

# Data Visualization - 2.

## Finding your way in R

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Code Horizons

December 10, 2023

# Getting to know R and RStudio

We want to draw  
graphs

reproducibly



# Abstraction in software

## Less

Easy things are awkward

Hard things are straightforward

Really hard things are possible



# Abstraction in software

## Less

Easy things are awkward  
Hard things are straightforward  
Really hard things are possible

## More

Easy things are trivial  
Hard things are awkward  
Really hard things are impossible



# Compare

D3

Grid

ggplot

Stata

Excel



# Two ways to use R and ggplot

## 1. Do everything in R from start to finish

Raw data ▷ Read, Clean, Analyse ▷ Tidy table ▷ Make figures

# Two ways to use R and ggplot

## 1. Do everything in R from start to finish

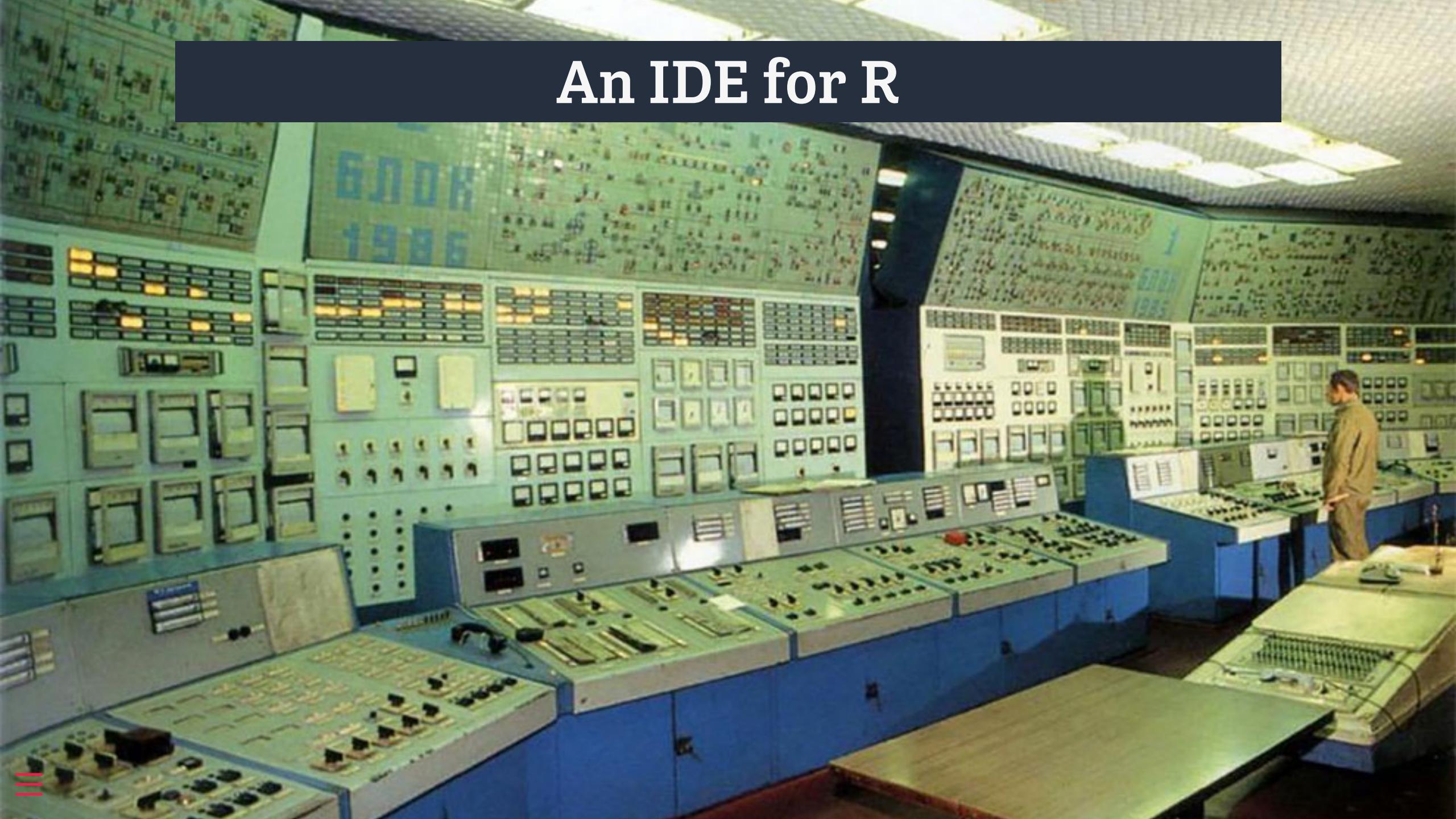
Raw data > Read, Clean, Analyse > Tidy table >  
Make figures

## 2. Just hand ggplot a table of results

Stata/SAS/etc > Tidy table > Read in to R > Make  
figures

# The RStudio IDE

# An IDE for R



# An IDE for Meals



The screenshot shows the RStudio IDE interface on a Mac OS X system. The title bar reads "covdata - main - RStudio".

The left pane contains a code editor with the following R Markdown code:

```
## Loading the Package
The 'covdata' package aims to make data related to the COVID-19
pandemic easily accessible to users of R. Once the package is
installed, load it in the usual way:
```{r setup}
library(tidyverse)
library(covdata)
```
Loading the package makes a variety of datasets available for use.
Because the data are in tibbles, the use of the 'tidyverse' suite of
functions is highly recommended.
```

The right pane shows the Environment tab of the Global Environment pane, which lists a single function:

| set | function (name, value) |
|-----|------------------------|
|-----|------------------------|

The bottom pane shows the file browser with the path "Home > Documents > source > covdata".

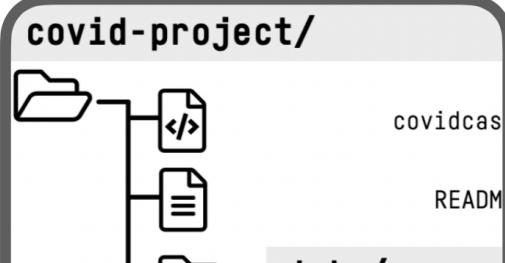
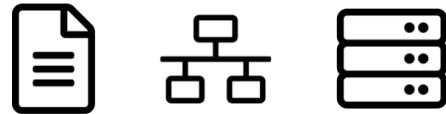
```
# COVID      covidcases.Rmd

## Get data from ECDC

```{r get-data}
covid_raw <- get_ecdc[url]
```

## Get data from the US

```{r get-data}
us_raw <- get_us[url]
```
```



# Current Document

```
# COVID      covidcases.Rmd  
## Get data from ECDC  
```{r get-data}  
covid_raw <- get_ecdc[url]  
# Read data from file  
# ...  
```{r get-data}  
us_raw <- get_us[url]  
...  
```{r get-data}
```

# Objects



covid-project/  
  └── covidcas  
      └── README

# Files,

Think in terms of **Data** +  
**Transformations**, written out as  
code, rather than a series of point-  
and-click steps

Our starting **data** + our **code** is  
what's “real” in our projects, not the  
final output or any intermediate  
objects

RStudio File Edit Code View Plots Session Build Debug Profile Tools Window Help

covdata - main - RStudio

covdata.Rmd x

```
15
16
17 ## Loading the Package
18
19 The 'covdata' package aims to make data related to the COVID-19
  pandemic easily accessible to users of R. Once the package is
  installed, load it in the usual way:
20
21 ````{r setup}
22   library(tidyverse)
23   library(covdata)
24 ````

