R language: a tour

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- **M1 MIDS**
- **Université Paris Cité**
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- Course Homepage

- Moodle

> **❗ Objectives**
>
> This workbook intends to walk you through basic aspects of the `R` language and programming environment.

Packages

Base `R` can do a lot. But the full power of `R` comes from a fast growing collection of `packages`.

Packages are first *installed* (that is downloaded from `cran` and copied somewhere on the hard drive), and if needed, *loaded* during a session.

- Installation can usually be performed using command `install.packages()`. In some circumstances, ad hoc installation commands (often from packages `devtools`) are needed
- Package `pak` offers an insteresting alternative to base `R` `install.packages()`
- Once a package has been installed/downloaded on your drive
  - if you want all objects exported by the package to be available in your session, you should *load* the package, using `library()` or `require()` (what's the difference?). Technically, this loads the `NameSpace` defined by the package.
  - if you just want to pick some objects exported from the package, you can use *qualified names* like `package_name::object_name` to access the object (function, dataset, …).

For example. when we write

```r
gapminder <- gapminder::gapminder
```

we assign dataframe/tibble `gapminder` from package `gapminder` to identifier `"gapminder"` in global environment 🙄.

Function `p_load()` from `pacman` (package manager) blends installation and loading: if the package named in the argument of `p_load()` is not installed (not among the `installed.packages()`), `p_load()` attempts to install the package. If installation is successful, the package is loaded.

```
if (! require(pak)){
  install.packages("pak")
}
```

```
to_be_loaded <- c("devtools",
                  "tidyverse",
                  "lobstr",
                  "ggforce",
                  "nycflights13",
                  "patchwork",
                  "glue",
                  "DT",
                  "kableExtra",
                  "viridis")

for (pck in to_be_loaded) {
  if (!require(pck, character.only = T)) {
    pak::pkg_install(pck, repos="http://cran.rstudio.com/")
    stopifnot(require(pck, character.only = T))
  }
}
```

Optional arguments

A very nice feature of `R` is that functions from base `R` as well as from packages have *optional* arguments with sensible *default* values. Look for example at documentation of `require()` using expression `?require`.
Optional settings may concern individual functions or the collection of functions exported by some packages. In the next *chunk*, we reset the default color scales used by graphical functions from `ggplot2`.

```
opts <- options()  # save old options

options(ggplot2.discrete.colour="viridis")
options(ggplot2.continuous.colour="viridis")
```

You shall not confuse *installing* (on your hard-drive) and *loading* (in session) a package.

Question for Pythonistas

- In 🐍 what is the analogue of `install.packages()`?
- In 🐍 what is the analogue of `require()/library()`?

Numerical (atomic) vectors

Numerical (atomic) vectors form the most primitive type of `R`.

Vector creation and assignment

The next three lines create three numerical atomic vectors.

In IDE `Rstudio`, have a look at the `environment` pane on the right before running the chunk, and after.

Use `ls()` to investigate the *environment* before and after the execution of the three assignments.

```
1 ls()
2 x <- c(1, 2, 12)
3 y <- 5:7
4 z <- 10:1
5 x ; y ; z
6 ls()
```

Question

- What are the identifiers known in the global environment before execution of lines 2-4?
- What are the identifiers known in the global environment after execution of lines 2-4?
- Which objects are attached to identifiers `x`, `y`, and `z`?

Question

What does the next chunk?

```
ls()
w <- y
ls()
```

Question

- Is the content of object denoted by `y` copied to a new object bound to `w`?
- Interpret the result of `w == y`.
- Interpret the result of `identical(w,y)` (use `help("identical")` if needed).

```
w == y
identical(w,y)
```

Indexation, slicing, modification

Slicing a vector can be done in two ways:

- providing a vector of indices to be selected. Indices need not be consecutive
- providing a Boolean mask, that is a logical vector to select a set of positions

```r
x <- c(1, 2, 12) ; y <- 5:7 ; z <- 10:1
```

Question

Explain the next lines

```r
z[1]   # slice of length 1
z[0]   # What did you expect?
z[x]   # slice of length ??? index error ?
z[y]
z[x %% 2]    # what happens with x[0] ?
z[0 == (x %% 2)] # masking
z[c(2, 1, 1)]
```

Question

If the length of mask and and the length of the sliced vector do not coincide, what happens?

