Using R for Data Analysis and Graphics

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1. Introduction

In this Chapter you will ...

... learn what R is

... see a few first examples

... learn how to operate R

... learn how to read in data

... learn how to quit an R session

1.1 What is R?

- R is a software environment for statistical computing.
- R is based on commands. Implements the S language.
- There is an inofficial menu based interface called R-Commander.
- Drawbacks of menus: difficult to store what you do. A script of commands
  - documents the analysis and
  - allows for easy repetition with changed data, options, ...
- R is free software. `http://www.r-project.org`
  Supported operating systems: Linux, Mac OS X, Windows
- Language for exchanging statistical methods among researchers

1.2 Other Statistical Software

- S+ (formerly “S-PLUS”) same programming language, commercial. Features a GUI.
- SPSS: good for standard procedures.
- SAS: all-rounder, good for large data sets, complicated analyses.
- Systat: Analysis of Variance, easy-to-use graphics system.
- Excel: Good for getting (a small!) dataset ready. Very limited collection of statistical methods.
  Not for serious data analysis!
- Matlab: Mathematical methods. Statistical methods limited. Similar “paradigm”, less flexible structure.

1.3 Introductory examples

A dataset that we have stored before in the system is called `d.sport`

```
              weit kugel hoch  disc stab speer punkte
OBRIEN        7.57 15.66  207 48.78  500 66.90   8824
BUSEMANN      8.07 13.60  204 45.04  480 66.86   8706
DVORAK        7.60 15.82  198 46.28  470 70.16   8664
 :             :    :      :   :      :   :       :
 :             :    :      :   :      :   :       :
 :             :    :      :   :      :   :       :
CHMARA        7.75 14.51  210 42.60  490 54.84   8249
```

Draw a histogram of the results of variable `kugel` : We type
`hist(d.sport[,"kugel"])`
The graphics window is opened automatically.
We have called the function `hist` with argument
`d.sport[,"kugel"]` .
`[, j]` is used to select the column `j` .

- Scatter plot: type
  `plot(d.sport[,"kugel"], d.sport[,"speer"])`
  - First argument: x coordinates; second: y coordinates
  - Many(!) optional arguments:

    ```
    plot(d.sport[,"kugel"],d.sport[,"speer"],
         xlab="shot put",ylab="javelin",pch=7)
    ```
- Scatter plot matrix
  `pairs(d.sport)`
  Every column of `d.sport` is plotted against all other columns.

1.4 Using R

- Within a window running R, you will see the prompt '>␣'.
  You type a command and get a result and a new prompt.

  ```
  > hist(d.sport[,"kugel"])
  >
  ```

  An incomplete statement can be continued on the next line

  ```
  > plot(d.sport[,"kugel"],
  +       d.sport[,"speer"])
  ```


An R statement[1] is typically either

- a name of an object $\longrightarrow$ object is displayed
  `> d.sport`
- a call to a function $\longrightarrow$ graphical or numerical result
  `> hist(d.sport[,"kugel"])`
- an assignment

  ```
  > a <- 2*pi/360
  > mn <- mean(d.sport[,"kugel"])
  ```

  stores the mean of `d.sport[,"kugel"]`
  under the name `mn`

[1] R "statement": more precisely R "function call"

Get a dataset from a text file on the internet and assign it to a name:

```
> d.sport <- read.table(
+   "http://stat.ethz.ch/Teaching/Datasets/WBL/sport.dat")
```

For data files with a one-line header (of column names), you need to set the option `header = TRUE`,

```
> d... <- read.table(... , header = TRUE)
```

To download the file first to the local computer, R provides

```
> download.file("http://stat.ethz.ch/Teaching/Datasets/WBL/sport.d
+               destfile = "sport_data.txt")
```

Use file browser (of the underlying operating system) to open a file:

```
> d.sport <- read.table(file.choose())
```


1.5 Scripts and Editors

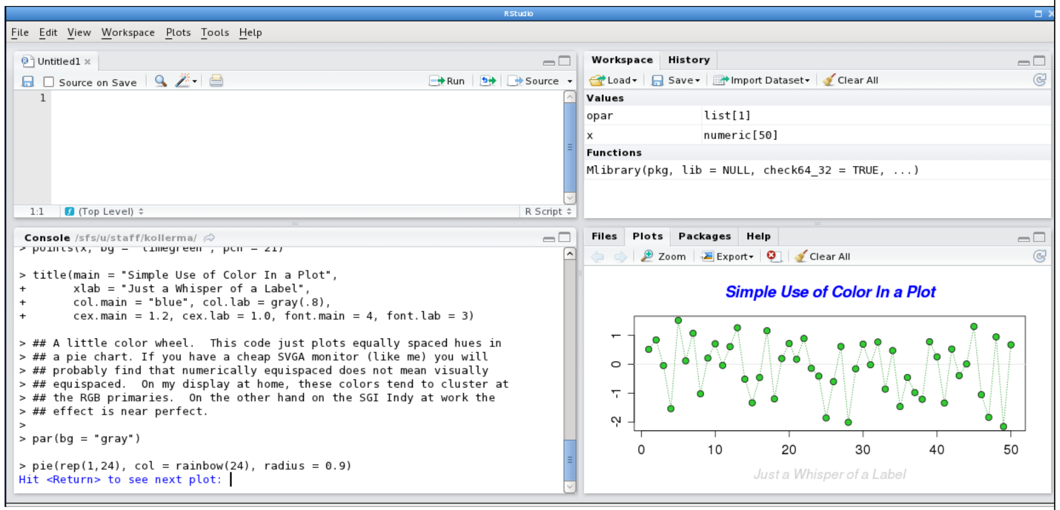
Instead of typing commands into the R console, you can generate commands by an editor and then "send" them to R ... and later modify (correct, expand) and send again. Text Editors supporting R

- R Studio: `http://rstudio.org/` new, available on all platforms (Free Software).
- Tinn-R: `http://www.sciviews.org/Tinn-R/`
- Emacs[2] with ESS: `http://ESS.r-project.org/`[3]
- WinEdt: `http://www.winedt.com/`
- Eclipse (via `StatET`)
- ...and several more, partly depending on platform (Windows / Mac / Linux) ......

[2] `http://www.gnu.org/software/emacs/`

[3] For Windows and Mac, on the Downloads tab, look for the "All-in-one installation" by Vincent Goulet

The R Studio Window



The Window has 2 $\times$ 2 panes; the top left pane will be our "R script file" or "R file", to be saved e.g., as `ex1.R`.

R Studio — Keyboard Shortcuts

Many shortcuts with which to work more efficiently in RStudio.
Menu `Help` → `Keyboard Shortcuts` gives two pages of shortcuts.
A few of important ones are[4]:

Description	Key (Mac: `Ctrl`=⌘)
Indent	Tab (at beginning of line)
Attempt completion	Tab
Cut / Paste / Copy	Ctrl + X / V / C
Insert assignment "arrow" ← (2 letter <-)	Alt + -
Run current line/selection	Ctrl + Enter
Run from document beginning to current line	Ctrl + Shift + B
Move cursor to beginning of line	Home
Move cursor to end of line	End
Save active document ("R file")	Ctrl + S
Show help	F1

[4] where, on the Mac, replace `Ctrl` by `Command` (= "Apple" = ⌘) and replace `Alt` by `Option` (left of "Apple")

Reading and Writing Data

Read a file in table format and create a data frame from it.
With cases corresponding to lines and variables to fields.

- Text-files:

```
> read.table(file, header = FALSE, sep = "",
+     dec = ".", row.names, col.names,...)
```

- Excel-files:

```
> read.csv(file, sep = ",", dec=".",...)
> read.csv2(file, sep = ";", dec=",",...)
```

Get all possible arguments and defaults with `?read.table`

Reading Data (ctd.)

- Tabulator-separated files:

```
> read.delim(file, sep = "\t", dec=".",...)
> read.delim2(file, sep = "\t", dec=",",...)
```

- R-Data:

```
> load(file="myanalysis.Rdata")
> load(file="C:/myanalysis.Rdata")
```


To save or write data to a file:

- Text-files:

```
> write.table(x, file = "", append = FALSE,
+     sep = " ",eol = "\n", na = "NA", dec = ".",
+     row.names = TRUE, col.names = TRUE, ...)
```

  where `x` is the data object to be stored.

- Excel-files:

```
> write.csv(...)
> write.csv2(...)
```

- R-Data files:

```
> save(..., file, ascii = FALSE,...)
```

  Example:

```
> x <- c(1:20)
> y <- d.sport$kugel
> save(x, y, file = "xy.Rdata")
```


- R stores all created "objects" in your workspace. List them by either `ls()` or equivalently, `objects()` :

```
> ls()
[1] "a"       "d.sport" "mn"
```

- Objects have names like `a, fun, d.sport`
- R provides a huge number of functions and other objects
- Arguments of functions are provided either by using their name, e.g. `read.table(...,header=TRUE)` , or by placing them at their defined position (as defined in the help-pages).
- You can see the function definition ("source") by typing its name without `()`:

```
> read.table
```

- Comments can be added using "#" :

```
> ls() ## Comments are ignored by R
```

Getting Help

- Documentation on the arguments etc. of a function (or dataset provided by the system):
  `> help(hist)` or `?hist`
  On the help page, the section "See Also..." contains related functions that could help you further.
- Search for a specific keyword:
  `> help.search("matrix")` Lists packages and functions related to or using "matrix".
  Note: Takes a long time when you have many extra R packages installed
- For many functions and data sets, examples are provided on the help page (`?matrix`). You can execute them directly,
  `> example("matrix")`

Resources on the internet

- R's Project page `http://www.r-project.org/`[5]
- CRAN: use Swiss mirror[6] `http://cran.CH.r-project.org/`: Links to **Search** (several search possibilites), **Task Views** (thematic collections of functions), **Contributed** (electronic Documentation, Introductions) and **FAQs**.

The following list could be extended "infinitely":

- `http://search.r-project.org/`: Search specific for R, also accessed via R function `RSiteSearch()` . Functions, Help, etc.
- `http://www.rseek.org/`: A "Google-type" search specific for R. Delivers Functions, Help Forums, etc.

[5] all URLs on this page are "clickable"
[6] the Swiss CRAN mirror is at `stat.ethz.ch`

Leaving the R session

Always store the script (*.R) files first.

Then quit the R session by
`> q()` in RStudio the same as menu `File` → `Quit R...`
You get the question:
`Save workspace image? [y/n/c]:`
If you answer "y", your objects will be available for your next session.

Note that we usually answer "`n`"[7], as we have stored the script (*.R) files and can quickly recreate all objects.

[7] and M.M. even *eliminates* that question by starting R as `R --no-save`

Using R for Data Analysis and Graphics

2. Basics

In this Chapter you will ...

... learn how to select elements from a data set
... find out about vectors (numerical, logical, character)
... use R as a calculator
... learn how to create and manipulate matrices

2.1 Vectors

Functions and operations are usually applied to whole "collections" instead of single numbers, including "vectors", "matrices", "data.frames" (`d.sport`)

- Numbers can be combined into "vectors" using the function `c()` ("combine"):

```
> v <- c(4,2,7,8,2)
> a <- c(3.1, 5, -0.7, 0.9, 1.7)
> u <- c(v,a)
> u
 [1]  4.0  2.0  7.0  8.0  2.0  3.1  5.0 -0.7  0.9  1.7
```


- Generate a sequence of consecutive integers:

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

Since such sequences are needed very often, a shorter form is `1:9`.

Equally spaced numbers: Use argument `by` (default: 1):

```
> seq(0, 3, by=0.5)
[1] 0.0 0.5 1.0 1.5 2.0 2.5 3.0
```

- Repetition:

```
> rep(0.7, 5)
[1] 0.7 0.7 0.7 0.7 0.7
> rep(c(1, 3, 5), length=8)
[1] 1 3 5 1 3 5 1 3
```


- Basic functions for vectors:

Call, Example	Description
`length(v)`	Length of a vector, number of elements
`sum(v)`	Sum of all elements
`mean(v)`	arithmetic mean
`var(v)`	empirical variance
`range(v)`	range

These functions have additional optional arguments. Check their help pages to find out more.

2.2 Arithmetic

Simple arithmetic is as expected:

- `> 2+5`

  `[1] 7`

  Operations: `+` `−` `*` `/` `^` (Exponentiation)

  See `?Arithmetic`. Further: logic (→ `?Logic`) and comparison (→ `?Comparison`) operators (see 2.4 below). A full list of available operators is also found in the manual[8]

- Priorities as usual. Use parentheses!

```
> (2:5) ^ 2
[1]  4  9 16 25
```

- These operations are applied to vectors elementwise.

```
> (2:5) ^ c(2,3,1,0)
[1]  4 27  4  1
```

[8] http://cran.r-project.org/doc/manuals/R-lang.html#Operators

- Elements are recycled if operations are carried out with vectors that do not have the same length:

```
> (1:6)*(1:2)
[1]  1  4  3  8  5 12
> (1:5) - (0:1) ## with a warning
[1] 1 1 3 3 5
Warning message:
    longer object length is not a multiple of
    shorter object length in: (1:5) - (0:1)
> (1:6)-(0:1)   ## no warning
[1] 1 1 3 3 5 5
```

Be careful, there is no warning in the last case!

2.3 Character Vectors

- Character strings: `"abc"` , `"nut 999"`
  Combine strings into vector of "mode" character:

```
> names <- c("Urs", "Anna", "Max", "Pia")
```

- Length (in characters) of strings:

```
> nchar(names)
[1] 3 4 3 3
```

- String manipulations:

```
> substring(names,3,4)
[1] "s"  "na" "x"  "a"
> paste(names, "Z.")
[1] "Urs Z."  "Anna Z." "Max Z."  "Pia Z."
> paste("X",1:3, sep="")
[1] "X1" "X2" "X3"
```


2.4 Logical Vectors

- Logical vectors contain elements `TRUE` , `FALSE` , or `NA`

```
> rep(c(TRUE, FALSE), length=6)
[1]  TRUE FALSE  TRUE FALSE  TRUE FALSE
```

- Often result from comparisons

`<   <=   >   >=   ==   !=`

```
> (1:5) >= 3
[1] FALSE FALSE  TRUE  TRUE  TRUE
```

- or logical operations: `&` (and), | (or), `!` (not):

```
> a
[1]  3.1  5.0 -0.7  0.9  1.7
> i <- (2 < a) & (a < 5)

> i
[1]  TRUE FALSE FALSE FALSE FALSE
```


2.5 Selecting elements

Select elements from vectors or data.frames: `[ ]` , `[,]`

```
> v
[1] 4 2 7 8 2
> v[c(1,3,5)]
[1] 4 7 2

> d.sport[c(1,3,5),1:3]
           weit kugel hoch
OBRIEN     7.57 15.66  207
DVORAK     7.60 15.82  198
HAMALAINEN 7.48 16.32  198
```

Drop elements, via *negative* indices:

```
>  d.sport[-(3:12), c("kugel","punkte")]
         kugel punkte
OBRIEN   15.66   8824
BUSEMANN 13.60   8706
SMITH    16.97   8271
MUELLER  14.69   8253
CHMARA   14.51   8249
```

For data.frames, use names of columns or rows:

```
> d.sport[c("OBRIEN","DVORAK"),          # 2 rows
+         c("kugel","speer","punkte")] # 3 columns
       kugel speer punkte
OBRIEN 15.66 66.90   8824
DVORAK 15.82 70.16   8664
```

Using logical vectors:

```
> a
[1]  3.1  5.0 -0.7  0.9  1.7
> a[c(TRUE,FALSE,TRUE,TRUE,FALSE)]
[1]  3.1 -0.7  0.9
```

Similarly use logical operations to select from a data.frame

```
> d.sport[d.sport[,"kugel"] > 16, c(2,7)]
           kugel punkte
HAMALAINEN 16.32   8613
PENALVER   16.91   8307
SMITH      16.97   8271
```


2.6 Matrices

Matrices are “data tables” like data.frames, but they can only contain data of a single type (numeric or character)

- Generate a matrix (1):

```
> m1 <- matrix(1:6, nrow=2, ncol=3); m1
     [,1] [,2] [,3]
[1,]    1    3    5
[2,]    2    4    6
> m2 <- matrix(1:6, ncol=2, byrow=TRUE); m2
     [,1] [,2]
[1,]    1    2
[2,]    3    4
[3,]    5    6
```

- Transpose: `t(m1)` equals `m2` .
- Selection of elements as with data.frames:

```
> m1[2, 2:3]
[1] 4 6
```


- Generate a matrix (2):

```
> rbind(m1, -(1:3)) ## add row
     [,1] [,2] [,3]
[1,]    1    3    5
[2,]    2    4    6
[3,]   -1   -2   -3
> cbind(m2, 100) ## add column
     [,1] [,2] [,3]
[1,]    1    2  100
[2,]    3    4  100
[3,]    5    6  100
```

- Vectors are typically treated as 1-column matrices and sometimes for convenience as 1-row matrices.
  `as.matrix(v)`, `cbind(v)`, `rbind(v)` explicitly convert a vector `v` to a matrix.

- Matrix multiplication:

```
> A <- m1 %*% m2; A
     [,1] [,2]
[1,]   35   44
[2,]   44   56
```

- Functions for linear algebra are available, e.g., $x = A^{-1}b$

```
> b <- 2:3
> x <- solve(A, b) ; x
[1] -0.83333  0.70833
> A %*% x # == b  -- as 1-col. matrix (!)
     [,1]
[1,]    2
[2,]    3
```

see `?solve`, `?crossprod`, `?qr`, `?eigen`, `?svd`,...[9].

[9] or for instance: `http://www.statmethods.net/advstats/matrix.html`

3. Simple Statistics

In this Chapter you will ...

