VECTORS in R

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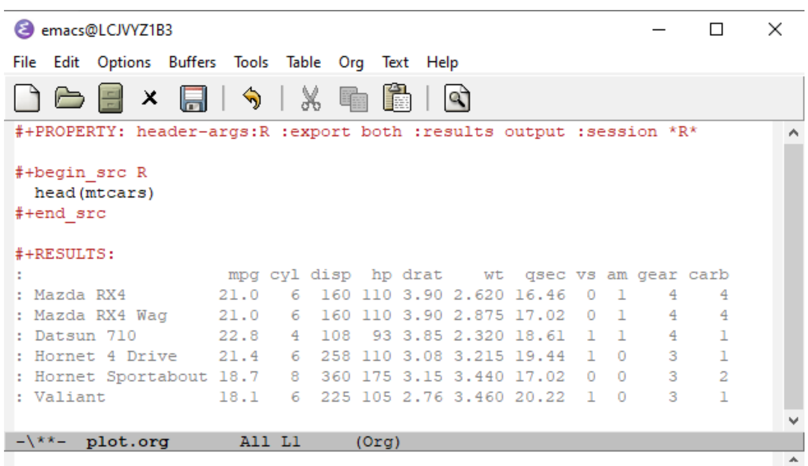
1 Preparations to code along



- Open a new Org-mode file `vectors.org` in Emacs
- Put this line at the top of the file `vectors.org`:

  ```
  #+PROPERTY: header-args:R :results output :session *R*
  ```

- Activate the code by putting your cursor on the line and entering `C-c C-c`. You should see the message `Local setup has been refreshed` in the minibuffer at the bottom of the editor.

- When you execute your first R code block, you'll be asked where you want the session named `*R*` to run: enter the path to `vectors.org`
- For plots, use the header `:results graphics file :file vectors.png` (this will overwrite the PNG file every time you create a new plot)
- When you leave Emacs, you'll be warned that the session `*R*` is active: you can ignore this warning

2 What will you learn?

After this lesson, you should be able to:

- Understand assignment in R
- Creating vectors, sequences and repetitions
- Sorting and measuring vector length
- Subsetting and extracting vector elements
- Vectorizing (rescaling)
- Classes and logical vectors

Most sections are accompanied by YouTube videos.

3 Everything is an object [video]

- R is a functional, object-oriented language
- There are usually many different ways to achive the same result
- Different solutions differ in: performance, clarity, ease of use
- PERFORMANCE: important for large data sets only
- CLARITY: essential when communicating methods, code, results
- EASE OF USE: determines the fun you have when programming

[Watch YouTube Playlist Vectors Part I]

R is a functional, object-oriented language: everything's an object, and functions rule, as you already know. Because functions rule, there are usually many different ways to achieve the same result. They often differ in terms of performance, ease of use, and clarity. Performance becomes important when you work with truly large data sets, otherwise not so much. Ease of use to some extent determines the fun you do or don't have when using the language. Clarity is essential when communicating your methods (including your code) and your results to others. This is not a nice to have. Views of different packages (like the Tidyverse) differ massively regarding all of these.

4 Assigning objects (video)

- You can use `<-` or `=` for assignment of values to variables
- Use `<-` for objects, and `=` to assign function parameters
- Object names must start with a letter and avoid reserved words
- Challenge:
  1. Create an object `a` that stores the value $3^2 \times 4^{1/8}$ and display it.
  2. Overwrite `a` with itself divided by 2.33. Print the result to the console.
  3. Create a new object `b` with the value -8.2×10^{-13} using scientific (e-) notation and print it to the console **without** scientific notation using the `format` function.
  4. Print the result of multiplying `a` and `b` to the console.
  5. Check all variables in the current session with `ls`.

5 Why we need vectors (video)

- We need vectors to handle multiple items in R
- Vectors contain observations or measurements of a single variable
- Each vector can have only one data type - e.g. `numeric` [1]
- Give three examples of such collections for vectors:

    - numbers, e.g. the heights of students in this class
    - text, e.g. the names of students of this class
    - logical values, e.g. sex of students of this class
- Define sample vectors `s_heights`, `s_names` and `s_male`.
- Print the vectors.

Solution:

1. the heights of every student of this class, in cm.
2. the first names of every student of this class (strings).
3. observations, if a student is male or not male (male means `TRUE`).

