Introduction to R: Session 01

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Contents

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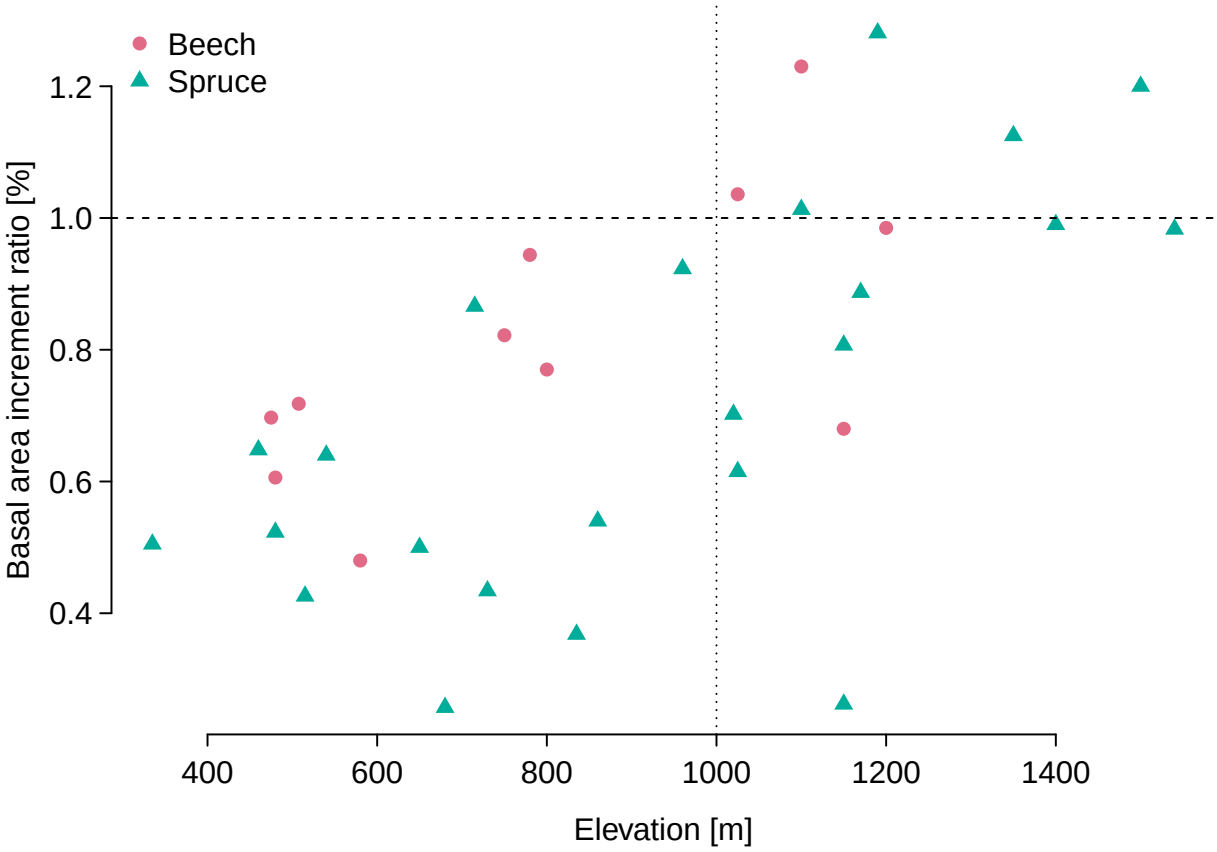
1 (Int)R(o)

1.1 What is R?

'A Language for Data Analysis and Graphics'

