Introduction to R

Matthew Suderman

Lecturer in Epigenetic Epidemiology

MRC Integrative Epidemiology Unit

University of BRISTOL

Things you can do with R

Description	R tool
Remember data	Variables
Calculate	Maths functions
Store and manipulate sequences of values	Vectors and lists
Calculate with vectors	Vector operations
Generate data	Vector-generating functions
Store and manipulate matrices	Matrices
Calculate with matrices	Matrix functions
Store and manipulate datasets	Data frames
Handle missing data	NA
Save and load data	Files
Statistical analyses	Statistics functions
Visualise data	Plots
Create and apply recipes	Functions
Repeatedly apply recipes	Loops and apply functions
Make decisions	If/else statements
Share	Packages

Getting started

what, why, downloading, opening, using, rstudio, help, errors

Getting started: what

- R is a statistical programming language (based on S)
- R is open source - researchers develop packages to implement new statistical methods, plots or applications
- R runs on Windows, MacOS and UNIX

John Chambers

Dirk Eddelbuettel

Getting started: why

... rather than S, STATA, SPSS, etc

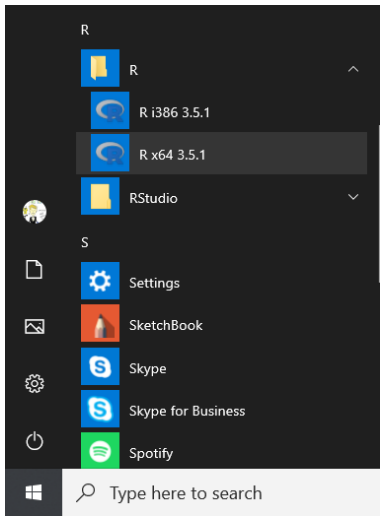
- R is free!
- R is flexible
- R is good at handling large datasets and multiple objects
- R has good plotting tools and packages for statistical analysis

Getting started: installing

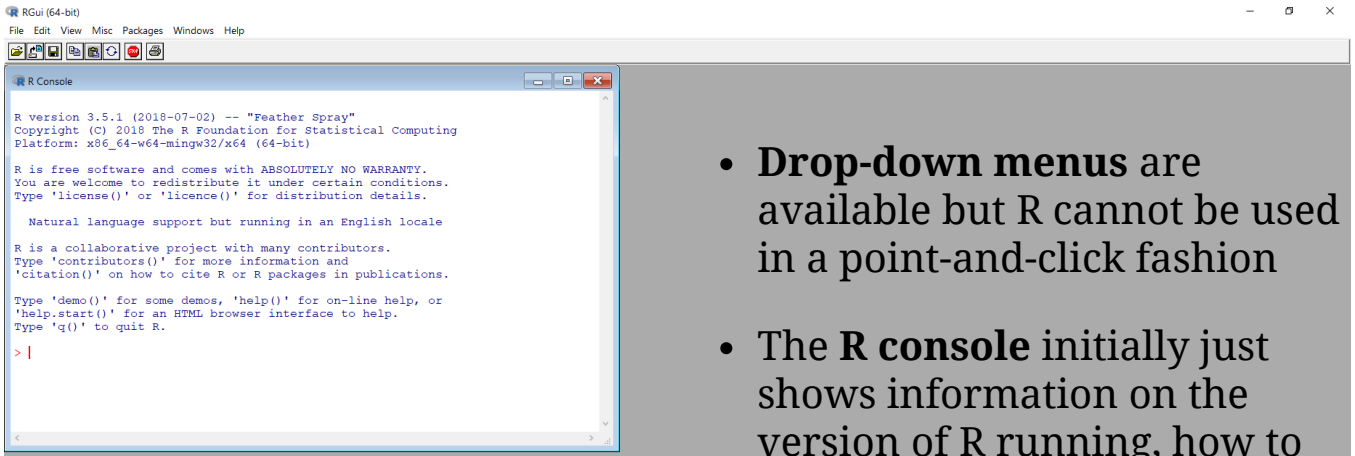
- Visit https://www.r-project.org and click "Download R"
- Choose your nearest CRAN mirror (such as http://www.stats.bris.ac.uk/R)
- Choose "Download R for [Windows/Mac/Linux]"
- Choose "base" for Windows and click on "Download R 3.5.2 for Windows"
- Choose "R-3.5.2.pkg" for Mac
- Once the .exe (Windows) or .pkg (Mac) have downloaded, run and install

Getting started: opening

- Click "Start" | "All Programs" | "R" | "R x64 3.6.0"

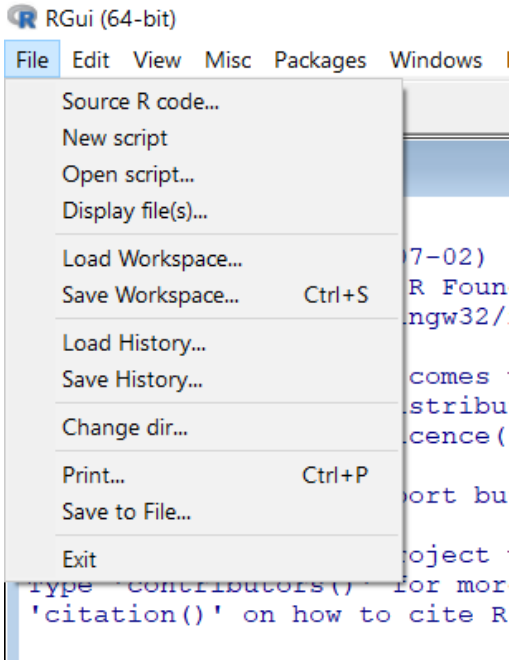


Getting started: navigating



- **Drop-down menus** are available but R cannot be used in a point-and-click fashion
- The **R console** initially just shows information on the version of R running, how to get help and how to quit
- At the bottom of the console is the **R command line** where you can tell R what to do