... learn how to obtain information on R objects

... repeat simple functions for descriptive statistics

... learn about factor variables

... compare groups of data

... perform a simple hypothesis test

3.1 Useful summary functions for objects

To get an overview of a data set and a summary of its variables:

- Dimension of data set

```
> dim(d.sport)
[1] 15  7
> nrow(d.sport); ncol(d.sport)
[1] 15
[1] 7
```

- First/Last few lines of a data set

```
> head(d.sport,n=2) ## default is n=6
         weit kugel hoch  disc stab speer punkte
OBRIEN   7.57 15.66  207 48.78  500 66.90   8824
BUSEMANN 8.07 13.60  204 45.04  480 66.86   8706
> tail(d.sport,n=1) ## default is n=6
       weit kugel hoch disc stab speer punkte
CHMARA 7.75 14.51  210 42.6  490 54.84   8249
```


- Get the names of the variables of a data.frame

```
> names(d.sport)
[1] "weit"   "kugel"  "hoch"   "disc"   "stab"   "speer"
[7] "punkte"
```

- Show the structure of an R object

```
> str(d.sport)
'data.frame': 15 obs. of  7 variables:
 $ weit  : num  7.57 8.07 7.6 7.77 7.48 7.88 7.64 7.61 7.27 7
 $ kugel : num  15.7 13.6 15.8 15.3 16.3 ...
 $ hoch  : int  207 204 198 204 198 201 195 213 207 204 ...
 $ disc  : num  48.8 45 46.3 49.8 49.6 ...
 $ stab  : int  500 480 470 510 500 540 540 520 470 470 ...
 $ speer : num  66.9 66.9 70.2 65.7 57.7 ...
 $ punkte: int  8824 8706 8664 8644 8613 8543 8422 8318 8307 8
> str(d.sport[, "kugel"])
 num [1:15] 15.7 13.6 15.8 15.3 16.3 ...
> str(hist)
function (x, ...)
```


- Show a summary of the values of the variables in a data.frame (min, quartiles and max for numeric variables, counts for factors – see below)

```
> summary(d.sport)
      weit            kugel              hoch             disc
 Min.   :7.25   Min.   :13.5   Min.   :195   Min.   :42.6
 1st Qu.:7.47   1st Qu.:14.6   1st Qu.:196   1st Qu.:44.3
 Median :7.60   Median :15.3   Median :204   Median :45.9
 Mean   :7.60   Mean   :15.2   Mean   :202   Mean   :46.4
 3rd Qu.:7.76   3rd Qu.:15.7   3rd Qu.:206   3rd Qu.:48.9
 Max.   :8.07   Max.   :17.0   Max.   :213   Max.   :49.8
      stab          speer             punkte
 Min.   :470   Min.   :52.2   Min.   :8249
 1st Qu.:480   1st Qu.:57.4   1st Qu.:8278
 Median :500   Median :64.3   Median :8318
 Mean   :498   Mean   :62.0   Mean   :8445
 3rd Qu.:510   3rd Qu.:66.5   3rd Qu.:8628
 Max.   :540   Max.   :70.2   Max.   :8824
```

3.2 Simple Statistical Functions

- Estimation of a “location parameter”: `mean(x)` `median(x)`

```
> mean(d.sport[,"kugel"])
[1] 15.199
> median(d.sport[,"kugel"])
[1] 15.31
```

- Quantiles `quantile(x)`

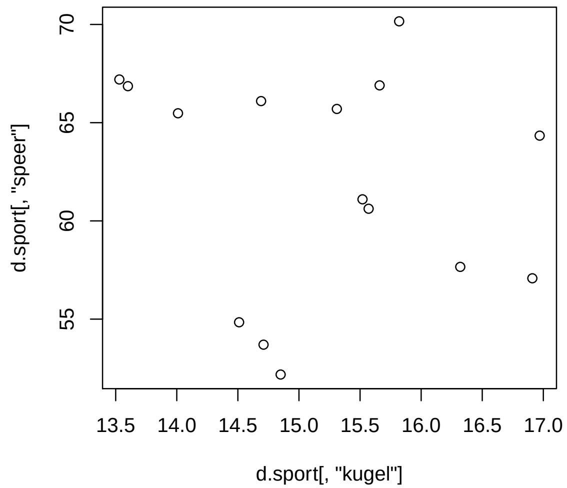
```
> quantile(d.sport[,"kugel"])
   0%   25%   50%   75%  100%
13.53 14.60 15.31 15.74 16.97
```

- Variance: `var(x)`

```
> var(d.sport[,"kugel"])
[1] 1.1445
```


- Correlation: `cor(x,y)` **– Look at a plot before!**

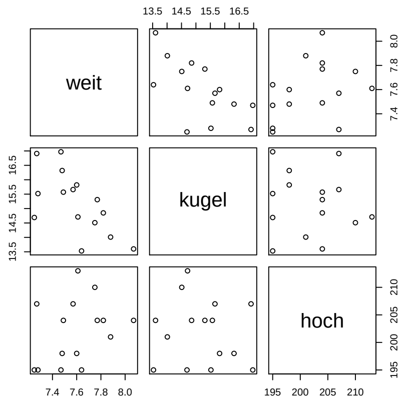
```
> plot(d.sport[,"kugel"], d.sport[,"speer"])
```




```
> cor(d.sport[,"kugel"], d.sport[,"speer"])
[1] -0.14645
```


- Correlation matrix:

```
> pairs(d.sport[,1:3])
```




```
> cor(d.sport[,1:3])
          weit     kugel      hoch
weit   1.00000 -0.630171  0.337752
kugel -0.63017  1.000000 -0.092819
hoch   0.33775 -0.092819  1.000000
```


3.3 Factors

Groups, or categorial variables are represented by factors, e.g. ID of a measurement station, type of species, type of treatment, etc.

In statistical analyses categorical variables MUST be coded as factors to produce correct results (e.g. in analysis of variance or for regression).

⟶ ALWAYS check your data (by `str()`) before starting an analysis.

To produce a factor variable:

- use `c()`, `rep()`, `seq()` to define a numeric or character vector
- and then the function `as.factor()`.

An example: Suppose the athletes listed in `d.sport` belong to 3 teams:

```
> teamnum <- rep(1:3,each=5)
```

```
> d.sport[,"team"] <- as.factor(teamnum)
> str(d.sport)
'data.frame': 15 obs. of  8 variables:
 $ weit  : num  7.57 8.07 7.6 7.77 7.48 7.88 7.64 7.61 7.27 7.49
 $ kugel : num  15.7 13.6 15.8 15.3 16.3 ...
 $ hoch  : int  207 204 198 204 198 201 195 213 207 204 ...
 $ disc  : num  48.8 45 46.3 49.8 49.6 ...
 $ stab  : int  500 480 470 510 500 540 540 520 470 470 ...
 $ speer : num  66.9 66.9 70.2 65.7 57.7 ...
 $ punkte: int  8824 8706 8664 8644 8613 8543 8422 8318 8307 8300
 $ team  : Factor w/ 3 levels "1","2","3": 1 1 1 1 1 2 2 2 2 2 ..
```

```
> levels(d.sport[,"team"])
[1] "1" "2" "3"
```

```
> levels(d.sport[,"team"]) <-
+     c("Zurich","New York","Tokyo")
```



```
> head(d.sport,n=10)
           weit kugel hoch  disc stab speer punkte     team
OBRIEN     7.57 15.66  207 48.78  500 66.90   8824   Zurich
BUSEMANN   8.07 13.60  204 45.04  480 66.86   8706   Zurich
DVORAK     7.60 15.82  198 46.28  470 70.16   8664   Zurich
FRITZ      7.77 15.31  204 49.84  510 65.70   8644   Zurich
HAMALAINEN 7.48 16.32  198 49.62  500 57.66   8613   Zurich
NOOL       7.88 14.01  201 42.98  540 65.48   8543 New York
ZMELIK     7.64 13.53  195 43.44  540 67.20   8422 New York
GANIYEV    7.61 14.71  213 44.86  520 53.70   8318 New York
PENALVER   7.27 16.91  207 48.92  470 57.08   8307 New York
HUFFINS    7.49 15.57  204 48.72  470 60.62   8300 New York
```

```
> nlevels(d.sport[,"team"])
[1] 3
```


3.4 Simple Statistical Functions (cont'd)

```
> summary(d.sport)
      weit           kugel              hoch             disc
 Min.   :7.25   Min.   :13.5   Min.   :195   Min.   :42.6
 1st Qu.:7.47   1st Qu.:14.6   1st Qu.:196   1st Qu.:44.3
 Median :7.60   Median :15.3   Median :204   Median :45.9
 Mean   :7.60   Mean   :15.2   Mean   :202   Mean   :46.4
 3rd Qu.:7.76   3rd Qu.:15.7   3rd Qu.:206   3rd Qu.:48.9
 Max.   :8.07   Max.   :17.0   Max.   :213   Max.   :49.8
      stab          speer            punkte            team
 Min.   :470   Min.   :52.2   Min.   :8249   Zurich  :5
 1st Qu.:480   1st Qu.:57.4   1st Qu.:8278   New York:5
 Median :500   Median :64.3   Median :8318   Tokyo   :5
 Mean   :498   Mean   :62.0   Mean   :8445
 3rd Qu.:510   3rd Qu.:66.5   3rd Qu.:8628
 Max.   :540   Max.   :70.2   Max.   :8824
```


- Count number of cases with same value:

```
> table(d.sport[,"team"])
  Zurich New York    Tokyo
       5        5        5
```

- Cross-table

```
> table(d.sport[,"kugel"],d.sport[,"team"])
        Zurich New York Tokyo
  13.53      0        1     0
  13.6       1        0     0
  14.01      0        1     0
  14.51      0        0     1
  14.69      0        0     1
  ...
```

$\longrightarrow$ The table function is not useful for numerical variables. Use `cut()` (see next slide).

- Subdivide a numerical variable into intervals, e.g. for cross-tables or plots: `cut()`

```
> table( cut( d.sport[,"kugel"], breaks=4 ),
+     d.sport[,"team"] )
               Zurich New York Tokyo
  (13.5,14.4]       1        2     0
  (14.4,15.2]       0        1     3
  (15.2,16.1]       3        1     1
  (16.1,17]         1        1     1
```


3.5 Comparison of Groups

Often in statistics, we want to compare measurements for different groups.

`d.sport` now contains data for 3 different teams with 5 people each.

Let's store the kugel results for each group separately:

```
> y1 <- d.sport[d.sport[,"team"]=="Zurich","kugel"]; y1
[1] 15.66 13.60 15.82 15.31 16.32

> y2 <- d.sport[d.sport[,"team"]=="New York","kugel"]
> y3 <- d.sport[d.sport[,"team"]=="Tokyo","kugel"]
```

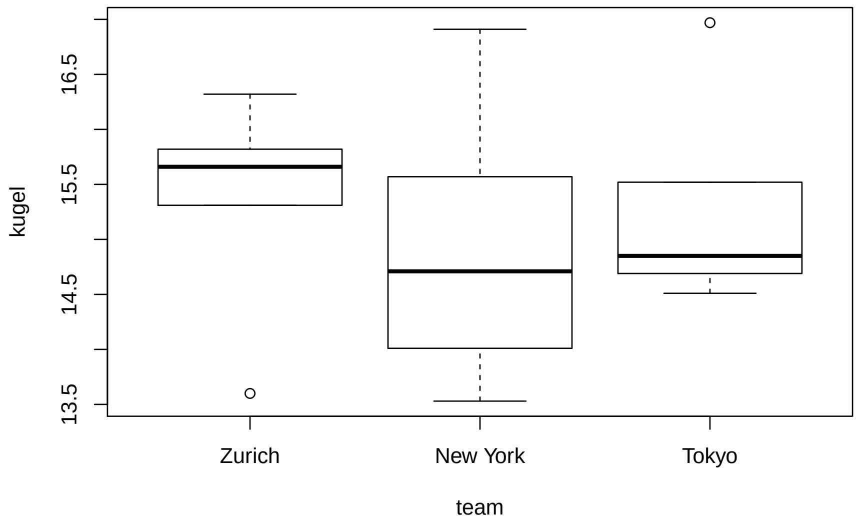
Comparison of the different groups:

- look at a cross-table (see above)
- plot the distribution of the results in each group (better!)
- use a statistical test to compare groups

$\longrightarrow$ Build hypotheses based on plots and prior knowledge!

Boxplot for several groups

```
> boxplot(y1,y2,y3, ylab="kugel", xlab="team",
+     names=levels(d.sport[,"team"]))
```



3.6 Hypothesis Tests

Do two groups differ in their "location"? (t-test in Exercises)
No assumption about distribution of data:
$\longrightarrow$ Wilcoxon's Rank Sum Test

```
> wilcox.test(y1,y3,paired=FALSE)
Wilcoxon rank sum test

data:  y1 and y3
W = 15, p-value = 0.6905
alternative hypothesis: true location shift is not equal to 0
> wilcox.test(y1,y2,paired=FALSE)
Wilcoxon rank sum test

data:  y1 and y2
W = 16, p-value = 0.5476
alternative hypothesis: true location shift is not equal to 0
```

4. Missing Values

In this Chapter you will ...

... see how missing values are specified

... learn how functions deal with missing values

... find out how to properly read in data with missing values

4.1 Identifying Missing Values

In practice, some data values may be missing.

- Here, we fake this situation

```
> kugel <- d.sport[,"kugel"]
> kugel[2] <- NA
> kugel
 [1] 15.66    NA 15.82 15.31 16.32 14.01 13.53 14.71 16.91
[10] 15.57 14.85 15.52 16.97 14.69 14.51
```

`NA` means ‘**N**ot **A**vailable’ and typically indicates missing data.

—

- Which elements of `kugel` are missing?

```
> kugel == NA
 [1] NA NA NA NA NA NA NA NA NA NA NA NA NA NA NA
```

This is not what we expected, we have to use `is.na()` instead

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


4.2 Missing Values and Function Calls

- Applying functions to vectors with missing values:

```
> mean(kugel)
[1] NA
> mean(kugel, na.rm=TRUE)
[1] 15.313
```

- Other simple functions also have the `na.rm` argument
- For more sophisticated functions (e.g. `wilcox.test`), the argument `na.action` defines how missing values are handled. `na.action=na.omit`: omit cases with NAs
- Plotting functions normally work with NAs.

- Manually dropping the NA elements:

```
> kugel[!is.na(kugel)]
 [1] 15.66 15.82 15.31 16.32 14.01 13.53 14.71 16.91 15.57
[10] 14.85 15.52 16.97 14.69 14.51
```

- more general method

```
> na.omit(kugel)
```

`na.omit(df)` drops rows of a data.frame `df` that contain missing value(s).

4.3 Reading data sets with coded missing values

- How to specify missings when reading in data:
  ```
  > d.dat <- read.table(..., na.strings=c(".","-999"))
  ```
  Default: empty fields are taken as NA for numerical variables.
- ... or clean your data later:
  ```
  > d.dat[d.dat[, "x"]==-999, "x"] <- NA
  ```


5. Write your own Function

In this chapter you will ...

... learn how to write your own functions

... and use them in other functions

... see a simple function example

Syntax:

```
fnname <- function( arg(s) ) { statements }
```

A simple function: Get the maximal value of a vector and its index.

```
> f.maxi <- function(data) {
+   mx <- max(data, na.rm=TRUE) # get max element
+   i <- match(mx, data)        # position of max in data
+   c(max=mx, pos=i)            # result of function
+ }
```

Output of f.maxi is a named vector. The use of `return()` is optional.

```
> f.maxi(c(3,4,78,2))
max pos
 78   3
```

(Note: R provides the function `which.max`)

This function can now be used in `apply`:

```
> apply(d.sport, 2, f.maxi)
    weit kugel hoch  disc stab speer punkte
max 8.07 16.97  213 49.84  540 70.16   8824
pos 2.00 13.00    8  4.00    6  3.00      1
```

Note: Use functions when you can. They make your code more legible and simplify the analysis.

You can include the functions at the end of your main programme, or collect all your functions in one R-script (e.g. `myfunctions.R`) and make the functions available by

```
> source("myfunctions.R")
```

More about best-practices in programming will follow in the last block of this lecture course.

R is open-source: Look at, and learn from, the existing functions!

6. Scatter- and Boxplots

In this lecture you will ...

... get a flavour of graphics systems available in R

... learn how to create scatter- and boxplots

... learn how to use formulae in plots

... learn how to add axis labels and titles to plots

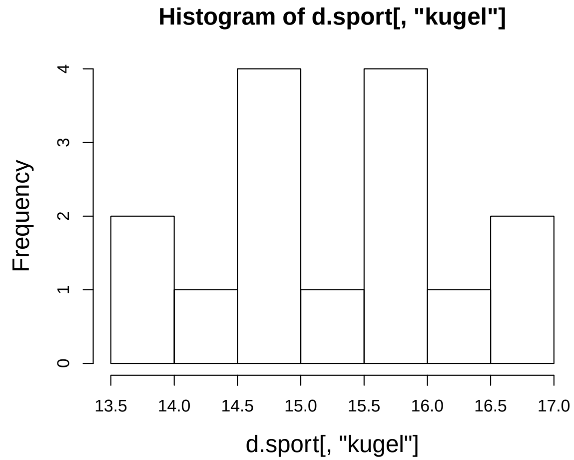
... learn to select color, type and size of symbols

... learn how to control the scales of axes

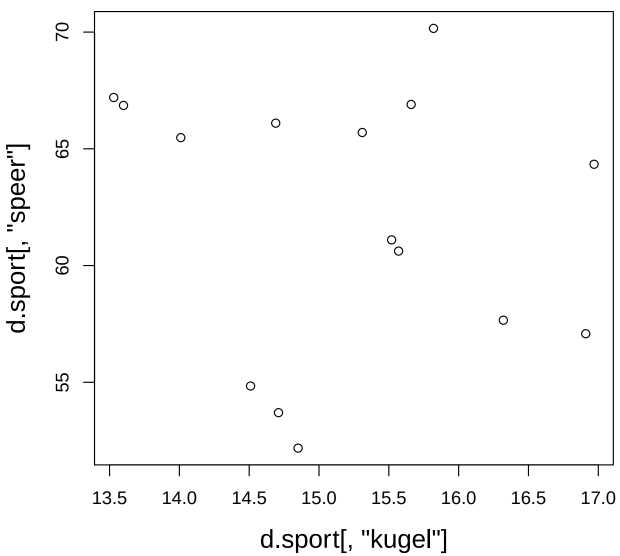
6.1 Overview

Several R graphics functions have been presented so far:

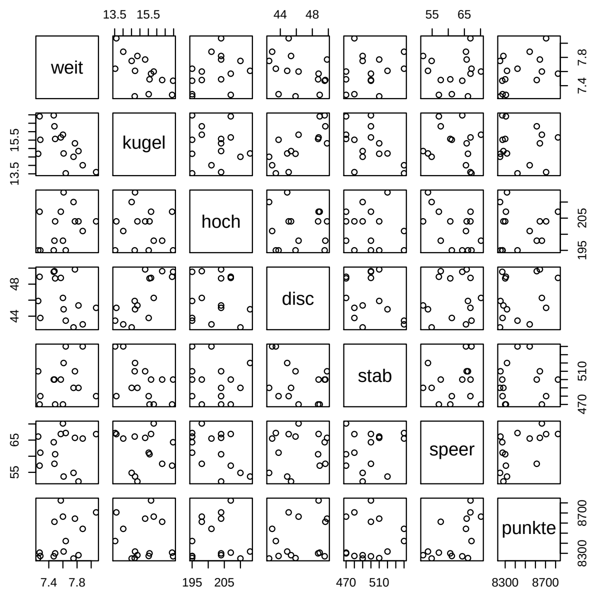
```
> hist(d.sport[,"kugel"])
```



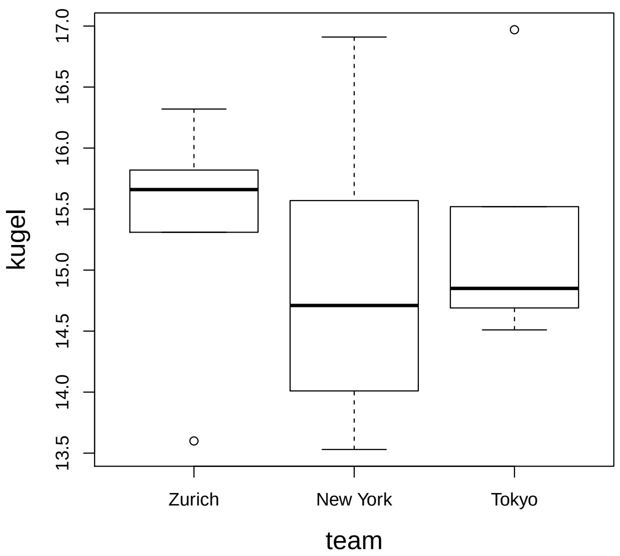

```
> plot(d.sport[,"kugel"], d.sport[,"speer"])
```




```
> pairs(d.sport)
```



```
> boxplot(y1,y2,y3,ylab="kugel",xlab="team")
```



Many more “standard” graphics functions to come:

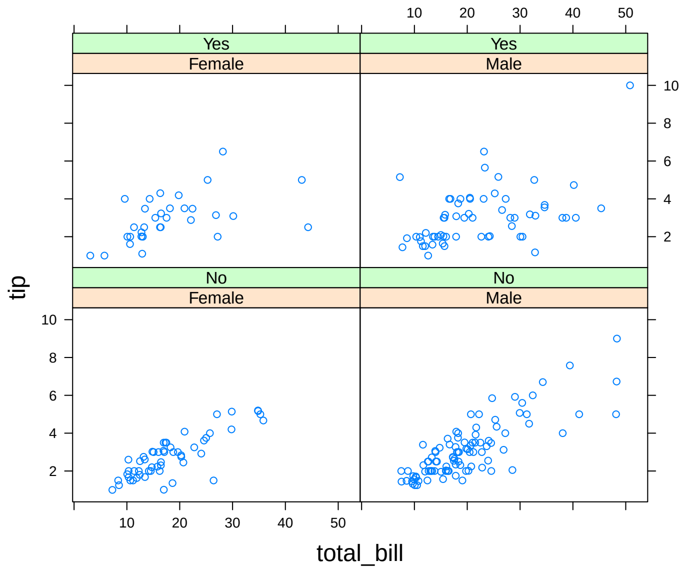
```
scatter.smooth , matplot , image ,...
lines , points , text ,...
par , identify , pdf , jpeg ,...
```

Alternatives to “standard” graphics functions

- ⇒ functions of package lattice
- ⇒ functions of package ggplot2

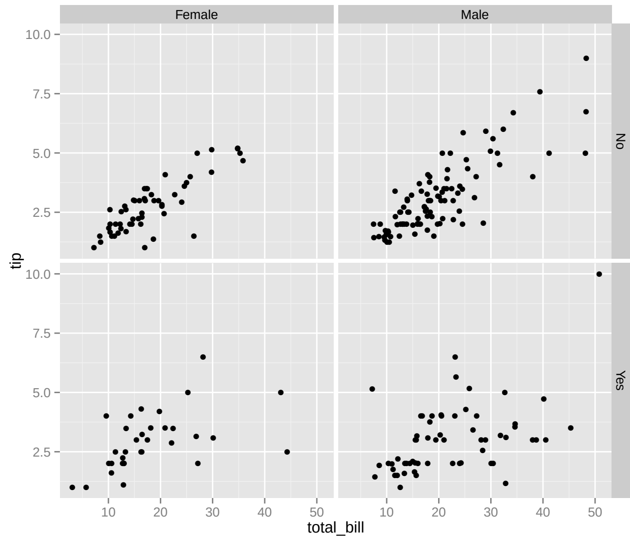
An example using function `xyplot` of package lattice

```
> data(tips, package="reshape"); library(lattice)
> xyplot(tip~total_bill|sex+smoker, data=tips)
```



Same plot using function `qplot` of package ggplot2

```
> library(ggplot2)
> qplot(x=total_bill, y=tip, data=tips,
+        facets=smoker~sex)
```



Five kinds of standard R graphics functions:

- High-level plotting functions such as `plot`
  ⇒ *to generate a new graphical display of data.*
- Low-level plotting functions such as `lines`
  ⇒ *to add further graphical elements to an existing graph.*
- "Interactive" functions such as `identify`
  ⇒ *to amend or collect information interactively from a graph.*
- "Device" control functions such as `pdf`
  ⇒ *to manipulate windows and files that display or store graphs.*
- "Control" functions such as `par`
  ⇒ *to control the appearance of graphs.*

6.2 Scatterplot

Display of the values of two variables plotted against each other.