A first example: **Scatter plot, data-management and descriptive analysis**

```
## A scatter-plot:
paint <- colorspace::qualitative_hcl(n = 2)
par(mar = c(3, 3, .1, .1), mgp = c(2, .5, 0), tcl = -.3)
plot(drought$elev, drought$bair, las = 1, bty = "n",
     xlab = "Elevation [m]", ylab = "Basal area increment ratio [%]",
     pch = c(16, 17)[1 + (drought$species == "Spruce")],
     col = paint[1 + (drought$species == "Spruce")])
abline(h = 1, lty = 2)
abline(v = 1000, lty = 3)
legend("topleft", pch = c(16, 17), col = paint, legend = c("Beech", "Spruce"),
       bg = "white", bty = "n")
```




```
## ... some data-management:
range(drought$elev)
```

```
## [1]  335 1540
```

```
(tmp <- range(drought$elev %/% 250))
```

```
## [1] 1 6
```

```
br <- seq(tmp[1] * 250, (tmp[2] + 1) * 250, by = 250)
(drought$elev_cut <- cut(drought$elev, breaks = br))
```

```
##  [1] (250,500]   (250,500]   (250,500]   (500,750]
##  [5] (500,750]   (500,750]   (500,750]   (500,750]
##  [9] (500,750]   (750,1e+03] (750,1e+03] (750,1e+03]
```

```
## [13] (1e+03,1.25e+03]   (1e+03,1.25e+03]   (1e+03,1.25e+03]   (1e+03,1.25e+03]
## [17] (1e+03,1.25e+03]   (1e+03,1.25e+03]   (1e+03,1.25e+03]   (1.25e+03,1.5e+03]
## [21] (1.25e+03,1.5e+03] (1.25e+03,1.5e+03] (1.5e+03,1.75e+03] (250,500]
## [25] (250,500]          (500,750]          (500,750]          (500,750]
## [29] (750,1e+03]        (750,1e+03]        (1e+03,1.25e+03]   (1e+03,1.25e+03]
## [33] (1e+03,1.25e+03]   (1e+03,1.25e+03]
## 6 Levels: (250,500] (500,750] (750,1e+03] ... (1.5e+03,1.75e+03]
```

```
## ... and some descriptive statistics:
library("plyr")
ddply(.data = drought, .variables = c("species", "elev_cut"), summarize, .drop = F,
      n = length(bair),
      mean_bair = mean(bair))
```

```
##    species           elev_cut n mean_bair
## 1    Beech          (250,500] 2 0.6515000
## 2    Beech          (500,750] 3 0.6733333
## 3    Beech        (750,1e+03] 2 0.8570000
## 4    Beech   (1e+03,1.25e+03] 4 0.9827500
## 5    Beech (1.25e+03,1.5e+03] 0       NaN
## 6    Beech (1.5e+03,1.75e+03] 0       NaN
## 7   Spruce          (250,500] 3 0.5586667
## 8   Spruce          (500,750] 6 0.5205000
## 9   Spruce        (750,1e+03] 3 0.6103333
## 10  Spruce   (1e+03,1.25e+03] 7 0.7952857
## 11  Spruce (1.25e+03,1.5e+03] 3 1.1050000
## 12  Spruce (1.5e+03,1.75e+03] 1 0.9830000
```

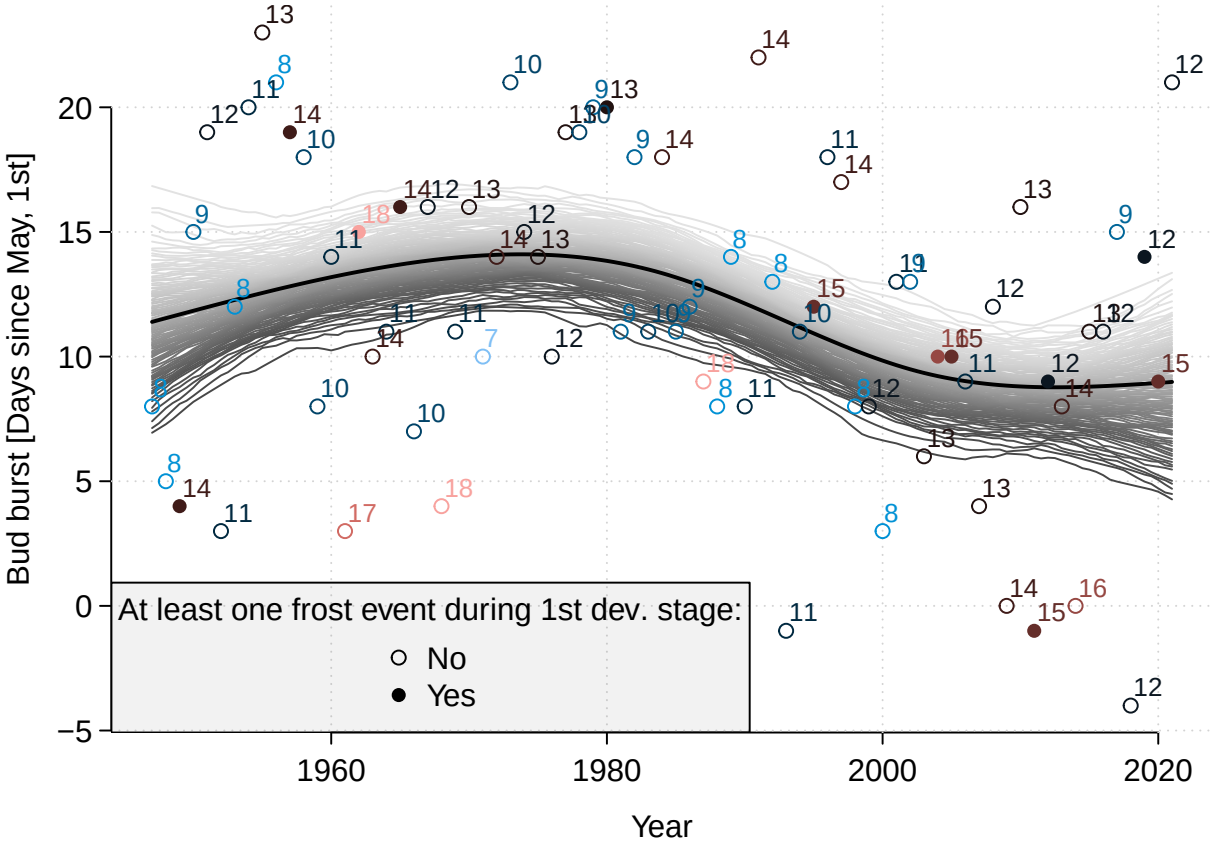
1.2 Why useR?

