Introduction to Data Analysis with R

Instructor: Selina Baldauf

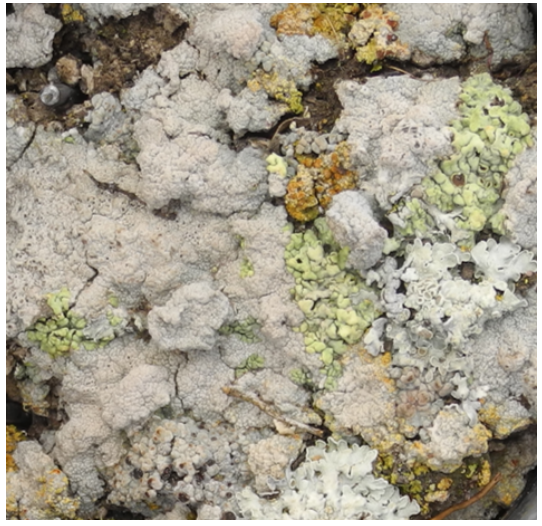
Freie Universität Berlin - Theoretical Ecology

2021-06-15 (updated: 2021-08-04)

Artwork by Allison Horst

Who am I?

- scientific modeller with ecology background
- working in the theoretical ecology group at Freie Universität
- PhD student at Freie Universität Berlin
    - Topic: Modelling the impact of biological soil crusts on dryland hydrology



Teaching

- Statistics with R for Biology Master students
- Workshops on R packages, R development, ...

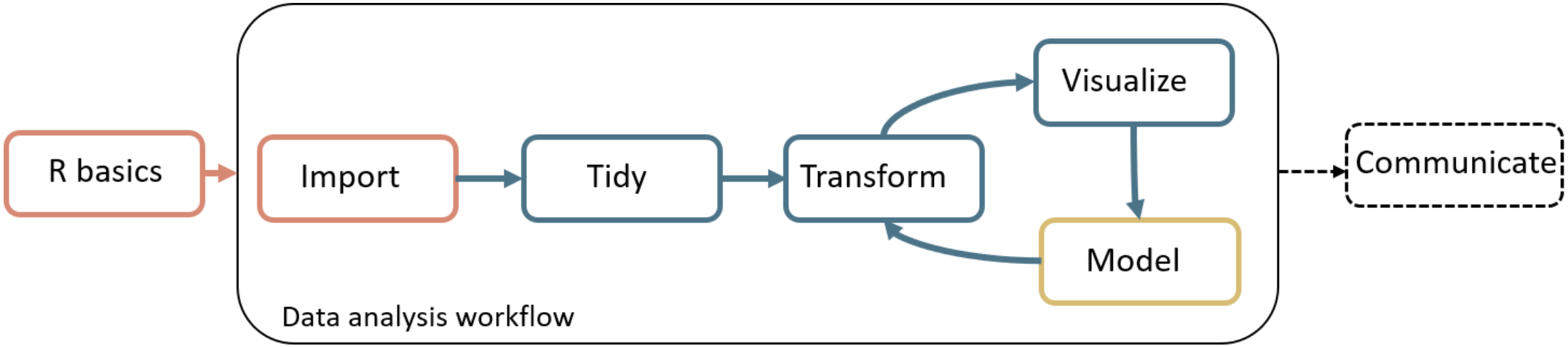
For what do I use R?

- Short answer: everything
- Long answer:
  - modelling biocrusts
  - cleaning data
  - visualizing data
  - writing documents
  - presentations
  - performing statistical analyses
  - wrangling data
  - workflow automation
  - ...

Who are you?

Results of questionnaire

The Workshop: Topics



Day 1: Introduction to R and RStudio and data import

Day 2: Data analysis with the tidyverse

Day 3: Statistical models with R

Day 4: Bring your own data

Image adapted from Wickham & Grolemund: R for Data Science

The Workshop: Schedule and Organization

🕘 9 a.m. - 4 p.m. (🥱 ~ 12 a.m. - 1 p.m.)
🔑 We will meet in the `General` meeting on Webex

Organization

- input sessions
  - presentation and demonstration of a topic
  - some examples
- tasks regarding this topic
  - solve them in small groups
- joint discussion of tasks and additional questions

The Workshop: Material

- All material can be found on the workshop's website
  - presentations
  - tasks
  - solutions
  - additional resources
- The complete material can be downloaded from the website after the workshop
- Joint document for all participants
  - collection of additional resources and helpful links that you found
  - things we could look at if we have enough time in the end
  - feedback and notes for me
  - collection of data for bring your own data day

Bring your own data

Learning by doing

- work on your own research data in small groups (or alone if you prefer)
  - I will also provide some real life data sets from different topics

Idea

- first define a question/goal together and then work on it
- use any of the methods from the course or try new things, ...
- present your results at the end of the day

Bring your own data - preparation

- keep the last workshop day in mind during the next days
  - remember if you learn something that might be applicable to your data
  - think of questions that you would like to answer for your data set
- during the group work
  - if there is time after the tasks: talk about your data, research questions and methods

➔ you might already find common interests and questions

Bring your own data - preparation

If you want to **propose a group project** using your data set:

- Add a description of the project idea to the joint joint document
- Prepare your data set to work seamlessly with R
  - We will learn about that today
- Send the data set to me beforehand then I can make sure that it's easy to get started with

If you want to **work alone** on your data set

- Add your name and the methods that you would like to use to the joint document

If you want to **join a group** project

- go through the proposals and add your name next to it

Before we get started I

This is the first time that I am doing this workshop.

So any feedback is very welcome.

I am curious to know

- what you liked/disliked
- which topics or methods you missed
- which tasks were too easy/too difficult or just right
- ...

Add any feedback to the feedback section of our joint document whenever something comes to your mind.

Before we get started II

Did anyone have problems installing R and RStudio?

Download and install R from https://cran.r-project.org

Download and install RStudio from https://www.rstudio.com

Let's get started

Why learn R?

There are many reasons to learn R. Some of them are

- free and open source
- lingua franca in computational statistics and data science
- regular updates
- large and supportive community
- packages for extensions
- easy documentation
- reproducible workflows
- ...

First things first

An introduction to RStudio for R programming

Difference between R and RStudio

R is the **programming language** and the **program** that does the actual work

- can be use with many different programming environments (But RStudio is the best for R)

RStudio is the **integrated development environment** (IDE)

- provides an interface to R
- specifically built around R code
- execute code
- syntax highlighting
- file and project management
- ...

