

# Introduction to R

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# Overview

Introduction

Basic concepts in R

- Vector

- R packages

- Data structures

R for data analysis

- Reading in data

- Analysis

- Write data

# RULES

1. **EVERY** time you do not understand... **RAISE YOUR HAND**
2. There are **NOT** stupid questions
3. Feel free to **interrupt me** every time you need

# Introduction

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## The R Project for Statistical Computing

- R is a free software environment for statistical computing and graphics
- Open source and cross platform (UNIX platforms, Windows and MacOS)
- Extensive graphics capabilities
- Diverse range of add-on packages
- Active community of developers
- Thorough documentation

# What R is?

## The R Project for Statistical Computing

You can find R here: <https://www.r-project.org>



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## The R Project for Statistical Computing

### Getting Started

R is a free software environment for statistical computing and graphics. It compiles and runs on a wide variety of UNIX platforms, Windows and MacOS. To [download R](#), please choose your preferred [CRAN mirror](#).

If you have questions about R like how to download and install the software, or what the license terms are, please read our [answers to frequently asked questions](#) before you send an email.

### News

- [R version 3.3.1 \(Bug In Your Hair\) prerelease versions](#) will appear starting Saturday 2016-06-11. Final release is scheduled for Tuesday 2016-06-21.
- [R version 3.3.0 \(Supposedly Educational\)](#) has been released on 2016-05-03.
- [R version 3.2.5 \(Very, Very Secure Dishes\)](#) has been released on 2016-04-14. This is a rebadging of the quick-fix release 3.2.4-revised.
- [Notice XQuartz users \(Mac OS X\)](#) A security issue has been detected with the Sparkle update mechanism used by XQuartz. Avoid updating over insecure channels.
- [The R Logo](#) is available for download in high-resolution PNG or SVG formats.
- [useR! 2016](#), will take place at Stanford University, CA, USA, June 27 - June 30, 2016.
- [The R Journal Volume 7/2](#) is available.
- [R version 3.2.3 \(Wooden Christmas-Tree\)](#) has been released on 2015-12-10.
- [R version 3.1.3 \(Smooth Sidewalk\)](#) has been released on 2015-03-09.

# What R is?

## The R Project for Statistical Computing

- R version 3.3.1 (released 2016-06-21)
- Currently, the CRAN (Comprehensive R Archive Network) package repository features 8609 available packages
  - [https://cran.r-project.org/web/packages/available\\_packages\\_by\\_name.html](https://cran.r-project.org/web/packages/available_packages_by_name.html)
- Currently, the Bioconductor repository features 1211 available packages
  - <http://www.bioconductor.org>
- Executed using command line, or a graphical user interface (GUI)
- On this course, we use the RStudio GUI
  - [www.rstudio.com](http://www.rstudio.com)

# Getting started

- R is a program which, once installed on your system, can be launched and is immediately ready to take input directly from the user

R can be launched in 2 ways:

1. From command line

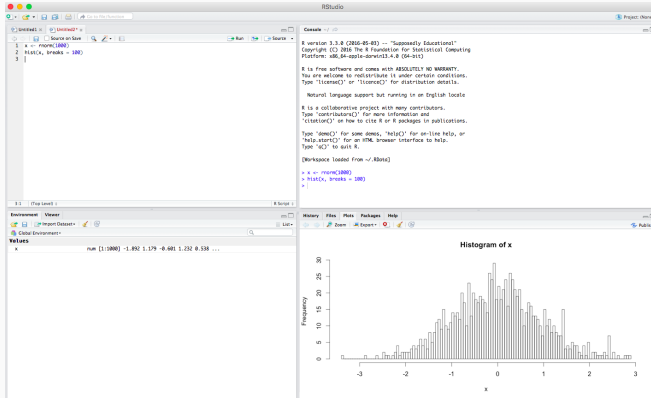
- To start R you need to enter the console (also called terminal or shell)
- To start R, at the prompt simply type: `R`

2. Using RStudio

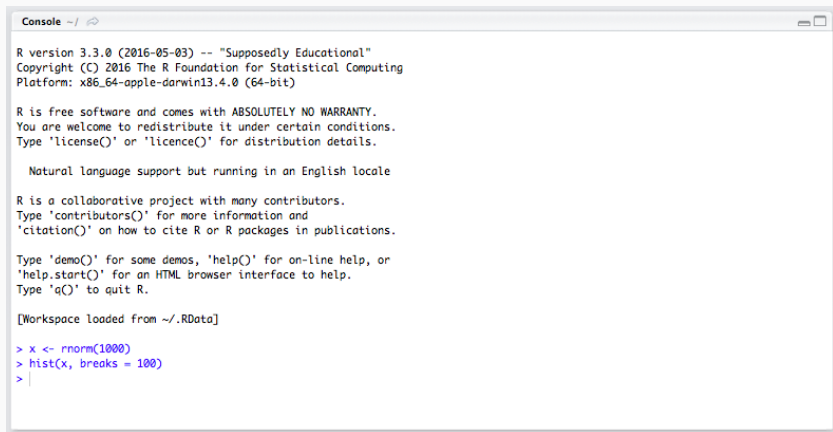
- To launch RStudio, find the RStudio icon and double-click




Since we will use RStudio in this course, let's have a look of the program



## R console



```
Console ~/ 

R version 3.3.0 (2016-05-03) -- "Supposedly Educational"
Copyright (C) 2016 The R Foundation for Statistical Computing
Platform: x86_64-apple-darwin13.4.0 (64-bit)

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

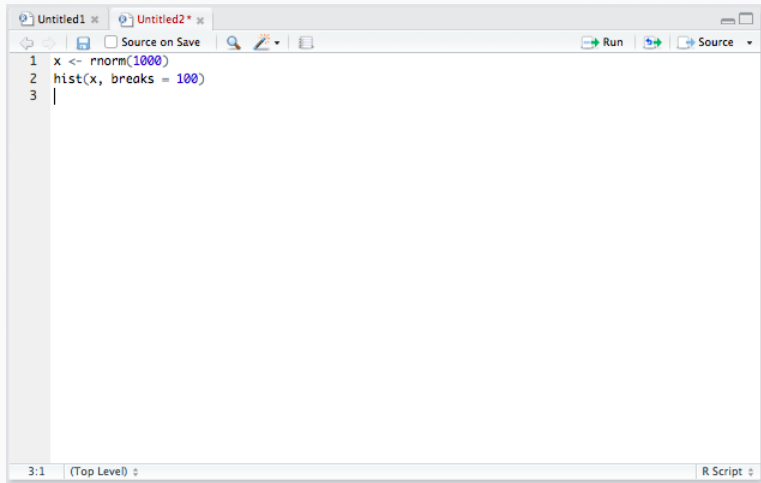
Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

[Workspace loaded from ~/.RData]

> x <- rnorm(1000)
> hist(x, breaks = 100)
> |
```