Syntax:

`plot(x, y, main=`c_1`, xlab=`c_2`, ylab=`c_3`, ...)`

x,y: two numeric vectors (must have same length)

c_1, c_2, c_2: any character strings (must be quoted)

For the meaning of `...` : ⇒ cf. `?plot`

Example: Exploring Meuse data on heavy metals in soil

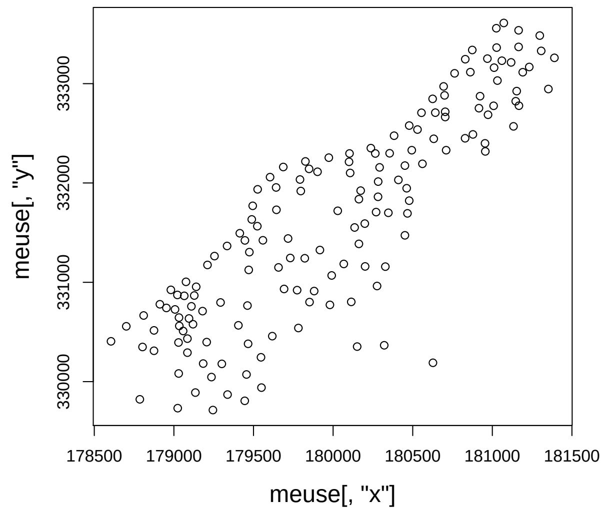
```
> library(sp); data(meuse)
> str(meuse)
```



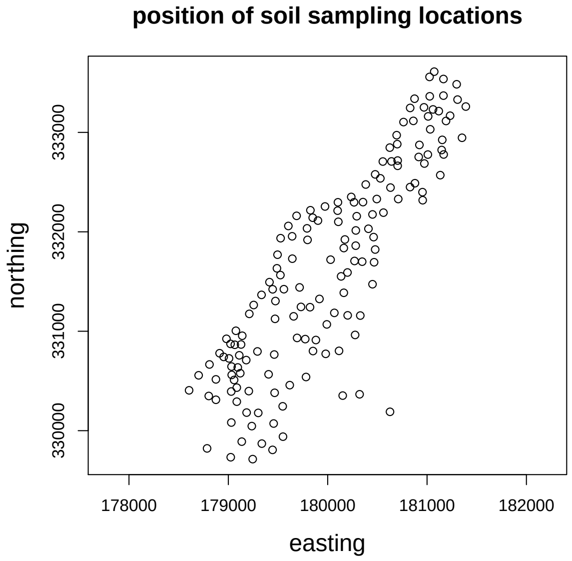
```
'data.frame': 155 obs. of  14 variables:
 $ x      : num  181072 181025 181165 181298 181307 ...
 $ y      : num  333611 333558 333537 333484 333330 ...
 $ cadmium: num  11.7 8.6 6.5 2.6 2.8 3 3.2 2.8 2.4 1.6 ...
 $ copper : num  85 81 68 81 48 61 31 29 37 24 ...
 $ lead   : num  299 277 199 116 117 137 132 150 133 80 ...
 $ zinc   : num  1022 1141 640 257 269 ...
 $ elev   : num  7.91 6.98 7.8 7.66 7.48 ...
 $ dist   : num  0.00136 0.01222 0.10303 0.19009 0.27709 ...
 $ om     : num  13.6 14 13 8 8.7 7.8 9.2 9.5 10.6 6.3 ...
 $ ffreq  : Factor w/ 3 levels "1","2","3": 1 1 1 1 1 1 1 1 1 1 .
 $ soil   : Factor w/ 3 levels "1","2","3": 1 1 1 2 2 2 2 1 1 2 .
 $ lime   : Factor w/ 2 levels "0","1": 2 2 2 1 1 1 1 1 1 1 ...
 $ landuse: Factor w/ 15 levels "Aa","Ab","Ag",..: 4 4 4 11 4 11 4
 $ dist.m : num  50 30 150 270 380 470 240 120 240 420 ...
```



```
> plot(x=meuse[,"x"], y=meuse[,"y"])
```



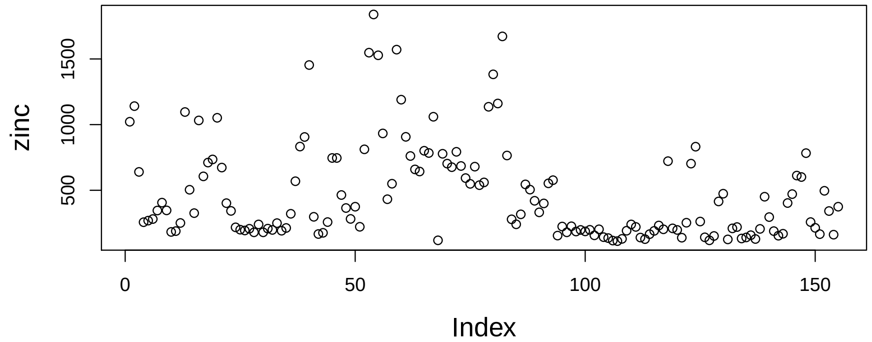
```
> plot(x=meuse[,"x"], y=meuse[,"y"], asp=1,
+       xlab="easting", ylab="northing",
+       main="position of soil sampling locations")
```



Three additional variants ways to invoke `plot` :

- Plot of the values of a single vector against the indices of the vector elements

```
> plot(meuse[,"zinc"], ylab="zinc")
```

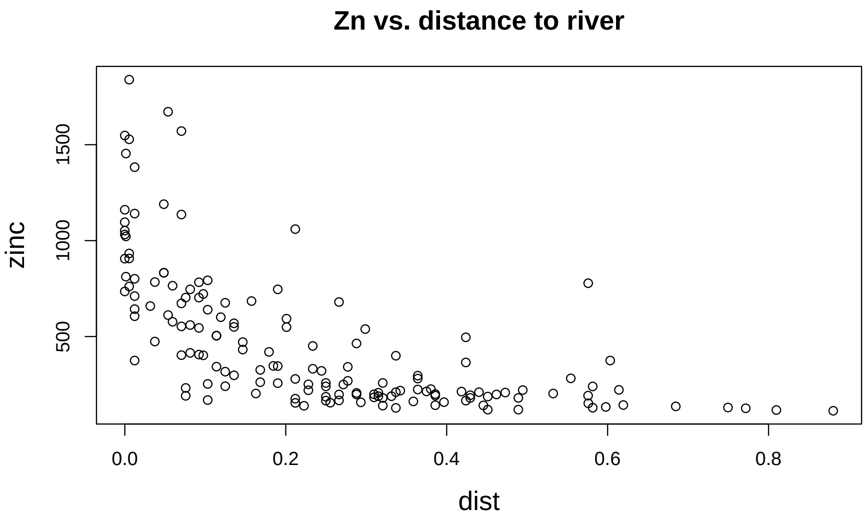


- Scatterplot of two columns of a matrix or a dataframe

```
> plot(meuse[,c("x","y")], asp=1)
```


- Use of a formula to specify the *x*- and *y*-variable out of a data frame (cf. `?plot.formula`)

```
> plot(zinc~dist, data=meuse,
+       main="Zn vs. distance to river")
```



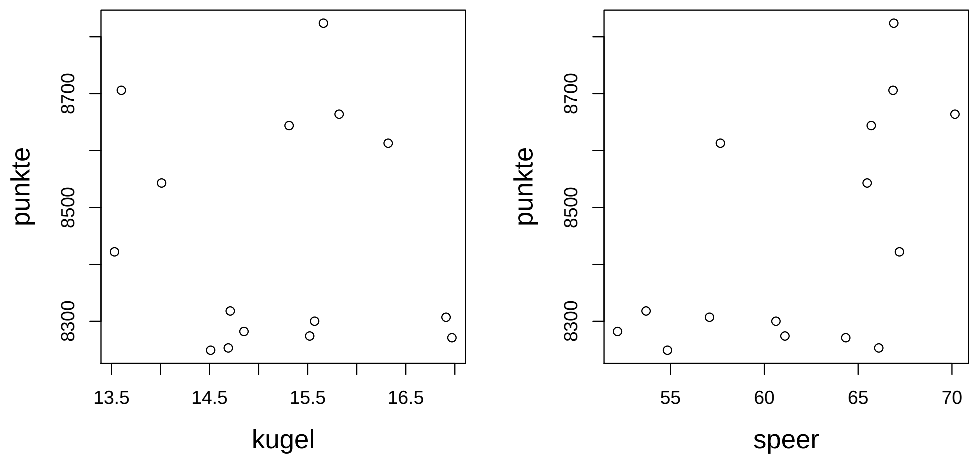
6.3 Digression: Statistical Models, Formula Objects

Statistics is concerned with relations between "variables".
Prototype: Relationship between target variable `Y`
and explanatory variables `X1, X2, ...` ⇒ Regression.

- Symbolic notation of such a relation: `Y ~ X1 + X2`
  This symbolic notation is an S object (of class `formula`)
  (The notation is also used in other statistical packages.)
- Further example for use of a formula:

  ```
  > plot(punkte~kugel+speer, data=d.sport)
  ```

  gives 2 scatterplots, `punkte` (vertical) against `kugel` and `speer` , respectively (horizontal axis).



6.4 Arguments common to many graphics functions

- `main="..." , xlab="..." , ylab="..."`

  `"..."` : any character string (must be quoted!)

  ⇒ to set title and labels of axes (cf. `?title`)

- `log="x" , log="y" , log="xy"`

  ⇒ for logarithmic scaling of axes (cf. `?plot.default`)

- `xlim=c(`$x_{\min}$`,`$x_{\max}$`) , ylim=c(`$y_{\min}$`,`$y_{\max}$`) ,`

  $x_{\min}$, $x_{\max}$, $y_{\min}$, $y_{\max}$: numeric scalars

  ⇒ to set range of values displayed (cf. `?plot.default`)

- `asp=`*n*

  n : numeric scalar

  ⇒ to set aspect ratio of axes (cf. `?plot.window`

Common arguments of `plot` (continued):

- `type=`*c*

  c: a single character such as `"p"` for points, `"l"` for lines, `"b"` for points **and** lines, ”n” for an “empty” plot, etc.

  ⇒ for selecting type of plot (cf. `?plot`)

- `pch=`*i* or `pch=`*c*

  i : an integer; *c*: a single character such as `"a"`

  ⇒ for choosing symbols (cf. `?points`)

- `cex=`*n*

  ⇒ for choosing size of symbols (cf. `?plot.default`)

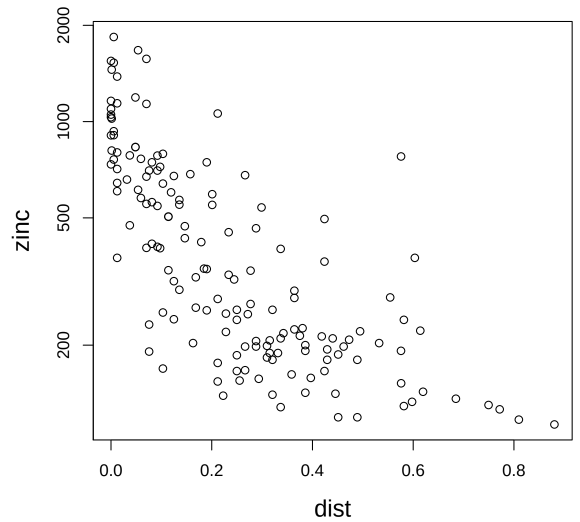
- `col=`*i* or `col=`*color*

  color: keyword such as `"red"` , `"blue"` , etc

  ⇒ for choosing color of symbols (cf. `?plot.default` and `colors()`)

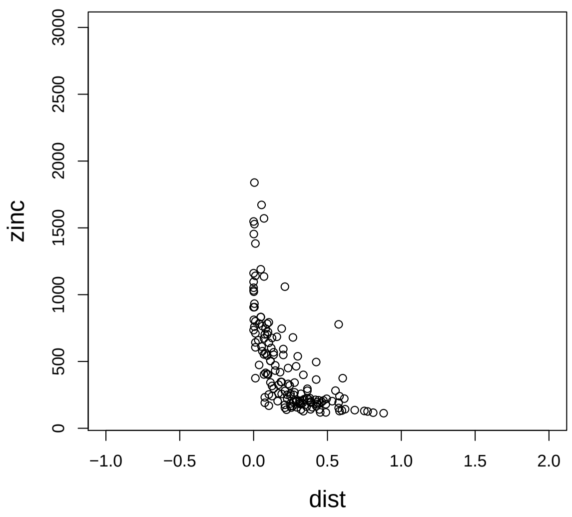
Example: logarithmic axes scale

```
> plot(zinc~dist, data=meuse, log="y")
```



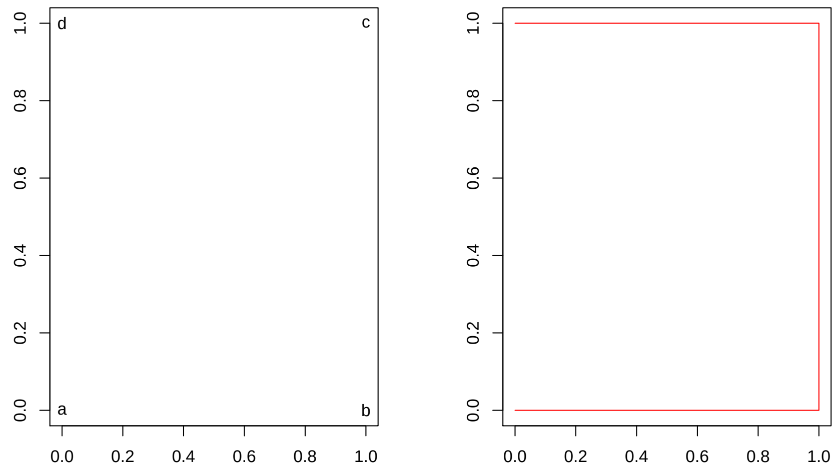
Example: setting the range of axes

```
> plot(zinc~dist, data=meuse,
+       xlim=c(-1,2), ylim=c(100,3000))
```



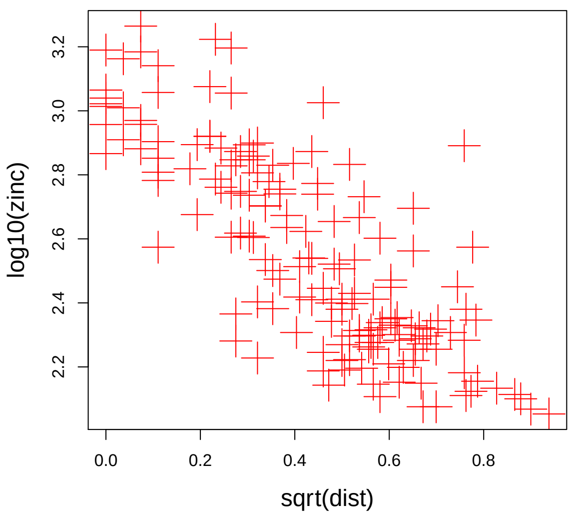
Example: connecting points by lines (cf. `?plot`)

```
> x <- c(0,1,1,0); y <- c(0,0,1,1)
> plot(x=x,y=y,type="p",xlab="",ylab="",pch=letters[1:4])
> plot(x=x,y=y,type="l",xlab="",ylab="",col="red")
```



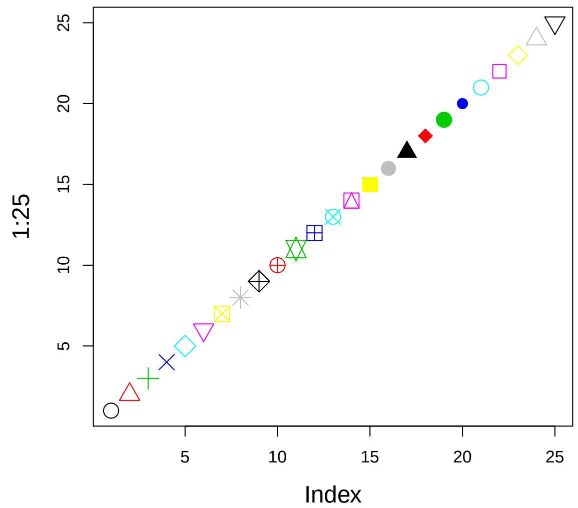
Example: choosing symbol type, color and size (cf. `?points`)

```
> plot(log10(zinc)~sqrt(dist), data=meuse,
+       pch=3, col="red", cex=3)
```



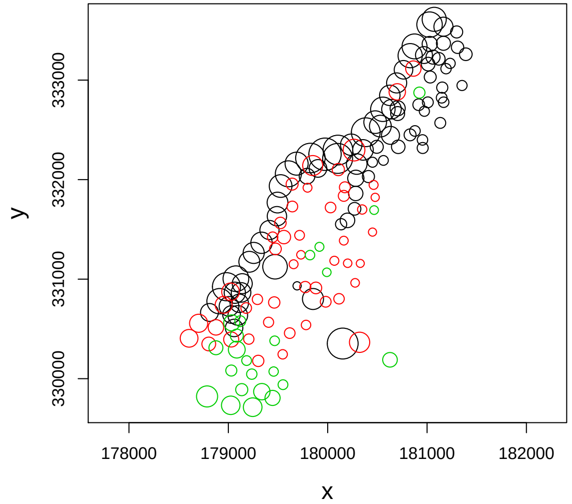
Example: choosing symbol type, color and size

```
> plot(1:25, pch=1:25, cex=2, col=1:8)
```



Example: choosing symbol type, color and size

```
> plot(y~x, data=meuse, asp=1, ## [asp]ect ratio := 1
+      col=as.numeric(ffreq),
+      cex=sqrt(zinc)/10)
```



6.5 Boxplot

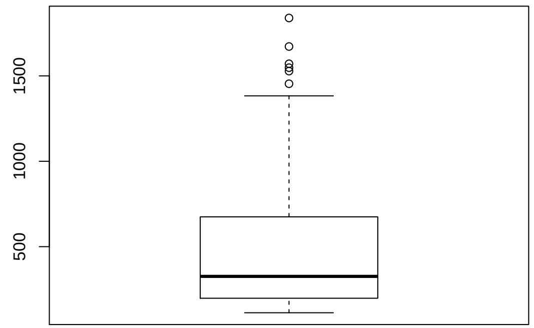
Syntax:

boxplot(x_1, x_2, ..., notch=l_1, horizontal=l_2, ...)

