

Get your dataset ready!

Using R and GIS

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Table of contents

1	Introduction	5
1.1	Mobility data	5
	Why R and GIS	7
1.2	Course objectives	7
	Introduce R Programming Basics	7
	Teach Data Manipulation Techniques	7
	Spatial Data Visualization	8
	Perform Basic Spatial Analysis	8
1.3	Target audience	8
1.4	Recommended readings	8
2	Course Structure	9
2.1	Day 1	9
	Morning	9
	Afternoon	9
2.2	Day 2	9
	Morning	9
	Afternoon	10
3	Detailed schedule (TBC)	11
4	Location	13
5	Resources	14
I	Day 1	15
6	Software	16
6.1	R	16
6.1.1	Windows	16
6.1.2	Mac	16
6.1.3	Ubuntu	17
6.2	RStudio	17
6.2.1	Windows 10/11	17
6.2.2	MacOS	18

6.2.3	Ubuntu	18
6.3	R packages	18
6.4	r5r	19
6.4.1	Java Development Kit	19
6.4.2	Windows and MacOS	19
6.4.3	Ubuntu	19
6.4.4	r5r	19
6.4.5	Open Route Service	20
7	R basics	21
7.1	Simple operations	21
7.1.1	Math operations	21
7.1.2	Basic shortpaths	22
7.2	Practical exercise	23
8	Data manipulation	28
8.1	Select variables	28
8.1.1	Using pipes!	29
8.2	Filter observations	29
8.3	Create new variables	30
8.4	Change data type	30
8.4.1	Factors	30
8.5	Arrange data	31
8.6	Join data tables	31
8.7	group_by and summarize	31
8.8	All together now!	31
9	Introduction to spatial data	33
10	Interactive maps	34
II	Day 2	35
11	OD pairs and desire lines	36
12	Georeferenced coordinates	37
13	Euclidean and routing distances	38
13.1	Euclidean distances	38
14	Open transportation data	39
15	Routing and Accessibility with r5r	40

16 Introduction	41
References	42

1 Introduction

Materials for the course delivered at the **EIT Doctoral Training Network Annual Forum**, in Gent (Belgium), 19th and 20th September 2024.



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This course aims to provide tools to deal with exploring and treating transportation datasets using R programming, an open-source and widely used tool for data analytics in urban mobility.

Additionally, this course provides guidance towards the use of reproducible methods to deal with large datasets that require manipulation and/or spatial analysis.

The course has a **hands-on** approach, where participants will learn the basics of **coding**, **data manipulation**, and **spatial analysis** for urban mobility and transportation.

1.1 Mobility data

There is an emerging increase in mobility data, through new forms of technology, which result in very large and diverse datasets.

Knowing how to get, treat and analyze complex datasets with the up-to-date technologies is extremely relevant for academia, policy makers and start-ups, since it allows them to:

1. acquire critical view on urban mobility based on data;
2. spatially identify locations in the city that require policy priorities;
3. and improve the efficiency of data analysis processes.

