R crash course

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1 Introduction

This document has no pretention of being comprehensive. The aim is just to help you to start with R. You will learn more during the other courses, by using the embedded help system and by reading the documents presented in the section 8. The section 9 will explain some of the terms used. You will find those terms in **bold** throughout this document. For the sake of clarity some aspects are probably exaggerately simplified. It is hoped this causes no harm.

1.1 History and availability

S was developped at Bell laboratories in 70s. It became soon *S-plus*. *R* was started as a free implementation of the *S/S-plus* language. The two languages remain mainly identical.

The **source code** for *R* is freely available can be **compiled** for a very wide range of platforms. **Executable binaries** are also available for platforms like Windows (98, 2000, XP, NT), MacOS (version IX and X), and several linux distributions. I have a computer at home, you should be able to run R easily.

1.2 Why should we use R ?

Software based on spreadsheets (*Microsoft*'s *Excel* is a popular one) are not the only way handle data. The R software will let you do all what you were doing, but will also let you go (far) beyond. A large number of **packages** written by renowned statisticians are available, and you will be able to write your own code.

1.3 Starting (and exiting) *R*

The installation procedure will not be detailed[1].

With Unix/Linux, just write *R*. Your terminal is now a R console.
With Windows, double-click on the *R* icon. An R process is started. A R console window is opened. The console shows a `>` waiting for your input.

R has a powerfull system to query help. By entering `help.start()` a browser will be started. You can navigate with the mouse through the help. Once this has been done, the results of help calls will be returned to the browser. The command `help` queries help. (`help()` is equivalent to `help(help)`).

[1] under windows all you need to do is to double-click on the executable you downloaded. The install program will guide you through

To exit, write `q()`. You are prompted to known if you want to save your working session. Answering `y` or `n` will lead you out.

1.4 Interactive browsing of examples

This document can be used interactively within *R*. To do so, you will need:

1. the packages *DynDoc* and *tkWidgets* installed
2. the files `.Rnw` and `.pdf` for this document (available at `http://www.cbs.dtu.dk/staff/laurent/teaching/crashR.Rnw` and `http://www.cbs.dtu.dk/staff/laurent/teaching/crashR.pdf`).
3. to enter the *R* code at `http://www.cbs.dtu.dk/staff/laurent/teaching/crashR_start.R` or enter blindly the following command in *R*

```
source(url("http://www.cbs.dtu.dk/laurent/teaching/crashR_start.R"))
```

2 Basics about the language

2.1 Like a pocket calculator (just bigger)

R is designed to do statistics, hence to handle numbers. You can enter the following line:

```
> 1 + 2
```

```
[1] 3
```

The results is 3, as one might have expected.

`"+"` is called an *arithmetic binary operator*. It is *arithmetic* because it does some maths. It is *binary* because it takes two arguments (1 and 2). It is an *operator* because it does something.

`+`	addition
`-`	substraction
`*`	multiply (product)
`/`	division. Divide the first argument by the second argument
`^`	power. Multiply the first argument the number of times given in the second argument. x^y writes `x ^ y` in R.
`%%`	modulo (remainder of the integer division). Example: `10 \%\% 3` returns 1.
`%\%`	integer division. Example: `10 %\% 3` returns 3.

Operators have a *precedence* (i.e. a relative priority). The parenthesis can be used to indicate in which order the computation should be performed.

```
> 2 + 3 * 4
```

```
[1] 14
```

```
> 2 + (3 * 4)
```

```
[1] 14
```

```
> (2 + 3) * 4
```

```
[1] 20
```

Many mathematical functions are also available. Example:
To name few of them:

- Trigonometric functions

  cos, acos cosinus, arc-cosine

  sin, asin sinus, arc-sine

  tan, atan tangent, arc-tangent

- Logarithm and exponentials

  log logarithm.

  log2 base-2 logarithm ($\log_2 x$ is done in *R:* `log2(x)`*).*

  exp *exponential (*$\exp^x$ *is done in R:* `exp(x)`*).*

- miscellaneous

  sqrt square-root ($\sqrt{x}$ is done in *R:* `sqrt(x)`*).*

```
> cos(pi/3)
```

```
[1] 0.5
```

2.2 variables (objects)