- x_1, x_2, ...: numeric vectors
- l_1 (logical): controls whether "notches" are added to roughly test whether group medians are significantly different
- l_2 (logical): controls whether horizontal boxplots are generated
- ... : many more arguments (cf. `?boxplot`)

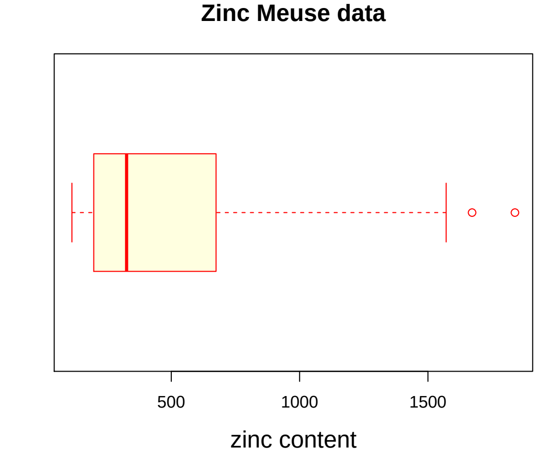
Example: a single boxplot

```
> boxplot(meuse[,"zinc"])
```



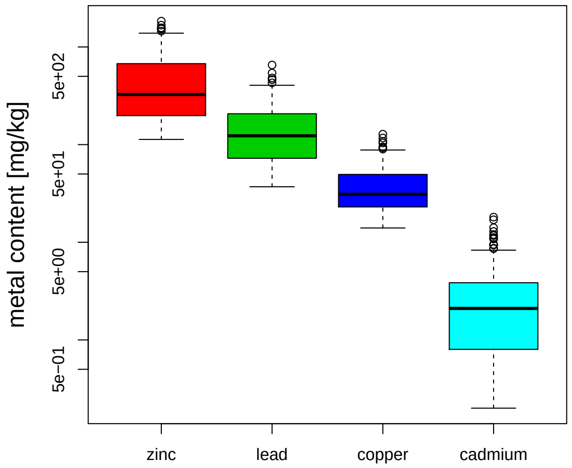
Example: a single boxplot with some decoration

```
> boxplot(x=meuse[,"zinc"], horizontal=TRUE, range=2,
+         col="lightyellow", border="red",
+         xlab="zinc content", main="Zinc Meuse data")
```



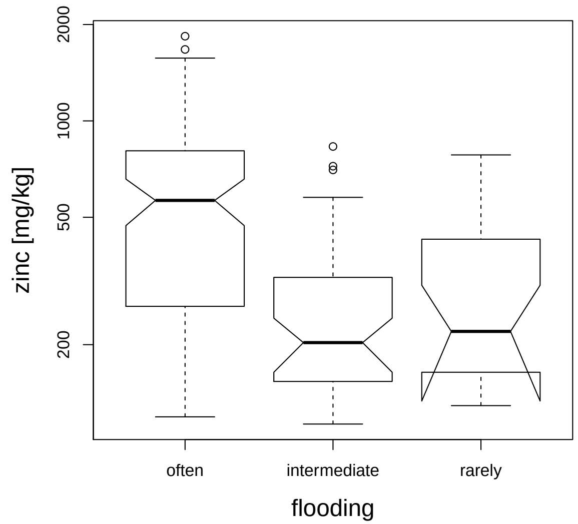
Example: variant to generate boxplots of several variables

```
> boxplot(meuse[,c("zinc","lead","copper","cadmium")],
+       log="y", ylab="metal content [mg/kg]", col = 2:5)
```



Example: boxplot of one variable for several groups of a factor

```
> boxplot(zinc~ffreq, data=meuse, log="y", notch=TRUE,
+         names= c("often", "intermediate", "rarely"),
+         xlab= "flooding", ylab= "zinc [mg/kg]")
```



In this lecture you have ...

... got a flavour of graphics systems available in R
⇒ **"standard" graphics**, **`lattice`**, **`ggplot2`**

... learnt how to create scatterplots and boxplots
⇒ functions **`plot`**, **`boxplot`**

... learnt how to use formulae for generating plots

... learnt how to connect points in a scatterplot by lines
⇒ argument **`type`**

... learnt how to add axis labels and titles to plots
⇒ arguments **`main`**, **`xlab`**, **`ylab`**

... learnt to select color, type and size of symbols
⇒ arguments **`col`**, **`pch`**, **`cex`**

... learnt how to control the scales of axes
⇒ arguments **`asp`**, **`log`**, **`xlim`**, **`ylim`**

7. Controlling the visual aspects of a graphic

In this lecture you will learn ...

... how to add points and lines to an existing plot,

... how to amend a plot by additional text and a legend,

... about the `par` function for fine-tuning your graphics,

... how to arrange several plots in one graphic,

... how to manage colors,

and in this week's exercise series you will explore additional high-level plotting functions

7.1 Adding further points and lines to a graphic

Use `points` to add further points to a graph created before by a high-level plotting function such as `plot` .

Syntax:

`points(x=`*x*`, y=`*y*`, pch=`i_1`, col=`i_2 or `col=`*color*`, cex=`*n*`)`

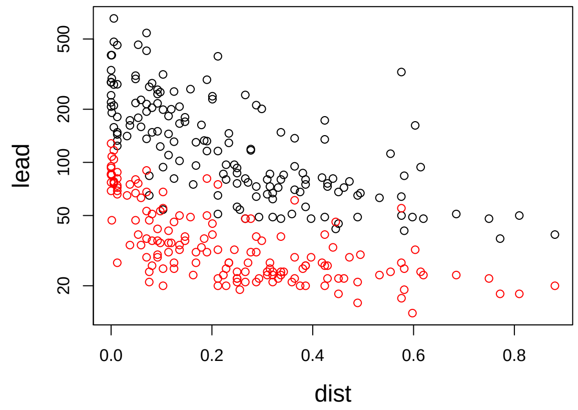
- *x*, *y*: two numeric vectors
- i_1, i_2: integers (scalars or vectors)
- *color*: color name (scalar or vector)
- *n*: numeric (scalar or vector)

Remarks:

- ± same arguments as for `plot`
- `points` can also be used with `formula` and `data` arguments (cf. `?points.formula`)

Example: adding Cu data to a plot of `lead~dist` for Meuse data

```
> plot(lead~dist, data=meuse, log="y",
+      ylim=range(c(copper,lead)))
> points(copper~dist, data=meuse, col="red")
```



Use `lines` to add lines that connect successive points to an existing plot.

Syntax:

`lines(x=`*x*`, y=`*y*`, lty=`*i* or `lty=`*line_type*`, lwd=`*n*`, ...)`

- *x*, *y*: two numeric vectors
- *i*: integer (scalar) to select line type (cf. `?par`)
- *line_type*: keyword such as `"dotted"` to select line type (cf. `?par`)
- *n*: numeric scalar to select line width
- ...: further arguments such as `col` to select line color

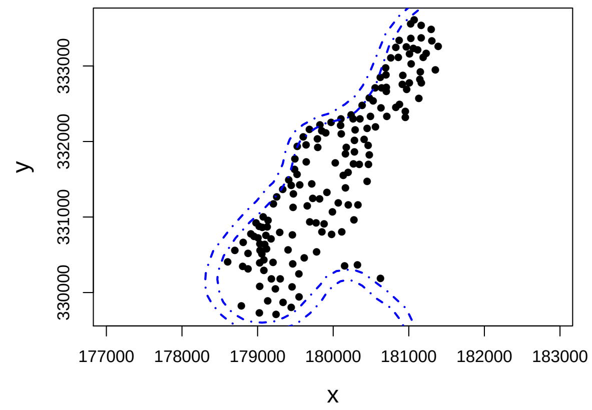
Remarks:

- ± same arguments as for `plot` and `points`
- `lines` can also be used with `formula` and `data` arguments (cf. `?lines.formula`)

Example: adding outline of river Meuse to plot of sampling locations

```
> data(meuse.riv)
> str(meuse.riv)
 num [1:176, 1:2] 182004 182137 182252 182314 182332 ...

> plot(y~x, data=meuse, asp=1, pch=16)
> lines(meuse.riv, lty="dotdash", lwd=2, col="blue")
```



Use abline to add straight lines to an existing plot.

Syntax:

```
abline(v=x, ...)
abline(h=y, ...)
abline(a=n1, b=n1, ...)
```

x: coordinate(s) where to draw vertical straight line(s) (scalar or vector)

y: coordinate(s) where to draw horizontal straight line(s) (scalar or vector)

n_1, n_2: numeric scalars for intercept and slope of straight line

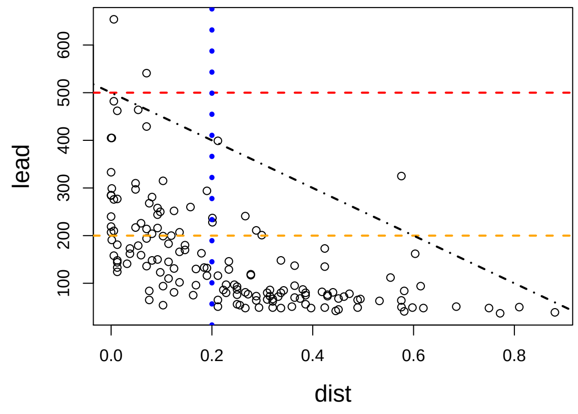
...: further arguments such as col , lty , lwd

Remarks:

- the straight lines extend over the entire plot window

Example: adding straight lines to a plot

```
> plot(lead~dist, data=meuse)
> abline(h=c(200, 500), col=c("orange", "red"),
+        lty="dashed", lwd=2)
> abline(v=0.2, col=4, lty=3, lwd=5)
> abline(a=500, b=-500, lty="dotdash", lwd=2,
+        col="black")
```



Further useful low-level plotting functions

- segments adds arbitrary line segments to an existing plot, cf. ?segments
- arrows adds arrows to a plot (± same syntax as segments , cf. ?arrows)
- polygon adds a polygon to an existing plot, cf. ?polygon

7.2 Amending plots by additional text and legends

Points in a scatterplot are labelled by text .

Syntax:

```
text(x=x, y=y, labels=c , pos=i, ...)
```

x, y: two numeric vectors

c: vector of character strings with the text to label the points

i: integer to control whether labels are plotted below (1), to the left (2), above (3) or to the right (4) of the points (scalar or vector)

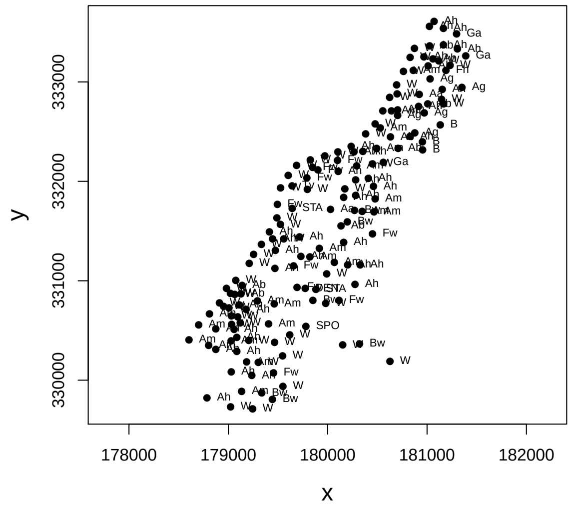
...: further arguments such as col and cex

Remarks:

- x and y may specify arbitrary coordinates within the plot window
- one can also use formula (along with a data argument) in text

Example: labelling sample points of Meuse data by landuse info

```
> plot(y~x, data=meuse, asp=1, pch=16)
> text(meuse[,c("x","y")], labels=meuse[,"landuse"],
+       pos=4, cex=0.7)
```



More sophisticated text annotation is added by `legend` to a plot.

Syntax:

`legend(x=x, y=y, legend=c, pch=i1, lty=i2 ,...)`

x, y: coordinates where the legend should be plotted

c: vector of character strings with labels of categories

i_1, i_2: vector of integers with type of plotting symbol **or** line type for categories

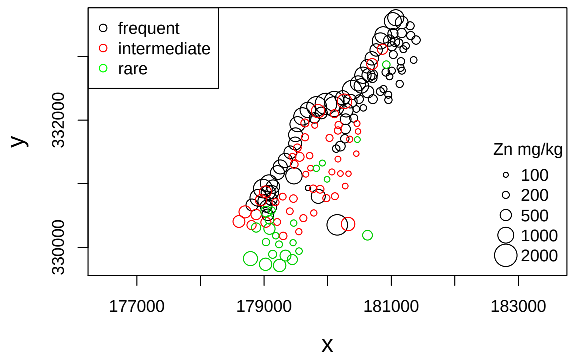
`...`: further arguments such as `col` and `cex`

Remarks:

- The position of the legend is either specified by x and y **or** by a keyword such as `"topright"`, `"bottomleft"`, etc. (cf. `legend` for allowed keywords).

Example: legends annotating flooding frequency and zinc concentration for Meuse data

```
> plot(y~x, data=meuse, asp=1, col=ffreq,
+     cex=sqrt(zinc)/15)
> legend("topleft", pch=1, col=c("black","red","green"),
+     legend=c("frequent","intermediate","rare"))
> legend("bottomright", pch=1,  title="Zn mg/kg",
+     legend=zn.label <- c(100,200,500,1000,2000),
+     pt.cex=sqrt(zn.label)/15, bty="n")
```



7.3 Controlling the visual aspects of a graphic

- So far we have used the arguments `pch`, `col`, `cex`, `lty` and `lwd` to tailor the visual appearance of graphics when calling high- and low-level plotting functions.
- There are many more arguments to control the visual aspects of graphics: `adj`, `ann`, ..., `yaxt`, cf. help page of `par`.
- Default values of these arguments are queried for the active graphics device by

```
> par()
$adj
[1] 0.5

$ann
[1] TRUE

...

$ylbias
[1] 0.2
```

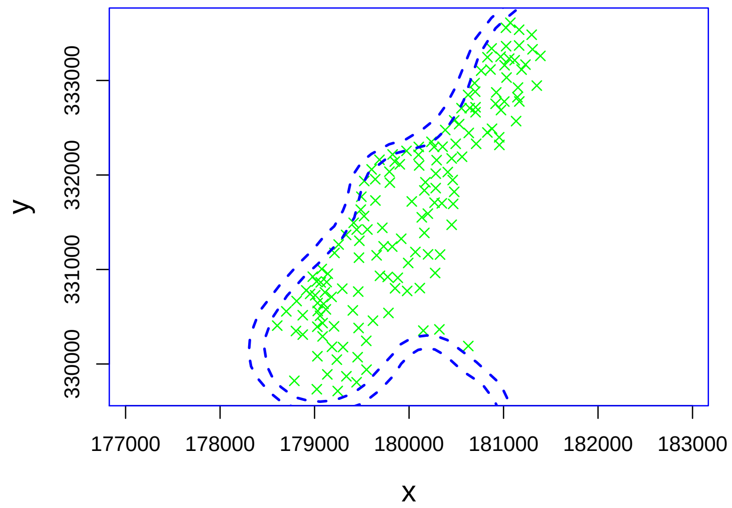
- Most of the arguments of `par` are effective in high-level plotting function calls.
- Many work also for low-level plotting functions.
- New default values of nearly all arguments are set for the active device by `par`:

```
> par("pch")
[1] 1
> par("lty")
[1] "solid"
```

```
> par(pch=4, lty="dashed", col="red")
> par("pch")
[1] 4
> par("lty")
[1] "dashed"
> par("col")
[1] "red"
```


and they remain effective as long as they are not changed

```
> plot(y~x, data=meuse, asp=1)
> lines(meuse.riv, lwd=2, col="blue")
```



Arguments and functions for the following tasks will be considered in more detail:

- placing several graphs onto a graphics device
- controlling color

For other aspects of tailoring the visual appearance of graphs (choice of text font, ...), see help page of `par`.

7.4 Placing several figures in one graphic

The arrangement of multiple plots in one graphic can be controlled by the arguments `mfrow` and `mfcol` of `par`.

Syntax:

`par(mfrow=c(`i_1`,`i_2`))` **or** `par(mfcol=c(`i_1`,`i_2`))`

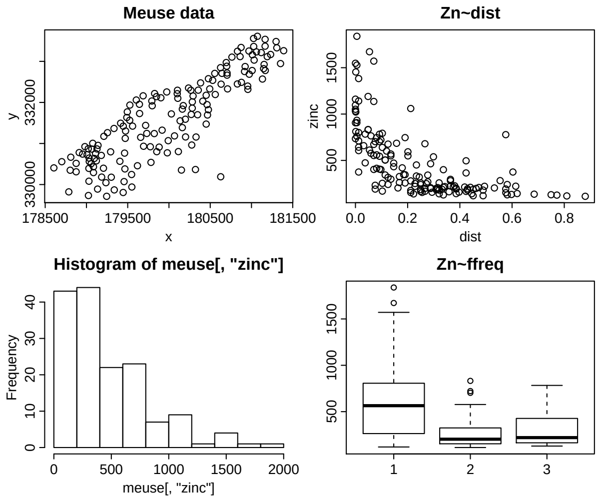
i_1, i_2: two integer scalars for the number of rows and columns into which the graphic device is split

Remarks:

- the graphics device is split into a matrix of $i_1 \times i_2$ figure regions; “rows” and “columns” have constant height and width
- successive calls of high-level plotting function populate the figure regions sequentially by plots
- sequence of plotting is either by rows (`mfrow`) or by columns (`mfcol`)
- alternatives: functions `layout` or `split.screen`

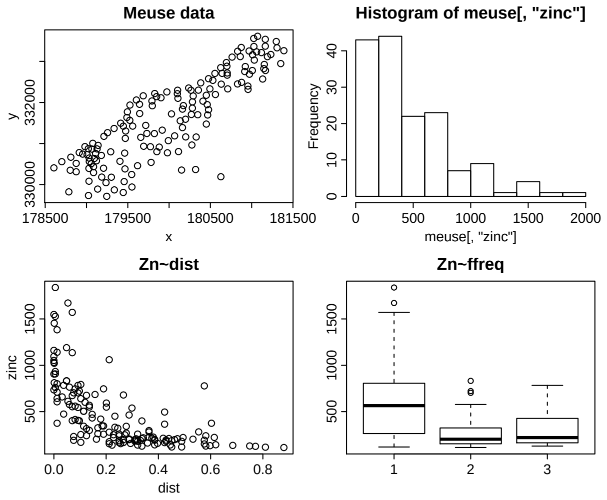
Example: multiple plots in same graphics (by rows)

```
> par(mfrow=c(2,2))
> plot(y~x, data=meuse, main="Meuse data")
> plot(zinc~dist, data=meuse, main="Zn~dist")
> hist(meuse[,"zinc"])
> boxplot(zinc~ffreq, data=meuse, main="Zn~ffreq")
```



Example: multiple plots in same graphics (by columns)

```
> par(mfcol=c(2,2))
> plot(y~x, data=meuse, main="Meuse data")
> plot(zinc~dist, data=meuse, main="Zn~dist")
> hist(meuse[,"zinc"])
> boxplot(zinc~ffreq, data=meuse, main="Zn~ffreq")
```



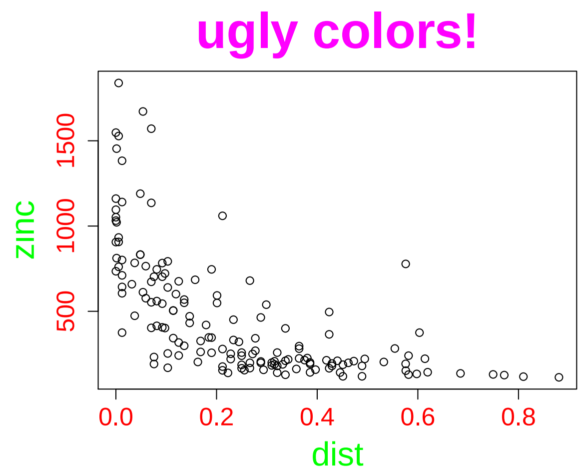
7.5 More on colors (and size)

The color (and size) of title, axes labels and tick mark labels is controlled by separate `col.`*xxx* (and `cex.`*xxx*) arguments passed to high-level functions or to `par`.

