Programming in R

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Introduction

Introduction

Who are we?

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Introduction

Who are you?

1. Position and research topics?
2. Previous knowledge and experience
    - with R?
    - with other statistical software?
    - with other programming languages?
3. Expectations for this workshop?

Motivation

Why care about R coding?

1. Increase efficiency!
    - Save time and nerves
    - Avoid errors and bugs
    - High transfer effect to other projects (with data analysis)
2. Successful collaborations (including with your future self!)
3. Code as deliverable (i.e., part of research paper)

Agenda

- Loops & iteration
- Functions (part I)
- Functions (part II)
- Functionals & split-apply-combine
- Good programming practices

Quick Recap

Basic *Objects* in R

Vectors	
logical	`TRUE`, `FALSE`, `NA`
integer	`1L`, `142`, `-5`, ..., `NA`
double	`1.0`, `1.25784`, `pi`, ..., `NA`
	`NaN`, `-Inf`, `Inf`
character	`"1"`, `"Some other string"`, ..., `NA`

Vectors can have multiple elements **of the same type** $\rightarrow$ `length()` starting from `0`

Basic *Objects* in R

More basic object types	
list	a **list** of vectors `list()`, `as.list()`
matrix	a **vector** with a `"dim"` argument: two dimensions `matrix()`, `as.matrix()` matrix algebra
array	a **vector** with with a `"dim"` argument
data.frame	a **list** with vectors of equal length `data.frame()`, `as.data.frame()`

`data.frame` vs `matrix`

A `data.frame` is a list of vectors → columns can be of different types.

Try it!

```
iris_dat <- head(iris)
is.list(iris_dat)
dim(iris_dat)
length(iris_dat)
iris_dat[1:2,]
```

`data.frame` vs `matrix`

A `matrix`/`array` is a vector with dimensions → all elements/columns are of the same type.

Try it!

```
iris_mat <- as.matrix(iris_dat)
dim(iris_mat)
length(iris_mat)
iris_mat[1:2,]
```

Loops & Iteration

Loops & iteration

R has specific tools (functions) that help organize the flow of computations.
You can repeat a similar computation multiple times typically with changing options ("iteration"). The most commonly used tools are:

- loops
  - `for`
  - `while`
  - `repeat`
- `apply` - family

Loops & Iteration - for

`for` statements have the basic form

```
for (element in vector) {
  computation
}
```

For each element in the vector, the computation is executed. Often, the computation depends on the element in that iteration.

Loops & Iteration - for

```r
# iterate over a numeric vector
for (index in 1:3){
  cat(" computation -")
}
```

```
>  computation - computation - computation -
```

```r
# iterate over a character vector
for (name in c("Alice", "Bob", "Casey")){
  if(name == "Bob") cat(" This was Bob -")
  else cat(" Not Bob -")
}
```

```
>  Not Bob - This was Bob - Not Bob -
```

Loops & Iteration - while

`while` statements have the basic form

```
while (condition){
  computation
}
```

As long as the condition is TRUE, the computation is executed. Often, the computation depends on something that is related to the condition.

Loops & Iteration - repeat

`repeat` statements have the basic form

```
repeat {
  computation
}
```

Without a `break` the computation is repeated infinite times

Loops & Iteration - next break

- `next` starts next iteration
- `break` ends iteration (of the innermost loop)

@

Loops & Iteration - next break

- `next` starts next iteration
- `break` ends iteration (of the innermost loop)

```
for(index in 1:8) {
  if (index %in% c(3, 5)) next
  if (index > 6) break
  print(index)
}


> [1] 1
> [1] 2
> [1] 4
> [1] 6
```

Loops & Iteration - nested loops

Nested loops (over the rows and columns of a matrix)

```
matrix <- matrix(NA, nrow = 2, ncol = 3)
for (rowNr in 1:2){
  for (colNr in 1:3){
    matrix[rowNr, colNr] <- rowNr * 10 + colNr
  }
}
matrix
```

```
>      [,1] [,2] [,3]
> [1,]   11   12   13
> [2,]   21   22   23
```

Iteration - Good practice

Programming advice

Use `seq()`, `seq_len()`, or `seq_along()`, not `1:length(x)`.

```
x <- numeric()
for (index in 1:length(x)){
  print(index)
}

> [1] 1
> [1] 0

for (index in seq_along(x)){
  print(index)
}
```

Loops & Iteration - Good practice

Programming advice

Don’t grow, replace.

```
x <- letters
result1 <- numeric()           # grow
result2 <- numeric(length(x)) # replace
for (index in seq_along(x)){
  result1 <- c(result1, paste(index, x[index]))  # grow
  result2[index] <- paste(index, x[index])       # replace
}
```

Loops & Iteration - apply

`apply` lets you iterate over rows or columns of a matrix or data.frame. You can *apply* a function to all rows/columns

```
apply(matrix,
      MARGIN = 1,          # 1 = iterate over rows
                           # 2 = iterate over columns
      FUN = function)      # function to apply to rows/columns
```

apply

- for objects with dimensions (matrix, array, data.frame)
- apply over (a) chosen dimension(s)

```
my_matrix <- matrix(1:6, nrow = 2)
apply(my_matrix, 1, max)    # apply per row

> [1] 5 6

apply(my_matrix, 2, max)    # apply per column

> [1] 2 4 6
```

apply

```
my_array <- array(1, dim = c(2, 3, 4))
apply(my_array, c(1, 2), sum)  # per row and column

>      [,1] [,2] [,3]
> [1,]    4    4    4
> [2,]    4    4    4

apply(my_array, 3, sum)        # per "third dimension"

> [1] 6 6 6 6
```

Exercises

Functions I

"To understand computations in R, two slogans are helpful: Everything that exists is an object. Everything that happens is a function call."