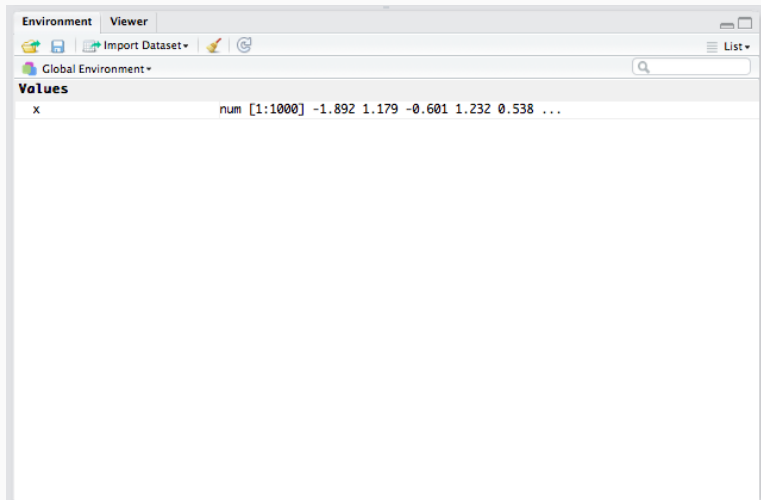
It is the place where you can interactively run R commands

## Source editor for R scripts



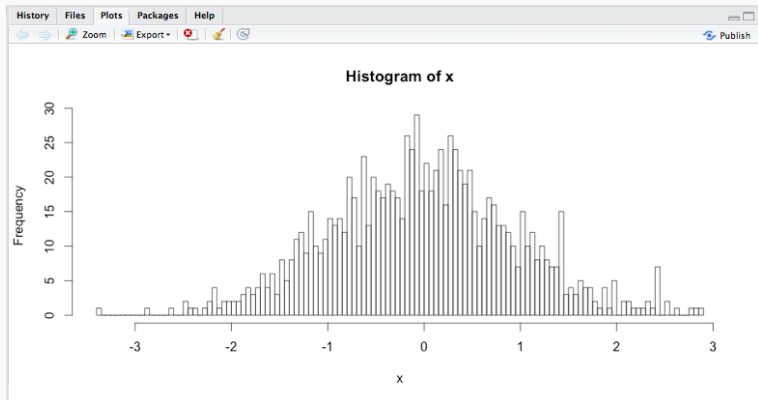
It is the place where you can write your scripts

## Workspace



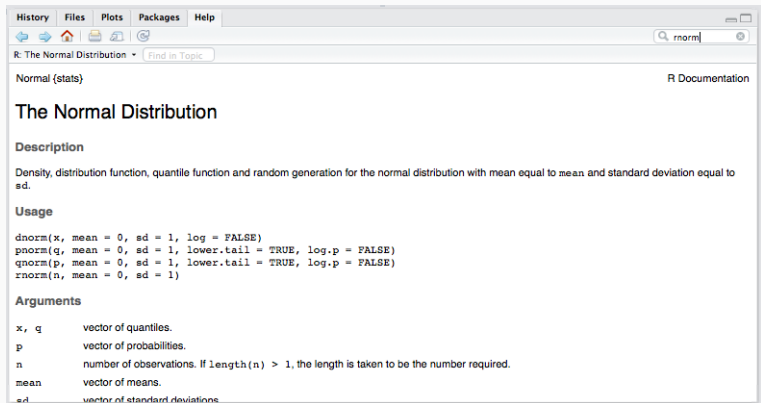
It is the place where you can view object in the global environment

## Plot panel



It is the place where you can view your plots

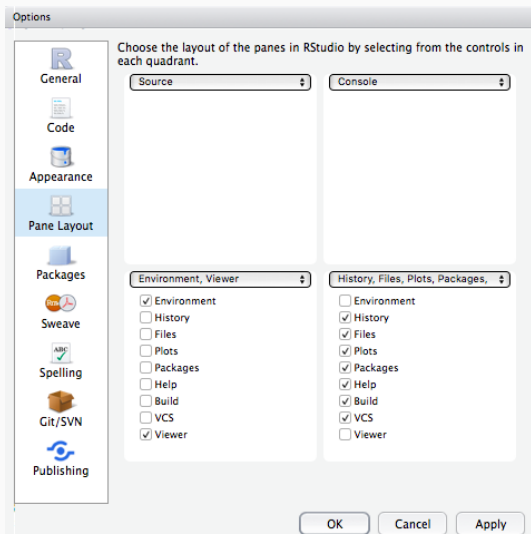
## R help



It is the place where you can find help

The GUI is divided into 4 main sub-windows

These sub-windows are customizable



# Basic concepts in R

---

Based on [https://github.com/lgatto/TeachingMaterial/tree/master/\\_basicr](https://github.com/lgatto/TeachingMaterial/tree/master/_basicr)



# Numbers

The command line can be used as a calculator

---

```
> 5 + 7
```

```
[1] 12
```

```
> 5 - 7
```

```
[1] -2
```

```
> 5 * 7
```

```
[1] 35
```

```
> 5 / 7
```

```
[1] 0.7142857
```

---

Note: The number in the square brackets is an indicator of the position in the output

You can solve simple or complex calculations

---

```
> (((20/5)^2)-((5+1/3+4/5-10)*(2-34))-20)  
[1] -127.7333
```

---

But, of course, R is not a calculator

# Variables

A **variable** is a letter or word which takes (or contains) a value.

We use the assignment 'operator', `<-`

- We can assign a number to a variable

---

```
> x <- 5
```

```
> x
```

```
[1] 5
```

---

- We can assign the result of an operation to a variable

---

```
> y <- 5 + 7
```

```
> y
```

```
[1] 12
```

---

# Variables

- We can assign use the variables to perform calculation
- 

```
> x + y  
[1] 17
```

---

- We can assign the change the content of the variable
- 

```
> x  
[1] 5  
> x <- x - y  
> x  
[1] -7
```

---

# Function

**Functions** in R perform operations on arguments (the input(s) to the function).

Arguments are always contained in parentheses, i.e. curved brackets `()`, separated by commas.

```
> sum(3, 4, 5, 6)
```

```
[1] 18
```

```
> max(3, 4, 5, 6)
```

```
[1] 6
```

```
> min(3, 4, 5, 6)
```

```
[1] 3
```

## Function extention

R contains a lot of pre-builtin functions, but through the so called *packages* is possible extend the R functionalities enormously. Alternately, you can write your own function

```
> summ <- function(a,b){ a + b }  
> summ(1,2)  
[1] 3
```

# Vector

The basic data structure in R is a **vector**, an ordered collection of values. R even treats single values as 1-element vectors.