➔ You can use R without RStudio but RStudio without R would be of very little use

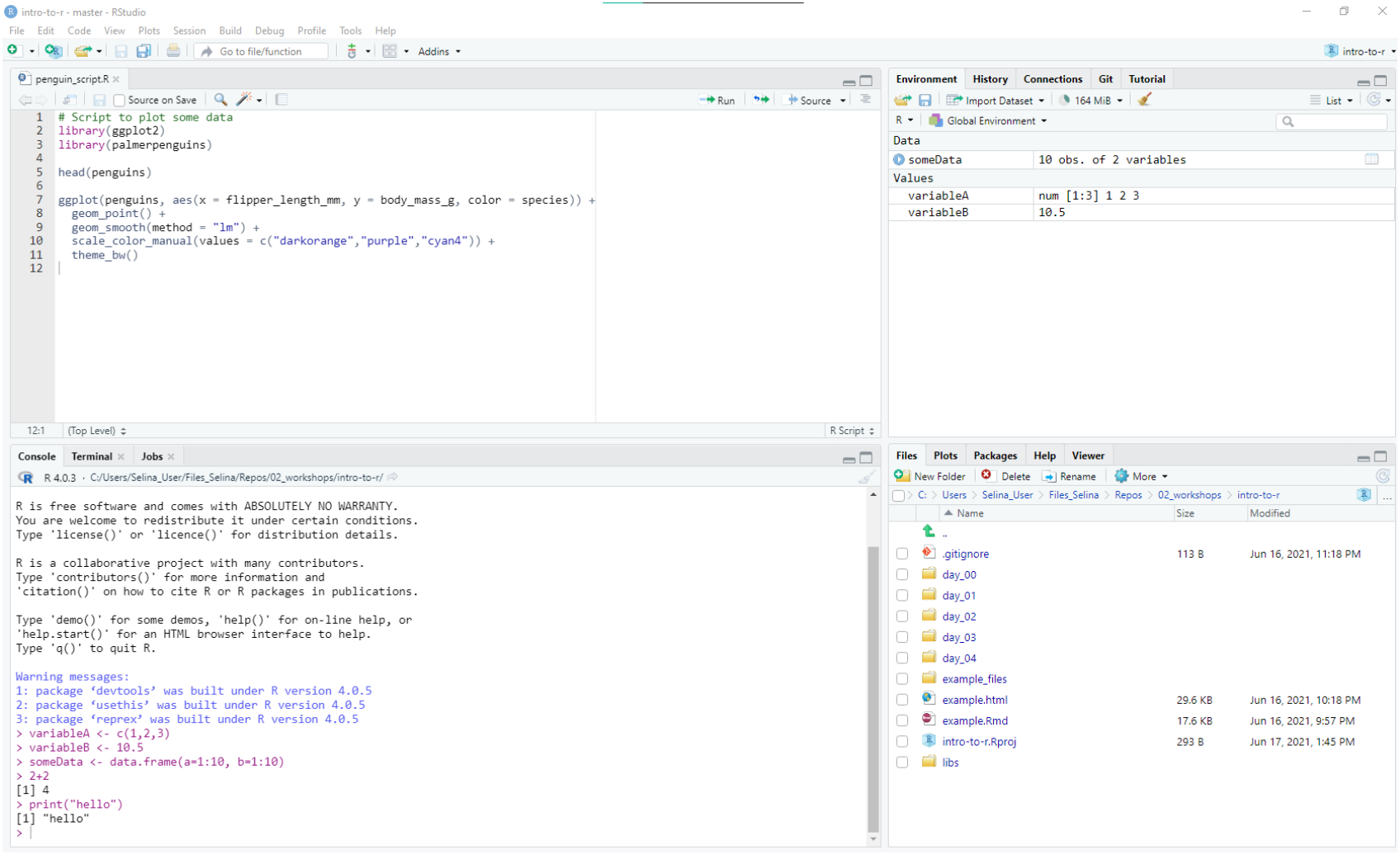
Difference between R and RStudio

R is like the engine

RStudio is more like the dashboard, etc.