— John Chambers, Extending R (2016)

Function Calls

Computing in R happens through function calls. A function is applied to one or more objects, and returns an object after the computation.

Figure 1: A function call.

The typical use is:

```
function(object1, argument = object2)
```

Function Calls

- Computations that seem not to be done using function calls are actually also function calls. Try `` `<-`(a, 5) `` or `` `>`(5, 2) ``
- most functions that seem not to return an object, return it invisibly. Check `(a <- 5)`.

Building Blocks

Functions are the building blocks of R code. Writing functions allows you to organize and optimize the computations that you want to do.
Functions should:

- have a clear purpose
- be well documented
- be portable

Stepping Stone

Central stepping stone for R users:

Move from solely using functions written by others to writing your own functions.

Function definition

- Name
- Arguments/Formals (input)
- Body (what happens inside, R-code with the computations)
- Output

Function definition

```
                                # Name
countNA <- function(x) {        # Arguments/Formals
  out <- sum(is.na(x))          # Body
  out                           # Output
}
```

Function Names

Every function needs a (meaningful) name!

- Usually **a verb** (what does the function do?)
- Avoid existing names
- Better longer than unclear
- CamelCase vs snake_case

Function Names

Good

- `computeAIC()`
- `removeNAs()`
- `drop_NA_rows()`
- `factor_to_dummies()`

Bad

- `myFun()`
- `foo()`
- `statistics()`
- `data_preparation()`

Arguments

Most functions take one or multiple inputs.
These are usually:

- One or two data arguments
- Additional Options

Arguments

Functions with zero arguments

- `getwd()`
- `Sys.time()`
- …

Arguments

Functions with one argument

- `dim()`
- `names()`
- ...

Arguments

Functions with multiple arguments

- `mean()`
- `median()`
- `lm()`
- …

Arguments

Programming advice

Less arguments = better!

Arguments

Often arguments have to be objects of a specific type.

```
sum(c("a", "b", "c"))  # gives an error

> Error in sum(c("a", "b", "c")): invalid 'type'
(character) of argument
```

The documentation typically gives (or should give) information about what objects the arguments should be. Check `?sum`

Default arguments

What happens if the user omits an argument?

```
countNA <- function(x, percent) {
  out <- sum(is.na(x))
  if(percent) out/length(x)
  out
}
x <- c(1, 5, NA, 3)
countNA(x = x)

> Error in countNA(x = x): argument "percent" is
missing, with no default
```

Default arguments

Default arguments are made for such instances!

```
countNA <- function(x, percent = FALSE) {
  out <- sum(is.na(x))
  if(percent) out/length(x)
  out
}
x <- c(1, 5, NA, 3)
countNA(x = x)

> [1] 1
```

Default arguments

Additional arguments give (the user) flexibility. Default arguments keep the function easy to use.

Try `?lm`

Programming advice

- Think about which arguments to include, and which should (not) have defaults
- Choose sensible defaults

Single return object

Pure functions return a single object.

- (Standard) The last evaluated object
- Object defined by return()

Figure 2: A pure function.

Return object

`return()` stops the computation, and returns the object.

```
return_early <- function(x, early) {
  x2 <- x*2
  if(early) (return(x2))
  out <- x + x2 # not executed
  out
}
return_early(2, early = TRUE)

> [1] 4

return_early(2, early = FALSE)

> [1] 6
```

Return object

Multiple return objects can be combined in a list!

```
                                                  # Name
do_this <- function(vector, other_vector) {       # Arguments
  # many computations                             # Body
  return(list(output1 = this,
              output2 = that))                    # Output
}
```

Return Object

The return object as a list with multiple objects.

```
get_info <- function(x){
  mean_x <- mean(x)
  median_x <- median(x)
  n_obs_x <- length(x)
  range_x <- range(x)
  return(list(mean = mean_x, median = median_x,
              n_obs = n_obs_x, range = range_x))
}
str(get_info(airquality$Wind))
```

```
> List of 4
>  $ mean  : num 9.96
>  $ median: num 9.7
>  $ n_obs : int 153
>  $ range : num [1:2] 1.7 20.7
```

Debugging

- browser()
- traceback()
- options(error = recover)
- options(warn = 2)

browser()

Inspecting a function interactively

```
some_function <- function(x, y) {
  z <- x + y
  browser()
  z
}
some_function(x = 1, y = 5)
```

browser()

```
> some_function <- function(x, y) {
+   z <- x + y
+   browser()
+   z
+ }
> some_function(x = 1, y = 5)
Called from: some_function(x = 1, y = 5)
Browse[1]>
```

browser()

Navigating within a browser:

ls()	Show existing objects in the current environment
c	Exit the browser and continue execution
Q	Exit the browser, return to top level
where	Show call stack