The simplest way to create a **vector** in R is by using the `c()` operator:

---

```
> c(1,2,3,50)
[1]  1  2  3 50
```

---



The simplest way to create a **sequence of numbers** is by using the ':' operator:

---

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

---

That gave us every integer between (and including) 1 and 10.

What happens if we do 15:1? Give it a try to find out.

What happens if we do 15:1? Give it a try to find out.

---

```
> 15:1
```

```
[1] 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
```

---

It counted backwards in increments of 1!

Remember that if you have questions about a particular R function, you can access its documentation with a question mark followed by the function name:

`?functionnamehere` (1)

However, in the case of an operator like the colon used above, you must enclose the symbol in backticks like this:

`?' : '` (2)

Often, we'll desire more control over a sequence we're creating than what the ':' operator gives us. The `seq()` function serves this purpose.

Try it: Remember what we said about the function arguments

Often, we'll desire more control over a sequence we're creating than what the ':' operator gives us. The `seq()` function serves this purpose.

Try it: Remember what we said about the function arguments

---

```
> seq(1,10)
[1] 1 2 3 4 5 6 7 8 9 10
```

---

This gives us the same output as `1:10`. However, let's say that instead we want a vector of numbers ranging from 0 to 4, incremented by 0.5. `seq(0, 4, by=0.5)` does just that.

Try it out.

This gives us the same output as `1:10`. However, let's say that instead we want a vector of numbers ranging from 0 to 4, incremented by 0.5. `seq(0, 4, by=0.5)` does just that.

Try it out.

---

```
> seq(0, 4, by = 0.5)
[1] 0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
```

---



Or maybe we don't care what the increment is and we just want a sequence of 10 numbers between 5 and 10. `seq(5, 10, length=10)` does the trick. Give it a shot now and store the result in a new variable called *mySeq*.

Try it out.

Or maybe we don't care what the increment is and we just want a sequence of 10 numbers between 5 and 10. `seq(5, 10, length=10)` does the trick. Give it a shot now and store the result in a new variable called *mySeq*.

Try it out.

---

```
> mySeq <- seq(5, 10, length=10)
> round(mySeq,1)
[1] 5.0 5.6 6.1 6.7 7.2 7.8 8.3 8.9 9.4 10.0
```

---

To confirm that `mySeq` has length 10, we can use the `length()` function.

Try it now

To confirm that `mySeq` has length 10, we can use the `length()` function.

Try it now

---

```
> length(mySeq)
[1] 10
```

---

# Vector

- Let's pretend we don't know the length of mySeq, but we want to generate a sequence of integers from 1 to N, where N represents the length of the mySeq vector.
- We want a new vector (1, 2, 3, ...) that is the same length as mySeq.
- There are several ways we could do this.
- One possibility is to combine the ':' operator and the length() function.

Give that a try

# Vector

- Let's pretend we don't know the length of `mySeq`, but we want to generate a sequence of integers from 1 to N, where N represents the length of the `mySeq` vector.
- We want a new vector `(1, 2, 3, ...)` that is the same length as `mySeq`.
- There are several ways we could do this.
- One possibility is to combine the `:` operator and the `length()` function.

Give that a try

---

```
> 1:length(mySeq)
[1]  1  2  3  4  5  6  7  8  9 10
```

---

Another option is to use `seq(along.with = mySeq)`. Give that a try.

---

```
> seq(along.with = mySeq)
[1] 1 2 3 4 5 6 7 8 9 10
```

---

R has a separate built-in function for this purpose

---

```
> seq_along(mySeq)
[1] 1 2 3 4 5 6 7 8 9 10
```

---

# Vector

- There are often **several approaches** to solving the same problem in R
- Simple approaches that involve **less typing** are generally best
- It is also important for your code to be **readable**, so that you and others can figure out what's going on without too much hassle

---

```
> # Create a sequence of 10 numbers  
> seq_along(mySeq)  
[1] 1 2 3 4 5 6 7 8 9 10
```

---

The comments in R begin with **hash**. You should have about 1/3 of your code commented.



One more function related to creating sequences of numbers is `rep()`, which stands for 'replicate'.

If we're interested in creating a vector that contains 1 and 0 five times, we can use `rep(c(1,0), times = 5)`.

Try it out

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If we're interested in creating a vector that contains 1 and 0 five times, we can use `rep(c(1,0), times = 5)`.

Try it out

---

```
> # Create a sequence of 1 and 0  
> rep(c(1,0), times = 5)  
[1] 1 0 1 0 1 0 1 0 1 0
```

---

If we want our vector to contain 5 ones and then 5 zeros, we can do this with the 'each' argument instead of 'times' argument.

Try it out

If we want our vector to contain 5 ones and then 5 zeros, we can do this with the 'each' argument instead of 'times' argument.

Try it out

---

```
> # Create a sequence of 1 and 0  
> rep(c(1,0), each = 5)  
[1] 1 1 1 1 1 0 0 0 0 0
```

---

# Vector

- We'll see, now, how to **extract** elements from a vector (subset)
- The square brackets `[]` indicate position within the vector
  - R even treats single values as 1-element vectors
  - The vector in R starts from position 1
- We can extract individual elements by using the `[]` notation

Try `mySeq[1:3]`

# Vector

- We'll see, now, how to **extract** elements from a vector (subset)
- The square brackets `[]` indicate position within the vector
  - R even treats single values as 1-element vectors
  - The vector in R starts from position 1
- We can extract individual elements by using the `[]` notation

Try `mySeq[1:3]`

---

```
> mySeq[1:3]
[1] 5.000000 5.555556 6.111111
```

---

If we want to 3th, 5th and 10th elements of the vector mySeq.  
Try it out

If we want to 3th, 5th and 10th elements of the vector `mySeq`.

Try it out

---

```
> round(mySeq, 1)
[1] 5.0 5.6 6.1 6.7 7.2 7.8 8.3 8.9 9.4 10.0
> round(mySeq[c(3,5,10)], 1)
[1] 6.1 7.2 10.0
```

---



If we want all the elements bigger than 7.

Try it out

If we want all the elements bigger than 7.

Try it out

---

```
> round(mySeq, 1)
[1] 5.0 5.6 6.1 6.7 7.2 7.8 8.3 8.9 9.4 10.0
> round(mySeq[mySeq > 7], 1)
[1] 7.2 7.8 8.3 8.9 9.4 10.0
```

---

## Vector

If we ask you to produce a vector of 1000 even numbers (from 2 to 2000), extract the 345th and the 987th elements and sum them, would you know how to do it?

Try it out

# Vector

If we ask you to produce a vector of 1000 even numbers (from 2 to 2000), extract the 345th and the 987th elements and sum them, would you know how to do it?