analogy and image from ModernDive Book

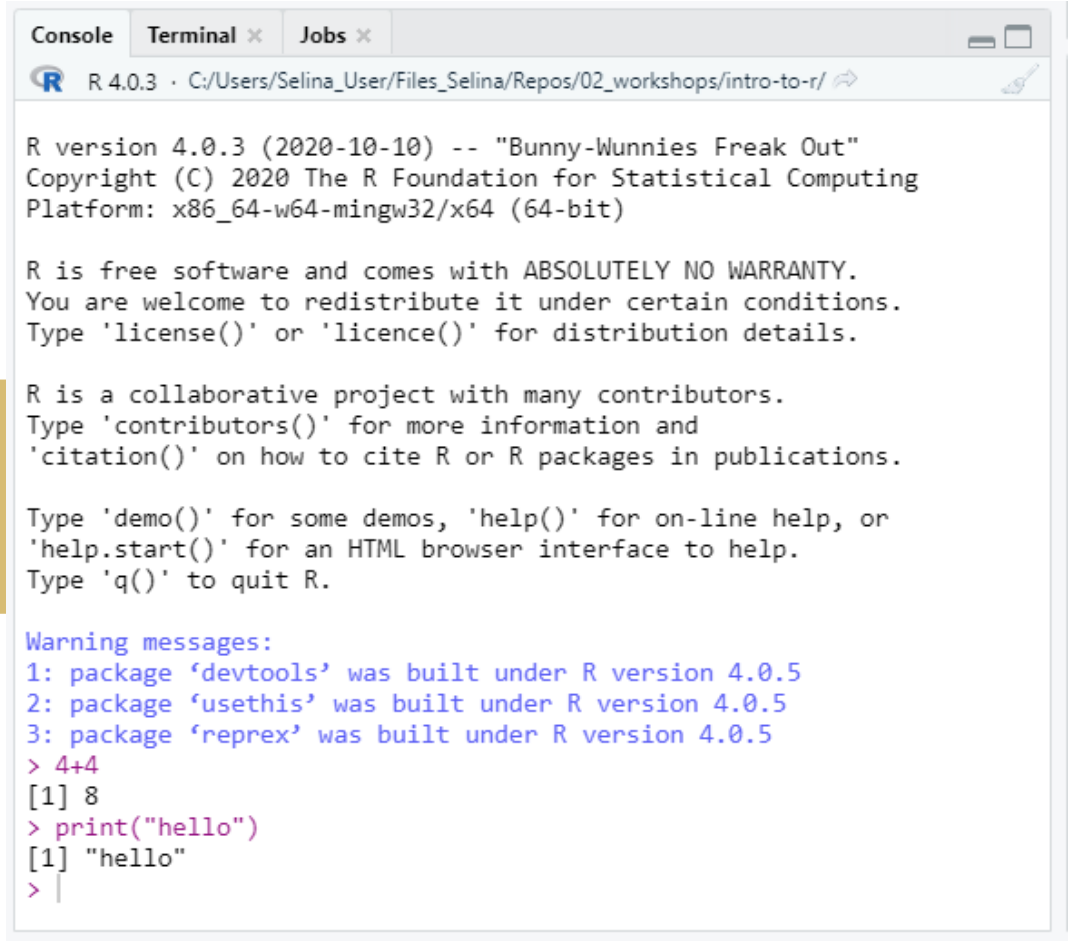
A quick tour around RStudio



Console pane

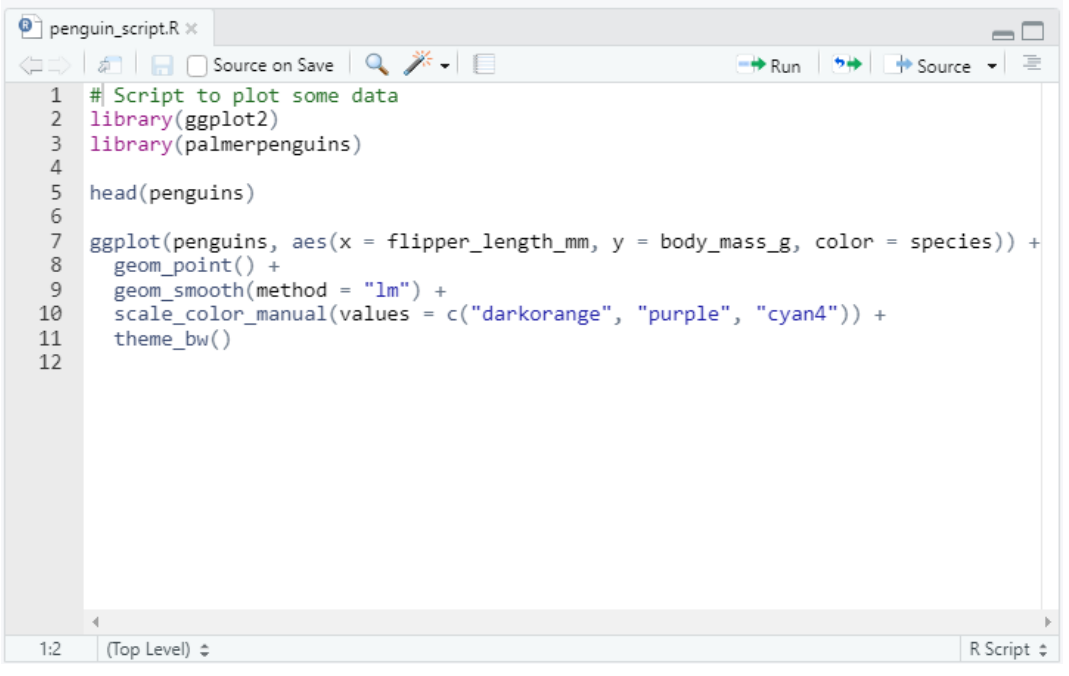
- execute R code
- output from R code in scripts is printed there
- type command into the console and execute with `Enter/Return`

💡 Use arrow keys to bring back last commands



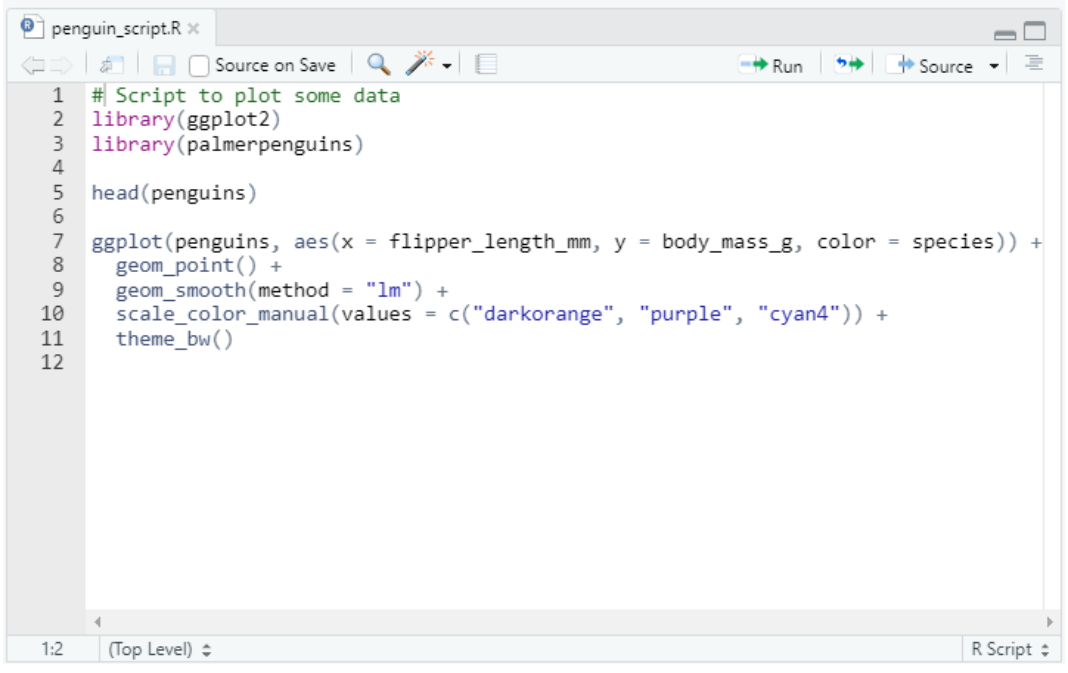
Script pane

- write scripts with R code
  - scripts are text files with R commands (file ending `.R`)
  - use scripts to save commands for reuse



Script pane

- create a new R script:
  `File -> New File -> R Script`
- save an R script:
  `File -> Save` (`Ctrl/Cmd + S`)
- run code line by line with `Run` button (`Ctrl + Enter/Cmd + Return`)
- you can open multiple scripts at the same time