☛

A scalar is just a vector of length 1!

```r
class(z)
```

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

```r
class(z[1])
```

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

```r
class(z[c(2,1)])
```

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

Question

Explain the next lines

```r
y[2:3] <- z[2:3]
y == z[-10]

z[-11]
```

Question

Explain the next line

```r
z[-(1:5)]
```

> **Question**
>
> How would you select the last element from a vector (say `z`)?

> **Question**
>
> Reverse the entries of a vector. Find two ways to do that.

In statistics, machine learning, we are often faced with the task of building grid of regularly spaced elements (these elements can be numeric or not). `R` offers a collection of tools to perform this. The most basic tool is `rep()`.

> **Question**
>
> - Repeat a vector 2 times
> - Repeat each element of a vector twice

Let us remove objects from the global environment.

```
rm(w, x, y ,z)
```

Numbers

So far, we told about numeric vectors. Numeric vectors are vectors of floating point numbers. `R` distinguishes several kinds of numbers.

- Integers
- Floating point numbers (`double`)

To check whether a vector is made of `numeric` or of `integer`, use `is.numeric()` or `is.integer()`. Use `as.integer`, `as.numeric()` to enforce type conversion.

Question

Explain the outcome of the next chunks

```
class(113L) ; class(113) ; class(113L + 113) ; class(2 * 113L) ; class(pi) ; as.integer(pi
```

```
[1] "integer"
[1] "numeric"
[1] "numeric"
[1] "numeric"
[1] "numeric"
[1] 3
```

```
class(as.integer(113))
```

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

```
pi ; class(pi)
```

```
[1] 3.141593
[1] "numeric"
```

```
floor(pi) ; class(floor(pi)) # mind the floor
```

```
[1] 3
[1] "numeric"
```

Integer arithmetic

```
29L * 31L ; 899L %/% 32L ; 899L %% 30L
```

```
[1] 899
```

```
[1] 28
```

```
[1] 29
```

R integers are not the natural numbers from Mathematics
R numerics are not the real numbers from Mathematics

```
.Machine$double.eps
```

```
[1] 2.220446e-16
```

```
.Machine$double.xmax
```

```
[1] 1.797693e+308
```

```
.Machine$sizeof.longlong
```

```
[1] 8
```

```
u <- double(19L)
v <- numeric(5L)
w <- integer(7L)
lapply(list(u, v, w), typeof)
```

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

[[2]]
[1] "double"

[[3]]
[1] "integer"
```

```
length(c(u, v, w))
```

```
[1] 31
```

```
typeof(c(u, v, w))
```

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

R is (sometimes) able to make sensible use of Infinite.

```
log(0)
```

```
[1] -Inf
```

```
log(Inf)
```

```
[1] Inf
```

```
1/0
```

```
[1] Inf
```

```
0/0
```

```
[1] NaN
```

```
max(c( 0/0,1,10))
```

```
[1] NaN
```

```
max(c(NA,1,10))
```

```
[1] NA
```

```
max(c(-Inf,1,10))
```

```
[1] 10
```

```
is.finite(c(-Inf,1,10))
```

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

```
is.na(c(NA,1,10))
```

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

```
is.nan(c(NaN,1,10))
```

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

Computing with vectors

Summing, scalar multiplication

```
x <- 1:3
y <- 9:7

sum(x) ; prod(x)
```

```
[1] 6
```

```
[1] 6
```

```
z <- cumsum(1:3)
w <- cumprod(3:5)

x + y
```

```
[1] 10 10 10
```

```
x + z
```

```
[1] 2 5 9
```

```
2 * w
```

```
[1]   6  24 120
```

```
2 + w
```

```
[1]  5 14 62
```

```
w / 2
```

```
[1]  1.5  6.0 30.0
```

Question

How would you compute a factorial?

Question

Approximate $\sum_{n=1}^{\infty} 1/n^2$ within 10^{-3}?

Question

How would you compute the inner product between two (atomic numeric) vectors?

What we have called `vectors` so far are indeed `atomic vectors`.

- Read Chapter on Vectors in `R advanced Programming`
- Keep an eye on package `vctrs` for getting insights into the `R` vectors.

Numerical matrices

`R` offers a `matrix` class.