Because of packages such as `mgcv` ! ... and because we can organize our whole working-with-data-process reproducibly (markdown!) in one place!

(Note: the following figure is much too overloaded!)

```
par(mar = c(3, 3, .1, .1), mgp = c(2, .5, 0), tcl = -.3)
plot(frost$year, frost$bud_burst_days_since_may1st, type = "n",
     xlab = "Year", ylab = "Bud burst [Days since May, 1st]",
     las = 1, bty = "n")
grid()
legend("bottomleft", pch = c(1, 16), legend = c("No", "Yes"),
       title = "At least one frost event during 1st dev. stage:",
       bg = rgb(.5, .5, .5, alpha = .1))
## library("mgcv")
m <- mgcv::gam(bud_burst_days_since_may1st ~ te(year), data = frost)
nd <- data.frame(year = seq(min(frost$year), max(frost$year), by = .5))
br <- mgcv::gam.mh(m, thin = 5, ns = 2000, rw.scale = 2)$bs
coda::effectiveSize(coda::as.mcmc(br))
Mu <- predict(m, newdata = nd, type = "lpmatrix") %*% t(br)
Mu_q <- apply(X = Mu, MAR = 1 , FUN = quantile,
              probs = seq(.01, .99, by = .01))
paint <- colorspace::sequential_hcl(n = nrow(Mu_q), pal = "Light Grays")
for (i in 1:nrow(Mu_q)) {
  lines(nd$year, Mu_q[i, ], col = paint[i])
}
lines(nd$year, predict(m, newdata = nd), lwd = 2)
tmp <- as.numeric(frost$end_1st_dev_stage - frost$bud_burst)
tmp <- tmp - min(tmp) + 1
paint <- colorspace::diverging_hcl(n = max(tmp), pal = "Berlin")
points(frost$year, frost$bud_burst_days_since_may1st, col = paint[tmp],
       pch = c(1, 16)[1 + (frost$n_frost > .5)])
```

```
text(frost$year, frost$bud_burst - frost$may1st,
     labels = frost$end_1st_dev_stage - frost$bud_burst,
     adj = c(-.1, -.5), cex = .8, col = paint[tmp])
```



1.3 Literature

1.3.1 Books...

- Everitt, Hothorn (2006): *A Handbook of Statistical Analyses using R*. Chapman and Hall.
- Ligges (2008): *Programmieren mit R*. Springer Verlag.
- Venables, Smith (2002): *An introduction to R*. Network Theory Verlag.
- Verzani (2005): *Using R for Introductory Statistics*. Chapman and Hall.
- Wickham (2016): *Advanced R*.

1.3.2 ... and the wide web:

- education.rstudio.com
- cran.r-project.org manual R-intro
- cran.r-project.org manual R-lang

1.4 R and RStudio

R:

- https://r-project.org
- Freely available
- Supported by all major operating system: Windows, Linux/Unix, Mac OS, ...

