Super Study Guide: Data Science Tools

Afshine Amidi and Shervine Amidi

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Contents

SECTION 1

Data retrieval with SQL

1.1 General concepts

❒ **Structured Query Language** – Structured Query Language, abbreviated as SQL, is a language that is largely used in the industry to query data from databases.

❒ **Query structure** – Queries are usually structured as follows:

SQL

```sql
-- Select fields                    mandatory
SELECT
    col_1,
    col_2,
     ... ,
    col_n

-- Source of data                   mandatory
FROM table t

-- Gather info from other sources   optional
JOIN other_table ot
  ON (t.key = ot.key)

-- Conditions                       optional
WHERE some_condition(s)

-- Aggregating                      optional
GROUP BY column_group_list

-- Sorting values                   optional
ORDER BY column_order_list

-- Restricting aggregated values    optional
HAVING some_condition(s)

-- Limiting number of rows          optional
LIMIT some_value
```

Remark: the `SELECT DISTINCT` command can be used to ensure not having duplicate rows.

❒ **Condition** – A condition is of the following format:

SQL

```sql
some_col some_operator some_col_or_value
```

where `some_operator` can be among the following common operations:

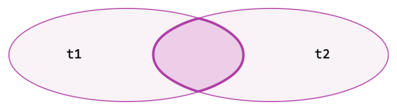
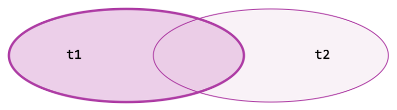
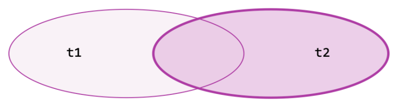
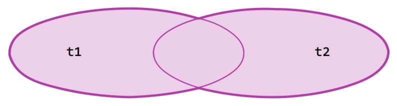
Category	Operator	Command
General	Equality / non-equality	`=` / `!=`, `<>`
	Inequalities	`>=`, `>`, `<`, `<=`
	Belonging	`IN (val_1, ..., val_n)`
	And / or	`AND` / `OR`
	Check for missing value	`IS NULL`
	Between bounds	`BETWEEN val_1 AND val_2`
Strings	Pattern matching	`LIKE '%val%'`

❒ **Joins** – Two tables `table_1` and `table_2` can be joined in the following way:

SQL

```sql
...
FROM table_1 t1
type_of_join table_2 t2
  ON (t2.key = t1.key)
...
```

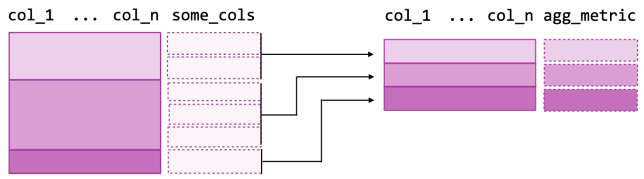
where the different `type_of_join` commands are summarized in the table below:

Type of join	Illustration
`INNER JOIN`	
`LEFT JOIN`	
`RIGHT JOIN`	
`FULL JOIN`	

Remark: joining every row of table 1 with every row of table 2 can be done with the `CROSS JOIN` command, and is commonly known as the cartesian product.

1.2 Aggregations

❒ **Grouping data** – Aggregate metrics are computed on grouped data in the following way:



The SQL command is as follows:

```
SQL
SELECT
    col_1,
    agg_function(col_2)
FROM table
GROUP BY col_1
```

❒ **Grouping sets** – The GROUPING SETS command is useful when there is a need to compute aggregations across different dimensions at a time. Below is an example of how all aggregations across two dimensions are computed:

```
SQL
SELECT
    col_1,
    col_2,
    agg_function(col_3)
FROM table
GROUP BY (
  GROUPING SETS
    (col_1),
    (col_2),
    (col_1, col_2)
)
```

❒ **Aggregation functions** – The table below summarizes the main aggregate functions that can be used in an aggregation query:

Category	Operation	Command
Values	Mean	AVG(col)
	Percentile	PERCENTILE_APPROX(col, p)
	Sum / # of instances	SUM(col) / COUNT(col)
	Max / min	MAX(col) / MIN(col)
	Variance / standard deviation	VAR(col) / STDEV(col)
Arrays	Concatenate into array	collect_list(col)

Remark: the median can be computed using the PERCENTILE_APPROX function with p equal to 0.5.

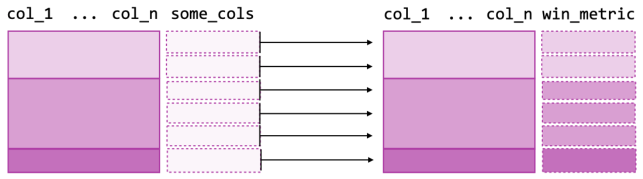
❒ **Filtering** – The table below highlights the differences between the WHERE and HAVING commands:

WHERE	HAVING
- Filter condition applies to individual rows - Statement placed right after FROM	- Filter condition applies to aggregates - Statement placed right after GROUP BY

Remark: if WHERE and HAVING are both in the same query, WHERE will be executed first.

1.3 Window functions

❒ **Definition** – A window function computes a metric over groups and has the following structure:



The SQL command is as follows:

```
SQL
some_window_function() OVER(PARTITION BY some_col ORDER BY another_col)
```

Remark: window functions are only allowed in the SELECT clause.

❒ **Row numbering** – The table below summarizes the main commands that rank each row across specified groups, ordered by a specific column:

Command	Description	Example
ROW_NUMBER()	Ties are given different ranks	1, 2, 3, 4
RANK()	Ties are given same rank and skip numbers	1, 2, 2, 4
DENSE_RANK()	Ties are given same rank and don't skip numbers	1, 2, 2, 3

❒ **Values** – The following window functions allow to keep track of specific types of values with respect to the partition:

Command	Description
FIRST_VALUE(col)	Takes the first value of the column
LAST_VALUE(col)	Takes the last value of the column
LAG(col, n)	Takes the n^{th} previous value of the column
LEAD(col, n)	Takes the n^{th} following value of the column
NTH_VALUE(col, n)	Takes the n^{th} value of the column

1.4 Advanced functions

❒ **SQL tips** – In order to keep the query in a clear and concise format, the following tricks are often done:

Operation	Command	Description
Renaming columns	`SELECT operation_on_column AS col_name`	New column names shown in query results
Abbreviating tables	`FROM table_1 t1`	Abbreviation used within query for simplicity in notations
Simplifying group by	`GROUP BY col_number_list`	Specify column position in `SELECT` clause instead of whole column names
Limiting results	`LIMIT n`	Display only n rows

❒ **Sorting values** – The query results can be sorted along a given set of columns using the following command:

SQL
```
... [query] ...
ORDER BY col_list
```

Remark: by default, the command sorts in ascending order. If we want to sort it in descending order, the `DESC` *command needs to be used after the column.*

❒ **Column types** – In order to ensure that a column or value is of one specific data type, the following command is used:

SQL
```
CAST(some_col_or_value AS data_type)
```

where `data_type` is one of the following:

Data type	Description	Example
`INT`	Integer	`2`
`DOUBLE`	Numerical value	`2.0`
`STRING` `VARCHAR`	String	`'teddy bear'`
`DATE`	Date	`'2020-01-01'`
`TIMESTAMP`	Timestamp	`'2020-01-01 00:00:00.000'`

Remark: if the column contains data of different types, the `TRY_CAST()` *command will convert unknown types to* `NULL` *instead of throwing an error.*

❒ **Column manipulation** – The main functions used to manipulate columns are described in the table below:

Category	Operation	Command
General	Take first non-`NULL` value	`COALESCE(col_1, col_2, ..., col_n)`
	Create a new column combining existing ones	`CONCAT(col_1, ..., col_n)`
Value	Round value to n decimals	`ROUND(col, n)`
String	Converts string column to lower / upper case	`LOWER(col) / UPPER(col)`
	Replace occurrences of `old` in `col` to `new`	`REPLACE(col, old, new)`
	Take the substring of `col`, with a given `start` and `length`	`SUBSTR(col, start, length)`
	Remove spaces from the left / right / both sides	`LTRIM(col) / RTRIM(col) / TRIM(col)`
	Length of the string	`LENGTH(col)`
Date	Truncate at a given granularity (`year`, `month`, `week`)	`DATE_TRUNC(time_dimension, col_date)`
	Transform date	`DATE_ADD(col_date, number_of_days)`

