00-IntRoduction

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- R is an open source software for statistical computing, graphics, and so much more
- RStudio is the perfect IDE for R → allows for a better, easier use of R
- R runs on Windows, MacOs, Unix

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If you choose not to use the R projects (what a bad, bad, bad idea), you need to know your directories:

```
getwd() # the working directory in which you are right now

dir() # list of what's inside the current working directory
```

Change your working directory:

```
setwd("C:/Users/huawei/OneDrive/Documenti/GitHub/RcouRse")
```

R projects for the win

Dealing with working directories is a pain in the neck you should try to avoid it at all costs

Besides, after months under review, the manuscript has finally come back and now you have to revise it. But where are the data. . . ? and the scripts with the analyses. . . ?

R projects for the win

Dealing with working directories is a pain in the neck you should try to avoid it at all costs

Besides, after months under review, the manuscript has finally come back and now you have to revise it. But where are the data. . . ? and the scripts with the analyses. . . ?

R projects for the win!

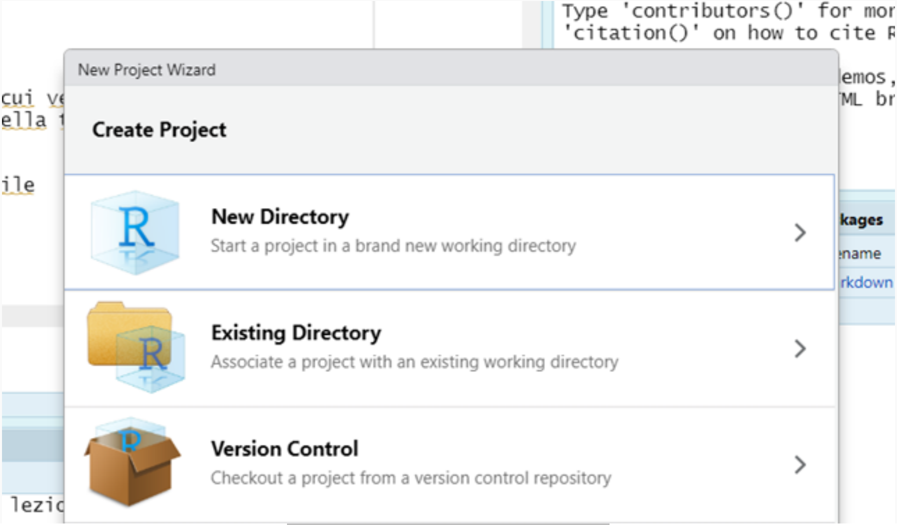
An R project automatically create an “Island” with its sub islands

They are pretty convenient for at least two reasons:

1. Allow for having multiple R instances open at the same time → You can work on multiple projects at the same time
2. All the files you need are there

Create an R project

File → New project:



Type 'contributors()' for mor
'citation()' on how to cite R

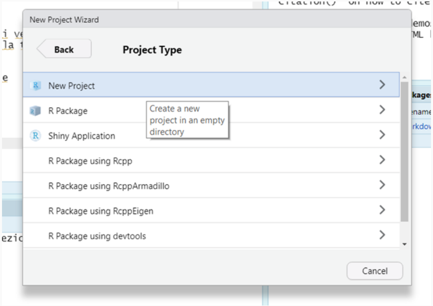
New Project Wizard

Create Project

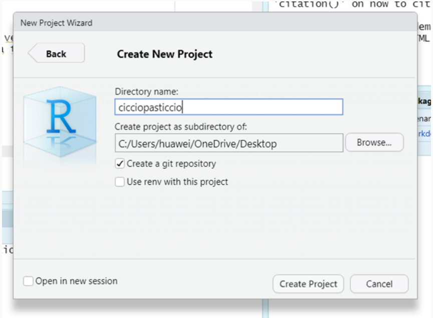
New Directory
Start a project in a brand new working directory