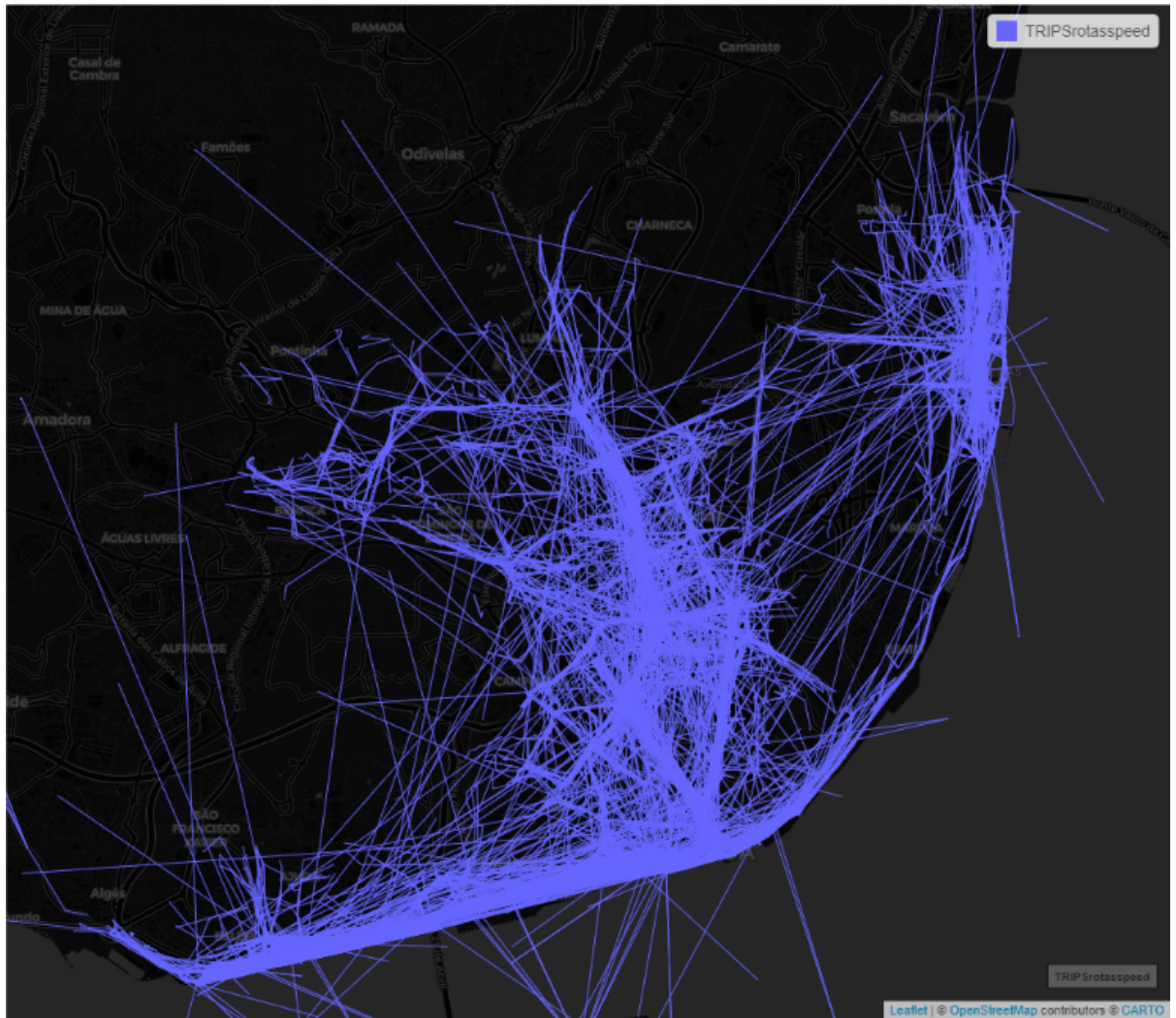


Figure 1.1: E-Scooter trip data in Lisbon. How to deal with it?

Why R and GIS

Most academic programs focus on teaching modelling and deep analysis of data. However, there is a need to learn how to explore and prepare a dataset for modelling. The use of **programming and GIS** techniques have enormous advantages, including their flexibility; reproducibility; and transparency and understanding the step-by-step process.

The use of GIS techniques in transportation is, traditionally, not considered in transportation learning programs, despite being of enormous relevance when doing accessibility analysis or reeling with georeferenced transportation data, such as bike sharing route trips' datasets, origin-destination flows datasets, home/work locations, GTFS public transit data, and so on. There is a need to learn how to locate these open datasets, how to explore them and how to integrate them into transportation and urban analysis. Additionally, the use of open source software and datasets allows researchers to perform methods that are reproducible and transparent.