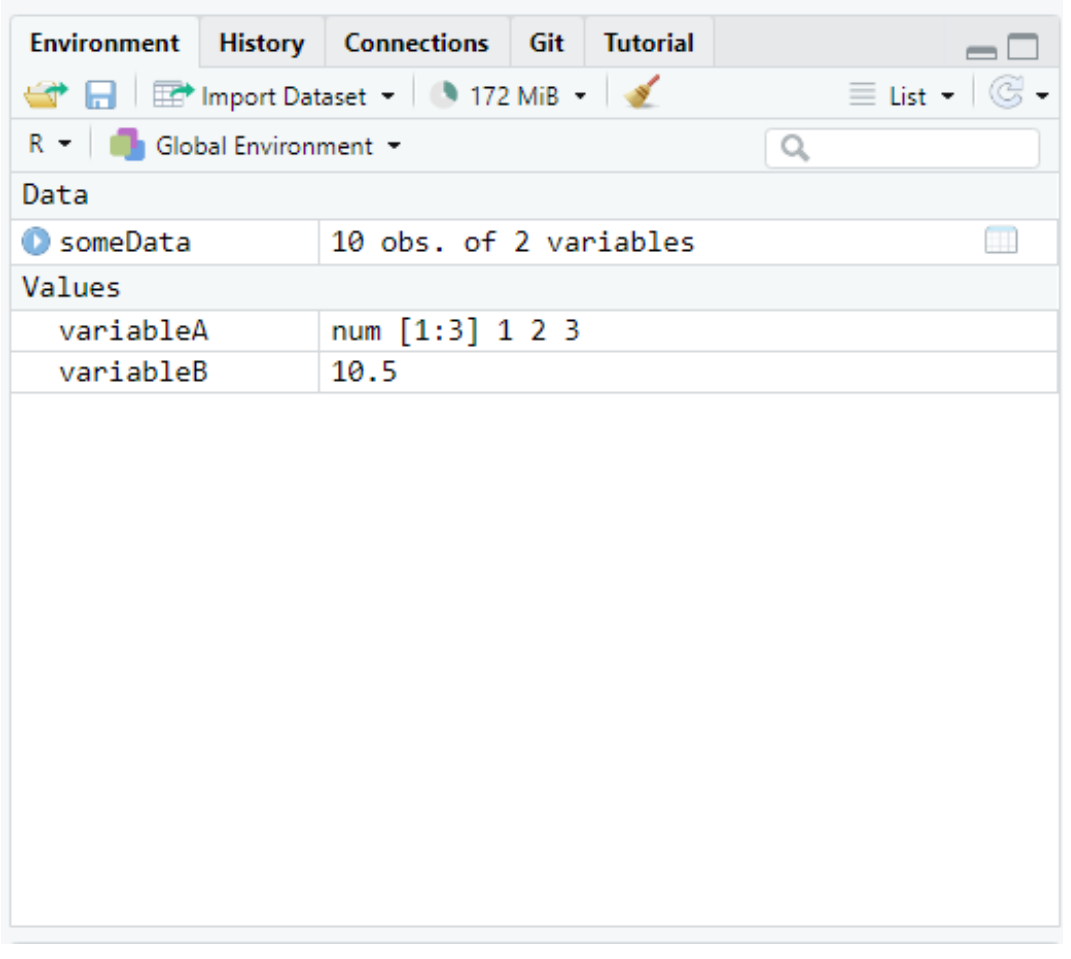


Use **scripts** for all your analysis and for commands that you want to save.

Use **console** for temporary commands, e.g. to test something.

