The Art and Science of Transportation Research in the AI Era

Introduction to R for Data Analysis (Hands-on Workshop)

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Learning Goals

#1 Running R code

#2 Packages & data import

#3 Wrangling data

#4 Visualising insights

#5 How to keep learning R and advance

Lecture Structure

#1	Orientation
#2	Rstudio & R basics
#3	Import and inspect data
#4	Wrangling with dplyr
#5	Visualisation with ggplot2
#6	Exporting, debugging and way forward

#1 Orientation

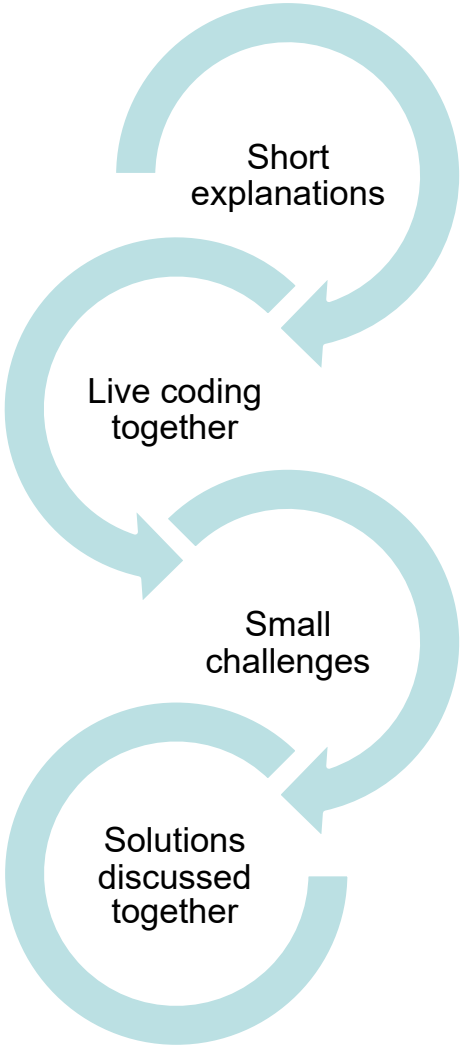
“R is a language for data analysis and graphics.”

- Ross Ihaka, co-creator of R

“Friends don’t let friends analyze data in Excel. They let them do it in R.”

- A wise data analyst

How this session will work:



Reasons to learn R

- Free and open source.

- Software for data science:
  - experiment/survey design
  - data retrieval
  - data wrangling
  - data analysis
  - reporting

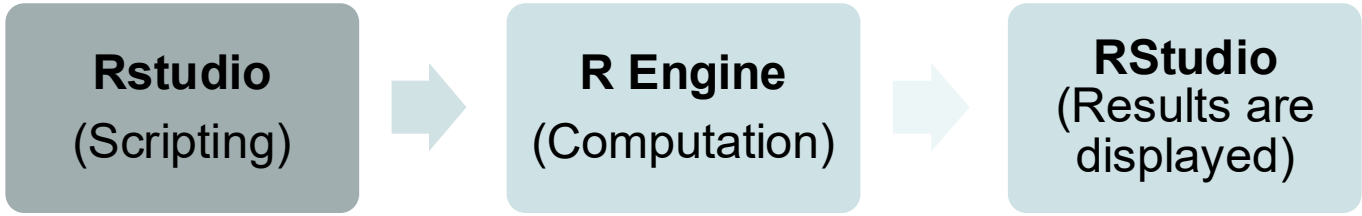
- A programming language, so we can use existing functions to code up our data science tasks or write new functions for customised/novel tasks

Tools we need installed:

R and **Rstudio**

What is R?

- A programming language
- A statistical computing engine
- Executes your code
- Produces results

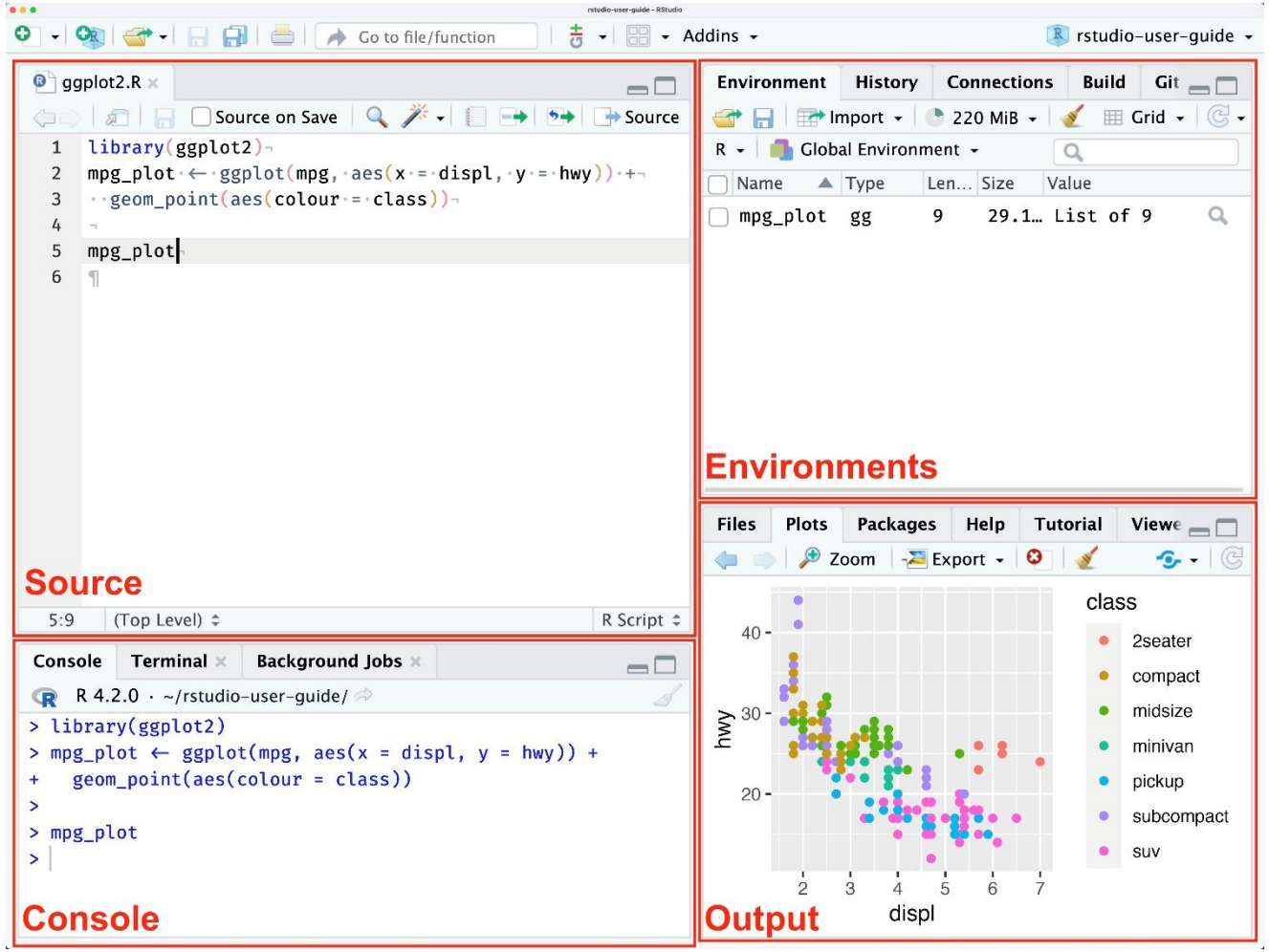


What is Rstudio?