Let's put some wood behind the arrow and define sample vectors for these:

```
s_heights <- c(180, 181, 158, 175, 179, 168)
s_names <- c("Vincent", "Natalija", "Adrian", "Andres", "Helena")
s_male <- c(TRUE, FALSE, TRUE, TRUE, FALSE)
```

6 R object `class`

- The function `class` (check the help) returns the R object type
- Object type is not the same as data type or storage type
- Besides types there are also data structures (like `vector`)
- Let's check the class for our three vectors with student data

In order to check what R thinks about your observation or data type, you can use the function `class`. Look at the help page for details and enter the examples at the bottom of the help page.

Let's call `class` for our three sample vectors:

```
class(s_heights) # what type vector is this?
class(s_names)   # what type vector is this?
class(s_male)    # what type vector is this?
```

The resulting session output:

```
> class(s_heights)
[1] "numeric"
> class(s_names)
[1] "character"
> class(s_male)
[1] "logical"
```

7 Creating vectors [(video)]

- The function to create a vector, or "combine values", is `c()`:

```
myvec <- c(1,3,1,42) # combine integers as vector
myvec                # prints 1 3 1 42
class(myvec)         # determine the data type - "numeric"
```

- Vector elements can be calculations or previously stored items:

```
foo <- 32.1
myvec2 <- c(3, -3, 3.45, 1e+03, 64^0.5, 2+(3-1.1)/9.44, foo)
myvec2
```

- Vector elements can even be vectors themselves:

```
myvec3 <- c(myvec, myvec2)
myvec3
class(myvec3)
```

- In the resulting output, the two vectors were put side by side. The new vector now has 11 = 4 + 7 elements.
- [ ]

  What about missing values, `NA`, and non-numbers, `NaN`, and what about the special values `Inf` and `-Inf` - can you have these in vectors, too? Can you think about a way to test this?

```
specvec <- c(NA, NaN) # a vector with a NA and a NaN
class(specvec)
is.nan(specvec)  # testing for NaN values
is.na(specvec)   # testing for NA values
specvec1 <- c(specvec, Inf, -Inf) # a new vector with Inf, Inf
is.finite(specvec1)  # testing for finiteness
is.infinite(specvec1)  # testing for infiniteness
class(specvec1)
```

8 Example: down the Nile (video)

- Open your Emacs Org-mode practice file `vectors.org`
- At the top, below the `#+PROPERTY:` line, add a headline like this:

```
* Vectors in R
```

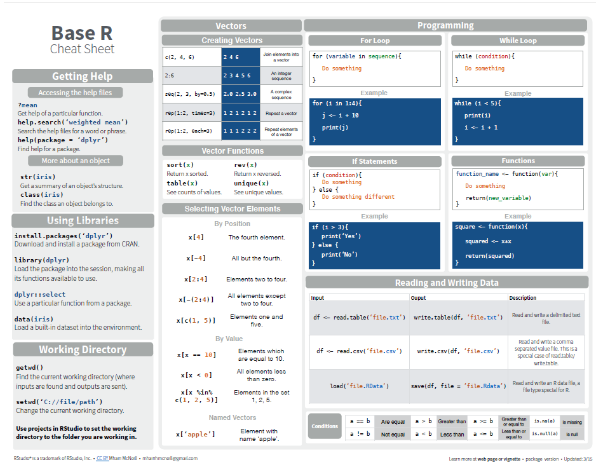
- Go to the bottom of your file with `M->`
- Add another headline

```
* Plotting the ~Nile~
```

- Additional code blocks should go below this headline

9 Base R - what's that again?

- Let's not forget that there are real data out there!
- R (i.e. "Base R") includes a number of built-in datasets



- Do you remember how to find these pre-loaded datasets? One of these is `Nile`. Do you remember how to get information on such a dataset (or on any R object)?

10 What data structure is `Nile`?

- `Nile` contains a so-called "time series", a sequence of numbers that correspond to measurements of the annual flow (in billion - 10^8 - cubic meters) of the river Nile at [Aswan](), measured between 1871-1970. You can use `class` to confirm it:

  ```
  class(Nile)  # what type of dataset is this?
  ```

  The output is `"ts"` or time series. You may remember that we previously looked at large datasets. `mtcars` for example was a "data frame" (we'll learn more about them later).

- How can we print this dataset, or parts of it, on the screen?