❒ **Conditional column** – A column can take different values with respect to a particular set of conditions with the `CASE WHEN` command as follows:

SQL
```
CASE WHEN some_condition THEN some_value
                ...
     WHEN some_other_condition THEN some_other_value
     ELSE some_other_value_n END
```

❒ **Combining results** – The table below summarizes the main ways to combine results in queries:

Category	Command	Remarks
Union	`UNION`	Guarantees distinct rows
	`UNION ALL`	Potential newly-formed duplicates are kept
Intersection	`INTERSECT`	Keeps observations that are in all selected queries

❒ **Common table expression** – A common way of handling complex queries is to have temporary result sets coming from intermediary queries, which are called common table expressions (abbreviated CTE), that increase the readability of the overall query. It is done thanks to the `WITH ... AS ...` command as follows:

SQL
```
WITH cte_1 AS (
SELECT ...
),
...

cte_n AS (
SELECT ...
)

SELECT ...
FROM ...
```

1.5 Table manipulation

❒ **Table creation** – The creation of a table is done as follows:

SQL
```
CREATE [table_type] TABLE [creation_type] table_name(
  col_1 data_type_1,
         ...       ,
  col_n data_type_n
)
[options];
```

where [table_type], [creation_type] and [options] are one of the following:

Category	Command	Description
Table type	Blank	Default table
	EXTERNAL TABLE	External table
Creation type	Blank	Creates table and overwrites current one if it exists
	IF NOT EXISTS	Only creates table if it does not exist
Options	location 'path_to_hdfs_folder'	Populate table with data from hdfs folder
	stored as data_format	Stores the table in a specific data format, e.g. parquet, orc or avro

❒ **Data insertion** – New data can either append or overwrite already existing data in a given table as follows:

SQL
```
WITH ...                            -- optional

INSERT [insert_type] table_name     -- mandatory

SELECT ...;                         -- mandatory
```

where [insert_type] is among the following:

Command	Description
OVERWRITE	Overwrites existing data
INTO	Appends to existing data

❒ **Dropping table** – Tables are dropped in the following way:

SQL
```
DROP TABLE table_name;
```

❒ **View** – Instead of using a complicated query, the latter can be saved as a view which can then be used to get the data. A view is created with the following command:

SQL
```
CREATE VIEW view_name AS complicated_query;
```

Remark: a view does not create any physical table and is instead seen as a shortcut.

SECTION 2

Working with data with R

2.1 Data manipulation

2.1.1 Main concepts

❐ **File management** – The table below summarizes the useful commands to make sure the working directory is correctly set:

Category	Action	Command
Paths	Change directory to another path	`setwd(path)`
	Get current working directory	`getwd()`
	Join paths	`file.path(path_1, ..., path_n)`
Files	List files and folders in a given directory	`list.files(path, include.dirs = TRUE)`
	Check if path is a file / folder	`file_test('-f', path)`
		`file_test('-d', path)`
	Read / write csv file	`read.csv(path_to_csv_file)`
		`write.csv(df, path_to_csv_file)`

❐ **Chaining** – The symbol `%>%`, also called "pipe", enables to have chained operations and provides better legibility. Here are its different interpretations:

- `f(arg_1, arg_2, ..., arg_n)` is equivalent to `arg_1 %>% f(arg_2, arg_3, ..., arg_n)`, and also to:
  - `arg_1 %>% f(., arg_2, ..., arg_n)`
  - `arg_2 %>% f(arg_1, ., arg_3, ..., arg_n)`
  - `arg_n %>% f(arg_1, ..., arg_n-1, .)`
- A common use of pipe is when a dataframe `df` gets first modified by `some_operation_1`, then `some_operation_2`, until `some_operation_n` in a sequential way. It is done as follows:

R
```r
# df gets some_operation_1, then some_operation_2, ...,
# then some_operation_n
df %>%
  some_operation_1 %>%
  some_operation_2 %>%
        ...        %>%
  some_operation_n
```

❐ **Exploring the data** – The table below summarizes the main functions used to get a complete overview of the data:

Category	Action	Command
Look at data	Select columns of interest	`df %>% select(col_list)`
	Remove unwanted columns	`df %>% select(-col_list)`
	Look at n first rows / last rows	`df %>% head(n)` / `df %>% tail(n)`
	Summary statistics of columns	`df %>% summary()`
Data types	Data types of columns	`df %>% str()`
	Number of rows / columns	`df %>% NROW()` / `df %>% NCOL()`

❐ **Data types** – The table below sums up the main data types that can be contained in columns:

Data type	Description	Example
`character`	String-related data	`'teddy bear'`
`factor`	String-related data that can be put in bucket, or ordered	`'high'`
`numeric`	Numerical data	`24.0`
`int`	Numeric data that are integer	`24`
`Date`	Dates	`'2020-01-01'`
`POSIXct`	Timestamps	`'2020-01-01 00:01:00'`

2.1.2 Data preprocessing

❐ **Filtering** – We can filter rows according to some conditions as follows:

R
```r
df %>%
  filter(some_col some_operation some_value_or_list_or_col)
```

where `some_operation` is one of the following:

Category	Operation	Command
Basic	Equality / non-equality	`==` / `!=`
	Inequalities	`<`, `<=`, `>=`, `>`
	And / or	`&` / `|`
Advanced	Check for missing value	`is.na()`
	Belonging	`%in% (val_1, ..., val_n)`
	Pattern matching	`%like% 'val'`

Remark: we can filter columns with the `select_if` *command.*

❐ **Changing columns** – The table below summarizes the main column operations:

Action	Command
Add new columns on top of old ones	`df %>% mutate(new_col = operation(other_cols))`
Add new columns and discard old ones	`df %>% transmute(new_col = operation(other_cols))`
Modify several columns in-place	`df %>% mutate_at(vars, funs)`
Modify all columns in-place	`df %>% mutate_all(funs)`
Modify columns fitting a specific condition	`df %>% mutate_if(condition, funs)`
Unite columns	`df %>% unite(new_merged_col, old_cols_list)`
Separate columns	`df %>% separate(col_to_separate, new_cols_list)`

❒ **Conditional column** – A column can take different values with respect to a particular set of conditions with the `case_when()` command as follows:

```
R
case_when(condition_1 ∼ value_1,   # If condition_1 then value_1
          condition_2 ∼ value_2,   # If condition_2 then value_2
             ...
          TRUE ∼ value_n)          # Otherwise, value_n
```

Remark: the `ifelse(condition_if_true, value_true, value_other)` can be used and is easier to manipulate if there is only one condition.

❒ **Mathematical operations** – The table below sums up the main mathematical operations that can be performed on columns:

Operation	Command
$\sqrt{x}$	`sqrt(x)`
$\lfloor x \rfloor$	`floor(x)`
$\lceil x \rceil$	`ceiling(x)`

❒ **Datetime conversion** – Fields containing datetime values can be stored in two different `POSIXt` data types:

Action	Command
Converts to datetime with seconds since origin	`as.POSIXct(col, format)`
Converts to datetime with attributes (e.g. time zone)	`as.POSIXlt(col, format)`

where `format` is a string describing the structure of the field and using the commands summarized in the table below:

Category	Command	Description	Example
Year	`'%Y'` / `'%y'`	With / without century	`2020` / `20`
Month	`'%B'` / `'%b'` / `'%m'`	Full / abbreviated / numerical	`August` / `Aug` / `8`
Weekday	`'%A'` / `'%a'`	Full / abbreviated	`Sunday` / `Sun`
	`'%u'` / `'%w'`	Number (1-7) / Number (0-6)	`7` / `0`
Day	`'%d'` / `'%j'`	Of the month / of the year	`09` / `222`
Time	`'%H'` / `'%M'`	Hour / minute	`09` / `40`
Timezone	`'%Z'` / `'%z'`	String / Number of hours from UTC	`EST` / `-0400`

Remark: data frames only accept datetime in `POSIXct` format.

❒ **Date properties** – In order to extract a date-related property from a datetime object, the following command is used:

```
R
format(datetime_object, format)
```

where `format` follows the same convention as in the table above.

