FEM11151
Lecture 1 - Introduction to R

Language design

- R is an interpreted language.
- Interaction with R takes place at the command prompt **>**.
- R interprets and executes the command, returns the output.
- Output can be returned on the console, on the graphic device or to a file.

Example: Type 2+2 at the R command prompt, and press enter.

```
> 2 + 2
```

```
[1] 4
```

! If a command is not completed at the end of a line, R will give a continuation prompt **+**, by default.

```
> 2 +
+   2
```

```
[1] 4
```

Solution: Finish the command or hit `Esc`.

Functions

- R has a pure functional core! Every computation happens by evaluating functions.
- A Function consists of:

1. Function name **`function.name`**
2. Function call `()`
3. Function *`arguments`* (can be variables, data, default values or other functions).

```
function.name(argument1 = var.x, argument3 = data, argument4 = TRUE,  ...)
```

- The function call passes arguments by **position** or by **name**. If any argument is passed by name the order in which it appears is irrelevant.
- Arguments with **default values** are omitted. If such an argument is not specified, R takes the default value.

Example: The linear model function `lm()` for fitting a linear regression model.

```
lm(formula, data, subset, weights, na.action, method = 'qr',
   model = TRUE, x = FALSE, y = FALSE, qr = TRUE, singular.ok = TRUE,
   contrasts = NULL, offset, ...)
```

Regressing `Temp` on `Ozone` from R's `airquality` data set (daily air quality measurements in New York, May to September 1973).

Option (1): Pass required arguments **by position**.

```
> lm(Ozone ~ Temp, airquality)

Call:
lm(formula = Ozone ~ Temp, data = airquality)

Coefficients:
(Intercept)         Temp
   -146.995        2.429
```

Option (2): Pass required arguments **by name**.

```
> lm(data = airquality, formula = Ozone ~ Temp)

Call:
lm(formula = Ozone ~ Temp, data = airquality)

Coefficients:
(Intercept)         Temp
   -146.995        2.429
```

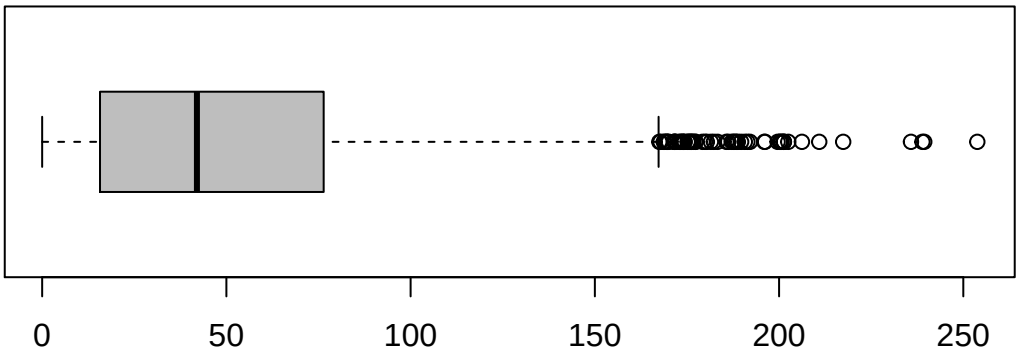
Example: The boxplot function `boxplot()` for producing a box-and-whisker plot.

```
boxplot(x, ..., range = 1.5, width = NULL, varwidth = FALSE, notch = FALSE,
       outline = TRUE, names, plot = TRUE, border = par('fg'), col = NULL,
       log = '', pars = list(boxwex = 0.8, staplewex = 0.5, outwex = 0.5),
       horizontal = FALSE, add = FALSE, at = NULL)")
```

Producing a horizontal boxplot in gray of the monthly numbers of sunspots from R's `sunspoth.month` data set.

Options (1) + (2): Pass arguments **by name and position**.

```
> boxplot(sunspot.month, col="gray", horizontal = TRUE)
```



! It is easier to remember the name of an argument than its position. If you can not remember the name or the position you can get help by using `?function.name` or `help(function.name)`.

Actions

1(a). **Plotting**. Producing graphical output (e.g., creating a plot in the graphic device).

1(b). **Printing**. Producing printed output (e.g., returning results on the console)

2. **Assignments**. Assign the output to a name.

- R operates on named data structures. The assignment operator <- points to the name receiving the value (Note: the assignment operator consists of the two characters < "less than" and - "minus").
- R names are unlimited in length.
- R names allow all alphanumeric symbols plus . and _ (only restriction: if a name starts with . the second character is not allowed to be a digit.)
- R names do not allow special symbols like ^,!, $, @, +, -, /, *.