TLDR

- Open-source tools widely used in data analytics and spatial analysis
- Flexibility and reproducibility in data manipulation and visualization
- Critical for urban mobility and transportation research, with spatial relevance
- Large transportation datasets are becoming increasingly common

1.2 Course objectives

Introduce R Programming Basics

- Equip participants with foundational skills in R programming
- Emphasize reproducible research practices to ensure transparency and replicability in analyses

Teach Data Manipulation Techniques

- Use key R packages for data cleaning, manipulation, and summarization of datasets
- Enable participants to efficiently handle large and complex transportation datasets

Spatial Data Visualization

- Introduce methods for quick and effective spatial data visualization using R and GIS tools
- Provide hands-on experience with creating interactive maps and visualizations

Perform Basic Spatial Analysis

- Teach participants how to perform spatial analysis of transportation datasets using GIS techniques with R
- Cover practical applications such as georeferencing data, accessibility analysis, and routing ODs
- Utilize real-world transportation data for practical, hands-on learning

1.3 Target audience

- Ph.D. candidates from DTN and other researchers
- Policy makers and practitioners in urban mobility
- Beginners to intermediate R users, no prior experience needed

1.4 Recommended readings

- Engel, Claudia A. (2023) [Introduction to R](#)
- Lovelace, Robin, Nowosad, Jakub & Muenchow, Johannes. (2023) [Geocomputation with R](#)
- Pereira, Rafael H. M. & Herszenhut, Daniel. (2023) [Introduction to urban accessibility: a practical guide with R](#). Ipea - Institute of Applied Economic Research

2 Course Structure

The course consists of an in-person 2-day course, taking place during the EIT DTN Annual Meeting on the **19th and 20th September 2024**.

The first day will focus on learning the basics of R programming and how to treat and explore datasets. The second day will focus on analyzing spatial datasets, and routing origins to destinations.

2.1 Day 1

Morning

- Introduction to **programming** techniques and **data structures**
- Introduction to R, and RStudio: **software installation** and main packages
- **R base and basics**: examples and exercises

Afternoon

- **Data manipulation**: using the dplyr package to select, filter, left-join, group and summarize
- Introduction to **GIS** and **spatial data**: import and visualize vector data
- R markdown and **interactive maps**

2.2 Day 2

Morning

- **Desire lines** from OD and transport zones
- **Georeference** coordinates: examples from surveys
- **Routing**: from euclidean distances to road networks

Afternoon

- **Open Transportation data:** where to find it
- **Accessibility analysis with R:** *r5r demo* (Rafael Pereira)
- Group exercise

3 Detailed schedule (TBC)

Day 1	
9.30	Introductions and Presentation of the course contents
10.00	Introduction to programming techniques and data structures
10.30	Introduction to R and RStudio: hands-on to install software and main packages
11.00	<i>Coffee break</i>
11.15	(cont.)
11.30	R basics: examples and exercises
12.30	<i>Lunch break</i>
13.30	Data manipulation: examples and exercises (select, filter, left-join, subset, group and summarize, using dplyr package)
15.00	Introduction to GIS and spatial data: import and visualize vector data
15.30	<i>Coffee break</i>
15.45	(cont.)
16.15	View and export interactive maps
17.00	<i>End of day 1</i>

Day 2	
9.30	Desire-lines from OD pairs and transport zones: examples and exercises
10.30	Georeferenced coordinates from survey responses: example and exercises
11.00	<i>Coffee break</i>
11.15	(cont.)
11.30	Euclidean and routing distances with sf and r5r
12.30	<i>Lunch break</i>
13.30	Open Transportation data: where to find it (OSM and GTFS)
14.00	Accessibility analysis with r5r
16.00	<i>Coffee break</i>

Day 2	
16.15	Using you data: manipulation and spatial analysis methods and further applications
16.45	Survey and feedback from participants
17.00	<i>End of day 2</i>

4 Location

The course will take place at Campus Sterre, Building S8, room 2.4.

```
Campus_S8_coord = c(3.7105372, 51.0241258)
Campus_S8 = sf::st_sfc(sf::st_point(Campus_S8_coord)) # create point
Campus_S8 = sf::st_as_sf(Campus_S8, crs = 4326) # assign crs

mapview::mapview(Campus_S8, map.types = "OpenStreetMap") # quick map view
```

5 Resources

- You laptop, with any OS
- Github repository with all the materials (data, code and guidelines)
- Survey datasets, school locations and public transport operator datasets

Part I

Day 1

6 Software

In this chapter we will guide you through the installation of R, RStudio and the packages you will need for this course.

R and **RStudio**¹ are separate downloads.

