

# Programming in R

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FDZ Spring Academy

# Introduction

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## Who are we?

### Dries Debeer

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## Who are you?

1. Occupation, employer?
2. Previous knowledge and experience
  - with R?
  - with other statistical software?
  - with other programming languages?
3. Specific interest/motivation for this workshop?

# Motivation

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

# Motivation

Two of your worst collaborators:

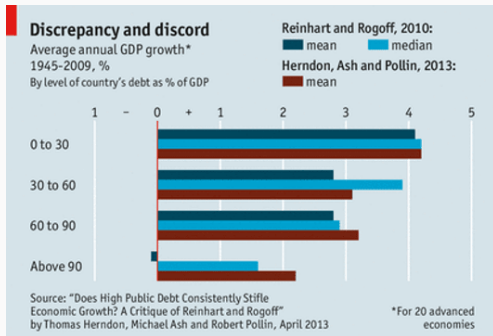
## 1. Past Self

- The biggest mess in existence
- did not document anything
- uses a completely different style of writing code
- does not reply to e-mails

## 2. Future Self

- has the memory of a goldfish
- will have zero understanding for your current brilliance

# Motivation



The Sunday Telegraph Sunday 17 May 2020

Coronavirus

## Selling behind lockdown was a reliable buggsy mess, claim experts

Data that predicted 500,000 could die in UK unless extreme measures were taken are impossible to replicate, say scientific teams

### Science

**By Hannah Ireland and Peter Dinkley**  
The Covid-19 modelling that used little as its lockdown, missing the economy and leaving millions out of work has been criticised by experts.

Prof Nick Ferguson's Imperial College computer coding was derided as "totally unreliable" by leading experts who warned it was "something you wouldn't stake your life on".

The model, credited with forcing the Government to close bars and introduce a nationwide lockdown, is a "buggy mess, where loads more than a level of eight last pasts than a busy street piece of programming", said David Forth, the co-founder of British data technology company Walekita.

"In our commercial reality, we would not agree for developing code like this and any business that relied on it to produce software for sale would likely go bust."

The comments are likely to relegate a row over whether the UK was right to go into lockdown, with conflicting models suggesting people may have already acquired substantial herd immunity and Covid-19 may have hit Britain earlier than first thought.

Scientists have also been split on the likely rate of Covid-19 which has resulted in vastly different models.

To add to the confusion, several models have been attacked by Imperial itself, which placed the fatality rate higher than others and predicted Covid-19 in the UK could be without a lockdown.

It was said to have prompted a dramatic change in government policy causing businesses, schools and restaurants to be shut immediately in March. The Bank of England has predicted that the economy could take a year to return to normal, after its worst recession in more than 80 years.

The Imperial model works by using code to simulate transport links, population size, social networks and using economic provisions to predict how consumers would spend. However, questions have emerged over whether the model is accurate, after researchers released its code, which in its original form was "dozens of lines" down speed over more than 10 years.

In its initial form the code was untestable, developers claimed, with some parts looking "like they were made

'In our commercial reality, we would fire anyone for developing code like this'

'Any business that relied on it to produce software for sale would likely go bust'

'It looks more like a bowl of angel hair pasta than a finely tuned piece of programming'

'The early 2000s were yet another confirmation that their modelling approach was flawed to the core'

chase translated from Fortran", an old coding language, according to John Carnall, a US developer, who helped clean the code before it was published.

Yet, the problems appear to go much deeper than messy coding. Many have claimed that it is almost impossible to replicate the same results from the same data, using the same code.

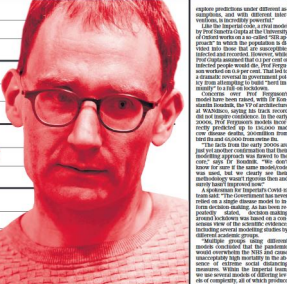
Scientists from the University of Edinburgh said they got different results when they used different ma-

chine, and even in some cases using the same machines. "There appears to be a bug in either the compiler or in use of the network file. If we attempt two completely identical runs, only varying in that the second should use the network file produced by the first, the results are quite different", the Edinburgh researchers wrote on the GitHub website.

After a discussion with a GitHub developer, it was provided. It is said to be one of a number of

bugs discovered within the system. GitHub developers said that the model was "dozens of lines" of code and "would give results with different seeds should be indicative to see average behaviour".