25
26 Loading the package makes a variety of datasets available for use.
  Because the data are in tibbles, the use of the 'tidyverse' suite of
```

6:37 # Get Started with covdata R Markdown

Console Jobs x

~/Documents/source/covdata/

R is a collaborative project with many contributors.

Environment History Connections Build Git Tutorial

Import Dataset

Global Environment

Functions

set function (name, value)

Files Plots Packages Help Viewer

New Folder Delete Rename More

Home > Documents > source > covdata

The screenshot shows the RStudio interface with the following details:

- Header:** RStudio, File, Edit, Code, View, Plots, Session, Build, Debug, Profile, Tools, Window, Help.
- Project:** stathorizons\_0820 - master - RStudio
- Code Editor (highlighted by a red box):** Contains the following R Markdown code:

```
1 ---  
2 title: "Data Visualization"  
3 author: "Kieran Healy"  
4 date: "10-January-2020"  
5 output: html_document  
6 ---  
7  
8 ## Data Visualization Notes  
9  
10 This is a starter RMarkdown project template to accompany courses taught with *Data Visualization*. You can use it to take notes, write your code, and produce a good-looking, reproducible document that records the work you have done. At the very top of the file is a section of *metadata*, or information about what the file is and what it does. The metadata is delimited by three dashes at the start and another three at the end. You should change the title, author, and date to the values that suit you. Keep the 'output' line as it is for now, however. Each line in the metadata has a structure. First the *key* ("title", "author", etc), then a colon, and then the *value* associated with the key.  
11  
12 ## This Document is an RMarkdown File  
13  
14 Markdown is a simple formatting syntax for authoring HTML, PDF, and MS Word documents. For more details on using R Markdown see <http://rmarkdown.rstudio.com>.  
15  
16 When you click the **Knit** button a document will be generated that includes both content
```
- Environment:** Shows "Environment is empty".
- File Explorer:** Shows the file structure: Home > Documents > courses > stathorizons\_0820. The contents of the folder are listed in a table:

Name	Size	Modified
..		
.gitignore	40 B	Jul 21, 2020, 11:16 AM
01_introduction.Rmd	4 KB	Jul 21, 2020, 11:16 AM
2020-07-21	2.9 KB	Jul 21, 2020, 11:16 AM

The screenshot shows the RStudio interface on a Mac OS X system. The window title is "stathorizons\_0820 - master - RStudio".

The left pane displays the code editor for the file "01\_introduction.Rmd". The content of the file is as follows:

```
1 ---  
2 title: "Data Visualization"  
3 author: "Kieran Healy"  
4 date: "10-January-2020"  
5 output: html_document  
6 ---  
7  
8 ## Data Visualization Notes  
9  
10 This is a starter RMarkdown project template to accompany courses taught with *Data Visualization*. You can use it to take notes, write your code, and produce a good-looking, reproducible document that records the work you have done. At the very top of the file is a section of *metadata*, or information about what the file is and what it does. The metadata is delimited by three dashes at the start and another three at the end. You should change the title, author, and date to the values that suit you. Keep the 'output' line as it is for now, however. Each line in the metadata has a structure. First the *key* ("title", "author", etc), then a colon, and then the *value* associated with the key.  
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15  
16 When you click the **Knit** button a document will be generated that includes both content
```

The right pane contains the following panels:

- Environment:** Shows the message "Environment is empty".
- Files:** A file browser showing the directory structure: Home > Documents > courses > stathorizons\_0820. The contents of the folder are listed in a table:

Name	Size	Modified
..		
.gitignore	40 B	Jul 21, 2020, 11:16 AM
01_introduction.Rmd	4 KB	Jul 21, 2020, 11:16 AM
02_get_started.Rmd	2.2 KB	Jul 21, 2020, 11:16 AM

The screenshot shows the RStudio interface with the following details:

- File Bar:** RStudio, File, Edit, Code, View, Plots, Session, Build, Debug, Profile, Tools, Window, Help.
- Project Bar:** stathorizons\_0820 - master - RStudio.
- Left Panel (Code Editor):** The file 01\_introduction.Rmd is open, displaying R Markdown code. The code includes metadata (title, author, date) and a section for Data Visualization Notes. A red box highlights the line "## This Document is an RMarkdown File".
- Right Panel (Environment):** The Global Environment pane shows that the environment is empty.
- Bottom Panel (File Browser):** The browser shows the project structure: Home > Documents > courses > stathorizons\_0820. It lists files: .., .gitignore, 01\_introduction.Rmd (4 KB), and 02\_get\_started.Rmd (3.3 KB).

```
1 ---  
2 title: "Data Visualization"  
3 author: "Kieran Healy"  
4 date: "10-January-2020"  
5 output: html_document  
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should change the title, author, and date to the values that suit you. Keep the 'output'  
line as it is for now, however. Each line in the metadata has a structure. First the *key*  
("title", "author", etc), then a colon, and then the *value* associated with the key.  
11  
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more details on using R Markdown see <http://rmarkdown.rstudio.com>.  
15  
16 When you click the **Knit** button a document will be generated that includes both content
```

The screenshot shows the RStudio interface with a red box highlighting the Environment pane. The code editor on the left contains an R Markdown file named '01\_introduction.Rmd' with the following content:

```
1 ---  
2 title: "Data Visualization"  
3 author: "Kieran Healy"  
4 date: "10-January-2020"  
5 output: html_document  
6 ---  
7  
8 ## Data Visualization Notes  
9  
10 This is a starter RMarkdown project template to accompany courses taught with \*Data Visualization\*. You can use it to take notes, write your code, and produce a good-looking, reproducible document that records the work you have done. At the very top of the file is a section of \*metadata\*, or information about what the file is and what it does. The metadata is delimited by three dashes at the start and another three at the end. You should change the title, author, and date to the values that suit you. Keep the 'output' line as it is for now, however. Each line in the metadata has a structure. First the \*key\* ("title", "author", etc), then a colon, and then the \*value\* associated with the key.  
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15  
16 When you click the Knit button a document will be generated that includes both content
```

The Environment pane on the right shows the Global Environment with the message "Environment is empty". Below the Environment pane is the Files pane, which displays the file structure of the project:

Name	Size	Modified
..		
.gitignore	40 B	Jul 21, 2020, 11:16 AM
01_introduction.Rmd	4 KB	Jul 21, 2020, 11:16 AM
02_get_started.Rmd	2.2 KB	Jul 21, 2020, 11:16 AM

Inspect objects you create

Use RMarkdown to produce  
and reproduce work

# Where we want to end up

## Covid Cases

Kieran Healy

4/18/2021

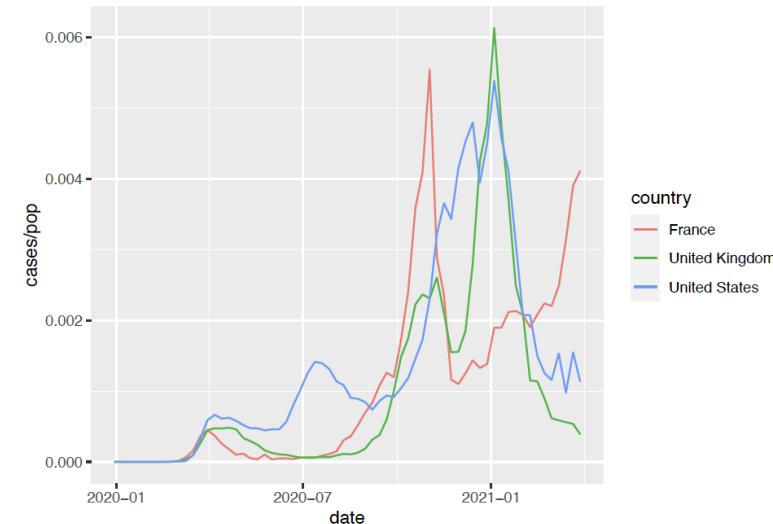
### LOREM IPSUM

LOREM IPSUM dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Table 1: Total cases in three countries.

country	cases
United States	30706129
France	4822470
United Kingdom	4359388

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# Where we want to end up

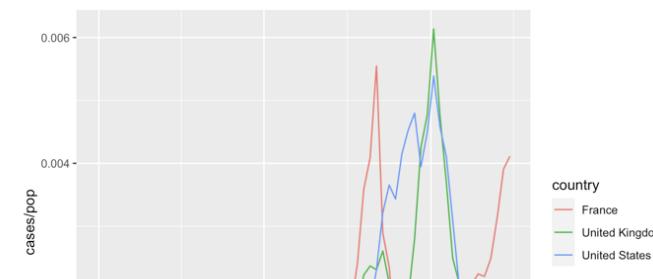
## Placeholder Content

Placeholder text for the content area. This is a long paragraph of placeholder text.

Total cases in three countries.

country	cases
United States	30706129
France	4822470
United Kingdom	4359388

Placeholder text for the content area. This is a long paragraph of placeholder text.



# Where we want to end up

## Covid Cases

Kieran Healy

4/18/2021

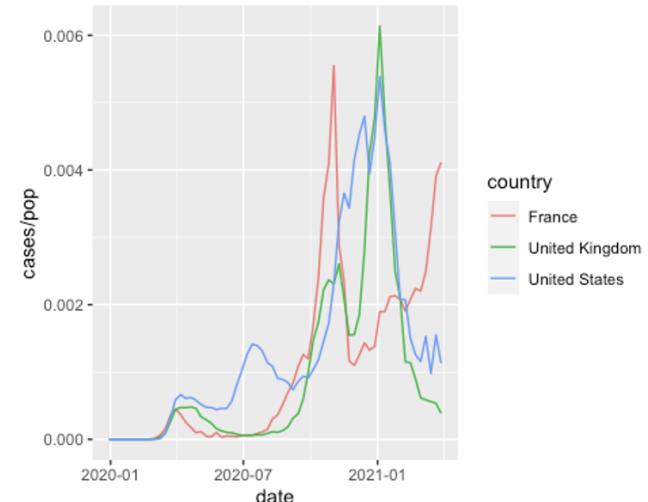
### **Lorem Ipsum**

*Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.*

*Total cases in three countries.*

country	cases
United States	30706129
France	4822470
United Kingdom	4359388

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# How to get there?

```
# COVID      covidcases.R
# Get data from ECDC
# FIXME Write a fn to
# do this
data_raw <- read_csv(url)

# Clean it
# Notes on the cleaning
# process.

covid <- data_raw %>%
  mutate(...) %>%
  select(...)

# Make some plots
covid %>%
  ggplot(...) +
```

We could write an **R script** with some notes inside, using it to create some figures and tables, paste them into our document.

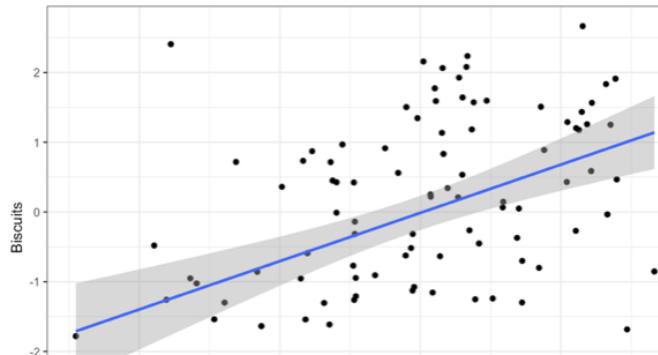
This will work, but we can do better.



# We can make this ...

## 1. Lorem Ipsum

Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.



# ... by writing this

## # Lorem Ipsum

  Lorem ipsum dolor sit amet, consectetur adipisicing elit,  
  sed do \*eiusmod tempor\* incididunt ut labore et dolore magna  
  aliqua. Ut enimad minim veniam, quis nostrud exercitation  
  ullamco laboris nisi ut aliquip ex ea commodo consequat.

```
library(ggplot2)
tea <- rnorm(100)
biscuits <- tea + rnorm(100, 0, 1.3)
data <- data.frame(tea, biscuits)
p <- ggplot(data, aes(x = tea, y = biscuits)) +
  geom_point() +
  geom_smooth(method = "lm") +
  labs(x = "Tea", y = "Biscuits") + theme_bw()
print(p)
```

# The code gets replaced by its output

## # Lorem Ipsum

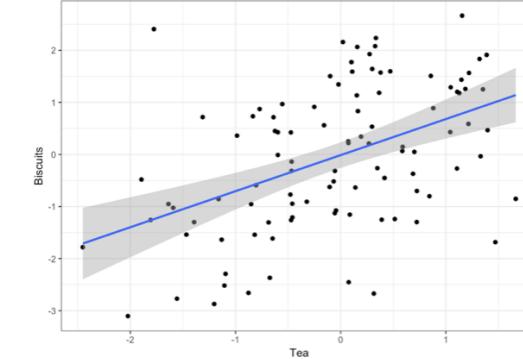
  Lorem ipsum dolor sit amet, consectetur adipisicing elit,  
  sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.

```
library(ggplot2)
tea <- rnorm(100)
biscuits <- tea + rnorm(100, 0, 1.3)
data <- data.frame(tea, biscuits)
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  geom_point() +
  geom_smooth(method = "lm") +
  labs(x = "Tea", y = "Biscuits") + theme_bw()
print(p)
```

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## 1. Lorem Ipsum

  Lorem ipsum dolor sit amet, consectetur adipisicing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.



Duis aute irure dolor in reprehenderit in voluptate velit esse cillum

```
---
```

```
title: "Covid Cases"
author: "Kieran Healy"
date: "4/18/2021"
output: html_document
---
```

```
```{r setup, include=FALSE}
knitr::opts_chunk$set(echo = FALSE)
```

```

```
## Introduction
```

```
We'll be looking at some COVID case data.
```

```
```{r libraries, message = FALSE}
```

```
library(tidyverse)
library(here)
library(janitor)
library(socviz)
```

```
```

```

```
```{r load-the-data, message = FALSE}
covid_cases <- read_csv("data/national_cases.csv")
```

```

```
---
```

```
title: "Covid Cases"
author: "Kieran Healy"
date: "4/18/2021"
output: html_document
---
```

```
```{r setup, include=FALSE}
knitr::opts_chunk$set(echo = FALSE)
```

## Introduction
```

```
We'll be looking at some COVID case data.
```

```
```{r libraries, message = FALSE}
library(tidyverse)
library(here)
library(janitor)
library(socviz)
```

```{r load-the-data, message = FALSE}
covid_cases <- read_csv("data/national_cases.csv")
```
```

## ◀ Header section with metadata



## ◀ Code chunk

◀ In RStudio, code chunks can be "played" one at a time

◀ Code chunks can have their own labels and options

# Report      notes.Rmd  
We can see this \*relationship\*  
in a scatterplot.