  Solution: there are different ways to look inside `Nile`:

  ```
  str(Nile)   # show dataset structure
  head(Nile)  # show first few elements
  Nile        # this prints the whole dataset
  ```

  Results from the session:

  ```
  > str(Nile)
  Time-Series [1:100] from 1871 to 1970: 1120 1160 963 1210 1160 1160 813 1230 1370 1140 ...
  > head(Nile)
  [1] 1120 1160  963 1210 1160 1160

  > Nile
  Time Series:
  Start = 1871
  End = 1970
  Frequency = 1
  [1] 1120 1160  963 1210 1160 1160  813 1230 1370 1140  995  935 1110  994 1020
  [16]  960 1180  799  958 1140 1100 1210 1150 1250 1260 1220 1030 1100  774  840
  [31]  874  694  940  833  701  916  692 1020 1050  969  831  726  456  824  702
  [46] 1120 1100  832  764  821  768  845  864  862  698  845  744  796 1040  759
  [61]  781  865  845  944  984  897  822 1010  771  676  649  846  812  742  801
  [76] 1040  860  874  848  890  744  749  838 1050  918  986  797  923  975  815
  ```

```
[76] 1040  860  874  848  890  744  749  838 1050  918  986  797  923  975  815
[91] 1020  906  901 1170  912  746  919  718  714  740
```

Because we don't know yet how to look at sub-vectors or individual vector elements, we cannot directly check what type the elements of `Nile` have, but the output seems to suggest that the Nile flow is measured in integer numbers.

You can also see from the print output of `Nile` how row labels work: there are 15 numbers per row, and the second row starts with the 16th number, indicated by `[16]`.

11 Plotting the nile [(video)]

- Plotting is often a good entry into exploring data
- `Nile` is a numeric vector of a single, continuous variable over time
- To visualize such data, *histograms* or *line plots* are useful
- What you're really after is a picture of a value *distribution*
- Why are *histograms* called "histograms"?

- How can you find out more about plotting a histogram in R?

  HELP: You know of course what to do at this point: call for help using `?hist`. Skip to the `Examples` section at the end, where you find the command `hist(islands)`. This creates a histogram of another dataset, `islands`. With the help of `?islands`, you find out quickly that this is a "named vector of 48 elements". Never mind what this means, but you can enter the command, which will generate a plot. This is a histogram: it plots frequency of the data and distributes them into bins[2]. Let's get back to the river Nile.

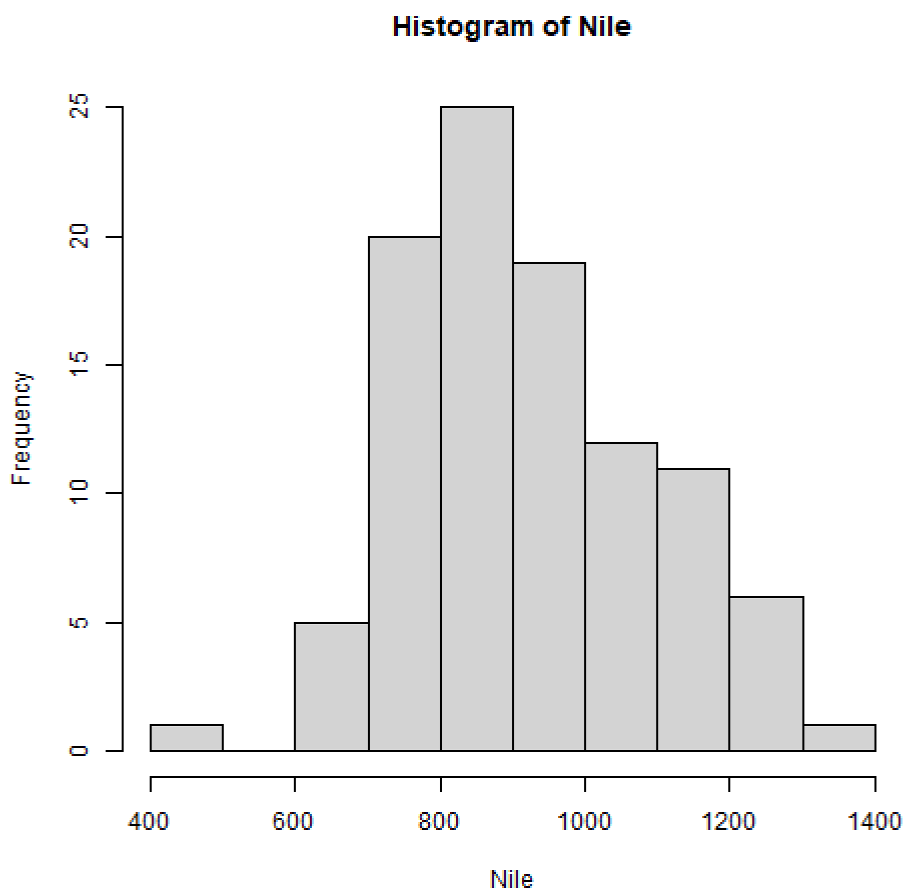
  Like most R functions, `hist` has many options. If you execute `hist(Nile)`, you get the same type of graph as in the example except that we know what the data are (annual Nile flow measurements in 10^8 m^3, or 100,000,000 (100 million) of cubic metres.