It has prompted questions from scientists, who say "models must be capable of passing the basic scientific test of providing the same results given the same initial set of parameters". Otherwise, there is simply no way of knowing whether they will be reliable.



explore predictions under different assumptions, and with different interventions, is incredibly powerful."

Like the Imperial code, a rival model by Prof Imperial College at the University of Oxford works on a so-called "SIR approach" in which the population is divided into those that are susceptible, infected and recovered. However, while Prof Gupta assumed that 0.1 per cent of infected people would die, Prof Ferguson worked on a 1 per cent. That led to a dramatic reversal in government policy from attempting to "lock" herd immunity to a full-on lockdown.

Concrete over Prof Ferguson's model have been raised, with Dr Fernando Bonabeau, the VP of architecture at Walekita, saying his track record did not inspire confidence. In the early 2000s, Prof Ferguson's models incorrectly predicted up to 100,000 road case deaths, accumulation from both his and his team from within the.

The facts from the early 2000s are not yet another confirmation that their modelling approach was flawed to the core," says Dr Bonabeau. "We don't know for sure if the same model/code was used, but we clearly see their methodology wasn't rigorous then and surely hasn't improved now."

A spokesman for Imperial's Covid-19 team said: "The Government has never relied on a single disease model to inform decision making. As has been previously stated, decision making during lockdown was based on a consensus view of the scientific evidence, including several modelling studies by different academic groups."

Multiple groups using different models concluded that the pandemic would overwhelm the NHS and cause unacceptable high mortality in the absence of effective social distancing measures. Within the Imperial team, we use several models of differing levels of complexity, all of which produce consistent results. We are working with legitimate academic groups and technology companies to develop and further document the simulation code, which is, however, not the partisan reviews of a few clearly ideological and motivated commentators.

"Epistemology is not a branch of computer science and the continuous arrival of lockdowns rely not on any mathematical model but on the scientific consensus that Covid-19 is highly transmissible with an infectious fatality rate exceeding 0.1 per cent in the UK."



## Concept of Technical Debt

- We write (messy) code for data cleaning/analyses
- We decide on data sets/models/graphs/tables/...
- We try to publish it, get a major revision
- We need to rerun some analyses
- Modifying/extending our code is more difficult than it should be

## Trade-off

- Being fast vs. writing (or refactoring) perfect code

## But also

- Write better R code

# Goal of this workshop

## An introduction to R as a Programming language

- Better practical R skills
- Better understanding of R (and programming)
- Different framing: R as a programming language

# Agenda

## Day 1

- RStudio setup
- Flow & conditional programming
- Loops & iteration
- Functions (part I)

## Day 2

- Functions (part II)
- Functional split-apply-combine
- Good programming practices

# RStudio setup

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# RStudio setup

1. Copy the course content from the usb-stick to a directory on your machine
2. Open RStudio
3. Choose `File < New Project ...`
4. Choose `Existing Directory`
5. Browse to the directory on your machine where you copied the course content and select the “Intro-R-programming” folder as the `Project working directory`
6. Click `Open in new session`
7. Click `Create Project`

## RStudio setup - optional

1. Choose Tools < Global options
2. Under General
  - DON'T Restore .RData into workspace at startup
  - NEVER Save workspace to .Rdata on exit:
3. Further personalize RStudio

# Flow & conditional programming

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# Flow & conditional programming

R has specific tools (functions) that help organize the flow of computations.

You can make computations conditional on other objects (“conditional computation”)

The most commonly used tools are:

- `if (+ else)`
- `ifelse`



# Conditional Computation - if

if statements have the basic form

```
if(test){  
    some_computations  
}
```

- test should be either TRUE or FALSE (or code that results in one of both).
- If test == TRUE, than some\_computations is executed, if test == FALSE, than not.
- **Important:** test should have length 1. If not, only the first element is considered.