```
```{r my-code}
p <- ggplot(data, mapping)
p + geom_point()
```

```

As you can see, this plot  
looks pretty nice.

knit in R

# Basic markdown summary

| Desired style          | Use the following Markdown annotation            |
|------------------------|--------------------------------------------------|
| Heading 1              | # Heading 1                                      |
| Heading 2              | ## Heading 2                                     |
| Heading 3              | ### Heading 3 (Actual heading styles will vary.) |
| Paragraph              | Just start typing                                |
| <b>Bold</b>            | <b>**Bold**</b>                                  |
| <i>Italic</i>          | <i>*Italic*</i>                                  |
| Images                 | [Alternate text for image](path/image.jpg)       |
| Hyperlinks             | [Link text](https://www.visualizingsociety.com/) |
| Unordered Lists        |                                                  |
| - First                | - First                                          |
| - Second.              | - Second                                         |
| - Third                | - Third                                          |
| Ordered Lists          |                                                  |
| 1. First               | 1. First                                         |
| 2. Second.             | 2. Second                                        |
| 3. Third               | 3. Third                                         |
| Footnote. <sup>1</sup> | Footnote[^notelabel]                             |

<sup>1</sup>The note's content. [^notelabel] The note's content.



# The right frame of mind

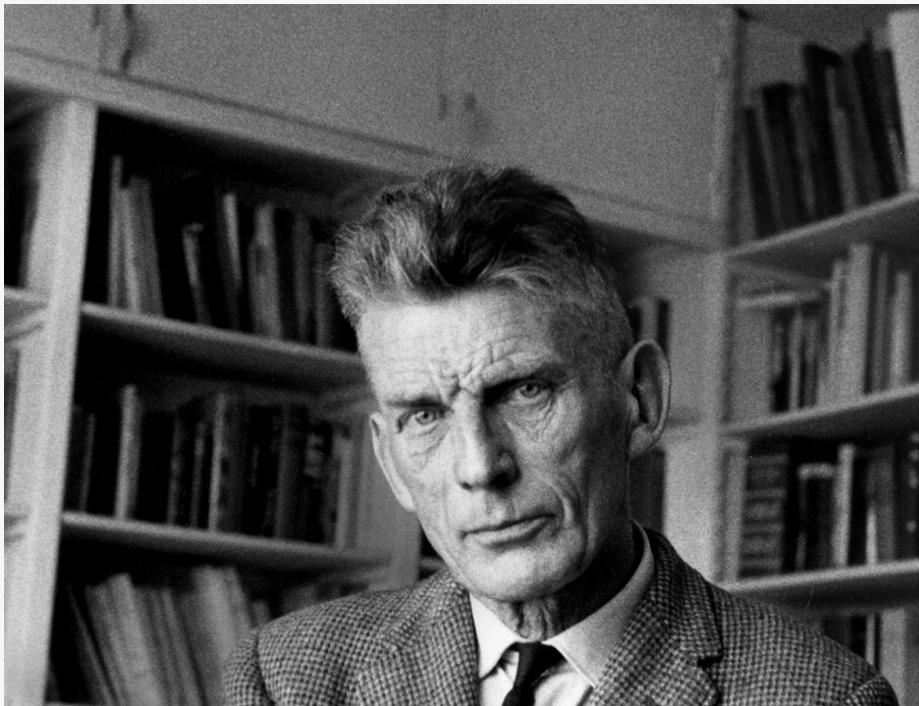
This is like learning how to drive a car, or how to cook in a kitchen ... or learning to speak a language.

After some orientation to what's where, you will learn best by *doing*.

Software is a pain, but you won't crash the car or burn your house down.

**TYPE OUT  
YOUR CODE**

**BY HAND**



Ever tried.  
Ever failed.  
No matter.  
Try again.  
Fail again.

# GETTING ORIENTED

# Loading the tidyverse libraries

```
library(tidyverse)
-- Attaching core tidyverse packages ━━━━━━━━━━ tidyverse 2.0.0 ━━━━━━
✓ dplyr    1.1.4      ✓ readr    2.1.4
✓forcats   1.0.0      ✓ stringr  1.5.1
✓ ggplot2   3.4.4      ✓ tibble   3.2.1
✓ lubridate 1.9.3      ✓ tidyrr   1.3.0
✓ purrr    1.0.2
-- Conflicts ━━━━━━━━━━ tidyverse_conflicts() ━━━━━━
✖ dplyr::filter() masks stats::filter()
✖ dplyr::lag()    masks stats::lag()
ℹ Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become
errors
```

The tidyverse has several components.

We'll return to this message about Conflicts later.

Again, the code and messages you see here is actual R output, produced at the same time as the slide.

# Tidyverse components

```
library(tidyverse)  
Loading tidyverse: ggplot2  
Loading tidyverse: tibble  
Loading tidyverse: tidyr  
Loading tidyverse: readr  
Loading tidyverse: purrr  
Loading tidyverse: dplyr
```

Call the package and ...

- ◀ Draw graphs
- ◀ Nicer data tables
- ◀ Tidy your data
- ◀ Get data into R
- ◀ Fancy Iteration
- ◀ Action verbs for tables



# What R looks like

Code you can type and run:

```
## Inside code chunks, lines beginning with a # character are comments  
## Comments are ignored by R  
  
my_numbers ← c(1, 1, 2, 4, 1, 3, 1, 5) # Anything after a # character is ignored as well
```

Output:

```
my_numbers  
[1] 1 1 2 4 1 3 1 5
```

This is equivalent to running the code above, typing `my_numbers` at the console, and hitting enter.



# What R looks like

By convention, code output in documents is prefixed by `##`

Also by convention, outputting vectors, etc, gets a counter keeping track of the number of elements. For example,

```
letters
```

```
[1] "a" "b" "c" "d" "e" "f" "g" "h" "i" "j" "k" "l" "m" "n" "o" "p" "q" "r" "s"  
[20] "t" "u" "v" "w" "x" "y" "z"
```

# Some things to know about R

# 0. It's a calculator

Arithmetic

```
(31 * 12) / 2^4
```

```
[1] 23.25
```

```
sqrt(25)
```

```
[1] 5
```

```
log(100)
```

```
[1] 4.60517
```

```
log(10^6 * 100)
```



# 0. It's a calculator

## Arithmetic

```
(31 * 12) / 2^4
```

```
[1] 23.25
```

```
sqrt(25)
```

```
[1] 5
```

```
log(100)
```

```
[1] 4.60517
```

## Logic

```
4 < 10
```

```
[1] TRUE
```

```
4 > 2 & 1 > 0.5 # The "&" means "and"
```

```
[1] TRUE
```

```
4 < 2 | 1 > 0.5 # The "/" means "or"
```

```
[1] TRUE
```



# Boolean and Logical operators

Logical equality and inequality (yielding a `TRUE` or `FALSE` result) is done with `=` and `!=`. Other logical operators include `<`, `>`, `<=`, `>=`, and `!` for negation.

```
## A logical test  
2 = 2 # Write `=` twice
```

```
[1] TRUE
```

```
## This will cause an error, because R will think you are trying to assign a value  
2 = 2
```

```
## Error in 2 = 2 : invalid (do_set) left-hand side to assignment
```

```
3 != 7 # Write `!` and then `=` to make `!=`
```

```
[1] TRUE
```



# Watch out!

Here's a gotcha. You might think you could write `3 < 5 & 7` and have it be interpreted as "Three is less than five and also less than seven [True or False?]:

```
3 < 5 & 7
```

```
[1] TRUE
```

It seems to work!

# Watch out!

But now try `3 < 5 & 1`, where your intention is “Three is less than five and also less than one [True or False?]”

```
3 < 5 & 1
```

```
[1] TRUE
```

What's happening is that `3 < 5` is evaluated first, and resolves to `TRUE`, leaving us with the expression `TRUE & 1`.

R interprets this as `TRUE & as.logical(1)`.

In Boolean algebra, `1` resolves to `TRUE`. Any other number is `FALSE`. So,

# Watch out!