Try it out

---

```
> a <- seq(2,2000,by=2)
> length(a)
[1] 1000
> a[345] + a[987]
[1] 2664
> # Short version
> sum(seq(2,2000,by=2)[c(345,987)])
[1] 2664
```

---

When applying all standard arithmetic operations to vectors,  
**application is element-wise.**

---

```
> x <- 1:10  
> y <- x * 2  
> y  
[1] 2 4 6 8 10 12 14 16 18 20
```

---

# Vector

Adding two vectors

---

```
> z <- x^2  
> y + z  
[1] 3 8 15 24 35 48 63 80 99 120
```

---

If vectors are not the same length, the shorter one will be recycled

---

```
> x  
[1] 1 2 3 4 5 6 7 8 9 10  
> x + 1:2  
[1] 2 4 4 6 6 8 8 10 10 12
```

---

# Vector

- All the vectors we have seen so far have contained numbers, but we can also store strings

---

```
> gene.names <- c("Pax6", "Beta-actin", "FoxP2", "Hox9")  
> gene.names  
[1] "Pax6"          "Beta-actin"    "FoxP2"         "Hox9"
```

---

- We can name elements of vectors using the *names* function

---

```
> gene.expression <- c(0, 3.2, 1.2, -2)  
> gene.expression  
[1] 0.0 3.2 1.2 -2.0  
> names(gene.expression) <- gene.names  
> gene.expression  
      Pax6 Beta-actin      FoxP2      Hox9  
      0.0      3.2      1.2      -2.0
```

---

## Exercise: genes and genomes

- Let's try some **vector arithmetic**. Here are the genome lengths and number of protein coding genes for several model organisms:

Species	Genome size (Mb)	Protein coding genes
<i>Homo sapiens</i>	3,102	20,774
<i>Mus musculus</i>	2,731	23,139
<i>Drosophila melanogaster</i>	169	13,937
<i>Caenorhabditis elegans</i>	100	20,532
<i>Saccharomyces cerevisiae</i>	12	6,692

- Create **genome.size** and **coding.genes** vectors to hold the data in each column using the `c` function
- Create a **species.name** vector and use this vector to name the values in the other two vectors.



## Exercise: genes and genomes

- Let's assume a **coding gene has an average length of 1.5 kilobases** (1.5 kilobases is 0.0015 Megabases)
- On average, how many base pairs of each genome is made of coding genes?
- **Create a new vector to record this called `coding.bases`**
- **What percentage of each genome is made up of protein coding genes?**
- Use your **`coding.bases`** and **`genome.size`** vectors to calculate this
- **How many times more bases are used for coding in the human genome compared to the yeast genome?**
- **How many times more bases are in the human genome in total compared to the yeast genome?**
- Look up indices of your vectors to find out.

## Exercise: genes and genomes

- Creating vectors:

---

```
> genome.size<-c(3102,2731,169,100,12)
> coding.genes<-c(20774,23139,13937,20532,6692)
> species.name<-c("H. sapiens","M. musculus","D. melanogaster","C.
+ cerevisiae")
> names(genome.size)<-species.name
> names(coding.genes)<-species.name
```

---

## Exercise: genes and genomes

- Creating vectors:

---

```
> genome.size<-c(3102,2731,169,100,12)
> coding.genes<-c(20774,23139,13937,20532,6692)
> species.name<-c("H. sapiens","M. musculus","D. melanogaster","C.
+ cerevisiae")
> names(genome.size)<-species.name
> names(coding.genes)<-species.name
```

---

- To calculate the number of coding bases, we need to use the same scale as we used for genome size: 1.5 kilobases is 0.0015 Megabases

---

```
> coding.bases<-coding.genes*0.0015
> coding.bases
```

H. sapiens	M. musculus	D. melanogaster	C. elegans	S.
31.1610	34.7085	20.9055	30.7980	

---

## Exercise: genes and genomes

- To calculate the percentage of coding bases in each genome:

---

```
> coding.pc<-coding.bases/genome.size*100
```

```
> coding.pc
```

H. sapiens	M. musculus	D. melanogaster	C. elegans	S. cerevisiae
1.004545	1.270908	12.370118	30.798000	1.000000

## Exercise: genes and genomes

- To calculate the percentage of coding bases in each genome:

---

```
> coding.pc<-coding.bases/genome.size*100
```

```
> coding.pc
```

H. sapiens	M. musculus	D. melanogaster	C. elegans	S. cerevisiae
1.004545	1.270908	12.370118	30.798000	1.000000

---

- To compare human to yeast:

---

```
> coding.bases[1]/coding.bases[5]
```

```
H. sapiens
```

```
3.104304
```

```
> genome.size[1]/genome.size[5]
```

```
H. sapiens
```

```
258.5
```

---

## Exercise: genes and genomes

- Note that if a new vector is created using a named vector, the names are usually carried across to the new vector. Sometimes this is what we want (as for **coding.pc**) but sometimes it is not (when we are comparing human to yeast). We can remove names by setting them to the special NULL value:

---

```
> names(coding.pc) <- NULL  
> coding.pc  
[1] 1.004545 1.270908 12.370118 30.798000 83.650000
```

---

# R packages

# R packages

- R comes ready loaded with various libraries of functions called **packages**. e.g. the function **sum()** is in the base package and **sd()**, which calculates the standard deviation of a vector, is in the stats package



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- The two repositories you will come across the most are
  - The Comprehensive R Archive Network (CRAN)
  - Bioconductor

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- CRAN is mirrored in many locations. Set your local mirror in RStudio using Tools > Options, and choose a CRAN mirror

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- The two repositories you will come across the most are
  - The Comprehensive R Archive Network (CRAN)
  - Bioconductor
- CRAN is mirrored in many locations. Set your local mirror in RStudio using Tools > Options, and choose a CRAN mirror
- Bioconductor packages are then loaded with the biocLite() function
  - `source("http://bioconductor.org/biocLite.R")`
  - `biocLite("PackageName")`

# Exercise

- Matrix is a CRAN extras packageUse
  - Use **install.packages()** function. . .
  - or in RStudio goto Tools > Install Packages. . . and type the package name
- aCGH is a BioConductor package ([www.bioconductor.org](http://www.bioconductor.org))

- R needs to be told to use the new functions from the installed packages
- Use **library(...)** function to load the newly installed features
- **library("Matrix")**; loads matrix functions

PS: `Library()`: Lists all the packages you've got installed locally

## R is designed to handle experimental data

- In this lesson, we'll cover **matrices** and **data frames**. Both represent 'rectangular' data types, meaning that they are used to store tabular data, with rows and columns
- The main difference, as you'll see, is that **matrices** can only contain a single class of data, while **data frames** can consist of many different classes of data

# Data frame

- A data frame is a **set of observations** of a set of variables in other words, the outcome of an experiment.