```
A <- matrix(1:50, nrow=5)
A
```

```
     [,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10]
[1,]    1    6   11   16   21   26   31   36   41    46
[2,]    2    7   12   17   22   27   32   37   42    47
[3,]    3    8   13   18   23   28   33   38   43    48
[4,]    4    9   14   19   24   29   34   39   44    49
[5,]    5   10   15   20   25   30   35   40   45    50
```

```
class(A)
```

```
[1] "matrix" "array"
```

Question

From the evaluation of the preceding chunk, can you guess whether it is easier the traverse a matrix in row-first order or in column-first order?

Creation, transposition and reshaping

A vector can be turned into a column matrix.

```
v <- as.matrix(1:5)
v
```

```
     [,1]
```

```
[1,]    1
[2,]    2
[3,]    3
[4,]    4
[5,]    5
```

A matrix can be transposed

```
t(v)  # transpose
```

```
     [,1] [,2] [,3] [,4] [,5]
[1,]    1    2    3    4    5
```

```
cat(dim(v), ' ', dim(t(v)), '\n')
```

```
5 1   1 5
```

```
A <- matrix(1, nrow=5, ncol=2) ; A
```

```
     [,1] [,2]
[1,]    1    1
[2,]    1    1
[3,]    1    1
[4,]    1    1
[5,]    1    1
```

Question

`lobstr::mem_used()` allows us to keep track of the amount of memory used by our `R` session. `lobstr::obj_size()` tells us the amount of memory used by the representation of an object.
Comment the next chunk

```
m1 <-lobstr::mem_used()
A <- matrix(rnorm(100000L), nrow=1000L)
m2 <- lobstr::mem_used()
lobstr::obj_size(A)
```

```
800,216 B
```

```
B <- t(A)
lobstr::obj_size(B)
```

```
800,216 B
```

```
m3 <- lobstr::mem_used()
m2-m1 ; m3-m2
```

```
805,856 B
986,984 B
```

> **Question**
>
> - Is there a difference between the next two assignments?
> - How would you assign value to all entries of a matrix?
>
> ```
> A <- matrix(rnorm(16), nrow=4)
> A[] <- 0 ; A
> ```
>
> ```
>      [,1] [,2] [,3] [,4]
> [1,]    0    0    0    0
> [2,]    0    0    0    0
> [3,]    0    0    0    0
> [4,]    0    0    0    0
> ```
>
> ```
> A   <- 0 ; A
> ```
>
> ```
> [1] 0
> ```

> **Question**
>
> What is the final shape of `A`?
>
> ```
> A <- matrix(1, nrow=5, ncol=2)
> A
> A[] <- 1:15
> A
> ```

We can easily generate diagonal matrices and constant matrices.

```
diag(1, 3)  # building identity matrix
```

```
     [,1] [,2] [,3]
[1,]    1    0    0
[2,]    0    1    0
[3,]    0    0    1
```

```
matrix(0, 3, 3) # building null matrix
```

```
     [,1] [,2] [,3]
[1,]    0    0    0
[2,]    0    0    0
[3,]    0    0    0
```

Question

Is there any difference between the next two assignments?

```
B <- A[]
B ; A
```

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

```
lobstr::obj_addr(B) ; lobstr::obj_addr(A)
```

```
[1] "0x5bc00c7e8330"
[1] "0x5bc00dcffd88"
```

```
B <- A
```

Indexation, slicing, modification

Indexation consists in getting one item from a vector/list/matrix/array/dataframe.

Slicing and subsetting consists in picking a substructure:

- subsetting a vector returns a vector
- subsetting a list returns a list
- subsetting a matrix/array returns a matrix/array (beware of implicit simplifications and dimension dropping)
- subsetting a dataframe returns a dataframe or a vector (again, beware of implicit simplifications).

Question

Explain the next results

```
A <- matrix(1, nrow=5, ncol=2)

dim(A[sample(5, 3), -1])
dim(A[sample(5, 3), 1])
length(A[sample(5, 3), 1])
is.vector(A[sample(5, 3), 1])
A[10:15]
A[60]
dim(A[])
```

Question

How would you create a fresh copy of a matrix?

Computing with matrices

`*` versus `%*%` `%*%` stands for matrix multiplication. In order to use it, the two matrices should have conformant dimensions.