RStudio and others editors for working with R:

- **RStudio** for Windows, Mac OS and Linux:
- RStudio website
- RStudio cheat sheet
- Previously, I presented a list of alternatives to RStudio, but in 2021, that doesn't seem suitable anymore!?

1.5 R is a language

- 'To understand computations in R, two slogans are helpful: Everything that exists is an object. Everything that happens is a function call.' (John M. Chambers)
- Interpreted language: *R* interprets and evaluates your function calls without a compilation step.
- Simple syntax with clear similarities to mathematical notation.

1.6 R is an environment for statistical computing

- rich toolbox for doing (graphical) statistics with an ever growing list of ever improving 'add-on' packages.
- R is freely available for anyone.
- R code is the product: it is transparent and allows you to reproduce any single step of your analysis.

1.7 A short history of R

- 1976: Development of programming language S at Bell Laboratories
- 1988: Software S-PLUS released (for purchase)
- 1992: Ross Ihaka and Robert Gentleman start project R
- 1995: R available for free under GPL
- 1998: Comprehensive R archive network (CRAN) is founded
- 2000: First 'complete' version R-1.0.0 released
- 2004: First conference on R (useR!) takes place
- 2021: Current version is *R-4.1.2* (November 2021)

2 Basic vector types

In R, there is no such thing as a single number, since in R, a single number is just a vector of length 1:

```
length(3)
```

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

R works on six basic vector types, of which four a used in our daily work as empirical researchers: `logical` (`TRUE`and `FALSE`), `integer` (numbers we know as ..., -1, 0, 1, 2, ...; explicitly created in R with suffix `L`), `real` (extending integers to 'any' value such as 1/3), and `string` (`'R'`, `'Beech'`, ...).

```
class(TRUE)
```

```
## [1] "logical"
```

```
class(-1L)
```

```
## [1] "integer"
```

```
class(1/3)
```

```
## [1] "numeric"
```

```
class("R")
```

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

Again, the difference between integers and reals is not important for applied work, so just think of `integer` and `real` as class that represent numerical values in a computer. The following section introduces some manipulations we can do with them, `logical` and `string` will be treated later.

3 Basic mathematical commands

Mathematical operation	Command
Addition	+
Subtraction	-
Multiplication	*
Division	\
Exponentiation	^
Rest of integer division (Modulo)	%%
Integer division	%\%
Brackets	()

3.1 Exercises

Run the following lines.

Note: First and third line define objects `a` and `b` by using an indexing command on data-object `drought`. You don't need to fully understand what this doeas at this point of the course, just think that objects `a` and `b` each represent a single number with some applied meaning (Basal area increment ratio at 1st, and 2nd plot, respectively).

```
a <- drought$bair[1] ## Basal area increment ratio at 1st plot
a ## ... growth is about a half in 2003 in comparison to growth in 2002
b <- drought$bair[2] ## Basal area increment ratio at 2nd plot
b ## ... growth is about two thirds in 2003 in comparison to growth in 2002
a - b ## Whats the difference of bair?
a / b ## Whats the ratio of bair?
b %/% a ## How often is 'b' contained in 'a'?
b %% a ## If 'b' is contained once in 'a', what's remaining?
(a + b)/2 ## Arithmetic mean of 'a' and 'b'
```

Did we just calculate an arithmetic mean 'by hand'?

```
mean(c(a, b))
```

```
## [1] 0.5765
```

4 Symbols and values

Objective	Call
Decimal sign	`.`
List and seperate objects, arguments, ...	`,`
Several *R*-calls in one line (not recommended)	`;`
'from-to' operator for integer sequences	`:`
Comments and help	`#`, `?`
Number π	`pi`
A concept called infinity	`Inf`
Base 10 exponential notation (eg. $10^{-3} = 0.001$)	`1e-3`
Integer value	`L`
Empty object	`NULL`
Missing value (*not available*)	`NA`
Non-defined value (*not a number*)	`NaN`
Comparison	`>`, `>=`, `==`, `!=`, `<=`, `<`
Boolean	`TRUE`, `T`, `FALSE`, `F`
Negation (*not*)	`!`
Conjunction (*and*)	`&`
Disjunction (*or*)	`|`

Remember, everything in R is an object or a function, so we even can't use `,` without a function call such as:

```
c(a, b) ## first two bair values in a vector
```

```
## [1] 0.505 0.648
```