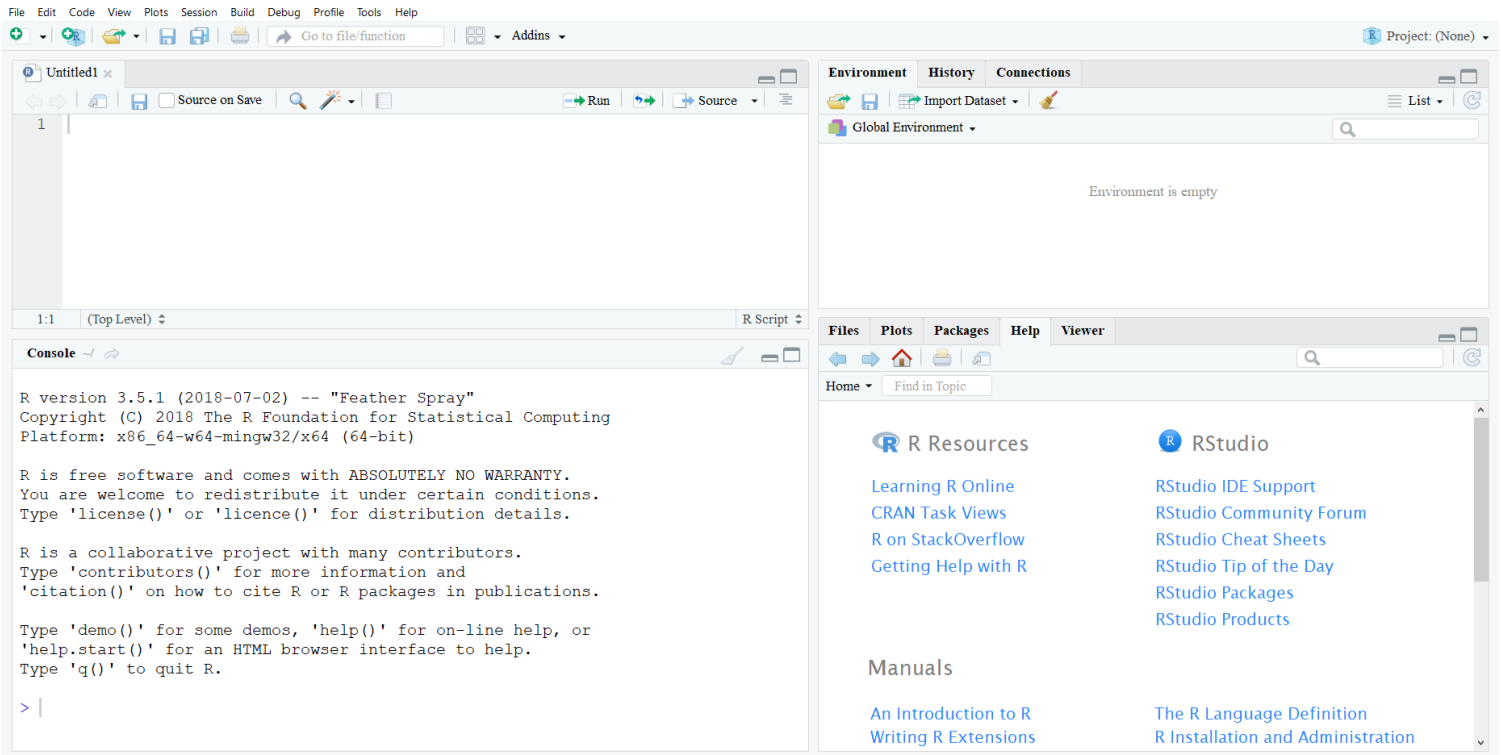
Getting started: menus



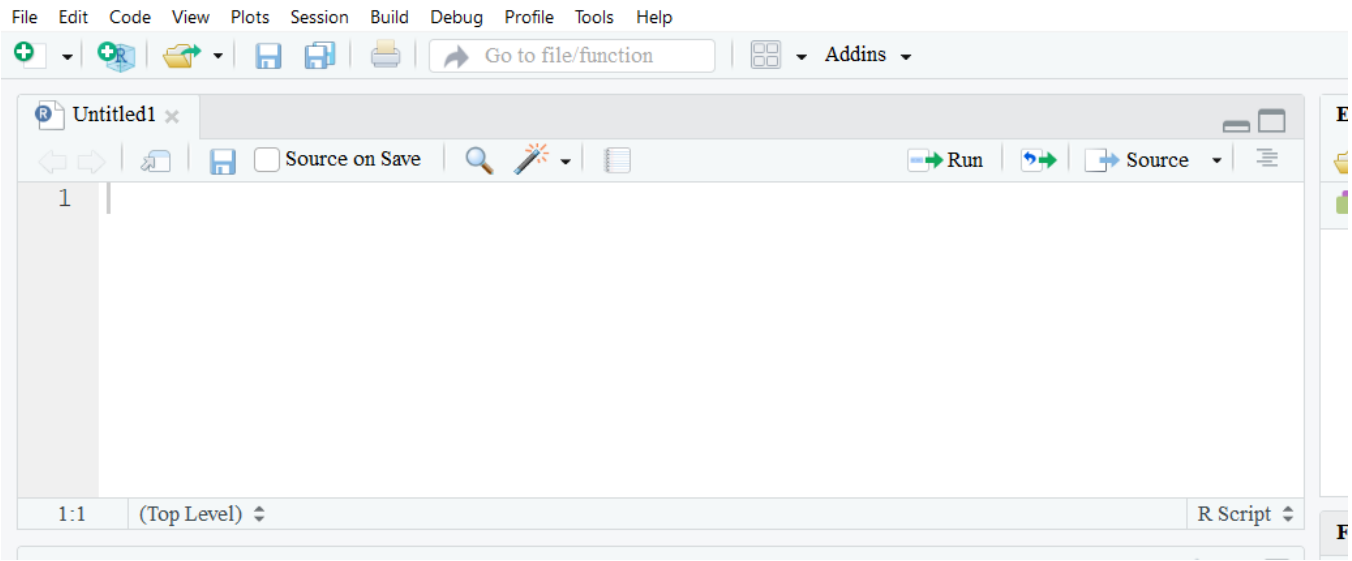
- A **script** is sequence of R commands. Creating or opening a script will open the script in a text editor.
- A **workspace** includes all the objects which are in R's memory at a given time. These can include data or results. To see what is in the current workspace type ls().
- The **history** includes all the commands which are displayed during an R session

Getting started: RStudio

- RStudio makes R easier to use
- It includes a code editor, debugging & visualization tools
- https://www.rstudio.com



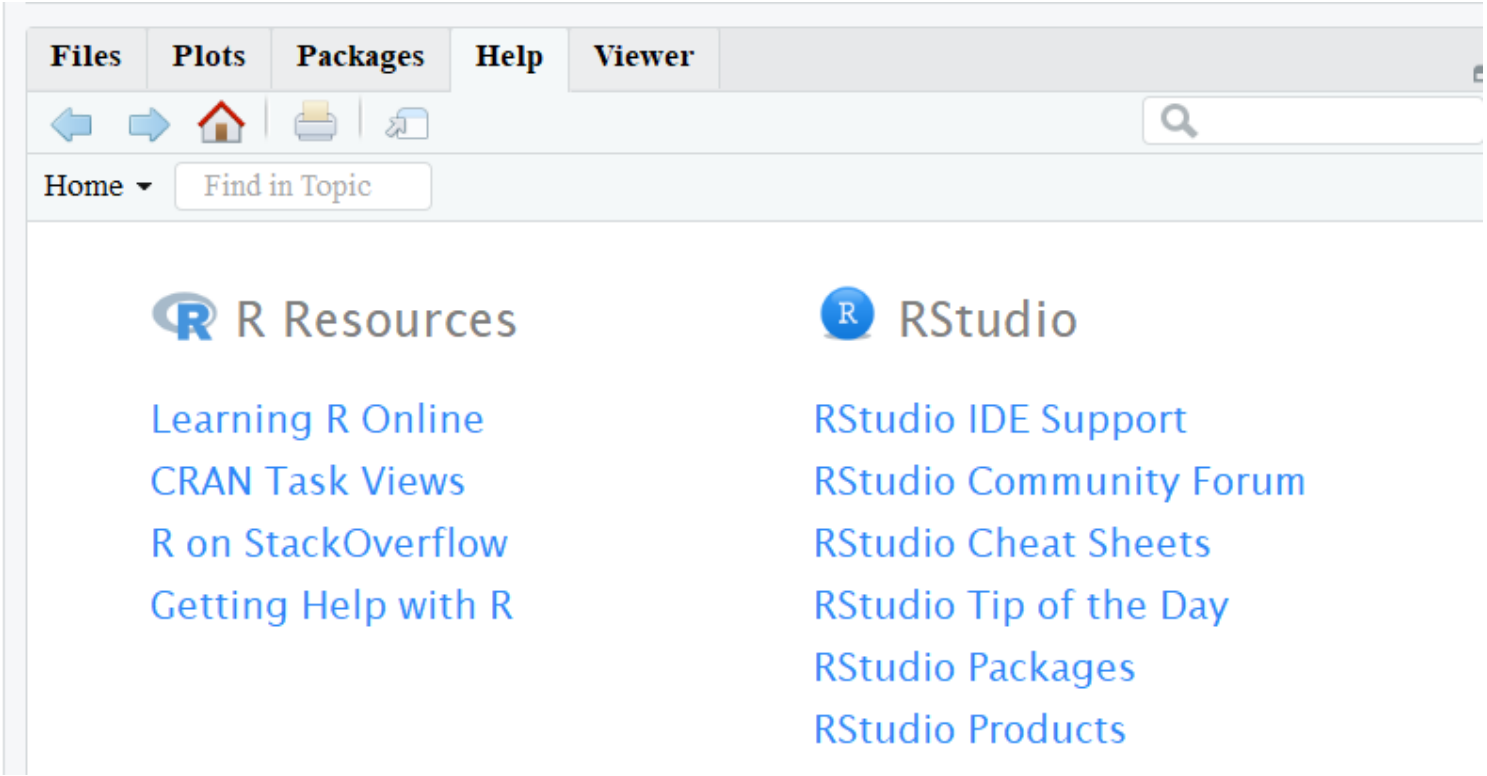
Getting started: RStudio script window



In the script window, you can **save a script** (disk image), **run** selected commands ("Run") and **run** the entire script ("Script").

Getting started: help!

- Use the command `help(topic)` or `?topic`
- In R this will open a web browser
- In RStudio this will open the Help tab



Getting started: `help(mean)`

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`mean {base}`

Arithmetic Mean

Description

Generic function for the (trimmed) arithmetic mean.

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Usage

```
mean(x, ...)

## Default S3 method:
mean(x, trim = 0, na.rm = FALSE, ...)
```

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Arithmetic Mean

Description

Generic function for the (trimmed) arithmetic mean.

Usage

```
mean(x, ...)

## Default S3 method:
mean(x, trim = 0, na.rm = FALSE, ...)
```

Arguments

`x`	An R object. Currently there are methods for numeric/logical vectors and date, date-time and time interval objects. Complex vectors are allowed for trim = 0, only.
`trim`	the fraction (0 to 0.5) of observations to be trimmed from each end of x before the mean is computed. Values of trim outside that range are taken as the nearest endpoint.
`na.rm`	a logical value indicating whether NA values should be stripped before the computation proceeds.
...	further arguments passed to or from other methods.

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...	further arguments passed to or from other methods.

Value

If `trim` is zero (the default), the arithmetic mean of the values in `x` is computed, as a numeric or complex vector of length one. If `x` is not `logical` (coerced to `numeric`), `numeric` (including `integer`) or `complex`, `NA_real_` is returned, with a warning.

Getting started: `help(mean)`

`mean {base}`

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Getting started: `help(mean)`

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See Also

`weighted.mean`, `mean.POSIXct`, `colMeans` for row and column means.

Getting started: `help(mean)`

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See Also

`weighted.mean`, `mean.POSIXct`, `colMeans` for row and column means.