```
t(v) %*% A
```

```
         [,1]      [,2]
[1,] 12.14066 -2.515752
```

There are a variety of reasonable products around. Some of them are available in `R`.

> **Question**
>
> How would you compute the Hilbert-Schmidt inner product between two matrices?
>
> $$\langle A, B \rangle_{\text{HS}} = \text{Trace}(A \times B^\top)$$

> **Question**
>
> How can you invert a square (invertible) matrix?

Logicals

- `R` has constants `TRUE` and `FALSE`.
- Numbers can be coerced to `logicals`.

> **Question**
>
> - Which numbers are truthies? falsies?
> - What is the value (if any) of `! pi & TRUE` ?
> - What is the meaning of `all( )` ?
> - What is the meaning of `any( )` ?
> - Recall *De Morgan's laws*. Check them with `R`.
> - Is `|` denoting an inclusive or an exclusive OR?

Handling three-valued logic

Question

```r
TRUE &  (1> (0/0))
(1> (0/0)) | TRUE
(1> (0/0)) | FALSE
TRUE || (1> (0/0))
TRUE |  (1> (0/0))
TRUE || stopifnot(4<3)
# TRUE |  stopifnot(4<3)
FALSE && stopifnot(4<3)
# FALSE & stopifnot(4<3)
```

Question

What is the difference between logical operators `||` and `|` ?

☛

Remark: favor `&`, `|` over `&&`, `||`.

`all` and `any`

Look at the definition of `all` and `any`.

Question

- How would you check that a square matrix is symmetric?
- How would you check that a matrix is diagonal?

Lists

While an instance of an atomic `vector` contains objects of the same type/class, an instance of `list` may contain objects of widely different types.

Question

Check an explain the output of the next chunk

```
p <- c(2, 7, 8)
q <- c("A", "B", "C")
x <- list(p, q)
x[2]
x
length(x)
rlang::is_vector(x)
rlang::is_atomic(x)
y <- c(p, q)
y
length(y)
rlang::is_atomic(y)
rlang::is_list(y)
```

Question

- How would you build a list made of `p`, `q`, and `x`?
- What is `x[2]` made of?
- How does it compare with `x[[2]]`?

Question

Read and understand the next expressions.

```
is_atomic(p);  is_atomic(p[2]) ; is_atomic(p[[2]])

is_list(q); is_atomic(q)

is_list(x); is_atomic(x) ; class(x)

class(x[2]) ; class(x[[2]])
length(x[2]) ; length(x[[2]])

identical(q, x[[2]]) ; identical(q, x[2])

obj_addr(q) ; obj_addr(x[[2]]) ; obj_addr(x[2])
ref(x)
obj_addrs(x)
identical(x[2],x[[2]])
```

Functions `is_atomic()`, `is_list()`, `...`, `obj_addr()` are from packages `rlang` and `lobstr`. See https://rlang.r-lib.org and https://lobstr.r-lib.org

Question

How would you replace `"A"` in `x` with `"K"`?

Read Chapter on Lists in `R advanced Programming`

Lookup tables (aka dictionaries) using named vectors

A lookup table maps strings to values. It can be implemented using named vectors. If we want to map: `"seine"` to `"75"`, `"loire"` to `"42"`, `"rhone"` to `"69"`, `"savoie"` to `"73"` we can proceed in the following way:

```
codes <- c(75L, 42L, 69L, 73L)
names(codes) <- c("seine", "loire", "rhone", "savoie")

codes["rhone"];  codes["aube"]
```

```
rhone
   69
```

```
<NA>
  NA
```

Question

What is the class of `codes` ?

Question

Capitalize the `names` used by `codes`

Package `stringr` offers a function `str_to_title()` that could be of interest.

Factors

Factors exist in Base `R`. They play a very important role. Qualitative/Categorical variables are implemented as Factors.

Meta-package `tidyverse` offers a package dedicated to `factor` engineering: `forcats`.