12 Plotting the histogram

- Let's plot the histogram of `Nile`

- If you're coding along, note that you need to add this to your code block header: `:results graphics file :file hist.png`

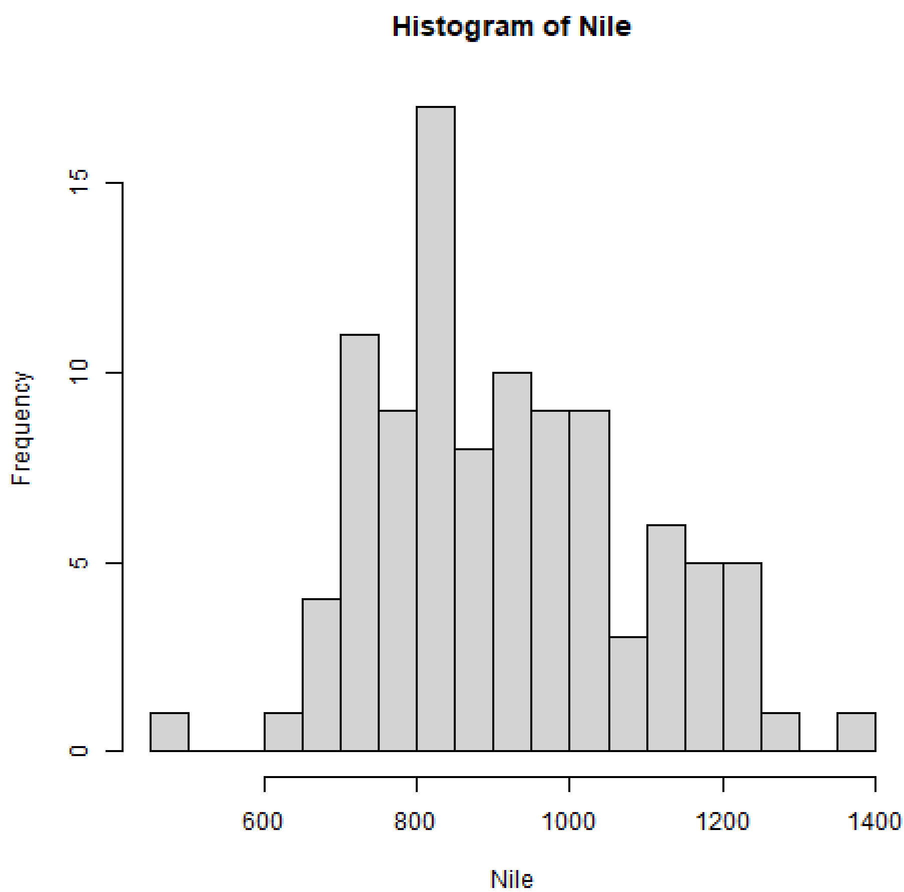
```
hist(Nile)
```



- [X] **Can you interpret the plot given what you know about the data?**
- [ ]

  Add the argument `breaks=20` to the `hist` function call. Change the file name in the code block header if you want to create a new PNG file

  ```
  hist(Nile, breaks=20)
  ```



The `hist` function creates 10 bins by default and distributes the data accordingly. You can alter this number of bins by changing the argument `breaks`, e.g. `hist(Nile, breaks=20)` (try it!).