Recover

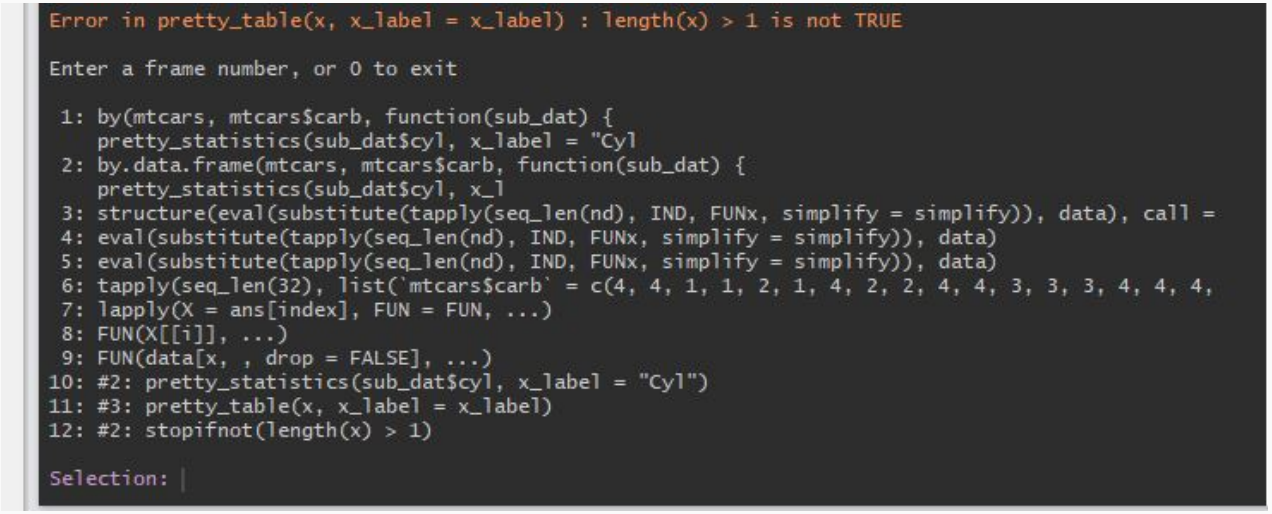
Being able to chose an environment from the call stack:

```
# on
options(error = recover)

# off
options(error = NULL)
```

Recover

Being able to choose an environment from a call stack:



Warnings

Turning warnings into errors

```
# on
options(warn = 2)

# off
options(warn = 1)
```

Exercises

Functions II

Reasons

Why write functions?

- They make code ...
  - shorter (less repetition)
  - easier to read and understand
- They help avoid copy-paste errors
- They make it easier to change your code
- They increase transfer
  - other use cases
  - other projects
  - other persons
- They keep your work space clean

Readability

Writing a function:

```
RMSE <- get_RMSE(predictions, observations)
```

Not writing a function:

```
diff <- observations - predictions
sq_diff <- diff^2
m_sq_diff <- mean(dif)
RMSE <- sqrt(m_sq_diff)
```

Side Effects

Functions can have **“side effects”**:

- console output
- plots
- write/save on drive
- ...

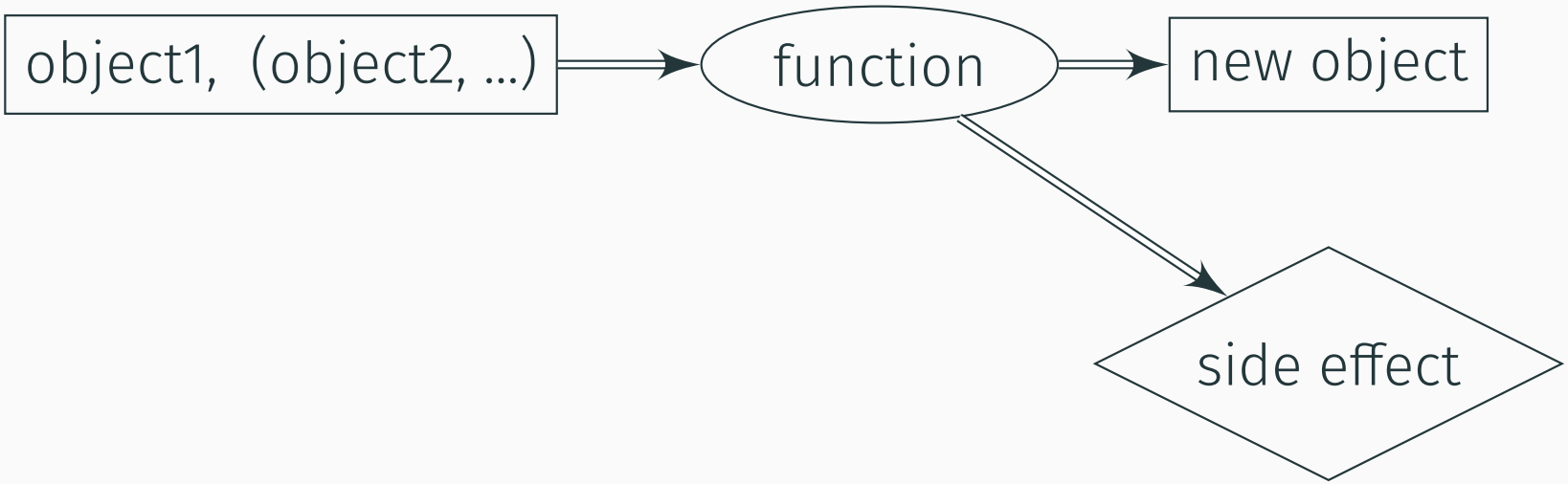


Figure 3: A function with side effect.