	Color	Size
title	`col.main`	`cex.main`
axes labels	`col.lab`	`cex.lab`
tick mark labels	`col.axis`	`cex.axis`

Example: settting the color and the size of text annotation

```
> par(col.main="magenta", cex.main=3,
+      col.lab="green", cex.lab=2,
+      col.axis="red", cex.axis=1.5)
> plot(zinc~dist, meuse, main="ugly colors!")
```



The background and foreground colors of a plot are queried and set by the arguments `bg` and `fg` of `par`.

Syntax:

`par(fg=`*color*`,bg=`*color*`)`

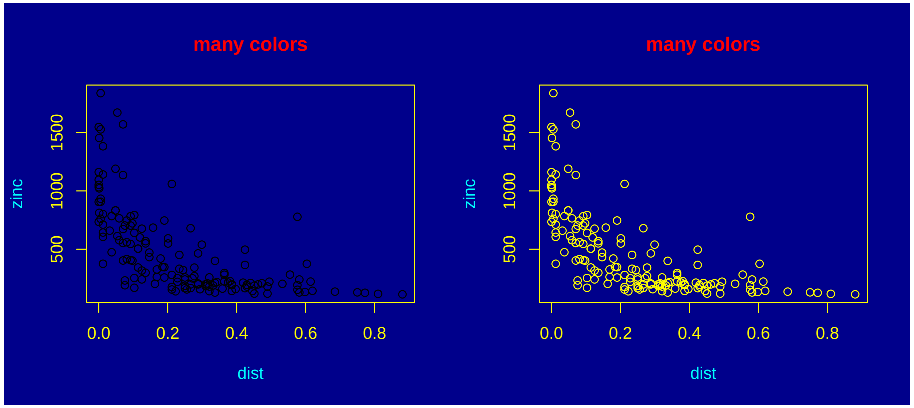
color: valid colors (integer scalar or keyword)

Remarks:

- the device region is colored by the background color; the background color can be set only by `par(bg=`*color*`)`
- `fg=`*color* can be used as argument for high-level plotting functions to set the color of the axes and the box around the plot region
- `par(fg=`*color*`)` sets in addition also the default color for points and lines plotted subsequently in the plot region
- `par(fg=`*color*`)` does not affect the color of text annotation; these colors must be set by the arguments `col.main`, `col.axis`, `col.lab`

Example: setting fore- and background colors

```
> par(mfrow=c(1,2))
> par(bg="darkblue", col.main="red", col.lab="cyan",
+     col.axis="yellow")
> plot(zinc~dist, meuse, main="many colors", fg="yellow")
> par(fg="yellow")
> plot(zinc~dist, meuse, main="many colors")
```



Colors can be either specified by integer or keywords. The color scale, i.e., the mapping of the integer numbers to particular colors, are queried and set by the function `palette`.

Syntax:

`palette(`*colorscale*`)`

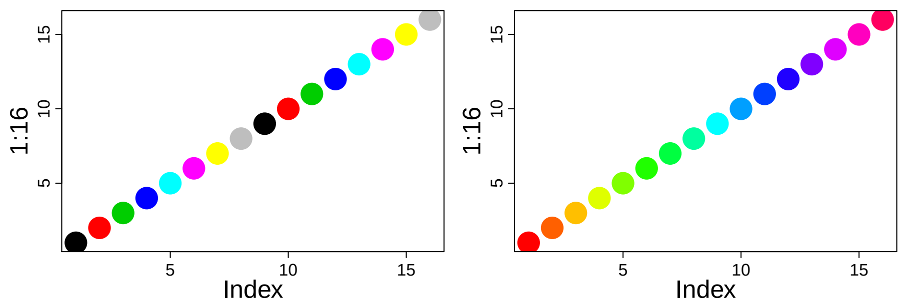
colorscale: an optional character vector with valid colors

Remarks:

- `palette()` shows the current color scale
- color vectors are preferably constructed by the built-in functions such as `rainbow`, `heat.colors`,...(cf. `?rainbow`) or by the more flexible function `colorRampPalette` (cf. `?colorRamp`).
- `palette("default")` restores the default color scale

Example: querying and setting color scales

```
> palette()
[1] "black"  "red"     "green3" "blue"   "cyan"    ...
> par(mfrow=c(1,2))
> plot(1:16, col=1:16, pch=16, cex=3)
> palette(rainbow(16))
> plot(1:16, col=1:16, pch=16, cex=3)
```




```
> palette("default"); palette()
[1] "black"  "red"     "green3" "blue"   "cyan"    ...
```

In this lecture you have learnt …

… how to add additional data to an existing plot by
  ⇒ functions **points** and **lines**

… how to draw horizontal and vertical straight lines by
  ⇒ function **abline**

… how to annotate points in a scatterplot by
  ⇒ function **text**

… how to add a legend by
  ⇒ function **legend**

… to query and set default values for arguments controlling the visual aspects of a graphic
  ⇒ function **par**

… that most of the **par** arguments can be specified “on the fly” in high-level and low-level plotting functions

… how to arrange several plots in one graphic
  ⇒ arguments **mfrow** , **mfcol** of function **par**

… how to control color
  ⇒ arguments **col.***xxx* , **fg** , **bg**
  ⇒ functions **palette** , **rainbow** , etc.

Introduction Part 2

in the second part of the Lecture “Using R ...” we

- ... introduce distributions and random numbers
- ... continue to program using functions
- ... learn about loops and control structures
- ... get to know further R building blocks (objects, classes, attributes)
- ... work with lists and apply
- ... see how to tailor the behaviour of R
- ... find out about packages and where to get help

8. More on Statistics

In this chapter you will learn about …

… distributions in R ($\mathcal{N}$, t, Binomial, Poisson, etc)

… visualizing them

… using them in computations

… draw random samples from them.

8.1 Distributions and Random Numbers

In statistics, we have two kinds of distributions:

1. *data* $(x_1, x_2, \ldots, x_n)$ and its empirical distribution $F_n(t)$, arithmetic mean $\bar{X} := 1/n \sum_{i=1}^{n} x_i$, standard deviation, etc. and
2. random variable, say X (*abstract!*) and its (theoretical) *distribution*, expectation $E(X)$, $Var(X)$, etc.

Such distributions are characterized by (either one of)

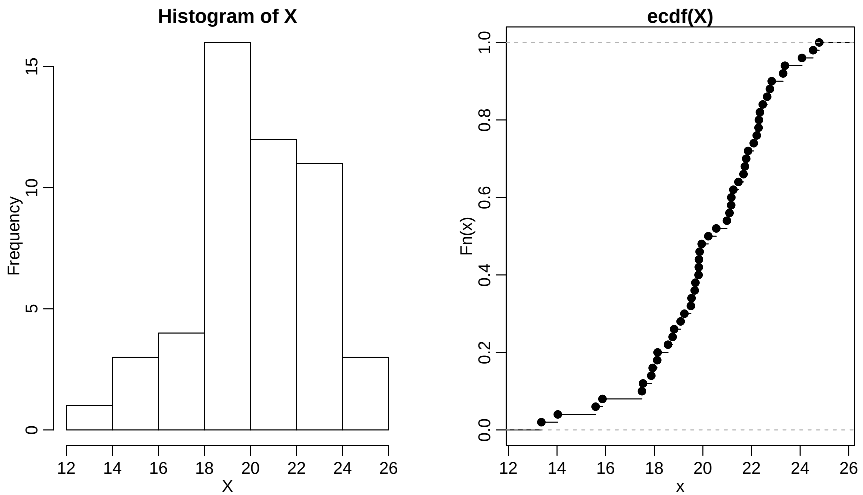
- a density $f(x)$,
- a cumulative distribution function $F(x) = \int_{-\infty}^{x} u\, f(u)\, du$,
- or a quantile function $q(\alpha) := F^{-1}(\alpha)$, $(\alpha \in (0,1))$.

Notation (mathematical / statistical):

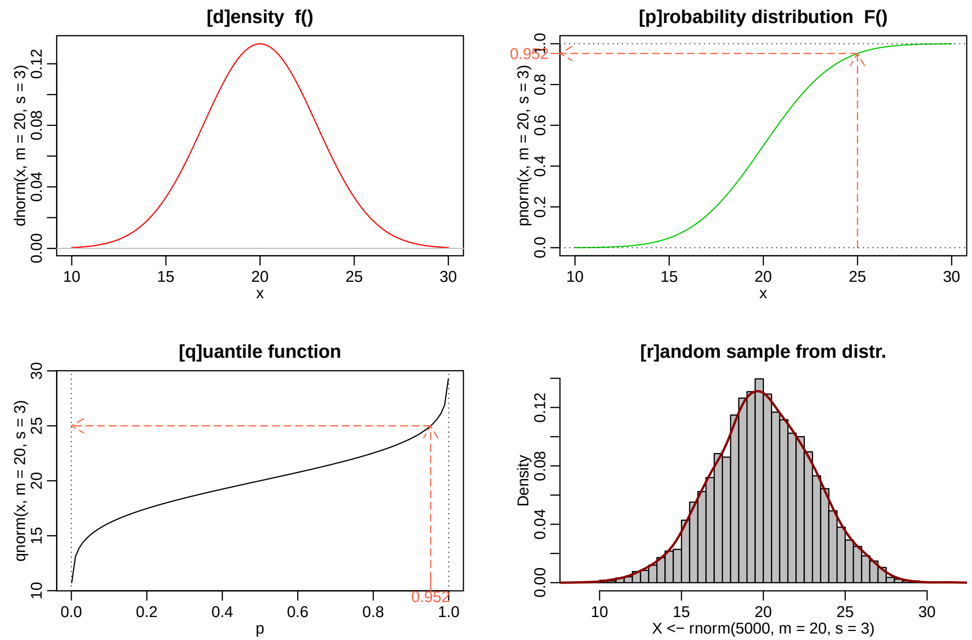
- $X \sim \mathcal{N}(20, 3^2)$ means "X is distributed according to a normal (aka "Gaussian") distribution with mean $\mu = 20$ and variance $\sigma^2 = 3^2 (= 9)$, and hence standard deviation $\sigma = 3$".
- $S \sim \chi^2_{10}$ means "S is distributed according to a χ^2–Distribution ("Chi square") with 10 degrees of freedom (parameter df$=$ 10)".
- $N \sim Pois(3.5)$ means "N is Poisson distributed with expectation 3.5 (or "$\lambda = 3.5$")".

(1) Data – empirical distribution

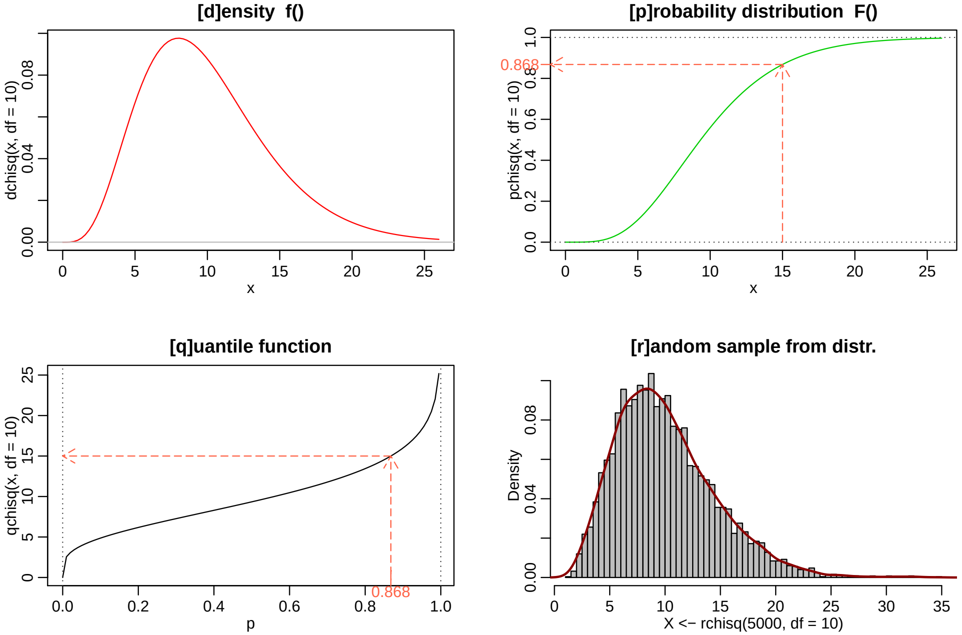
```
> par(mfcol = 1:2)
> hist(X) ; plot( ecdf(X) )
```



(2) Random Variable $X \sim \mathcal{N}(20, 3^2)$: $F(t)$, $f(t) = F'(t)$



Random Variable $X \sim \chi^2_{10}$: $F(t)$ and $f(t) = F'(t)$



Distributions in R — $4 \times n$ functions

"d", "p", "q", "r"

4 functions for *every* distribution family

E.g., the normal distribution is characterized by:

- **D**ensity function $f(x)$ (here, $f(x) = \phi(x) := \frac{1}{\sqrt{2\pi}} e^{-x^2/2}$)

```
> dnorm(0.5, mean=0, sd=1)
[1] 0.35207
```

- Cumulative **P**robability function $F(x) = \int_{-\infty}^{x} f(t)\, dt$

```
> pnorm(c(1, 1.96), mean=0, sd=1)
[1] 0.84134 0.97500
```

- **Q**uantile function ($q(p) = F^{-1}(p)$, i.e., $F(q(p)) = p$):

```
> qnorm(c(0.25,0.975), mean=100, sd=10)
[1]  93.255 119.600
```

- **R**andom number generator function ($\rightarrow X_1, X_2, \ldots, X_n \sim F$ i.i.d.):

```
> rnorm(5, mean=2, sd=2)
[1] 2.75264 4.07480 0.93534 1.60891 3.17285
```


Poisson distribution: `dpois, ppois, qpois, rpois`

```
> rpois(10, lambda=3.5)
 [1] 4 5 3 1 2 5 4 1 7 3
```

Prepend "d", "p", "q", or "r" to these distribution "name stems":

Discrete Distributions	
`binom`	Binomial distribution
`pois`	Poisson distribution
`hyper`	Hypergeometric distribution
...	... (more) ...

Continuous Distributions	
`unif`	Uniform distribution
`exp`	Exponential distribution
`norm`	Normal distribution
`lnorm`	Log-Normal distribution
`t, f, chisq`	t-, F-, χ^2– (Chisquare-) distribution
`weibull, gamma`	Weibull, Gamma distribution
...	... (many more) ...

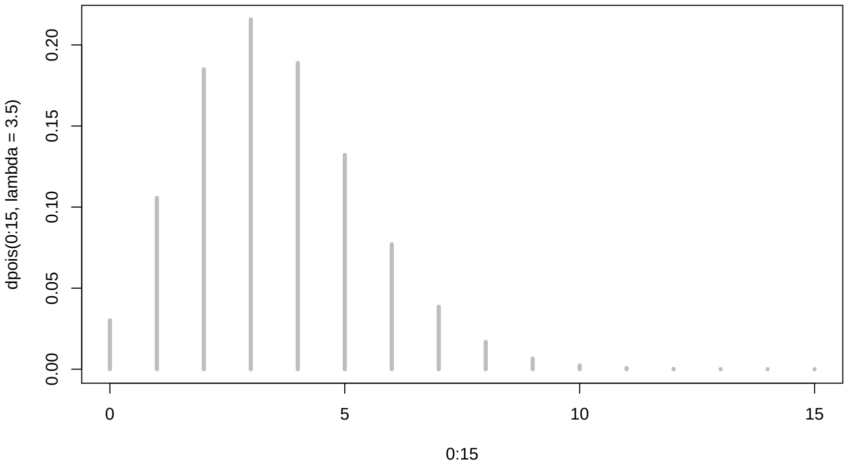
Prepend "d", "p", "q", or "r" to distribution "name", e.g.:

```
> dunif( (0:10)/10 ) # density of *uniform* is constant!
 [1] 1 1 1 1 1 1 1 1 1 1 1
> pbinom( 0:5, size = 5, prob = 1/2)
[1] 0.03125 0.18750 0.50000 0.81250 0.96875 1.00000
> pexp(1:3, rate = 1/2)
[1] 0.39347 0.63212 0.77687
> qnorm(0.975) # ``the famous number''
[1] 1.96
> qt    (0.975, df = c(3,10,20, 100)) # larger
[1] 3.1824 2.2281 2.0860 1.9840
```

8.2 Visualization of distributions

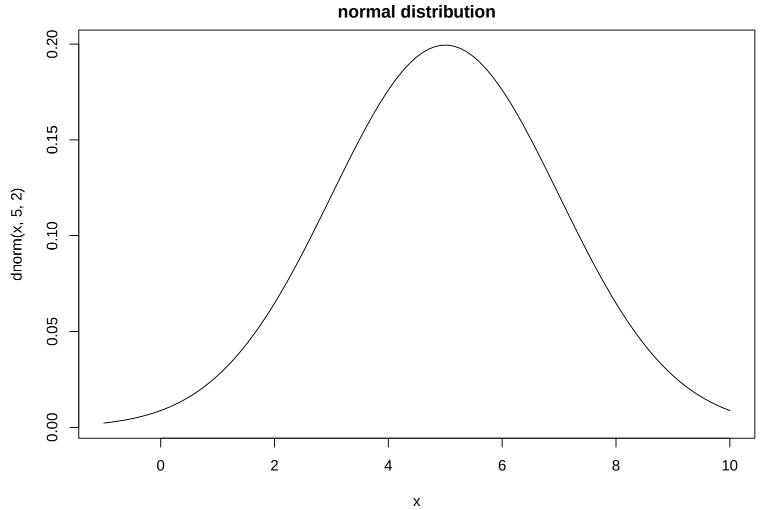
- Discrete distributions:

```
> plot(0:15, dpois(0:15, lambda=3.5),
+       type="h", lwd = 4, col = "gray")
```



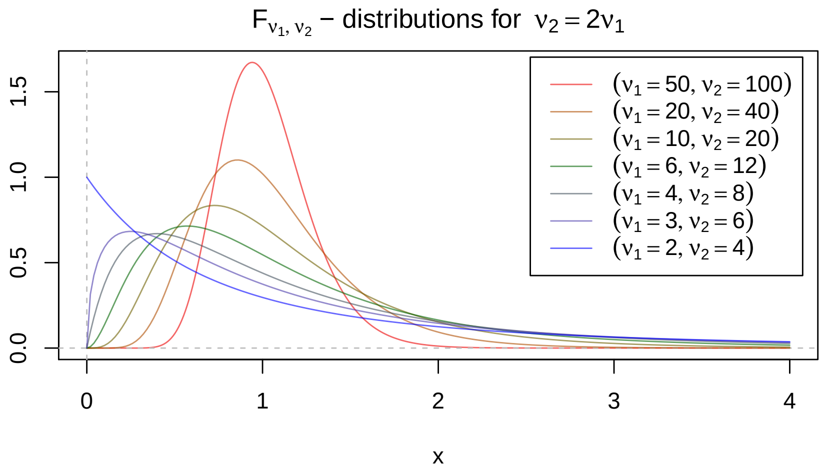
- Continuous distributions:

```
> curve(dnorm(x,5,2), xlim=c(-1,10),
+       main="normal distribution")
```



Example: Densities of F ("Fisher") distributions, `df`:

```
> curve(df(x, df1=n1[1], df2=2*n1[1]), 0, 4, col=1, n=400, ylab="
+       main=expression(F[list(nu[1],nu[2])] * " - distributions f
> abline(h=0,v=0, col="gray", lty=2)
> for(j in 2:length(n1))
+   curve(df(x, df1=n1[j], df2=2*n1[j]), add=TRUE, col=j, n = 200)
> legend("topright", l.exp, lty=1, col= 1:length(n1), inset=.02)
```



8.3 Random Numbers

- "Random" numbers are generated by a deterministic function. Nevertheless, two identical calls give different results.

```
> runif(4)
[1] 0.603293 0.778659 0.002771 0.386036
> runif(4)
[1] 0.13957 0.63444 0.45651 0.31127
```

  How this? The function gets a vector `.Random.seed`.