4.1 Exercises

Run the following lines and ask yourself *What is the applied question behind each line?*.

```
pi ## Okay, there is no applied meaning here, it's just a number, an important one, though :)
a / b == pi
a > b
a < b
a == a & b != 2/3
a > b | b < 2/3
a / 0
0 / 0 ## Let: x = 0 / 0. So: 0 * x = 0, which is true for any number x.
```

5 Mathematical functions

Mathematical function	Call
Exponential function with basis e	`exp()`
Natural logarithm	`log()`
Square root	`sqrt()`
Absolute value	`abs()`
Trigonometric functions	`sin()`, `cos()`, `tan()`
Sum and product	`sum()`, `prod()`
Round (up and down)	`round()` (`floor()`, `ceiling()`)
Maximum and minimum value	`max()`, `min()`
Factorial $n! = 1 \cdot 2 \cdot 3 \cdot \ldots \cdot n$	`factorial()`
Binomial coefficient $\binom{n}{k}$	`choose()`

... for further functions, see `?Special` and `?groupGeneric`.

Also note: There are only countable many numbers that a computer is able to represent. Therefore, computers can also only represent some real numbers, and as a consequence, 'rounding' is more complicated than we might think! Here are some explanations why R results in `0 2 2 4 4 6 6` instead of `0 1 2 3 4 5 6` when it does `round(seq(0.5, 6.5))`. Many thanks to Jan Schick for pointing me towards this 'rounding' standard in R, as well as providing me this nice example. Session 05 will also briefly touch upon R and computers and the 'density' of real numbers.

5.1 Exercises

Run the following lines.

```
a <- drought$bair[1]; a; b <- drought$bair[2]; b ## Basal are increment ratio values of first two st
exp(x = a)
sqrt(x = a)
a - b
abs(x = a - b)
```

(Computers construct real values)[https://en.wikipedia.org/wiki/Floating-point_arithmetic]:

```
sin(x = pi)
```

```
## [1] 1.224647e-16
```

```
round(sin(pi), digits = 5)
```

```
## [1] 0
```

```
cos(x = pi)
```

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

```
sum(a, b)
max(a, b)
```

6 Functions basics

(We will have a more detailed focus on functions in the third session.)

Basic properties of functions in R:

- Function call of function `f` using brackets: `f()`
- Documentation (*'help-page'*) using preceded question mark (`?f`), or calling `help(f)`
- Search for documentation of `f` by: `help.search('f')`
- Syntax:

```
f(arg1 = value1, arg2 = value2, ...) ## '...' is for optional further arguments.
```

- Arguments often have default objects, eg. for `pch` in `plot()`:

```
plot(x = a, y = b)
```

```
plot(x = a, y = b, pch = 1) ## same!
```

- Giving objects to arguments is not optional in any case:

```
sin(pi/2)
```

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

```
sin(x = pi/2) ## Same
```

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

```
plot(pi, pi, 1) ## Error!
```

```
## Error in plot.xy(xy, type, ...): ungültiger Plottyp
```

7 Documentation

Structure:

- **Description**: In brief, what is this function about?
- **Usage**: How to call the function? What are mandatory arguments?
- **Arguments**: Explaining each argument
- **Details**: Some text about implementation, scope, ...
- **Value**: Explaining the resulting object
- **Authors** and **References** and **See also** and ...
- **Examples**: Always at the bottom, always scroll down there, you will never be disappointed!

7.1 Exercises

Go to the documentation for `lm`.

- What is this function about?
- Copy-paste and run the example.

8 Objects

Basic Conventions:

- Objects store values, results or algorithms, ie. functions.
- Assignment of contents by <- or = (or very seldomly ->).
- Type of contents is described by object classes.

```
(a <- drought$bair[1]); (a = drought$bair[1])
```

```
## [1] 0.505
```

```
## [1] 0.505
```

```
log(b <- drought$bair[2]); b
```

```
## [1] -0.4338646
```

```
## [1] 0.648
```

```
(a <- b)
```

```
## [1] 0.648
```

8.1 Objekt names

There are few hard technical restrictions on how to name objects in R, and a few soft rules that make life much simpler:

- Object names are requared to begin with a lower or upper case letter, no numbers or any other signs are allowed.
- As a second or any trailing character, numbers and some signs (restrict yourself to underscore _ and .) are allowed
- Don't use ?, $, %, ^, &, *, (,), -, #, ?, , , <, >, /, |, \, [,] ,{, and @
- **As short as possible, as long as needed!**
- This trade-off is simple, but (hopefully) still very useful: long object names mean more typing (RStudio weakens this point by auto-complete), but leave less room for questions on content (*What was a again?*).
- So try to give 'telling names', ie. contents (and units!) should be clearly visible from the object's name: `first_bair_measurement` is better than `a`, `elev_m` is better than `elev`.
- Ask yourself: Will I be able to immediately remember the contents from the name after two weeks without working on this project?