Examples

```
x <- c(0:10, 50)
xm <- mean(x)
c(xm, mean(x, trim = 0.10))
```

Getting started: error messages

Suppose you type the following but variable 'a' has not been created.

```
> 10*a
```

Getting started: error messages

Suppose you type the following but variable 'a' has not been created.

```
> 10*a
```

```
Error: object 'a' not found
```

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R provides informative error messages

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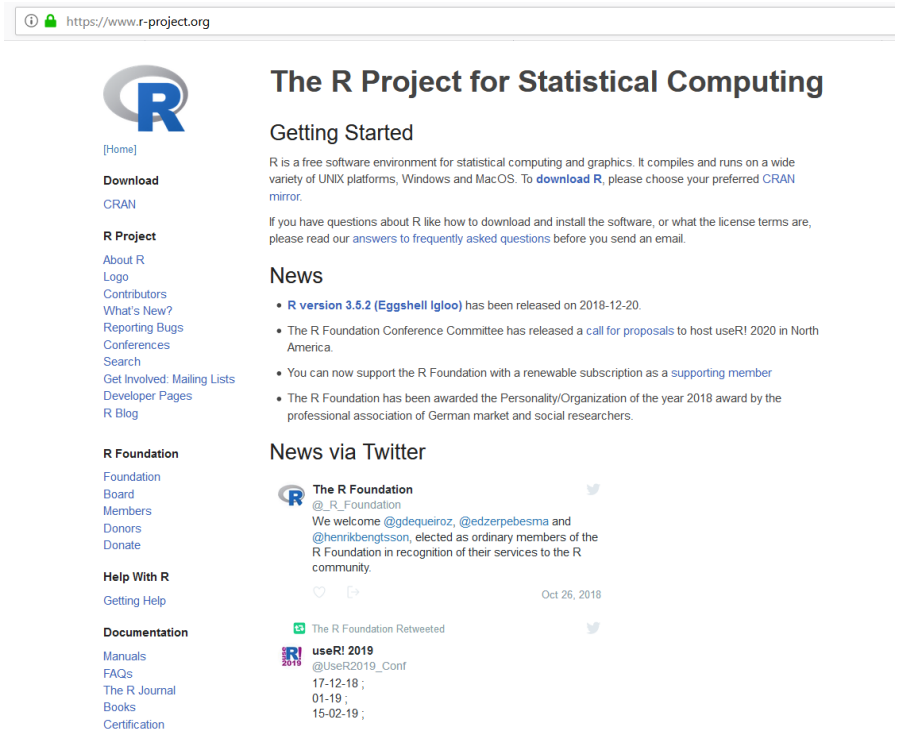
R provides informative error messages

Getting started: www.r-project.org

Note:

- R Project | Search
- Help with R
- Manuals
- FAQs



Getting started: forums

- Mailing list archive and forum http://r.789695.n4.nabble.com
- Stack Overflow https://stackoverflow.com
- Google!

Things you can do with R

remember, calculate, store, generate, analyse, visualise, save, repeat, apply, decide, share

Remember data

A **variable** is a storage location for data with a name.

Store data ...

```
> x <- 3
> y <- 4.2
> name <- "abcdef"
> skip <- TRUE
```

Recall data ...

```
> x
[1] 3
> name
[1] "abcdef"
> nchar(name)
[1] 6
> z
Error: object 'z' not found
```

Query data type ...

```
> is.numeric(x)
[1] TRUE

> is.logical(name)
[1] FALSE
```

Change data type ...

```
> as.character(x)
[1] "3"

> as.numeric("3.14")
[1] 3.14

> as.logical("abc")
[1] NA

> as.logical(x)
[1] TRUE
```

Calculate

```
> x + y + 0.8
[1] 8
```

Calculate

```
> x + y + 0.8
[1] 8
```

```
> 4*x/2
[1] 6
```

Calculate

```
> x + y + 0.8
[1] 8
```

```
> 4*x/2
[1] 6
```

```
> log10(100)
[1] 100
> 2^x
[1] 8
> sin(pi/2)
[1] 1
> ln(exp(1))
[1] 1
> sqrt(x^2)
[1] 3
```

Store and manipulate sequences of values

A **vector** is a sequence of variables of the same type.

```
> x <- c(11,12,13,14,15,16,17,18,19,20)
> x
```

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```
[1] 11 12 13 14 15 16 17 18 19 20
```

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```
[1] 11 12 13 14 15 16 17 18 19 20
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```
> x[3] ## show the third
```

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> x
```

```
[1] 11 12 13 14 15 16 17 18 19 20
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> x[3] ## show the third
```

```
[1] 13
```

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> x
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```
[1] 11 12 13 14 15 16 17 18 19 20
```

```
> x[3] ## show the third
```

```
[1] 13
```

```
> length(x)
```

Store and manipulate sequences of values

A **vector** is a sequence of variables of the same type.

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> x <- c(11,12,13,14,15,16,17,18,19,20)
> x
```

```
[1] 11 12 13 14 15 16 17 18 19 20
```

```
> x[3] ## show the third
```

```
[1] 13
```

```
> length(x)
```

```
[1] 10
```

Store and manipulate sequences of values (continued)

Vectors can be subset and combined.

```
> x[c(1, 5, 7)]
```

Store and manipulate sequences of values (continued)

Vectors can be subset and combined.

```
> x[c(1, 5, 7)]
```

```
[1] 11 15 17
```

Store and manipulate sequences of values (continued)

Vectors can be subset and combined.

```
> x[c(1, 5, 7)]
```

```
[1] 11 15 17
```

```
> x[-c(1, 5, 7)]
```

Store and manipulate sequences of values (continued)

Vectors can be subset and combined.

```
> x[c(1, 5, 7)]
```

```
[1] 11 15 17
```

```
> x[-c(1, 5, 7)]
```

```
[1] 12 13 14 16 18 19 20
```

Store and manipulate sequences of values (continued)

Vectors can be subset and combined.

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> x[c(1, 5, 7)]
```

```
[1] 11 15 17
```

```
> x[-c(1, 5, 7)]
```

```
[1] 12 13 14 16 18 19 20
```

```
> x[x>13]
```

Store and manipulate sequences of values (continued)

Vectors can be subset and combined.

```
> x[c(1, 5, 7)]
```

```
[1] 11 15 17
```

```
> x[-c(1, 5, 7)]
```

```
[1] 12 13 14 16 18 19 20
```

```
> x[x>13]
```

```
[1] 14 15 16 17 18 19 20
```

Store and manipulate sequences of values (continued)

Vectors can be subset and combined.

```
> x[c(1, 5, 7)]
```

```
[1] 11 15 17
```

```
> x[-c(1, 5, 7)]
```

```
[1] 12 13 14 16 18 19 20
```

```
> x[x>13]
```

```
[1] 14 15 16 17 18 19 20
```

```
y <- c("Dog", "Cat")
z <- c(x[1:3], y)
z
```

Store and manipulate sequences of values (continued)

Vectors can be subset and combined.

```
> x[c(1, 5, 7)]
```

```
[1] 11 15 17
```

```
> x[-c(1, 5, 7)]
```

```
[1] 12 13 14 16 18 19 20
```

```
> x[x>13]
```

```
[1] 14 15 16 17 18 19 20
```

```
y <- c("Dog", "Cat")
z <- c(x[1:3], y)
z
```

```
[1] "11" "12" "13" "Dog" "Cat"
```

Calculate with vectors

```
> x+1
```

Calculate with vectors

```
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```

```
[1] 12 13 14 15 16 17 18 19 20 21
```

Calculate with vectors

```
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```

```
[1] 12 13 14 15 16 17 18 19 20 21
```

```
> 3*x
```

Calculate with vectors

```
> x+1
```

```
[1] 12 13 14 15 16 17 18 19 20 21
```

```
> 3*x
```

```
[1] 33 36 39 42 45 48 51 54 57 60
```

Calculate with vectors

```
> x+1
```

```
[1] 12 13 14 15 16 17 18 19 20 21
```

```
> 3*x
```

```
[1] 33 36 39 42 45 48 51 54 57 60
```

```
> x/2
```

Calculate with vectors

```
> x+1
```

```
[1] 12 13 14 15 16 17 18 19 20 21
```

```
> 3*x
```

```
[1] 33 36 39 42 45 48 51 54 57 60
```

```
> x/2
```

```
[1] 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
```

Calculate with vectors

```
> x+1
```

```
[1] 12 13 14 15 16 17 18 19 20 21
```

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[1] 33 36 39 42 45 48 51 54 57 60
```

```
> x/2
```

```
[1] 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
```

```
> log10(x)
```

Calculate with vectors

```
> x+1
```

```
[1] 12 13 14 15 16 17 18 19 20 21
```

```
> 3*x
```

```
[1] 33 36 39 42 45 48 51 54 57 60
```

```
> x/2
```

```
[1] 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
```

```
> log10(x)
```

```
[1] 1.041393 1.079181 1.113943 1.146128 1.176091 1.204120 1.230449 1.255273
[9] 1.278754 1.301030
```

Calculate with vectors (continued)

```
> y <- x + 1
> x + y
```

Calculate with vectors (continued)

```
> y <- x + 1
> x + y
```

```
[1] 23 25 27 29 31 33 35 37 39 41
```

Calculate with vectors (continued)

```
> y <- x + 1
> x + y
```

```
[1] 23 25 27 29 31 33 35 37 39 41
```

```
> x-y
```

Calculate with vectors (continued)

```
> y <- x + 1
> x + y
```

```
[1] 23 25 27 29 31 33 35 37 39 41
```

```
> x-y
```

```
[1] -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

Calculate with vectors (continued)

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```

```
> x*y
```

```
[1] 132 156 182 210 240 272 306 342 380 420
```

Calculate with vectors (continued)

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> x + y
```

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[1] 23 25 27 29 31 33 35 37 39 41
```

```
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```

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```

```
> x*y
```

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```

```
> x/(y-1)
```

Calculate with vectors (continued)

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> x + y
```

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[1] 23 25 27 29 31 33 35 37 39 41
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```
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```

```
[1] -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
```

```
> x*y
```

```
[1] 132 156 182 210 240 272 306 342 380 420
```

```
> x/(y-1)
```

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

Generate data: `seq()`

```
> a <- seq(0, 100, by=5)
> a
```

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```
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```
[1] 0 5 10 15 20 25 30 35 40 45 50
[12] 55 60 65 70 75 80 85 90 95 100
```

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> a <- seq(0, 100, by=5)
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```
[1] 0 5 10 15 20 25 30 35 40 45 50
[12] 55 60 65 70 75 80 85 90 95 100
```

```
> length(a)
```

Generate data: `seq( )`

```
> a <- seq(0, 100, by=5)
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```

```
[1] 0 5 10 15 20 25 30 35 40 45 50
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```

Generate data: `rep()`

```
> b <- c(1, 1, 1, 1, 1)
> b
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```

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

Generate data: `rep()`

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