```
yraw <- c("g1","g1","g2","g2","g2","g3")
print(yraw)
```

```
[1] "g1" "g1" "g2" "g2" "g2" "g3"
```

```r
summary(yraw)
```

```
   Length     Class      Mode 
        6 character character 
```

```r
is.vector(yraw) ; is.atomic(yraw)
```

```
[1] TRUE
```

```
[1] TRUE
```

> **Question**
>
> `yraw` takes few values. It makes sense to make it a `factor`. How does it change the behavior of *generic* function `summary` ?

Load the (celebrated) `iris` dataset, and inspect variable `Species`

```r
data(iris)

species <- iris$Species

levels(species)
```

```
[1] "setosa"     "versicolor" "virginica" 
```

```r
summary(species)
```

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

> **Question**
>
> We may want to collapse `virginica` and `versicolor` into a single level called `versinica`

> `forcats` offer a function `fct_collapse()`.

Factors are used to represent *categorical* variables.

> **Question**
>
> - Load the `whiteside` data from package `MASS`.
> - Have a glimpse.
> - Assign column `Insul` to `y`

> **Question**
>
> - What is the `class` of `y`?
> - Is `y` a `vector`
> - Is `y` *ordered*? What does *ordered* mean here?
> - What are the `levels` of `y` ? How many levels has `y`?
> - Can you slice `y` ?
> - What are the binary representations of the different levels of `y`?

> **Question**
>
> Summarize factor `y`

Factors nuts and bolts

When coercing a vector (integer, character, …) to a factor, use `forcats::as_factor()` rather than base R `as.factor()`.

> 👉 Useful function to make nice `barplots` when constructing `barplots`.
> Recall that when you want to display counts for a univariate *categorical* sample, you use a `barplot`. It is often desirable to rank the levels according to the displayed statistics (usually a count).
> This can be done in a seamless way using functions like `forcats::fct_infreq()`.

```
forcats::fct_count(y, prop = TRUE)
```

```
# A tibble: 2 x 3
  f           n     p
  <fct>   <int> <dbl>
1 Before     26 0.464
2 After      30 0.536
```

```
z <- sample(y, length(y), replace = TRUE)  # permutation of whiteside$Insul

sort(forcats::fct_infreq(z))       # first level is most frequent one
```

```
 [1] After  After  After  After  After  After  After  After  After  After 
[11] After  After  After  After  After  After  After  After  After  After 
[21] After  After  After  After  After  After  After  After  After  Before
[31] Before Before Before Before Before Before Before Before Before Before
[41] Before Before Before Before Before Before Before Before Before Before
[51] Before Before Before Before Before Before
Levels: After Before
```

```
forcats::fct_count(z)
```

```
# A tibble: 2 x 2
  f           n
```

```
  <fct>  <int>
1 Before    27
2 After     29
```

Question

Make `z` ordered with level `After` preceding `Before`. Does ordering impact the behavior of `forcats::fct_count()`?

Read Chapter on Factors in `R for Data Science`

Dataframes, `tibbles` and `data.tables`

A dataframe is a list of vectors with equal lengths. This is the way `R` represents and manipulates multivariate samples.

Any software geared at data science supports some kind of dataframe

- `Python Pandas`
- `Python Dask`
- `Spark`
- …

The `iris` dataset is the "Hello world!" of dataframes.

```
data(iris)

iris %>%
  glimpse()
```

```
Rows: 150
Columns: 5
$ Sepal.Length <dbl> 5.1, 4.9, 4.7, 4.6, 5.0, 5.4, 4.6, 5.0, 4.4, 4.9, 5.4, 4.~
$ Sepal.Width  <dbl> 3.5, 3.0, 3.2, 3.1, 3.6, 3.9, 3.4, 3.4, 2.9, 3.1, 3.7, 3.~
$ Petal.Length <dbl> 1.4, 1.4, 1.3, 1.5, 1.4, 1.7, 1.4, 1.5, 1.4, 1.5, 1.5, 1.~
$ Petal.Width  <dbl> 0.2, 0.2, 0.2, 0.2, 0.2, 0.4, 0.3, 0.2, 0.2, 0.1, 0.2, 0.~
$ Species      <fct> setosa, setosa, setosa, setosa, setosa, setosa, setosa, s~
```

A `matrix` can be transformed into a `data.frame`

```
A <- matrix(rnorm(10), ncol=2)
data.frame(A)
```

```
          X1         X2
1  0.1812309 -1.3443358
2 -1.1115432  0.4512774
3 -1.3838882 -0.2421729
4 -0.8209666  1.4208832
5 -0.1400378 -0.8857219
```

There are several flavors of dataframes in `R`: `tibble` and `data.table` are modern variants of `data.frame`.

