
  - `mtext()` – writes on the margins, can be used to add multiline legends
- These two functions can print mathematical expressions created with `expression()`

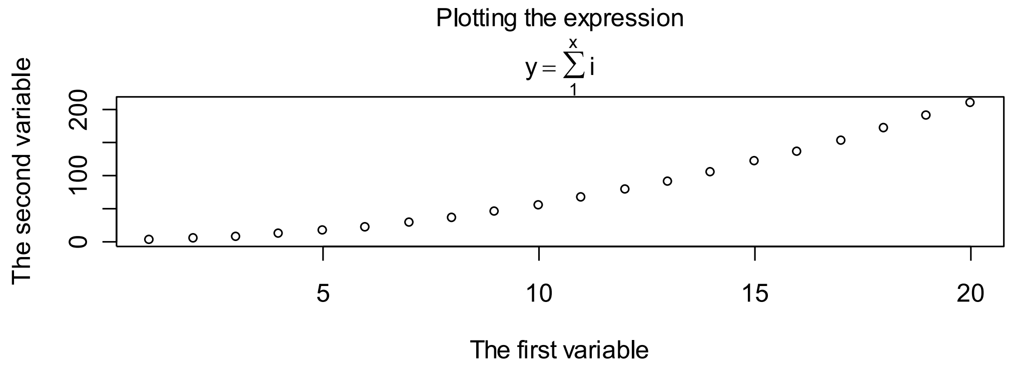
Plotting Two Data Series

```
> x <- seq(0,2*pi, by = 0.1)
> y <- sin(x)
> y1 <- cos(x)
> plot(x,y, col = "green", type = "l", lwd = 3)
> lines(x,y1, col = "red", lwd = 3)
> mtext("Sine and Cosine Plot", side = 3, line = 1)
```

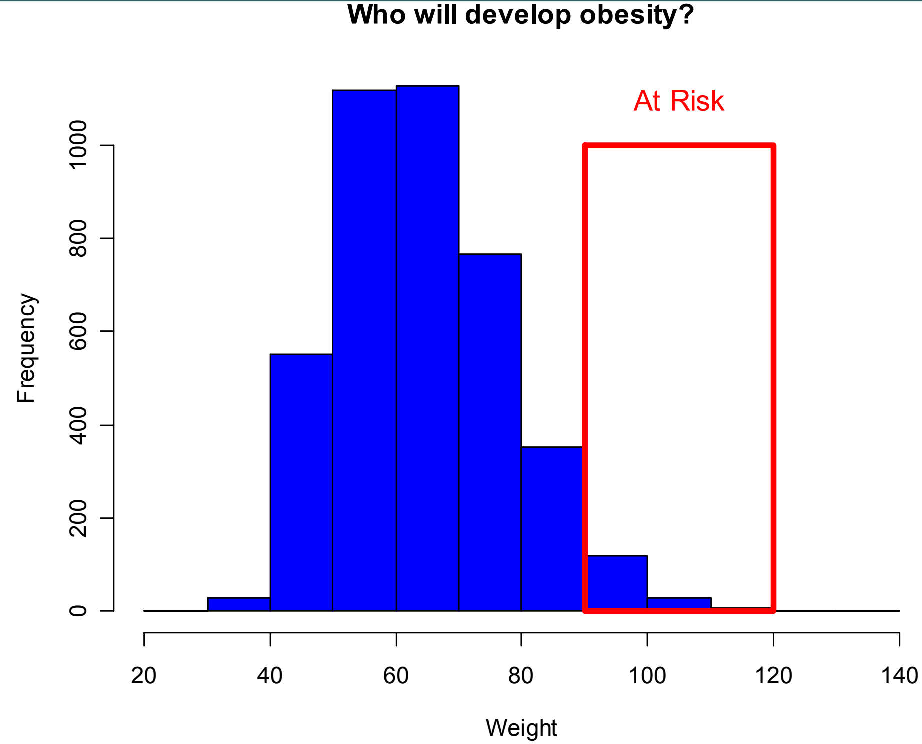


Printing on Margins, Using Symbolic Expressions

```
> f <- function(x) x * (x + 1) / 2
> x <- 1:20
> y <- f(x)
> plot(x, y, xlab = "", ylab = "")
> mtext("Plotting the expression", side = 3, line = 2.5)
> mtext(expression(y == sum(i,1,x,i)), side = 3, line = 0)
> mtext("The first variable", side = 1, line = 3)
> mtext("The second variable", side = 2, line = 3)
```



Adding a Label Inside a Plot




```
> hist(dataset$Weight, xlab = "Weight",
       main = "Who will develop obesity?", col = "blue")
> rect(90, 0, 120, 1000, border = "red", lwd = 4)
> text(105, 1100, "At Risk", col = "red", cex = 1.25)
```