Example: Calculate the mean of the monthly numbers of sunspots and name the result `mean.sunspot`.

```
> mean.sunspot <- mean(sunspot.month)
```

Print out the result on the console.

```
> Mean.sunspot
```

```
Error: object 'Mean.sunspot' not found
```

! R is **case sensitive**! Capitalisation does matter. Here, `M` and `m` are different symbols and refer to different objects.

3. **Subsetting**. Extracting elements from an object.

Example: Investigating R's `airquality` data set.

```
> head(airquality)
```

```
  Ozone Solar.R Wind Temp Month Day
1    41     190  7.4   67     5   1
2    36     118  8.0   72     5   2
3    12     149 12.6   74     5   3
4    18     313 11.5   62     5   4
5    NA      NA 14.3   56     5   5
6    28      NA 14.9   66     5   6
```

Select all observation days with more than 20 mph of windspeed.

```
> subset(airquality, subset=Wind>20)
```

```
   Ozone Solar.R Wind Temp Month Day
9      8      19 20.1   61     5   9
48    37     284 20.7   72     6  17
```

The very basics

Data types

R has three basic data types:

1(a). **Numeric** ("real numbers").

⇒ The two most common numeric types are `double` (double precision floating point numbers) and `integer` (without floating point).

1(b). **Complex** ("real and imaginary numbers").

2. **Logical** ("boolean").

⇒ Reserved words for denoting logical constants are `TRUE` and `FALSE` (and `NA` for missing value).

3. **Character**.

⇒ Data type for storing letters and symbols (strings, text).

Data structures

1. **Scalar**.
2. **Vector**. Collection of elements of a single ("atomic") data type.
3. **Matrix**. Collection of elements arranged in a two-dimensional rectangular layout (a two-dimensional generalization of a vector). Same as vector, all elements must be of a single data type.
4. **Data frame**. More general matrix like structure ("data matrix"). Different columns can have different data types.
5. **List**. Generic vector containing other objects. No restriction on data types or length of the single components.

Vectors

Concatinating elements together with `c()`.

```
> c(0.5, 0.6, 0.25)            # double
> c(9L, 10L, 11L, 12L, 13L)    # integer
> c(9:13)                      # integer sequence
> c(TRUE, FALSE, FALSE)        # logical
> c(1+0i, 2+4i)                # complex
> c("a", "b", "c")             # character
```

Vector actions

Assign the vectors to names:

```
> dbl <- c(0.5, 0.6, 0.25)
> chr <- c("a", "b", "c")
```

Print out the `dbl` and `chr` vectors on the console:

```
> dbl
```

```
[1] 0.50 0.60 0.25
```

```
> chr
```

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

Check the number of elements in `dbl` and `chr`:

```
> length(dbl)
```

```
[1] 3
```

```
> length(chr)
```

```
[1] 3
```

Check the data type `dbl` and `chr`:

```
> typeof(dbl)
```

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

```
> typeof(chr)
```

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

Combine two vectors:

```
> c(dbl,dbl)
```

```
[1] 0.50 0.60 0.25 0.50 0.60 0.25
```

```
> c(dbl, chr)
```

```
[1] "0.5"  "0.6"  "0.25" "a"    "b"    "c"
```

! The automatic change of the data type of the resulting vector is called **coercion**. Coercion ensures the same data type for each element in the vector is maintained.

Vector arithmetic

Define two new numeric vectors `a` and `b` each having 4 elements:

```
> a <- c(1, 2, 3, 4)
> b <- c(10, 20, 30, 40)
```

Multiply each element in `a` by 5 (scalar multiplication):

```
> a * 5
```

```
[1]  5 10 15 20
```

Multiply the elements in `a` by the elements in `b` (vector multiplication):

```
> a * b
```

```
[1]  10  40  90 160
```

Multiply the elements in `a` by the elements of some numeric vector `v` of length 5:

```
> v <- c(1.1, 1.2, 1.3, 1.4, 1.5)
> a * v
```

```
Warning in a * v: Länge des längeren Objektes
     ist kein Vielfaches der Länge des kürzeren Objektes
```

```
[1] 1.1 2.4 3.9 5.6 1.5
```

! Arithmetic operations of vectors are performed **elementwise**. If two vectors are of unequal length, the shorter vector will be **recycled** in order to match the longer one (here, the first element in `a` is used again).