```
TRUE & as.logical(1)
```

```
[1] TRUE
```

```
3 < 5 & 3 < 1
```

```
[1] FALSE
```

You have to make your comparisons explicit.



# Logic and floating point arithmetic

Let's evaluate  $0.6 + 0.2 = 0.8$

# Logic and floating point arithmetic

Let's evaluate  $0.6 + 0.2 = 0.8$

```
0.6 + 0.2 = 0.8
```

```
[1] TRUE
```

# Logic and floating point arithmetic

Let's evaluate  $0.6 + 0.2 = 0.8$

```
0.6 + 0.2 = 0.8
```

```
[1] TRUE
```

Now let's try  $0.6 + 0.3 = 0.9$

# Logic and floating point arithmetic

Let's evaluate  $0.6 + 0.2 = 0.8$

```
0.6 + 0.2 = 0.8
```

```
[1] TRUE
```

Now let's try  $0.6 + 0.3 = 0.9$

```
0.6 + 0.3 = 0.9
```

```
[1] FALSE
```

Er. That's not right.

# Welcome to floating point math!

In Base 10, you can't precisely express fractions like  $\frac{1}{3}$  and  $\frac{1}{9}$ . They come out as repeating decimals: 0.3333... or 0.1111... You *can* cleanly represent fractions that use a prime factor of the base, which in the case of Base 10 are 2 and 5.

# Welcome to floating point math!

In Base 10, you can't precisely express fractions like  $\frac{1}{3}$  and  $\frac{1}{9}$ . They come out as repeating decimals: 0.3333... or 0.1111... You *can* cleanly represent fractions that use a prime factor of the base, which in the case of Base 10 are 2 and 5.

Computers represent numbers as binary (i.e. Base 2) floating-points. In Base 2, the only prime factor is 2. So  $\frac{1}{5}$  or  $\frac{1}{10}$  in binary would be repeating.

# Logic and floating point arithmetic

When you do binary math on repeating numbers and convert back to decimals you get tiny leftovers, and this can mess up *logical* comparisons of equality. The `all.equal()` function exists for this purpose.

```
print(.1 + .2)
```

```
[1] 0.3
```

```
print(.1 + .2, digits=18)
```

```
[1] 0.30000000000000044
```

```
all.equal(.1 + .2, 0.3)
```

```
[1] TRUE
```

See e.g. <https://0.3000000000000004.com>



More later on  
why this might

bite you, and how  
to deal with it

For now, “Be very careful about doing logical comparisons on floating-point numbers” is not a bad rule.

# 1. Everything in R has a name

```
my_numbers # We created this a few minutes ago
```

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

```
letters # This one is built-in
```

```
[1] "a" "b" "c" "d" "e" "f" "g" "h" "i" "j" "k" "l" "m" "n" "o" "p" "q" "r" "s"  
[20] "t" "u" "v" "w" "x" "y" "z"
```

```
pi # Also built-in
```

```
[1] 3.141593
```

# Some names are forbidden

Or it's a *really* bad idea to try to use them

```
TRUE  
FALSE  
Inf  
NaN  
NA  
NULL
```

```
for  
if  
while  
break  
function
```

## 2. Everything is an object

There are a few built-in objects:

```
letters
```

```
[1] "a" "b" "c" "d" "e" "f" "g" "h" "i" "j" "k" "l" "m" "n" "o" "p" "q" "r" "s"  
[20] "t" "u" "v" "w" "x" "y" "z"
```

```
pi
```

```
[1] 3.141593
```

```
LETTERS
```

```
[1] "A" "B" "C" "D" "E" "F" "G" "H" "I" "J" "K" "L" "M" "N" "O" "P" "Q" "R" "S"  
[20] "T" "U" "V" "W" "X" "Y" "Z"
```



# 3. You can create objects

In fact, this is mostly what we will be doing.

Objects are created by **assigning** a thing to a name:

```
## name ... gets ... this stuff  
my_numbers ← c(1, 2, 3, 1, 3, 5, 25, 10)
```

```
## name ... gets ... the output of the function `c()`  
your_numbers ← c(5, 31, 71, 1, 3, 21, 6, 52)
```

The **c()** function *combines* or *concatenates* things

# The assignment operator

The assignment operator performs the action of creating objects

Use a keyboard shortcut to write it:

Press **option** and **-** on a Mac

Press **alt** and **-** on Windows



# Assignment with =

You can use `=` as well as `←` for assignment.

```
my_numbers = c(1, 2, 3, 1, 3, 5, 25)
```

```
my_numbers
```

```
[1] 1 2 3 1 3 5 25
```

On the other hand, `=` has a different meaning when used in functions.

I'm going to use `←` for assignment throughout.

Be consistent either way.



# Assignment with =



It isn't  
*wrong* but  
we just  
don't do it

# 4. Do things to objects with functions

```
## this object ... gets ... the output of this function  
my_numbers ← c(1, 2, 3, 1, 3, 5, 25, 10)
```

```
your_numbers ← c(5, 31, 71, 1, 3, 21, 6, 52)
```

```
my_numbers
```

```
[1] 1 2 3 1 3 5 25 10
```

# 4. Do things to objects with functions

Functions can be identified by the parentheses after their names.

```
my_numbers
```

```
[1] 1 2 3 1 3 5 25 10
```

```
## If you run this you'll get an error  
mean()
```



# What functions usually do

They take **inputs** to **arguments**

They perform **actions**

They produce, or return, **outputs**

**mean(x = my\_numbers)**

# What functions usually do

They take **inputs** to **arguments**

They perform **actions**

They produce, or return, **outputs**

**mean(x = my\_numbers)**

[1] **6.25**

# What functions usually do

```
## Get the mean of what? Of x.  
## You need to tell the function what x is  
mean(x = my_numbers)
```

```
[1] 6.25
```

```
mean(x = your_numbers)
```

```
[1] 23.75
```

# What functions usually do

If you don't *name* the arguments, R assumes you are providing them in the order the function expects.

```
mean(your_numbers)
```

```
[1] 23.75
```

# What functions usually do

What arguments? Which order? Read the function's help page

```
help(mean)
```

```
## quicker  
?mean
```

How to read an R help page?



# What functions usually do

Arguments often tell the function what to do in specific circumstances

```
missing_numbers ← c(1:10, NA, 20, 32, 50, 104, 32, 147, 99, NA, 45)  
mean(missing_numbers)
```

```
[1] NA
```

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

```
[1] 32.44444
```

Or select from one of several options

```
## Look at ?mean to see what `trim` does  
mean(missing_numbers, na.rm = TRUE, trim = 0.1)
```

```
[1] 27.25
```



# What functions usually do

There are all kinds of functions. They return different things.

```
summary(my_numbers)
```

| Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max.  |
|------|---------|--------|------|---------|-------|
| 1.00 | 1.75    | 3.00   | 6.25 | 6.25    | 25.00 |

# What functions usually do

You can assign the output of a function to a name, which turns it into an object. (Otherwise it'll send its output to the console.)

```
my_summary ← summary(my_numbers)
```

```
my_summary
```

| Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max.  |
|------|---------|--------|------|---------|-------|
| 1.00 | 1.75    | 3.00   | 6.25 | 6.25    | 25.00 |

# What functions usually do

Objects hang around in your work environment until they are overwritten by you, or are deleted.