2.1.3 Data frame transformation

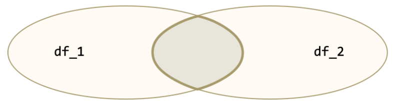
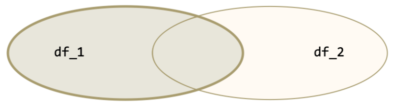
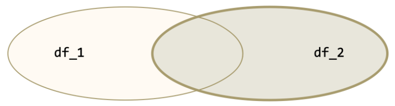
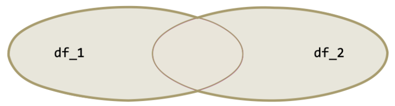
❒ **Merging data frames** – We can merge two data frames by a given field as follows:

```
R
merge(df_1, df_2, join_field, join_type)
```

where `join_field` indicates fields where the join needs to happen:

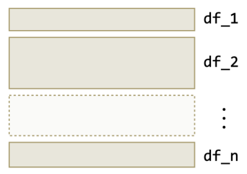
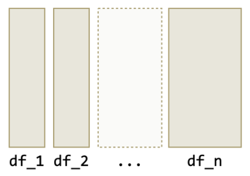
Case	Fields are equal	Different field names
Command	`by = 'field'`	`by.x = 'field_1', by.y = 'field_2'`

and where `join_type` indicates the join type, and is one of the following:

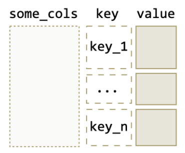
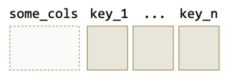
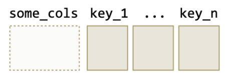
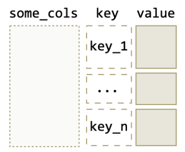
Join type	Option	Illustration
Inner join	default	
Left join	`all.x = TRUE`	
Right join	`all.y = TRUE`	
Full join	`all = TRUE`	

Remark: if the `by` *parameter is not specified, the merge will be a cross join.*

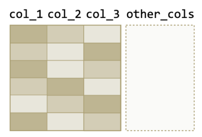
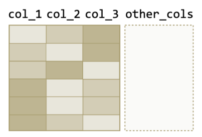
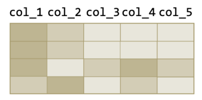
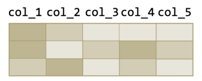
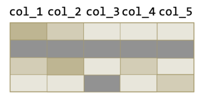
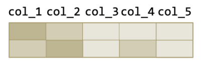
❒ **Concatenation** – The table below summarizes the different ways data frames can be concatenated:

Type	Command	Illustration
Rows	`rbind(df_1, ..., df_n)`	
Columns	`cbind(df_1, ..., df_n)`	

❒ **Common transformations** – The common data frame transformations are summarized in the table below:

Type	Command	Illustration: Before	Illustration: After
Long to wide	`spread( df, key = 'key', value = 'value' )`		
Wide to long	`gather( df, key = 'key' value = 'value', c(key_1, ..., key_n) )`		

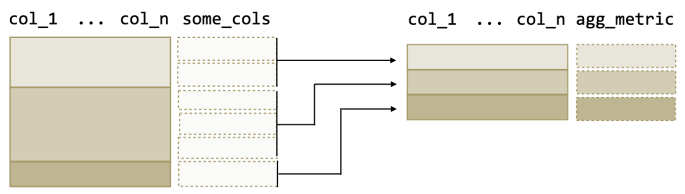
❒ **Row operations** – The following actions are used to make operations on rows of the data frame:

Action	Command	Illustration: Before	Illustration: After
Sort with respect to columns	`df %>% arrange(col_1, ..., col_n)`		
Dropping duplicates	`df %>% unique()`		
Drop rows with at least a null value	`df %>% na.omit()`		

Remark: by default, the `arrange` *command sorts in ascending order. If we want to sort it in descending order, the* `-` *command needs to be used before a column.*

2.1.4 Aggregations

❒ **Grouping data** – Aggregate metrics are computed across groups as follows:



The R command is as follows:

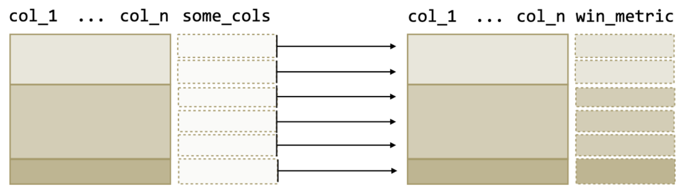
```
R
df %>%                                              # Ungrouped data frame
  group_by(col_1, ..., col_n) %>%                   # Group by some columns
  summarize(agg_metric = some_aggregation(some_cols)) # Aggregation step
```

❒ **Aggregate functions** – The table below summarizes the main aggregate functions that can be used in an aggregation query:

Category	Action	Command
Properties	Count of observations	n()
Values	Sum of values of observations	sum()
	Max / min of values of observations	max() / min()
	Mean / median of values of observations	mean() / median()
	Standard deviation / variance across observations	sd() / var()

2.1.5 Window functions

❒ **Definition** – A window function computes a metric over groups and has the following structure:



The R command is as follows:

```
R
df %>%                                    # Ungrouped data frame
  group_by(col_1, ..., col_n) %>%         # Group by some columns
  mutate(win_metric = window_function(col)) # Window function
```

Remark: applying a window function will not change the initial number of rows of the data frame.

❒ **Row numbering** – The table below summarizes the main commands that rank each row across specified groups, ordered by a specific field:

Join type	Command	Example
row_number(x)	Ties are given different ranks	1, 2, 3, 4
rank(x)	Ties are given same rank and skip numbers	1, 2.5, 2.5, 4
dense_rank(x)	Ties are given same rank and do not skip numbers	1, 2, 2, 3

❒ **Values** – The following window functions allow to keep track of specific types of values with respect to the group:

Command	Description
first(x)	Takes the first value of the column
last(x)	Takes the last value of the column
lag(x, n)	Takes the n^{th} previous value of the column
lead(x, n)	Takes the n^{th} following value of the column
nth(x, n)	Takes the n^{th} value of the column

2.2 Data visualization

2.2.1 General structure

❒ **Overview** – The general structure of the code that is used to plot figures is as follows:

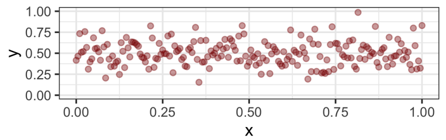
```
R
ggplot(...) +           # Initialization
  geom_function(...) +  # Main plot(s)
  facet_function(...) + # Facets (optional)
  labs(...) +           # Legend (optional)
  scale_function(...) + # Scales (optional)
  theme_function(...)   # Theme (optional)
```

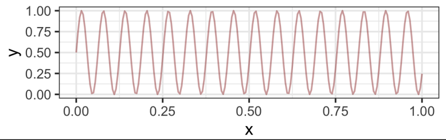
We note the following points:

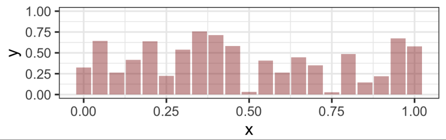
- The ggplot() layer is mandatory.
- When the data argument is specified inside the ggplot() function, it is used as default in the following layers that compose the plot command, unless otherwise specified.
- In order for features of a data frame to be used in a plot, they need to be specified inside the aes() function.