Existing Directory
Associate a project with an existing working directory

Version Control
Checkout a project from a version control repository



Create a new project in an empty directory



Directory name: cicciopasticcio

Create project as subdirectory of: C:/Users/huawei/OneDrive/Desktop

☑ Create a git repository

□ Use renv with this project

□ Open in new session

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CalculatoR

```
3 + 2   # plus
3 - 2   # minus
3 * 2   # times
3 / 2   # divide
sqrt(4) # square root
log(3)  # natural logarithm
exp(3)  # exponential
```

Parentheses and friends

() [] {} "" : ; ,

Use brackets as you would do in a normal equation:

```
(3 * 2)/ sqrt(25 + 4) # Look at me!
```

R ignores everything after # (it's a comment)

Assign

The results of the operations can be "stored" into objects with specific names defined by the users.

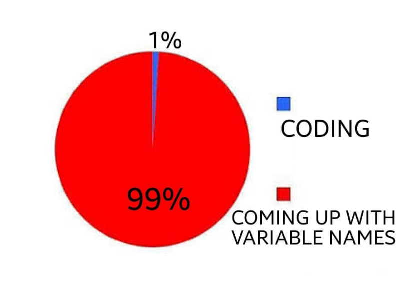
To assign a value to an object, there are two operators:

1. `x = exp(2^2)`
2. `X <- log(2^2)`

The elements on the right are assigned to the object on the left

Careful! R is case sensitive: `x` and `X` are two different objects!!!

Variable names



Valid variable names are letters, numbers, dots, underscores (e.g., `variable_name`)

Variable names cannot start with numbers

Again, R is case sensitive

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R community is the best feature of R

Just copy & paste any error message or warning in Google or ask Google "how to **[something]** in r"

Ask R to help you! Type `?` in your console followed by the name of the function:

```
?mean()
```

Will show you the help page of the `mean()` function

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Organize your files

R projects are the best way to organize your files (and your workflow)

They allow you to have all your files in a folder organized in sub folders

You don't have to worry about the wording directories because it's all there!

By creating a new project, you can also initialize a Shiny app

Create a new R project

File → New project and choose what is best for you (unless you have already initialized a directory for your project, select a new directory):

- R project “basic”
- R package
- Shiny project

and so much more

Take out the trash

The R environment should be always tidy

If it feels like you're losing it, just clean it up:

```
ls() # list objects in the envrinoment
rm(A) # remove object A from the environment
rm(list=ls()) # remove everything from the environment
```

Save the environment

It might be useful to save all the computations you have done:

```r
save.image("my-computations.RData")
```

Then you can upload the environment back:

```r
load("my-Computations.RData")
```

When to save the environment

The computations are slow and you need them to be always and easily accessible

The best practice is to save the script and document it in an `RMarkdown` file → Reproducibilty!

Your turn!

- Create an R project for this course in your “documents” folder (choose a nice name :)
- Create a new R script (`shift + ctrl + n`)
- Calculator Using the script:
  - $\sqrt{(15)} * 14 - \frac{22}{4}$ [48.72177]
  - $\frac{\sqrt{7-\pi}}{3\ (45-34)}$ [0.05952372]
- Save the script
- Assign the results of the first equation to a variable named `my_results`

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Functions and arguments (pt. I)

Almost everything in R is done with functions, consisting of:

- a name: mean
- a pair of brackets: ()
- some arguments: na.rm = TRUE

```
mean(1:5, trim = 0, na.rm = TRUE)
```

```
[1] 3
```

Arguments may be set to default values; what they are is documented in ?mean()

Functions and arguments (pt. II)

Arguments can be passed

- without name (in the defined order)
- with name (in arbitrary order) → *keyword matching*

```
mean(x, trim = 0.3, na.rm = TRUE)
```

No arguments? No problems, just brackets:

`ls(), dir(), getwd()`

Want to see the code of a function? Just type its name in the console without brackets:

```
chisq.test
```

concatenate

`c()`

Concatenates several objects together to combine them into a unique object →

```
x = c(1, 2, 3) # create a vector as a concatenation of "1", "2", "3
x
```

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

```
X = 1:3 # create the same identical vector
X
```

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

```
x == X
```

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

Vectors

Vectors are created by **c**ombining together different objects

Vectors are created by using the `c()` function.