- An IDE for R
- Makes R easier to use
- Editor, console, plots, help
- Does NOT replace R

RStudio IDE (Integrated Development Environment):

The **Source pane** is where you can edit and save R or Python scripts or author computational documents.



The **Environment pane** displays temporary R objects as created during that R session.

The **Console pane** is used to write short interactive R commands.

The **Output pane** displays the plots, tables, or HTML outputs of executed code along with files saved to disk.

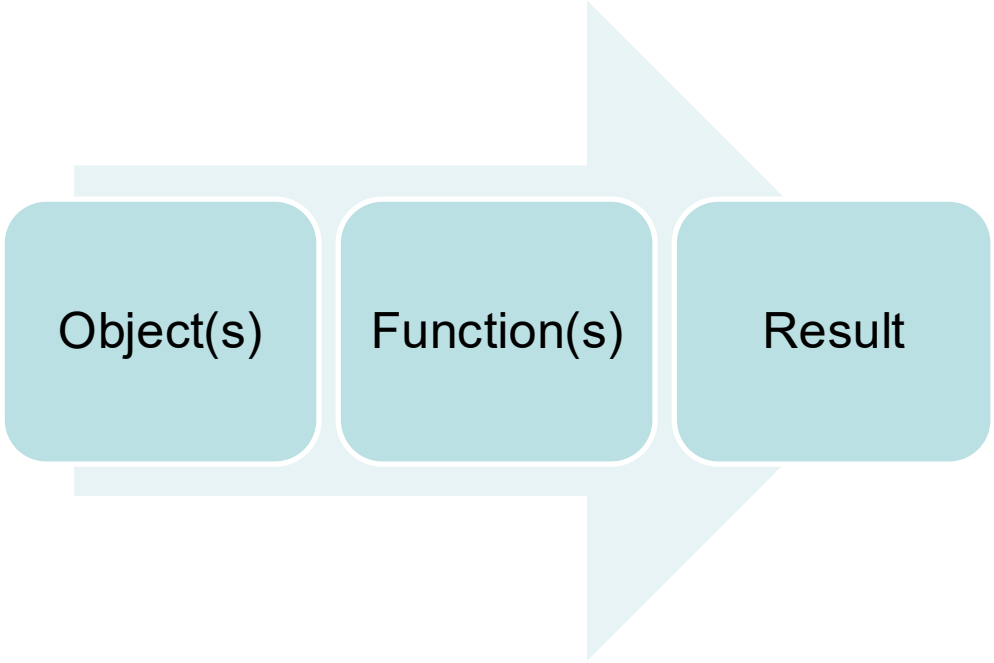
Image source: https://docs.posit.co/ide/user/ide/get-started/

How R works (conceptually):

R and **Rstudio**

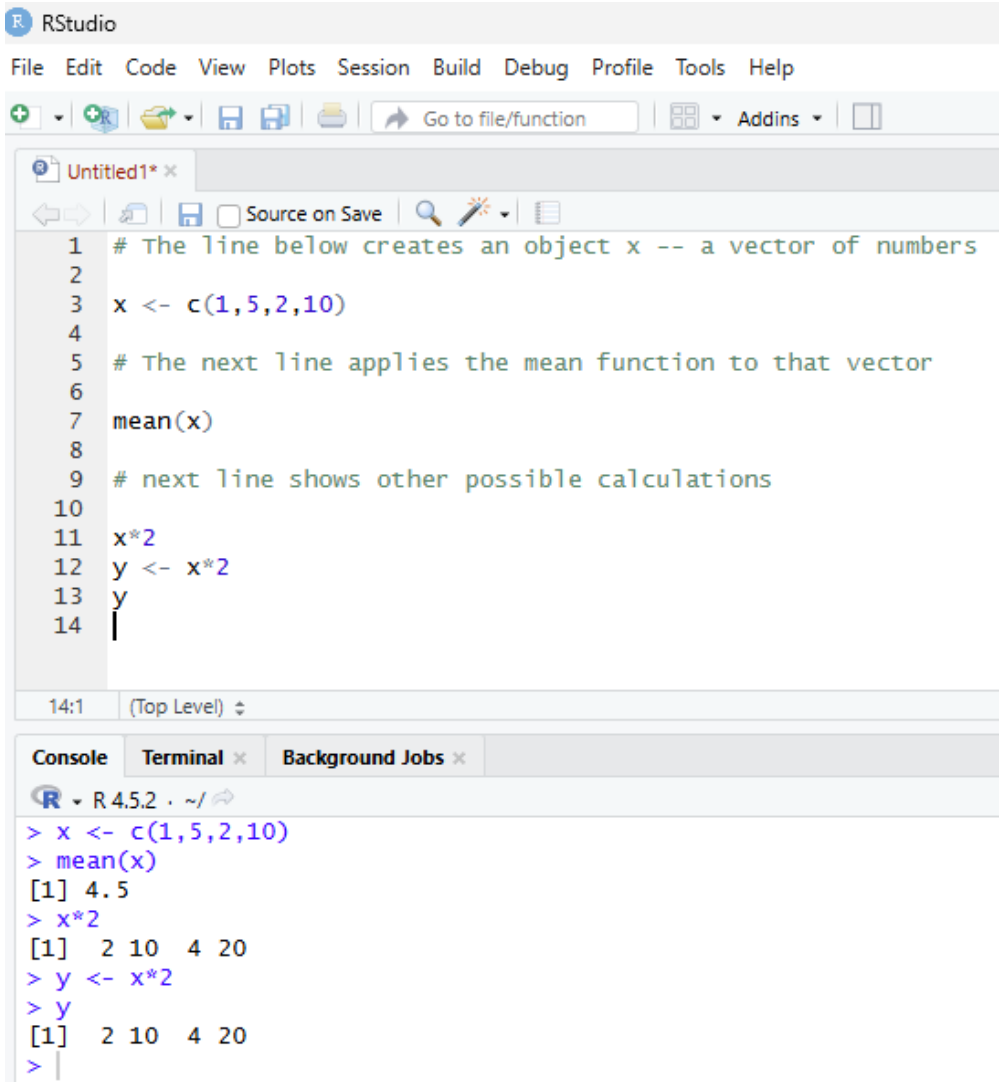
- You create **objects** (values, variables, tables, etc.)
- Objects have **names**
- **Functions** take objects as input
- Functions return new **objects** or **results**