An *R* **environment** can be thought of as a working space. Naturally you can store *things* (eventually to re-use them later) in it. The *things* or objects you store are like boxes in a storage room. To find something, or actually to ask *R* to give you something, it is convenient to have a *name* for it. The `"<-"` operator performs what is called **assignment**. The first **argument** is a *name* for the *object* given in the second **argument**. If one does

```
> x <- 1
```

the numerical value 1 is stored under the name `x`. To query this object, just call it by its *name*:

```
> x
```

```
[1] 1
```

In *R*, a copy of the object is made during an assignment:

```
> print(x)
```

```
[1] 1
```

```
> y <- x
> print(x)
```

```
[1] 1

> print(y)

[1] 1

> x <- 2
> print(x)

[1] 2

> print(y)

[1] 1
```

Variables are very convenient to store intermediate results. Example:

```
> alpha <- 0.34
> a <- cos(alpha)
> b <- sin(alpha)
> (a^2) + (b^2)

[1] 1
```

The example above probably reminded you of something:

$$\forall \alpha, \cos^2 \alpha + \sin^2 \alpha = 1$$

The function `objects` returns the names of the objects in an *environment* (or working space).

```
> objects()

[1] "a"     "alpha" "b"     "x"     "y"
```

The function `rm(object)` removes the object (*i.e.* deteles it).

```
> foo <- 33
> objects()

[1] "a"     "alpha" "b"     "foo"   "x"     "y"

> rm(foo)
> objects()

[1] "a"     "alpha" "b"     "x"     "y"
```

2.3 mode (or type)

The objects we have seems were all numbers, but we can manipulate more than numbers.

```
> name <- "George"
> age <- 43
> sex <- factor("MALE", levels = c("MALE", "FEMALE"))
> married <- TRUE
```

The *type* of the object is also called the **mode** in *R*. Knowing what an object is important for the system to know how to handle it. Example:

```
name + age
```

returns:

```
Error in name + age : non-numeric argument to binary operator
```

R did not know how to perform `"+"` using a **character** and a **numeric**.

The different modes are:

- The mode **character** is for strings.
- The mode **numeric** deals with *real* numbers.
- The mode **integer** concerns integers.
- The mode **logical** would be called *boolean* in other languages. It is linked to something called *boolean logic*. Boolean operators are:

`x && y`	x AND y
`x || y`	x OR y
`! x`	NOT x
`xor(x, y)`	x XOR y

They can be combined to verify

```
> has.plane.ticket <- TRUE
> has.VISA <- TRUE
> can.travel <- has.plane.ticket & has.VISA
> print(can.travel)

[1] TRUE

> cannot.travel <- (!has.plane.ticket) | (!has.VISA)
```

- The mode **factor** is for categories. A factor can have different *levels*.
- The mode **list**. More will taught in Section 2.5.

2.4 vectors, matrices, arrays

Some have probably already noticed a `[1]` in the front of the *R* output. This means that what is returned on this line starts with the element number 1. *R* is oriented to handle **vector**s. A **vector** can be thought of as sequence of elements of the same **mode**. What we manipulated so far were just vectors of length 1. Let's see with an example:

```
> x <- c(1, 2, 3)
> print(x)

[1] 1 2 3

> y <- c("a", "b", "c")
> print(y)
```

```
[1] "a" "b" "c"
```

The function +c()+ concatenates all its arguments into one vector. Other useful functions are `seq` and `rep`:

```
> seq(1, 3)

[1] 1 2 3

> 1:3

[1] 1 2 3

> seq(1, 3, by = 0.5)

[1] 1.0 1.5 2.0 2.5 3.0

> rep(1, 3)

[1] 1 1 1

> rep(1:3, 2)

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

Many functions in *R* are designed to operate on vectors.

```
> x <- c(-1, 2, 3)
> min(x)

[1] -1

> max(x)

[1] 3

> mean(x)

[1] 1.333333

> x + x

[1] -2  4  6
```

You can try with other functions defined in the section 2.1.

One important thing in *R* is what is called the *recycling rule*. Vectors that are shorter than they should see their elements *recycled* when looping through.