All elements inside the `c()` function **must** be separated by a comma

Different types of objects → types of vectors:

- `int`: numeric integers
- `num`: numbers
- `logi`: logical
- `chr`: characters
- `factor`: factor with different levels

int and num

int: refers to integer: -3, -2, -1, 0, 1, 2, 3

```
months = c(5, 6, 8, 10, 12, 16)
```

```
[1]  5  6  8 10 12 16
```

num: refers to all numbers from $-\infty$ to ∞: 1.0840991, 0.8431089, 0.494389, -0.7730161, 2.9038161, 0.9088839

```
weight = seq(3, 11, by = 1.5)
```

```
[1]  3.0  4.5  6.0  7.5  9.0 10.5
```

logi

Logical values can be TRUE (T) or FALSE (F)

```
v_logi = c(TRUE, TRUE, FALSE, FALSE, TRUE)
```

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

logical vectors are often obtained from a comparison:

```
months > 12
```

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

chr and factor

chr: characters: a, b, c, D, E, F

```
v_chr = c(letters[1:3], LETTERS[4:6])
```

```
[1] "a" "b" "c" "D" "E" "F"
```

factor: use numbers or characters to identify the variable levels

```
ses = factor(rep(c("low", "medium", "high"), each = 2))
```

```
[1] low    low    medium medium high   high
Levels: high low medium
```

Change order of the levels:

```
ses1 = factor(ses, levels = c("medium", "high", "low"))
```

```
[1] low    low    medium medium high   high
Levels: medium high low
```

Create vectors

Concatenate elements with `c()`: `vec = c(1, 2, 3, 4, 5)`

Sequences:

```
-5:5 # vector of 11 numbers from -5 to 5
```

```
 [1] -5 -4 -3 -2 -1  0  1  2  3  4  5
```

```
seq(-2.5, 2.5, by = 0.5) # sequence in steps of 0.5
```

```
 [1] -2.5 -2.0 -1.5 -1.0 -0.5  0.0  0.5  1.0  1.5  2.0  2.5
```

Repeating elements:

```
rep(1:3, 4)
```

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

Create vectors II

```
rep(c("condA", "condB"), each = 3)
```

```
[1] "condA" "condA" "condA" "condB" "condB" "condB"
```

```
rep(c("on", "off"), c(3, 2))
```

```
[1] "on"  "on"  "on"  "off" "off"
```

```
paste0("item", 1:4)
```

```
[1] "item1" "item2" "item3" "item4"
```

Don’t mix them up unless you truly want to

int + num → num

int/num + logi → int/num

int/num + factor → int/num

int/num + chr → chr

chr + logi → chr

Vectors and operations

Vectors can be summed/subtracted/divided and multiplied with one another

```
a = c(1:8)
a
```

```
[1] 1 2 3 4 5 6 7 8
```

```
b = c(4:1)
b
```

```
[1] 4 3 2 1
```

```
a - b
```

```
[1] -3 -1  1  3  1  3  5  7
```

If the vectors do not have the same length, you get a warning

Vectors and operations PT. II

The function is applied to each value of the vector:

```
sqrt(a)
```

```
[1] 1.000000 1.414214 1.732051 2.000000 2.236068 2.449490 2.6
```

The same operation can be applied to each element of the vector:

```
(a - mean(a))^2 # squared deviation
```

```
[1] 12.25  6.25  2.25  0.25  0.25  2.25  6.25 12.25
```

Your turn!