❒ **Basic plots** – The main basic plots are summarized in the table below:

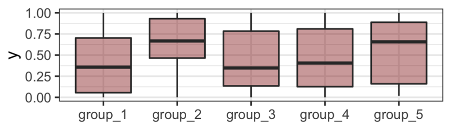
Type	Command	Illustration

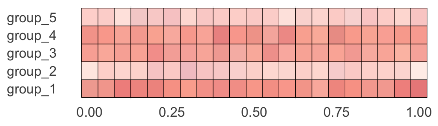
Scatter plot	`geom_point(`
	`  x, y, params`
	`)`
		

Line plot	`geom_line(`
	`  x, y, params`
	`)`
		

Bar chart	`geom_bar(`
	`  x, y, params`
	`)`
		

Type	Command	Illustration

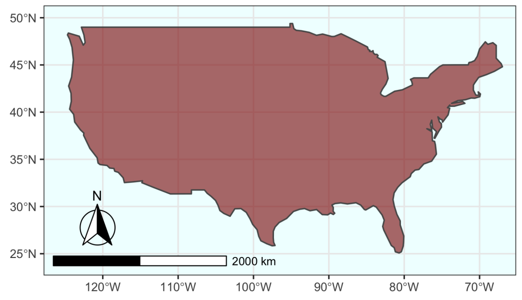
Box plot	`geom_boxplot(`
	`  x, y, params`
	`)`
		

Heatmap	`geom_tile(`
	`  x, y, params`
	`)`
		

where the possible parameters are summarized in the table below:

Command	Description	Use case
`color`	Color of a line / point / border	`'red'`
`fill`	Color of an area	`'red'`
`size`	Size of a line / point	`4`
`shape`	Shape of a point	`4`
`linetype`	Shape of a line	`'dashed'`
`alpha`	Transparency, between 0 and 1	`0.3`

❒ **Maps** – It is possible to plot maps based on geometrical shapes as follows:



The following table summarizes the main commands used to plot maps:

Category	Action	Command
Map	Draw polygon shapes from the `geometry` column	`geom_sf(data)`
Additional elements	Add and customize geographical directions	`annotation_north_arrow(l)`
	Add and customize distance scale	`annotation_scale(l)`
Range	Customize range of coordinates	`coord_sf(xlim, ylim)`

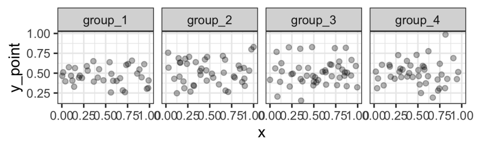
❒ **Animations** – Plotting animations can be made using the `gganimate` library. The following command gives the general structure of the code:

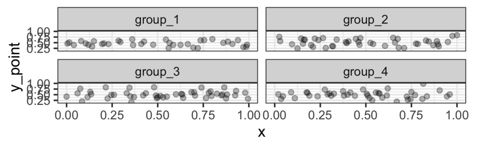
```r
# Main plot
ggplot() +
  ... +
  transition_states(field, states_length)

# Generate and save animation
animate(plot, duration, fps, width, height, units, res, renderer)
anim_save(filename)
```

2.2.2 Advanced features

❒ **Facets** – It is possible to represent the data through multiple dimensions with facets using the following commands:

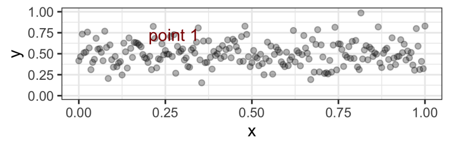
Type	Command	Illustration

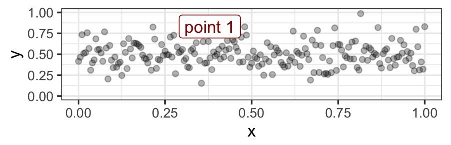
Grid (1 or 2D)	`facet_grid(`
	`  row_var ~ column_var`
	`)`
		

Wrapped	`facet_wrap(`
	`  vars(x1, ..., xn),`
	`  nrow, ncol`
	`)`
		

❐ **Text annotation** – Plots can have text annotations with the following commands:

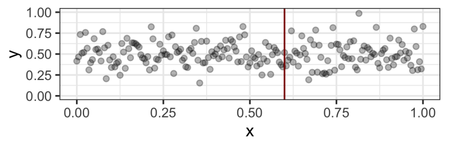
Command	Illustration

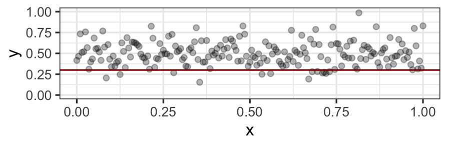
`geom_text(`
`  x, y, label,`
`  hjust, vjust`
`)`
	

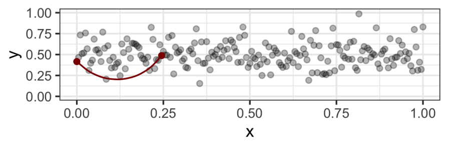
`geom_label_repel(`
`  x, y, label,`
`  nudge_x, nudge_y`
`)`
	

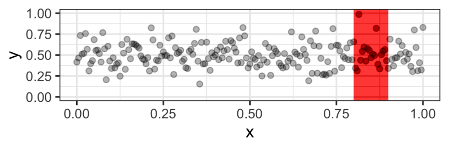
❐ **Additional elements** – We can add objects on the plot with the following commands:

Type	Command	Illustration

Line	`geom_vline(`
	`  xintercept, linetype`
	`)`
		

	`geom_hline(`
	`  yintercept, linetype`
	`)`
		

Curve	`geom_curve(`
	`  x, y, xend, yend`
	`)`
		

Rectangle	`geom_rect(`
	`  xmin, xmax, ymin, ymax`
	`)`
		

2.2.3 Last touch

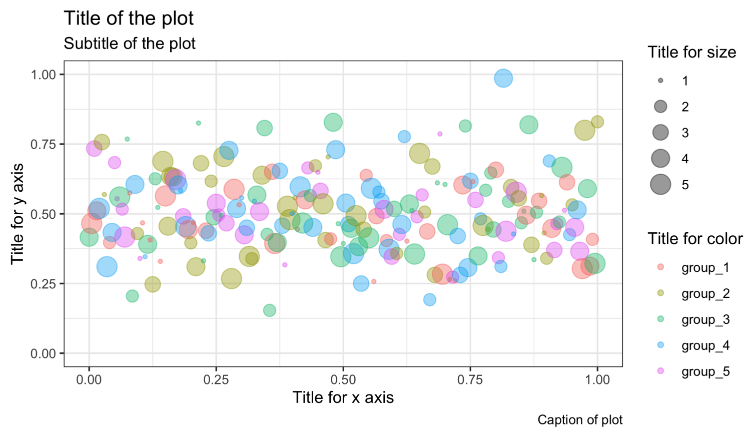
❐ **Legend** – The title of legends can be customized to the plot with the following command:

```r
plot + labs(params)
```

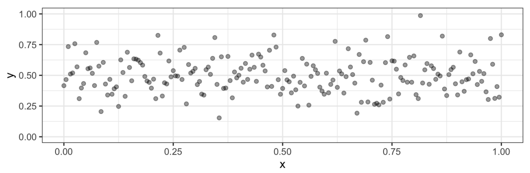
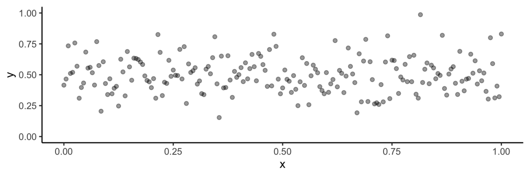
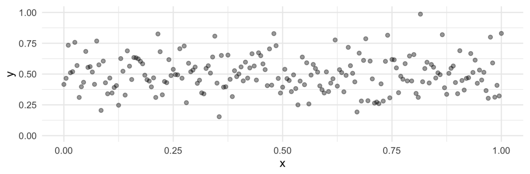
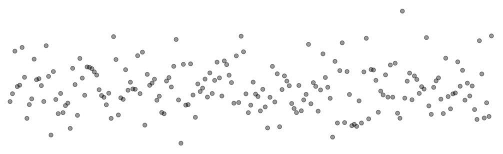
where the `params` are summarized below:

Element	Command
Title / subtitle of the plot	`title = 'text'` / `subtitle = 'text'`
Title of the x / y axis	`x = 'text'` / `y = 'text'`
Title of the size / color	`size = 'text'` / `color = 'text'`
Caption of the plot	`caption = 'text'`

This results in the following plot:



❒ **Plot appearance** – The appearance of a given plot can be set by adding the following command:

Type	Command	Illustration
Black and white	`theme_bw()`	
Classic	`theme_classic()`	
Minimal	`theme_minimal()`	
None	`theme_void()`	

In addition, `theme()` is able to adjust positions/fonts of elements of the legend.