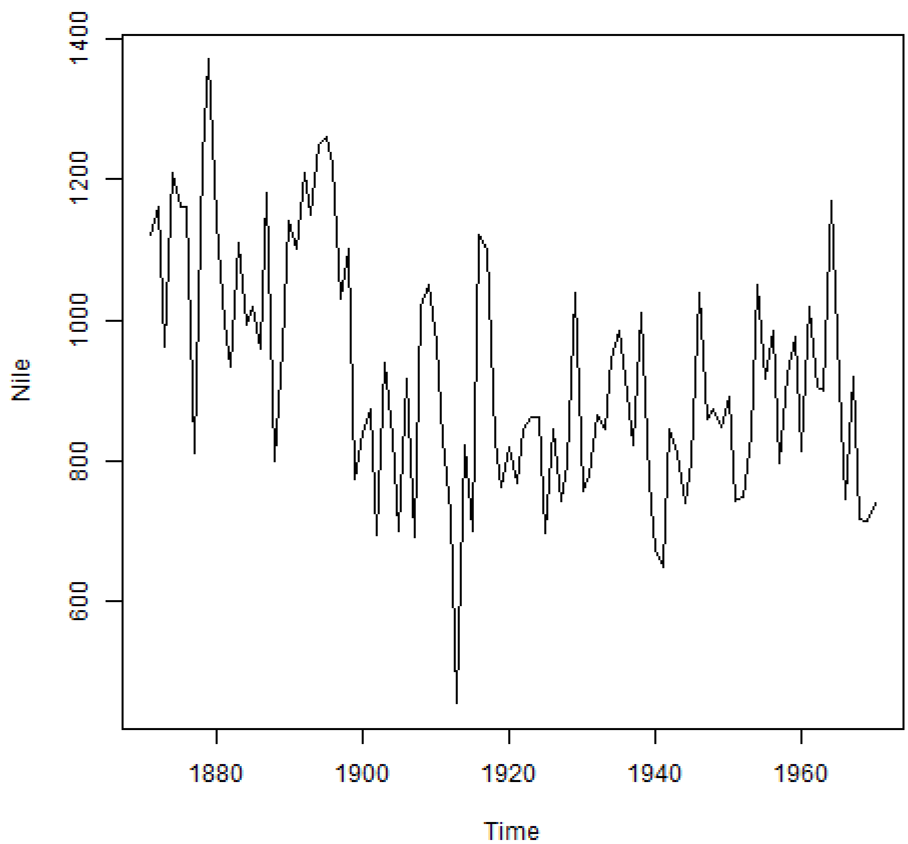
We'll get back to the `Nile` once we know more about vectors! In the next four sections, we're going to look at useful functions.

13 Plotting the line plot

- Since `Nile` is a time series, every data point has a time label
- You can easily plot the evolution of the date over time with `plot`
- A line plot is useful to visualize two continuous numeric variables

- This leads to a so-called *line plot*

```
plot(Nile)
```



- `[ ]` **Can you interpret the plot given what you know about the data?**

14 Asking for help

- When you see a new function or dataset, look it up
- Use fuzzy help search (`??`) or regular help (`?`, `help`)
- Scroll down to check out (and run) the `examples`
- Get an overview of the available options

In the following, I won't waste more space with the obvious: whenever I mention a new function or dataset, or keyword, look the corresponding help up immediately. More often than not, you will take something away from it - at the very minimum an example. Over time, you'll understand things even though you don't know how you possibly could: this is because you've begun to develop a habit by using a system of learning - looking up the help content - and the more you look at help pages, the more you recognize known concepts.

15 Creating sequences and repetitions (video)

16 The colon : operator

- `1:n` creates a sequence of numbers separated by intervals of 1

```
3:21
```

- Check what type of R object `3:21` is by applying the functions:
  - `class` (R object class),
  - `mode` (R object storage mode)
  - `is.vector` (R vector check)

```
class(3:27)
mode(3:27)
is.vector(3:27)
```

- Sequences created this way can also be stored.

```
foo <- 5.3
bar <- foo:10
bar
```

- What happens if the first argument of : is smaller than the second?

```
x <- 10:foo
x
```

- You can perform computations to specify the range.

```
baz <- foo:(-47+1.5)
baz
```

Try to understand what happened here by checking the numbers: the first value of the sequence is `foo = 5.3`. The last value is a negative value, `-47+1.5 = -45.5`. In order to generate the sequence, R counts down in steps of `1` from the first to the last value. It stops at `-44.7`, because the next value, `-45.7` would be outside of the interval $[5.3, -45.5]$).