- To obtain the same numbers again, use ...

```
> set.seed(27)
> runif(1)
[1] 0.97175
> set.seed(27)
> runif(1)
[1] 0.97175
```

Random Numbers ⟶ Simulation !

Very important application: "Simulation" of complicated models, situations, etc *via* random numbers:

E.g., what is a "correct" 90%–confidence interval for the 10%-trimmed mean of 20 observations $X_i \sim t_3$ $(i = 1, \dots, 20)$?

Answer not known from theory . . . ..
⇒Simulation gives a good approximate result easily:

```
> Sim <- rep(NA, 1000)
> for(i in 1:1000)
+   Sim[i] <- mean(rt(20, df=3), trim = 0.10)
```

and from this empirical distribution (given by its sample values `Sim[i]`, get a 90%-interval by cutting 5% on each side:

```
> quantile(Sim, c(0.05, 0.95))
      5%      95%
-0.50644  0.45538
```


8.4 Sampling from arbitrary distributions

Syntax: sample(x, size, replace=FALSE, prob=NULL)

where
x vector with more than one element
(note: if *x* has just one element, `sample` behaves differently)
size non-negative integer giving the number of items to sample

```
> set.seed(27)
> sample(1:10,4)
[1] 10  1  7  3
> sample(1:10,4,replace = TRUE)
[1] 3 5 1 1
> sample(letters,5)
[1] "d" "e" "o" "t" "l"
```


Using R for Data Analysis and Graphics

9. Programming in R - Functions and Control Structures

In this chapter you will learn about . . .

- . . . How to write a function (repetition from part I)
- . . . Error messages, debugging etc
- . . . Control structures, i.e. loops, if–else, etc.

9.1 Writing Functions

Syntax:

fnname <- `function(` arg(s) `)` { statements }

A simple function: Get the maximal value of a vector and its index.

```
> f.maxi <- function(data) {
+   mx <- max(data, na.rm=TRUE) # get max element
+   i <- match(mx, data)        # position of max in data
+   c(max=mx, pos=i)            # result of function
+ }
```

Output of f.maxi is a named vector. The use of `return()` is optional.

```
> f.maxi(c(3,4,78,2))
max pos
 78   3
```

(Note: R provides the function `which.max`)

Defaults and Optional Arguments

Many functions have optional arguments and default values. For instance look at function code of `hist()` or `?hist`:

```
function (x, breaks = "Sturges", freq = NULL, probability = !fre
    include.lowest = TRUE, right = TRUE, density = NULL, angle =
    col = NULL, border = NULL, main = paste("Histogram of", xnar
    xlim = range(breaks), ylim = NULL, xlab = xname, ylab, axes
    plot = TRUE, labels = FALSE, nclass = NULL, warn.unused = TF
    ...)
{
```


Optional Arguments in our f.maxi()

```
> f.maxi.names <- function(data,my.names=c("max","pos")) {
+   ## Function finds maximum in data vector and its index,
+   ##        NAs handled. Names of output can be user-defined
+   ## Arguments
+   ## data      vector
+   ## my.names  char vector w names for Maxi and Index
+   ##           Default: c("max","pos")
+   ## Value
+   ##           Named vector containing Maximum and Index
+
+   mx <- max(data, na.rm=TRUE) # get max element
+   i <- match(mx, data)        # position of max in data
+   res <- c(mx, i)             # result of function
+   names(res) <- my.names      # naming of result
+   res                         # or return(res)
+ }
> f.maxi.names(c(3,4,78,2),
+              my.names=c("Maximum","Indexposition"))

    Maximum Indexposition
         78             3
```


9.2 Error Handling

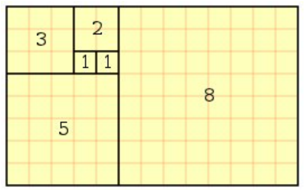
- Error messages are often helpful ...
  sometimes, you have no clue – mostly, if they occur in a function that was called by a function ...
- Show the "stack" of function calls:
  `> traceback()`
- Ask an experienced user ...
- If you write your own functions:
  - use print statements (if simple code)
  - `?debug`
  - `options(error=recover)` calls `browser` when an error occurs.
  - `browser()` as a statement in the function: stops execution and lets you inspect all variables.

9.3 Control Structures: Loops

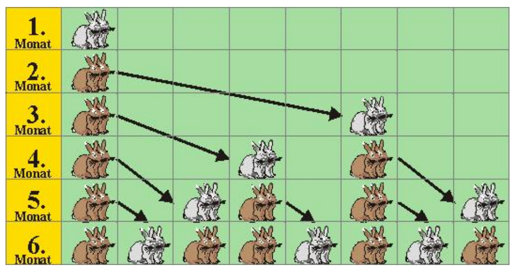
Loops are basic for programming. Most important one: `for`

Syntax: `for ( i in ... ){ commands}`

Example: The Fibonacci series. Illustration of the first 6 elements:



and applications:



Example: Fibonacci Series

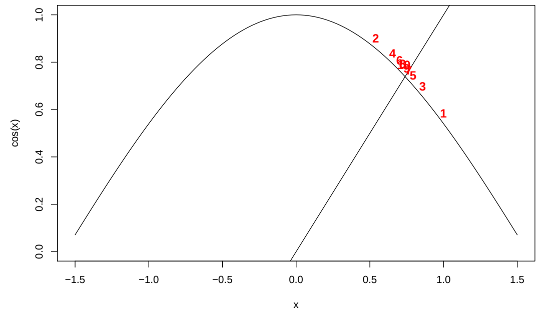
Goal: Calculate the first twelve elements of the Fibonacci series.

```
> fib <- c(1,1)
> for(i in 1:10)
+     fib <- c(fib, fib[i]+fib[i+1])
> fib
 [1]   1   1   2   3   5   8  13  21  34  55  89 144
> fib <- c(1,1)
> for(i in 1:10){
+     fib <- c(fib, fib[i]+fib[i+1])
+     print(fib)
+   }
[1] 1 1 2
[1] 1 1 2 3
[1] 1 1 2 3 5
[1] 1 1 2 3 5 8
[1]  1  1  2  3  5  8 13
[1]  1  1  2  3  5  8 13 21
[1]  1  1  2  3  5  8 13 21 34
 [1]  1  1  2  3  5  8 13 21 34 55
 [1]  1  1  2  3  5  8 13 21 34 55 89
 [1]   1   1   2   3   5   8  13  21  34  55  89 144
```


Other loop constructs – while

`while(cond){...}`

```
> x <- 1
> while(abs(x - (cx <- cos(x))) > 10^-8) {
+     x <- cx
+     cat(".")
+ }
...........................................
> c(x, cos(x)) # the same
[1] 0.73909 0.73909
```



Other loop constructs – repeat, break

`repeat {...}`

which needs `break` to jump out of the loop:

```
> plot(1:10)
> ## repeat until "right-click" :
> repeat {
+   loc <- locator(1,type="l")
+   x0 <- loc$x
+   y0 <- loc$y
+     if(length(x0) < 1)## right clicking leaves loop
+         break
+
+     points( x0,y0 , pch=19)
+ }
```


Note

Instead of `for` loops, you can (and should!) often use more elegant and efficient operations,

- e.g., instead of

  ```
  > n <- length(x); y <- x
  > for(i in 1:n)
  +     y[i] <- x[i] * sin(pi * x[i])
  ```

  use simply

  ```
  > Y <- x * sin(pi * x)
  ```

  Of course, that's equivalent:

  ```
  > identical(Y, y)
  [1] TRUE
  ```

- In more complicated cases, it is often advisable to `apply()` functions instead of `for(.){...}`, see next week!

9.4 Control Structures: if – else

- Conditional evaluation: `if(.){...}  [ else{...} ]`
  Syntax:

  `if(`*logical*`)` *A* or
  `if(`*logical*`)` A_1 `else` A_2

  E.g., For the Fibonacci construction loop,

```
> fib <- c(1,1) ; i <- 1
> repeat {
+     fib <- c(fib, fib[i]+fib[i+1])
+     if ( fib[(i <- i+1)+1] > 10000 ) break
+ }
> fib
 [1]     1     1     2     3     5     8    13    21    34
[12]   144   233   377   610   987  1597  2584  4181  6765 10
```

- with optional `else`

```
>  if(sum(y) > 0) log(sum(y)) else "negative sum"
[1] "negative sum"
```


Control Str...: if – else return value; NULL

`if(cond) A` *always* returns a value:

```
> u <- 1
> x1 <- if(u^2 == u) "are the same" ; x1
[1] "are the same"
> u <- 2
> x2 <- if(u^2 == u) "are the same" ; x2
NULL
```

`if(`*cond*`) A` when *cond* is false, has value `NULL`

What is "NULL" ?? Not the same as '0':

```
>  length(NULL) ## has length zero
[1] 0
> is.null(NULL) ## query whether an output is NULL
[1] TRUE
> c(2,NULL,pi) ## does not show up in vectors
[1] 2.0000 3.1416
```


Examples

- A (simplistic!) example of computing "significance stars" from P-values:

```
> myStar <- function(x) { if(x < .01) "**" else
+                         if(x < .05) "*" else "" }
> myStar(0.024)
[1] "*"
> myStar(0.2)
[1] ""
> myStar(0.002)
[1] "**"
```



- ```
  > tst3 <- function(x) {
  +    if(x %% 3 == 0) paste("HIT:", x) else format(x %% 3)
  + }
  > c(tst3(17), tst3(27))
  [1] "2"        "HIT: 27"
  ```
- ```
  > tst4 <- function(x) {
  +     if(x < -2) "pretty negative"
  +     else if(x < 1) "close to zero"
  +     else if(x < 3) "in [1, 3)" else "large"
  + }
       x    tst4(x)
  [1,] "-5" "pretty negative"
  [2,] "-1" "close to zero"
  [3,] "0"  "close to zero"
  [4,] "1"  "in [1, 3)"
  [5,] "2"  "in [1, 3)"
  [6,] "3"  "large"
  [7,] "4"  "large"
  ```

9.5 Control Structures ctd.: switch, ifelse

- Instead of nested `if (..) A else if (..) B else C` clauses, sometimes can use `switch()`, e.g.

```
> center <- function(x, type) {
+   switch(type,
+          mean = mean(x),
+          median = median(x),
+          trimmed = mean(x, trim = .1))
+ }
> x <- rcauchy(10)
> center(x, "mean")
[1] -2.2591
> center(x, "median")
[1] -1.2115
> center(x, "trimmed")
[1] -1.8803
```


`ifelse(⟨cond⟩, r1, r2)`

`ifelse()` is a "*vectorized*" `if` function. The output vector always has the same length as the input vector. I.e. the `NULL` value cannot be provided as output!

- Select elements from 2 vectors based on condition:

```
> x <- 1:12
> ifelse(x > 5, 10, x)
 [1]  1  2  3  4  5 10 10 10 10 10 10 10
```

- can be nested:

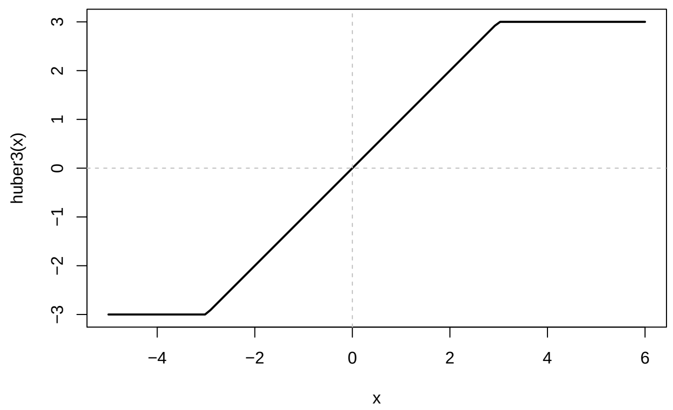
```
> ifelse(x < 5, 5, ifelse(x > 9, 10, x))
 [1]  5  5  5  5  5  6  7  8  9 10 10 10
```

- This does not work - try it out!

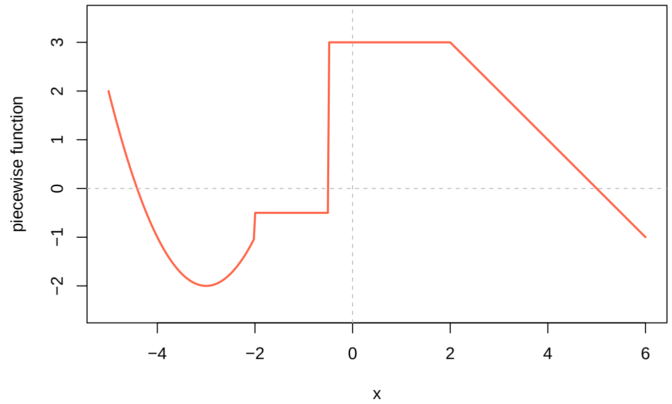
```
>  ifelse(x > 5, 10, NULL)
```


`ifelse()` allows to define *vectorized* piecewise functions:

```
> huber3 <- function(x) ifelse(x < -3, -3,
+                               ifelse(x < 3, x, 3))
> curve(huber3, -5, 6,  lwd=2, asp=1)
> abline(h=0,v=0, col="gray", lty=2)
```




```
> curve(ifelse(x < -2, (x+3)^2 -2,
+              ifelse(x < -1/2, -0.5,
+                     ifelse(x < 2, 3, 5-x))),
+       col="tomato", n=400,xlim=c(-5,6),lwd=2,asp=1,
+       ylab="piecewise function")
> abline(h=0,v=0, col="gray", lty=2)
```



10. Objects, Lists and Apply

In this chapter you will learn about ...

... basics of R objects

... how to work with arrays and lists

... the efficient use of `apply`

10.1 R Objects

The basic building blocks of R
are called "objects". – They come in "classes":

- numeric, character, ... one-dim. sequence of numbers, strings,
- ...; "building blocks" of R : called *atomic*[10] vectors
- matrix — two dimensional array of numbers, character strings, ...
- array — (1–, 2–, 3–, ...)dimensional; 2-dim. array =: matrix.
- data.frame — two dimensional, (numbers, "strings", factors, ...)
- formula — specifying (regression, plot, ...) "model"
- function — also an object!
- list — very *general* collection of objects, → see below
- call, ... — and more

[10] see help page `?is.atomic`, or maybe `demo(is.things)` for more

`array` — *k*-dimensional matrix

Matrices are 2-dimensional, an `array` can be *k*-dimensional ($k \geq 1$).
E.g., 3-dimensional, a "stack of matrices":

```
> a <- array(1:30, dim=c(3,5,2))
> a
, , 1

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

, , 2

     [,1] [,2] [,3] [,4] [,5]
[1,]   16   19   22   25   28
[2,]   17   20   23   26   29
[3,]   18   21   24   27   30
```


`array` — (2)

```
> a <- array(1:30, dim=c(3,5,2))
> is.array(a)
[1] TRUE
> dim(a[ 1, , ])     # the first slice of a[]
[1] 5 2
> m <- a[ , 2, ] ; m
     [,1] [,2]
[1,]    4   19
[2,]    5   20
[3,]    6   21
> is.matrix(m)       # a "slice" of a 3-d array is a matrix
[1] TRUE
```

There are specific functions to examine the kind of an object[11]. In particular the "inner" structure of an object, is available by `str()` :

```
> str(d.sport)
'data.frame': 15 obs. of  7 variables:
 $ weit  : num  7.57 8.07 7.6 7.77 7.48 7.88 7.64 7.61 7.27 7.49
 $ kugel : num  15.7 13.6 15.8 15.3 16.3 ...
 $ hoch  : int  207 204 198 204 198 201 195 213 207 204 ...
 $ disc  : num  48.8 45 46.3 49.8 49.6 ...
 $ stab  : int  500 480 470 510 500 540 540 520 470 470 ...
 $ speer : num  66.9 66.9 70.2 65.7 57.7 ...
 $ punkte: int  8824 8706 8664 8644 8613 8543 8422 8318 8307 8300
> str(m)
 int [1:3, 1:2] 4 5 6 19 20 21
> str(a)
 int [1:3, 1:5, 1:2] 1 2 3 4 5 6 7 8 9 10 ...
```

[11] e.g. `class()` , `mode()` and `typeof()` (see also next week).

10.2 Lists

Objects of any kind can be collected into a list:

```
> v <- c(Hans=2, Fritz=-1, Elsa= 9, Trudi=0.4, Olga=100.)
> list(v, you="nice")
[[1]]
 Hans Fritz  Elsa Trudi  Olga
  2.0  -1.0   9.0   0.4 100.0

$you
[1] "nice"
```

As with `c(...)` , all arguments are collected, names can be given to the components.

Lists are an important (additional) `class` of objects, since most statistical functions produce a list that collects the results.

```
> hi.k <- hist(d.sport[,"kugel"], plot=FALSE)
> hi.k
$breaks
[1] 13.5 14.0 14.5 15.0 15.5 16.0 16.5 17.0

$counts
[1] 2 1 4 1 4 1 2

$intensities
[1] 0.26667 0.13333 0.53333 0.13333 0.53333 0.13333 0.26667

$density
[1] 0.26667 0.13333 0.53333 0.13333 0.53333 0.13333 0.26667

$mids
[1] 13.75 14.25 14.75 15.25 15.75 16.25 16.75

$xname
[1] "d.sport[, \"kugel\"]"

$equidist
```


- Get a sublist of the list: `[ ]`

  ```
  > hi.k[2:3]
  $counts
  [1] 2 1 4 1 4 1 2

  $intensities
  [1] 0.26667 0.13333 0.53333 0.13333 0.53333 0.13333 0.26667
  ```

  or `hi.k[c("breaks","intensities")]`

- Get a component: `[[ ]]`

  ```
  > hi.k[[2]]
  [1] 2 1 4 1 4 1 2
  > identical(hi.k[[2]], hi.k[["counts"]])
  [1] TRUE
  ```

  or also `hi.k$counts` . These components are all vectors.

  Note: `hi.k["counts"]` is a list with one component.

- Hint: A data.frame is a list with additional attributes.
  ⟶ Single columns (variables) can be selected by `$` :

```
> k <- d.sport$kugel
> ## select elements from it:
> d.sport$kugel[4:6]     # but preferrably
[1] 15.31 16.32 14.01
> d.sport[4:6, "kugel"] # treat it like a matrix
[1] 15.31 16.32 14.01
```


- Make a list of subsets of a vector:

```
> split(1:7, c(1, 1, 2, 3, 3, 2, 1))
$`1`
[1] 1 2 7

$`2`
[1] 3 6

$`3`
[1] 4 5
```

- `unlist` concatenates all elements of all components into a single vector.

```
> unlist(hi.k[1:2])
breaks1 breaks2 breaks3 breaks4 breaks5 breaks6 breaks7 breaks
   13.5    14.0    14.5    15.0    15.5    16.0    16.5    17
counts2 counts3 counts4 counts5 counts6 counts7
    1.0     4.0     1.0     4.0     1.0     2.0
```


10.3 Apply

Loops can and should be avoided in many cases!