- Functions in R are written to operate on whole vectors at once
- A **vector** in R is an ordered collection of values of the same type. A vector is R's way of storing many values under one name.
- Columns in data tables are vectors



First R code-along

- Create an object with the assign symbol **<-**
  - **<-** assigns
- Use functions with **()**
  - Example: **mean()**
- Run code line by line
  - Type into the script pane
  - **Ctrl + Enter** or **Cmd + Enter** to run the line
- R prints or returns results
- **R is case sensitive!**



Exercise

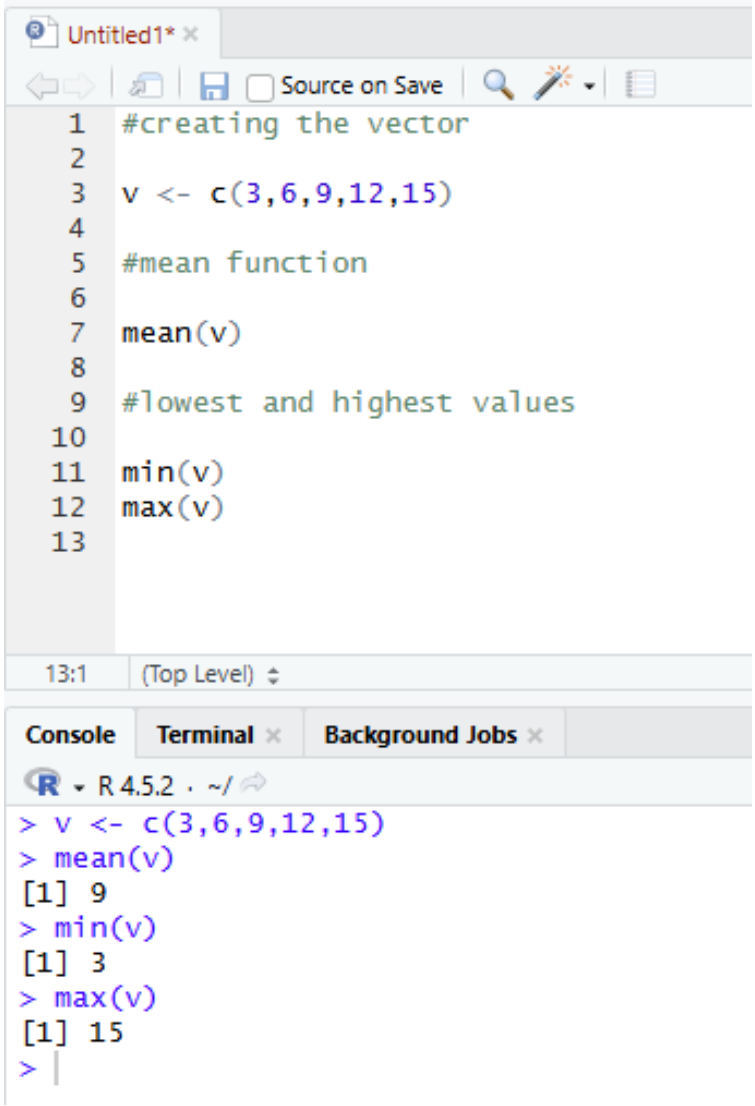
- Create a numeric vector with 5 values
- Compute mean, highest value, and lowest value
- Functions are **mean(), min(), max()**

Try this simple exercise

- Create a numeric vector with 5 values
- Compute mean, highest value, and lowest value
- Functions are **`mean(), min(), max()`**

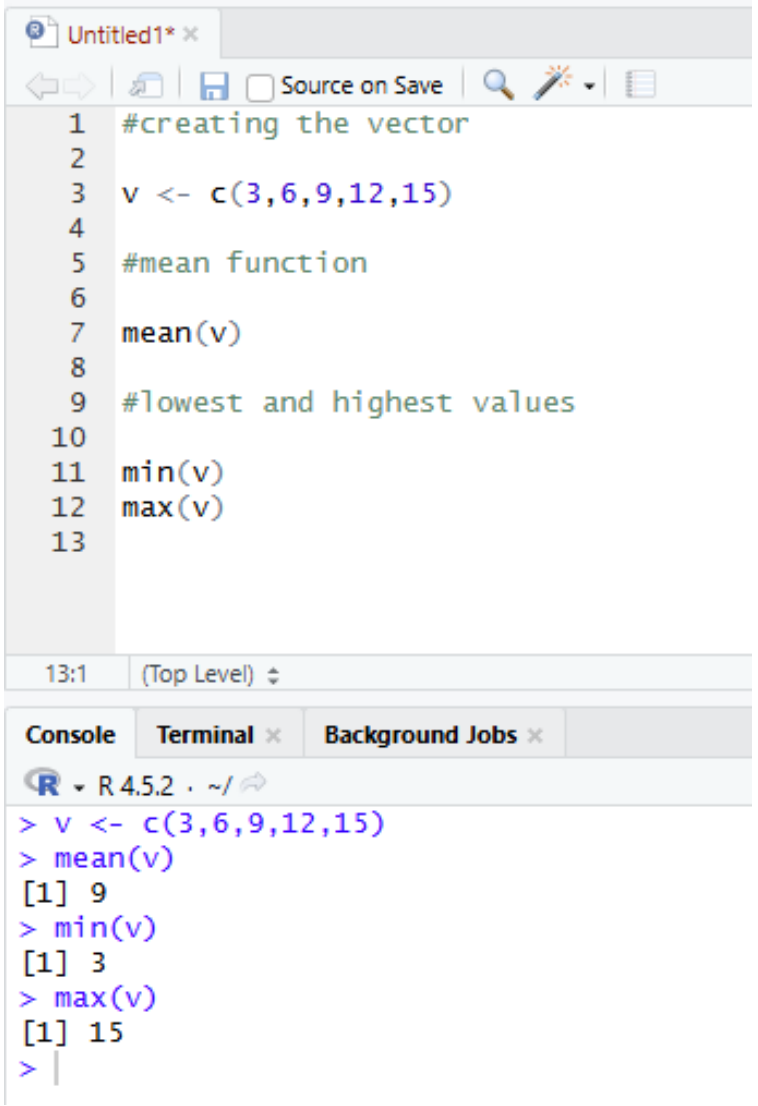
- **Solution:**

```
#creating the vector v

v <- c(3, 6, 9, 12, 15)

#using the mean, min and max functions

mean(v)
min(v)
max(v)
```



Scripts ensure Reproducibility of codes

- While working on code that you want to reuse -- always work from a script (source pane)
- **Save early, save often**
- **Comments should be used to label or describe the code**



What are packages?