[Wickham, H. (2014). Tidy Data. Journal of Statistical Software, 59(10), 1 - 23]

- For example, we might want to analyse information about a set of patients. To start with, let's say we have ten patients and for each one we know their **name, sex, age, weight and whether they give consent** for their data to be made public
- We are going to create a data frame called 'patients', which will have ten rows (observations) and seven columns (variables).
- **The columns must all be equal lengths**



## The patients data frame

```
> patients
  firstName secondName paste.firstName..secondName. sex age weight consent
1      Adam      Jones      Adam Jones    Male  50   70.8     TRUE
2       Eve     Parker     Eve Parker Female  21   67.9     TRUE
3      John     Evans     John Evans    Male  35   75.3    FALSE
4      Mary     Davis     Mary Davis Female  45   61.9     TRUE
5     Peter     Baker     Peter Baker    Male  28   72.4    FALSE
6      Paul   Daniels     Paul Daniels    Male  31   69.9    FALSE
7   Joanna Edwards Joanna Edwards Female  42   63.5    FALSE
8   Matthew     Smith     Matthew Smith    Male  33   71.5     TRUE
9     David   Roberts     David Roberts    Male  57   73.2    FALSE
10    Sally    Wilson     Sally Wilson Female  62   64.8     TRUE
```

# Data frame

- **Each column is a vector**, like previous vectors we have seen, for example:

---

```
> age<-c(50, 21, 35, 45, 28, 31, 42, 33, 57, 62)
> weight<-c(70.8, 67.9, 75.3, 61.9, 72.4, 69.9, 63.5, 71.5, 73.2, 64.8)
```

---

- We can define the names using character vectors:

---

```
> firstName<-c('Adam', 'Eve', 'John', 'Mary', 'Peter', 'Paul',
+              'Joanna', 'Matthew', 'David', 'Sally')
> secondName<-c('Jones', 'Parker', 'Evans', 'Davis', 'Baker',
+               'Daniels', 'Edwards', 'Smith', 'Roberts', 'Wilson')
```

---

- We also have a new type of vector, the logical vector, which only contains the values TRUE and FALSE:

---

```
> consent<-c(TRUE, TRUE, FALSE, TRUE, FALSE, FALSE, FALSE, TRUE, FALSE, TRUE)
```

---

# Data structures

- **Vectors can only contain one type of data**; we cannot mix numbers, characters and logical values in the same vector
- If we try this, R will convert everything to characters:

---

```
> c(20, 'a string', TRUE)
[1] "20"          "a string" "TRUE"
```

---

- We can see the type of a particular vector using the mode function

---

```
> mode(firstName)
[1] "character"
> mode(age)
[1] "numeric"
> mode(weight)
[1] "numeric"
> mode(consent)
[1] "logical"
```

---

# Data structures

- Character vectors are fine for some variables, like names
  - But sometimes we have categorical data and we want R to recognize this
  - **A factor is R's data structure for categorical data**
- 

```
> sex
[1] "Male"   "Female" "Male"   "Female" "Male"   "Male"   "Female" "Male"
[9] "Male"   "Female"
> factor(sex)
[1] Male    Female Male    Female Male    Male    Female Male    Male    Female
Levels: Female Male
```

---

- R has converted the strings of the sex character vector into two levels, which are the categories in the data
- Note the values of this factor are not character strings, but levels
- We can use this factor to compare data for males and females

## Creating a data frame

- We can construct a data frame from other objects

---

```
> patients<-data.frame(firstName, secondName, paste(firstName,secondName),  
+                      sex, age, weight, consent)  
> patients
```

	firstName	secondName	paste.firstName..secondName.	sex	age	weight	consent
1	Adam	Jones	Adam Jones	Male	50	70.8	TRUE
2	Eve	Parker	Eve Parker	Female	21	67.9	TRUE
3	John	Evans	John Evans	Male	35	75.3	FALSE
4	Mary	Davis	Mary Davis	Female	45	61.9	TRUE
5	Peter	Baker	Peter Baker	Male	28	72.4	FALSE
6	Paul	Daniels	Paul Daniels	Male	31	69.9	FALSE
7	Joanna	Edwards	Joanna Edwards	Female	42	63.5	FALSE
8	Matthew	Smith	Matthew Smith	Male	33	71.5	TRUE
9	David	Roberts	David Roberts	Male	57	73.2	FALSE
10	Sally	Wilson	Sally Wilson	Female	62	64.8	TRUE

---

- The paste function joins character vectors together
- We can access particular variables using the dollar operator

---

```
> patients$age  
[1] 50 21 35 45 28 31 42 33 57 62
```

---

## Naming data frame variables

- R has inferred the names of our data frame variables from the names of the vectors or the commands (eg the paste command)
- We can name the variables after we have created a data frame using the **names** function, and we can use the same function to see the names

---

```
> names(patients)<-c('First_Name', 'Second_Name', 'Full_Name', 'Sex',  
+                   'Age', 'Weight', 'Consent')  
> names(patients)  
[1] "First_Name" "Second_Name" "Full_Name"   "Sex"         "Age"  
[6] "Weight"     "Consent"
```

---

- Or we can name the variables when we define the data frame

---

```
> patients<-data.frame(First_Name=firstName, Second_Name=secondName,  
+                      Full_Name=paste(firstName,secondName), Sex=sex,  
+                      Age=age, Weight=weight, Consent=consent)  
> names(patients)  
[1] "First_Name" "Second_Name" "Full_Name"   "Sex"         "Age"  
[6] "Weight"     "Consent"
```

---

## Matrices

- Data frames are R speciality, but R also handles matrices

---

```
> e <- matrix(1:10, nrow=5, ncol=2)
```

```
> e
  [,1] [,2]
[1,]  1   6
[2,]  2   7
[3,]  3   8
[4,]  4   9
[5,]  5  10
```

```
> f <- matrix(1:10, nrow=2, ncol=5)
```

```
> f
  [,1] [,2] [,3] [,4] [,5]
[1,]  1   3   5   7   9
[2,]  2   4   6   8  10
```

---

## Lists

- We have seen that vectors can only hold data of one type.
- How can we store data of multiple types?
- Or vectors of different lengths in one object?
- We can use lists; a list can contain **objects of any type**

---

```
> a <- 1:10
> b <- matrix(runif(100),ncol=10,nrow=10)
> c <- data.frame(a, month.name[1:10])
> myList<-list( ls.obj.1=a, ls.obj.2=b,ls.obj.3=c )
> summary(myList)
```

	Length	Class	Mode
ls.obj.1	10	-none-	numeric
ls.obj.2	100	-none-	numeric
ls.obj.3	2	data.frame	list

```
> names(myList)
[1] "ls.obj.1" "ls.obj.2" "ls.obj.3"
```

---



## Indexing data frames and matrices

- You can index multidimensional data structures like:  
**object [ rows , columns ]**
- If you don't provide an index for either rows or columns, all of the rows or columns will be returned