```
t <- tibble::tibble(x=1:3, a=letters[11:13], d=Sys.Date() + 1:3)

head(t)
```

```
# A tibble: 3 x 3
      x a     d
  <int> <chr> <date>
1     1 k     2024-09-06
2     2 l     2024-09-07
3     3 m     2024-09-08
```

```
glimpse(t)
```

```
Rows: 3
Columns: 3
$ x <int> 1, 2, 3
$ a <chr> "k", "l", "m"
$ d <date> 2024-09-06, 2024-09-07, 2024-09-08
```

```
ref(t)
```

```
 [1:0x5bc00e2c40f8] <tibble[,3]>
 x = [2:0x5bc00b3adb20] <int>
 a = [3:0x5bc00e4700e8] <chr>
 d = [4:0x5bc00e435c68] <date>
```

> ! Read Chapter on data frames and tibbles in Advanced R

> **Question**
>
> Perform a random permutation of the columns of a data.frame/tibble.

> Function `sample()` from base `R` is very convenient

`nycflights` data

Wrestling with tables is part of the data scientist job. Out of the box data are often messy. In order to perform useful data analysis, we need *tidy* data. The notion of tidy data was elaborated during the last decade by experienced data scientists.

You may benefit from looking at the following online documents.

Tidy data in R for Data Science

Introduction to Table manipulation in R for Data Science in `R`.

More data of that kind is available following guidelines from https://github.com/hadley/nycflights13

In this exercise, you are advised to use functions from dplyr.

> `dplyr` is a grammar of data manipulation, providing a consistent set of verbs that help you solve the most common data manipulation challenges.

```
data <- nycflights13::flights
```

> **Question**
>
> - Have a glimpse at the data.
> - What is the `class` of object `data`?
> - What kind of object is `data`?

Hint: use `class(), is.data.frame() tibble::is_tibble()`

> **Question**
>
> Extract the name and the type of each column.

Compute the mean of the numerical columns

Base `R` has plenty of functions that perform statistical computations on univariate samples. Look at the documentation of `mean` (just type `?mean`). For a while, leave aside the optional arguments.

In database parlance, we are performing *aggregation*

```
mean(data$dep_delay)
```

```
[1] NA
```

```
# mean(data[["dep_delay"]])
```

If we want the mean of all numerical columns, we need to project the data frame on numerical columns.

A verb of the `summarize` family can be useful.

> Have a look at `across` in latest versions of `dplyr()`
> Use `across()` from `dplyr` 1.x. See Documentation

If applied to a data.frame, `summary()`, produces a summary of each column. The summary depends on the column type. The output of `summary` is a shortened version the list of outputs obtained from applying `summary` to each column (`lapply(data, summary)`).

```
data %>%
  summary()
```

```
      year          month            day           dep_time     sched_dep_time
```

```
 Min.   :2013   Min.   : 1.000   Min.   : 1.00   Min.   :   1   Min.   : 106
 1st Qu.:2013   1st Qu.: 4.000   1st Qu.: 8.00   1st Qu.: 907   1st Qu.: 906
 Median :2013   Median : 7.000   Median :16.00   Median :1401   Median :1359
 Mean   :2013   Mean   : 6.549   Mean   :15.71   Mean   :1349   Mean   :1344
 3rd Qu.:2013   3rd Qu.:10.000   3rd Qu.:23.00   3rd Qu.:1744   3rd Qu.:1729
 Max.   :2013   Max.   :12.000   Max.   :31.00   Max.   :2400   Max.   :2359
                                                 NA's   :8255
   dep_delay          arr_time    sched_arr_time   arr_delay
 Min.   : -43.00   Min.   :   1   Min.   :   1   Min.   : -86.000
 1st Qu.:  -5.00   1st Qu.:1104   1st Qu.:1124   1st Qu.: -17.000
 Median :  -2.00   Median :1535   Median :1556   Median :  -5.000
 Mean   :  12.64   Mean   :1502   Mean   :1536   Mean   :   6.895
 3rd Qu.:  11.00   3rd Qu.:1940   3rd Qu.:1945   3rd Qu.:  14.000
 Max.   :1301.00   Max.   :2400   Max.   :2359   Max.   :1272.000
 NA's   :8255      NA's   :8713                  NA's   :9430
   carrier              flight       tailnum             origin
 Length:336776      Min.   :   1   Length:336776      Length:336776
 Class :character   1st Qu.: 553   Class :character   Class :character
 Mode  :character   Median :1496   Mode  :character   Mode  :character
                    Mean   :1972
                    3rd Qu.:3465
                    Max.   :8500