- R comes with basic functionality
- R community develops packages
- Packages add new functions
- Package is a collection of functions
- Written for a specific goals
- We load packages when we need them

- Most packages come from CRAN (The Comprehensive R Archive Network)
- Some packages are also on GitHub
- To find the right packages, search the web with your objective..Eg:
  package for creating scatterplots

Installing packages

- Install = download it using R onto your PC
- Done once for a package
- Requires internet connection
- Packages usually come from CRAN
- Packages need to **loaded** for each session

- Install the packages now: dplyr and ggplot2
  - Install.packages(“dplyr”)
  - Install.packages(“ggplot2”)

- Install ≠ load...the function for loading is **library()**
  - Library(dplyr)
  - Library(ggplot2)

Working Directory (How R finds files)

- R is always working inside one assigned folder
- This folder is called the working directory

- To check it, use the function:
  - **`getwd()`**

- Function to list the files (R can access) in the folder:
  - **`list.files()`**

- If you open an Rstudio Project, the working directory is automatically the project folder

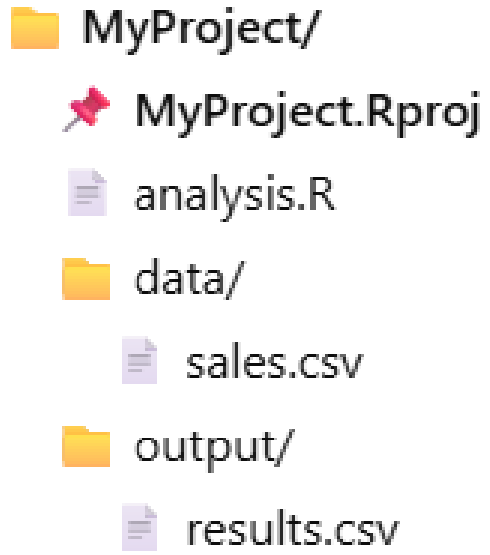
- Otherwise it is a default folder (documents, etc.)

RStudio Project (Solution to file path problems)

An Rstudio Project is a dedicated workspace folder.
When you use a project, Rstudio automatically:

- Sets the working directory
- Keeps scripts + data together
- Makes your work portable

Ideal Project Folder Structure



How data enters R

- Common source formats: CSV, Excel, Text files
- There are also built-in datasets (great for practice)

To import a CSV file we can use **read.csv()** function

Some functions to examine the imported data:

- **head()** function shows the first few rows of the dataset (quick preview)
- **names()** function shows the column names (what variables you have)
- **summary()** function gives a quick statistical summary of each column
- **str()** function shows the structure of the dataset – number of rows/columns + each columns **datatype** and example values

Code-along

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- Lets use the built in dataset “mtcars” and try the functions to examine the data

```
data(mtcars)   # load dataset (optional)
head(mtcars)   # first rows
names(mtcars)  # column names
str(mtcars)    # structure + data types
summary(mtcars)# quick statistics
```

Output obtained using the function: head(mtcars)

```
> head(mtcars)
                   mpg cyl disp  hp drat    wt  qsec vs am gear carb
Mazda RX4         21.0   6  160 110 3.90 2.620 16.46  0  1    4    4
Mazda RX4 Wag     21.0   6  160 110 3.90 2.875 17.02  0  1    4    4
Datsun 710        22.8   4  108  93 3.85 2.320 18.61  1  1    4    1
Hornet 4 Drive    21.4   6  258 110 3.08 3.215 19.44  1  0    3    1
Hornet Sportabout 18.7   8  360 175 3.15 3.440 17.02  0  0    3    2
Valiant           18.1   6  225 105 2.76 3.460 20.22  1  0    3    1
```

Your turn: Inspect the dataset

- Assign the dataset “iris” to a new object (hint: **df <- iris**)
- Use the data, head, names, str and summary function on this object

- How many rows and columns does the dataset have?
- What are the different variables (column names) in the dataset?

Solutions: Inspect the dataset

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- Assign the dataset “iris” to a new object (hint: **df <- iris**)
- Use the head, names, str and summary function on this object

```
df <- iris

head(df)
names(df)
str(df)
summary(df)
dim(df)
```

- How many rows and columns does the dataset have? **150 rows, 5 columns**
- What are the different variables (column names) in the dataset? **Sepal.Length, Sepal.Width, Petal.Length, Petal.Width, Species**

View the data

- The function view() opens a dataset in a table view (similar to excel)
- Useful for quickly checking rows and columns
- It does not change your data

- Try running these codes:

```
View(df)
View(iris)
View(mtcars)
```

- Additional tip: use ? To learn about a dataset or a function:

```
?mtcars
?iris
```

Missing values in datasets : (NA)

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- **'NA'** means **'missing value'**
- When importing data, R converts blank values to NA automatically.

- **Try this in RStudio:**

```
x <- c(1, 2, NA, 4)

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

- **na.rm = TRUE** tells R to ignore missing values
- If even one value is missing, many calculations return NA unless you handle it. Eg: mean()
- But sometimes missing values are written differently (like N/A, ?, -) and then R does not recognise them.

What is data wrangling?

- **Data wrangling = preparing data for analysis**
- Typical tasks:
  - Selecting useful columns
  - Filtering rows
  - Creating new variables
  - Fixing missing values
  - Preparing data for plots and summaries

Pipes (%>%)

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The pipe **%>%** passes the **output of one step** into the **next function**. So instead of writing nested functions, we can write it step by step.

So instead of nested functions like this:

```
select(filter(mtcars, cyl == 6), mpg, hp)
```

We use this:

```
mtcars %>%
  filter(cyl == 6) %>%
  select(mpg, hp)
```

Read it like: take mtcars, then filter, then select

💡 **Shortcut:**

in RStudio press **Ctrl + Shift + M** to insert **%>%**

Filtering rows with `filter()` function

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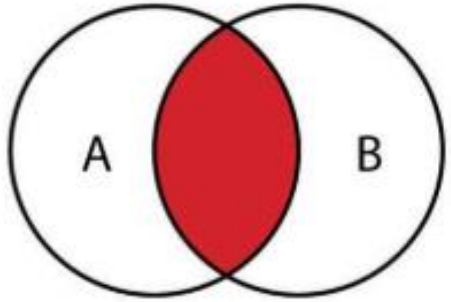
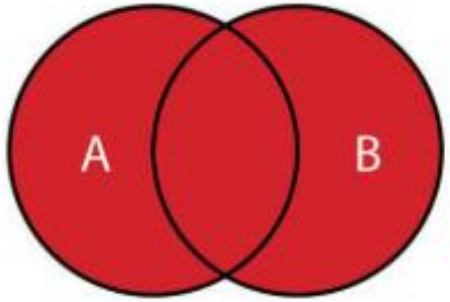
filter() keeps only rows that match condition(s)

Try these examples in RStudio using the "iris" dataset on flowers:



AND



OR

- **One condition:** keep only flowers that are "setosa"