Side Effects

Console output: `?cat` and `?print`

```
print_info <- function(x){
  info <- get_info(x)
  cat("There are ", info$n_obs,
      " observed values. \nThe mean is ",
      round(info$mean, 2), ". \nThe median is ",
      round(info$median, 2), ". \n", sep = "")
}
print_info(airquality$Wind)
```

```
> There are 153 observed values.
> The mean is 9.96.
> The median is 9.7.
```

Output

Programming advice

- Write pure functions (no-side effects)
- Write separate functions for side effects
- Plotting functions should return `NULL` or the plot as an object

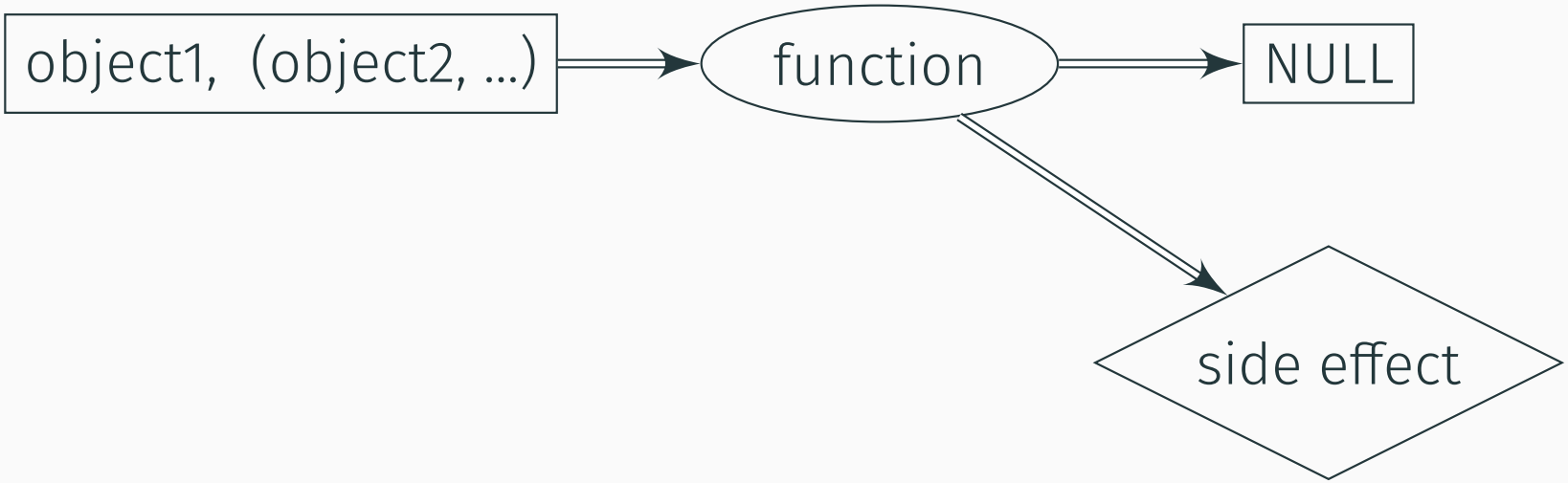


Figure 4: A side effect function.

Error, warning, & message

Error: computation is interrupted without return object!

`?stop`

```
get_log_xtox <- function(x) {
  if(!is.numeric(x)) stop("This does not work!")
  x_x <- x^x
  return(log(x_x))
}
get_log_xtox("a")
```

```
> Error in get_log_xtox("a"): This does not work!
```

Error, warning, & message

Error: computation is interrupted without return object!

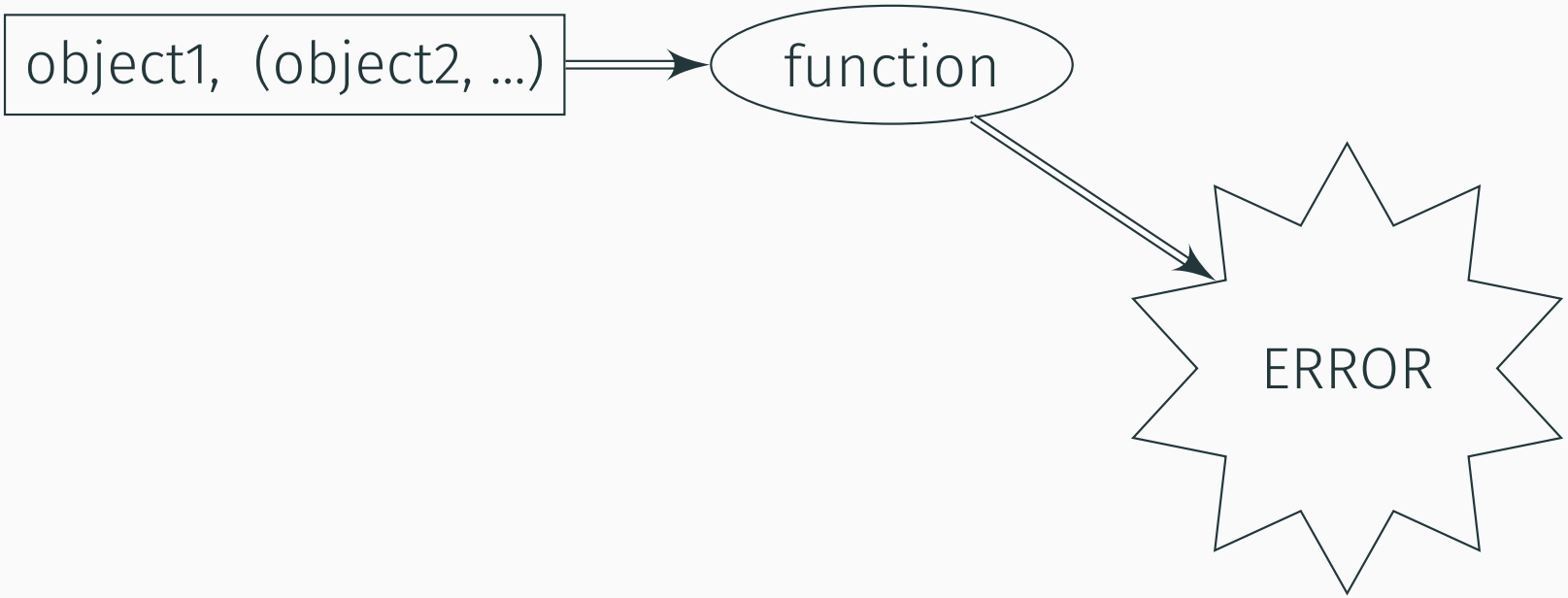


Figure 5: Computation with Error.