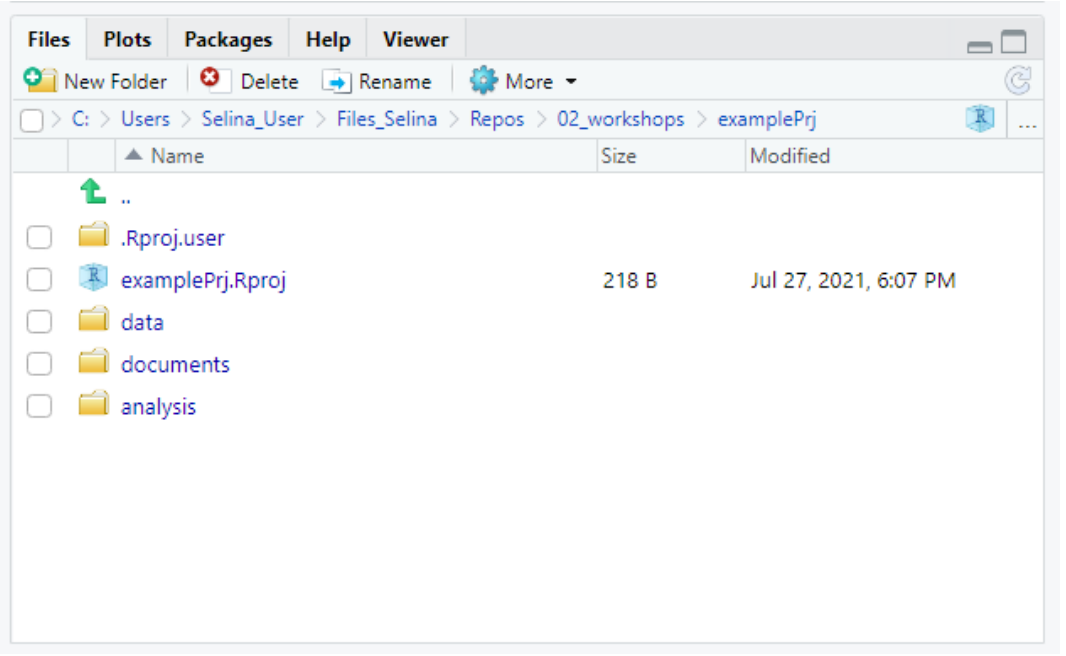
Environment pane

- shows objects currently present in the R session
- is empty if you start R



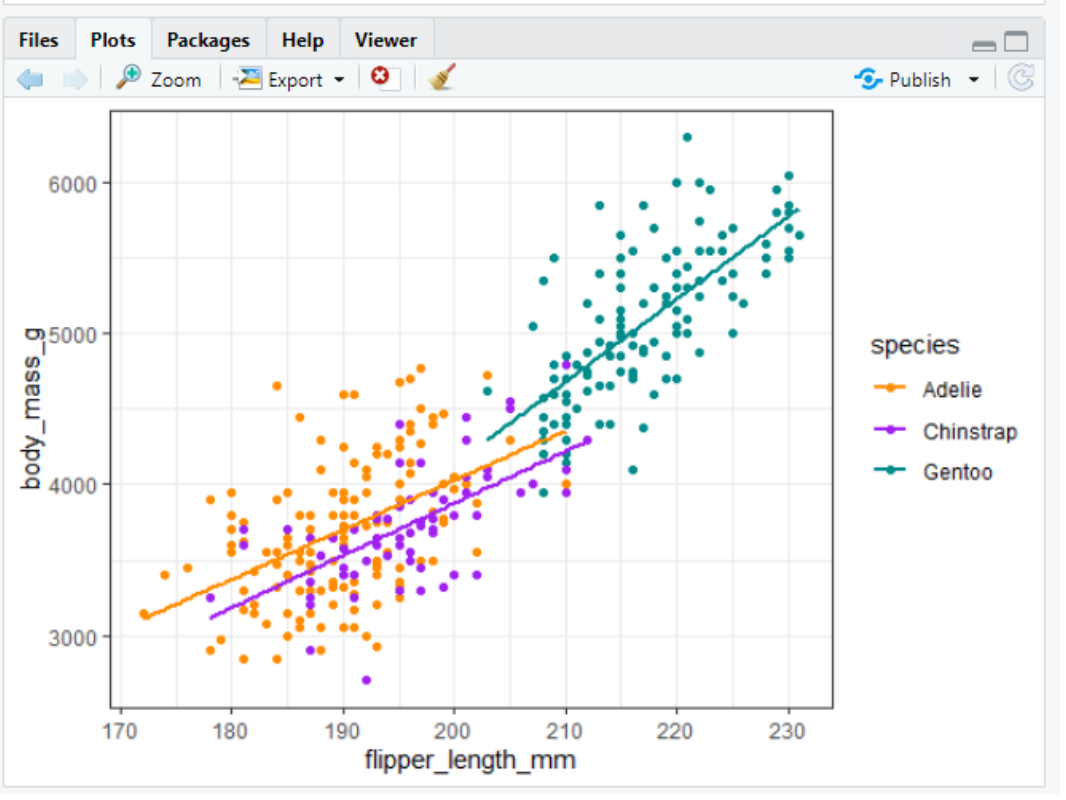
Files pane

- similar to Explorer/Finder
- browse project structure and files
  - find and open files
  - create new folders
  - delete files
  - rename files
  - ...



Plot pane

- Plots that are created with R will be shown here
- You can export plots by clicking on export button
    - but better to do it by code



Project oriented workflow with RStudio

- one directory with all files relevant for project
  - scripts, data, plots, documents, ...
- an RStudio project is just a normal directory with an `*.Rproj` file
- advantages of using RStudio projects
  - easy to navigate in R Studio (`File` pane)
  - easy to find and access scripts in RStudio
  - project root is working directory
  - open multiple projects simultaneously in separate RStudio instances

```
Project
|
|- data
|
|- documents
|    |
|    |- notes
|    |- reports
|
|- analysis
|    |
|    |- clean_data.R
|    |
|    |- statistics.R
|
|- *.RProj
```

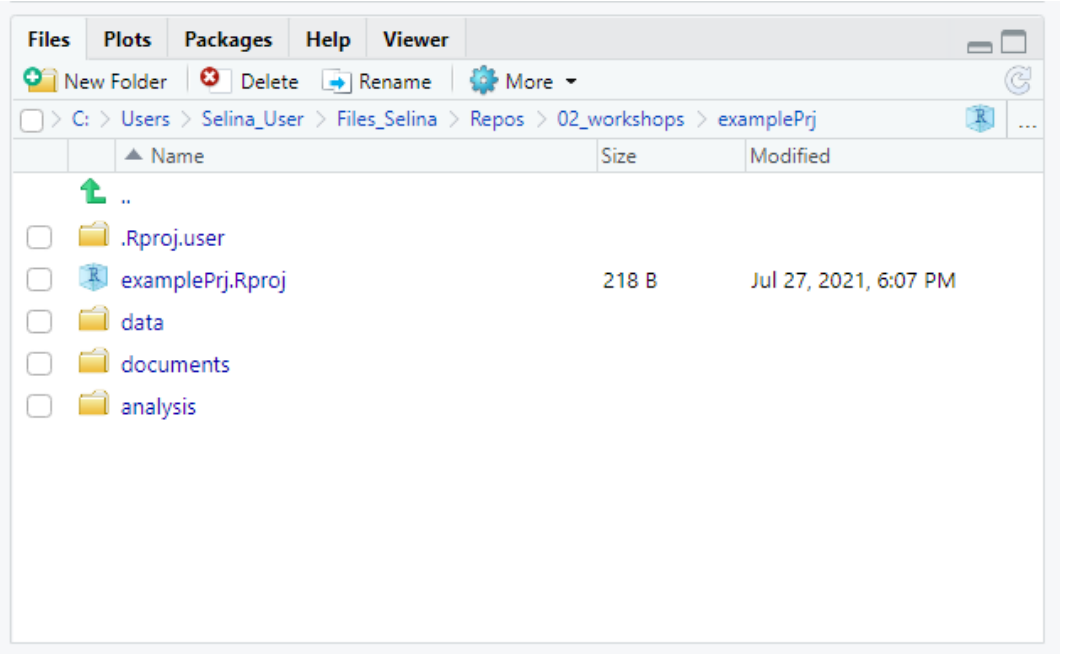
Example project structure

Create an RStudio project

Create a project from scratch:

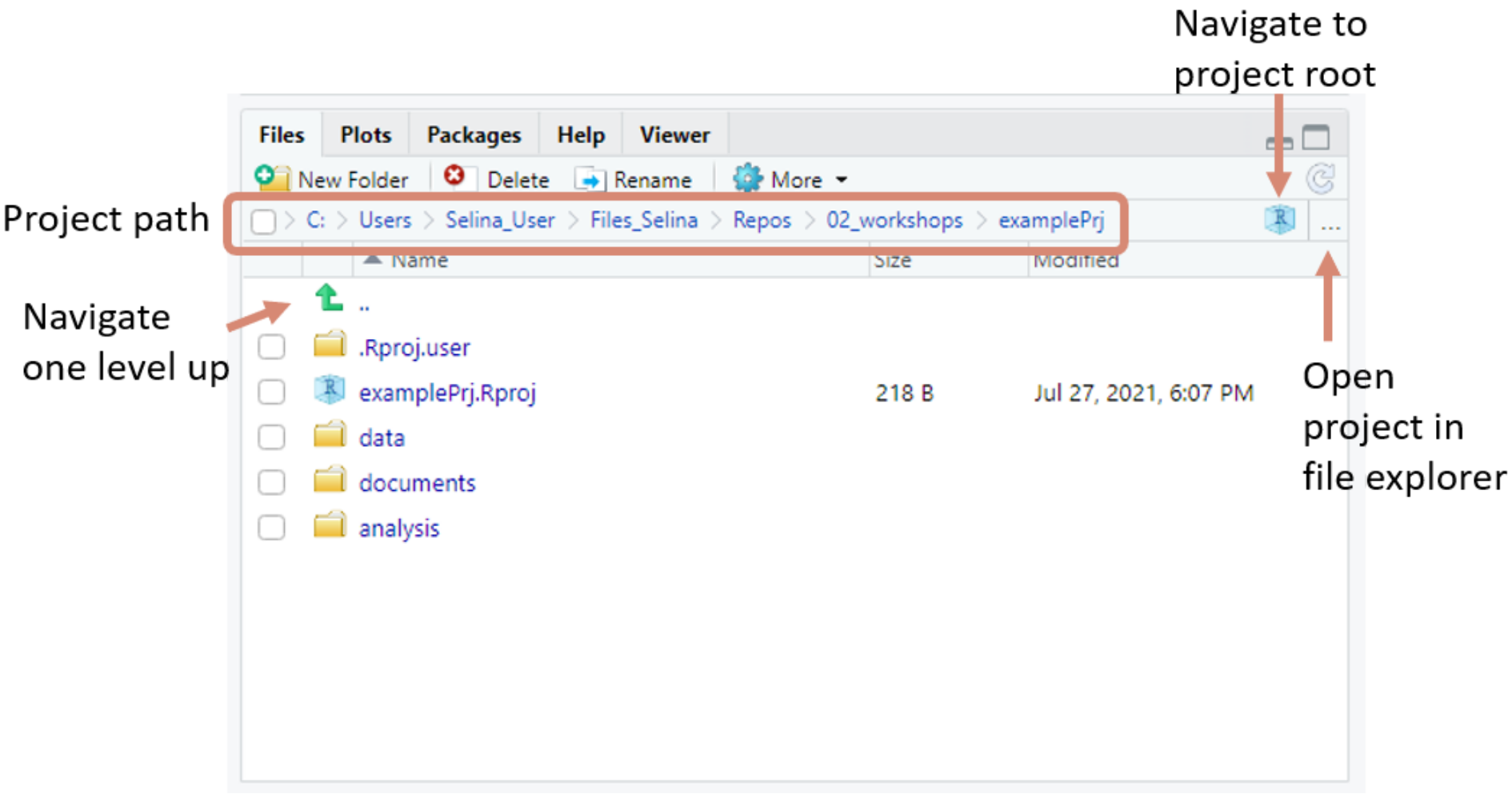
1. `File -> New Project -> New Directory -> New Project`
2. Enter a directory name (this will be the name of your project)
3. Choose the Directory where the project should be initiated
4. `Create Project`

RStudio will now create and open the project for you.



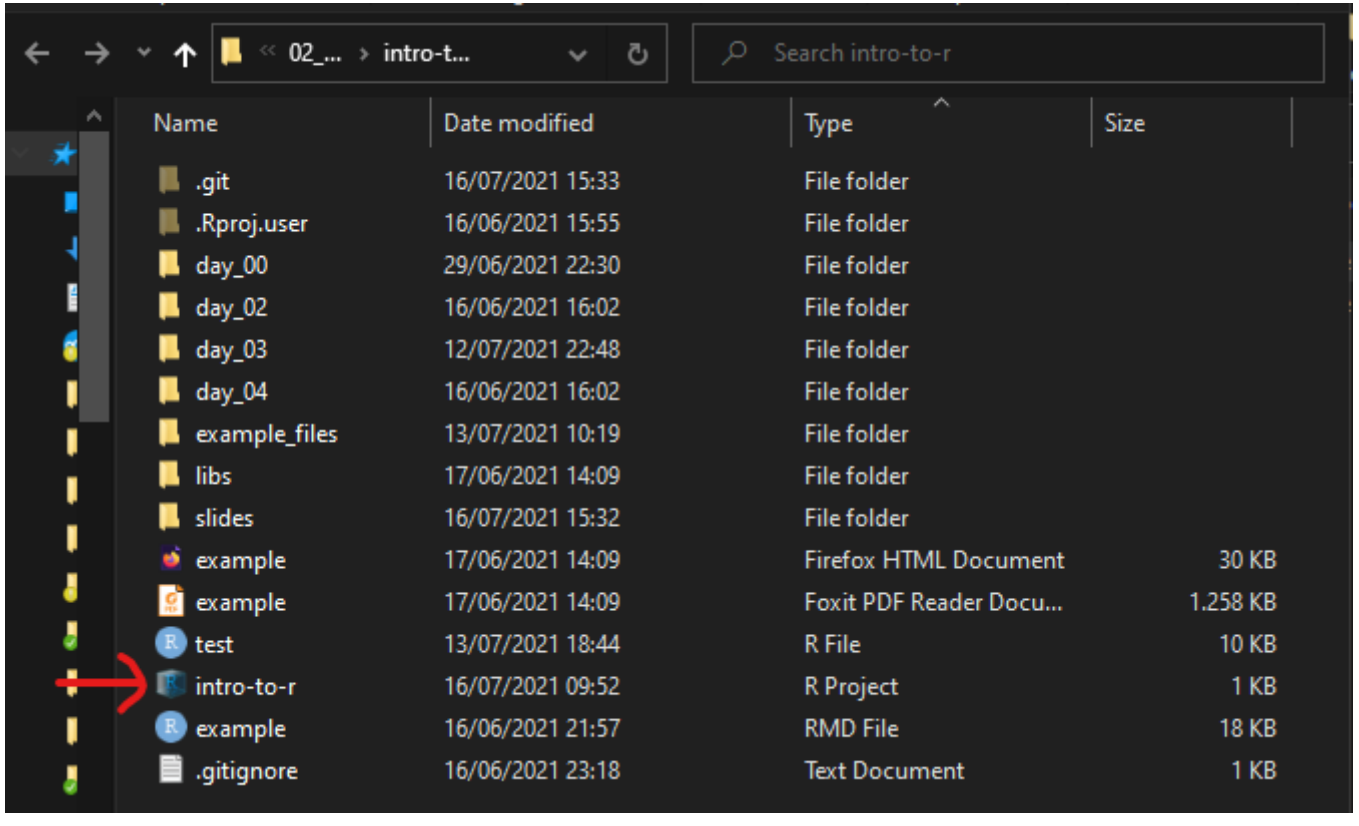
Example project structure in RStudio

Navigate an RStudio project



Open a project from outside RStudio

To open an RStudio project from your file explorer/finder, just double click on the `*.Rproj` file



Now you

Task 1: Set up your own RStudio project for this workshop

Find the task description here

Introduction to R

R as a calculator

Arithmetic operators

Addition	+
Subtraction	-
Multiplication	*
Division	/
Modulo	%%
Power	^

```
# Addition
2 + 2
# Subtraction
5.432 - 34234
# Multiplication
33 * 42
# Division
3 / 42
# Modulo (Remainder)
2 %% 2
# Power
2^2
# Combine operations
((2 + 2) * 5)^(10 %% 10)
```