```
> b <- rep(1, 5)
> b
```

Generate data: `rep()`

```
> b <- c(1, 1, 1, 1, 1)
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> b <- rep(1, 5)
> b
```

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[1] 1 1 1 1 1
```

```
> rep(c(1,2,3),4)
```

Generate data: `rep()`

```
> b <- c(1, 1, 1, 1, 1)
> b
```

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

```
> b <- rep(1, 5)
> b
```

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

```
> rep(c(1,2,3),4)
```

```
[1] 1 2 3 1 2 3 1 2 3 1 2 3
```

Store and manipulate matrices

A **matrix** is a set of elements laid out in rows and columns.

```
> x <- rep(1, 5)
> y <- c("A","B","A","B","C")
> z <- matrix(c(x, y), nrow=5)
> z
```

Store and manipulate matrices

A **matrix** is a set of elements laid out in rows and columns.

```
> x <- rep(1, 5)
> y <- c("A","B","A","B","C")
> z <- matrix(c(x, y), nrow=5)
> z
```

```
     [,1] [,2]
[1,] "1"  "A"
[2,] "1"  "B"
[3,] "1"  "A"
[4,] "1"  "B"
[5,] "1"  "C"
```

Store and manipulate matrices

A **matrix** is a set of elements laid out in rows and columns.

```
> x <- rep(1, 5)
> y <- c("A","B","A","B","C")
> z <- matrix(c(x, y), nrow=5)
> z
```

```
[,1] [,2]
[1,] "1" "A"
[2,] "1" "B"
[3,] "1" "A"
[4,] "1" "B"
[5,] "1" "C"
```

```
> dim(z) ## dimensions
```

Store and manipulate matrices

A **matrix** is a set of elements laid out in rows and columns.

```
> x <- rep(1, 5)
> y <- c("A","B","A","B","C")
> z <- matrix(c(x, y), nrow=5)
> z
```

```
[,1] [,2]
[1,] "1" "A"
[2,] "1" "B"
[3,] "1" "A"
[4,] "1" "B"
[5,] "1" "C"
```

```
> dim(z) ## dimensions
```

```
[1] 5 2
```

Store and manipulate matrices (continued)

```
> t(z) ## transpose
```

Store and manipulate matrices (continued)

```
> t(z) ## transpose
```

```
[,1] [,2] [,3] [,4] [,5]
[1,] "1" "1" "1" "1" "1"
[2,] "A" "B" "A" "B" "C"
```

Store and manipulate matrices (continued)

```
> t(z) ## transpose
```

```
[,1] [,2] [,3] [,4] [,5]
[1,] "1" "1" "1" "1" "1"
[2,] "A" "B" "A" "B" "C"
```

```
> cbind(0:4, z)
```

Store and manipulate matrices (continued)

```
> t(z) ## transpose
```

```
[,1] [,2] [,3] [,4] [,5]
[1,] "1" "1" "1" "1" "1"
[2,] "A" "B" "A" "B" "C"
```

```
> cbind(0:4, z)
```

```
[1,] "0" "1" "A"
[2,] "1" "1" "B"
[3,] "2" "1" "A"
[4,] "3" "1" "B"
[5,] "4" "1" "C"
```

Store and manipulate matrices (continued)

```
> t(z) ## transpose
```

```
[,1] [,2] [,3] [,4] [,5]
[1,] "1" "1" "1" "1" "1"
[2,] "A" "B" "A" "B" "C"
```

```
> cbind(0:4, z)
```

```
[1,] "0" "1" "A"
[2,] "1" "1" "B"
[3,] "2" "1" "A"
[4,] "3" "1" "B"
[5,] "4" "1" "C"
```

```
> rbind(c("0","X"), z)
```

Store and manipulate matrices (continued)

```
> t(z) ## transpose
```

```
[,1] [,2] [,3] [,4] [,5]
[1,] "1" "1" "1" "1" "1"
[2,] "A" "B" "A" "B" "C"
```

```
> cbind(0:4, z)
```

```
[1,] "0" "1" "A"
[2,] "1" "1" "B"
[3,] "2" "1" "A"
[4,] "3" "1" "B"
[5,] "4" "1" "C"
```

```
> rbind(c("0","X"), z)
```

```
[1,] "0" "X"
[2,] "1" "A"
[3,] "1" "B"
[4,] "1" "A"
[5,] "1" "B"
[6,] "1" "C"
```

Store and maniplute matrices (continued)

```
> z[,1]
```

Store and maniplute matrices (continued)

```
> z[,1]
```

```
[1] "1" "1" "1" "1" "1"
```

Store and maniplute matrices (continued)

```
> z[,1]
```

```
[1] "1" "1" "1" "1" "1"
```

```
> z[1,2]
```

Store and maniplute matrices (continued)

```
> z[,1]
```

```
[1] "1" "1" "1" "1" "1"
```

```
> z[1,2]
```

```
[1] "A"
```

Store and maniplute matrices (continued)

```
> z[,1]
```

```
[1] "1" "1" "1" "1" "1"
```

```
> z[1,2]
```

```
[1] "A"
```

```
> z[2,]
```

Store and maniplute matrices (continued)

```
> z[,1]
```

```
[1] "1" "1" "1" "1" "1"
```

```
> z[1,2]
```

```
[1] "A"
```

```
> z[2,]
```

```
[1] "1" "B"
```

Store and maniplute matrices (continued)

```
> z[,1]
```

```
[1] "1" "1" "1" "1" "1"
```

```
> z[1,2]
```

```
[1] "A"
```

```
> z[2,]
```

```
[1] "1" "B"
```

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

Store and maniplute matrices (continued)

```
> z[,1]
```

```
[1] "1" "1" "1" "1" "1"
```

```
> z[1,2]
```

```
[1] "A"
```

```
> z[2,]
```

```
[1] "1" "B"
```

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

```
[1] "A" "A"
```

Calculate with matrices

```
> m <- rbind(c(1,2,3),
             c(3,2,1),
             c(5,6,4))
> m
[1,]  1  2  3
[2,]  3  2  1
[3,]  5  6  4
```

Calculate with matrices

```
> m <- rbind(c(1,2,3),
             c(3,2,1),
             c(5,6,4))
> m
[1,]  1  2  3
[2,]  3  2  1
[3,]  5  6  4
```

```
> m + 1
[1,]  2  3  4
[2,]  4  3  2
[3,]  6  7  5
```

Calculate with matrices

```
> m <- rbind(c(1,2,3),
             c(3,2,1),
             c(5,6,4))
> m
[1,]  1  2  3
[2,]  3  2  1
[3,]  5  6  4
```

```
> m + 1
[1,]  2  3  4
[2,]  4  3  2
[3,]  6  7  5
```

```
> m %*% solve(m) ## multiple m by its inverse

     [,1]          [,2]         [,3]
[1,]    1 -2.220446e-16 2.220446e-16
[2,]    0  1.000000e+00 2.220446e-16
[3,]    0  0.000000e+00 1.000000e+00
```

Store and maniplate datasets: lists

A **list** is like a vector, but it can contain elements of different types.

```
> y <- diag(2)
> w <- list(x=1, y=y, z="abc")
```

Store and maniplate datasets: lists

A **list** is like a vector, but it can contain elements of different types.

```
> y <- diag(2)
> w <- list(x=1, y=y, z="abc")
```

```
w$y
```

Store and maniplate datasets: lists

A **list** is like a vector, but it can contain elements of different types.

```
> y <- diag(2)
> w <- list(x=1, y=y, z="abc")
```

```
w$y
```

```
     [,1] [,2]
[1,]    1    0
[2,]    0    1
```

```
names(r)
```

Store and maniplate datasets: lists

A **list** is like a vector, but it can contain elements of different types.

```
> y <- diag(2)
> w <- list(x=1, y=y, z="abc")
```

```
w$y
```

```
     [,1] [,2]
[1,]    1    0
[2,]    0    1
```

```
names(r)
```

```
[1] "x" "y" "z"
```

Store and maniplate datasets: data frames

A **data frame** is like a matrix but the columns can be different types. You could think of it as a list of vectors each of the same length.

```
> x <- rep(1, 5)
> y <- c("A","B","A","B","C")
> d <- data.frame(a=x, b=y)
```

Store and maniplate datasets: data frames

A **data frame** is like a matrix but the columns can be different types. You could think of it as a list of vectors each of the same length.

```
> x <- rep(1, 5)
> y <- c("A","B","A","B","C")
> d <- data.frame(a=x, b=y)
```

```
> d[2,]
  a b
2 1 B
```

Store and maniplate datasets: data frames

A **data frame** is like a matrix but the columns can be different types. You could think of it as a list of vectors each of the same length.

```
> x <- rep(1, 5)
> y <- c("A","B","A","B","C")
> d <- data.frame(a=x, b=y)
```

```
> d[2,]
  a b
2 1 B
```

```
> d$a
[1] 1 1 1 1 1
```

Store and maniplate datasets: data frames

A **data frame** is like a matrix but the columns can be different types. You could think of it as a list of vectors each of the same length.

```
> x <- rep(1, 5)
> y <- c("A","B","A","B","C")
> d <- data.frame(a=x, b=y)
```

```
> d[2,]
  a b
2 1 B
```

```
> d$a
[1] 1 1 1 1 1
```

```
> class(d$a)
[1] "numeric"
```

Store and maniplate datasets: data frames

A **data frame** is like a matrix but the columns can be different types. You could think of it as a list of vectors each of the same length.

```
> x <- rep(1, 5)
> y <- c("A","B","A","B","C")
> d <- data.frame(a=x, b=y)
```

```
> d[2,]
  a b
2 1 B
```

```
> d$a
[1] 1 1 1 1 1
```

```
> class(d$a)
[1] "numeric"
```

```
> class(d$b)
[1] "character"
```

```
stop("Time for a break")
```

We will resume after `Sys.sleep(10*60)`.