```
## rm() function removes objects  
rm(my_summary)  
  
my_summary  
  
## Error: object 'my_summary' not found
```



# Functions can be nested

```
c(1:20)
```

```
[1] 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
```

```
mean(c(1:20))
```

```
[1] 10.5
```

```
summary(mean(c(1:20)))
```

| Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max. |
|------|---------|--------|------|---------|------|
| 10.5 | 10.5    | 10.5   | 10.5 | 10.5    | 10.5 |

```
names(summary(mean(c(1:20))))
```

```
[1] "Min."      "1st Qu."   "Median"    "Mean"      "3rd Qu."   "Max."
```

```
length(names(summary(mean(c(1:20)))))
```

```
[1] 6
```

Nested functions are evaluated from the inside out.



# Use the pipe operator: |>

Instead of deeply nesting functions in parentheses, we can use the *pipe operator*:

```
c(1:20) %> mean() %> summary() %> names() %> length()
```

```
[1] 6
```

Read this operator as “*and then*”



# Use the pipe operator: |>

Better, vertical space is free in R:

```
c(1:20) |>  
mean() |>  
summary() |>  
names() |>  
length()
```

```
[1] 6
```

# Pipelines make code more **readable**

Not great, Bob:

```
serve(stir(pour_in_pan(whisk(crack_eggs(get_from_fridge(eggs), into = "bowl"), len = 40), temp = "med-high")))
```

Notice how the first thing you read is the last operation performed.



# Pipelines make code more **readable**

We can use vertical space and indents, but it's really not much better:

```
serve(
  stir(
    pour_in_pan(
      whisk(
        crack_eggs(
          get_from_fridge(eggs),
          into = "bowl"),
        len = 40),
      temp = "med-high")
    )
  )
```



# Pipelines make code more **readable**

Much nicer:

```
eggs ▷  
get_from_fridge() ▷  
crack_eggs(into = "bowl") ▷  
whisk(len = 40) ▷  
pour_in_pan(temp = "med-high") ▷  
stir() ▷  
serve()
```

We'll still use nested parentheses quite a bit, often in the context of a function working inside a pipeline. But it's good not to have too many levels of nesting.

# The other pipe: %>%

The Base R pipe operator, `>` is a relatively recent addition to R.

Piping operations were originally introduced in a package called `magrittr`, where it took the form `%>%`

# The other pipe: %>%

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It's been so successful, a version of it has been incorporated into Base R. It *mostly* but does not *quite* work the same way as `%>%` in every case.



# The other pipe: %>%

The Base R pipe operator, `>` is a relatively recent addition to R.

Piping operations were originally introduced in a package called `magrittr`, where it took the form `%>%`. It's been so successful, a version of it has been incorporated into Base R. It *mostly* but does not *quite* work the same way as `%>%` in every case. We'll use the Base R pipe in this course, but you'll see the Magrittr pipe a lot out in the world.

With the Base R pipe, you can only pass an object to the *first* argument in a function. This is fine for most tidyverse pipelines, where the first argument is usually (implicitly) the data. But it does mean that most Base R functions will continue not to be easily piped, as most of them do not follow the convention of passing the current data as the first argument.



# Functions are bundled into packages

Packages are loaded into your working environment using the `library()` function:

```
## A package containing a dataset rather than functions
library(gapminder)

gapminder
```

```
# A tibble: 1,704 × 6
  country continent year lifeExp      pop gdpPercap
  <fct>     <fct>   <int>   <dbl>    <int>     <dbl>
1 Afghanistan Asia     1952     28.8  8425333     779.
2 Afghanistan Asia     1957     30.3  9240934     821.
3 Afghanistan Asia     1962     32.0  10267083    853.
4 Afghanistan Asia     1967     34.0  11537966    836.
5 Afghanistan Asia     1972     36.1  13079460    740.
6 Afghanistan Asia     1977     38.4  14880372    786.
7 Afghanistan Asia     1982     39.9  12881816    978.
8 Afghanistan Asia     1987     40.8  13867957    852.
9 Afghanistan Asia     1992     41.7  16317921    649.
10 Afghanistan Asia    1997     41.8  22227415    635.
# i 1,694 more rows
```



# Functions are bundled into packages

You need only *install* a package once (and occasionally update it):

```
## Do at least once for each package. Once done, not needed each time.  
install.packages("palmerpenguins", repos = "http://cran.rstudio.com")  
  
## Needed sometimes, especially after an R major version upgrade.  
update.packages(repos = "http://cran.rstudio.com")
```

# Functions are bundled into packages

But you must *load* the package in each R session before you can access its contents:

```
## To load a package, usually at the start of your RMarkdown document or script file
library(palmerpenguins)
penguins
```

```
# A tibble: 344 × 8
  species   island bill_length_mm bill_depth_mm flipper_length_mm body_mass_g
  <fct>     <fct>        <dbl>        <dbl>          <int>        <int>
1 Adelie    Torgersen      39.1         18.7          181        3750
2 Adelie    Torgersen      39.5         17.4          186        3800
3 Adelie    Torgersen      40.3          18           195        3250
4 Adelie    Torgersen       NA            NA             NA          NA
5 Adelie    Torgersen      36.7         19.3          193        3450
6 Adelie    Torgersen      39.3         20.6          190        3650
7 Adelie    Torgersen      38.9         17.8          181        3625
8 Adelie    Torgersen      39.2         19.6          195        4675
9 Adelie    Torgersen      34.1         18.1          193        3475
10 Adelie   Torgersen       42           20.2          190        4250
# i 334 more rows
# i 2 more variables: sex <fct>, year <int>
```



# Grabbing a single function with ::

“Reach in” to an unloaded package and grab a function directly, using  
`<package> :: <function>`

# Grabbing a single function with ::

```
## A little glimpse of what we'll do soon
penguins %>
  select(species, body_mass_g, sex) %>
  gtsummary::tbl_summary(by = species) #<<
```

| Characteristic            | Adelie, N = 152       | Chinstrap, N = 68     | Gentoo, N = 124       |
|---------------------------|-----------------------|-----------------------|-----------------------|
| body_mass_g, Median (IQR) | 3,700 (3,350 – 4,000) | 3,700 (3,488 – 3,950) | 5,000 (4,700 – 5,500) |
| Unknown                   | 1                     | 0                     | 1                     |
| sex, n (%)                |                       |                       |                       |
| female                    | 73 (50)               | 34 (50)               | 58 (49)               |
| male                      | 73 (50)               | 34 (50)               | 61 (51)               |
| Unknown                   | 6                     | 0                     | 5                     |



# Remember those conflicts?

Notice how some functions in different packages have the same names.



Related concepts of *namespaces* and *environments*.

# The scope of names

```
x ← c(1:10)  
y ← c(90:100)
```

```
x
```

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

```
y
```

```
[1] 90 91 92 93 94 95 96 97 98 99 100
```

```
mean()
```

```
## Error in mean.default() : argument "x" is missing, with no default
```

# The scope of names

```
mean(x) # argument names are internal to functions
```

```
[1] 5.5
```

```
mean(x = x)
```

```
[1] 5.5
```

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

```
[1] 95
```

```
x
```

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

```
y
```

```
[1] 90 91 92 93 94 95 96 97 98 99 100
```



## 5. Objects come in **types** and **classes**

I'm going to speak somewhat loosely here for now, and gloss over some distinctions between object classes and data structures, as well as kinds of objects and their attributes.

# 5. Objects come in **types** and **classes**

I'm going to speak somewhat loosely here for now, and gloss over some distinctions between object classes and data structures, as well as kinds of objects and their attributes.

The object inspector in RStudio is your friend.

You can ask an object what it is at the console, too:

```
class(my_numbers)
```

```
[1] "numeric"
```

```
typeof(my_numbers)
```

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

# 5. Objects come in **types** and **classes**

Objects can have more than one (nested) class:

```
summary(my_numbers)
```

| Min. | 1st Qu. | Median | Mean | 3rd Qu. | Max.  |
|------|---------|--------|------|---------|-------|
| 1.00 | 1.75    | 3.00   | 6.25 | 6.25    | 25.00 |

```
my_smry ← summary(my_numbers) # remember, outputs can be assigned to a name, creating an object
```

```
class(summary(my_numbers)) # functions can be nested, and are evaluated from the inside out
```

```
[1] "summaryDefault" "table"
```

```
class(my_smry) # equivalent to the previous line
```

```
[1] "summaryDefault" "table"
```

# 5. Objects come in **types** and **classes**

```
typeof(my_smry)
```

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

```
attributes(my_smry)
```

```
$names  
[1] "Min."     "1st Qu."  "Median"   "Mean"      "3rd Qu."  "Max."
```

```
$class  
[1] "summaryDefault" "table"
```

```
## In this case, the functions extract the corresponding attribute  
class(my_smry)
```

```
[1] "summaryDefault" "table"
```

```
names(my_smry)
```

```
[1] "Min."     "1st Qu."  "Median"   "Mean"      "3rd Qu."  "Max."
```



# Kinds of vector



Hadley Wickham, *Advanced R*



# Kinds of vector



```
my_int ← c(1, 3, 5, 6, 10)  
is.integer(my_int)
```

```
[1] FALSE
```

```
is.double(my_int)
```

```
[1] TRUE
```

```
my_int ← as.integer(my_int)  
is.integer(my_int)
```

```
[1] TRUE
```

```
my_chr ← c("Mary", "had", "a", "little", "lamb")
```

# Kinds of vector



```
## Factors are for storing unordered or ordered categorical variables  
x ← factor(c("Yes", "No", "No", "Maybe", "Yes", "Yes", "Yes", "No"))  
x
```

```
[1] Yes   No    No    Maybe Yes   Yes   Yes   No  
Levels: Maybe No Yes
```

```
summary(x) # Alphabetical order by default
```

```
Maybe    No    Yes  
1       3      4
```

```
typeof(x)      # Underneath, a factor is a type of integer ...
```

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

```
attributes(x)  # ... with labels for its numbers, or "levels"
```



# Vector types can't be heterogenous

Objects can be manually or automatically coerced from one class to another. Take care.

```
class(my_numbers)
```

```
[1] "numeric"
```

```
my_new_vector ← c(my_numbers, "Apple")
```

```
my_new_vector # vectors are homogeneous/atomic
```

```
[1] "1"      "2"      "3"      "1"      "3"      "5"      "25"     "10"     "Apple"
```

```
class(my_new_vector)
```

```
[1] "character"
```



# Vector types can't be heterogenous

Objects can be manually or automatically coerced from one class to another. Take care.

```
my_dbl ← c(2.1, 4.77, 30.111, 3.14519)  
is.double(my_dbl)
```

```
[1] TRUE
```

```
my_dbl ← as.integer(my_dbl)
```

```
my_dbl
```

```
[1] 2 4 30 3
```

# A table of data is a kind of **list**

```
gapminder # tibbles and data frames can contain vectors of different types
```

```
# A tibble: 1,704 × 6
  country continent year lifeExp      pop gdpPercap
  <fct>     <fct>   <int>    <dbl>    <int>     <dbl>
1 Afghanistan Asia     1952     28.8  8425333     779.
2 Afghanistan Asia     1957     30.3  9240934     821.
3 Afghanistan Asia     1962     32.0 10267083     853.
4 Afghanistan Asia     1967     34.0 11537966     836.
5 Afghanistan Asia     1972     36.1 13079460     740.
6 Afghanistan Asia     1977     38.4 14880372     786.
7 Afghanistan Asia     1982     39.9 12881816     978.
8 Afghanistan Asia     1987     40.8 13867957     852.
9 Afghanistan Asia     1992     41.7 16317921     649.
10 Afghanistan Asia    1997     41.8 22227415     635.
# i 1,694 more rows
```

```
class(gapminder)
```

```
[1] "tbl_df"     "tbl"        "data.frame"
```

```
typeof(gapminder) # hmm
```

```
[1] "list"
```



# A table of data is a kind of **list**

Lists *can* be heterogenous. Underneath, most complex R objects are some kind of list with different components.

A *data frame* is a list of vectors of the same length, where the vectors can be of different types (e.g. numeric, character, logical, etc)

A *tibble* is an enhanced data frame

# Some classes are versions of others

Base R's trusty `data.frame`

```
library(socviz)
titanic
```

|   | fate     | sex    | n    | percent |
|---|----------|--------|------|---------|
| 1 | perished | male   | 1364 | 62.0    |
| 2 | perished | female | 126  | 5.7     |
| 3 | survived | male   | 367  | 16.7    |
| 4 | survived | female | 344  | 15.6    |

```
class(titanic)
```

[1] "data.frame"

```
## The ` `$` idiom picks out a named column here;
## more generally, the named element of a list
titanic$percent
```



# Some classes are versions of others

Base R's trusty `data.frame`

```
library(socviz)
titanic

  fate    sex     n percent
1 perished male 1364    62.0
2 perished female 126     5.7
3 survived male  367    16.7
4 survived female 344    15.6
```

```
class(titanic)
```

```
[1] "data.frame"
```

```
## The ` `$` idiom picks out a named column here;
## more generally, the named element of a list
titanic$percent
```

The Tidyverse's enhanced `tibble`

```
## tibbles are build on data frames
titanic_tb ← as_tibble(titanic)
titanic_tb
```

```
# A tibble: 4 × 4
  fate    sex     n percent
  <fct>   <fct>   <dbl>   <dbl>
1 perished male    1364    62
2 perished female  126     5.7
3 survived male    367    16.7
4 survived female  344    15.6
```

```
class(titanic_tb)
```

```
[1] "tbl_df"      "tbl"        "data.frame"
```



# All of this will be clearer in use

gss\_sm

```
# A tibble: 2,867 × 32
  year   id ballot      age child� sibs degree race   sex   region income16
  <dbl> <dbl> <labelled> <dbl> <dbl> <labe> <fct> <fct> <fct> <fct> <fct>
1 2016     1 1           47     3 2    Bache... White Male New E... $170000...
2 2016     2 2           61     0 3    High ... White Male New E... $50000 ...
3 2016     3 3           72     2 3    Bache... White Male New E... $75000 ...
4 2016     4 1           43     4 3    High ... White Fema... New E... $170000...
5 2016     5 3           55     2 2    Gradu... White Fema... New E... $170000...
6 2016     6 2           53     2 2    Junio... White Fema... New E... $60000 ...
7 2016     7 1           50     2 2    High ... White Male New E... $170000...
8 2016     8 3           23     3 6    High ... Other Fema... Middl... $30000 ...
9 2016     9 1           45     3 5    High ... Black Male Middl... $60000 ...
10 2016    10 3          71     4 1   Junio... White Male Middl... $60000 ...
# i 2,857 more rows
# i 21 more variables: relig <fct>, marital <fct>, padeg <fct>, madeg <fct>,
# partyid <fct>, polviews <fct>, happy <fct>, partners <fct>, grass <fct>,
# zodiac <fct>, pres12 <labelled>, wtssall <dbl>, income_rc <fct>,
# agegrp <fct>, ageq <fct>, siblings <fct>, kids <fct>, religion <fct>,
# biareaion <fct>. partners_rc <fct>. obama <dbl>
```

Tidyverse tools are generally *type safe*, meaning their functions return the same type of thing every time, or fail if they cannot do this. So it's good to know about the various data types.



# 6. Arithmetic on vectors

In R, all numbers are vectors of different sorts. Even single numbers (“scalars”) are conceptually vectors of length 1.

Arithmetic on vectors (and arrays generally) follows a series of *recycling rules* that favor ease of expression of vectorized, “elementwise” operations.

See if you can predict what the following operations do:

# 6. Arithmetic on vectors