17 Sequences

- The function `seq` allows modifying the step-width with `by`:

```
seq(from = 3, to = 27, by = 3)
```

- `seq` always starts at `from` but not always end on `to`:

```
seq(from=1, to=10, by=2) # range even, stepsize even
seq(from=1, to=11, by=2) # range odd, stepsize even
```

- To end exactly on the last value, use `length.out`:

```
seq(from=1, to=10, length.out=10) # either by or length.out
seq(from = 3, to = 27, length.out = 40)
```

- [ ]

  What is the step-width in the last case? Compute it and use it to create a sequence of 40 numbers from 3 to 27 exactly, with `seq`.

```
s <- seq(from = 3, to = 27, length.out = 40)
s[2]-s[1] # step-width
seq(from = 3, to = 27, by = s[2]-s[1])
```

- `length.out` can only be positive (there is no 'negative length').
- [ ]

  Create a decreasing sequence of length 5 from 5 to -5. Use `length.out` first, then use `by` to achieve the same result.

```
myseq <- seq(from=5, to=-5, length.out=5)
myseq
```

```
myseq1 <- seq(from=5, to=-5, by = -2.5)
myseq1
```

18 Repetition

- Use `rep` to repeat a value, e.g. the number 1, four times:

```
rep( x = 1, times = 4)
```

- You can repeat any R object, e.g. the vector `c(3, 62, 8, 3)`, or the scalar `foo`, or an arbitrary arithmetic expression:

```
rep(x=c(3,62,8,3),times=3)
rep(x=foo, times=2)
rep(x=2*2, times=(foo*2)) # times must be a positive integer
```

- The `each` argument of `rep(x)` says how many times each element of `x` is repeated:

```
rep(x=c(3,62), times=3)  # repeat vector three times
rep(x=c(3,62), each=2)   # repeat each vector element twice
rep(x=c(3,62), times=3, each=2) # repeat each vector element twice,
                                # and repeat the result three times
```

- `[ ]` The default of `times` and `each` is `1`. What is `rep(c(3,62))` ?

- As with `seq`, you can include the result of `rep` in a vector of the same data type (e.g. `numeric`):

```
foo <- 4 # store 4 in foo

## create vector with rep and seq
c(3, 8.3, rep(x=32,times=foo), seq(from=-2,to=1,length.out=foo+1))
```

19 Repetition with characters

- `rep` also works for characters and character vectors:

```
rep(x="data science", times=2)
rep(x=c("data","science"), times=2)
rep(x=c("data","science"), times=2, each=2)
```

- `[ ]`

  What happens if you try to mix characters, numbers, Booleans? Repeat an expression that has all three data types in it.

```
rep(x=c("data", 1, TRUE), times=2)
```

When you call a function with an argument of the wrong type, or, as in the case of `c`, you try to create a vector of different data types, R responds with "coercion" to make it happen.

20 Sorting and measuring lengths (video)

21 Sorting vector elements

- *Sorting* is important because we don't care about memory locations
- `sort(x)` arranges the elements of x according to size

- The default order is ascending, or `decreasing = FALSE`

```
sort(x = c(2.5, -1, -10, 3.44))  # sort ascending
sort(x = c(2.5, -1, -10, 3.44), decreasing = FALSE) # sort ascending
sort(x = c(2.5, -1, -10, 3.44), decreasing = TRUE)  # sort descending
```

- Special values are removed, put last or first with `na.last`. This works for all special values - `NA`, `NaN` and `Inf`.

```
sort(x = c(2.5, -1, -10, 3.44,NA), na.last=TRUE)  # put NA last
sort(x = c(2.5, -1, -10, 3.44,NaN), na.last=TRUE) # put NaN last
sort(x = c(2.5, -1, -10, 3.44,Inf), na.last=TRUE) # put Inf last
sort(x = c(2.5, -1, -10, 3.44,NA), na.last=FALSE) # put NA first
sort(x = c(2.5, -1, -10, 3.44,NA), na.last=NA)    # remove NA
```

- [ ]

Remember that `NA` is a `logical` object. How can you check that?

```
class(NA)
```

22 Length of vectors

- The `length` function gets or sets the length of vectors[3]:

```
length(x = c(3,2,8,1,10))  # vector of 5 elements
length(x = 5:13)           # vector of 9 elements
length(x = c(3,2,2^3,5*3)) # vector of 4 elements
length(1000)               # scalar/vector of 1 element
```