- Create a new script & save it in your R project!
- Assign the following values to a variable named `my_var` (you have to *concantate* the values)
  23, 24, 25, 27, 28, 29, 30
- Compute the mean using the function `mean()`
- Compute the mean of vector using the functions `sum()` and `length()`
- Find the minimum (`min()`) and maximum (`max()`) value of the vector

Index the elements in a vector

```r
names = c("Pasquale", "Egidio", "Giulia", "Livio", "Andrea")
```

Pasquale	Egidio	Giulia	Livio	Andrea
1	2	3	4	5

Index the elements in a vector

```
names = c("Pasquale", "Egidio", "Giulia", "Livio", "Andrea")
```

Pasquale	Egidio	Giulia	Livio	Andrea
1	2	3	4	5

```
vector_name[index]
```

Index the elements in a vector II

Pasquale	Egidio	Giulia	Livio	Andrea
1	2	3	4	5

Index the elements in a vector II

Pasquale	Egidio	Giulia	Livio	Andrea
1	2	3	4	5

`names[1]` →

Index the elements in a vector II

Pasquale	Egidio	Giulia	Livio	Andrea
1	2	3	4	5

`names[1]` → Pasquale

`names[3]` →

Index the elements in a vector II

Pasquale	Egidio	Giulia	Livio	Andrea
1	2	3	4	5

`names[1]` → Pasquale

`names[3]` → Giulia

`names[seq(2, 5, by = 2)]` →

Index the elements in a vector II

Pasquale	Egidio	Giulia	Livio	Andrea
1	2	3	4	5

`names[1]` → Pasquale

`names[3]` → Giulia

`names[seq(2, 5, by = 2)]` → Egidio, Livio

Index the elements in a vector: Examples

```
weight
```

```
[1]  3.0  4.5  6.0  7.5  9.0 10.5
```

```
weight[2]          # second element of weight
```

```
[1] 4.5
```

```
(weight[6] = 15.2) # replace the sixth element of weight
```

```
[1] 15.2
```

```
weight[seq(1, 6, by = 2)] # elements 1, 3, 5
```

```
[1] 3 6 9
```

```
weight[2:6]        # elements from 2 to 6 (included)
```

```
[1]  4.5  6.0  7.5  9.0 15.2
```

```
weight[-2]        # remove the second element
```

```
[1]  3.0  6.0  7.5  9.0 15.2
```

Index with logic

```r
weight
```

```
[1]  3.0  4.5  6.0  7.5  9.0 15.2
```

Index with logic

```
weight
```

```
[1]  3.0  4.5  6.0  7.5  9.0 15.2
```

Which are the values > 7?

```
weight > 7
```

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

Index with logic

```
weight
```

```
[1]  3.0  4.5  6.0  7.5  9.0 15.2
```

Which are the values > 7?

```
weight > 7
```

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

“Filter” the vector with logic

```
weight[weight > 7] # only weights > 7
```

```
[1]  7.5  9.0 15.2
```

```
weight[weight >= 4.5 & weight < 8] # values between 4.5 and 8
```

```
[1] 4.5 6.0 7.5
```

Your turn!

- Considering `my_var`
  - Third element
  - Extract all the odd elements and assign them to a new variable `my_vector1`
  - Extract all elements $>$ 25 from `my_vector1`

Matrices and arrays

```
matrix(data, nrow, ncol, byrow = TRUE)
```

Matrices and arrays

```
matrix(data, nrow, ncol, byrow = TRUE)
```

Create a 3 × 4 matrix:

```
A = matrix(1:12, nrow=3, ncol = 4, byrow = TRUE)
```

Label and transpose:

```
rownames(A) = paste("a", 1:nrow(A), sep =
colnames(A) = paste("b", 1:ncol(A), sep = "_")
A
```

```
    b_1 b_2 b_3 b_4
a_1   1   2   3   4
a_2   5   6   7   8
a_3   9  10  11  12
```

```
t(A)
```

```
    a_1 a_2 a_3
b_1   1   5   9
b_2   2   6  10
b_3   3   7  11
b_4   4   8  12
```

Matrices and arrays

Matrix can be created by concatenating columns or rows:

```
cbind(a1 = 1:4, a2 = 5:8, a3 = 9:12) # column bind
```

```
     a1 a2 a3
[1,]  1  5  9
[2,]  2  6 10
[3,]  3  7 11
[4,]  4  8 12
```

```
rbind(a1 = 1:4, a2 = 5.8, a3 = 9:12) # row bind
```

```
   [,1] [,2] [,3] [,4]
a1  1.0  2.0  3.0  4.0
a2  5.8  5.8  5.8  5.8
a3  9.0 10.0 11.0 12.0
```