R as a calculator

Relational operators

Equal to	`==`
Not equal to	`!=`
Less than	`<`
Greater than	`>`
Less or equal than	`<=`
Greater or equal than	`>=`

```
2 == 2
```

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

```
2 != 2
```

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

```
33 <= 32
```

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

```
20 < 20
```

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

R as a calculator

Logical operators

Not	`!`

```
!TRUE
```

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

```
!(3 < 1)
```

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

R as a calculator

Logical operators

Not	`!`
And	`&`

```
(3 < 1) & (3 == 3) # FALSE & TRUE = FALSE
```

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

```
(1 < 3) & (3 == 3) # TRUE & TRUE = TRUE
```

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

```
(3 < 1) & (3 != 3) # FALSE & FALSE = FALSE
```

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

R as a calculator

Logical operators

Not	`!`
And	`&`
Or	`|`

```
(3 < 1) | (3 == 3) # FALSE | TRUE = TRUE
```

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

```
(1 < 3) | (3 == 3) # TRUE | TRUE = TRUE
```

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

```
(3 < 1) | (3 != 3) # FALSE | FALSE = FALSE
```

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

Comments in R

```
# Reading and cleaning the data -----------------

data <- read_csv("data/my-data.csv")
# clean all column headers
# (found on https://stackoverflow.com/questions/68177507/)
data <- janitor::clean_names(data)

# Analysis ---------------------------------------
```

- notes that make code more readable or add information
- Everything that follows a `#` is a comment
- Comments are not evaluated
- Comments can be used for
    - Explanation of code (if necessary)
    - Include links, names of authors, ...
    - Mark different sections of your code (💡 try `Ctrl/Cmd + Shift + R`)

Objects and data types in 

Variables

- store values under meaningful names to reuse them
- a variable has a name and value and is created using the assignment operator

```
radius <- 5
```

- variables are available in the global environment
- R is case sensitive: radius != Radius
- choose meaningful variable names
    - make your code easier to read
    - variable names should start with a letter

Variables

```r
# create a variable
radius <- 5
# use it in a calculation and save the result
circumference <- 2 * pi * radius
# change value of variable radius
radius <- radius + 1
```

```r
# print a variable's value ----------------------
radius # just use the name to print the value
# or print it in a sentence
print(paste0("With a radius of ", radius, " the circumference is ",
             circumference))
# does this print the correct circumference for radius?
```

```r
# Remove variables from global environment -------
rm(radius) # remove variable radius
rm(list = ls()) # remove all elements
```

Atomic data types

There are 6 so-called atomic data types in R. The 4 most important are:

Numeric: There are two numeric data types:

- Double: can be specified in decimal (`1.243` or `-0.2134`), scientific notation (`2.32e4`) or hexadecimal (`0xd3f1`)
- Integer: numbers that are not represented by fraction. Must be followed by an `L` (`1L`, `2038459L`, `-5L`)

Logical: only two possible values `TRUE` and `FALSE` (abbreviation: `T` or `F` - but better use non-abbreviated form)

Character: also called string. Sequence of characters surrounded by quotes (`"hello"` , `"sample_1"`)

Check the type of a variable

- check the type of a variable with `typeof()`
- check if a variable is of a specific data type with `is.*()`

Check the type of a variable

```
var <- 123L
typeof(var)
```

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

```
is.double(var)
```

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

```
is.integer(123)
```

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

Check the type of a variable

```
var2 <- TRUE
is.logical(var2)
```

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

```
is.character(var2)
```

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

```
var3 <- "TRUE"
is.logical(var3)
```

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

```
is.character(var3)
```

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

Explicit type conversion

You can convert a value from one data type to the other using `as.*()`

```
as.character(1L)
```

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

`TRUE` is converted to 1 and `FALSE` is converted to 0:

```
as.numeric(TRUE)
```

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

```
as.numeric(FALSE)
```

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

Explicit type conversion

Strings can be converted to numbers if possible

```
as.integer("hello")
```

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

```
as.integer("2")
```

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

Implicit type conversion

Type conversion can happen implicitly

```
typeof(1L + 2.5) # integer -> double
```

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

```
typeof(1L + TRUE) # logical -> integer (TRUE = 1, FALSE = 0)
```

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

```
typeof(1.34 + FALSE) # logical -> double
```

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

```
typeof("hello" + FALSE) # Error: no implicit conversion from string to other data types
```

```
## Error in "hello" + FALSE: non-numeric argument to binary operator
```

Vectors

Vectors

Vectors are data structures that are built onto atomic data types.

Imagine a vector as a **collection of values** that are all **of the same data type**.

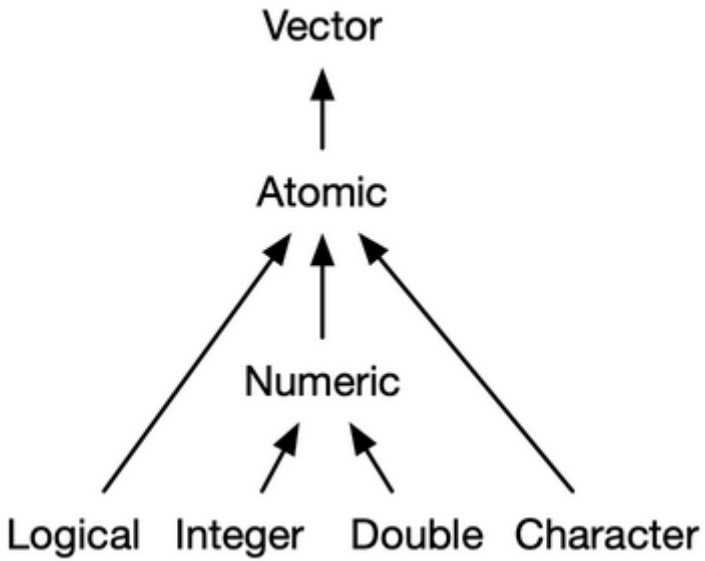


Image from Advanced R book

Creating vectors: `c()`

Use the function `c()` to *combine* values into a vector

```
lgl_var <- c(TRUE, TRUE, FALSE)
dbl_var <- c(2.5, 3.4, 4.3)
int_var <- c(1L, 45L, 234L)
chr_var <- c("These are", "just", "some strings")
```

You can also combine multiple vectors into one:

```
# Combine multiple vectors
v1 <- c(1,2,3)
v2 <- c(800, 83, 37)
v3 <- c(v1, v2)
```

Be aware of implicit type conversion when combining vectors of different types

```
c(int_var, lgl_var)
```

```
## [1]   1  45 234   1   1   0
```