# Conditional Computation - if

else can be added, but it is optional

```
if(test){  
    some_computations  
} else if (test_2){  
    other_computations  
} else {  
    more_computations  
}
```

## Typical test functions

Vectorized, elementwise	
<code>==</code>	equal to
<code>!=</code>	NOT equal to
<code>&gt;, &lt;</code>	is greater, less than
<code>&gt;=, &lt;=</code>	is greater, less than or equal to
<code>&amp;</code>	AND operator
<code> </code>	OR operator
<code>xor</code>	exclusive OR

## Typical test functions

Not Vectorized	
<code>identical()</code>	identical to
<code>any()</code>	at least one TRUE
<code>all()</code>	all TRUE
<code>&amp;&amp;</code>	AND operator
<code>  </code>	OR operator
<code>is.character(), is.data.frame(), ...</code>	

# Typical test functions

Compare:

```
c(TRUE, TRUE) & c(FALSE, TRUE)
```

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

```
c(TRUE, TRUE) && c(FALSE, FALSE)
```

```
> [1] FALSE
```

# Conditional Computation - if

The *test* should have length 1!

```
# only the first element is evaluated
age <- c(8, 17, 39, 55)
if (age >= 18) {
  "can vote"
} else {
  "too young"
}
```

```
> Warning in if (age >= 18) {: Bedingung hat Länge > 1 und nur
das erste Element wird benutzt
```

```
> [1] "too young"
```

# Conditional Computation - if

## Typical uses

```
if(any(is.na(x))){  
  stop("computation impossible due to NA values")  
}  
  
if(!is.integer(vector)){  
  warning("'vector' is automatically converted to interger.  
          This may affect the results")  
  vector <- as.integer(vector)  
}  
  
if(is.null(argument)){  
  # default computations  
} else if (argument == specific_value) {  
  # other computations  
}
```

# Conditional Computation - if

## Programming advice

- *if* is almost always used inside of functions or loops
- If possible, avoid using *else*
- Use meaningful initialization, early `return()`, `stop()`, etc. instead



# Conditional Computation - if

Solution using *if* and *else*

```
age <- 17
if (age >= 18) {
  vote <- "can vote"
} else {
  vote <- "too young"
}
vote

> [1] "too young"
```

# Conditional Computation - if

Solution using meaningful initialization

```
age <- 17
vote <- "too young"
if (age >= 18) {
  vote <- "can vote"
}
vote

> [1] "too young"
```

# Conditional Computation - ifelse

A vectorized version is `ifelse()`.

```
# all elements are evaluated
```

```
age <- c(8, 17, 39, 55)
```

```
ifelse(age >= 18,  
       yes = "can vote",  
       no  = "too young")
```

```
> [1] "too young" "too young" "can vote"  "can vote"
```

# Conditional Computation - ifelse

Go-to tool for conditional recoding

```
age_estimated <- c(10, 20, 35, 60)
age_self_rep <- c(NA, 17, 39, NA)

# Use available information, prioritize self report
ifelse(!is.na(age_self_rep),
      yes = age_self_rep,
      no = age_estimated)

> [1] 10 17 39 60
```

# Exercises



# Loops & Iteration

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# 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 (repeat, while, for)
- functionals (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

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

> computation - computation - computation -

# 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 - for

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
```

# 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 - while

Sample five random values from a normal distribution, the distance between the minimum and maximum should be at least 4.

```
max_dif <- 0
while (max_dif <= 4){
  cat("|")
  values <- rnorm(5)
  max_dif <- max(values) - min(values)
}
```

```
> | | | | | | | | | | | | | | | | | | | |
```

```
max_dif
```

```
> [1] 4.041407
```

```
round(values, 3)
```

```
> [1] 0.177 0.462 1.367 2.675 0.764
```

# 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)

```
index <- 0
repeat {
  index <- index + 1
  if (index %in% c(3, 5)) next
  if (index > 6) break
  print(index)
}
```

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

# Iteration - Good practice

## Programming advice

Use `seq()`, `seq_len()`, or `seq_along()`.

```
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
}
```



TODO: shorter introduction, focus on simple cases:

- apply examples
- lapply examples
- goodpractice: use lapply (see tomorrow)

# Loops & Iteration - Functionals

A functional is a function that takes another function as an argument.

Focus on the `apply`-family. These functions *apply* a function repeatedly.

Can be seen as an abstraction of a for loop, with the following advantages

- requires less code to write
- does not store intermediate results
- no need to replace / grow

# Functionals

The most commonly used functionals are:

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

All of which have an argument that should be a function.

# lapply

data.frames are lists with the columns as elements:

```
lapply(iris, FUN = class)
```

```
> $Sepal.Length
```

```
> [1] "numeric"
```

```
>
```

```
> $Sepal.Width
```

```
> [1] "numeric"
```

```
>
```

```
> $Petal.Length
```

```
> [1] "numeric"
```

```
>
```

```
> $Petal.Width
```

```
> [1] "numeric"
```

```
>
```

```
> $Species
```

```
> [1] "factor"
```

# lapply

- any type of element can be used
- other arguments can be passed through