- If you have functions inside the object definition, `length` gives you the number of entries *after* the inner functions have been executed:

```
foo <- 4
bar <- c(3,8.3,rep(x=32,times=foo),seq(from=-2,to=1,length.out=foo+1))
bar
length(bar)
```

- [ ]

  R's display options are stored in `options()`, which is a `list`. Lists have a length like options. How many options does `options()` have?

```
class(options())   # class of options()
length(options())  # length of options() : number of options
class(options)     # class of options as a function
class(options()$digits) # class of one options() element
length(options()$digits) # length of one options() element
```

23 Practice: creating vectors

- Practice what you've learnt by solving problems independently
- Save the raw practice file from GitHub as an Org-mode file
- Complete the file in Emacs by using R code blocks
- Submit the result on Canvas no later than Monday September 26 8 am (to give me an opportunity to check and grade your results)

24 Naming vectors

- Naming vector elements makes code more readable.

```
c(apple = 1, banana = 2, "kiwi fruit" = 3, 4)
```

- Or you can name elements explicitly using the function `names`[4]

```
x <- 1:4
names(x) <- c("apple", "bananas", "kiwi fruit", "")
x
names(x)
```

- Looking under the hood of `names`:

```
foo <- 1:4  # vector 1,2,3,4
names(foo)  # vector is not named (NULL)
names(foo) <- letters[1:4]  # assign letter names
names(foo)
foo  # default display includes names
str(foo)  # structures reveals names as attributes
attributes(foo) # attributes is a list of 1 element, $names
str(attributes(foo))
```

25 Length of `names` vs. vector

- What if your names are too short (or too long) for your vector?
- Define a vector `week` whose elements are the names of weekdays

```
week <- c("Mon", "Tue", "Wed", "Thu", "Fri", "Sat", "Sun")
week
```

- Define a vector `foo` that contains seven numbers, and name its elements according to the `week`.

```
foo <- 1:7
names(foo) <- week
foo
```

- Copy `week` to `workweek`, and remove `"Saturday"` and `"Sunday"` from the `workweek`.

```
workweek <- week[1:5] # or week[-(6:7)]
workweek
```

- Copy `foo` to `bar`, and overwrite `names(bar)` with `workweek`.

```
bar <- foo
bar
names(bar) <- workweek
names(bar[6:7])  # names of the last two elements missing - NA
names(bar) <- NULL # remove names altogether
bar
```

26 Indexing vectors

- Passing a vector of positive numbers returns the slice of the vector containing the elements at those locations.

```
x <- (1:5)^2    # example vector
x
x[1] # extract the first element only
x[c(1,3,5)] # extract elements with indices 1,3,5
```

- Passing a vector of negative numbers returns the slice of the vector containing the elements everywhere except at those locations.

```
x[c(-2,-4)]
```

- Passing a logical vector returns the slice of the vector containing the elements where the index is `TRUE`.

```
x[c(TRUE, FALSE, TRUE, FALSE, TRUE)]
```

- For named vectors, passing a character vector of names returns the slice of the vector containing the elements with those names.

```
names(x) <- c("one", "four", "nine", "sixteen", "twenty five")
x[c("one", "nine", "twenty five")]
```

27 Coercion

- All vector elements have to be of the same `class` or type
- When you try to mix them, R will create vectores with "coercion":

```
foo <- c("a",NA,1)
foo
class(foo)  # foo becomes a character vector
```

- Missing values `NA` are not coerced to `character` (e.g. `"NA"`) because this would mean altering their main property, to be missing.
- Still, the whole vector is a `character` vector object:

```
mode(foo)  # R storage mode
class(foo) # R object class
```

- You can also explicitly convert elements using the functions `as.character`, `as.logical` or `as.numeric`.

```
as.character(c(1,2,TRUE)) # convert vector to character values
as.numeric(c("a",2,TRUE)) # R turns characters and Booleans into NA
as.logical(c("a",0,TRUE)) # R turns characters and numerics into NA
```

- Conversion with `as.logical` has a surprise: any non-zero number is turned into `TRUE` if the vector is `numeric`.

```
as.logical(c(1,0,-1, 0.333, -Inf, NaN ))
```

- The lesson: don't mix data types in vectors if you can avoid it!