```
library(dplyr)
iris %>% filter(Species == "setosa")
```

- **AND (&) condition:** keep only flowers that are "setosa" & Sepal.Length > 5

```
iris %>% filter(Species == "setosa" &
Sepal.Length > 5)
```

- **OR (|) condition:** keep only flowers that are "setosa" OR have Sepal.Length > 7

```
iris %>% filter(Species == "setosa" |
Sepal.Length > 7)
```

Your turn: Filtering rows with `filter()` function

Using the built-in dataset “mtcars”, write R code to:

- **One condition:** Keep only cars with 6 cylinders (cyl == 6)
- **AND (&) condition:** Keep only cars with 8 cylinders (cyl == 8) AND fuel efficiency < 15 (mpg < 15)
- **OR (|) condition:** Keep cars with horsepower > 200 (hp > 200) OR weight > 4 (wt > 4)

💡 Hint: use filter() and ==, <, >

Solutions: Filtering rows with `filter()` function

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- **One condition:** Keep only cars with 6 cylinders (cyl == 6)
- **AND (&) condition:** Keep only cars with 8 cylinders (cyl == 8) AND fuel efficiency < 15 (mpg < 15)
- **OR (|) condition:** Keep cars with horsepower > 200 (hp > 200) OR weight > 4 (wt > 4)

```
library(dplyr)

# 1) One condition: 6 cylinders
mtcars %>% filter(cyl == 6)

# 2) AND condition: 8 cylinders AND mpg < 15
mtcars %>% filter(cyl == 8 & mpg < 15)

# 3) OR condition: hp > 200 OR wt > 4
mtcars %>% filter(hp > 200 | wt > 4)
```

Selecting columns with `select()` function

- select() keeps only the columns you choose (drops the rest)
- It returns a new data frame (table)

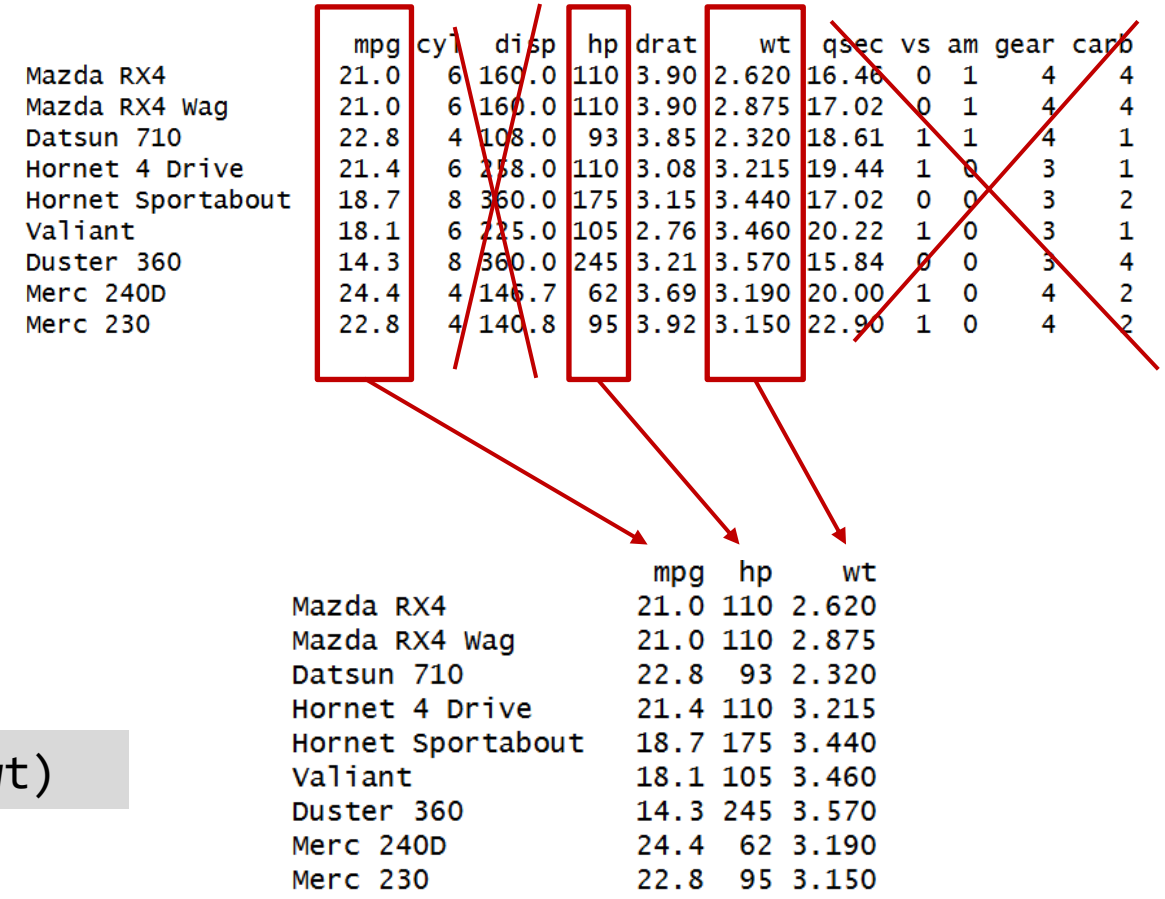
- *Try these example out:*

```
library(dplyr)

mtcars %>%
  select(mpg, hp, wt)
```

- *You may also save it as a new object:*

```
small_df <- mtcars %>% select(mpg, hp, wt)
```



Your turn: Selecting columns

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- Use the dataset “iris”
- Select any 2 variables/columns out of the available ones (eg: Petal.Length, Petal.Width, Species, etc.)
- Save the result into a new object called iris_small

- *Hint:*

```
library(dplyr)

iris_small <- iris %>%
  select(...)
```

- *Then check your result:*

```
head(iris_small)
```

Creating new variables with `mutate()` function

- mutate() creates new columns (new variables) in a dataset
- Can also modify existing columns (by overwriting them)

- *Try this example out in RStudio:*

```
library(dplyr)

iris_new <- iris %>%
  mutate(petal_ratio = Petal.Length /
Petal.Width)
```

- *Check the result:*