6.1 R

You will need **R** installed on your computer. **R stats** (how it is also known) is a programming language and free software environment for statistical computing and graphics supported by the R Foundation for Statistical Computing.

The download links live at [The Comprehensive R Archive Network](#) (aka CRAN). The most recent version is 4.4.1, but you can use `>= 4.1.x` if you already have it installed.

6.1.1 Windows

[Download R-4.4.1 for Windows](#) and run the executable file.

You will also need to install Rtools, which is a collection of tools necessary to build R packages in Windows.

6.1.2 Mac

[Download R-4.4.1 for MacOX](#). You will have to choose between the arm64 or the x86-64 version.

Download the `.pkg` file and install it as usual.

¹We will use RStudio, although if you already use other studio such as VScode, that's also fine.

6.1.3 Ubuntu

These are instructions for Ubuntu. If you use other linux distribution, please follow the instructions on [The Comprehensive R Archive Network - CRAN](#).

You can look for R in the Ubuntu **Software Center** or install it via the terminal:

```
# sudo apt update && sudo apt upgrade -y
sudo apt install r-base
```

Or, if you prefer, you can install the latest version of R from CRAN:

```
# update indices
sudo apt update -qq
# install two helper packages we need
sudo apt install --no-install-recommends software-properties-common dirmngr
# add the signing key (by Michael Rutter) for these repos
wget -qO- https://cloud.r-project.org/bin/linux/ubuntu/marutter_pubkey.asc | sudo tee -a /etc/apt/trusted.gpg
# add the R 4.0 repo from CRAN -- adjust 'focal' to 'groovy' or 'bionic' as needed
sudo add-apt-repository "deb https://cloud.r-project.org/bin/linux/ubuntu $(lsb_release -c -s)"
```

Then run:

```
sudo apt install r-base r-base-core r-recommended r-base-dev
```

[Optional] To keep up-to-date r version and packages, you can follow the instructions at [r2u](#)

After this installation, you don't need to open R base. Please proceed to install RStudio.

6.2 RStudio

RStudio Desktop is an integrated development environment (IDE) for R. It includes a console, syntax-highlighting editor that supports direct code execution, as well as tools for plotting, history, debugging and workspace management.

RStudio is available for free download from [Posit RStudio](#).

6.2.1 Windows 10/11

[Download RStudio 2024.04](#) and run the executable file.

6.2.2 MacOS

Download [RStudio 2024.04](#) and install it as usual.

6.2.3 Ubuntu

These are instructions for Ubuntu **22** / Debian 12. If you use other linux distribution, please follow the instructions on [Posit RStudio](#).

Install it via the terminal:

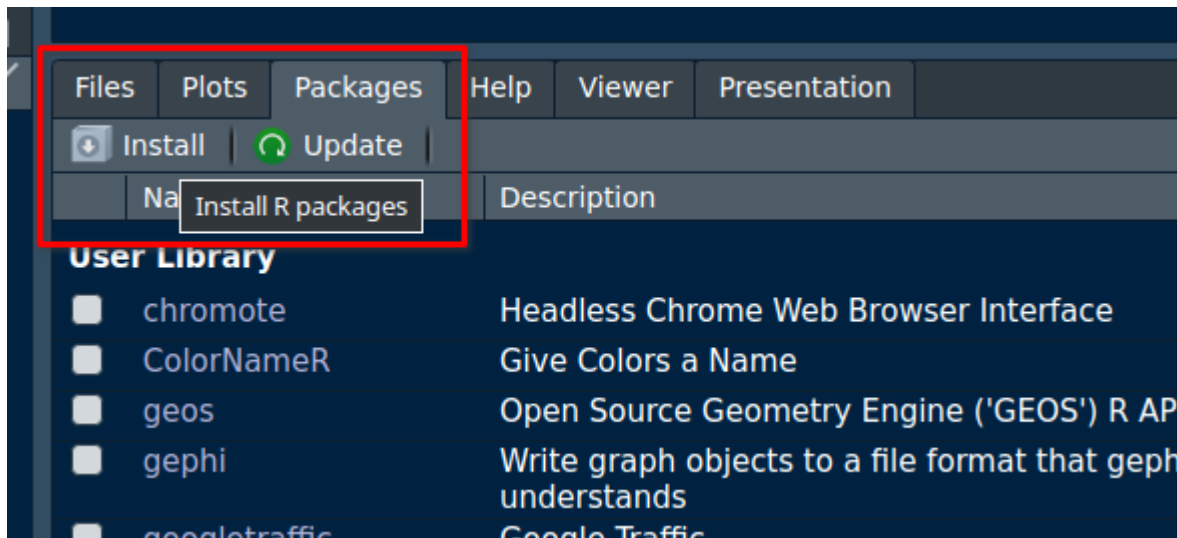
```
sudo apt install libssl-dev libclang-dev
wget https://download1.rstudio.org/electron/jammy/amd64/rstudio-2024.04.2-764-amd64.deb
sudo dpkg -i rstudio*
rm -v rstudio*
```