```
means <- lapply(airquality, FUN = mean, na.rm = TRUE)
str(means)
```

```
> List of 6
> $ Ozone   : num 42.1
> $ Solar.R: num 186
> $ Wind    : num 9.96
> $ Temp    : num 77.9
> $ Month   : num 6.99
> $ Day     : num 15.8
```

# apply

- for objects with dimension (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

# 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

## 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

```
countNA <- function(x) {  
  out <- sum(is.na(x))  
  out  
}
```

# Name  
# Arguments/Formals  
# Body  
# 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

Examples for zero arguments

- `getwd()`
- `Sys.time()`

Examples for one argument

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

# Arguments

Examples for 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
```

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



# Output

Functions usually return a single object, namely the last evaluated object.

```
get_log_xtox <- function(x) {  
  x_x <- x^x  
  out <- log(x_x)  
  out  
}  
get_log_xtox(2)  
  
> [1] 1.386294
```

# Exercises



## Functions II

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## 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 transferability to ...
  - other use cases
  - other projects
  - other persons
- They keep your work space clean

## Writing a function:

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

## Not writing a function:

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

## Writing a function:

```
summary(mtcars$mpg)
```

```
>      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
>   10.40   15.43   19.20   20.09   22.80   33.90
```

## Not writing a function:

```
round(c("Min." = min(mtcars$mpg),  
      "1st Qu." = as.numeric(quantile(mtcars$mpg)[2]),  
      "Median" = median(mtcars$mpg),  
      "Mean" = mean(mtcars$mpg),  
      "3rd Qu." = as.numeric(quantile(mtcars$mpg)[4]),  
      "Max." = max(mtcars$mpg)), 2)
```

```
>      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.  
>    10.40   15.43   19.20   20.09   22.80   33.90
```

# Single return object

Pure functions return a single object.

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



**Figure 2:** A pure function.



# Single return object

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

```
return_early <- function(x = 1) {  
  x2 <- x*2  
  return(x2)  
  out <- x + x2    # not executed  
  out  
}  
return_early(2)  
  
> [1] 4
```

# Single 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
}
```

# Single Return Object

The return object is 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))  
}
```

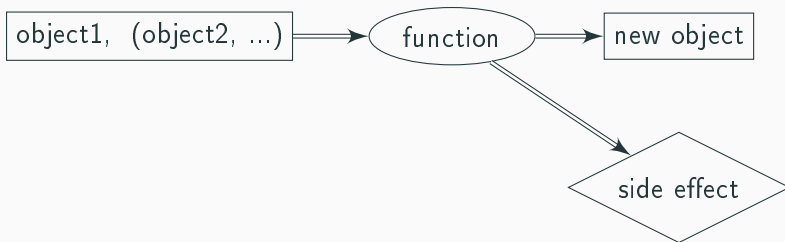
```
str(get_info(airquality$Wind))
```

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

# 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.
```

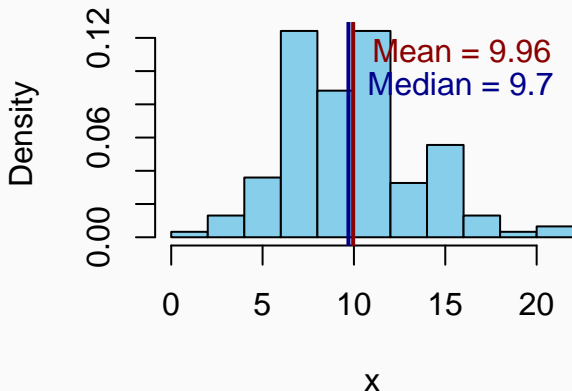
Graphics output: Standard plot, ggplot2, lattice