Symbolic Math
Example from `demo(plotmath)`

Big Operators	
sum(x[i], i = 1, n)	$\sum_{1}^{n} x_i$
prod(plain(P)(X == x), x)	$\prod_{x} \mathrm{P}(X = x)$
integral(f(x) * dx, a, b)	$\int_a^b f(x)dx$
union(A[i], i == 1, n)	$\bigcup_{i=1}^{n} A_i$
intersect(A[i], i == 1, n)	$\bigcap_{i=1}^{n} A_i$
lim(f(x), x %->% 0)	$\lim_{x \to 0} f(x)$
min(g(x), x >= 0)	$\min_{x \geq 0} g(x)$
inf(S)	$\inf S$
sup(S)	$\sup S$

Further Customization

- The `par()` function can change defaults for graphics parameters, affecting subsequent calls to `plot()` and friends.

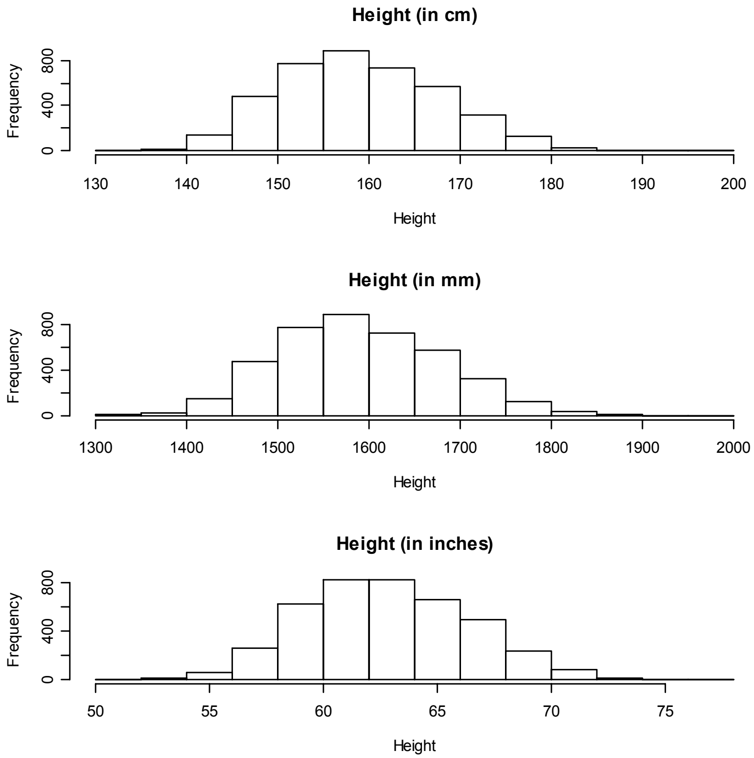
- Parameters include:
  - `cex, mex` – text character and margin size
  - `pch` – plotting character
  - `xlog, ylog` – to select logarithmic axis scaling

Multiple Plots on A Page

- Set the `mfrow` or `mfcol` options
  - Take 2 dimensional vector as an argument
  - The first value specifies the number of rows
  - The second specifies the number of columns
- The 2 options differ in the order individual plots are printed

Multiple Plots

```
> par(mfcol = c(3,1))
> hist(dataset$Height,
  breaks = 10,
  main = "Height (in cm)",
  xlab = "Height")
> hist(dataset$Height * 10,
  breaks = 10,
  main = "Height (in mm)",
  xlab = "Height")
> hist(dataset$Height / 2.54,
  breaks = 10,
  main = "Height (in inches)",
  xlab = "Height")
```



Outputting R Plots

- R usually generates output to the screen
- In Windows and the Mac, you can point and click on a graph to copy it to the clipboard
- However, R can also save its graphics output in a file that you can distribute or include in a document prepared with Word or LATEX

Selecting a Graphics Device

- To redirect graphics output, first select a device:
  - `pdf()` – high quality, portable format
  - `postscript()` – high quality format
  - `png()` – low quality, but suitable for the web

- After you generate your graphics, simply close the device
  - `dev.off()`

Example of Output Redirection

```
> x <- runif(100)
> y <- runif(100) * 0.5 + x * 0.5

# This graph is plotted on the screen
> plot(x, y, ylab = "This is a simple graph")

# This graph is plotted to the PDF file
> pdf("my_graph.pdf")
> plot(x, y, ylab = "This is a simple graph")
> dev.close()

# Where does this one go?
> plot(x, y, ylab = "This is a simple graph")
```