Handle missing data

```
> y <- c("A","B","A","B","C")
> y[2] <- 2
> y[3] <- NA
> y
[1] "A" "2" NA "A" "B" "C"
```

Handle missing data

```
> y <- c("A","B","A","B","C")
> y[2] <- 2
> y[3] <- NA
> y
[1] "A" "2" NA "A" "B" "C"
```

```
> is.na(y)
[1] FALSE FALSE TRUE FALSE FALSE FALSE
```

Handle missing data

```
> y <- c("A","B","A","B","C")
> y[2] <- 2
> y[3] <- NA
> y
[1] "A" "2" NA "A" "B" "C"
```

```
> is.na(y)
[1] FALSE FALSE TRUE FALSE FALSE FALSE
```

```
> is.na(y[3])
[1] TRUE
```

Handle missing data

```
> y <- c("A","B","A","B","C")
> y[2] <- 2
> y[3] <- NA
> y
[1] "A" "2" NA "A" "B" "C"
```

```
> is.na(y)
[1] FALSE FALSE TRUE FALSE FALSE FALSE
```

```
> is.na(y[3])
[1] TRUE
```

```
> na.omit(y)
[1] "A" "2" "A" "B" "C"
```

Save and load data: working directory

To open files, you will need to tell R where the files are. To do this, it helps to know where R will start looking. This is called the 'working directory'.

```
> getwd()
[1] "C:/"
```

Save and load data: working directory

To open files, you will need to tell R where the files are. To do this, it helps to know where R will start looking. This is called the 'working directory'.

```
> getwd()
[1] "C:/"
```

You can change this using `setwd`.

```
> setwd("O:/Documents")
```

The working directory can also be chosen using the Session menu in RStudio.

Save and load data: reading csv files

Suppose I have a spreadsheet stored in CSV format.

```
"id","age","sex","diet","bmi"
1,32,"M",0,25.7957231474661
2,35,"M",0,28.8952139451377
3,41,"M",0,29.9258448186199
4,29,"M",0,27.3383500990741
5,33.5,"M",1,28.2469210985821
6,33.2,"M",1,27.0473176810354
7,32.9,"M",1,30.3031786852156
8,32.6,"F",1,28.5621419729205
9,32.3,"F",1,28.05344654591
10,32,"F",1,28.8864676350323
...
```

Save and load data: reading csv files

Suppose I have a spreadsheet stored in CSV format.

```
"id","age","sex","diet","bmi"
1,32,"M",0,25.7957231474661
2,35,"M",0,28.8952139451377
3,41,"M",0,29.9258448186199
4,29,"M",0,27.3383500990741
5,33.5,"M",1,28.2469210985821
6,33.2,"M",1,27.0473176810354
7,32.9,"M",1,30.3031786852156
8,32.6,"F",1,28.5621419729205
9,32.3,"F",1,28.05344654591
10,32,"F",1,28.8864676350323
...
```

`read.csv` will read csv files and save them as data frames.

```
> dat <- read.csv("bmi.csv")
```

```
> dat[1:5,]
  id  age sex diet      bmi
1  1 32.0   M    0 25.79572
2  2 35.0   M    0 28.89521
3  3 41.0   M    0 29.92584
4  4 29.0   M    0 27.33835
5  5 33.5   M    1 28.24692
```

```
> dat$bmi[1:5]
[1] 25.79572 28.89521 29.92584 27.338
> dat[5,]
  id  age sex diet      bmi
5  5 33.5   M    1 28.24692
```

Save and load data: writing csv files

`write.csv` saves a data frame as a csv file.

```
> dat.corrected <- dat
> dat.corrected$sex[5] <- "F" ## make correction
> write.csv(dat.corrected, "bmi-corrected.csv", row.names=F, quote=F)
```

`write.table` is similar but allows the user to change the column separator character. Here we separate columns by a semicolon rather than a comma.

```
> write.table(dat, "bmi-corrected.csv", row.names=F, quote=F, sep=";")
```

Save and load data: writing csv files

`write.csv` saves a data frame as a csv file.

```
> dat.corrected <- dat
> dat.corrected$sex[5] <- "F" ## make correction
> write.csv(dat.corrected, "bmi-corrected.csv", row.names=F, quote=F)
```

`write.table` is similar but allows the user to change the column separator character. Here we separate columns by a semicolon rather than a comma.

```
> write.table(dat, "bmi-corrected.csv", row.names=F, quote=F, sep=";")
```

Note: There is similarly a function `read.table()` just like `read.csv()` but more flexible.

Statistical analyses: basic summaries

```
> mean(dat$bmi)                    ## mean
[1] 27.60761
```

Statistical analyses: basic summaries

```
> mean(dat$bmi)                    ## mean
[1] 27.60761
```

```
> median(dat$bmi)                  ## median
[1] 27.58069
```

Statistical analyses: basic summaries

```
> mean(dat$bmi)                    ## mean
[1] 27.60761
```

```
> median(dat$bmi)                  ## median
[1] 27.58069
```

```
> sd(dat$bmi)                      ## standard deviation
[1] 1.47353
```

Statistical analyses: basic summaries

```
> mean(dat$bmi)                    ## mean
[1] 27.60761
```

```
> median(dat$bmi)                  ## median
[1] 27.58069
```

```
> sd(dat$bmi)                      ## standard deviation
[1] 1.47353
```

```
> min(dat$bmi)                     ## min
[1] 25.34356
```

Statistical analyses: basic summaries

```
> mean(dat$bmi)                    ## mean
[1] 27.60761
```

```
> median(dat$bmi)                  ## median
[1] 27.58069
```

```
> sd(dat$bmi)                      ## standard deviation
[1] 1.47353
```

```
> min(dat$bmi)                     ## min
[1] 25.34356
```

```
> quantile(dat$bmi, probs=0.25) ## first quartile
    25%
26.60918
```

Statistical analyses: basic summaries

```
> mean(dat$bmi)                    ## mean
[1] 27.60761
```

```
> median(dat$bmi)                  ## median
[1] 27.58069
```

```
> sd(dat$bmi)                      ## standard deviation
[1] 1.47353
```

```
> min(dat$bmi)                     ## min
[1] 25.34356
```

```
> quantile(dat$bmi, probs=0.25) ## first quartile
    25%
26.60918
```

```
> table(dat$sex)                   ## frequencies
F  M
13 7
```

Statistical analyses: dataset summaries

The `summary` function can be used to summarize single variables

```
> summary(dat$bmi)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  25.34   26.61   27.58   27.61   28.64   30.30
```

Statistical analyses: dataset summaries

The `summary` function can be used to summarize single variables

```
> summary(dat$bmi)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  25.34   26.61   27.58   27.61   28.64   30.30
```

or entire datasets.

```
> summary(dat)
       id              age            sex                diet            bmi
 Min.   : 1.00   Min.   :29.00   Length:20          Min.   :0.00   Min.   :25.34
 1st Qu.: 5.75   1st Qu.:30.12   Class :character   1st Qu.:0.00   1st Qu.:26.61
 Median :10.50   Median :31.55   Mode  :character   Median :1.00   Median :27.58
 Mean   :10.50   Mean   :31.85                      Mean   :0.55   Mean   :27.61
 3rd Qu.:15.25   3rd Qu.:32.67                      3rd Qu.:1.00   3rd Qu.:28.64
 Max.   :20.00   Max.   :41.00                      Max.   :1.00   Max.   :30.30
```

Statistical analyses: evaluating associations

There is a fairly strong association between BMI and age.

```
> cor(dat$bmi, dat$age)
[1] 0.5705649
```

Here is the association.

```
> fit <- lm(bmi~age, data=dat)
> fit
Call:
lm(formula = bmi ~ age, data = dat)

Coefficients:
(Intercept)          age
    17.6770       0.3118
```

Statistical analyses: evaluating associations

There is a fairly strong association between BMI and age.

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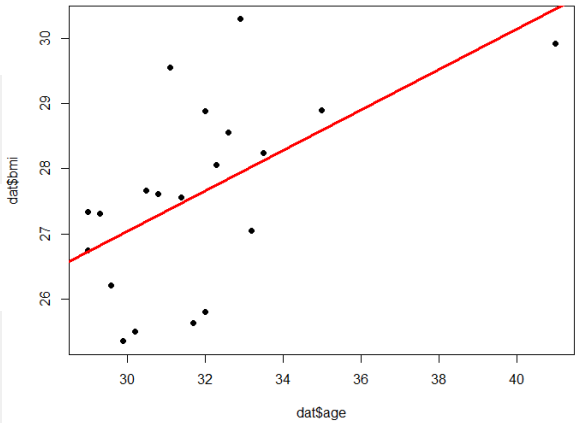
Call:
lm(formula = bmi ~ age, data = dat)

Coefficients:
(Intercept)          age
    17.6770       0.3118
```



The **regression line** in the plot runs from `(29, 17.6770 + 0.3118*29)=(29, 26.7192)` to `(41, 17.6770 + 0.3118*41)=(41, 30.4608)`.

Statistical analyses: summarizing regression model fits

```
> summary(fit)

Call:
lm(formula = bmi ~ age, data = dat)

Residuals:
    Min      1Q  Median      3Q     Max
-1.9334 -0.7760  0.2152  0.5293  2.3682

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  17.6770     3.3805   5.229 5.67e-05 ***
age           0.3118     0.1058   2.948  0.00861 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.243 on 18 degrees of freedom
Multiple R-squared:  0.3255,  Adjusted R-squared:  0.2881
F-statistic: 8.688 on 1 and 18 DF,  p-value: 0.008612
```

Statistical analyses: fitting multiple variable models