     dest              air_time        distance          hour
 Length:336776      Min.   : 20.0   Min.   :  17   Min.   : 1.00
 Class :character   1st Qu.: 82.0   1st Qu.: 502   1st Qu.: 9.00
 Mode  :character   Median :129.0   Median : 872   Median :13.00
                    Mean   :150.7   Mean   :1040   Mean   :13.18
                    3rd Qu.:192.0   3rd Qu.:1389   3rd Qu.:17.00
                    Max.   :695.0   Max.   :4983   Max.   :23.00
                    NA's   :9430
     minute        time_hour
 Min.   : 0.00   Min.   :2013-01-01 05:00:00.00
 1st Qu.: 8.00   1st Qu.:2013-04-04 13:00:00.00
 Median :29.00   Median :2013-07-03 10:00:00.00
 Mean   :26.23   Mean   :2013-07-03 05:22:54.64
 3rd Qu.:44.00   3rd Qu.:2013-10-01 07:00:00.00
 Max.   :59.00   Max.   :2013-12-31 23:00:00.00
```

Handling NAs

We add now a few NAs to the data....

```
data2 <- data
data2$arr_time[1:10] <- NA
```

Houston, we have a problem!

Question

How should we compute the column means now?

It is time to look at optional arguments of function `mean`.

Question

Decide to ignore `NA` and to compute the mean with the available data

Question

It is possible to remove all rows that contain at least one `NA`.
Show this leads to a different result.

Question

Compute the minimum, the median, the mean and the maximum of numerical columns

Question

Obtain a *nicer* output!
Check with https://dplyr.tidyverse.org/reference/scoped.html?q=funs#arguments

Question

Mimic `summary` on numeric columns

Question

Compute a new `itinerary` column concatenating the `origin` and `dest` one.
Have a look at Section Operate on a selection of variables

Question

Compute the coefficient of variation (ratio between the standard deviation and the mean) for each itinerary. Can you find several ways?

> **Question**
>
> Compute for each flight the ratio between the `distance` and the `air_time` in different ways and compare the execution time (use `Sys.time()`).

> **Question**
>
> Which carrier suffers the most delay?

Puzzle

```r
year <- 2012L

data %>%
  dplyr::select(year, dest, origin) %>%
  head()
```

```
# A tibble: 6 x 3
   year dest  origin
  <int> <chr> <chr>
1  2013 IAH   EWR
2  2013 IAH   LGA
3  2013 MIA   JFK
4  2013 BQN   JFK
5  2013 ATL   LGA
6  2013 ORD   EWR
```

```r
data %>%
  dplyr::filter(year==year) %>%
  dplyr::summarize(n())
```

```
# A tibble: 1 x 1
   `n()`
   <int>
1 336776
```

```r
data %>%
  dplyr::filter(year==2012L) %>%
  dplyr::summarize(n())
```

```
# A tibble: 1 x 1
  `n()`
  <int>
1     0
```

```r
data %>%
  dplyr::filter(year==.env$year) %>%
  dplyr::summarize(n())
```

```
# A tibble: 1 x 1
  `n()`
  <int>
1     0
```

```
data %>%
  dplyr::filter(year==.data$year) %>%
  dplyr::summarize(n())
```

```
# A tibble: 1 x 1
   `n()`
   <int>
1 336776
```

> **Question**
>
> Can you explain what happens?

Flow control

`R` offers the usual flow control constructs:

- branching/alternative `if (...) {...} else {...}`
- iterations (while/for) `while (...) {...}` `for (it in iterable) {...}`
- function calling `callable(...)` (how do we pass arguments? how do we rely on defaults?)

`If () then {} else {}`

If expressions `yes_expr` and `no_expr` are complicated it makes sense to use the `if (...) {...} else {...}` construct

There is also a conditional statement with an optional `else {}`