```
hist2 <- function(x, title){  
  info <- get_info(x)  
  mean_median <- as.numeric(info[c("mean", "median")])  
  hist(x, col = "skyblue", freq = FALSE,  
       main = paste0(title, " (n = ", info$n_obs, ")"))  
  abline(v = mean_median, lwd = 2,  
         col = c("darkred", "darkblue"))  
  text(mean_median, y = c(.11, .09),  
       labels = paste(c("Mean", "Median"),  
                     round(mean_median, 2),  
                     sep = " = "),  
       col = c("darkred", "darkblue"), pos = 4)  
}  
hist2(airquality$Wind, "Wind")
```

## Side effects

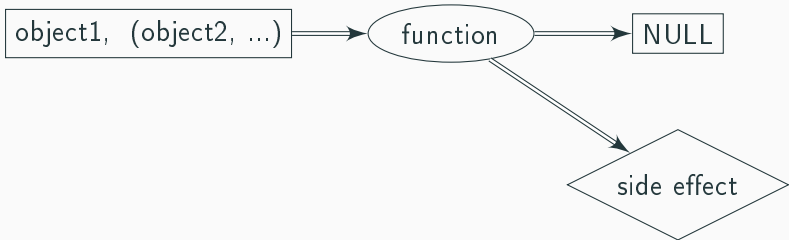
Graphics output

### Wind (n = 153)



## 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

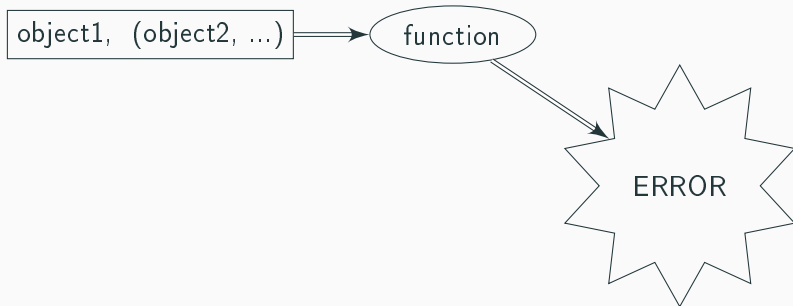
Error: computation is interrupted without return object!

?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) ist nicht 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

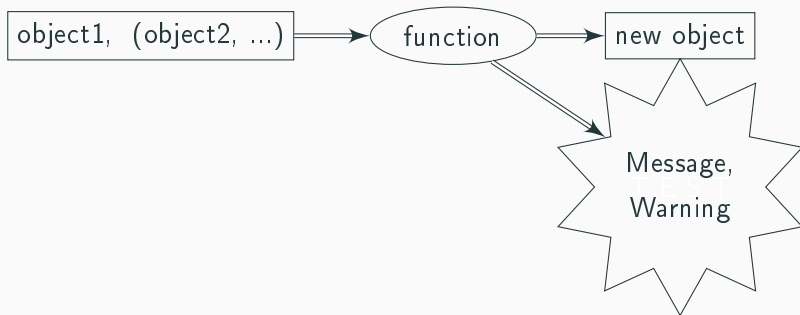
```
get_log_xtox <- function(x) {  
  if(x < 0 && (x %% 2 == 0))  
    warning("Not sure you can trust the result.",  
           call. = FALSE)  
  x_x <- x^x  
  return(log(x_x))  
}  
get_log_xtox(-2)
```

```
> 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.

## Programming advice

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

# Default arguments

What happens if the user omits an argument?

```
add_ten <- function(x) {  
  return(x + 10)  
}  
add_ten()
```

```
> Error in add_ten(): Argument "x" fehlt (ohne Standardwert)
```



# Default arguments

Default arguments are made for such instances!

```
add_ten_default <- function(x = 0) {  
  return(x + 10)  
}  
add_ten_default()  
  
> [1] 10
```

# Default arguments

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

Try ?lm

## Programming advice

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

# Lazy Evaluation

R only considers (evaluates) an argument when it is used.

```
add_ten_lazy <- function(x, y) {  
  return(x + 10)  
}  
add_ten_lazy(2, y = stop("This is not evaluated"))  
  
> [1] 12
```

# Lazy Evaluation

R only considers (evaluates) an argument when it is used. But, you can force the evaluation:

```
add_ten_force <- function(x, y) {  
  force(y)  
  return(x + 10)  
}  
add_ten_force(2, y = stop("Evaluation was forced"))  
  
> Error in force(y): Evaluation was forced
```

?force

# 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`
- ...



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

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`

A popular alternative from the tidyverse: `purrr`

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

Our focus: `lapply` and `Map`

**Why?**

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

# lapply

`lapply` takes mainly two 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 '...'.  
lapply

```
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
```

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

Atomic 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"
```

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.

# Map

Works very similar to `lapply`, with a few differences:

- Multiple input lists/vectors
- The list input should be named explicitly
- The order of the function and the list-input is switched