Matrices and arrays

```
array(data, c(nrow, ncol, ntab))
```

```r
my_array = array(1:30, c(2, 5, 3)) # 2 x 5 x 3 array
```

```
, , 1

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

, , 2

     [,1] [,2] [,3] [,4] [,5]
[1,]   11   13   15   17   19
[2,]   12   14   16   18   20

, , 3

....
```

Index elements in matrices

	[,1]	[,2]	[,3]
[1,]	$1,1$	$1,2$	$1,3$
[2,]	$2,1$	$2,2$	$2,3$
[3,]	$3,1$	$3,2$	$3,3$

```
matrix_name[row, column]
```

Index elements in matrices I

```
A[2, 3] # cell in row 2 column 3
```

```
[1] 7
```

```
A[2, ] # second row
```

```
b_1 b_2 b_3 b_4
  5   6   7   8
```

```
A[, 3] # third column
```

```
a_1 a_2 a_3
  3   7  11
```

Index elements in arrays

```
array_name[row, col, tab]
```

```
my_array[2, 1, 3] # cell in 2nd row 1st col of 3rd tab
```

```
my_array[, , 3] # 3rd tab

my_array[1, ,2] # 1st row in tab 2
```

Your turn!

- Create a 3×3 matrix with the 3-times table up to 24
- Assign the matrix to the variable `my_mat`
- Name the row names as “row” and the column names as “column”
- Traspose `my_mat` and assign it to the variable `my_t`
- Index from `my_t`:
  - The first row
  - The second column
  - The cell $[3, 3]$

Lists

Can store different objects (e.g., vectors, data frames, other lists):

```
my_list = list(w = weight, m = months, s = ses1, a = A)
```

The components of the list can be indexed with $ or [[]] and the name (or position) of the component:

Index `months`:

```
my_list[["m"]] # my_list$m
```

```
[1]  5  6  8 10 12 16
```

Index `weight`:

```
my_list[[1]] # my_list$weight or my_list[["w"]]
```

```
[1]  3.0  4.5  6.0  7.5  9.0 15.2
```

Your turn!

- Create a a list with the following elements
    - `my_mat`
    - `my_mat1`
    - The elements $>$ 25 of `my_var`
    - Assign the list to the variable `my_list`
- Date un nome ad ogni elemento all'interno della lista

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Data frames are lists that consist of vectors and factors of equal length. The rows in a data frame refer to one unit:

```
id = paste0("sbj", 1:6)
babies = data.frame(id, months, weight)
```

```
babies
```

```
    id months weight
1 sbj1      5    3.0
2 sbj2      6    4.5
3 sbj3      8    6.0
4 sbj4     10    7.5
5 sbj5     12    9.0
6 sbj6     16   15.2
```

Working with data frames

Index elements in a data frame:

```
babies$months # column months of babies
```

```
[1]  5  6  8 10 12 16
```

```
babies$months[2] # second element of column months
```

```
[1] 6
```

```
babies[, "id"] # column id
```

```
[1] "sbj1" "sbj2" "sbj3" "sbj4" "sbj5" "sbj6"
```

```
babies[2, ] # second row of babies (obs on baby 2)
```

```
    id months weight
2 sbj2      6    4.5
```

Working with data frames I

Logic applies:

```
babies[babies$weight > 7, ] # all obs above 7 kg
babies[babies$id %in% c("sbj1", "sbj6"), ] # obs of sbj1
                                           # and sbj7
```

Working with data frames II

```
dim(babies) # show the dimensions of the data frame
```

```
[1] 6 3
```

```
names(babies) # variable names (= colnames(babies))
```

```
[1] "id"     "months" "weight"
```

```
View(babies) # open data viewer

plot(babies) # pariwise plot
```