Error, warning, & message

`?stopifnot` is an abbreviation for `if(!test) stop()`:

```
get_log_xtox <- function(x) {
  stopifnot(is.numeric(x))
  x_x <- x^x
  return(log(x_x))
}
get_log_xtox("a")

> Error in get_log_xtox("a"): is.numeric(x) is not TRUE
```

Error, warning, & message

Message: To inform the user about something.

```
?message
```

```
get_log_xtox <- function(x) {
  x_x <- x^x
  message("Thank you for using this function!")
  return(log(x_x))
}
get_log_xtox(2)
```

```
> Thank you for using this function!

> [1] 1.386294
```

Error, warning, & message

Warning: Warn the user that something may be fishy.

```
?warning
```

```
get_log_xtox <- function(x) {
  if(x < 0 && (x %% 2 == 0))
    warning("Not sure you can trust the result.",
            call. = FALSE)
  x_x <- x^x
  return(log(x_x))
}
get_log_xtox(-2)
```

```
> Warning: Not sure you can trust the result.

> [1] -1.386294
```

Error, warning, & message

Message & warning: computation is NOT interrupted!

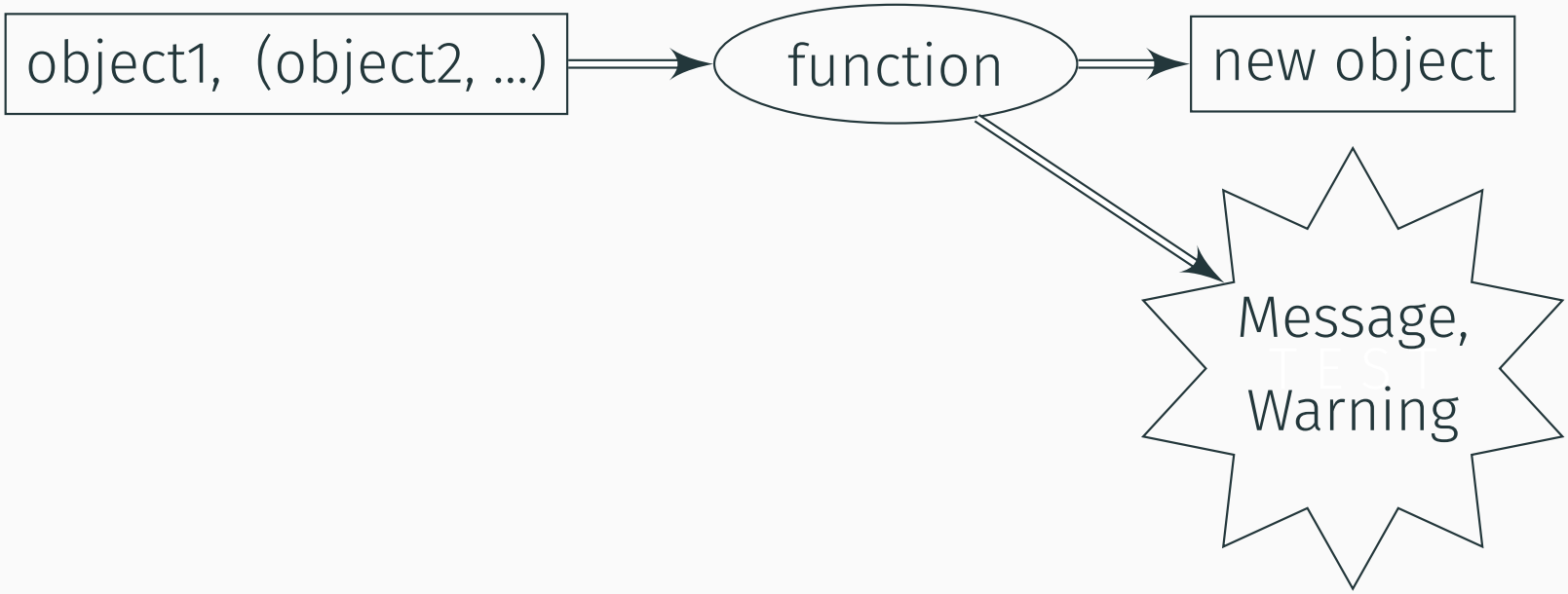


Figure 6: A message or warning.

Output

Programming advice

- Choose carefully when something warrants a message, warning or error
- Write clear and helpful warnings, errors, messages

Where does a function find objects?

R uses specific rules to find objects, which lead to the following:

```
a <- 55
add_a <- function(x){
  return(x + a)
}
add_a(5)

> [1] 60
```

When a function is called, the computations in the body are run line by line. When R cannot find an object inside the function, it looks outside the function.

Where does a function find objects?

Name masking!

Objects inside the function mask objects outside the function with the same name.

```
a <- 55
add_a <- function(x){
  a <- 5
  return(x + a)
}
add_a(5)

> [1] 10
```

`...` dot-dot-dot

R has a special argument (in the definition of the function):

`...` (dot-dot-dot)

Useful when you don't know how many arguments there will be. **Examples:**

- `?sum`
- `?save`
- `?cbind`
- `?paste`
- ...