```
> x <- c(-1, 2, 3, 3)
> x + 1

[1] 0 3 4 4

> x + c(1, 2)

[1] 0 4 4 5
```

```
> x - mean(x)

[1] -2.75  0.25  1.25  1.25
```

Many other functions than `c()` prove useful when dealing with vector. Some are:

- `rep(x, y)` repeat x y times.
- `seq(x, y)` generate a sequence of integers from x to y. A syntactic sugar for `rep()` is `:`. `1:10` is equivalent to `rep(1,10)`.
- `rev(x)` returns x in the reverse order
- `sort(x)` returns x sorted in ascending order.

Matrices are very convenient objects to make computation. They are vey similar to vectors.

```
> m <- matrix(c(1, 2, 3), nrow = 3, ncol = 3)
> m

     [,1] [,2] [,3]
[1,]    1    1    1
[2,]    2    2    2
[3,]    3    3    3

> m + m

     [,1] [,2] [,3]
[1,]    2    2    2
[2,]    4    4    4
[3,]    6    6    6
```

Some of the useful matrix facilites are:

matrix multiplication	`m %*% m`
transpose	`t(m)`
diagonal elements	`diag(m)`
eigen values	`eigen(m)`

2.5 list and data frames

A **list** is also a vector of mode **list**, but the *content* of a list can be anything. This allows to bundle together heterogeneous things.

```
> list(1:10, c("a", "b", "c", "d"))

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

[[2]]
[1] "a" "b" "c" "d"
```

Elements in a list can be named:

```
> list(a = 1:10, b = c("a", "b", "c", "d"))
```

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

$b
[1] "a" "b" "c" "d"
```

A **data.frame** is a list with a convenient particularity: each of its *components* are vectors of the same length. You can picture it as a table having each column filled with elements of the same **mode**. This is particularly convenient to store most of the datasets:

name	age	sex	married
George	43	MALE	TRUE
Anna	14	FEMALE	FALSE
Sarah	58	FEMALE	FALSE
Tom	35	MALE	FALSE
...	...	...	...

Objects **data.frame** can be *attached* and *detached* (functions `attach()` and `detach()` respectively). Their content becomes then directly accessible.

2.6 subseting, indexing

The objects we have presented have several elements. The access to one or more of these elements is called *subseting*. It is a very efficient technique in *R*. We will show how to do it with vectors, matrices, lists and data frames.

```
> x <- c(2, 0, 1, 3, 4)
> x[1]

[1] 2

> xIndex <- c(1, 3)
> x[xIndex]

[1] 2 1
```

The subseting operator is `"["`. A vector is used to tell which elements to select. A **logical** vector can also be used to select elements.

```
> x[c(TRUE, FALSE, TRUE, FALSE, FALSE)]

[1] 2 1

> isSmall <- (x < 3)
> x[isSmall]

[1] 2 0 1

> indexSmall <- which(isSmall)
> x[indexSmall]

[1] 2 0 1
```

For matrices, we have to specify two vectors of indices

```
> m <- matrix(1:9, nrow = 3, ncol = 3)
> m

     [,1] [,2] [,3]
[1,]    1    4    7
[2,]    2    5    8
[3,]    3    6    9

> m[1, 1]

[1] 1

> m[1, ]

[1] 1 4 7

> m[c(1, 2), c(1, 2)]

     [,1] [,2]
[1,]    1    4
[2,]    2    5

> indexDiag <- matrix(rep(1:3, 2), nr = 3, nc = 2)
> m[indexDiag]

[1] 1 5 9
```

We saw in Section **??** that a *list* can have *named* elements. The subseting can be done by the name, using the operator `[` with name or a number. Access to elements is done with the operator `[[` or the operator `"$"`

```
> l <- list(letter = c("a", "b"), number = c(1, 2, 3, 4))
> l

$letter
[1] "a" "b"

$number
[1] 1 2 3 4

> l["letter"]

$letter
[1] "a" "b"

> l[1]

$letter
[1] "a" "b"

> l$letter
```

```
[1] "a" "b"
```

```
> l[[1]]
```

```
[1] "a" "b"
```

For data frames:

```
> df <- data.frame(name = c("George", "Anna"), age = c(43, 14))
> df
```

```
    name age
1 George  43
2   Anna  14
```

```
> df[1, 1]
```

```
[1] George
Levels: Anna George
```

By default, vectors of **character** are converted to **factor** in **data.frame**.