---

```
> patients[1,2]
[1] Jones
10 Levels: Baker Daniels Davis Edwards Evans Jones Parker Roberts ... Wilson
```

```
> patients[1,]
  First_Name Second_Name Full_Name Sex Age Weight Consent
1      Adam      Jones Adam Jones Male  50   70.8    TRUE
```

```
> patients[patients$Age>50, ]
  First_Name Second_Name Full_Name Sex Age Weight Consent
9      David   Roberts David Roberts Male  57   73.2  FALSE
10     Sally     Wilson  Sally Wilson Female 62   64.8   TRUE
```

---

## Indexing data frames and matrices

- There is a simpler way to refer to variables by name in a **data frame**
  - Namely separating the **data frame name** from the **name of the variable** with a dollar sign (**\$**)
- 

```
> patients$Age
[1] 50 21 35 45 28 31 42 33 57 62
> patients$Age < 30
[1] FALSE  TRUE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE
```

---

## Advanced indexing

- As values in R are really vectors, so indices are actually vectors, and can be numeric or logical
- 

```
> s <- letters[1:5]
> s
[1] "a" "b" "c" "d" "e"
> s[c(TRUE, FALSE, TRUE, FALSE, FALSE)]
[1] "a" "c"
> a<-1:5
> a<3
[1] TRUE TRUE FALSE FALSE FALSE
> s[a<3]
[1] "a" "b"
> s[a>1 & a<3]
[1] "b"
> s[a==2]
[1] "b"
```

---

## Operators

- arithmetic

$\wedge$  , / , \* , - , +

- comparison

$\neq$  ,  $==$  ,  $>$  ,  $<=$  ,  $>$  ,  $<$

- logical

! , & , |

## Exercise

- Create a data.frame using the following vectors
  - `n = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10`
  - `sex = male, female, male, female, male, female, male, female, male, female`
  - `age = 23, 22, 21, 22, 24, 30, 23, 29, 19, 29`
  - `weight = 72, 90, 120, 80, 75, 65, 91, 58, 78, 50`
  - `height = 171, 185, 210, 170, 189, 150, 168, 165, 188, 143`

## Exercise

- Which is the average age? [use the function **mean**]
- Which is the maximum female weight? [Subset the data frame and use the function **max**]
- Which is the minimum male weight? [Subset the data frame and use the function **min**]
- How many are the male over 180cm? [Subset the data frame]
- Which is their average age?
- Who is the younger and lighter female? [this has to be done in 2 steps; use the function **order**]
- Who is the person with the minimum BMI [weight/height<sup>2</sup>; this also has to be done in 2 steps; use the function **which.min**]

### NOTE:

1. To know how to use a function use '?'; e.g. ?mean
2. In R there are several ways to achieve the same result

## Exercise

- Create a data.frame using the following vectors

---

```
> n <- 1:10
> sex <- rep(c('male', 'female'), 5)
> age <- c(23, 22, 21, 22, 24, 30, 23, 29, 19, 29)
> weight <- c(72, 90, 120, 80, 75, 65, 91, 58, 78, 50)
> height <- c(171, 185, 210, 170, 189, 150, 168, 165, 188, 143)
> df <- data.frame(n = n, sex = sex, age = age, weight = weight, height = height)
> df
```

	n	sex	age	weight	height
1	1	male	23	72	171
2	2	female	22	90	185
3	3	male	21	120	210
4	4	female	22	80	170
5	5	male	24	75	189
6	6	female	30	65	150
7	7	male	23	91	168
8	8	female	29	58	165
9	9	male	19	78	188
10	10	female	29	50	143

---

## Exercise

- Which is the average age?



## Exercise

- Which is the average age?

---

```
> mean(df$age)
[1] 24.2
```

---

## Exercise

- Which is the average age?

---

```
> mean(df$age)
[1] 24.2
```

---

- Which is the maximum female weight?

## Exercise

- Which is the average age?

---

```
> mean(df$age)
[1] 24.2
```

---

- Which is the maximum female weight?

---

```
> ind <- df$sex == 'female'
> ind
[1] FALSE TRUE FALSE TRUE FALSE TRUE FALSE TRUE
> tmp <- df[ind,]
> tmp
   n    sex age weight height
2  2 female  22     90    185
4  4 female  22     80    170
6  6 female  30     65    150
8  8 female  29     58    165
10 10 female  29     50    143
> max(tmp$weight)
[1] 90
```

## Exercise

- Which is the average age?

---

```
> mean(df$age)
[1] 24.2
```

---

- Which is the maximum female weight?

---

```
> ind <- df$sex == 'female'
> ind
[1] FALSE TRUE FALSE TRUE FALSE TRUE FALSE TRUE
> tmp <- df[ind,]
> tmp
   n  sex age weight height
2  2 female 22    90    185
4  4 female 22    80    170
6  6 female 30    65    150
8  8 female 29    58    165
10 10 female 29    50    143
> max(tmp$weight)
[1] 90
> max(df[df$sex == 'female',]$weight)
[1] 90
> max(df[df$sex == 'female',4])
[1] 90
> max(subset(df, sex == 'female')$weight)
[1] 90
```

## Exercise

- Which is the minimum male weight?

## Exercise

- Which is the minimum male weight?

---

```
> min(df[df$sex == 'male',]$weight)
[1] 72
```

---

## Exercise

- Which is the minimum male weight?

---

```
> min(df[df$sex == 'male',]$weight)
[1] 72
```

---

- How many are the male over 180cm?

## Exercise

- Which is the minimum male weight?

---

```
> min(df[df$sex == 'male',]$weight)
[1] 72
```

---

- How many are the male over 180cm?

---

```
> df[(df$sex == 'male' & df$height > 180),]
  n sex age weight height
3 3 male 21    120    210
5 5 male 24     75    189
9 9 male 19     78    188
```

---



## Exercise

- Which is the minimum male weight?

---

```
> min(df[df$sex == 'male',]$weight)
[1] 72
```

---

- How many are the male over 180cm?

---

```
> df[(df$sex == 'male' & df$height > 180),]
  n sex age weight height
3 3 male 21    120    210
5 5 male 24     75    189
9 9 male 19     78    188
```

---

- Which is their average age?

## Exercise

- Which is the minimum male weight?

---

```
> min(df[df$sex == 'male',]$weight)
[1] 72
```

---

- How many are the male over 180cm?

---

```
> df[(df$sex == 'male' & df$height > 180),]
  n sex age weight height
3 3 male 21   120    210
5 5 male 24    75    189
9 9 male 19    78    188
```

---

- Which is their average age?

---

```
> mean(df[(df$sex == 'male' & df$height > 180),]$age)
[1] 21.33333
```

---

## Exercise

- Who is the younger and lighter female?

## Exercise

- Who is the younger and lighter female?