... dot-dot-dot

A function that checks for multiple objects if they are character vectors. (A wrapper around (?is.character))

```
is_character <- function(...){
  input <- list(...)
  out <- logical(length(input))
  for(ell_nr in seq_along(input)){
    out[ell_nr] <- is.character(input[[ell_nr]])
  }
  names(out) <- names(input)
  out
}
is_character(a = "Awesome", b = 5, new = "YES")
```

```
>      a     b   new
>   TRUE FALSE  TRUE
```

`...` dot-dot-dot

`...` can take *any* number of additional arguments.
Useful for passing arguments to other functions like:

- `apply`-family
- `plot`-family
- ...

... dot-dot-dot

`apply` example:

```
get_quantiles <- function(x, ...){
  if(is.null(dim(x))) return(quantile(x, ...))
  apply(x, 2, quantile, ...)
}
get_quantiles(airquality, na.rm = TRUE,
              probs = c(.2, .8))
```

```
>      Ozone Solar.R  Wind Temp Month Day
> 20%    14       92  6.90   69   5.4   7
> 80%    73      266 12.96   86   8.0  25
```

... dot-dot-dot

WARNING!
Watch out with spelling mistakes, arguments can get lost!

```
get_quantiles <- function(x, ...){
  if(is.null(dim(x))) return(quantile(x, ...))
  apply(x, 2, quantile, ...)
}
get_quantiles(airquality, na.rm = TRUE,
              prosb = c(.2, .8))
```

```
>       Ozone Solar.R Wind Temp Month Day
> 0%     1.00    7.00  1.7   56     5   1
> 25%   18.00  115.75  7.4   72     6   8
> 50%   31.50  205.00  9.7   79     7  16
> 75%   63.25  258.75 11.5   85     8  23
> 100% 168.00  334.00 20.7   97     9  31
```

Writing Functions

Before creating a function

- What should my function do?
- Which input objects (Arguments)?
- Which additional options (Arguments)?
- What should the output object be?

After creating a function

- Test it
- Add input validation
- Document

Exercises

Functionals

Higher Order Functions

Higher order functions are functions that either **take functions as input** or **return functions as output**.

Functionals

As defined by Hadley Wickham: A **functional** is a function that takes another function as an input. Common argument names are `FUN` or `f`.

Examples

- `apply`-family
- `Reduce`, `Filter`
- `nlm`
- `optimize`
- ...

`apply`-family

The `apply`-family *applies* a function repeatedly. This can be seen as an abstraction of a for loop, with the following advantages:

- requires less code to write
- can be easier to read / understand
- does not store intermediate results
- no need to replace / grow

`apply`-family

The members of the `apply`-family in Base R are:

- `lapply` vector / list $\rightarrow$ list
- `sapply` vector / list $\rightarrow$ vector (matrix)
- `apply` matrix / array / data.frame $\rightarrow$ vector (matrix)
- `tapply`, `by`
- `mapply`, `Map`
- `rapply`, `eapply`, `vapply`

apply-family

A popular alternative from the tidyverse: purrr-package

- `map` vector / list $\rightarrow$ list
- `map2` multiple vectors / lists $\rightarrow$ list
- ...

lapply

Our focus: `lapply`

Why?

- Consistent output
- Fast
- No dependencies
- We want to understand R basics

lapply

`lapply` has two main arguments

`X` the input list/vector

`FUN` the function that should be repeatedly applied

```
example_list <- list(vec1 = c(1, 3, 4),
                     vec2 = c(4, 2, 10),
                     vec3 = c(2, NA, 1))
lapply(example_list, FUN = mean)
```

```
> $vec1
> [1] 2.666667
>
> $vec2
> [1] 5.333333
>
> $vec3
> [1] NA
```

lapply

Other arguments can be passed through `lapply` via '`...`'.

```
example_list <- list(vec1 = c(1, 3, 4),
                     vec2 = c(4, 2, 10),
                     vec3 = c(2, NA, 1))
lapply(example_list, FUN = mean, na.rm = TRUE)
```

```
> $vec1
> [1] 2.666667
>
> $vec2
> [1] 5.333333
>
> $vec3
> [1] 1.5
```

lapply

We can use our own functions as input.

```
dropNAs <- function(x) {
  x[!is.na(x)]
}
lapply(example_list, FUN = dropNAs)
```

```
> $vec1
> [1] 1 3 4
>
> $vec2
> [1]  4  2 10
>
> $vec3
> [1] 2 1
```

lapply

Anonymous functions can be used as input.

```
lapply(example_list, FUN = function(x) x[!is.na(x)])
```

```
> $vec1
> [1] 1 3 4
>
> $vec2
> [1]  4  2 10
>
> $vec3
> [1] 2 1
```

lapply

Data.frames are lists, too.

```
lapply(iris, FUN = class)


> $Sepal.Length
> [1] "numeric"
>
> $Sepal.Width
> [1] "numeric"
>
> $Petal.Length
> [1] "numeric"
>
> $Petal.Width
> [1] "numeric"
>
> $Species
> [1] "factor"
```

lapply

Vectors can be used as input, but often vectorization could be used instead.

```
lapply(c(1, 2, 3), FUN = function(x) {
  paste0("ID", x)
})


> [[1]]
> [1] "ID1"
>
> [[2]]
> [1] "ID2"
>
> [[3]]
> [1] "ID3"
```