Matrices

Option (1): Combining two vectors columnwise with `cbind()`:

```
> A <- cbind(a, b)    # two columns
> A
```

```
     a  b
[1,] 1 10
[2,] 2 20
[3,] 3 30
[4,] 4 40
```

Option (2): Combining two vectors rowwise with `rbind()`:

```
> B <- rbind(a, b)    # two rows
> B
```

```
  [,1] [,2] [,3] [,4]
a    1    2    3    4
b   10   20   30   40
```

Option (3): Creating a matrix from elements of a vector with `matrix()`:

```
> A <- matrix(a, ncol=2, nrow=2)     # matrix with 2 columns and 2 rows
> A
```

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

The arguments *nrow* and *ncol* indicate the number of rows and number of columns the resulting matrix consists of.

! For 4 elements and *ncol* = 2 the matrix can only have 2 rows. Thus, there is no need to specify both arguments.

```
> A <- matrix(a, ncol=2)              # matrix with 2 columns and 2 rows
> A
```

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

! By default the matrix is filled up column after column (R treats a matrix object internally as a column vector). If the matrix should be filled up row after row the argument *byrow=* TRUE is required.

```
> B <- matrix(a, ncol=2, byrow=TRUE) # matrix filled-up rowwise
> B
```

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

Matrix actions

Checking the number of rows:

```
> nrow(B)
```

```
[1] 2
```

Checking the number of columns:

```
> ncol(B)
```

```
[1] 2
```

Checking the dimension [nrow, ncol]:

```
> dim(B)
```

```
[1] 2 2
```

Combine two matrices:

```
> D.wide <- cbind(A,A)
> D.wide
```

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

```
> D.long <- rbind(A,A)
> D.long
```

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

```
D <- cbind(D.wide, D.long)
```

```
Error in cbind(D.wide, D.long) : object 'D.wide' not found
```

! Two matrices of unequal dimensions (number of rows or number of columns) cannot be combined.

Matrix arithmetic

Matrix addition:

```
> B + B
```

```
     [,1] [,2]
[1,]    2    4
[2,]    6    8
```

Scalar multiplication:

```
> B * 2
```

```
     [,1] [,2]
[1,]    2    4
[2,]    6    8
```

Elementwise multiplication:

```
> B * B
```

```
     [,1] [,2]
[1,]    1    4
[2,]    9   16
```

Matrix multiplication:

```
> B %*% B
```

```
     [,1] [,2]
[1,]    7   10
[2,]   15   22
```

More matrix arithmetic

- Transpose **t()**

```
> D.wide
```

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

```
> t(D.wide)
```

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

- Determinant **det()**

```
> det(B)
```

```
[1] -2
```

- Inverse **solve()** (only if **det()** $\neq 0$)

```
> solve(B)
```

```
     [,1] [,2]
[1,] -2.0  1.0
[2,]  1.5 -0.5
```

- Eigenvalues **eigen()** (only for square and symmetric matrices)

```
> eigen(B)
```

```
eigen() decomposition
$values
[1]  5.3722813 -0.3722813

$vectors
           [,1]       [,2]
[1,] -0.4159736 -0.8245648
[2,] -0.9093767  0.5657675
```

Data frames

```
> dbl <- c(0.5, 0.6, 0.25, 1.2, 0.333)      # double
> int <- c(9L, 10L, 11L, 12L, 13L)          # integer
> lgl <- c(TRUE, FALSE, FALSE, TRUE, TRUE)  # logical
> chr <- c("a", "b", "c", "d", "e")         # character
> df <- data.frame(dbl,int,lgl,chr)
> df
```

```
    dbl int   lgl chr
1 0.500   9  TRUE   a
2 0.600  10 FALSE   b
3 0.250  11 FALSE   c
4 1.200  12  TRUE   d
5 0.333  13  TRUE   e
```

Data frame actions

Checking the number of rows:

```
> nrow(df)
```

```
[1] 5
```

Checking the number of columns:

```
> ncol(df)
```

```
[1] 4
```

Checking the dimension [nrow, ncol]:

```
> dim(df)
```

```
[1] 5 4
```

Lists

```
> a <- 1L                                   # scalar
> dbl <- c(0.5, 0.6, 0.25, 1.2, 0.333)      # numeric vector of length 5
> chr <- c("a", "b", "c"        )           # charcter vector of length 3
> v <- c(1.1, 1.2, 1.3, 1.4)
> mat <- matrix(v, ncol=2)                  # 2 x 2 matrix
>
```

```
> l <- list(a, dbl, chr, mat)
> l
```

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

[[2]]
[1] 0.500 0.600 0.250 1.200 0.333

[[3]]
[1] "a" "b" "c"

[[4]]
     [,1] [,2]
[1,]  1.1  1.3
[2,]  1.2  1.4
```