Subsetting by name can be done with any kind of vector, given that its elements were previously named. The operator `[[` introduced for the *list* subsets and does not keep the name.

```
> x <- c(2, 0, 1, 3, 4)
> names(x) <- c("a", "b", "c", "d", "e")
> x[3]
```

```
c
1
```

```
> x["c"]
```

```
c
1
```

```
> x[[3]]
```

```
[1] 1
```

2.7 Exercises

- compute with R:

$$\frac{e^{sin(\pi/16)}}{1 - e^{sin(\pi/16)}}$$

- generate a vector x of 30 random numbers (normal distribution) using the function `rnorm`.
- create a vector y that only contains the positive elements of x.
- create a vector z that censors the negative elements of x with zeros.

3 Branching conditions and loops

- *if(condition)*: Tests for *condition* to be *TRUE*. If it is the case the block is executed.

```
> x <- TRUE
> if (x) {
+     print("x is TRUE")
+ }
```

```
[1] "x is TRUE"
```

- *if (condition) ... else*: *if (condition)* tests for *condition* to be *TRUE*. If it is the case the first block is executed, otherwise the second block is executed.

```
> x <- FALSE
> if (x) {
+     print("x is TRUE")
+ } else {
+     print("x is FALSE")
+ }
```

```
[1] "x is FALSE"
```

- *while (condition)*: execute the block as long as *condition* is *TRUE*.

```
> x <- 10
> while (x > 0) {
+     x <- (x - 3)
+ }
> x
```

```
[1] -2
```

- *for (variable in vector)*: goes through each element of *vector* (one after the other), assign the current element to *variable* and execute the block.

```
> x <- c(1, 2, 3)
> for (i in x) {
+     print(i)
+ }
```

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

```
> x <- c("a", "b", "c")
> for (i in x) {
+     print(i)
+ }
```

```
[1] "a"
[1] "b"
[1] "c"
```

4 Functions

4.1 writing your own functions

A function is made of *arguments* and a *body*. The *arguments* are what is given to the function, the *body* is the 'machinery' of the function. Let's define a function to calculate the hypothenuse of a triangle:

```
> hypothenuse <- function(x, y) {
+     z <- sqrt(x^2 + y^2)
+     return(z)
+ }
> hypothenuse(1, 1)

[1] 1.414214
```

A function can *return* something (i.e. gives back a result). Our function returns a result. We indicate what to return with the function *return()* (surprise ...).

The arguments are *(x,y)*. It is possible to define *optional arguments* (or arguments with a default value). This is achieved in our example by doing something like `function(x, y=2)`.

4.2 editing a function

The function `edit` can be used to edit *R* objects, including functions. An editor is opened with the **source code** of the function.

```
hypo.modif <- edit(hypothenuse)
```

The default editor may depends on your installation, but unless exotic settings it should be the *notepad* for Windows and *vi* for Unices. You can specify an alternative editor with the parameter `editor`. Example:

```
hypo.modif <- edit(hypothenuse, editor="nedit")
```

or with *Microsoft Windows*:

```
hypo.modif <- edit(hypothenuse, editor="notepad")
```

To make correction to an existing function, one can use `fix`:

```
fix(hypothenuse)
```

An alternative practice is to use your favorite text editor as copy/paste your code in the *R* console.

4.3 Miscellaneous useful functions

- `str(object)`. Dump the structure of the object.
- `traceback()`. Give indications about where the last error occured.
- `object.size(object)`. Return an aproximate of the memory used by an object

- `gc()`. Garbage collector. 'Clean' the memory and give the memory usage.
- `capabilities()`. Tell about the capabilities of the version of R you are using.

4.4 Exercises

- create a function `cube`: `cube`$(x) = x^3$
- create a function `factorial`: `fact`(y) =y!
- create a function `f`: $f(x, y) =$ `cube`$(x) -$ `fact`(y)