lapply

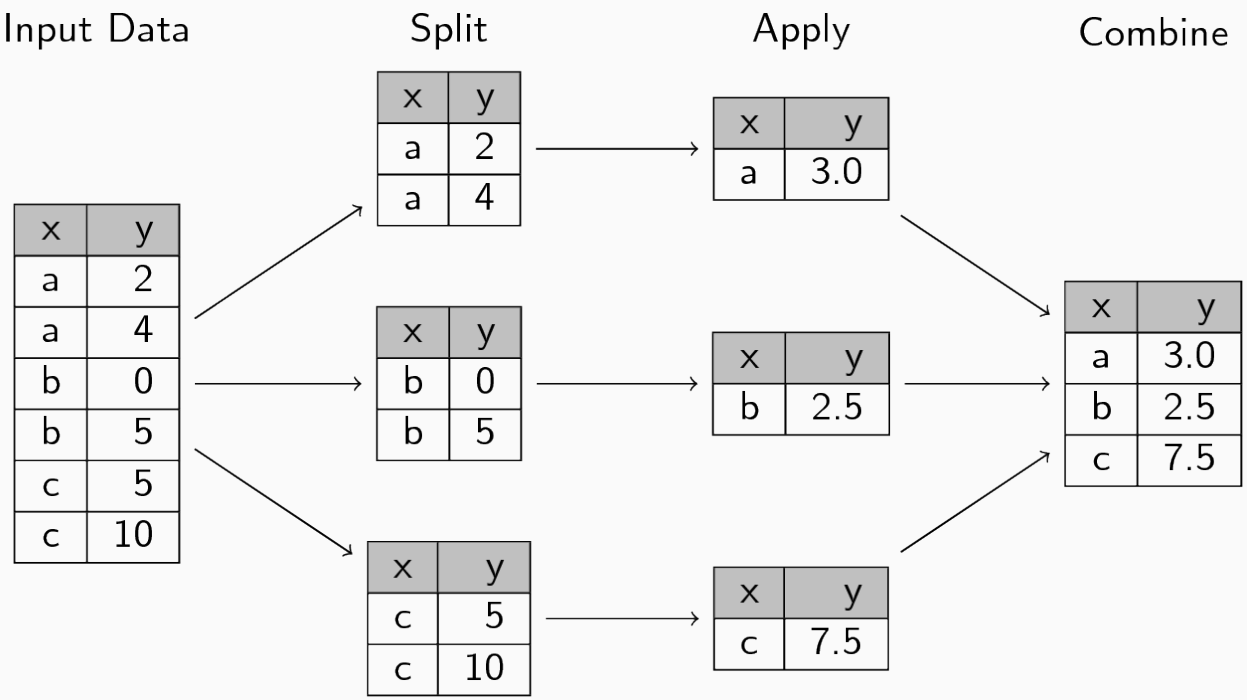
Limitation of `lapply`:
Only a single list/vector can be supplied as input. `Map` is a generalization of `lapply`! It is usually needed less often but a very powerful tool.

Split & Apply & Combine

A common use case for the `apply`-family is the **Split & Apply & Combine** paradigm. Here, we want to perform the same analyses for various subgroups in our data set:

- **split** a data.frame or vector (`?split`)
- **apply** computations on each split (`?lapply`)
- **combine** the results (`?do.call`)

Split & Apply & Combine



Split & Apply & Combine

```
head(iris)

>   Sepal.Length Sepal.Width Petal.Length Petal.Width Species
> 1          5.1         3.5          1.4         0.2  setosa
> 2          4.9         3.0          1.4         0.2  setosa
> 3          4.7         3.2          1.3         0.2  setosa
> 4          4.6         3.1          1.5         0.2  setosa
> 5          5.0         3.6          1.4         0.2  setosa
> 6          5.4         3.9          1.7         0.4  setosa

table(iris$Species)

>
>     setosa versicolor  virginica
>         50         50         50
```

Split & Apply & Combine

Splitting the data set via a single (or multiple) grouping variables

```
data_list <- split(iris, f = iris$Species)
class(data_list)

> [1] "list"

length(data_list)

> [1] 3
```

Split & Apply & Combine

Apply the same computation to all data sets

```
out_list <- lapply(data_list, function(subdat) {
  mod <- lm(Sepal.Length ~ Sepal.Width, data = subdat)
  sum_mod <- summary(mod)
  out <- c(Intercept = coef(mod)[[1]],
    Slope = coef(mod)[[2]],
    r2 = sum_mod$r.squared)
  round(out, 3)
})
```

Split & Apply & Combine

```
out_list[["virginica"]]

> Intercept      Slope         r2
>     3.907      0.902      0.209
```

Split & Apply & Combine

Combine the results

```
do.call(rbind, out_list)
```

```
>            Intercept Slope    r2
> setosa         2.639 0.690 0.551
> versicolor     3.540 0.865 0.277
> virginica      3.907 0.902 0.209
```

Exercises

Good programming practices

“Write code for humans, not for machines!”

Code Style

Invest time in writing readable R-code.

- It will make collaborations easier
- It will make debugging easier
- It will make your analyses more reproducible

There is a complete *tidyverse* style-guide.