If you already use Ubuntu **24**, please check and replace the correct url from [RStudio Dailies](#)

6.3 R packages

You will need to install some packages to work with the data and scripts in this course.

You can install them in RStudio by searching for them in the **Packages** tab:



or by running the following code in the console:

```
install.packages("tidyverse")
install.packages("readxl")

install.packages(c("remotes", "devtools", "usethis"))
install.packages("sf")
install.packages("mapview")
install.packages("rmarkdown")
```

6.4 r5r

6.4.1 Java Development Kit

It is also known as JDK 21. You will need this to work with the **r5r** package.

6.4.2 Windows and MacOS

Go to [Java Development Kit 21](#), download the latest 21 build corresponding to your operating system and run the executable file.

6.4.3 Ubuntu

Install it via the terminal:

```
sudo apt install -y openjdk-21-jdk openjdk-21-jre
java -version
```

6.4.4 r5r

Install the **r5r** package:

```
install.packages("r5r")

# development version:
# devtools::install_github("ipeaGIT/r5r", subdir = "r-package")
```

6.4.5 Open Route Service

[Sign up for an account](#) and create a token. Copy your API.

In RStudio console, run:

```
# install.packages("openrouteservice")
openrouteservice::ors_api_key("YOUR-API-KEY")
```

This will store your key on your `.Renviron` file, meaning that every time you open RStudio, you won't need to run this command again.

This is useful also to write your `openrouteservice` scripts without sharing your key with others.

7 R basics

In this chapter we will introduce to the R basics and some exercises to get familiar to how R works.

7.1 Simple operations

7.1.1 Math operations

7.1.1.1 Sum

```
1+1
```

```
[1] 2
```

7.1.1.2 Subtraction

```
5-2
```

```
[1] 3
```

7.1.1.3 Multiplication

```
2*2
```

```
[1] 4
```

7.1.1.4 Division

```
8/2
```

```
[1] 4
```

7.1.1.5 Round the number

```
round(3.14)
```

```
[1] 3
```

```
round(3.14, 1) # The "1" indicates to round it up to 1 decimal digit.
```

```
[1] 3.1
```

You can use help `?round` in the console to see the description of the function, and the default arguments.

7.1.2 Basic shortpaths

7.1.2.1 Perform Combinations

```
c(1, 2, 3)
```

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

```
c(1:3) # The ":" indicates a range between the first and second numbers.
```

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

7.1.2.2 Create a comment with `ctrl + shift + m`

```
# Comments help you organize your code. The software will not run the comment.
```

7.1.2.3 Create a table

A simple table with the number of trips by car, PT, walking, and cycling in a hypothetical street segment at a certain period.

Define variables

```
modes <- c("car", "PT", "walking", "cycling") # you can use "=" or "<-"  
Trips = c(200, 50, 300, 150) # uppercase letters modify
```

Join the variables to create a table

```
table_example = data.frame(modes, Trips)
```

Take a look at the table

Visualize the table by clicking on the “Data” in the “Environment” page or use :

```
View(table_example)
```

7.2 Practical exercise

Dataset: the number of trips between all municipalities in the Lisbon Metropolitan Area, Portugal (Instituto Nacional de Estatística 2018).

7.2.0.1 Import dataset

You can click directly in the file under the “Files” pan, or:

```
data = readRDS("data/TRIPSmode_mun.Rds")
```

Note that after you type " you can use **tab** to navigate between folders and files and **enter** to autocomplete.