```
> fit <- lm(bmi ~ age + sex + diet, data=dat)
```

Statistical analyses: fitting multiple variable models

```
> fit <- lm(bmi ~ age + sex + diet, data=dat)
```

```
> summary(fit)

Call:
lm(formula = bmi ~ age + sex + diet, data = dat)

Residuals:
    Min      1Q  Median      3Q     Max
-2.2978 -0.6210  0.0106  0.8208  1.7891

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  18.4784     3.7464   4.932  0.00015 ***
age           0.2643     0.1228   2.152  0.04700 *
sexM          0.3512     0.6866   0.512  0.61596
diet          1.0671     0.5532   1.929  0.07168 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.188 on 16 degrees of freedom
Multiple R-squared:  0.4528,  Adjusted R-squared:  0.3502
F-statistic: 4.413 on 3 and 16 DF,  p-value: 0.01921
```

Statistical analyses: retrieving model fit elements

```
> coef(fit)
(Intercept)         age        sexM        diet
 18.4783563   0.2643460   0.3512052   1.0671192
```

Statistical analyses: retrieving model fit elements

```
> coef(fit)
(Intercept)         age        sexM        diet
 18.4783563   0.2643460   0.3512052   1.0671192
```

```
> coef(summary(fit))
             Estimate Std. Error   t value     Pr(>|t|)
(Intercept) 18.4783563  3.7463529 4.9323587 0.0001500352
age          0.2643460  0.1228288 2.1521491 0.0469973143
sexM         0.3512052  0.6865686 0.5115369 0.6159621270
diet         1.0671192  0.5532367 1.9288657 0.0716810178
```

Statistical analyses: retrieving model fit elements

```
> coef(fit)
(Intercept)         age        sexM        diet
 18.4783563   0.2643460   0.3512052   1.0671192
```

```
> coef(summary(fit))
             Estimate Std. Error   t value     Pr(>|t|)
(Intercept) 18.4783563  3.7463529 4.9323587 0.0001500352
age          0.2643460  0.1228288 2.1521491 0.0469973143
sexM         0.3512052  0.6865686 0.5115369 0.6159621270
diet         1.0671192  0.5532367 1.9288657 0.0716810178
```

```
> coef(summary(fit))["age","Estimate"]
[1] 0.264346
```

Statistical analyses: retrieving model fit elements

```
> coef(fit)
(Intercept)         age        sexM        diet
 18.4783563   0.2643460   0.3512052   1.0671192
```

```
> coef(summary(fit))
             Estimate Std. Error   t value     Pr(>|t|)
(Intercept) 18.4783563  3.7463529 4.9323587 0.0001500352
age          0.2643460  0.1228288 2.1521491 0.0469973143
sexM         0.3512052  0.6865686 0.5115369 0.6159621270
diet         1.0671192  0.5532367 1.9288657 0.0716810178
```

```
> coef(summary(fit))["age","Estimate"]
[1] 0.264346
```

```
> names(summary(fit))
 [1]  "call"          "terms"         "residuals"
 [4]  "coefficients"  "aliased"       "sigma"
 [7]  "df"            "r.squared"     "adj.r.squared"
 [10] "fstatistic"    "cov.unscaled"
```

Statistical analyses: retrieving model fit elements

```
> coef(fit)
(Intercept)         age        sexM        diet
 18.4783563   0.2643460   0.3512052   1.0671192
```

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             Estimate Std. Error   t value     Pr(>|t|)
(Intercept) 18.4783563  3.7463529 4.9323587 0.0001500352
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```

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 [1] "call"          "terms"         "residuals"
 [4] "coefficients"  "aliased"       "sigma"
 [7] "df"            "r.squared"     "adj.r.squared"
[10] "fstatistic"    "cov.unscaled"
```

```
> summary(fit)$adj.r.squared
[1] 0.3502004
```

Visualise: scatterplot

```
plot(dat$age, dat$bmi,
     main="age vs BMI",
     xlab="age",
     ylab="BMI")
```

Visualise: scatterplot

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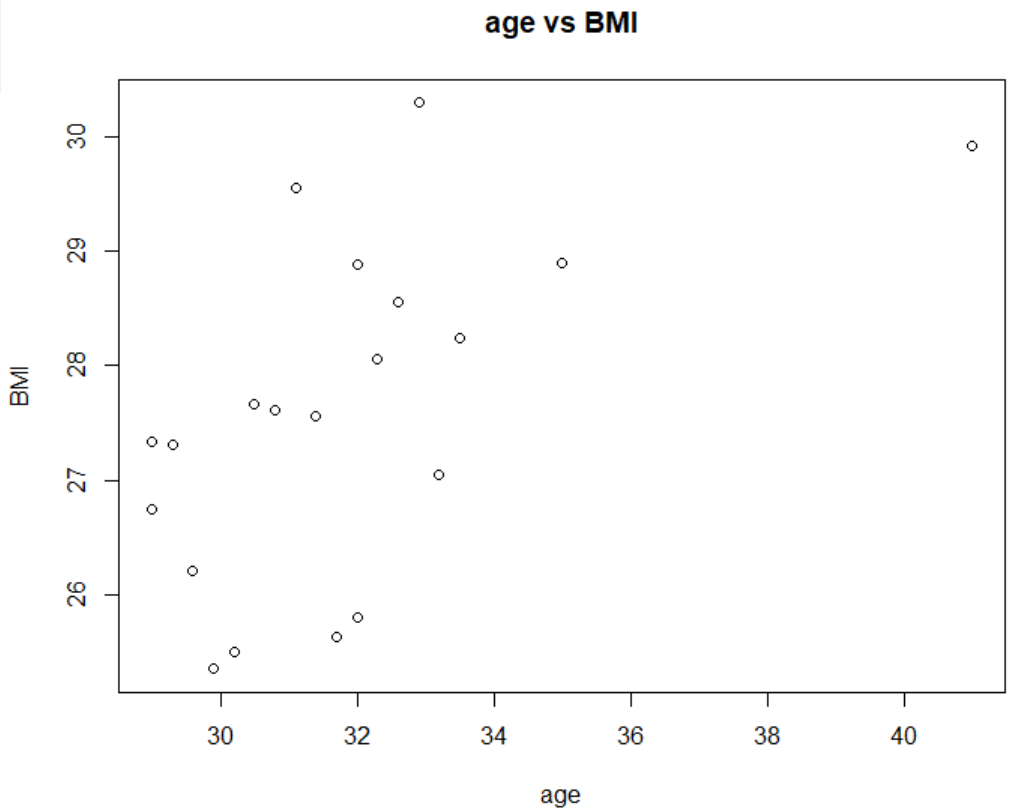
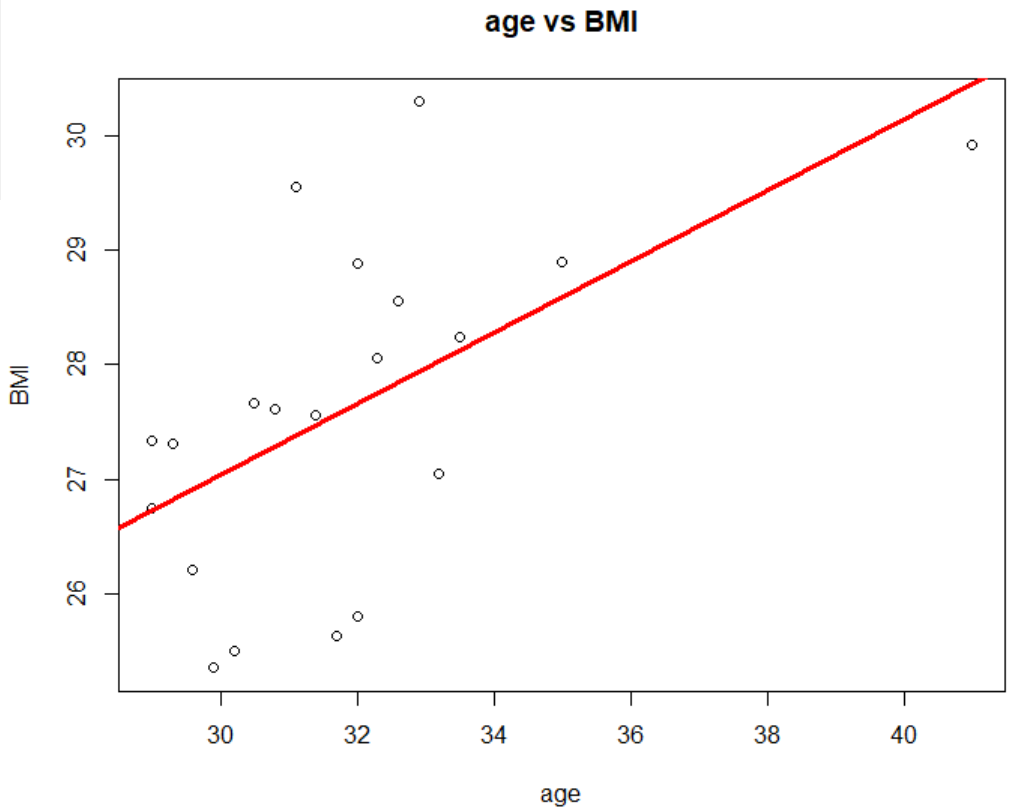