We get an error message:

```
3values <- c(1, 2, 4)
```

```
## Error: <text>:1:2: unerwartetes Symbol
## 1: 3values
##       ^
```

```
three_values <- c(1, 2, 4)
```

8.2 Save and load

```
save(frost, file = "frost_data.RData")
load(file = "frost_data.RData")
```

Where will my files be stored? See section *Preparatory Work in R* in Session 04.

8.3 Litter service

- Names of objects in current session: `ls()`
- Litter service using `rm()`
- `dput()` comes as a helper

```
ls()
```

```
##  [1] "a"            "b"            "br"           "df"           "drought"
##  [6] "frost"        "i"            "m"            "Mu"           "Mu_q"
## [11] "nd"           "paint"        "three_values" "tmp"
```

```
dput(ls())
```

```
## c("a", "b", "br", "df", "drought", "frost", "i", "m", "Mu", "Mu_q",
## "nd", "paint", "three_values", "tmp")
```

```
dput(ls()[!(ls() %in% c("drought", "frost", "df"))])
```

```
## c("a", "b", "br", "i", "m", "Mu", "Mu_q", "nd", "paint", "three_values",
## "tmp")
```

```
rm("a", "b", "br", "i", "m", "Mu", "Mu_q", "nd", "paint", "three_values", "tmp")
ls()
```

```
## [1] "df"      "drought" "frost"
```

9 Dataobject classes

9.1 Vector

A vector is a one-dimensional combination of length 1 vectors of the same basic vector type.

9.1.1 Basics

Objective	Call
Combination of elements	`c(A, B)`
Indexing	`c(A, B)[1]`
Length of vector	`length(x)`
Integer sequence	`A:B`
Flexible sequence	`seq(A, B, length = N)`, `seq(A, B, by = K)`
Repeat	`rep(A, times = N)`, `rep(c(A, B), each = K)`
Sort elements	`sort(c(A, B), decreasing = FALSE)`
Order of elements	`order(c(A, B))`

9.1.2 Exercises

Copy-paste and run each line: describe what it does and what it results in.

```
a <- drought$elev[1]; b <- drought$elev[2]
(x <- c(a, b))
c(x, a)
c(x, x)
x[2] <- drought$elev[3]; x
length(x)
a:b
seq(a, b, by = .5)
seq(a, b, by = 5)
seq(a, b, length = 10) ## Sequenz
rep(x, times = 3)
rep(x, each = 3)
rep(x, length = 7)
sort(x, decreasing = TRUE)
order(c(x, 100))
a <- as.character(drought$species[1]); b <- as.character(drought$species[2])
(x <- c(a, b))
c(x, "Beech")
c(x, 2)
```

9.2 Calculations

- Basic calculations operate independently on all elements
- Function calls work (usually) with vectorized arguments
- Summary of the content: `summary()`
- Frequency table: `table()` (see Session 04 for much more detail)

9.2.1 Exercises

Copy-paste and run each line: describe what it does and what it results in.

```
x <- drought$bair
x^2
sin(x)
```

```
length(x)
summary(x)
boxplot(x)
stripchart(x, add = T, pch = 16, method = "jitter", vertical = T)
```

```
species <- drought$species
xtabs(~ species)
xtabs(~ species + (drought$elev > 1000))
```

9.3 Matrix

A vector is a two-dimensional combination of single-element objects of the same class.