Creating vectors: `:` and `seq()`

The `:` operator creates a sequence between to numbers with an increment of (-)1

```
1:10
```

```
##  [1]  1  2  3  4  5  6  7  8  9 10
```

The `seq()` function creates a sequence of values

```
seq(from = 1, to = 10, by = 1) # specify increment of sequence with by
```

```
##  [1]  1  2  3  4  5  6  7  8  9 10
```

```
seq(from = 1, to = 10, length.out = 10) # specify desired length with length.out
```

```
##  [1]  1  2  3  4  5  6  7  8  9 10
```

Creating vectors: `rep()`

Repeat values multiple times with `rep()`

```
rep("hello", times = 5)
```

```
## [1] "hello" "hello" "hello" "hello" "hello"
```

You can also repeat entire vectors

```
rep(c(TRUE, FALSE, TRUE), times = 2) # repeat the whole vector twice
```

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

```
rep(c(1, 2 ,3), each = 2) # repeat each element of the vector twice
```

```
## [1] 1 1 2 2 3 3
```

Working with vectors

Let's create some vectors to work with.

```
# list of 10 biggest cities in Europe
cities <- c("Istanbul", "Moscow", "London", "Saint Petersburg", "Berlin", "Madrid", "Kyiv",
"Rome", "Bucharest", "Paris")

population <- c(15.1e6, 12.5e6, 9e6, 5.4e6, 3.8e6, 3.2e6, 3e6, 2.8e6, 2.2e6, 2.1e6)

area_km2 <- c(2576, 2561, 1572, 1439,891,604, 839, 1285, 228, 105 )
```

We can check the length of a vector using the `length()` function:

```
length(cities)
```

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

Working with vectors

Divide the population and area vector to calculate the population density in each city:

```
population / area_km2
```

```
##  [1]  5861.801  4880.906  5725.191  3752.606  4264.871  5298.013  3575.685  2178.988  9649.123
20000.000
```

The operation is performed separately for each element of the two vectors and the result is a vector.

The same happens, if a vector is divided by vector of length 1 (i.e. a single number). The result is always a vector.

```
mean_population <- mean(population) # calculate the mean of vector population
population / mean_population
```

```
##  [1] 2.5549915 2.1150592 1.5228426 0.9137056 0.6429780 0.5414552 0.5076142 0.4737733 0.3722504
0.3553299
```

Working with vectors

We can also work with relational and logical operators

```
population > mean_population
```

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

The result is a vector containing `TRUE` and `FALSE`, depending on whether the city's population is larger than the mean population or not.

Logical and relational operators can be combined

```
# population larger than mean population OR population larger than 3 million
population > mean_population | population > 3e6
```

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

Working with vectors

The `%in%` operator checks whether *multiple* elements occur in a vector.

So instead of writing this:

```
cities == "Istanbul" | cities == "Berlin" | cities == "Madrid"
```

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

we can also write this:

```
to_check <- c("Istanbul", "Berlin", "Madrid")
cities %in% to_check
```

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

For each element of `cities`, `%in%` checks whether that element is contained in `to_check`

Indexing vectors

You can use square brackets `[]` to access specific elements from an object.

The basic structure is:

vector [vector of indexes to select]

```
cities[5]
```

```
## [1] "Berlin"
```

```
cities[1:3] # the three most populated cities
```

```
## [1] "Istanbul" "Moscow"   "London"
```

```
cities[length(cities)] # the last entry of the cities vector
```

```
## [1] "Paris"
```

Indexing vectors

Change the values of a vector at specified indexes using the assignment operator `<-`

Imagine for example, that the population of

- Istanbul (index 1) increased to 20 Million
- Rome (index 8) changed but is unknown
- Paris (index 10) decreased by 200,000.

```
# first copy the original vector to leave it untouched
population_new <- population
# Update Istanbul (1) and Rome(8)
population_new[c(1, 8)] <- c(20e6, NA) # NA means missing value
# Update Paris (10)
population_new[10] <- population_new[10] - 200000
```

```
population_new
```

```
##  [1] 20000000 12500000  9000000  5400000  3800000  3200000  3000000       NA  2200000  1900000
```

Indexing vectors

You can also index a vector using logical tests. The basic structure is:

vector [logical vector of same length]

```
mega_city <- population > mean_population
mega_city
```

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

Now extract only the cities that return `TRUE` for the comparison of their population against the mean population

```
cities[mega_city] # or short: cities[population > mean_population]
```

```
## [1] "Istanbul" "Moscow"   "London"
```

Indexing vectors

We also use `%in%` for logical indexing.

```
population[ cities %in% c("Berlin", "Paris", "Stockholm", "Madrid")]
```

```
## [1] 3800000 3200000 2100000
```

- returns only 3 values for population, because Stockholm is not a city in our vector
  - no city in `cities` returns `TRUE` for the comparison with `"Stockholm"`

Summary I

- Variables have a name and a value and are created using the assignment operator `<-`, e.g.

```
radius <- 5
```

- Vectors are a collection of values of the same data type:
    - character (`"hello"`)
    - numeric: integer (`23L`) and double (`2.23`)
    - logical (`TRUE` and `FALSE`)
- Be careful about implicit type conversion:
    - numeric to character
    - logical to character
    - logical to numeric

Summary II

Data types

```
# check the data type of a variable
typeof("hello")

# check if a variable is of a certain data type
is.*()
is.integer(1L)

# convert a variable into a certain data type
as.*()
as.logical("hello")
```

Summary III

Create vectors

```
# combine objects into vector
c(1,2,3)

# create a sequence of values
seq(from = 3, to = 6, by = 0.5)
seq(from = 3, to = 6, length.out = 10)
2:10

# repeat values from a vector
rep(c(1,2), times = 2)
rep(c("a", "b"), each = 2)
```

Summary IV

Indexing and subsetting vectors

```
# By index
v[3]
v[1:4]
v[c(1,5,7)]

# Logical indexing with 1 vector
v[v > 5]
v[v != "bird" | v == "rabbit"]
v[v %in% c(1,2,3)] # same as v[v == 1 | v == 2 | v == 3]

# Logical indexing with two vectors of same length
v[y == "bird"] # return the value in v for which index y == "bird"
v[y == max(y)] # return the value in v for which y is the maximum of y
```

Summary V

Working with vectors

```
# length
length(v)
# rounding numbers
round(v, digits = 2)
# sum
sum(v)
# mean
mean(v)
# median
median(v)
# standard deviation
sd(v)
# find the min value
min(v)
# find the max value
```

Now you

Task 2: Data types and vectors

Find the task description here