---

```
> df1 <- df[df$sex == 'female',]  
> df1[order(df1$age,df1$weight),][1,]  
  n    sex age weight height  
4 4 female 22     80     170
```

---

## Exercise

- Who is the younger and lighter female?

---

```
> df1 <- df[df$sex == 'female',]  
> df1[order(df1$age,df1$weight),][1,]  
  n    sex age weight height  
4 4 female 22     80     170
```

---

- Who is the person with the minimum BMI  $[\text{weight}/\text{height}^2]$

## Exercise

- Who is the younger and lighter female?

---

```
> df1 <- df[df$sex == 'female',]  
> df1[order(df1$age,df1$weight),][1,]  
  n    sex age weight height  
4 4 female 22    80    170
```

---

- Who is the person with the minimum BMI  $[\text{weight}/\text{height}^2]$

---

```
> df2 <- df$weight / df$height^2  
> df2  
[1] 0.002462296 0.002629657 0.002721088 0.002768166 0.002099605 0.002888889  
[7] 0.003224206 0.002130395 0.002206881 0.002445107  
> which.min(df2)  
[1] 5  
> df[which.min(df2),]  
  n    sex age weight height  
5 5 male  24    75    189
```

---

# R for data analysis

---

# 3 steps to Basic data analysis

---

## 1. Reading in data

- `read.table()`; `read_table()`; ...
- `read.csv()`; `read_csv()`; ...
- `read_excel()`

## 2. Analysis

- Manipulating and reshaping the data [dplyr]
- Any maths you like
- Plotting the outcome

## 3. Writing out results

- `write.table()`; `write_delim()`; ...
- `write.csv()`; `write_csv`; `write_tsv`; ...



## R can import several types of data

- From disk
  - csv
  - txt
  - excel
  - SAS
  - ...
- From database
  - SQL
  - ...
- From the web
  - xml
  - json
  - ...

R can import several types of data

- **From disk**
  - csv
  - txt
  - excel
  - SAS
  - ...
- From database
  - SQL
  - ...
- From the web
  - xml
  - json
  - ...

## Import txt files

- Base package
- dplyr
- Set working directory

```
> a <- getwd()
> a
[1] "/Users/marco/Documents/Courses/201606_Rcourse/Presentations/Rbasic"
> setwd("~/Documents/Courses/201606_Rcourse/resources/")
> getwd()
[1] "/Users/marco/Documents/Courses/201606_Rcourse/resources"
> setwd(a)
```

## Import txt files

- Base package

```
> x <- read.table("~/Documents/Courses/201606_Rcourse/resources/dataset1.txt",header = T, sep = '\t')
> colnames(x)
[1] "Protein.IDs2" "tr_1"          "tr_2"          "tr_3"          "control_1"
[6] "control_2"    "control_3"     "Protein.IDs"  "Desc"          "Organism"
[11] "imput_c"      "imput_t"       "X"            "xantho"        "control"
[16] "pval"         "qval"          "logFC"         "log10pvalue"   "DEP"
[21] "reg"
```

```
> x
  Protein.IDs2   tr_1   tr_2   tr_3 control_1 control_2 control_3
1  AOA024FR39 26.96356 26.96774 26.83135 27.17617 27.11247 26.80980
2      Q93XQ8 26.16409 26.06764 25.56439 26.80968 27.51322 26.75455
3  AOA075FFX7 26.73660 26.92286 26.77919 26.98869 26.71162 27.25169
4      W5AMD4 24.56663 23.63068 25.53709 24.16331 28.49121 25.09237
5  AOA076U5I7 25.96446 26.44176 26.01270 25.85310 26.10767 26.63229
6      Q9ZR95 31.98475 31.96712 31.83729 31.94705 32.36001 32.23640
7  AOA077S3F8 29.72457 29.88584 29.51700 28.80156 29.29588 28.80934
8  AOA077RAG2 28.94403 28.46933 28.53797 28.53768 28.90383 28.55604
9  AOA077RAQ3 29.34575 29.02155 28.95127 29.31594 29.60316 29.31488
10      W5C129 25.66863 25.95098 25.92402 25.86568 25.73946 26.15684
11  AOA077RF15 27.20303 26.56834 26.53060 26.54460 27.26758 26.92445
12  AOA077RF25 23.49216 23.82299 23.88204 21.40254 21.63313 21.62811
13  AOA077RF72 27.17341 26.15374 26.82529 25.99434 26.16850 26.10857
14      W5BV61 25.91433 26.65840 26.58978 25.92198 25.78721 26.18579
15  AOA077RNT9 25.22659 25.17032 24.97504 21.40254 21.63313 21.62811
```

## Import txt files

- Base package
  - Table difficult to watch (especially if very large)
  - 'head' command can help
  - 'View' command to inspect the table in the viewer
- dplyr

## Import txt files

- Base package
- dplyr

```
> library(readr)
> x2 <- read_delim(file = '~/Documents/Courses/201606_Rcourse/resources/dataset1.txt', delim = '\t')
> x2
Source: local data frame [99 x 21]
```

	Protein.IDs2	tr_1	tr_2	tr_3	control_1	control_2	control_3
	(chr)	(dbl)	(dbl)	(dbl)	(dbl)	(dbl)	(dbl)
1	A0A024FR39	26.96356	26.96774	26.83135	27.17617	27.11247	26.80980
2	Q93XQ8	26.16409	26.06764	25.56439	26.80968	27.51322	26.75455
3	A0A075FFX7	26.73660	26.92286	26.77919	26.98869	26.71162	27.25169
4	W5AMD4	24.56663	23.63068	25.53709	24.16331	28.49121	25.09237
5	A0A076U5I7	25.96446	26.44176	26.01270	25.85310	26.10767	26.63229
6	Q9ZR95	31.98475	31.96712	31.83729	31.94705	32.36001	32.23640
7	A0A077S3F8	29.72457	29.88584	29.51700	28.80156	29.29588	28.80934
8	A0A077RAG2	28.94403	28.46933	28.53797	28.53768	28.90383	28.55604
9	A0A077RAQ3	29.34575	29.02155	28.95127	29.31594	29.60316	29.31488
10	W5C129	25.66863	25.95098	25.92402	25.86568	25.73946	26.15684
..	...	...	...	...	...	...	...

Variables not shown: Protein.IDs (chr), Desc (chr), Organism (chr), imput\_c (int), imput\_t (int), NA (chr), xantho (dbl), control (dbl), pval (dbl), qval (dbl), logFC (dbl), log10pvalue (dbl), DEP (int), reg (int)

## Import txt files

- dplyr
  - Try 'class(x2)'
  - The object 'x2' has different classes
  - On the top of the output you can see the data.frame dimentionions
  - If there is not space for all the columns to be displayed, they are reported anyway

---

```
> library(readr)
> class(x2)
[1] "tbl_df"      "tbl"        "data.frame"
```

---

### Import csv files

Give a try!!