Go easy on your eyes

- with spaces before and after: `- + / * = <- < == >`
- always use `<-` for assignments
- only use `=` in function calls
- use indentation (largely automatic in RStudio)
- `CamelCaseNames` vs `snake_case_names`
- be consistent!
- wrap long lines at column 70-80 (Rstudio)

White space

```
new_var=(var1*var2/2)-5/(var3+var4)

# versus

new_var <- (var1 * var2 / 2) - 5 / (var3 + var4)
```

Indentation

```
for(name in names){formula=as.formula(paste0("y~.-",name))
fit<-lm(formula,data=my_data)
coefs[["name"]]=coef(fit)
print(name)
print(summary(fit))}

# versus

for(name in names){
  formula <- as.formula(paste0("y~.-", name))
  fit <- lm(formula, data = my_data)
  coefs[["name"]] <- coef(fit)
  print(name)
  print(summary(fit))
}
```

Wrap long lines

```
final_results <- data.frame(first_variable =
sqrt(results$mean_squared_error), second_variable =
paste0(results$condition, results$class, sep = ":"),
third_variable = results$bias)

# versus

final_results <- data.frame(
  first_variable = sqrt(results$mean_squared_error),
  second_variable = paste0(results$condition,
                           results$class, sep = ":"),
  third_variable = results$bias)
```

Go easy on your mind

- use meaningful names: “self-explainable”
- always write the formal arguments in function calls (except the first)
- benefit from autocompletion (`<tab>`) => embrace longer names
- use `TRUE` and `FALSE` not `T` and `F`
- comment, comment, comment
  - NOT what (should be clear from the code)
  - but why
  - explain the reasoning, not the code

Use meaningful names

```
V <- myFun(m1_B)

# versus

RMSE_age_gender <- get_RMSE(lm_age_gender)
```

Programming advice

Use `verbs` for functions and **nouns** for other objects.

Write formal arguments

Benefit from auto completion using `tab`

```
m1_B <- lm(outcome ~ age*gender,
           exp1, condition_1, freq)

# versus

lm_age_gender <- lm(outcome ~ age * gender,
                    data = exp1,
                    subset = condition_1,
                    weigths = freq)
```

Comment, comment, comment

```
## Start every Rscript with a comment that explains
##  what the code in the script does, why it does
##  this, and to which project it belongs.
##  Your future self will be very thankful!
##
## Mention which packages you are using in this Rscript.

## Use sections to separate chunks ----------------------

## Maybe even subsections ==============================

## Recode variables so that missings are coded as "NA"
dat[dat %in% c(99, 999)] <- NA  # missings coded 99 or 999
```

Keep your code slim

Try to limit your *package-dependencies*.

Only load `library()` the packages that you absolutely need. If you are only using `dplyr`, it does not make sense to load the complete `tidyverse`.

Controversial: when possible, use the `::` operator (and consider not loading the package).
`<package>::<function>`

- explicit dependencies
- less name conflicts

Never Attach

Forget about `attach()`!

Don't use it, unless you completely understand what happens (see `?attach`).

Use `with(data.frame, expression)` instead.

```
# using with()
n <- 2e+4
data <- data.frame(x = runif(n),
                   y = runif(n),
                   z = seq_len(n))
result <- with(data, exp(x) / log(z) + 5 * sqrt(y))
```

Testing R code

Writing code is error prone. Incorporate tests and checks in your workflow.

- minimal examples
- write tests and checks
- helpful packages: `testthat`, `RUnit`, `testit`, ...

Speed

Computing speed can become an issue. Avoid common pitfalls:

- don't grow, but replace
- vectorize where possible
- check the computing speed

`?system.time`, microbenchmark or profiling tools

```
n <- 2e+4
data <- data.frame(x = runif(n),
                   y = runif(n),
                   z = seq_len(n))
```

Speed

Don’t grow!

```
system.time({
  new_data <- NULL

  for(row_nr in seq_len(NROW(data))){
    new_data <- cbind(
      data[row_nr,],
      result = exp(data$x[row_nr]) /
        log(data$z[row_nr]) +
        5 * sqrt(data$y[row_nr]))
  }
})

>    user  system elapsed
>    2.16    0.09    2.27
```

Speed

Replace!

```
system.time({
  n_rows <- dim(data)[1]
  data$result <- rep(NA, n_rows)

  for(row_nr in seq_len(n_rows)){
    data$result[row_nr] <- exp(data$x[row_nr]) /
      log(data$z[row_nr]) +
      5 * sqrt(data$y[row_nr])
  }
})

>    user  system elapsed
>    0.25    0.61    0.88
```

Speed

Vectorize!

```
system.time({
  data$result <- exp(data$x) / log(data$z) +
    5 * sqrt(data$y)
})

>    user  system elapsed
>       0       0       0
```

Speed

Compare the speed of different implementations using:

`microbenchmark::microbenchmark`

```
get_mean1 <- function(x){
  weight <- 1/length(x)
  out <- 0
  for(i in seq_along(x)){
    out <- out + x[i] * weight
  }
  return(out)
}

get_mean2 <- function(x){
  sum(x)/length(x)
}
```

Speed

Compare the speed of different implementations using:

`microbenchmark::microbenchmark`

```
x <- rnorm(500)
microbenchmark::microbenchmark(
  mean(x), get_mean1(x), get_mean2(x))

> Error in loadNamespace(x): there is no package called
'microbenchmark'
```

Speed

Programming advice

Don’t worry about speed before it becomes an issue.

Wrap Up

General Advice

- Investing time in learning R pays off
- It's a steady learning curve
- Learn from masters
- Rewrite important code - the first attempt is usually not the best approach

General R Advice

- Document well
- Use a consistent style
- Write functions
- Split long functions in smaller ones
- Write wrappers
- Use Iteration (don’t copy paste)
- Use matrix operations and vectorized functions instead of loops
- Use git

Literature Recommendations

R Resources

- Avanced R Ed. 1
- Avanced R Ed. 21
- R Inferno
- R Packages
- Clean Code

Thank you for your attention!

Thank you for your attention!

Questions? Remarks?