9.3.1 Basics

P×P matrix with content `content`:

```
A <- matrix(nrow = P, ncol = Q, data = content)
```

Fill matrix column- (default) or linewise using argument `byrow = TRUE`:

- Indexing of one element: `A[1, 1]`
- Indexing of first row (result is vector): `A[1, ]`
- Indexing of several rows (result is matrix): `A[1:3, ]`
- Indexing of first column (result is vector): `A[, 1]`
- Indexing of several columns (result is matrix): `A[, 1:3]`
- Indexing of several rows and columns (result is matrix): `A[1:3, 1:3]`

9.3.2 Exercises

```
a <- drought$elev
b <- drought$bair
length(a) == length(b)
A <- matrix(nrow = length(a), ncol = 2, data = c(a, b))
all(A[, 1] == a)
A[1:3, ]
A[1:3, 2]
A[c(1:3, 29), ]
B <- matrix(nrow = 3, ncol = 3, data = 1:9); B
diag(B)
B %*% B
B %*% c(1, 1, 1)
rowSums(B)
c(1, 1, 1) %*% B
colSums(B)
```

9.4 List

A list is a general 'container' object.

9.4.1 Basics

- Lists may contain elements storing objects of varying classes, lengths, ... (`character`, `numeric`, `integer`, `factor`, ...)
- Construct a list using `list(...)`
- Indexing: `x[[1]]` or `x[['name']]` or `x$name`
- `str` gives the structure

- For lists of 'consistent' classes (or generic functions):

```
lapply(X = mylist, FUN = myfun)
```

9.4.2 Exercises

```
beech <- list(species = "Fagus",
              n = sum(drought$species == "Beech"),
              data = subset(drought, species == "Beech"))
beech
beech[[1]]
beech[['species']]
beech$species
str(beech)
lapply(beech, FUN = dim)
lapply(beech, FUN = summary)
```

9.5 Synthesis and indexing

- We may provide names for elements of vectors, matrices and lists:
- `dimnames(A)`, `rownames(A)`, `colnames(A)` for matrices
- Select a named element by using the `$` sign
- Select elements by `[[]]` (for lists), `[]` (for vectors), and `[, ]` (for matrices).

9.5.1 Exercises

```
c(one = 1, two = 2, four = 4)
x <- c(1, 2, 4)
x
names(x) <- c("one", "two", "four")
x
names(beech)
A <- matrix(nrow = 10, ncol = 2, data = c(drought$elev[1:10], drought$bair[1:10]))
colnames(A)
colnames(A) <- c("elev", "bair")
colnames(A)
rownames(A)
names(A)
dimnames(A)
```

9.6 Dataframe

Based on their object properties, dataframes can be classified between matrices and lists, whereby the columns (the so-called 'variables') of the dataframe correspond to the elements of a list:

- Dataframes are more rigid than lists because all columns must have the same length,
- Dataframes are more flexible than matrices, since all columns can contain different contents (numbers, strings, ...).
- Dataframes are generated with `data.frame ()`
- Indexing:
- Rows and columns can be indexed in the same way as the elements of a matrix,
- Columns can be indexed in the same way as the elements of a list (we have already used this by `drought$elev`).

9.6.1 Exercises

```
weather <- data.frame(day = c("Monday", "Tuesday", "Wednesday"),
                      daily_mean_temperature_C = c(12, 14, 11),
                      precipitation_sum_mm = c(5, 9, 25),
                      site = "Goettingen")
weather
weather[1:2, ]
weather$day[1:2]
weather[["daily_mean_temperature_C"]][3]
weather[1:2, c("daily_mean_temperature_C", "precipitation_sum_mm")]
weather[1:2, c("day", "precipitation_sum_mm")]
```

9.7 Functions on dataframes

- `summary`: Summary of each of the variables in the dataframe
- `str`: overview of the structure of the dataframe
- `dim`: Dimension of the dataframe (number of rows and columns)
- The first `N` lines of a dataframe `df` are extracted with `head(df, n = N)`, and
- the last `N` lines of a dataframe `df` are extracted with `tail (d, n = N)`.

9.7.1 Exercises

```
summary(weather)
str(weather)
head(weather, n = 2)
dim(weather)
```

10 Functions for character strings

If we want to change character strings (such as variable names of a dataframe), the following functions can be helpful:

nchar

Returns the number of characters of a string:

```
nchar(names(weather))
```

```
## [1]  3 24 20  4
```

tolower und toupper

Replaces uppercase with lowercase letters (and vice versa).

```
toupper(c("Beech", "BEech", "beech"))
```

```
## [1] "BEECH" "BEECH" "BEECH"
```

```
tolower(c("Beech", "BEech", "beech"))
```

```
## [1] "beech" "beech" "beech"
```