```
#| eval: false
#| collapse: false
if (condition) {
  ...
} else {
  ...
}
```

> **Question**
>
> Is there an `elif` construct in `R`?

👉 `R` also offers a `switch`

```
switch (object,
  case1 = {action1},
```

```
  case2 = {action2},
  ...
)
```

There exists a selection function `ifelse(test, yes_expr, no_expr)`.

```
ifelse(test, yes, no)
```

Note that `ifelse(...)` is vectorized.

```
x <-  1L:6L
y <-  rep("odd", 6)
z <- rep("even", 6)

ifelse(x %% 2L, y, z)
```

```
[1] "odd"  "even" "odd"  "even" "odd"  "even"
```

👉 This is a vectorized function

Iterations `for (it in iterable) {...}`

Have a look at Iteration section in R for Data Science

Question

Create a lower triangular matrix which represents the 5 first lines of the Pascal triangle.

Recall

$$\binom{n}{k} = \binom{n-1}{k-1} + \binom{n-1}{k}$$

Question

Locate the smallest element in a numerical vector

While (condition) {...}

Question

Find the location of the minimum in a vector `v`

Question

Write a loop that checks whether vector `v` is non-decreasing.

Functions

To define a function, whether named or not, you can use the `function` constructor.

```
foo <- function(arg1, arg2=def2) {
  # body

}
```

Question

Write a function that checks whether vector `v` is non-decreasing.

Question

Write a function with integer parameter n, that returns the Pascal Triangle with $n+1$ rows.

Question

How would you generate a Fibonacci sequence of length n ?

Recall the Fibonacci sequence is defined by

$$F_{n+2} = F_{n+1} + F_n \qquad F_1 = F_2 = 1$$

Question

Write a function that perform binary search in a non-decreasing vector.

Read Chapter on functions in Advanced R
In `R`, argument evalution is surprising, powerful but taming argument evaluation is real work.

Functional programming

In `R`, functions are first class entities, they can be defined at run-time, they can be used as function arguments. You can define list of functions, and iterate over them.

Try to use https://purrr.tidyverse.org.

Anonymous functions

```
\(x) body
```

is a shorthand for

```
function (x) {
  body
}
```

Operators `purrr::map_???`

Question

Write truth tables for `&`, `|`, `&&`, `||`, `!` and `xor`
Hint: use `purrr::map`, function `outer()`

Question

Write a function that takes as input a square matrix and returns `TRUE` if it is lower triangular.

Question

Use `map` , `choose` and proper use of pronouns to deliver the `n` first lines of the Pascal triangle using one line of code.
As far as the total number of operations is concerned, would you recommend this way of computing the Pascal triangle?

Read [Chapter on Functional Programming in Advanced R]

Further exploration

This notebook walked you through some aspects of `R` and its packages. We just saw the tip of the iceberg.

We barely mentioned:

- (Non-standard) Lazy evaluation
- Different flavors of object oriented programming
- Connection with `C++`: `RCpp`
- Connection with databases: `dbplyr`
- Building modeling pipelines: `tidymodels`
- Concurrency
- Building packages
- Building interactive Apps: `Shiny`

- Attributes (metadata)
- Formulae `formula`
- Strings `stringi`, `stringr`
- Dates `lubridate`
- and plenty other things ….

References

- https://www.statmethods.net/index.html
- https://www.datacamp.com/courses/free-introduction-to-r
- dplyr videos
- ggplot2 video tutorial
- cheatsheets

⚠ Readers who really want to learn `R` should spend time on

- R for Data Science by Wickham, Çetinkaya-Rundel, and Grolemund.
- Advanced R 2nd Edition by Wickham
- Advanced R Solutions by Grosser and Bumann
- Hands-On Programming with R by Grolemund

Don't go without Base R cheatsheet