```
head(iris_new)
```

Original dataset:

	Sepal.Length	Sepal.Width	Petal.Length	Petal.Width	Species
1	5.1	3.5	1.4	0.2	setosa
2	4.9	3.0	1.4	0.2	setosa
3	4.7	3.2	1.3	0.2	setosa
4	4.6	3.1	1.5	0.2	setosa
5	5.0	3.6	1.4	0.2	setosa
6	5.4	3.9	1.7	0.4	setosa
7	4.6	3.4	1.4	0.3	setosa
8	5.0	3.4	1.5	0.2	setosa
9	4.4	2.9	1.4	0.2	setosa

New dataset with an added column:

```
> iris_new
```

	Sepal.Length	Sepal.Width	Petal.Length	Petal.Width	Species	petal_ratio
1	5.1	3.5	1.4	0.2	setosa	7.000000
2	4.9	3.0	1.4	0.2	setosa	7.000000
3	4.7	3.2	1.3	0.2	setosa	6.500000
4	4.6	3.1	1.5	0.2	setosa	7.500000
5	5.0	3.6	1.4	0.2	setosa	7.000000
6	5.4	3.9	1.7	0.4	setosa	4.250000
7	4.6	3.4	1.4	0.3	setosa	4.666667
8	5.0	3.4	1.5	0.2	setosa	7.500000
9	4.4	2.9	1.4	0.2	setosa	7.000000

Your turn: Create a new variable with `mutate()` function

- Using the dataset iris, create a new dataset called iris_new2
- Add a new column called sepal_ratio
- sepal_ratio = Sepal.Length / Sepal.Width

- Hint:

```
Library(dplyr)

iris_new2 <- iris %>%
  mutate(sepal_ratio = ...)
```

- Then check your result

```
head(iris_new2)
```

Solution: Create a new variable with `mutate()` function

- A new column is added to the dataset
- Calculated row by row (for every row)

- *Solution:*

```
library(dplyr)

iris_new2 <- iris %>%
  mutate(sepal_ratio = Sepal.Length /
Sepal.Width)

head(iris_new2)
```

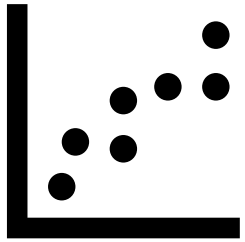
- *Optional quick check:*

```
summary(iris_new2$sepal_ratio)
```

The **$ operator** is used to access **one column (variable)** inside a data frame. So the code here means “Give me the sepal_ratio column from the dataset iris_new2”

Visualizations (using R)

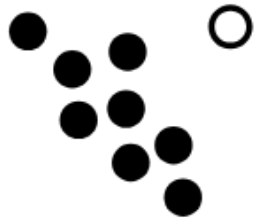
- Visualization helps us quickly see:



Patterns
(trends, relationships)

Comparisons
(groups, categories)

Insights
(what matters in the data)



Outliers
(unusual values)

- We're going to use **ggplot2**, the most popular plotting package in R.

First plot in ggplot2: Scatter plot

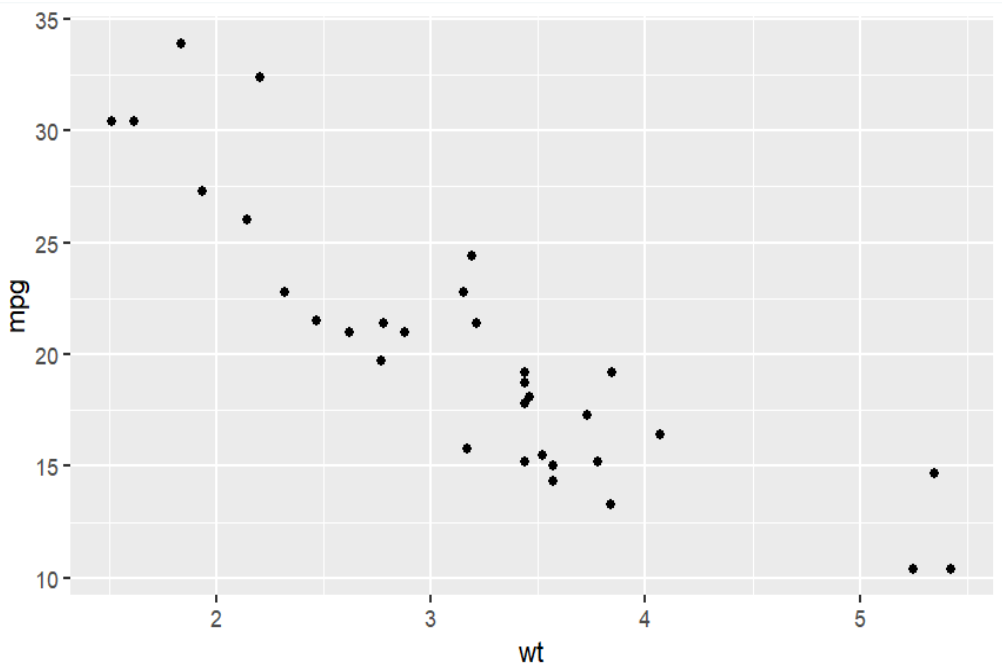
- Goal: visualize the relationship between two numeric variables
- In a scatter plot each point is one observation
- In mtcars, each point would represent a car

Ggplot2 recipe:

1. Choose dataset
2. Map variables to axes -- `aes()`
3. Choose a geometry (plot type)

```
library(ggplot2)

ggplot(mtcars, aes(x = wt, y = mpg)) +
  geom_point()
```



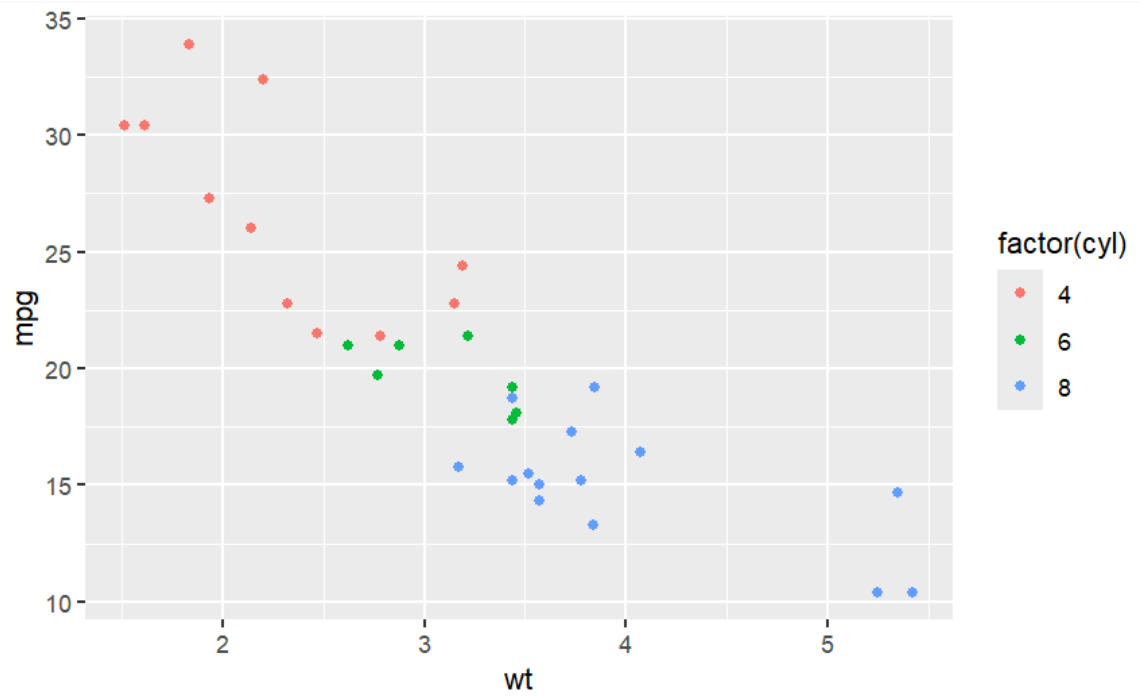
Color encodes information (not decoration)

- Color can represent a **variable** in plots
- This helps us **compare groups** in the same plot
- We usually colour by a **category** (eg: number of cylinders)
- In mtcars, cyl (cylinders) is numeric, but we treat it as a category

- Try this code in RStudio:

```
mtcars %>%

  ggplot(aes(x = wt, y = mpg, color =
factor(cyl))) +
  geom_point()
```



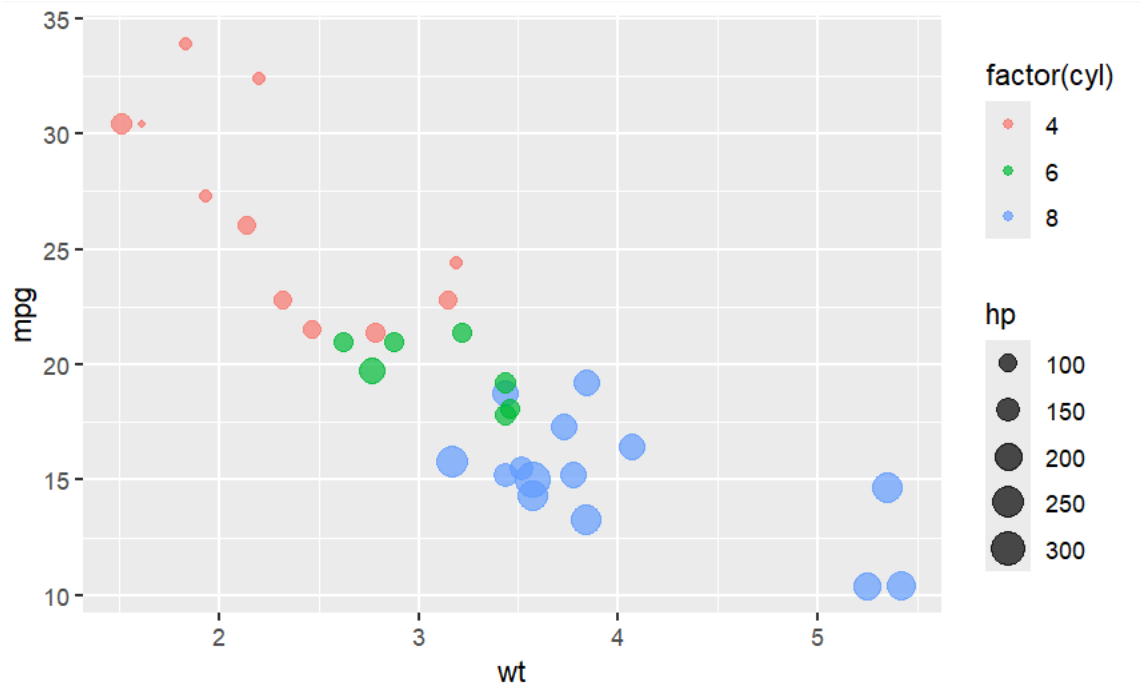
The plot now shows differences between **4, 6, and 8 cylinder cars**

More information on the same plot (colour + size)

- In addition to colour, we can use size to visualize another extra variable in a scatter plot
- Colour – categorical variable
- Size – numeric variable (eg: weight, horsepower, fuel efficiency)

- Try this code in RStudio:

```
mtcars %>%
  ggplot(aes(x = wt, y = mpg,
             color = factor(cyl),
             size = hp)) +
  geom_point(alpha = 0.7)
```



We added cylinders (colour) + horsepower (size)

Your turn: Scatter plot (colour + size)

- Use mtcars to create a scatter plot
  - x-axis: wt
  - y-axis: mpg
- Add 2 extra variables
  - One for colour (categorical)
  - One for size (numeric)

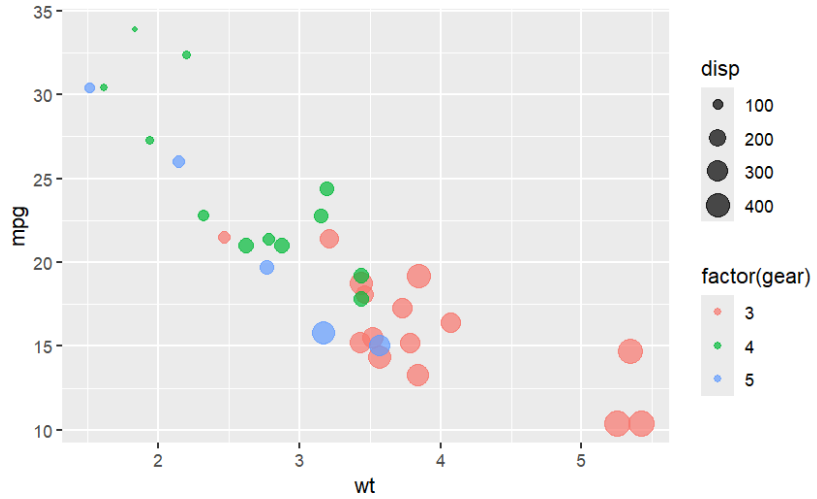
- Choose options you have not used yet. E.g.:
  - colour = factor(gear) (number of gears)
  - colour = factor(am) (0 = automatic, 1 = manual)
  - size = qsec (1/4 mile time)
  - size = disp (engine displacement)