7.2.0.2 Take a first look at the data

Summary statistics

```
summary(data)
```

Origin_mun	Destination_mun	Total	Walk
Length:315	Length:315	Min. : 7	Min. : 0
Class :character	Class :character	1st Qu.: 330	1st Qu.: 0
Mode :character	Mode :character	Median : 1090	Median : 0
		Mean : 16825	Mean : 4033
		3rd Qu.: 5374	3rd Qu.: 0
		Max. :875144	Max. :306289

Bike	Car	PTransit	Other
Min. : 0.00	Min. : 0	Min. : 0.0	Min. : 0.0
1st Qu.: 0.00	1st Qu.: 263	1st Qu.: 5.0	1st Qu.: 0.0
Median : 0.00	Median : 913	Median : 134.0	Median : 0.0
Mean : 80.19	Mean : 9956	Mean : 2602.6	Mean : 152.4
3rd Qu.: 0.00	3rd Qu.: 4408	3rd Qu.: 975.5	3rd Qu.: 62.5
Max. :5362.00	Max. :349815	Max. :202428.0	Max. :11647.0

Check the structure of the data

```
str(data)
```

```
'data.frame': 315 obs. of 8 variables:
 $ Origin_mun : chr "Alcochete" "Alcochete" "Alcochete" "Alcochete" ...
 $ Destination_mun: chr "Alcochete" "Almada" "Amadora" "Barreiro" ...
 $ Total : num 20478 567 188 867 114 ...
 $ Walk : num 6833 0 0 0 0 ...
 $ Bike : num 320 0 0 0 0 0 0 0 91 0 ...
 $ Car : num 12484 353 107 861 114 ...
 $ PTransit : num 833 0 81 5 0 ...
 $ Other : num 7 214 0 0 0 0 0 0 0 0 ...
```

Check the first values of each variable

```
data
```

```
head(data, 3) # first 3 values
```

	Origin_mun	Destination_mun	Total	Walk	Bike	Car	PTransit	Other
1	Alcochete	Alcochete	20478	6833	320	12484	833	7
2	Alcochete	Almada	567	0	0	353	0	214
3	Alcochete	Amadora	188	0	0	107	81	0

Check the number of rows (observations) and columns (variables)


```
nrow(data)
```

```
[1] 315
```

```
ncol(data)
```

```
[1] 8
```

Open the dataset

```
View(data)
```

7.2.0.3 Explore the data

Check the total number of trips

Use `$` to select a variable of the data

```
sum(data$Total)
```

```
[1] 5299853
```

Percentage of car trips related to the total

```
sum(data$Car)/sum(data$Total) * 100
```

```
[1] 59.17638
```

Percentage of active trips related to the total

```
(sum(data$Walk) + sum(data$Bike)) / sum(data$Total) * 100
```

```
[1] 24.44883
```

7.2.0.4 Modify original data

Create a column with the sum of the number of trips for active modes

```
data$Active = data$Walk + data$Bike
```

Filter by condition (create new tables)

Filter trips only with origin from Lisbon

```
data_Lisbon = data[data$Origin_mun == "Lisboa",]
```

Filter trips with origin **different** from Lisbon

```
data_out_Lisbon = data[data$Origin_mun != "Lisboa",]
```

Filter trips with origin **and** destination in Lisbon

```
data_in_Out_Lisbon = data[data$Origin_mun == "Lisboa" & data$Destination_mun == "Lisboa",]
```

Remove a column

Look at the first row

```
data[1,] #rows and columns start from 1
```

	Origin_mun	Destination_mun	Total	Walk	Bike	Car	PTransit	Other	Active
1	Alcochete	Alcochete	20478	6833	320	12484	833	7	7153

Look at first row and column

```
data[1,1]
```

```
[1] "Alcochete"
```

Remove the first column

```
data = data[, -1] #first column
```

Create a table only with origin, destination and walking trips

There are many ways to do the same operation.

```
names(data)
```

```
[1] "Destination_mun" "Total"          "Walk"          "Bike"
[5] "Car"             "PTransit"       "Other"         "Active"
```

```
data_walk2 = data[,c(1,2,4)]
```

```
data_walk3 = data[, -c(3,5:9)]
```

7.2.0.5 Export data

Save data in .csv and .Rds

```
write.csv(data, 'data/dataset.csv', row.names = FALSE)
saveRDS(data, 'data/dataset.Rds') #Choose a different file.
```

7.2.0.6 Import data

```
csv_file = read.csv("data/dataset.csv")
rds_file = readRDS("data/dataset.Rds")
```

8 Data manipulation

In this chapter we will use some very useful `dplyr` functions to handle and manipulate data.