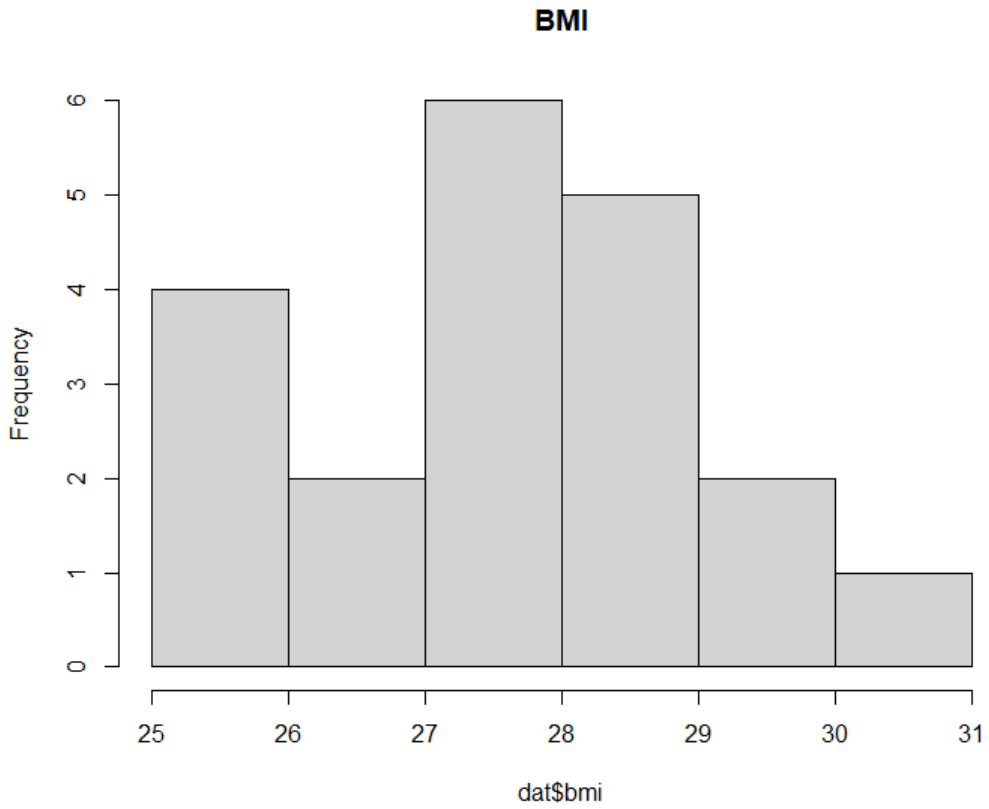
Visualise: scatterplot with regression line

```
plot(dat$age, dat$bmi,
     main="age vs BMI",
     xlab="age",
     ylab="BMI")
fit <- lm(bmi ~ age,
          data=dat)
abline(fit, col="red", lwd=3)
```



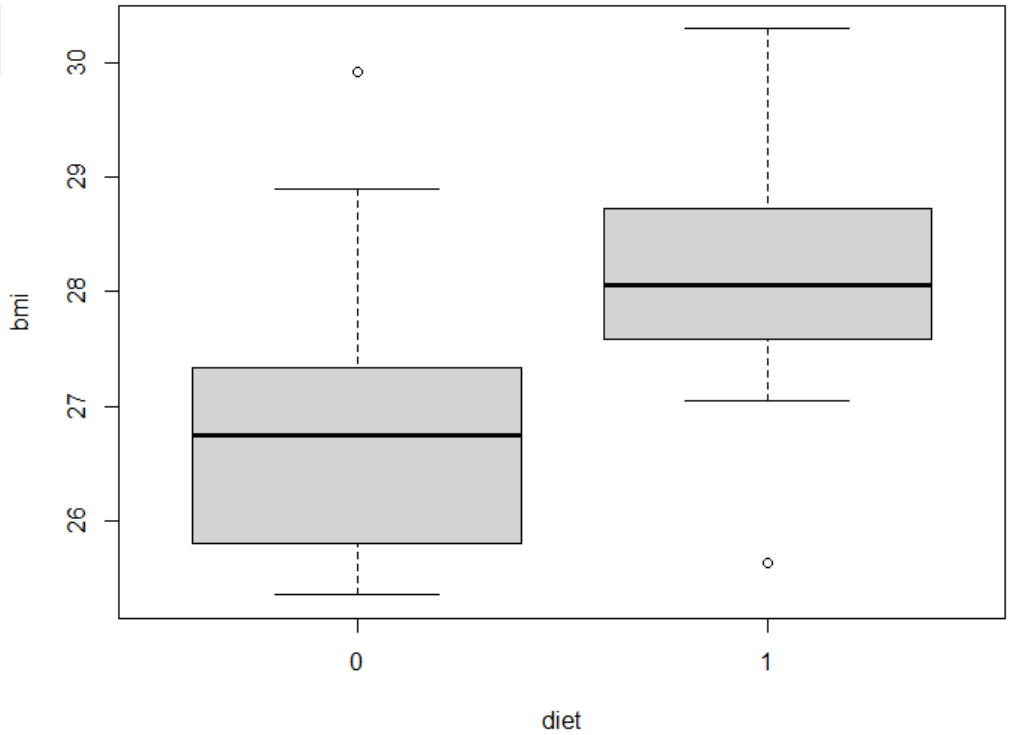
Visualise: histogram

```
hist(dat$bmi, main="BMI")
```

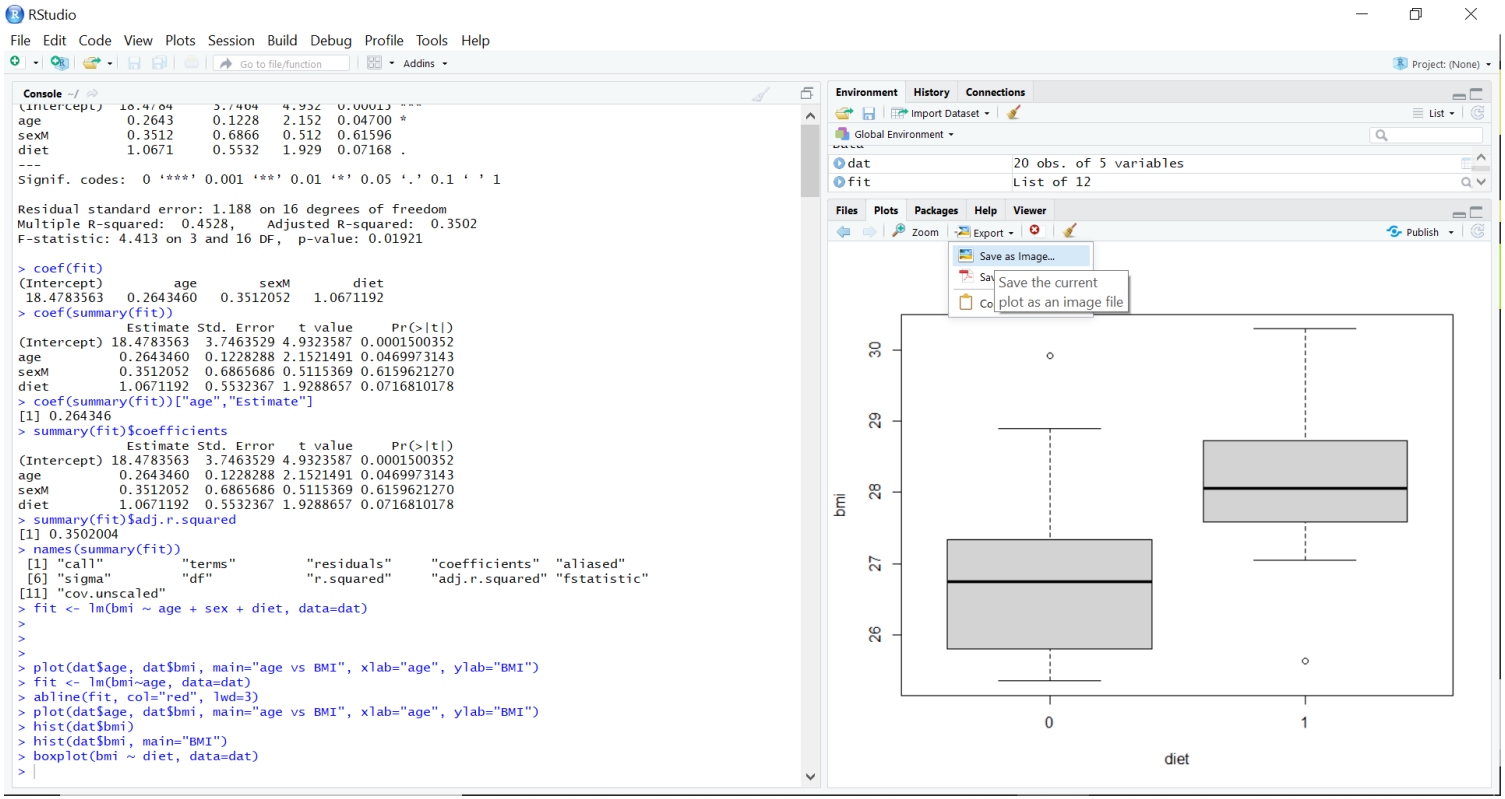


Visualise: boxplot

```
boxplot(bmi ~ diet, data=dat)
```



Visualise: saving



Visualise: saving *like a total maniac*

```
> png(filename="boxplot.png", width=10, height=10, units="cm", res=500)
> boxplot(bmi~diet, data=dat)
> dev.off()
```

Recipes: create and apply

Functions consist of a sequence of commands applied to a set of variables that return some output.

R provides many functions such as `help`, `cor`, `median`.