Remark: in order to fix the same appearance parameters for all plots, the `theme_set()` *function can be used.*

❒ **Scales and axes** – Scales and axes can be changed with the following commands:

Category	Action	Command

Range	Specify range of x / y axis	`xlim(xmin, xmax)`
		`ylim(ymin, ymax)`

Nature	Display ticks in a customized manner	`scale_x_continuous()`
		`scale_x_discrete()`
		`scale_x_date()`

Magnitude	Transform axes	`scale_x_log10()`
		`scale_x_reverse()`
		`scale_x_sqrt()`

Remark: the `scale_x()` *functions are for the x axis. The same adjustments are available for the y axis with* `scale_y()` *functions.*

❒ **Double axes** – A plot can have more than one axis with the `sec.axis` option within a given scale function `scale_function()`. It is done as follows:

```r
scale_function(sec.axis = sec_axis(~ .))
```

❒ **Saving figure** – It is possible to save figures with predefined parameters regarding the scale, width and height of the output image with the following command:

```r
ggsave(plot, filename, scale, width, height)
```

SECTION 3

Working with data with Python

3.1 Data manipulation

3.1.1 Main concepts

❒ **File management** – The table below summarizes the useful commands to make sure the working directory is correctly set:

Category	Action	Command
Paths	Change directory to another path	`os.chdir(path)`
	Get current working directory	`os.getcwd()`
	Join paths	`os.path.join(path_1, ..., path_n)`
Files	List files and folders in a directory	`os.listdir(path)`
	Check if path is a file / folder	`os.path.isfile(path)` `os.path.isdir(path)`
	Read / write csv file	`pd.read_csv(path_to_csv_file)` `df.to_csv(path_to_csv_file)`

❒ **Chaining** – It is common to have successive methods applied to a data frame to improve readability and make the processing steps more concise. The method chaining is done as follows:

Python
```python
# df gets some_operation_1, then some_operation_2, ..., then some_operation_n
(df
.some_operation_1(params_1)
.some_operation_2(params_2)
.      ...
.some_operation_n(params_n))
```

❒ **Exploring the data** – The table below summarizes the main functions used to get a complete overview of the data:

Category	Action	Command
Look at data	Select columns of interest	`df[col_list]`
	Remove unwanted columns	`df.drop(col_list, axis=1)`
	Look at n first rows / last rows	`df.head(n)` / `df.tail(n)`
	Summary statistics of columns	`df.describe()`
Paths	Data types of columns	`df.dtypes` / `df.info()`
	Number of (rows, columns)	`df.shape`

❒ **Data types** – The table below sums up the main data types that can be contained in columns:

Data type	Description	Example
`object`	String-related data	`'teddy bear'`
`float64`	Numerical data	`24.0`
`int64`	Numeric data that are integer	`24`
`datetime64`	Timestamps	`'2020-01-01 00:01:00'`

3.1.2 Data preprocessing

❒ **Filtering** – We can filter rows according to some conditions as follows:

Python
```python
df[df['some_col'] some_operation some_value_or_list_or_col]
```

where `some_operation` is one of the following:

Category	Operation	Command
Basic	Equality / non-equality	`==` / `!=`
	Inequalities	`<`, `<=`, `>=`, `>`
	And / or	`&` / `|`
Advanced	Check for missing value	`pd.isnull()`
	Belonging	`.isin([val_1, ..., val_n])`
	Pattern matching	`.str.contains('val')`

❒ **Changing columns** – The table below summarizes the main column operations:

Operation	Command
Add new columns on top of old ones	`df.assign( new_col=lambda x: some_operation(x) )`
Rename columns	`df.rename(columns={ 'current_col': 'new_col_name'} })`
Unite columns	`df['new_merged_col'] = ( df[old_cols_list].agg('-'.join, axis=1) )`

❒ **Conditional column** – A column can take different values with respect to a particular set of conditions with the `np.select()` command as follows:

Python
```
np.select(
  [condition_1, ..., condition_n],  # If condition_1, ..., condition_n
  [value_1, ..., value_n],          # Then value_1, ..., value_n respectively
  default=default_value             # Otherwise, default_value
)
```

Remark: the `np.where(condition_if_true, value_true, value_other)` command can be used and is easier to manipulate if there is only one condition.

❒ **Mathematical operations** – The table below sums up the main mathematical operations that can be performed on columns:

Operation	Command
$\sqrt{x}$	`np.sqrt(x)`
$\lfloor x \rfloor$	`np.floor(x)`
$\lceil x \rceil$	`np.ceil(x)`

❒ **Datetime conversion** – Fields containing datetime values are converted from string to datetime as follows:

Python
```
pd.to_datetime(col, format)
```

where `format` is a string describing the structure of the field and using the commands summarized in the table below:

Category	Command	Description	Example
Year	'%Y' / '%y'	With / without century	2020 / 20
Month	'%B' / '%b' / '%m'	Full / abbreviated / numerical	August / Aug / 8
Weekday	'%A' / '%a'	Full / abbreviated	Sunday / Sun
	'%u' / '%w'	Number (1-7) / Number (0-6)	7 / 0
Day	'%d' / '%j'	Of the month / of the year	09 / 222
Time	'%H' / '%M'	Hour / minute	09 / 40
Timezone	'%Z' / '%z'	String / Number of hours from UTC	EST / -0400

❒ **Date properties** – In order to extract a date-related property from a datetime object, the following command is used:

Python
```
datetime_object.strftime(format)
```

where `format` follows the same convention as in the table above.

3.1.3 Data frame transformation

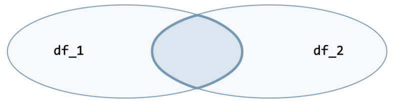
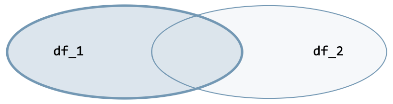
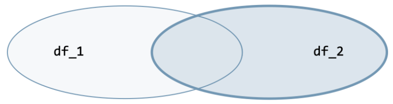
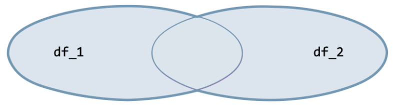
❒ **Merging data frames** – We can merge two data frames by a given field as follows:

Python
```
df1.merge(df2, join_field, join_type)
```

where `join_field` indicates fields where the join needs to happen:

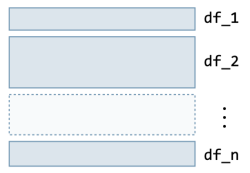
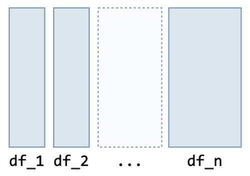
Case	Fields are equal	Fields are different
Command	on='field'	left_on='field_1', right_on='field_2'

and where `join_type` indicates the join type, and is one of the following:

Join type	Option	Illustration
Inner join	how='inner'	
Left join	how='left'	
Right join	how='right'	
Full join	how='outer'	

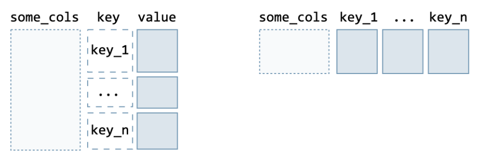
Remark: a cross join can be done by joining on an undifferentiated column, typically done by creating a temporary column equal to 1.