You can load the `dplyr` package directly, or load the entire tidy universe (`tidyverse`).

```
# library(tidyverse)
library(dplyr)
```

Using the same dataset as in [R basics](#) but with slightly differences¹.

We will do the same operations but in a simplified way.

```
TRIPS = readRDS("data/TRIPsOrigin.Rds")
```

Note that it is very important to understand the R basics, that's why we started from there, even if the following functions will provide the same results.

You don't need to know everything! And you don't need to know by heart. The following functions are the ones you will probably use most of the time to handle data.

8.1 Select variables

Have a look at your dataset. You can open using `View()`, look at the information at the “Environment” panel, or even print the same information using `glimpse()`

```
glimpse(TRIPS)
```

We will create a new dataset with *Origin*, *Walk*, *Bike* and *Total*. This time we will use the `select()` function.

```
TRIPS_new = select(TRIPS, Origin_mun, Walk, Bike, Total) # the first argument is the dataset
```

¹This dataset includes the number of trips with origin in each neighborhood, divided by mode of transport, and inter or intra municipal trips.

The first argument, as usually in R, is the dataset, and the remaining ones are the columns to select.

With most of the `dplyr` functions you don't need to refer to `data$...` you can simply type the variable names (and even without the "..."). This makes coding in R simpler :)

You can also remove columns that you don't need.

```
TRIPS_new = select(TRIPS_new, -Total) # dropping the Total column
```

8.1.1 Using pipes!

Now, let's introduce pipes. Pipes are a rule as: “**For this, do this.**”

This is useful to skip the first argument of the functions (usually the dataset to apply the function).

Applying a pipe to the `select()` function, we can write as:

```
TRIPS_new = TRIPS |> select(Origin_mun, Walk, Bike, Total)
```

Two things to **note**:

1. The pipe symbol can be written as `|>` or `%>%`.² To write it you may also use the `ctrl+shift+m` shortcut.
2. After typing `select(` you can press `tab` and the list of available variables of that dataset will show up! `Enter` to select. With this you prevent typo errors.

8.2 Filter observations

You can filter observations based on a condition using the `filter()` function.

```
TRIPS2 = TRIPS[TRIPS$Total > 25000,] # using r-base, you cant forget the comma  
TRIPS2 = TRIPS2 |> filter(Total > 25000) # using dplyr, it's easier
```

You can have other conditions inside the condition.

```
summary(TRIPS$Total)  
TABLE2 = TABLE2 |> filter(Total > median(Total))
```

²You can change this in RStudio > Tools > Global Options > Code.

8.3 Create new variables

You can also try again to create a variable of Car percentage using pipes! To create a new variable or change an existing one (overwriting), you can use the `mutate()` function.

```
TRIPS$Car_perc = TRIPS$Car/TRIPS$Total * 100 # using r-base

TRIPS = TRIPS |> mutate(Car_perc = Car/Total * 100) # using dplyr
```

8.4 Change data type

Data can be in different formats. For example, the variable *Origin* is a character, but we can convert it to a numeric variable.

```
class(TRIPS$Origin)
TRIPS = TRIPS |>
  mutate(Origin_num = as.integer(Origin)) # you can use as.numeric() as well
class(TRIPS$Origin_num)
```

Most used data types are:

- integer (`int`)
- numeric (`num`)
- character (`chr`)
- logical (`logical`)
- date (`Date`)
- factor (`factor`)

8.4.1 Factors

Factors are useful to deal with categorical data. You can convert a character to a factor using `as.factor()`, and also use labels and levels for categorical ordinal data.