```
list1 <- list(mtcars[1:2, 1:3], iris[1:2, c(1, 2, 5)])  
list2 <- list(mtcars[3:4, 1:3], iris[3:4, c(1, 2, 5)])
```

```
Map(rbind, x = list1, y = list2)
```

# Map

```
> [[1]]  
>           mpg cyl disp  
> Mazda RX4      21.0   6  160  
> Mazda RX4 Wag  21.0   6  160  
> Datsun 710      22.8   4  108  
> Hornet 4 Drive 21.4   6  258  
>  
> [[2]]  
> Sepal.Length Sepal.Width Species  
> 1           5.1           3.5  setosa  
> 2           4.9           3.0  setosa  
> 3           4.7           3.2  setosa  
> 4           4.6           3.1  setosa
```

Again, anonymous functions can be supplied as input:

```
list1 <- list(mtcars[1:2, 1:3], iris[1:2, c(1, 2, 5)])  
list2 <- list(mtcars[3:4, 1:3], iris[3:4, c(1, 2, 5)])
```

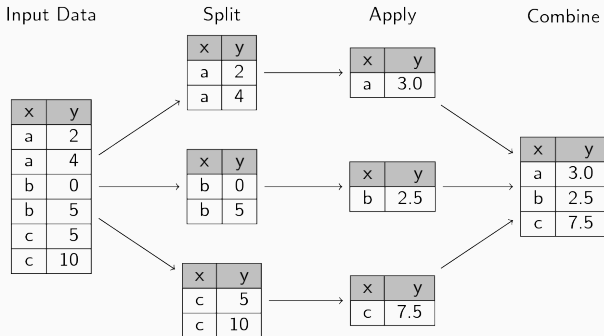
```
Map(function(x, y) {  
  rbind(x, y)  
},  
x = list1, y = list2)
```

# 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



# Functions III

---

## 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
```

# Where does a function find objects?

R uses specific rules to find objects.

```
a <- b <- c <- d <- "fourth"
find_object <- function(a, b = "third", c = "third"){
  a <- "first"
  return(c(a = a, b = b, c = c, d = d))
}
find_object(b = "second")

>      a      b      c      d
> "first" "second" "third" "fourth"
```

# Where does a function find objects?

R uses specific rules to find objects.

1. in the function body
2. in the function call
3. in the function definition
4. outside the function

Watch out with number 4! Frequently restart R: `Ctrl + shift + F10`

# Functional programming

The return object should only depend on the arguments of the function, ***not*** on the context!

**BAD:**

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

> [1] 60
```

# Functional programming

The return object should only depend on the arguments of the function, ***not*** on the context!

**GOOD:**

```
add_a <- function(x, a = 55){  
  return(x + a)  
}  
add_a(5)  
  
> [1] 60
```

# Functional programming

The function should not change the context.

## BAD

```
a <- 55
change_a <- function(new_a){
  a <- new_a
  return(invisible(NULL))
}
change_a(5)
a

> [1] 5
```

## ... 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
- ...

## ... dot-dot-dot

... can take *any* number of additional arguments

Useful for passing arguments to other functions like:

- ?apply
- ?plot
- ...



... dot-dot-dot

TO DO: include example where the number of arguments is unknown. plot example

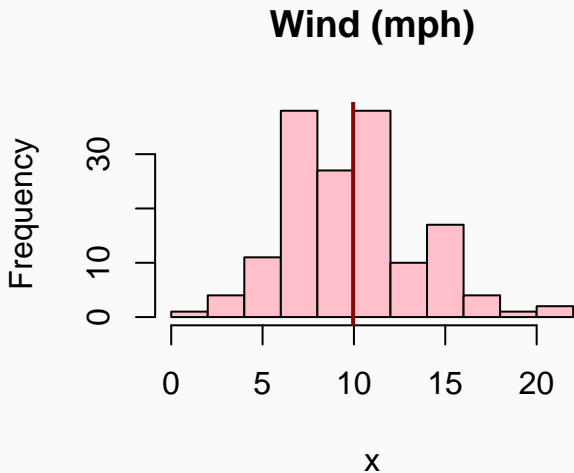
## ... dot-dot-dot

plot example

```
hist3 <- function(x, ...){  
  hist(x, ...)  
  abline(v = mean(x, ...),  
         col = "darkred",  
         lwd = 2)  
}  
hist3(airquality$Wind, col = "pink",  
      main = "Wind (mph)")
```

... dot-dot-dot

plot example



## ... dot-dot-dot

apply example.