You can use these commands also on other R objects

Working with data frames III

```
str(babies) # show details on babies
```

```
'data.frame':   6 obs. of  3 variables:
 $ id    : chr  "sbj1" "sbj2" "sbj3" "sbj4" ...
 $ months: num  5 6 8 10 12 16
 $ weight: num  3 4.5 6 7.5 9 15.2
```

```
summary(babies) # descriptive statistics
```

```
      id                months          weight      
 Length:6           Min.   : 5.0   Min.   : 3.000  
 Class :character   1st Qu.: 6.5   1st Qu.: 4.875  
 Mode  :character   Median : 9.0   Median : 6.750  
                    Mean   : 9.5   Mean   : 7.533  
                    3rd Qu.:11.5   3rd Qu.: 8.625  
                    Max.   :16.0   Max.   :15.200  
```

Sorting

`order()`:

```
babies[order(babies$weight), ] # sort by increasing weight
```

```
    id months weight
1 sbj1      5    3.0
2 sbj2      6    4.5
3 sbj3      8    6.0
4 sbj4     10    7.5
5 sbj5     12    9.0
6 sbj6     16   15.2
```

```
babies[order(babies$weight,    # sort by decreasing weight
             decreasing = T), ]
```

Multiple arguments in order:

```
babies[order(babies$weight, babies$months, decreasing = TRUE), ]
```

Aggregating

Aggregate a response variable according to grouping variable(s) (e.g., averaging per experimental conditions):

```r
# Single response variable, single grouping variable
aggregate(y ~ x, data = data, FUN, ...)

# Multiple response variables, multiple grouping variables
aggregate(cbind(y1, y2) ~ x1 + x2, data = data, FUN, ...)
```

Aggregating: Example

```r
ToothGrowth # Vitamin C and tooth growth (Guinea Pigs)
```

```
    len supp dose
1   4.2   VC  0.5
2  11.5   VC  0.5
3   7.3   VC  0.5
....
```

```r
aggregate(len ~ supp + dose, data = ToothGrowth, mean)
```

```
  supp dose   len
1   OJ  0.5 13.23
2   VC  0.5  7.98
3   OJ  1.0 22.70
4   VC  1.0 16.77
5   OJ  2.0 26.06
6   VC  2.0 26.14
```

Reshaping: Long to wide

Data can be organized in wide format (i.e., one line for each statistical unit) or in long format (i.e., one line for each observation).

```
Indometh # Long format
```

```
   Subject time conc
1        1 0.25 1.50
2        1 0.50 0.94
3        1 0.75 0.78
4        1 1.00 0.48
5        1 1.25 0.37
6        1 2.00 0.19
....
```

Long to wide

```
# From long to wide
df.w <- reshape(Indometh, v.names = "conc", timevar = "time",
    idvar = "Subject", direction = "wide")
```

```
   Subject conc.0.25 conc.0.5 conc.0.75 conc.1 conc.1.25 conc.2 con
1        1      1.50     0.94      0.78   0.48      0.37   0.19 0
12       2      2.03     1.63      0.71   0.70      0.64   0.36 0
23       3      2.72     1.49      1.16   0.80      0.80   0.39 0
34       4      1.85     1.39      1.02   0.89      0.59   0.40 0
45       5      2.05     1.04      0.81   0.39      0.30   0.23 0
56       6      2.31     1.44      1.03   0.84      0.64   0.42 0
   conc.5 conc.6 conc.8
....
```

Reshaping: Wide to long

```
# From wide to long
df.l <- reshape(df.w, varying = list(2:12), v.names = "conc",
    idvar = "Subject", direction = "long", times = c(0.25, 0.5,
        0.75, 1, 1.25, 2, 3, 4, 5, 6, 8))
```

```
       Subject time conc
1.0.25       1 0.25 1.50
2.0.25       2 0.25 2.03
3.0.25       3 0.25 2.72
....
```

```
df.l[order(df.l$Subject), ] # reorder by subject
```

```
       Subject time conc
1.0.25       1 0.25 1.50
1.0.5        1 0.50 0.94
1.0.75       1 0.75 0.78
....
```

Your turn!