- Apply a function to each column (or row) of a data.frame or matrix:

```
> apply(d.sport, 2, mean)
    weit     kugel      hoch       disc      stab      speer
  7.5967   15.1987  202.0000    46.3760  498.0000    61.9947 8
```

  Second argument: `1` for "summary" of rows, `2` for columns

- If the function needs more arguments, they are provided as additional arguments:

```
> apply(d.sport, 2, mean, trim=0.3)
    weit     kugel      hoch       disc      stab      speer
  7.5914   15.1871  201.8571    46.4171  495.7143    63.0000 8
```


Functions for vectorized Programming

Function / Operator	Description
`%*%`	Vector product / matrix multiplication
`%x%, kronecker(X,Y, FUN="*")`	Kronecker product; the latter applies an arbitrary bivariate function `FUN`
`%o%, outer(X,Y, FUN="*")`	"outer" product; the latter applies any `FUN()`.
`sum(v),prod(v),all(L),...`	Sum, product, ... of all elements
`colSums(),rowSums()`	Fast column / row sums
`colMeans(),rowMeans()`	Fast column / row means
`apply()`	column- or row-wise application of function on matrices and arrays
`lapply()`	elementwise application of function on lists, data frames, vectors
`sapply()`	**s**implified `lapply`: returns simple vector, matrix, ... (if possible)
`vapply()`	(more robust, slightly faster) version of `sapply`
`rapply()`	**r**ecursive version of `lapply`
`mapply()`	**m**ultivariate version of `lapply`
`tapply()`	**t**able producing `*apply`, grouped by factor(s)

List–Apply: `lapply()` — *the* most important one

- Apply a function to each component of a list:

```
> hi <- hist(kugel, plot=FALSE)
> typeof(hi)
[1] "list"
> lapply(hi[1:2], length)
$breaks
[1] 8

$counts
[1] 7
```

- `sapply` = [S]implified `lapply`
  The result is `unlist()`ed into a vector, named and possibly reshaped into a matrix[12].

```
> sapply(hi[1:4], length)
     breaks      counts intensities     density
          8           7           7           7
```

[12] or higher array, with argument `simplify = "array"`

List - Apply (Further examples)

- Compute the list mean for each list element

```
> # generate list
> x <- list(a = 1:10, beta = exp(-3:3),
+            logic = c(TRUE,FALSE,FALSE,TRUE))
> # list with mean of each list element
> lapply(x,mean)
$a
[1] 5.5

$beta
[1] 4.5351

$logic
[1] 0.5
> sapply(x,mean)# a named numeric vector
     a   beta  logic
5.5000 4.5351 0.5000
```


- Median and quartiles for each list element

```
> lapply(x, quantile, probs = 1:3/4)
$a
 25%  50%  75%
3.25 5.50 7.75

$beta
    25%     50%     75%
0.25161 1.00000 5.05367

$logic
25% 50% 75%
0.0 0.5 1.0
> sapply(x, quantile)
         a      beta logic
0%    1.00  0.049787   0.0
25%   3.25  0.251607   0.0
50%   5.50  1.000000   0.5
75%   7.75  5.053669   1.0
100% 10.00 20.085537   1.0
```


- Example with linear regressions (“Anscombe” data)
  (here, without R output, unless at the very end):

```
> data(anscombe)                          # Load the data
> anscombe                                # view the small d
> ans.reg <- vector(4, mode = "list")# empty list
> # Store 4 regressions (y_i vs x_i) in list:
> for(i in 1:4){
+   form <- as.formula(paste("y",i," ~ x",i, sep=""))
+   ans.reg[[i]] <- lm(form, data = anscombe)
+ }
> lapply(ans.reg, coef)# a list, of length-2 vectors
> sapply(ans.reg, coef)# simplified into 2 x 4 matrix
                [,1]    [,2]    [,3]    [,4]
(Intercept) 3.00009 3.0009 3.00245 3.00173
x1          0.50009 0.5000 0.49973 0.49991
```

Can use "anonymous" functions directly inside apply - functions.

Example: Retrieve i-th col/row of all matrices that are elements of a list

```
> set.seed(1234)# define list of matrices
> sl <- list(A= matrix(rnorm(25,10,1),ncol=5),
+            B= matrix(runif(20),ncol=5))
> #retrieve 3rd column from both matrices
> sapply(sl,function(x){x[,3]})
$A
[1]  9.5228  9.0016  9.2237 10.0645 10.9595

$B
[1] 0.174650 0.848392 0.864834 0.041857
```

Note: `sapply` creates different types of objects depending on output. Try out

```
> typeof(sapply(sl, function(x) x[2,]) ) # a matrix
> typeof(sapply(sl, function(x) x[,3]) ) # a list, because
>           # matrices in sl do not have same no of rows
```


`sapply()` → `replicate()` as shortcut

`replicate()` is an efficient variant of `sapply()` especially for random number simulation.

Our small simulation from section "random numbers"

```
> set.seed(11); Sim <- rep(NA, 1000)
> for(i in 1:1000)
+   Sim[i] <- mean(rt(20, df=3), trim = 0.10)
```

Now, with `sapply()`, this can be shortened to

```
> set.seed(11)
> Sim2 <- sapply(1:1000, function(i)
+                    mean(rt(20, df=3), trim = 0.10))
```

and as the function value uses random numbers and does not *explicitly* depend on `i`, this can be shortened to the equivalent

```
> set.seed(11); Sim3 <- replicate(1000,
>                          mean(rt(20, df=3), trim = 0.10))
> c(identical(Sim, Sim2), identical(Sim2, Sim3))
[1] TRUE TRUE
```


10.3 Apply — More *apply Variants

- There are quite a few more variants of `apply()`:

```
> apropos("apply$") # all objects *ending*  in 'apply'
 [1] "apply"      "dendrapply" "eapply"     "kernapply" "lapp
 [6] "mapply"     "rapply"     "sapply"     "tapply"    "vapp
> sapply(apropos("apply$"), function(nm) {
+     cat(sprintf("%10s:",nm));str(get(nm))}) -> trash
     apply:function (X, MARGIN, FUN, ...)
dendrapply:function (X, FUN, ...)
    eapply:function (env, FUN, ..., all.names = FALSE, USE.NA
 kernapply:function (x, ...)
    lapply:function (X, FUN, ...)
    mapply:function (FUN, ..., MoreArgs = NULL, SIMPLIFY = TR
    rapply:function (object, f, classes = "ANY", deflt = NULL,
    "replace", "list"), ...)
    sapply:function (X, FUN, ..., simplify = TRUE, USE.NAMES
    tapply:function (X, INDEX, FUN = NULL, ..., simplify = TR
    vapply:function (X, FUN, FUN.VALUE, ..., USE.NAMES = TRUE
```


10.3 Apply — More *apply Variants - 2 -

Only those with 0 or 1 letter before "`apply`":

```
> sapply(apropos("^.?apply$"), function(nm) {
+     cat(sprintf("%10s:",nm));str(get(nm))}) -> trash
     apply:function (X, MARGIN, FUN, ...)
    eapply:function (env, FUN, ..., all.names = FALSE, USE.NAMES
    lapply:function (X, FUN, ...)
    mapply:function (FUN, ..., MoreArgs = NULL, SIMPLIFY = TRUE, U
    rapply:function (object, f, classes = "ANY", deflt = NULL, how
    "replace", "list"), ...)
    sapply:function (X, FUN, ..., simplify = TRUE, USE.NAMES = TRU
    tapply:function (X, INDEX, FUN = NULL, ..., simplify = TRUE)
    vapply:function (X, FUN, FUN.VALUE, ..., USE.NAMES = TRUE)
```

10.3 Apply — Multi-argument sapply: `mapply`

- `sapply(x, function(x, a) ..., a=4)` varies along `x`, i.e., for `x[i]`, $i = 1, 2, \dots,$ `length(x)`.
- If instead, it should vary two or even more arguments, we use `mapply()`, e.g.,

```
> word <- function(C,k)
+   paste(rep.int(C,k), collapse='')
> word("C", 5)
[1] "CCCCC"
> sapply(letters[1:4], word, k=3) ## as expected ..
    a     b     c     d
"aaa" "bbb" "ccc" "ddd"
> ## now vary *both* arguments  'C'  and 'k' :
> mapply(word, LETTERS[1:6], 6:1)
       A        B        C        D        E        F
"AAAAAA"  "BBBBB"   "CCCC"    "DDD"     "EE"      "F"
```


tapply – a “ragged” array

Summaries over groups of data:

```
> n <- 17
> fac <- factor(rep(1:3, length = n), levels = 1:4)
> fac # last level not present:
 [1] 1 2 3 1 2 3 1 2 3 1 2 3 1 2 3 1 2
Levels: 1 2 3 4
> table(fac)
fac
1 2 3 4
6 6 5 0
> tapply(1:n, fac, sum)
 1  2  3  4
51 57 45 NA
```


`tapply()` simplifies the result by default, *when* possible,

```
> tapply(1:n, fac, sum, simplify = FALSE)  # simplify=FALSE
$`1`
[1] 51

$`2`
[1] 57

$`3`
[1] 45

$`4`
NULL
> tapply(1:n, fac, quantile)  # simplification not possible
$`1`
   0%   25%   50%   75%  100%
 1.00  4.75  8.50 12.25 16.00

$`2`
   0%   25%   50%   75%  100%
 2.00  5.75  9.50 13.25 17.00

$`3`
   0%   25%   50%   75% 100%
```


tapply — by()

`by(data,index,fun,...)`

Summaries by groups of data, uses `tapply()` internally!

```
> # help(warpbrakes)
> # split by tension-levels
> by(warpbreaks[, 1:2], warpbreaks[,"tension"], summary)
> # split by tension-and-wool levels
> by(warpbreaks[, 1],   warpbreaks[, -1],       summary)
warpbreaks[, "tension"]: L
     breaks      wool
 Min.   :14.0   A:9
 1st Qu.:26.0   B:9
 Median :29.5
 Mean   :36.4
 3rd Qu.:49.2
 Max.   :70.0
--------------------------------------------------------
warpbreaks[, "tension"]: M
     breaks      wool
 Min.   :12.0   A:9
 1st Qu.:18.2   B:9
 Median :27.0
 Mean   :26.4
 3rd Qu.:33.8
 Max.   :42.0
```

Perform linear regression separately for the 3 tension levels:

```
> by(warpbreaks, warpbreaks[,"tension"],
+     function(x) lm(breaks ~ wool, data = x))

> ## now suppose we want to extract the coefficients
> ## by group
> tmp <- with(warpbreaks,
+             by(warpbreaks, tension,
+                function(x) lm(breaks ~ wool, data = x)))
> sapply(tmp, coef)
                 L       M       H
(Intercept)  44.556 24.0000 24.5556
woolB       -16.333  4.7778 -5.7778
> ## with(warpbreaks,interaction.plot(tension,wool,breaks))
```


tapply — Aggregate

Summaries over groups of data:

- ```
  > # help(sleep)
  > aggregate(sleep[,"extra"],
  +           list(sleep[,"group"]), median)
    Group.1    x
  1       1 0.35
  2       2 1.75
  ```
  Result is a `data.frame`.
  Many groups ⟶ Analyze summaries using new `data.frame`!
- Conceptually similar to `by()` (and hence `tapply()`).
  Compare output of `by()` above to
  ```
  > aggregate(warpbreaks[,1:2],
  +           list(Tension=warpbreaks[,"tension"]),
  +           summary)
  ```


Using R for Data Analysis and Graphics

11. More R: Objects, Methods,..

In this chapter you will learn . . .

. . . more on objects, their classes, attributes and (S3) methods

. . . more on functions

. . . using `options()` (and `par()`)

11.1 R Objects - this slide repeated from above

Slide from 10.1: The basic building blocks of R are called “objects”. – They come in “classes”:

- numeric, character, . . . one-dim. sequence of numbers, strings,
- . . . ; “building blocks” of R : called *atomic*[13] vectors
- matrix two dimensional array of numbers, character strings, . . .
- array (1–, 2–, 3–, . . .)dimensional; 2-dim. array =: matrix.
- data.frame two dimensional, (numbers, “strings”, factors, . . .)
- formula specifying (regression, plot, . . .) “model”
- function also an object!
- list very *general* collection of objects, → see below
- call, . . . and more

[13] see help page `?is.atomic`, or maybe `demo(is.things)` for more
  ```

There are specific functions to examine the kind of an object, apart from `class()` (see also below),

```
> class(d.sport)
[1] "data.frame"
```

lower level functions `mode()` and `typeof()` can be useful. This information and more, namely the "inner" structure of an object, is available by `str()`:

```
> str(d.sport)
'data.frame': 15 obs. of  7 variables:
 $ weit  : num  7.57 8.07 7.6 7.77 7.48 7.88 7.64 7.61 7.27 7.49
 $ kugel : num  15.7 13.6 15.8 15.3 16.3 ...
 $ hoch  : int  207 204 198 204 198 201 195 213 207 204 ...
 $ disc  : num  48.8 45 46.3 49.8 49.6 ...
 $ stab  : int  500 480 470 510 500 540 540 520 470 470 ...
 $ speer : num  66.9 66.9 70.2 65.7 57.7 ...
 $ punkte: int  8824 8706 8664 8644 8613 8543 8422 8318 8307 8300
```


11.2 Object Oriented Programming

- Each object has a class, shown by `class(`*object*`)`:

```
> class(a)
[1] "array"
> c(class(m), class(m[,1]), class(d.sport)) # save space on s
[1] "matrix"     "integer"    "data.frame"
```

- Many functions do rather different things according to the `class` of the first argument.
  Most prominently: `print()` or `plot()` are "generic function"s.
  Examine class of first argument and then call a "method" (function) accordingly.

  Example: `plot(speer~kugel, data=d.sport)`
  calls the "`formula` method" of the "`plot` generic function", as `class(speer~kugel)` is `"formula"`

Generic Functions

- The most basic generic function is print() [14].
  Example: `> r.t` (or `print(r.t)`) calls the `"htest"` "method" of `print`:

```
> r.t <- wilcox.test(extra ~ group, data=sleep)
> r.t
Wilcoxon rank sum test with continuity correction

data:  extra by group
W = 25.5, p-value = 0.06933
alternative hypothesis: true location shift is not equal to 0
```

Note: The `print()` function is called *whenever* no explicit function is called [15]: R is "auto – printing".

[14] and/or `show()` for formal classes (aka "S4" classes)

[15] and the `invisible()` flag has not been activated; e.g., "`A <- b`" is "invisible"

(where the *internal* structure is quite different:

```
> str(r.t)
List of 7
 $ statistic  : Named num 25.5
  ..- attr(*, "names")= chr "W"
 $ parameter  : NULL
 $ p.value    : num 0.0693
 $ null.value : Named num 0
  ..- attr(*, "names")= chr "location shift"
 $ alternative: chr "two.sided"
 $ method     : chr "Wilcoxon rank sum test with continuity correc
 $ data.name  : chr "extra by group"
 - attr(*, "class")= chr "htest"
```

)

Generic Functions – Methods

Find available methods

```
> length(methods(print)) # ** MANY **
[1] 174
> methods(print)
 [1] "print.acf"      "print.anova"    "print.aov"      "print.ao
 [5] "print.ar"       "print.Arima"    "print.arima0"   "print.As
 [9] "print.aspell"   "print.basedInt" "print.bibentry" "print.Bik
[13] "print.by"       "print.checkFF"  "print.checkRd"  "print.che
[17] "print.citation" "print.codoc"    "print.Date"     "print.dDA
[21] "print.default"  "print.density"  "print.difftime" "print.dis
[25] "print.DLLInfo"  "print.ecdf"     "print.factanal" "print.fac
[29] "print.family"   "print.formula"  "print.ftable"   "print.fur

......
```


Find available methods[16] for `plot()` :

```
> length(methods(plot)) # ** MANY **
[1] 28
> methods(plot)
 [1] plot.acf*          plot.data.frame*    plot.decomposed.ts*
 [4] plot.default       plot.dendrogram*    plot.density
 [7] plot.ecdf          plot.factor*        plot.formula*
[10] plot.function      plot.hclust*        plot.histogram*
 .......
 .......
[28] plot.TukeyHSD

   Non-visible functions are asterisked
```

[16] strictly, the *"S3 methods"* only. S3 is the first "informal" object system in S and R; the *"formal"* object system, "S4", defines classes and methods formally, via `setClass()`, `setMethod()` etc; and lists methods via `showMethods()` instead of `methods()`


```
> methods(plot)
 [1] plot.acf*          plot.data.frame*    plot.decomposed.ts*
 [4] plot.default       plot.dendrogram*    plot.density
 .......
 .......
[25] plot.table*        plot.ts             plot.tskernel*
[28] plot.TukeyHSD

   Non-visible functions are asterisked
```

Now, from these, we have already used *implicitly*

- `plot.default`, the default method,
- `plot.formula`, in `plot(y ~ x, ...)`,
- `plot.factor` (which gave boxplots),
- `plot.data.frame` (giving a scatter plot *matrix*, as with `pairs()`),

etc

Summary: Many functions in R are *generic* functions, which "dispatch" to calling a "method" depending on the class of the first argument:

Generic Functions—Class—Method:

⟨*generic-func*⟩ (⟨*obj*⟩, ...)

dispatches to calling

⟨*generic-func*⟩.⟨*class*⟩ (⟨*obj*⟩, ...)

where ⟨*class*⟩ is the class of ⟨*obj*⟩, or it calls

⟨*generic-func*⟩`.default` (⟨*obj*⟩, ...)

if there is no ⟨*generic-func*⟩.⟨*class*⟩ method.

e.g., after `x <- seq(-4, 4, by = 0.05)`,

- (In "top level",) `x` calls `print(x)` which really calls `print.default(x)`
- `summary(d.sport)` really calls `summary.data.frame(d.sport)`
- `plot(y ~ x, ....)` really calls `plot.formula(y ~ x, ....)`
- `plot(x, sin(x))` really calls `plot.default(x, sin(x))` (as there is no `plot.numeric()`)

- Apart from basic classes like `matrix`, `formula`, `list`, etc, many functions, notably those fitting a statistical model, return their result of a specific `class`.
  Example: Linear regression ($\longrightarrow$ function `lm()`)

```
> r.lm <- lm(speer ~ kugel, data=d.sport)
> class(r.lm)
[1] "lm"
```

- These classes come with "methods" for
  `print`, `plot`, `summary`
  `> summary(r.lm)`
  `> plot(r.lm)` ## explained in another lecture ...
- `methods(class = "lm")` lists the methods for `"lm"`.