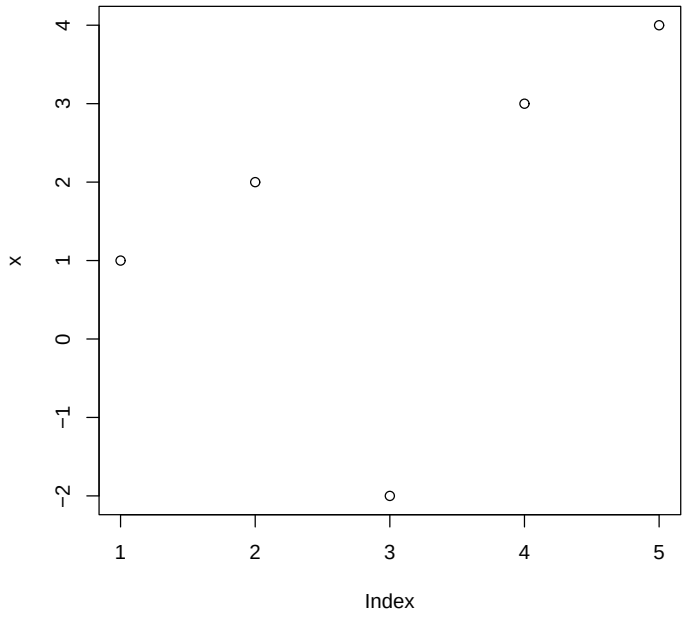
5 Graphics

R is a powerful tool to generate graphics. Vizualization of data can help the analysis.

5.1 plot

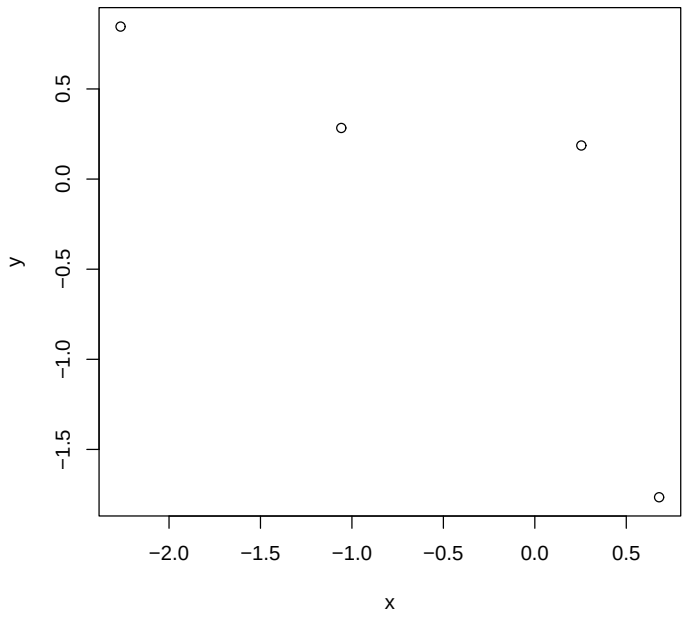
The call to `plot(object)` will create a plot for the object.

```
> x <- c(1, 2, -2, 3, 4)
> plot(x)
```



Several objects can be passed to the plot function.

```
> x <- rnorm(4)
> y <- rnorm(4)
> plot(x, y)
```



The function plot accepts optional parameters (see figure 1). They are too many to be detailed here. We only introduce few of them. The parameter *type* can be *"p"* for points, *"l"* for lines, *"b"* for both, *"s"* for steps, *"n"* for nothing.

The behavior of the function `plot` changes according to the object(s) it is used with.

5.2 other high-level plots

- barplot(x): barplot of values in x
- hist(x): histogram for the values in x
- pie(x): pie chart of values in x
- pairs(m): matrix of scatter plot of matrix m.
- image(m): *image* of a matrix m.
- boxplot(x, y, ...): box and whiskers plot of vectors x, y, ...

5.3 low-level graphical functions

- `points(x, y)`: add points to a plot at coordinates (x,y).
- `lines(x, y)`: add lines to a plot, using coordinates (x,y).
- `text(x, y, labels)`: a the labels at the coordinates (x,y).

```
> par(mfrow = c(2, 2))
> plot(x, y)
> plot(x, y, pch = 1, col = "red")
> plot(x, y, pch = 1, col = c("red", "red", "green", "red"))
> plot(x, y, type = "l")
```