- Create a data frame with 10 observations and the folowing columns:
    - `id`: `character`, repondents IDs
    - `ses`: `factor`, socio-economic level with three levels, `low`, `medium`, `high` (3 `low`, 5 `medium`, 2 `high`)
    - `income`: `numeric` (e.g., `runif(10, min = 1110, max = 5430)`) possibly coeherent with the variable `ses`
- Filter the data set
    - responents with ‘ses == high“
    - responents with `income` > 2000

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Reading tabular txt files:

ASCII text files in tabular or spread sheet form (one line per observation, one column per variable) are read using `read.table()`

```
data = read.table("C:/RcouRse/file.txt", header = TRUE)
```

`data` is a data frame where the original numerical variables are converted in numeric vectors and character variables are converted in factors (not always).

Arguments:

- `header`: variable names in the first line? `TRUE/FALSE`
- `sep`: which separator between the columns (e.g., comma, `\t`)
- `dec`: `1.2` or `1,2`?

Reading other files

```
data = read.csv("C:/RcouRse/file.csv",
                header = TRUE, sep = ";",
                dec = ",")
```

From SPSS (file `.sav`):

```
install.packages("foreign")
library(foreign)
data = read.spss("data.sav", to.data.frame = TRUE)
```

Combine data frames

If they have the same number of columns/rows

```
all_data = rbind(data, data1, data2) # same columns
all_data = cbind(data, data1, data2) # same rows
```

If they have different rows/columns but they share at least one characteristic (e.g., `ID`):

```
all_data = merge(data1, data2,
                 by = "ID")
```

If there are different IDs in the two datasets → added in new rows

`all_data` contains all columns in `data1` and `data2`. The columns of the IDs in `data1` but not in `data2` (and vice versa) will be filled with `NA`s accordingly

Export data

Writing text (or csv) file:

```
write.table(data, # what you want to write
            file = "mydata.txt", # its name + extension
            header = TRUE, # first row with col names?
            sep = "\t",  # column separator
            ....) # other arguments
```

R environment (again):

```
save(dat, file = "exp1_data.rda") # save something specific
save(file = "the_earth.rda")      # save the environment
load("the_earth.rda")             # load it back
```

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Be ready to make mistakes (a lot of mistakes)

Coding is ~~hard~~ art

Eyes on the prize, but take your time (and the necessary steps) to get there

Remember: You're not alone → `stackoverflow` (or Google in general) is your best friend

ifelse()

Conditional execution:

Easy: `ifelse(test, if true, if false)`

```
ifelse(weight > 7, "big boy", "small boy")
```

```
[1] "small boy" "small boy" "small boy" "big boy"   "big boy"
```

Pros

- Super easy to use
- Can embed multiple `ifelse()` cycles

Cons

- It works fine until you have simple tests

if () {} else {}

If you have only one condition:

```
if (test_1) {
  command_1
} else {
  command_2
}
```

if () {} else {}

Multiple conditions:

```
if (test_1) {
  command_1
} else if (test_2) {
  command_2
} else {
  command_3
}
```

test_1 (and test_2, if you have it) **must** evaluate in either TRUE or FALSE

```
if(!is.na(x)) y <- x^2 else stop("x is missing")
```

Loops

`for()` and `while()`

Repeat a command over and over again:

```
# Don't do this at home
x <- rnorm(10)
y <- numeric(10)   # create an empty container
for(i in seq_along(x)) {
y[i] <- x[i] - mean(x)
}
```

The best solution would have been:

```
y = x - mean(x)
```

Avoiding loops

Don't loop, `apply()`!

`apply()`

```
X <- matrix(rnorm(20),
            nrow = 5, ncol = 4)
apply(X, 2, max) # maximum for each column
```

```
[1] 1.4203744 1.0716663 2.3329026 0.9084482
```

Avoiding loops

Don't loop, apply()!

apply()

```
X <- matrix(rnorm(20),
              nrow = 5, ncol = 4)
apply(X, 2, max) # maximum for each column
```

```
[1] 1.4203744 1.0716663 2.3329026 0.9084482
```

for()

```
y = NULL
for (i in 1:ncol(X)) {
  y[i] = max(X[, i])
}
```