```
get_quantiles <- function(x, ...){  
  out <- lapply(x, quantile, ...)  
  return(do.call(rbind, out))  
}  
get_quantiles(airquality, na.rm = TRUE,  
              probs = c(.25, .5, .27))
```

```
>           25%   50%   27%  
> Ozone      18.00  31.5  18.05  
> Solar.R  115.75 205.0 127.00  
> Wind       7.40   9.7   7.40  
> Temp      72.00  79.0  73.00  
> Month      6.00   7.0   6.00  
> Day       8.00  16.0   9.00
```

## ... dot-dot-dot

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

```
get_quantiles <- function(x, ...){  
  out <- lapply(x, quantile, ...)  
  return(do.call(rbind, out))  
}  
get_quantiles(airquality, na.rm = TRUE,  
              probs = c(.25, .5, .75))
```

```
>           0%    25%   50%   75%  100%  
> Ozone      1.0  18.00  31.5  63.25 168.0  
> Solar.R    7.0 115.75 205.0 258.75 334.0  
> Wind       1.7   7.40   9.7  11.50  20.7  
> Temp      56.0  72.00  79.0  85.00  97.0  
> Month      5.0   6.00   7.0   8.00   9.0  
> Day        1.0   8.00  16.0  23.00  31.0
```

## on.exit()

Performing an action when the function terminates.

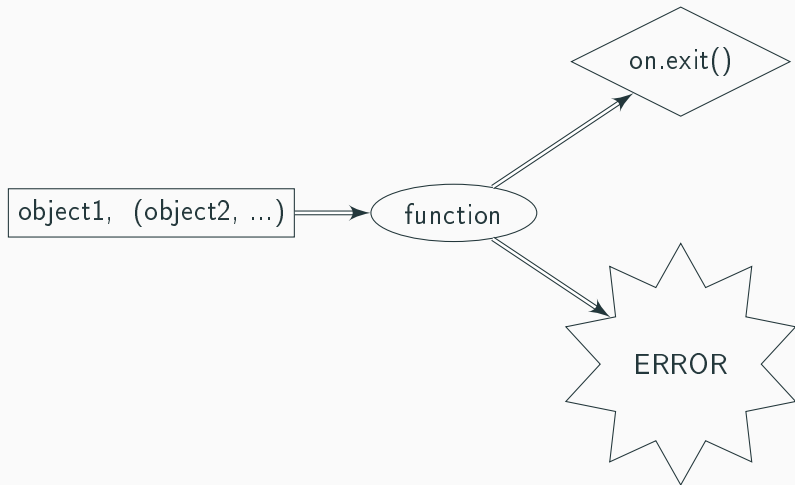
```
add_ten_on_exit <- function(x) {  
  on.exit(cat("Finished 'add_ten_on_exit', with input '",  
             x, "'. \n", sep = ""))  
  return(x + 10)  
}  
add_ten_on_exit(1)  
  
> Finished 'add_ten_on_exit', with input '1'.  
> [1] 11
```

## on.exit()

Performing an action when the function terminates.

```
add_ten_on_exit <- function(x) {  
  on.exit(cat("Finished 'add_ten_on_exit', with input '",  
             x, "'. \n", sep = ""))  
  return(x + 10)  
}  
add_ten_on_exit("one")  
  
> Error in x + 10: nicht-numerisches Argument für binären  
Operator  
  
> Finished 'add_ten_on_exit', with input 'one'.
```

## Error, warning, & message



**Figure 7:** on.exit() with error.

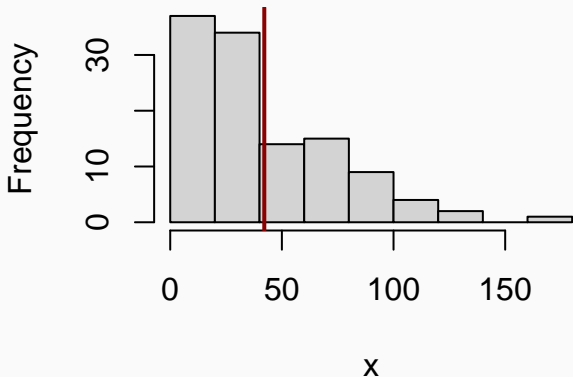


Useful when your function has side effects:

```
hist3 <- function(x, ...){  
  old_options <- getOption("warn")  
  on.exit(options(warn = old_options))  
  options(warn = -1)  
  hist(x, ...)  
  abline(v = mean(x, ...),  
         col = "darkred", lwd = 2)  
}  
hist3(airquality$Ozon, na.rm = TRUE)
```

Useful when your function has side effects:

## Histogram of x



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

— John Chambers

# Functions are objects

Functions are also objects. They can be arguments.

- apply-family
- ...