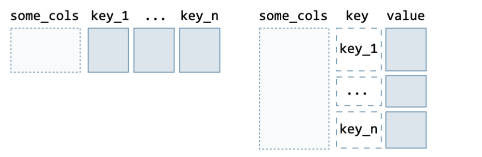
❒ **Concatenation** – The table below summarizes the different ways data frames can be concatenated:

Type	Command	Illustration
Rows	`pd.concat([df_1, ..., df_n], axis=0)`	
Columns	`pd.concat([df_1, ..., df_n], axis=1)`	

❒ **Common transformations** – The common data frame transformations are summarized in the table below:

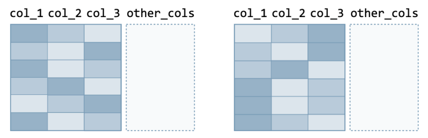
Type	Command	Illustration	
		Before	After

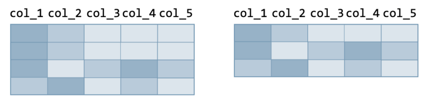
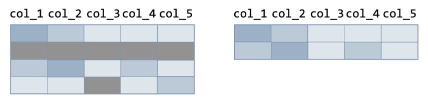
Long to wide	`pd.pivot_table(`
	`  df, values='value',`
	`  index=some_cols,`
	`  columns='key',`
	`  aggfunc=np.sum`
	`)`
		 some_cols key value
		key_1
		...
		key_n
		some_cols key_1 ... key_n	

Wide to long	`pd.melt(`
	`  df, var_name='key',`
	`  value_name='value',`
	`  value_vars=[`
	`    'key_1', ..., 'key_n'`
	`  ], id_vars=some_cols`
	`)`
		 some_cols key_1 ... key_n
		some_cols key value
		key_1
		...
		key_n	

❒ **Row operations** – The following actions are used to make operations on rows of the data frame:

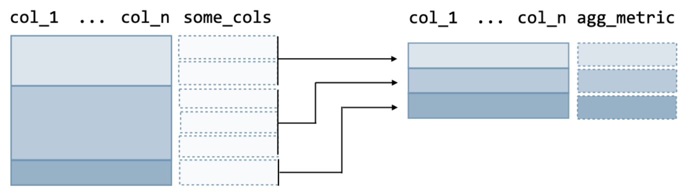
Action	Command	Illustration	
		Before	After

Sort with respect to columns	`df.sort_values(`
	`  by=['col_1', ..., 'col_n'],`
	`  ascending=True`
	`)`
		 col_1 col_2 col_3 other_cols
		col_1 col_2 col_3 other_cols	

Dropping duplicates	`df.drop_duplicates()`	 col_1 col_2 col_3 col_4 col_5 col_1 col_2 col_3 col_4 col_5	
Drop rows with at least a null value	`df.dropna()`	 col_1 col_2 col_3 col_4 col_5 col_1 col_2 col_3 col_4 col_5	

3.1.4 Aggregations

❒ **Grouping data** – A data frame can be aggregated with respect to given columns as follows:



The Python command is as follows:

```python
(df
.groupby(['col_1', ..., 'col_n'])
.agg({'col': builtin_agg})
```

where `builtin_agg` is among the following:

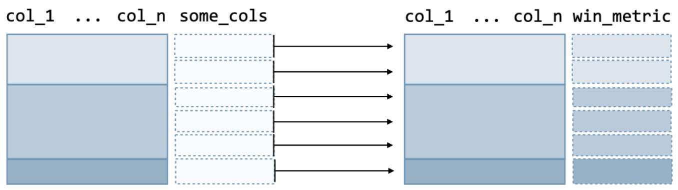
Category	Action	Command
Properties	Count of observations	'count'
Values	Sum of values of observations	'sum'
	Max / min of values of observations	'max' / 'min'
	Mean / median of values of observations	'mean' / 'median'
	Standard deviation / variance across observations	'std' / 'var'

❒ **Custom aggregations** – It is possible to perform customized aggregations by using lambda functions as follows:

Python
```
df_agg = (
  df
  .groupby(['col_1', ..., 'col_n'])
  .apply(lambda x: pd.Series({
    'agg_metric': some_aggregation(x)
  }))
)
```

3.1.5 Window functions

❒ **Definition** – A window function computes a metric over groups and has the following structure:



The Python command is as follows:

Python
```
(df
.assign(win_metric = lambda x:
           x.groupby(['col_1', ..., 'col_n'])['col'].window_function(params))
```

Remark: applying a window function will not change the initial number of rows of the data frame.

❒ **Row numbering** – The table below summarizes the main commands that rank each row across specified groups, ordered by a specific field:

Join type	Command	Example
x.rank(method='first')	Ties are given different ranks	1, 2, 3, 4
x.rank(method='min')	Ties are given same rank and skip numbers	1, 2.5, 2.5, 4
x.rank(method='dense')	Ties are given same rank and do not skip numbers	1, 2, 2, 3

❒ **Values** – The following window functions allow to keep track of specific types of values with respect to the group:

Command	Description
x.shift(n)	Takes the n^{th} previous value of the column
x.shift(-n)	Takes the n^{th} following value of the column

3.2 Data visualization

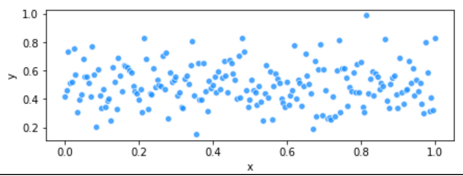
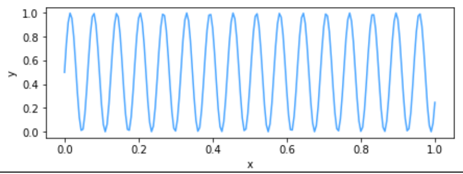
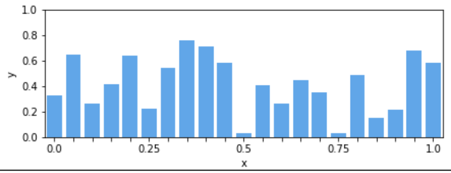
3.2.1 General structure

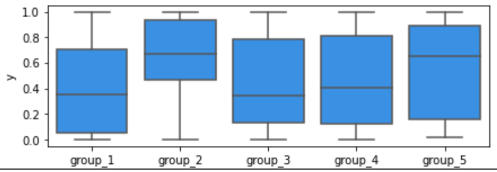
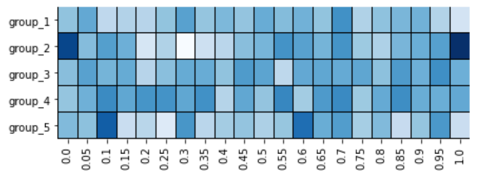
❒ **Overview** – The general structure of the code that is used to plot figures is as follows:

Python
```
# Plot
f, ax = plt.subplots(...)
ax = sns...

# Legend
plt.title()
plt.xlabel()
plt.ylabel()
```

We note that the `plt.subplots()` command enables to specify the figure size.

❒ **Basic plots** – The main basic plots are summarized in the table below:

Type	Command	Illustration
Scatter plot	`sns.scatterplot( x, y, params )`	
Line plot	`sns.lineplot( x, y, params )`	
Bar chart	`sns.barplot( x, y, params )`	

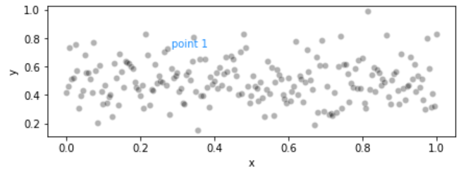
Type	Command	Illustration
Box plot	`sns.boxplot( x, y, params )`	
Heatmap	`sns.heatmap( data, params )`	

where the meaning of parameters are summarized in the table below:

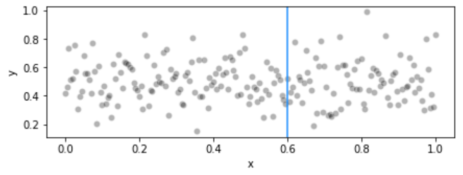
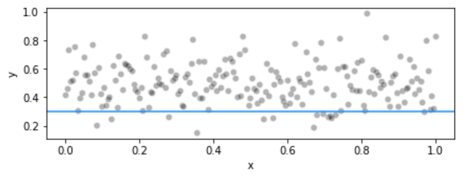
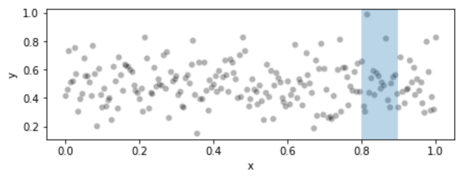
Command	Description	Use case
`hue`	Color of a line / point / border	'red'
`fill`	Color of an area	'red'
`size`	Size of a line / point	4
`linetype`	Shape of a line	'dashed'
`alpha`	Transparency, between 0 and 1	0.3

3.2.2 Advanced features

❒ **Text annotation** – Plots can have text annotations with the following commands:

Type	Command	Illustration
Text	`ax.text( x, y, s, color )`	

❒ **Additional elements** – We can add objects on the plot with the following commands:

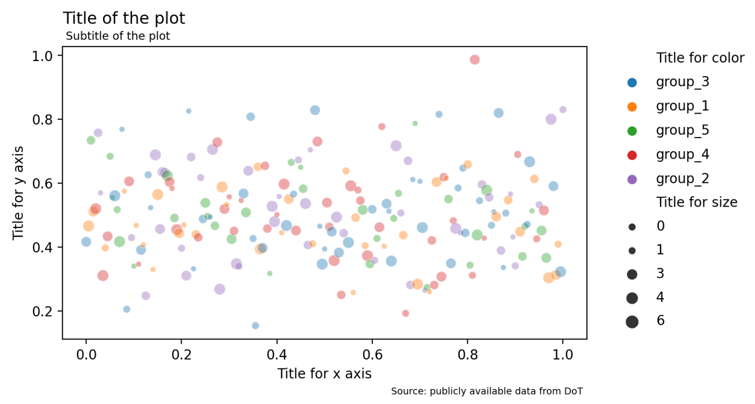
Type	Command	Illustration
Line	`ax.axvline( x, ymin, ymax, color, linewidth, linestyle )`	
	`ax.axhline( y, xmin, xmax, color, linewidth, linestyle )`	
Rectangle	`ax.axvspan( xmin, xmax, ymin, ymax, color, fill, alpha )`	

3.2.3 Last touch

❒ **Legend** – The title of legends can be customized to the plot with the commands summarized below:

Element	Command
Title / subtitle of the plot	`ax.set_title('text', loc, pad)` `plt.suptitle('text', x, y, size, ha)`
Title of the x / y axis	`ax.set_xlabel('text')` / `ax.set_ylabel('text')`
Title of the size / color	`ax.get_legend_handles_labels()`
Caption of the plot	`ax.text('text', x, y, fontsize)`

This results in the following plot:



❒ **Double axes** – A plot can have more than one axis with the `plt.twinx()` command. It is done as follows:

Python
```python
ax2 = plt.twinx()
```

❒ **Figure saving** – There are two main steps to save a plot:

- Specifying the width and height of the plot when declaring the figure:

Python
```python
f, ax = plt.subplots(1, figsize=(width, height))
```

- Saving the figure itself:

Python
```python
f.savefig(fname)
```

SECTION 4

Engineering productivity tips with Git, Bash and Vim

4.1 Working in groups with Git

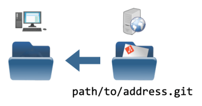
4.1.1 Overview

❒ **Overview** – Git is a version control system (VCS) that tracks changes of different files in a given repository. In particular, it is useful for:

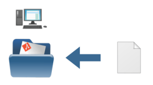
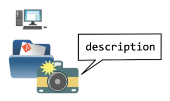
- keeping track of file versions
- working in parallel thanks to the concept of branches
- backing up files to a remote server

4.1.2 Main commands

❒ **Getting started** – The table below summarizes the commands used to start a new project, depending on whether or not the repository already exists:

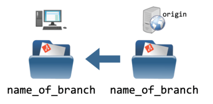
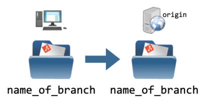
Case	Action	Command	Illustration
No existing repository	Initialize repository from local folder	`git init`	
Repository already exists	Copy repository from remote to local	`git clone git_address`	

❒ **File check-in** – We can track modifications made in the repository, done by either modifying, adding or deleting a file, through the following steps:

Step	Command	Illustration
1. Add modified, new, or deleted file to staging area	`git add file`	
2. Save snapshot along with descriptive message	`git commit -m 'description'`	

Remark 1: `git add .` *will have all modified files to the staging area.*
Remark 2: files that we do not want to track can be listed in the `.gitignore` *file.*

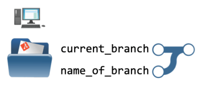
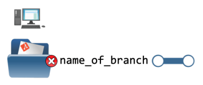
❒ **Sync with remote** – The following commands enable changes to be synchronized between remote and local machines:

Action	**Command**	**Illustration**
Fetch most recent changes from remote branch	`git pull name_of_branch`	
Push latest local changes to remote branch	`git push name_of_branch`	

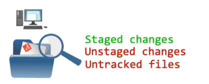
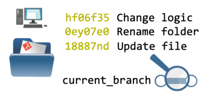
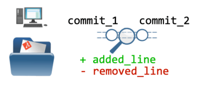
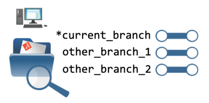
❒ **Parallel workstreams** – In order to make changes that do not interfere with the current branch, we can create another branch `name_of_branch` as follows:

```
Bash
git checkout -b name_of_new_branch    # Create and checkout to that branch
```

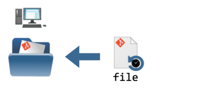
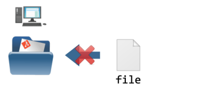
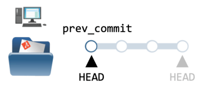
Depending on whether we want to incorporate or discard the branch, we have the following commands:

Action	**Command**	**Illustration**
Merge with initial branch	`git merge initial_branch`	
Remove branch	`git branch -D name_of_branch`	

❒ **Tracking status** – We can check previous changes made to the repository with the following commands:

Action	**Command**	**Illustration**
Check status of modified file(s)	`git status`	
View last commits	`git log --oneline`	 hf06f35 Change logic 0ey07e0 Rename folder 18887nd Update file current_branch
Compare changes made between two commits	`git diff commit_1 commit_2`	
View list of local branches	`git branch`	

❒ **Canceling changes** – Canceling changes is done differently depending on the situation that we are in. The table below sums up the most common cases:

Case	**Action**	**Command**	**Illustration**
Unstaged	Revert file to last commit	`git checkout -- file`	
Staged	Remove file from staging area	`git reset HEAD file`	
Committed	Go back to a previous commit	`git reset --hard prev_commit`	

4.1.3 Project structure

❒ **Structure of folders** – It is important to keep a consistent and logical structure of the project. One example is as follows:

```
Terminal
my_project/
  analysis/
      graph/
      notebook/
  data/
```

```
        query/
        raw/
        processed/
    modeling/
        method/
        tests
    README.md
```

4.2 Working with Bash

❒ **Basic terminal commands** – The table below sums up the most useful terminal commands:

Category	Action	Command
Exploration	Display list of files (including hidden ones)	`ls (-a)`
	Show current directory	`pwd`
	Show content of file	`cat path_to_file`
	Show statistics of file (lines/words/characters)	`wc path_to_file`
File management	Make new folder	`mkdir folder_name`
	Change directory to folder	`cd path_to_folder`
	Create new empty file	`touch filename`
	Copy-paste file (folder) from origin to destination	`scp (-R) origin destination`
	Move file/folder from origin to destination	`mv origin destination`
	Remove file (folder)	`rm (-R) path`
Compression	Compress folder into file	`tar -czvf comp_folder.tar.gz folder`
	Uncompress file	`tar -xzvf comp_folder.tar.gz`
Miscellaneous	Display message	`echo "message"`
	Overwrite / append file with output	`output > file.txt` / `output >> file.txt`
	Execute `command` with elevated privileges	`sudo command`
	Connect to a remote machine	`ssh remote_machine_address`

❒ **Chaining** – It is a concept that improves readability by chaining operations with the pipe `|` operator. The most common examples are summed up in the table below:

Action	Command
Count number of files in a folder	`ls path_to_folder | wc -l`
Count number of lines in file	`cat path_to_file | wc -l`
Show last n commands executed	`history | tail -n`

❒ **Advanced search** – The `find` command allows the search of specific files and manipulate them if necessary. The general structure of the command is as follows:

Bash
```
find path_to_folder/. [conditions] [actions]
```

The possible conditions and actions are summarized in the table below:

Category	Action	Command
Conditions	Certain names, regex accepted	`-name 'certain_name'`
	Certain file types (d/f for directory/file)	`-type certain_type`
	Certain file sizes (c/k/M/G for B/kB/MB/GB)	`-size file_size`
	Opposite of a given condition	`-not [condition]`
Actions	Delete selected files	`-delete`
	Print selected files	`-print`

Remark: the flags above can be combined to make a multi-condition search.