```
> methods(class = "lm")
 [1] add1.lm*           alias.lm*          anova.lm
 [4] case.names.lm*     confint.lm*        cooks.distance.lm*
 [7] deviance.lm*       dfbeta.lm*         dfbetas.lm*
[10] drop1.lm*          dummy.coef.lm*     effects.lm*
[13] extractAIC.lm*     family.lm*         formula.lm*
[16] hatvalues.lm       influence.lm*      kappa.lm
[19] labels.lm*         logLik.lm*         model.frame.lm
[22] model.matrix.lm    nobs.lm*           plot.lm
[25] predict.lm         print.lm           proj.lm*
[28] qr.lm*             residuals.lm       rstandard.lm
[31] rstudent.lm        simulate.lm*       summary.lm
[34] variable.names.lm* vcov.lm*

   Non-visible functions are asterisked
```


11.3 Attributes

In order to store all kinds of useful information along with an object, each object can have "attributes".

- Some attributes we have met before: `class` and `names`, the latter for (simple, e.g., numeric) vectors but also lists.
- `dim` is an attribute of matrices and arrays
- `dimnames` (optionally) contains column- and row names for matrices and arrays. For data frames, the corresponding attributes are `names` and `row.names`.
- All of the above are also accessed by a *function* with the same name, e.g.,

```
> dim(d.sport)
[1] 15  7
```

  but in general, you'd need `attributes()` and `attr()`:

- All attributes of an object can be seen by `attributes`:

```
> attributes(d.sport)
$names
[1] "weit"   "kugel"  "hoch"   "disc"   "stab"   "speer"  "pu

$class
[1] "data.frame"

$row.names
 [1] "OBRIEN"    "BUSEMANN"  "DVORAK"    "FRITZ"     "HAMA
 [6] "NOOL"      "ZMELIK"    "GANIYEV"   "PENALVER"  "HUFF
[11] "PLAZIAT"   "MAGNUSSON" "SMITH"     "MUELLER"   "CHMA
```

- You will rarely use attributes explicitely !
  Often, you do not see them when you just "print" an object
  (the method of the object's class for print does not show them.)
  In other words, they are "intestines" of R .

11.4 Functions in R – part 2

Learned already syntax

`fnname <- function( arg(s) ) { exp1 ; exp2 ; ... }`

Now: More on how functions in R are

- defined
- documented
- "called", i.e., what happens with arguments

previously had the example (shortened here)

```
> f.maxi <- function(data) {
+   mx <- max(data, na.rm=TRUE) # get max element
+   c(max = mx, pos = match(mx, data)) # result of function
+ }
```

where the "output", better, the "return value" of our function is a (named) vector, and the use of `return(.)` is optional, since always

the last evaluated expression is returned as function value

If you "forget the ( )", the function is `print`ed to the console, e.g.,

```
> mean
function (x, ...)
UseMethod("mean")
```

from which you can see that it is a (S3) generic function, and you can look up the `methods` via

```
> methods(mean) # and then
[1] mean.data.frame mean.Date       mean.default    mean.difftime
[5] mean.POSIXct    mean.POSIXlt
> mean.default  # is the *default* function
function (x, trim = 0, na.rm = FALSE, ...)
{
    if (!is.numeric(x) && !is.complex(x) && !is.logical(x)) {
        warning("argument is not numeric or logical: returning NA")
        return(NA_real_)
    }
    if (na.rm)
        x <- x[!is.na(x)]
    if (!is.numeric(trim) || length(trim) != 1L)
        stop("'trim' must be numeric of length one")
    n <- length(x)
    if (trim > 0 && n) {
```


- Now, typically you should consult `help(mean)` and/or `help(mean.default)` before using it.
- If you *know* the function, you'd want mainly the *arguments*, their names and defaults:

```
> str(mean.default)
function (x, trim = 0, na.rm = FALSE, ...)
```

- Here: only `x` is needed and the other arguments have "default"s, i.e., need not (but can be) specified:

```
> x <- c(rnorm(20), 100)
> mean(x)# is the same as
[1] 4.883365
> mean(x, trim = 0) # but
[1] 4.883365
> mean(x, trim = 0.10) # may be more reasonable here
[1] 0.2343412
```


- Function arguments and their defaults are also shown on `help(.)` page, in section `Usage:`.
  Try `?mean.default`

Summary: R functions

- with several argument often have *defaults*,
- < *argname* > = < *default* >
- "visible" from the help page's `Usage:` section or `str()`.
- Functions *return* the last evaluated expression, typically, the last line.
- `return()` is hence optional and not often used.
- look at the function definition by just (auto-) `print()` ing it

Function arguments can be abbreviated

```
> seq(1, 20, len = 6)
[1]  1.0  4.8  8.6 12.4 16.2 20.0
```

works, even though

```
> str(seq.default)
function (from = 1, to = 1, by = ((to - from)/(length.out - 1)),
    length.out = NULL, along.with = NULL, ...)
```

as long as the short name can be expanded uniquely among the argument names.

Arbitrary number of further arguments: The `...` "argument"
Many plotting functions and functions and methods: have a `...` argument.

- match an arbitrary number of further arguments
- `...` can be passed on to further functions called
- `...` can be worked with explicitly via `al <- list(...)`

Advanced: Inside a function

- find if an argument has been specified: `missing(<var>)`

```
> example(missing)
missng> myplot <- function(x, y) {
missng+                 if(missing(y)) {
missng+                         y <- x
missng+                         x <- 1:length(y)
missng+                 }
missng+                 plot(x, y)
missng+         }
```

- find the *number* of arguments specified: From `help(nargs)`:

```
> tst <- function(a, b = 3, ...) {nargs()}
> tst() # 0
[1] 0
> tst(clicketyclack) # 1 (even non-existing)
[1] 1
> tst(c1, a2, rr3) # 3
[1] 3
```


11.5 Options

- Options taylor some aspects[17] of R's behavior to your desires:

```
> (x <- pi * c(1, 10, 100, 0.1))
[1]   3.1415927  31.4159265 314.1592654   0.3141593
> options(digits = 3)
> ## ==> results are  _printed_  to (>= 3) significant 
> (x <- pi * c(1, 10, 100, 0.1))##.. the *same* x in bo
[1]   3.142  31.416 314.159   0.314
> x[1] == pi #  true, of course
[1] TRUE
> print(x[1:3], digits= 15) # (alternative)
[1]   3.14159265358979  31.41592653589793 314.15926535897933
> ## revert to default : 7 (significant) digits printin
> options(digits = 7)
```

[17] mostly only how R *outputs*, i.e., `print()`s or `format()`s things

- Enquire `options()` (or also `par()`)

```
> options("digits")
$digits
[1] 7
> ## or, often more conveniently:
> getOption("digits")
[1] 7
> str(par("mar", "col", "cex", "pch"))# a list
List of 4
 $ mar: num [1:4] 5.1 4.1 4.1 2.1
 $ col: chr "black"
 $ cex: num 1
 $ pch: int 1
```


- Good R programming practice:
  reset options at end to previous values, either for `options()`,

```
> op <- options(digits = 13, width = 30)
> pi * 100^(0:2)
[1]     3.14159265359
[2]   314.15926535898
[3] 31415.92653589793
> ## reset to previous values -- we do *not* need to kn
> options(op)
> ## if we were curious, here's what's going on:
> str(op)
List of 2
 $ digits: int 7
 $ width : int 75
```

or also for `par()`:

```
> old.par <- par(mfrow = c(2,2), mgp = c(2,1,0))
> for(i in 1:4)  curve(sin(i * pi* x), main = paste("si
> par(old.par)
> par("mfrow")# areback to  (1, 1)
[1] 1 1
```


- The setting of `options` (and `par`) is "lost" at the end of the R session.
- In order to always set options and other initial action, use the startup mechanism, see `?Startup`;
  e.g., on Linux or Mac: can provide a file '`~/.Rprofile`'; e.g., at the Seminar für Statistik ETH, we have (among other things)

```
> options(repos= c(CRAN= "http://cran.ch.r-project.org"),
+         pdfviewer = "evince",
+         browser = "firefox")
```

  as default for everyone, in a group-wide `Rprofile` file.

12. R packages, CRAN, etc: the R Ecosystem

In this chapter you will learn more on . . .

. . . exploring and installing R packages

. . . CRAN, etc: a glimpse of "The R World"

. . . how to get help regarding R

. . . how to communicate with the operating system and manipulate files

12.1 Packages

- In R, by default you "see" only a basic set of functions, e.g., `c, read.table, mean, plot, ...,....`
- They are found in your "search path" of packages

```
> search() # the first is "your workspace"
[1] ".GlobalEnv"        "package:graphics"  "package:grDevices
[4] "package:datasets"  "package:stats"     "package:utils"
[7] "package:methods"   "Autoloads"         "package:base"
> ls(pos=1) # == ls()  ~= "your workspace" - learned in
[1] "Mlibrary" "pkg"      "tpkgs"
> str(ls(pos=2)) # content of the  2nd  search() entry
 chr [1:88] "abline" "arrows" "assocplot" "axis" "Axis" ...
> str(ls(pos=9)) # content of the  9th  search() entry
 chr [1:1166] "^" "~" "<" "<<-" "<=" "<-" "=" "==" ...
```


- The default list of R objects (functions, some data sets) is actually not so small: Let's call `ls()` on each `search()` entry:

```
> ls.srch <- sapply(grep("package:", search(),
+                        value=TRUE), # "package:<name>
+                   ls, all.names = TRUE)
> fn.srch <- sapply(ls.srch, function(nm) {
+     nm[ sapply(lapply(nm, get), is.function) ] })
> rbind(cbind(ls    = (N1 <- sapply(ls.srch, length)),
+             funs = (N2 <- sapply(fn.srch, length))),
+       TOTAL = c(sum(N1), sum(N2)))
                    ls funs
package:graphics    89   89
package:grDevices  107  104
package:datasets   102    0
package:stats      505  504
package:utils      194  192
package:methods    376  227
package:base      1255 1224
TOTAL             2628 2340
```

i.e., 2340 functions in R version 2.15.2

- Till now, we have used functions from packages "`base`", "`stats`", "`utils`", "`graphics`", and "`grDevices`" without a need to be aware of that.
- `find("`⟨*name*⟩`")` can be used:

```
> c(find("print"), find("find"))
[1] "package:base"  "package:utils"
> ## sophisticated version of  rbind(find("mean"), find
> cbind(sapply(c("mean", "quantile", "read.csv", "plot"
+               find))
         [,1]
mean     "package:base"
quantile "package:stats"
read.csv "package:utils"
plot     "package:graphics"
```


- R already comes with $14 + 15 = 29$ packages pre-installed, namely the "standard (or "base") packages

  `base, compiler, datasets, graphics, grDevices, grid, methods, parallel, splines, stats, stats4, tcltk, tools, utils`

  and the "recommended" packages

  `boot, class, cluster, codetools, foreign, KernSmooth, lattice, MASS, Matrix, mgcv, nlme, nnet, rpart, spatial, survival`

- Additional functions (and datasets) are obtained by (possibly first *installing* and then) loading additional "packages".
- `> library(MASS)` or `require(MASS)`
- How to find a command and the corresponding package?
  `> help.search("...")` [18], (see Intro)
- On the internet: CRAN (`http://cran.r-project.org`, see Resources on the internet (slide 15) is a huge repository[19] of R packages, written by many experts.
- CRAN Task Views help find packages by application area
- What does a package do?
  `> help(package = class)` or (⟷)
  `> library(help = class)` .
  Example (of small recommended) package:

  `> help(package = class)`

[18] can take l..o..n..g.. (only the first time it's called in an R session !)
[19] actually a distributed Network with a server and many mirrors,


```
> help(package = class)
Information on package 'class'

Description:

Package:            class
Priority:           recommended
Version:            7.3-5
Date:               2012-10-03
Depends:            R (>= 2.5.0), stats, utils
Imports:            MASS
Authors@R:          c(person("Brian", "Ripley", role = c("aut",
                    "cre", "cph"), email =
                    "ripley@stats.ox.ac.uk"))
Author:             Brian Ripley <ripley@stats.ox.ac.uk>.
Maintainer:         Brian Ripley <ripley@stats.ox.ac.uk>
Description:        Various functions for classification.
Title:              Functions for Classification
License:            GPL-2 | GPL-3
URL:                http://www.stats.ox.ac.uk/pub/MASS4/
LazyLoad:           yes
Packaged:           2012-10-03 16:46:40 UTC; ripley
Repository:         CRAN
```


Second part of

```
> help(package = class)
Built:              R 2.15.1; x86_64-unknown-linux-gnu; 2012-10-04
                    00:12:11 UTC; unix

Index:

SOM                 Self-Organizing Maps: Online Algorithm
batchSOM            Self-Organizing Maps: Batch Algorithm
condense            Condense training set for k-NN classifier
knn                 k-Nearest Neighbour Classification
knn.cv              k-Nearest Neighbour Cross-Validatory
                    Classification
knn1                1-nearest neighbour classification
lvq1                Learning Vector Quantization 1
lvq2                Learning Vector Quantization 2.1
lvq3                Learning Vector Quantization 3
lvqinit             Initialize a LVQ Codebook
lvqtest             Classify Test Set from LVQ Codebook
multiedit           Multiedit for k-NN Classifier
olvq1               Optimized Learning Vector Quantization 1
reduce.nn           Reduce Training Set for a k-NN Classifier
somgrid             Plot SOM Fits
```


Installing packages from CRAN

- Via the "Packages" menu (in RStudio or other GUIs for R)
- Directly via `install.packages()`[20].
  Syntax:

  `install.packages(`*pkgs*`,` *lib*`,` *repos* = *getOption*("*repos*"), ...)

  pkgs: character vector names of packages whose current versions should be downloaded from the repositories.

  lib: character vector giving the library directories where to install the packages. If missing, defaults to the first element of `.libPaths()`.

  repos: character with base URL(s) of the repositories to use, typically from a CRAN mirror. You can choose it interactively via `chooseCRANmirror()` or explicitly by `options(repos= c(CRAN="http://..."))` .

  ...: many more (*optional*) arguments.

[20] which is called anyway from the menus mentioned above

Installing packages – Examples

- Install once, then use it via `require()` or `library()`:

```
> chooseCRANmirror()
> install.packages("sfsmisc")
> ## For use:
> require(sfsmisc) # to ``load and attach'' it
```

-

```
> install.packages("sp", # using default 'lib'
+         repos = "http://cran.CH.r-project.org")
```
- or into a non-default *library* of packages:

```
> install.packages("sp", lib = "my_R_folder/library",
+         repos = "http://cran.CH.r-project.org")
> ## and now load it from that library (location):
> library(sp, lib = "my_R_folder/library")
```

Note that you need "*write permission*" in the corresponding "library", i.e., folder of packages (by default: `.libPaths()[1]`).

Maintaining your package installations

Packages are frequently updated or improved. When new R versions are released, some packages need changing too. Therefore it is necessary to maintain your package installations. An easy way to do this is also via command line:

```
> update.packages()
```

This will invoke a dialogue where you can select which packages you would like to update. It will list the current version of the package and the version installed on your computer.

Interaction with the Operating System

Often it is useful to send commands to the Operating System (OS) from R, for instance to

- create files, list the content of directories, or start other programmes
- run jobs in batch mode
- include functions and libraries that are written in another language such as Fortran, C, C++, Java, etc.

You have already used R-functions to communicate with the OS: The functions `pdf()` or `jpeg()` can create a pdf- (or jpg-) file on your file system. In addition,

- it is possible to create, modify or remove files and directories.
- the manipulation of strings helps in generating the filenames you require.

System Commands

R has several functions to interact with the OS, notably, `Sys.*()`:

```
> apropos("^Sys\\.", ignore.case=FALSE)
 [1] "Sys.chmod"       "Sys.Date"        "Sys.getenv"
 [4] "Sys.getlocale"   "Sys.getpid"      "Sys.glob"
 [7] "Sys.info"        "Sys.localeconv"  "Sys.readlink"
[10] "Sys.setenv"      "Sys.setFileTime" "Sys.setlocale"
[13] "Sys.sleep"       "Sys.time"        "Sys.timezone"
[16] "Sys.umask"       "Sys.unsetenv"    "Sys.which"
> Sys.Date() ; Sys.time()
[1] "2012-12-10"
[1] "2012-12-10 19:21:27 CET"
> Sys.info()
                  sysname                  release
                  "Linux"   "3.5.3-1.fc17.x86_64"
                  version                 nodename
".. Aug 29 18:46:34 2012"                  "lynne"
                  machine                    login
                 "x86_64"               "maechler"
                     user           effective_user
               "maechler"               "maechler"
```

System Commands (cont'd)

In addition, the function `system()` can be used to send commands to the OS. For instance on a **Unix** (Linux / Apple OSX / Android) system

```
> system("ls")
```

will show a listing of the current working directory, but you really should rather use

```
> list.files()
```

instead, as that works platform independently.

For **Windows**, there are two special function to interact with the OS, and to start programmes

```
> shell("command")
> shell.exec("myWordFile.doc")
```

The latter will start your text operator on Windows, e.g. Microsoft Word, and open the specified Word document.

Manipulating strings

For efficient creation of files and directories, string manipulation is necessary. A list from Uwe Ligges's book[21] below shows some of the available functions. Look at the respective help pages for more information. A few examples follow next.

Tabelle 2.6. Funktionen zum Umgang mit Zeichenketten

Funktion	Beschreibung
`cat()`	Ausgabe in Konsole und Dateien
`deparse()`	*expression* in Zeichenfolge konvertieren
`formatC()`	Sehr allgemeine Formatierungsmöglichkeiten
`grep()`	Zeichenfolgen in Vektoren suchen
`match()`, `pmatch()`	Suchen von (Teil)-Zeichenketten in anderen
`nchar()`	Anzahl Zeichen in einer Zeichenkette
`parse()`	Konvertierung in eine *expression*
`paste()`	Zusammensetzen von Zeichenketten
`strsplit()`	Zerlegen von Zeichenketten
`sub()`, `gsub()`	Ersetzen von Teil-Zeichenfolgen
`substring()`	Ausgabe und Ersetzung von Teil-Zeichenfolgen
`toupper()`, `tolower()`	Umwandlung in Groß- bzw. Kleinbuchstaben

[21] Uwe Ligges: Programmieren in R, Springer.

Examples String Manipulation

Combine numeric and text output for messages or to write to files:

```
> pp <- round(2*pi,2)
> cat("Two times Pi is:", pp, "\n", sep = "\t")
Two times Pi is: 6.28
> cat("Two times Pi is:", pp, "\n", sep = "\t",
+      file = "myOutputMessage.txt")
```

Useful string manipulations:

```
> nam  <- "Cornelia Schwierz" # create string
> nchar(nam) # how many letters
[1] 17
> ## substitute parts of strings (useful for Umlauts etc):
> (nam2 <- gsub("Cornelia","Conny",nam) )
[1] "Conny Schwierz"
> toupper(nam2) # convert to upper case
[1] "CONNY SCHWIERZ"
```


Examples String Manipulation (cont'd)

Create numbered filenames:

```
> filenames <- paste("File", 1:3, ".txt", sep = "")
```

Split the string at specified separator; Note the "protection" (escape) `"\\"` for special characters such as "."

```
> unlist(strsplit(filenames[1],"\\."))
[1] "File1" "txt"
```

Personalize file names:

```
> (nn <- unlist(strsplit(nam2, " ")))# split string at " "
[1] "Conny"    "Schwierz"
> # get first letters as new string:
> (nn2 <- paste(sapply(nn, function(x) substring(x,1,1)),
+              collapse = ""))
[1] "CS"
> (myfiles <- paste(unlist(strsplit(filenames,".txt")),
+                   "_", nn2, ".txt", sep=""))
[1] "File1_CS.txt" "File2_CS.txt" "File3_CS.txt"
```

Directories and Files

R offers specific functions to handle directories and files. Again an overview of the commands is given below, with examples following.

Tabelle 9.1. Funktionen für den Umgang mit Dateien und Verzeichnissen

Funktion	Beschreibung
file.access()	Aktuelle Berechtigungen für eine Datei anzeigen.
file.append()	Eine Datei an eine andere anhängen.
file.copy()	Dateien kopieren.
file.create()	Eine neue, leere Datei erzeugen.
file.exists()	Prüfen, ob eine Datei bzw. ein Verzeichnis existiert.
file.info()	Informationen über eine Datei anzeigen (z.B. Größe, Datum und Uhrzeit des Anlegens bzw. Änderns, ...).
file.remove()	Dateien löschen.
file.rename()	Eine Datei umbenennen.
file.show()	Den Inhalt einer Datei anzeigen.
file.symlink()	Eine symbolische Verknüpfung erstellen (nicht unter allen Betriebssystemen).
basename()	Dateinamen aus einer vollst. Pfadangabe extrahieren.
dir.create()	Ein Verzeichnis erstellen.
dirname()	Verzeichnisnamen aus einer vollst. Pfadangabe extrahieren.
file.path()	Einen Pfadnamen aus mehreren Teilen zusammensetzen.
list.files()	Inhalt eines Verzeichnisses anzeigen (auch: dir()).
unlink()	Verzeichnis löschen (inkl. Dateien, auch rekursiv).

Quelle: Buch Uwe Ligges

Examples

- Listing of files in your working directory

```
> getwd()
> (flist <- list.files(getwd()))
> file.info(flist[1])
```

- Create a directory and list what it contains

```
> file.exists("myDir/") # does the directory exist?
> dir.create("myDir"); file.exists("myDir/")
> setwd("myDir") # change into the new directory
> list.files(".") # list files in current directory
```


Examples (cont'd)

- Writing and adding to text files:

```
> cat("my first line",file=myfiles[1],"\n") # write a l
> list.files(".") # list files in current directory
> file.show(myfiles[1]) # show the file content
> # append a second line:
> cat("my second line",file=myfiles[1],"\n",append=TRUE
> list.files(".") # list files in current directory
> file.show(myfiles[1]) # show the content
```

- Of course it is also possible to write data or graphics to files using the functions you already know `write.table()`, `write.csv()`, `jpg()`, `pdf()`, etc.

Examples (cont'd)

- Removing files

```
> file.remove(myfiles[1]) # remove file from directory
> list.files(".") # list files in current directory
> # the variable myfiles in your R workspace
> # still exists!
> myfiles[1]
```