```
do_this_that <- function(function1, function2, x){  
  function2(function1(x))  
}  
do_this_that(sum, log, 0:3)  
  
> [1] 1.791759
```

# Writing Functions

Before creating the function

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

After creating the function

- Test it
- Add input validation
- Document

# What makes a good function?

## Pure functions!

- no side effects
- no dependency on global environment
- only input via arguments (functional programming)

Results in easier understanding and higher portability.

# Exercises



# Good programming practices

---



“Write code for humans, not for machines!”

Invest time in writing readable R-code.

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

There is a complete *tidyverse* style-guide

<https://style.tidyverse.org/>.

# 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>`)  $\Rightarrow$  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,  
                    weights = 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))
```

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

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

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))
```

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 verstrichen  
>      2.17      0.02      2.25
```

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 verstrichen  
>      0.39      0.00      0.41
```



Vectorize!

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

```
>      User      System verstrichen  
>      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)  
}
```

Compare the speed of different implementations using:

```
microbenchmark::microbenchmark
```

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

> Unit: nanoseconds

	expr	min	lq	mean	median	uq	max	neval
>	mean(x)	2400	3400	4406	3700	4050	19400	100
>	get_mean1(x)	13600	22150	56914	23700	25150	3359700	100
>	get_mean2(x)	800	1100	14346	1200	1400	1299100	100

## Programming advice

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

“Every project should get an RStudio Project!”

Don't use `setwd("path\to\my\local_folder")`

Issues when:

- folders names are changed
- folders are moved
- a shared drive is used
- you ZIP and send the folder

Don't save work space to `.RData`.

- Tools < Global Options < Workspace < Save workspace ....
- Save the code instead!
- Use `saveRDS()` and `readRDS()` for objects that require long computations

Don't use `rm(list = ls())` at the start of an Rscript.

- Start clean, every time.
- Keep it clean. No outside code, no outside computing.
- Regularly completely clean the work space (or restart the session).

```
.rs.restartR()
```

Keep it clean

- one folder per project!
- work on different projects in different RStudio instances!
- each with own R console, working directory, ...



# Working with RStudio

Organize your project folder

- R-folder with R scripts
- Data-folder with data
- split long scripts in meaningful chunks
- use relative paths (alternative: here-package)

```
# read data
this_data <- read.csv("Data\\the-correct-file.csv")

# source Rscript
source("R\\0_first-script-to-source.R")
```

## Use keyboard shortcuts

- Can make working in RStudio more efficient
- Completely tunable: Tools < Modify Keyboard Shortcuts...
- Useful shortcuts (defaults):
  - jump to editor: `ctrl + 1`
  - jump to console: `ctrl + 2`
  - jump to ...: `ctrl + 3-9`
  - jump to next tab: `ctrl + tab`
  - jump to previous tab: `ctrl + shift + tab`

More useful shortcuts (defaults):

- run selection/selected line: `ctrl + enter`
- save current file: `ctrl + s`
- close current file: `ctrl + w`
- restart R: `ctrl + shift + F10`
- Show help (for function at cursor) `F1`
- Show source code (for function at cursor) `F2`

More on this [HERE](#).

# Exercises



## Wrap Up

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- 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

## R Resources

- Advanced R Ed. 1 (<http://adv-r.had.co.nz/>)
- Advanced R Ed. 2 (<https://adv-r.hadley.nz/>)
- R Inferno ([https://www.burns-stat.com/pages/Tutor/R\\_inferno.pdf](https://www.burns-stat.com/pages/Tutor/R_inferno.pdf))
- R Packages (<https://r-pkgs.org/>)
- Clean Code (<https://enos.itcollege.ee/~jpoial/oop/naited/Clean%20Code.pdf>)



Thank you for your attention!

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Questions? Remarks?