We can change the `Lisbon` variable to a factor, and `Internal` too.

```
TRIPS = TRIPS |>
  mutate(Lisbon_factor = factor(Lisbon, labels = c("No", "Yes")),
         Internal_factor = factor(Internal, labels = c("Intermunicipal", "Intramunicipal"))
```

But how do we know which levels come first? A simple way is to use `table()` or `unique()` functions.

```
# first number to appear is the first level
unique(TRIPS$Internal) # this will show all the different values
table(TRIPS$Lisbon) # this will show the frequency of each value
```

8.5 Arrange data

8.6 Join data tables

```
Municipalities = readRDS("data/Municipalities_names.Rds")
```

8.7 group_by and summarize

8.7.0.1

8.8 All together now!

This is the pipes magic.

```
TRIPS_pipes = TRIPS |>
  select(Origin, Walk, Bike, Total) |>

  mutate(Origin_num = as.integer(Origin)) |>
  mutate(Internal_factor = factor(Internal, labels = c("Intermunicipal", "Intramunicipal"))

  filter(Internal_factor == "Intramunicipal",
         Lisbon == 1) |>

  left_join(Municipalities, by = c("Origin" = "Code")) |>

  group_by(Origin) |>
  summarize(Total = sum(Total),
           Walk = sum(Walk),
           Bike = sum(Bike),
           Car = sum(Car),
           Car_perc = Car/Total * 100) |>
```

```
arrange(desc(Total))
```

With this code we will have a table with the total number of internal trips in Lisbon, by mode, with their names instead of codes, arranged by the total number of trips.

```
TRIPS_pipes
```


9 Introduction to spatial data

This is a book created from markdown and executable code.

See Knuth (1984) for additional discussion of literate programming.

```
42 + 3.14
```

```
[1] 45.14
```

10 Interactive maps

This is a book created from markdown and executable code.

See Knuth (1984) for additional discussion of literate programming.

```
42 + 3.14
```

```
[1] 45.14
```

Part II

Day 2

11 OD pairs and desire lines

This is a book created from markdown and executable code.

See Knuth (1984) for additional discussion of literate programming.

```
42 + 3.14
```

```
[1] 45.14
```

12 Georeferenced coordinates

This is a book created from markdown and executable code.

See Knuth (1984) for additional discussion of literate programming.

```
42 + 3.14
```

```
[1] 45.14
```

13 Euclidean and routing distances

We will show how to estimate euclidean distances (*as crown flights*) using `sf` package, and the distances using a road network using `r5r` package (demonstrative).

13.1 Euclidean distances

Taking the municipality centroids, or survey respondents' location

See Knuth (1984) for additional discussion of literate programming.

```
42 + 3.14
```

```
[1] 45.14
```

14 Open transportation data

This is a book created from markdown and executable code.

See Knuth (1984) for additional discussion of literate programming.

```
42 + 3.14
```

```
[1] 45.14
```

15 Routing and Accessibility with r5r

This is a book created from markdown and executable code.

See Knuth (1984) for additional discussion of literate programming.

```
42 + 3.14
```

```
[1] 45.14
```


16 Introduction

This is a book created from markdown and executable code.

See Knuth (1984) for additional discussion of literate programming.

```
data = readRDS("data/TRIPMode_mun.Rds")
data_walk = data[,c("Origin_mun", "Destination_mun", "Walk")]
head(data_walk)
```

	Origin_mun	Destination_mun	Walk
1	Alcochete	Alcochete	6833
2	Alcochete	Almada	0
3	Alcochete	Amadora	0
4	Alcochete	Barreiro	0
5	Alcochete	Cascais	0
6	Alcochete	Lisboa	69

References

- Instituto Nacional de Estatística. 2018. “Mobilidade e Funcionalidade Do Território Nas Áreas Metropolitanas Do Porto e de Lisboa: 2017.” Lisboa. https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_publicacoes&PUBLICACOESpub_boui=349495406&PUBLICACOESmodo=2&xlang=pt.
- Knuth, Donald E. 1984. “Literate Programming.” *Comput. J.* 27 (2): 97–111. <https://doi.org/10.1093/comjnl/27.2.97>.