gsub

Replace a pattern:

```
names(weather)
```

```
## [1] "day"                      "daily_mean_temperature_C"
## [3] "precipitation_sum_mm"     "site"
```

```
names(weather) <- gsub(names(weather), pattern = "_mm", replacement = "__mm", fixed = T)
names(weather) <- gsub(names(weather), pattern = "_C", replacement = "__C", fixed = T)
names(weather)
```

```
## [1] "day"                       "daily_mean_temperature__C"
## [3] "precipitation_sum__mm"     "site"
```

substring

Substrings from `first` to `last`.

```
substring(names(weather), first = 1, last = 5)
```

```
## [1] "day"   "daily" "preci" "site"
```

strsplit

Splits strings according to a certain pattern (`strsplit` always returns a list).

```
names(weather) <- gsub(names(weather), pattern = "__", replacement = "_", fixed = T)
(tmp <- strsplit(names(weather), split = "_", fixed = T))
```

```
## [[1]]
## [1] "day"
##
## [[2]]
## [1] "daily"       "mean"        "temperature" "C"
```

```
##
## [[3]]
## [1] "precipitation" "sum"           "mm"
##
## [[4]]
## [1] "site"
```

paste

Merges strings (arguments sep orcollapse).

```
sapply(tmp, FUN = function(x){paste(x, collapse = "_")})
```

```
## [1] "day"                       "daily_mean_temperature_C"
## [3] "precipitation_sum_mm"      "site"
```

11 Factors

For the analysis of qualitative characteristics, it makes sense to represent variables with character strings as **factors**.

A factor comes with three ingredients:

- data vector `x`
- `levels`
- `labels`

We can generate a factor without specification of levels and labels: In this case, factor levels (`levels`) are generated (in alphabetical order), numbered internally (see this numeric expression using `as.numeric`), and represented externally by the original values of the character string.

```
(tmp <- factor(x = c("Beech", "Spruce", "Beech")))
```

```
## [1] Beech  Spruce Beech
## Levels: Beech Spruce
```

```
attributes(tmp)
```

```
## $levels
## [1] "Beech"  "Spruce"
##
## $class
## [1] "factor"
```

```
levels(tmp)
```

```
## [1] "Beech"  "Spruce"
```

```
as.numeric(tmp)
```

```
## [1] 1 2 1
```

```
as.character(tmp)
```

```
## [1] "Beech"  "Spruce" "Beech"
```

We can provide levels, to which the numerical representation will refer to:

```
(tmp <- factor(x = c("Beech", "Spruce", "Beech"),
               levels = c("Spruce", "Beech")))
```

```
## [1] Beech  Spruce Beech
## Levels: Spruce Beech
```

```
attributes(tmp)
```

```
## $levels
## [1] "Spruce" "Beech"
##
## $class
## [1] "factor"
```

```
levels(tmp)
```

```
## [1] "Spruce" "Beech"
```

```
as.numeric(tmp)
```

```
## [1] 2 1 2
```

```
as.character(tmp)
```

```
## [1] "Beech"  "Spruce" "Beech"
```

Using labels, the values represented externally are the result of the mapping from `levels` to `labels`

```
(tmp <- factor(x = c("Beech", "Spruce", "Beech"),
               levels = c("Beech", "Spruce"),
               labels = c("Fagus sylvatica", "Picea abies")))
```

```
## [1] Fagus sylvatica Picea abies     Fagus sylvatica
## Levels: Fagus sylvatica Picea abies
```

```
attributes(tmp)
```

```
## $levels
## [1] "Fagus sylvatica" "Picea abies"
##
## $class
## [1] "factor"
```

```
levels(tmp)
```

```
## [1] "Fagus sylvatica" "Picea abies"
```

```
as.numeric(tmp)
```

```
## [1] 1 2 1
```

```
as.character(tmp)
```

```
## [1] "Fagus sylvatica" "Picea abies"     "Fagus sylvatica"
```

11.1 Exercises

```
tmp <- factor(x = c("Beech", "Spruce", "Beech", "Oak"),
               levels = c("Beech", "Spruce"),
               labels = c("Fagus sylvatica", "Picea abies"))
attributes(tmp)
levels(tmp)
as.numeric(tmp)
as.character(tmp)
tmp <- factor(x = c("Beech", "Spruce", "Beech", "Oak"),
               levels = c("Beech", "Oak", "Spruce"),
               labels = c("Deciduous", "Deciduous", "Conifer"))
attributes(tmp)
levels(tmp)
as.numeric(tmp)
as.character(tmp)
```