- Locate the file 'dataset2.csv'
- Read the csv file in using the Base package [read.csv]
- Read the csv file in using the readr package [read\_csv]



### Import Excel files

Give a try!!

- Install the package readxl
- Load the package
- Locate the file dataset3.xlsx
- Read in the dataset3

Using RStudio GUI

DEMO

## Steps of data analysis

- Data visualization
- Data Mining
- Reporting Results

## Steps of data analysis

- **Data visualization**
- Data Mining [Enrico in the afternoon]
- Reporting Results

## Data visualization

This part is based on 'Base Graphics' lesson in swirl package

- Base
- Lattice
- ggplot2

## Data visualization

This part is based on 'Base Graphics' lesson in swirl package

- **Base**
- Lattice
- ggplot2

## Data visualization

- One of the greatest strengths of R is the ability to create publication-quality graphics
- We cover a basic portions of graphics in R
- We will use the 'cars' data set

---

```
> data(cars)
```

---

- We will work with this simple data frames
- Our main goal is to introduce various plotting functions and their arguments
- Pull up the help page for cars

## Data visualization

- Before plotting, it is always a good idea to get a sense of the data
- The key R commands for doing so include, `dim()`, `names()`, `head()`, `tail()` and `summary()`

Try them!



## Data visualization

- Run the **plot()** command on the cars data frame ['plot' is short for scatterplot]

## Data visualization

- Run the **plot()** command on the cars data frame ['plot' is short for scatterplot]
- R notes that the data frame you have given it has just two columns, so it assumes that you want to plot one column versus the other
- R uses the names of the columns as labels for either axis

## Data visualization

- Run the **plot()** command on the cars data frame ['plot' is short for scatterplot]
- R notes that the data frame you have given it has just two columns, so it assumes that you want to plot one column versus the other
- R uses the names of the columns as labels for either axis
- What will it happen if the dataset contains more than 2 columns?

Give a try!

## Data visualization

- Use `plot()` command to show dist on the x-axis and speed on the y-axis

## Data visualization

- Use `plot()` command to show `dist` on the x-axis and `speed` on the y-axis
- R is not sure what you want to use as the labels on the axes, so dollar signs are used
- The plot function can be customized; try `plot(x = cars$dist, y = cars$dist, xlab = 'Speed')`

Give a try!

## Data visualization

- Recreate the plot with the label of the y-axis set to 'Stopping Distance'

## Data visualization

- Recreate the plot with the label of the y-axis set to 'Stopping Distance'
- Plot cars with a main title of 'My Plot'; Note that the argument for the main title is 'main' not 'title'

## Data visualization

- Recreate the plot with the label of the y-axis set to 'Stopping Distance'
- Plot cars with a main title of 'My Plot'; Note that the argument for the main title is 'main' not 'title'
- Plot cars with a sub title of 'My Plot Subtitle'; the argument is 'sub'



## Data visualization

- Recreate the plot with the label of the y-axis set to 'Stopping Distance'
- Plot cars with a main title of 'My Plot'; Note that the argument for the main title is 'main' not 'title'
- Plot cars with a sub title of 'My Plot Subtitle'; the argument is 'sub'
- The plot help page (`?plot`) only covers a small number of the many arguments that can be passed in to `plot()` [look at `?par` for other arguments]

## Data visualization

- Plot cars so that the plotted points are colored red; use `col = 'red'`

## Data visualization

- Plot cars so that the plotted points are colored red; use `col = 'red'`
- Plot cars while limiting the x-axis to 10 through 15; use `xlim = c(10, 15)`

## Data visualization

- Plot cars so that the plotted points are colored red; use `col = 'red'`
- Plot cars while limiting the x-axis to 10 through 15; use `xlim = c(10, 15)`
- You can also change the shape of the symbols in the plot; use `pch = 2` [?point to see all the possible shapes]

Let's now look at some other functions in base graphics

## Data visualization

- Load the mtcars data frame; `data(mtcars)`

## Data visualization

- Load the mtcars data frame; `data(mtcars)`
- Explore the dataset; `dim()`, `head()`, `summary()`, ...

## Data visualization

- Load the mtcars data frame; `data(mtcars)`
- Explore the dataset; `dim()`, `head()`, `summary()`, ...
- Plot the boxplot of mpg column

## Data visualization

- Load the mtcars data frame; `data(mtcars)`
- Explore the dataset; `dim()`, `head()`, `summary()`, ...
- Plot the boxplot of mpg column
- Plot the boxplot of mpg column in function of the number of cylinder; `boxplot(formula = mpg ~ cyl, data = mtcars)`



## Data visualization

- Load the mtcars data frame; `data(mtcars)`
- Explore the dataset; `dim()`, `head()`, `summary()`, ...
- Plot the boxplot of mpg column
- Plot the boxplot of mpg column in function of the number of cylinder; `boxplot(formula = mpg ~ cyl, data = mtcars)`
- The plot shows that mpg is much lower for cars with more cylinders
- We can use the same set of arguments that we explored with `plot()` above to add axis labels, titles and so on
- Label the x-axis: 'Cylinder'; the y-axis: 'MPG'; title: 'Boxplot of mtcars'

## Data visualization

- When looking at a single variable, histograms are a useful tool
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- Use `hist()` with the vector `mtcars$mpg` to create a histogram
- Create a beautiful histogram using the `mtcars` dataset
- How to export a high quality plot?

## High quality plot

```
png(...', units = 'mm', width = 180, height = 180, res =  
300)
```

```
plot(x)
```

```
dev.off()
```

# Write data

- Base package
  - `write.table()`
  - `write.csv()`
- readr package
  - `write_table()`
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Have a look of the help page

## Final exercise

Exercise This practical is **difficult**. You have to use functions that I did not mention before. Use the R help and internet resources to complete the task.

- Read in file (raw data)
- Do some operation
  - Transform the data in log2 scale
  - Add columns containing the mean for 'control' and 'treated' condition [hint: rowMeans & cbind functions]
  - Add columns containing the standard deviation for 'control' and 'treated' condition [hint: apply function]
  - Filter out the column with a standard deviation higher than ...
- Plot and save
  - Boxplot
  - Histogram
  - Scatterplot
- Write out the final table



## Useful resources

- <https://github.com/lgatto/TeachingMaterial>
- swirl package
- [www.coursera.org](http://www.coursera.org)
- Official documentation on:  
<http://cran.r-project.org/manuals.html>
- A good repository of R recipes:  
<http://www.statmethods.net/>
- R forums (stackoverflow & official):  
<http://stackoverflow.com/questions/tagged/r>
- Textbooks:  
<http://www.r-project.org/doc/bib/R-books.html>
- ...