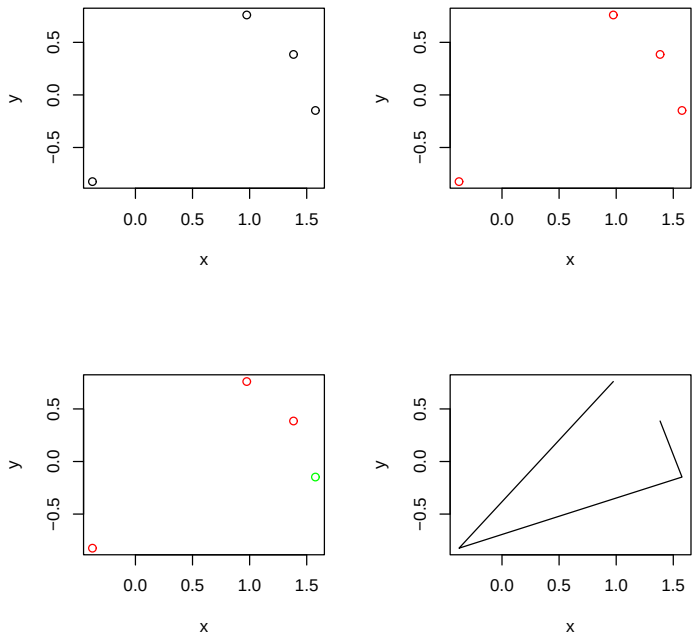


Figure 1: The upper left plot is the result of *plot(x, y)*, upper right plot is the result of *plot(x, y, pch=1, col="red")*, the lower left plot is the result of *plot(x, y, pch=1, col=c("red", "red", "green", "red"))*, and the lower right plot is the result of *plot(x, y, type="l")* (the numbers are added aftwards and correspond to the order of the values in x and y).

5.4 other nifty things

`par(mfrow=c(x, y))` splits your ploting device into x rows and y columns.

5.5 printing your plot

R functions with *devices*. We show below how to print in a *postscript* device.

```
dev.print(postscript, file="where/myfile.ps")
```

5.6 Exercise

- generate a vector x with 100 random values using the function *rnorm* (mean zero, standard deviation equal to one), then plot an histogram. Repeat the operation few times. You can observe differences (sampling effect).
- generate a vector y with 100 random values using the function *rnorm* (mean zero, standard deviation equal to one). Make a scatter plot x vs y, using different 4 different colors (one for $x < 0, y < 0$, one for $x < 0, y > 0$, one for $x > 0, y > 0$ and one for $x > 0, y < 0$).

6 Reading and writing files

6.1 *R* scripts

- `source(filename)`: read and execute *R* code in the file *filename*.

6.2 data files

- `read.table(filename)`: read the data file *filename* and store data in a **data.frame**. A lot of optional parameters can be specified. Useful ones are *sep* to specify the separator used, *skip* to skip lines.

7 Packages

Packages of objects can be loaded using the function `library`. By default the packages *base* and *ctest* (classical tests) are loaded.

For example, to load the package *mva* (MultiVariate Analysis):

```
> library(mva)
```

Documented topics in a package can be listed with the function `library`, using the parameter *help*:

```
> library(help = mva)
```

8 To know more

- Introduction to R, by W.M. Venables, D.M. Smith and the R Developement Core Team. It can be downloaded from
  `http://cran.r-project.org/doc/manuals/R-intro.pdf`
- R for Beginners, by Emmanuel Paradis. It can be downloaded from:
  `http://cran.r-project.org/doc/contrib/rdebuts_en.pdf`

. . . and remember to use the help system !

9 vocabulary

You will find here a summary explanation for some of the technical terms. Refer to your programming course (or teacher) for details.

array *Table* of elements of the same **mode**. A **matrix** is an **array**

character mode for strings of characters.

compilation Transform *source code* into executable code.

complex mode for complex numbers

data.frame **list** in which all the elements have the same length.

environment can thought of as a *working space*. Objects are in a given environment. The default environment for user defined objects is called `.GlobaEnv`.

factor mode for factors (i.e. categories).

integer mode for integers

list objects constituted of ordered *components* of independant **mode**. *Components* can be called by position number or name.

logical two values possible *TRUE* or *FALSE*.

matrix 2-ways arrays. Elements can be accessed knowing their location (row number and column number)

mode Sometimes called *type*. The main ones are: **integer**, **numeric**, **complex**, **logical**, **character**, **factor** and **list**.

numeric mode real numbers.

source code The program (as written by the programmer).

subset extract a subset of an object. `[` in general, "[[" to access an element of a **list**.

type See **mode**

vector Sequence of elements of the same **mode**