❒ **Changing permissions** – The following command enables to change the permissions of a given `file` (or folder):

Bash
```
chmod (-R) three_digits file
```

with `three_digits` being a combination of three digits, where:

- the first digit is about the owner associated to the file
- the second digit is about the group associated to the file
- the third digit is anyone irrespective of their relation to the file

Each digit is one of (`0`, `4`, `5`, `6`, `7`), and has the following meaning:

Representation	Binary	Digit	Explanation
`---`	000	`0`	No permission
`r--`	100	`4`	Only read permission
`r-x`	101	`5`	Both read and execution permissions
`rw-`	110	`6`	Both read and write permissions
`rwx`	111	`7`	Read, write and execution permissions

For instance, giving read, write, execution permissions to everyone for a `given_file` is done by running the following command:

```bash
chmod 777 given_file
```

Remark: in order to change ownership of a file to a given user and group, we use the command `chown user:group file`.

❒ **Terminal shortcuts** – The table below summarizes the main shortcuts when working with the terminal:

Action	Command
Search previous commands	`Ctrl` + `r`
Go to beginning / end of line	`Ctrl` + `a` / `Ctrl` + `e`
Remove everything after the cursor	`Ctrl` + `k`
Clear line	`Ctrl` + `u`
Clear terminal window	`Ctrl` + `l`

4.3 Automating tasks

❒ **Create aliases** – Shortcuts can be added to the `~/.bash_profile` file by adding the following code:

```bash
shortcut="command"
```

❒ **Bash scripts** – Bash scripts are files whose file name ends with `.sh` and where the file itself is structured as follows:

```bash
#!/bin/bash

... [bash script] ...
```

❒ **Crontabs** – By letting the day of the month vary between 1-31 and the day of the week vary between 0-6 (Sunday-Saturday), a crontab is of the following format:

```
  *        *        *        *        *
minute    hour     day     month     day
                of month           of week
```

❒ **tmux** – Terminal multiplexing, often known as tmux, is a way of running tasks in the background and in parallel. The table below summarizes the main commands:

Category	Action	Command
Session management	Open a new / last existing session	`tmux` / `tmux attach`
	Leave current session	`tmux detach`
	List all open sessions	`tmux ls`
	Remove session_name	`tmux kill-session -t session_name`
Window management	Open / close a window	`Cmd + b + c` / `Cmd + b + x`
	Move to n^{th} window	`Ctrl + b + n`

4.4 Mastering editors

❒ **Vim** – Vim is a popular terminal editor enabling quick and easy file editing, which is particularly useful when connected to a server. The main commands to have in mind are summarized in the table below:

Category	Action	Command
File handling	Go to beginning / end of line	`0` / `$`
	Go to first / last line / i^{th} line	`gg` / `G` / `i G`
	Go to previous / next word	`b` / `w`
	Exit file with / without saving changes	`:wq` / `:q!`
Text editing	Copy line n line(s), where $n \in \mathbb{N}$	`nyy`
	Insert n line(s) previously copied	`p`
Searching	Search for expression containing name_of_pattern	`/name_of_pattern`
	Next / previous occurrence of name_of_pattern	`n` / `N`
Replacing	Replace old with new expressions with confirmation for each change	`:%s/old/new/gc`

❒ **Jupyter notebook** – Editing code in an interactive way is easily done through Jupyter notebooks. The main commands to have in mind are summarized in the table below:

Category	Action	Command
Cell transformation	Transform selected cell to text / code	Click on cell + `m` / `y`
	Delete selected cell	Click on cell + `dd`
	Add new cell below / above selected cell	Click on cell + `b` / `a`

SECTION A

Conversion between R and Python: data manipulation

A.1 Main concepts

❒ **File management** – The table below summarizes the useful commands to make sure the working directory is correctly set:

Category	R Command	Python Command
Paths	`setwd(path)`	`os.chdir(path)`
	`getwd()`	`os.getcwd()`
	`file.path(path_1, ..., path_n)`	`os.path.join(path_1, ..., path_n)`
Files	`list.files( path, include.dirs = TRUE )`	`os.listdir(path)`
	`file_test('-f', path)`	`os.path.isfile(path)`
	`file_test('-d', path)`	`os.path.isdir(path)`
	`read.csv(path_to_csv_file)`	`pd.read_csv(path_to_csv_file)`
	`write.csv(df, path_to_csv_file)`	`df.to_csv(path_to_csv_file)`

❒ **Exploring the data** – The table below summarizes the main functions used to get a complete overview of the data:

Category	R Command	Python Command
Look at data	`df %>% select(col_list)`	`df[col_list]`
	`df %>% head(n) / df %>% tail(n)`	`df.head(n) / df.tail(n)`
	`df %>% summary()`	`df.describe()`
Data types	`df %>% str()`	`df.dtypes / df.info()`
	`df %>% NROW() / df %>% NCOL()`	`df.shape`

❒ **Data types** – The table below sums up the main data types that can be contained in columns:

R Data type	Python Data type	Description
`character`	`object`	String-related data
`factor`		String-related data that can be put in bucket, or ordered
`numeric`	`float64`	Numerical data
`int`	`int64`	Numeric data that are integer
`POSIXct`	`datetime64`	Timestamps

A.2 Data preprocessing

❒ **Filtering** – We can filter rows according to some conditions as follows:

R
```
df %>%
  filter(some_col some_operation some_value_or_list_or_col)
```

where `some_operation` is one of the following:

Category	R Command	Python Command
Basic	`==` / `!=`	`==` / `!=`
	`<, <=, >=, >`	`<, <=, >=, >`
	`&` / `|`	`&` / `|`
Advanced	`is.na()`	`pd.isnull()`
	`%in% (val_1, ..., val_n)`	`.isin([val_1, ..., val_n])`
	`%like% 'val'`	`.str.contains('val')`

❒ **Mathematical operations** – The table below sums up the main mathematical operations that can be performed on columns:

Operation	R Command	Python Command
$\sqrt{x}$	`sqrt(x)`	`np.sqrt(x)`
$\lfloor x \rfloor$	`floor(x)`	`np.floor(x)`
$\lceil x \rceil$	`ceiling(x)`	`np.ceil(x)`

A.3 Data frame transformation

❒ **Common transformations** – The common data frame transformations are summarized in the table below:

Category	R Command	Python Command
Concatenation	`rbind(df_1, ..., df_n)`	`pd.concat([df_1, ..., df_n], axis=0)`
	`cbind(df_1, ..., df_n)`	`pd.concat([df_1, ..., df_n], axis=1)`
Dimension change	`spread(df, key, value)`	`pd.pivot_table( df, values='some_values', index='some_index', columns='some_column', aggfunc=np.sum )`
	`gather(df, key, value)`	`pd.melt( df, id_vars='variable', value_vars='other_variable' )`

SECTION B

Conversion between R and Python: data visualization

B.1 General structure

❒ **Basic plots** – The main basic plots are summarized in the table below:

Type	R Command	Python Command
Scatter plot	`geom_point( x, y, params )`	`sns.scatterplot( x, y, params )`
Line plot	`geom_line( x, y, params )`	`sns.lineplot( x, y, params )`
Bar chart	`geom_bar( x, y, params )`	`sns.barplot( x, y, params )`
Box plot	`geom_boxplot( x, y, params )`	`sns.boxplot( x, y, params )`
Heatmap	`geom_tile( x, y, params )`	`sns.heatmap( x, y, params )`

where the meaning of parameters are summarized in the table below:

Command	Description	Use case
`color` / `hue`	Color of a line / point / border	`'red'`
`fill`	Color of an area	`'red'`
`size`	Size of a line / point	`4`
`linetype`	Shape of a line	`'dashed'`
`alpha`	Transparency, between 0 and 1	`0.3`

B.2 Advanced features

❒ **Additional elements** – We can add objects on the plot with the following commands:

Type	R Command	Python Command
Line	`geom_vline( xintercept, linetype )` `geom_hline( yintercept, linetype )`	`ax.axvline( x, ymin, ymax, color, linewidth, linestyle )` `ax.axhline( y, xmin, xmax, color, linewidth, linestyle )`
Rectangle	`geom_rect( xmin, xmax, ymin, ymax )`	`ax.axvspan( xmin, xmax, ymin, ymax )`
Text	`geom_text( x, y, label, hjust, vjust )`	`ax.text( x, y, s, color )`