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Users can create their own functions for repetitive tasks, e.g. a function for the distance of a point from 0.

```
euclidean.norm <- function(x) {
  res <- sqrt(sum(x^2))
  return(res)
}
```

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```
euclidean.norm <- function(x) {
  res <- sqrt(sum(x^2))
  return(res)
}
```

```
> euclidean.norm(c(3,4))
[1] 5

> euclidean.norm(c(2,3,6))
[1] 7

> euclidean.norm(c(1,4,8))
[1] 9
```

Recipes: repeat

Given a vector `people`:

```
> people <- c("bill",
              "jane",
              "bob",
              "felicia",
              "carl",
              "apple")
> scores <- c(90, 80,
              60, 95,
              75, 99)
```

Suppose we want to make a list of people who obtained high scores.

Recipes: repeat

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> people <- c("bill",
              "jane",
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> scores <- c(90, 80,
              60, 95,
              75, 99)
```

Suppose we want to make a list of people who obtained high scores.

Step 1. Create a function for determining a high score.

```
is.high <- function(s) {
  return(s > 90)
  ## or something
  ## really complicated
  ## takes into account
  ## grade barriers
  ## and homework
  ## completed and
  ## the name of
  ## first pet.
}
```

Recipes: repeat

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  ## grade barriers
  ## and homework
  ## completed and
  ## the name of
  ## first pet.
}
```

Step 2. Construct the list of people by applying `is.high()`.

Two equivalent ways:

Option 1. For-loop

```
n <- length(people)
high <- character()
for (i in 1:n) {
  if (is.high(scores[i])
    high <- c(high, peop
}
```

Option 2. `sapply()`

```
yes <- sapply(scores, is
high <- people[yes]
```

Decisions: ask questions

```
> x <- 11:15
```

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> x[3] == 13                    ## 13 equals 13
[1] TRUE
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> x[3] != 12                    ## 13 not equal to 12
```

Decisions: ask questions

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> x <- 11:15
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> x[3] == 13                    ## 13 equals 13
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> x[3] != 12                    ## 13 not equal to 12
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```
> x[3] < x[4]                   ## 13 less than 14
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```
> x[3] == 13                    ## 13 equals 13
[1] TRUE
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> x[3] != 12                    ## 13 not equal to 12
```

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> x[3] < x[4]                   ## 13 less than 14
```

```
> x[1] <= x[2] & !x[2] > x[3]   ## 11 <= 12 and 12 not greater than 13
```

Decisions: ask questions

```
> x <- 11:15
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```
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> x[1] <= x[2] & !x[2] > x[3]   ## 11 <= 12 and 12 not greater than 13
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```
> x[1] < x[2] | x[2] > x[3]     ## 11 < 12 or 12 > 13
```

Decisions: ask questions

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```

```
> x[1] < x[2] | x[2] > x[3]     ## 11 < 12 or 12 > 13
```

```
> x > 12
[1] TRUE FALSE FALSE FALSE FALSE
```

Decisions: ask questions

```
> x <- 11:15
```

```
> x[3] == 13                    ## 13 equals 13
[1] TRUE
```

```
> x[3] != 12                    ## 13 not equal to 12
```

```
> x[3] < x[4]                   ## 13 less than 14
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```
> x[1] <= x[2] & !x[2] > x[3]   ## 11 <= 12 and 12 not greater than 13
```

```
> x[1] < x[2] | x[2] > x[3]     ## 11 < 12 or 12 > 13
```

```
> x > 12
[1] TRUE FALSE FALSE FALSE FALSE
```

```
> all(x < 12)                   ## each value in x < 12
[1] TRUE
```

Decisions: alternatives

```
if (score > 85) {
  grade <- "A"
} else {
  grade <- "F"
}
```

Decisions: alternatives

```
if (score > 85) {
  grade <- "A"
} else {
  grade <- "F"
}
```

```
grade <- ifelse(score > 85, "A", "F")
```

Decisions: alternatives

```
if (score > 85) {
  grade <- "A"
} else {
  grade <- "F"
}
```

```
grade <- ifelse(score > 85, "A", "F")
```

```
if (score > 85) {
  grade <- "A"
} else if (score > 75)
  grade <- "B"
} else {
  grade <- "F"
}
```

Decisions: alternatives

```r
if (score > 85) {
  grade <- "A"
} else {
  grade <- "F"
}
```

```r
grade <- ifelse(score > 85, "A", "F")
```

```r
if (score > 85) {
  grade <- "A"
} else if (score > 75)
  grade <- "B"
} else {
  grade <- "F"
}
```

```r
grade <- ifelse(score > 85, "A", ifelse(score > 75, "B", "F"))
```

Share: loading packages

An **R package** is acollection of functions and/or data sets created for use by other R users. A package can be loaded using `library`.

```
> library(Hmisc)
Attaching package: ‘Hmisc’
```

Share: loading packages

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```
> library(Hmisc)
Attaching package: 'Hmisc'
```

After loading, functions and data provided by the package can be used.

```
> describe(c(1,1,2,1,3,5,1,3,5,2,3,4))
       n  missing distinct     Info
      12        0        5    0.944
    Mean      Gmd
   2.583    1.742

lowest : 1 2 3 4 5, highest: 1 2 3 4 5

Value          1     2     3     4
Frequency      4     2     3     1
Proportion 0.333 0.167 0.250 0.083

Value          5
Frequency      2
Proportion 0.167
```

Share: installing packages

If the package has not been installed, you'll see an error message like this.

```
> library(Hmisc)
Error in library(Hmisc) : there is no package called ‘Hmisc’
```

Share: installing packages

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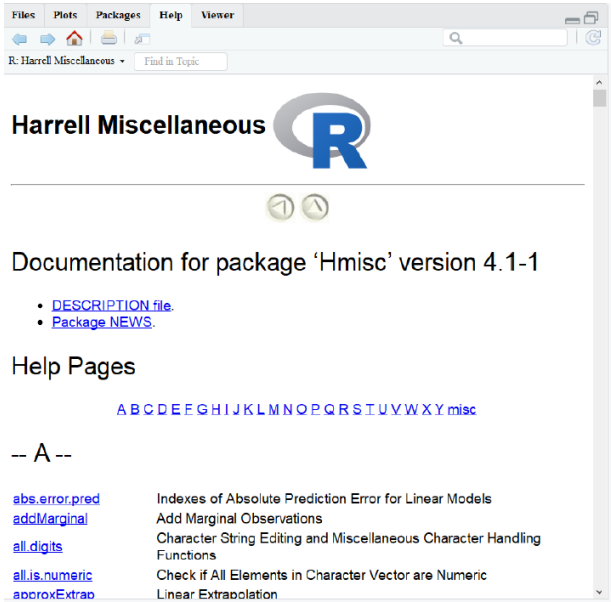
```
> library(Hmisc)
Error in library(Hmisc) : there is no package called ‘Hmisc’
```

The package can be installed using `install.packages`.

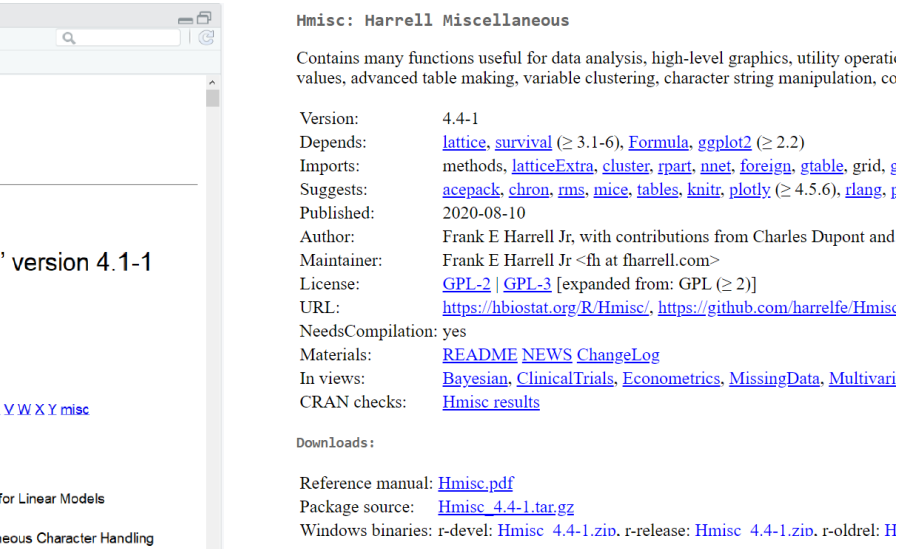
```
> install.packages("Hmisc")

Installing package into ‘C:/Users/dude/Documents/R/win-library/4.0’
(as ‘lib’ is unspecified)
also installing the dependencies ‘png’, ‘jpeg’, ‘Formula’,
‘latticeExtra’, ‘gridExtra’, ‘htmlTable’, ‘viridis’

trying URL 'https://cran.rstudio.com/bin/windows/contrib/4.0/png_0.1-7.zip'
Content type 'application/zip' length 336667 bytes (328 KB)
downloaded 328 KB

...

package ‘Hmisc’ successfully unpacked and MD5 sums checked

The downloaded binary packages are in
  C:\Users\dude\AppData\Local\Temp\RtmpS221DR\downloaded_packages
```

Share: package help

The *help* function can be used to open the documentation for an R package, e.g. `help(package="Hmisc")`



Search the package list on CRAN https://cran.r-project.org/web/packages/Hmisc/



Share: learn R with "swirl"

swirl (http://swirlstats.com/students.html) allows you to learn R within R itself.


```
> install.packages("swirl")
> library(swirl)
| Hi! Type swirl() when you are ready to begin.
```

Share: creating packages for others

If you have a set of R functions and/or a dataset that you think others might like to use, create a package and put them in it!

Here is a good place to get started:

https://support.rstudio.com/hc/en-us/articles/200486488-Developing-Packages-with-RStudio

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