28 Summary with examples

- R is a functional language in which everything's an object.
- R functions differ in: performance (speed), ease-of-use and clarity.
- To assign values to objects, use the `<-` operator.
- To assign values to arguments in functions, use the `=` operator.
- The elements of a numeric, character or logical vector are numbers, letters or truth values.
- A vector can have arithmetic calculations or vectors as elements.
- A histogram distributes data by frequency across evenly spaced bins.
- Sequences of numbers can be created using the colon operator, or the functions `seq` or `rep`.
- Vectors can be sorted with `sort` in either direction.

- Vector length can be measured as the number of vector elements with `length`.
- Index vectors can be used to select sub-vectors.

- Negative index values delete the corresponding vector elements

R CODE EXAMPLES:

`x <- 5`	assign `5` to object `x`
`x <- x+1`	overwrite `x` (new value)
`c(1,2,3,4)`	define (numerical) vector
`class(bar)`	check type of object `bar`
`hist(x,breaks=foo)`	histogram of dataset `x` with `foo` bins
`m:n`	sequence `m` to `n` at intervals `= 1`
`seq(from=foo,to=bar,by=baz)`	sequence from `foo` to `bar` intervals `=baz`
`seq(from=foo,to=bar,length.out=fuz)`	seq. `foo` to `bar`, `fuz` equal intervals
`rep(x=foo,times=bar,each=baz)`	repeat `foo` times `bar`, and
	repeat each element of `foo` times `baz`
`vector("numeric",foo), numeric(foo)`	empty numeric vector of length `foo`
`vector("character",foo), character(foo)`	empty numeric vector of length `foo`
`vector("logical",foo), logical(foo)`	empty numeric vector of length `foo`
`sort(x=foo, decreasing=FALSE)`	sort vector `foo` from smallest to largest
`sort(x=foo, decreasing=TRUE)`	sort vector `foo` from largest to smallest
`length(x=foo)`	print length of vector `foo`
`[n]`, `[n:m]`, `[-n]`	indices `n`, `n` to `m`, deleting element `n`
`prod(foo)`, `sum(foo)`	multiply / sum up all elements of vector foo
`names(x)`	return names of vector `x` (or `NULL`)
`as.character`, `as.numeric`, `as.logical`	coerce arguments to the resp. class

29 Concept summary

- In R mathematical expressions are evaluated according to the *PEMDAS* rule.
- The natural logarithm $ln(x)$ is the inverse of the exponential function e^x.
- In the scientific or e-notation, numbers are expressed as positive or negative multiples of 10.
- Each positive or negative multiple shifts the digital point to the right or left, respectively.
- Infinity `Inf`, not-a-number `NaN`, and not available numbers `NA` are *special values* in R.

30 Code summary

CODE	DESCRIPTION
`log(x=,b=)`	logarithm of `x`, base `b`
`exp(x)`	e^x, exp[onential] of x
`is.finite(x)`	tests for finiteness of `x`
`is.infinite(x)`	tests for infiniteness of `x`
`is.nan(x)`	checks if `x` is not-a-number
`is.na(x)`	checks if `x` is not available
`all.equal(x,y)`	tests near equality
`identical(x,y)`	tests exact equality
`1e2`, `1e-2`	$10^2 = 100$, $10^{-2} = \frac{1}{100}$

31 References

- Richard Cotton (2013). Learning R. O'Reilly Media.
- Tilman M. Davies (2016). The Book of R. (No Starch Press).
- Rafael A. Irizarry (2020). Introduction to Data Science (also: CRC Press, 2019).
- Norman Matloff (2020). fasteR: Fast Lane to Learning R!.

Footnotes:

[1] Note: If a vector contains different data types, R coerces the vector elements to conform to one type, as we will see later. A data type that can hold any type of value is called a `list`.

[2] The Wikipedia entry for "histogram" is not bad as a start, lots of examples and you'll soon find out how to make these yourself! The origin of the name "histogram" is not clear - it was probably invented by Pearson, who introduced this type of graph, and is short for "HISTorical diaGRAM".

[3] Both `length` and `sort`, as you can read in the respective help pages, work both for vectors and for factors. These are necessary whenever we deal with qualities or categories (like "male" or "female") rather than quantities. You'll learn about them soon!

[4] You should look up the examples in `help(names)`: the data set `islands` is a named vector suited to play around with vector naming.

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