```
mtcars %>%
  ggplot(aes(x = wt, y = mpg,
             color = factor(gear),
             size = disp)) +
  geom_point(alpha = 0.7)
```

Solution: Scatter plot (colour + size)

- There many correct answers
- Two example solutions:

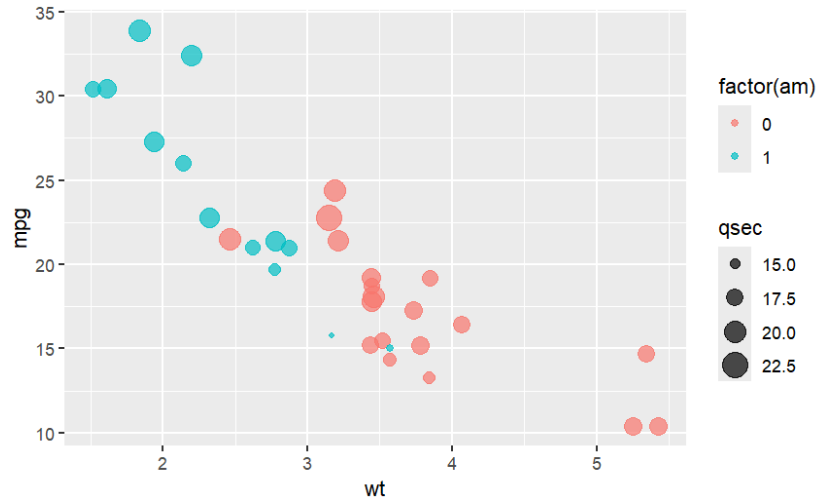
```
mtcars %>%
  ggplot(aes(x = wt, y = mpg,
             color = factor(gear),
             size = disp)) +
  geom_point(alpha = 0.7)
```



- You can swap the variables:
  - **Color:** gear or am
  - **Size:** disp or qsec

The "**+**" is important!!

```
mtcars %>%
  ggplot(aes(x = wt, y = mpg,
             color = factor(am),
             size = qsec)) +
  geom_point(alpha = 0.7)
```



Saving results

- We often want to save a table from R to a file
- The easiest format is CSV
- Use write.csv() to export a data frame

- Example (save the first 10 rows):

```
result <- mtcars %>%
  select(mpg, wt, hp) %>%
  head(10)

write.csv(result, "mtcars_sample.csv",
row.names = FALSE)
```

- The file will be saved in your working directory (check the Files pane)

Saving plots

- After creating a plot, we often want to save it as an image
- `ggsave()` saves the most recent plot
- Common formats:
  - PNG (best for slides + web)
  - PDF (best for reports)

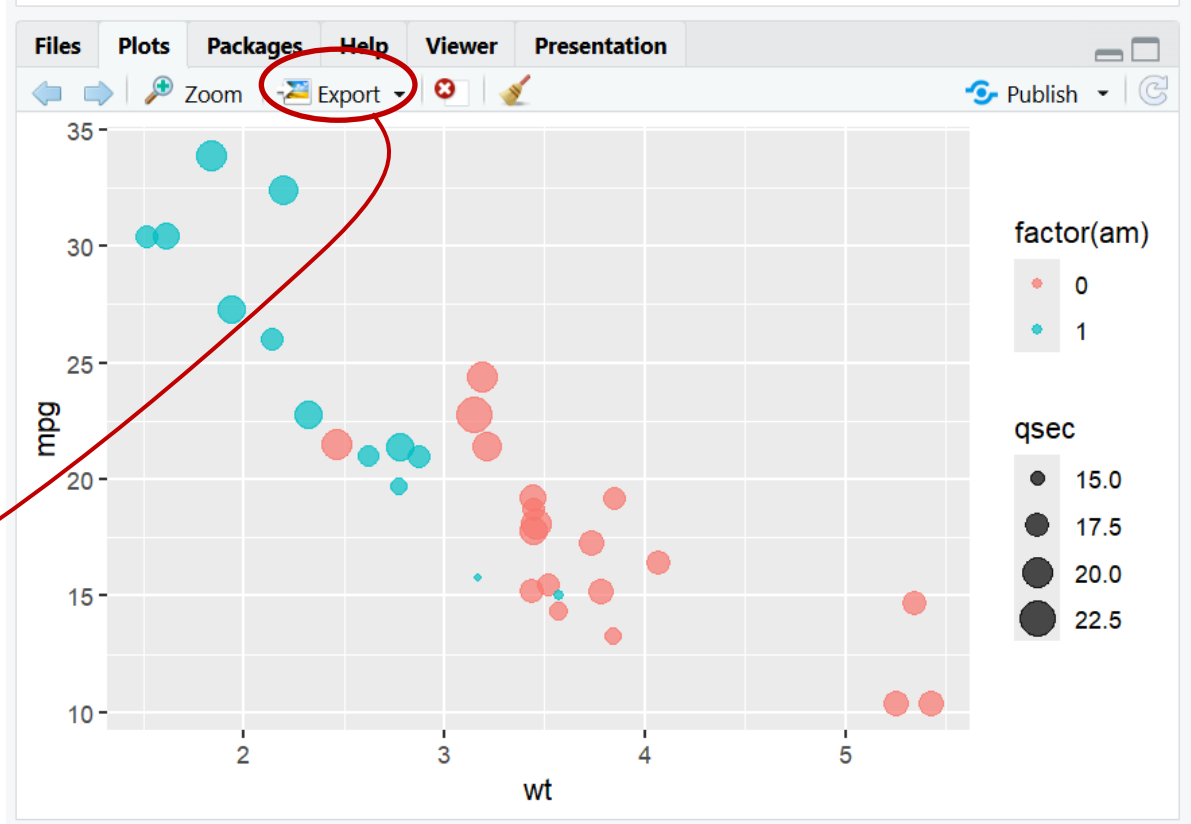
- Save the last plot you created using ggsave():

```
ggsave("my_plot.png", width = 6, height = 4)
```

- The file is saved in your working directory

OR (manual export):

- In the **Plots** pane:
- you can click **Export**
- Then **Save as Image / Save as PDF**



When things dont work: Debugging checklist

- Read the error message
- Check if you loaded the package in use:

```
library(dplyr)
library(ggplot2)
```

- Check if the object exists. This function lists the names of everything you created like vectors, data frames

```
ls()
```

- Inspect the data

```
head(df)
str(df)
names(df)
```

- Check the function help

```
?filter
?ggplot
```

- Search the exact search message online: copy and paste the full error message into Google

Resources for learning and help

- In **RStudio** (fastest help):
  - ?Function_name → e.g.: ?mean → opens documentation for a function
  - ??plot → searches help pages by keyword

- Cheat sheets (quick reference)
  - **Posit** “Data Transformation” (dplyr)
  - **Posit** “Data Visualization” (ggplot2)

- Learn by **examples and tutorials**
  - Search: “ggplot scatter plot examples”
  - Search: “dplyr filter select mutate examples”

- Community help (when you’re stuck)
  - **Stack Overflow**
  - **RStudio Community**

Final message

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You don't need to know everything. You need to know how to find and use what you need.

- **THANK YOU**
- **DANKE**