```
my_numbers
```

```
[1] 1 2 3 1 3 5 25 10
```

```
result1 ← my_numbers + 1
```

# 6. Arithmetic on vectors

```
my_numbers
```

```
[1] 1 2 3 1 3 5 25 10
```

```
result1 ← my_numbers + 1
```

```
result1
```

```
[1] 2 3 4 2 4 6 26 11
```



# 6. Arithmetic on vectors

```
result2 ← my_numbers + my_numbers
```

# 6. Arithmetic on vectors

```
result2 ← my_numbers + my_numbers
```

```
result2
```

```
[1] 2 4 6 2 6 10 50 20
```

# 6. Arithmetic on vectors

```
two_nums ← c(5, 10)  
result3 ← my_numbers + two_nums
```

# 6. Arithmetic on vectors

```
two_nums ← c(5, 10)  
result3 ← my_numbers + two_nums  
result3
```

```
[1] 6 12 8 11 8 15 30 20
```

# 6. Arithmetic on vectors

```
three_nums ← c(1, 5, 10)  
result4 ← my_numbers + three_nums
```

Warning in my\_numbers + three\_nums: longer object length is not a multiple of shorter object length

# 6. Arithmetic on vectors

```
three_nums ← c(1, 5, 10)  
  
result4 ← my_numbers + three_nums
```

Warning in my\_numbers + three\_nums: longer object length is not a multiple of shorter object length

```
result4
```

```
[1]  2  7 13  2  8 15 26 15
```

Note that you get a *warning* here. It'll still do it, though! Don't ignore warnings until you understand what they mean.

# 7. R will be frustrating

The IDE tries its best to help you. Learn to attend to what it is trying to say.

```
Warning message:  
In my_numbers + two_nums :  
  longer object length is not a multiple of shorter object length
```

```
 38   ↵    ↵  make a plot ↵  
✖ 39 p <- ggplot(data = gapminder  
  ↵      expected ',' after expression| x = gdpPercap,  
  ↵      ↵                      y = lifeExp))  
  ↵ 42 |
```

```
 39 p <- ggplot(data = gapminder,  
  ↵           mapping = aes(x = gdpPercap,  
✖ 40           ↵                   y = lifeExp)))  
  ↵ 41           ↵  
  ↵     unexpected token ')' |  
  ↵ 42 ↵ `` |
```



# Let's Go!

# Time to make a plot

Like before:

```
gapminder
```

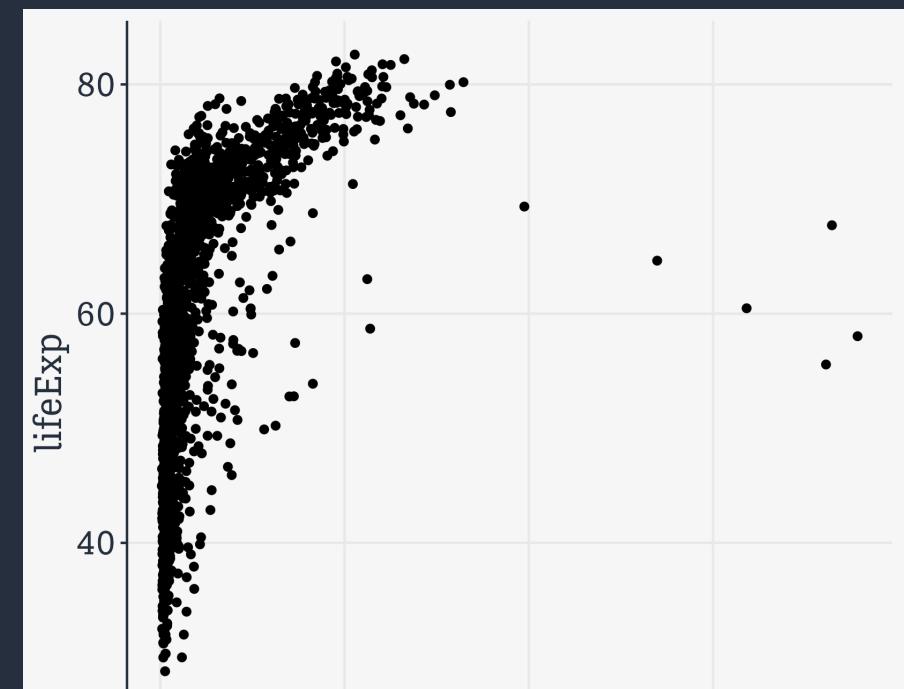
```
# A tibble: 1,704 × 6
  country   continent   year lifeExp      pop gdpPercap
  <fct>     <fct>     <int>   <dbl>    <int>     <dbl>
1 Afghanistan Asia       1952     28.8  8425333     779.
2 Afghanistan Asia       1957     30.3  9240934     821.
3 Afghanistan Asia       1962     32.0  10267083    853.
4 Afghanistan Asia       1967     34.0  11537966    836.
5 Afghanistan Asia       1972     36.1  13079460    740.
6 Afghanistan Asia       1977     38.4  14880372    786.
7 Afghanistan Asia       1982     39.9  12881816    978.
8 Afghanistan Asia       1987     40.8  13867957    852.
9 Afghanistan Asia       1992     41.7  16317921    649.
10 Afghanistan Asia      1997     41.8  22227415    635.
# i 1,694 more rows
```

# Like before

```
library(tidyverse)
library(gapminder)

p ← ggplot(data = gapminder,
            mapping = aes(x = gdpPercap,
                           y = lifeExp))

p + geom_point()
```



# What we did

```
library(tidyverse)  
library(gapminder)
```

Load the packages we need: `tidyverse` and `gapminder`



# What we did

```
p ← ggplot(data = gapminder,  
            mapping = aes(x = gdpPercap,  
                            y = lifeExp))
```

]

New object named **p** gets the output of the **ggplot()** *function*, given these *arguments*

Notice how one of the arguments, **mapping**, is itself taking the output of a function named **aes()**



# What we did

```
p + geom_point()
```

Show me the output of the `p` object and the `geom_point()` function.

The `+` here acts just like the `>` pipe, but for ggplot functions only. (This is an accident of history.)

# And what is R doing?

R objects are just lists of **stuff to use** or **things to do**

# Objects are like Bento Boxes



## Data

```
# A tibble: 1,704 x 6
  country continent year lifeExp
  <fctr>    <fctr> <int>   <dbl>   <dbl>
1 Afghanistan Asia     1952 28.801 8425
2 Afghanistan Asia     1957 30.332 9240
3 Afghanistan Asia     1962 31.997 10267
4 Afghanistan Asia     1967 34.020 11537
5 Afghanistan Asia     1972 36.088 13079
6 Afghanistan Asia     1977 38.438 14880
7 Afghanistan Asia     1982 39.854 12881
8 Afghanistan Asia     1987 40.822 13867
9 Afghanistan Asia     1992 41.674 16317
10 Afghanistan Asia    1997 41.763 22227
```

## Mappings

— Represent or Map  
“**lifeExp**” using the x axis

— Represent or Map  
“**gdpPercap**” using the y axis

— Represent or Map  
“**continent**” using colors

Environment History Connections Git Tutorial

 Import Dataset |  297 MiB | 

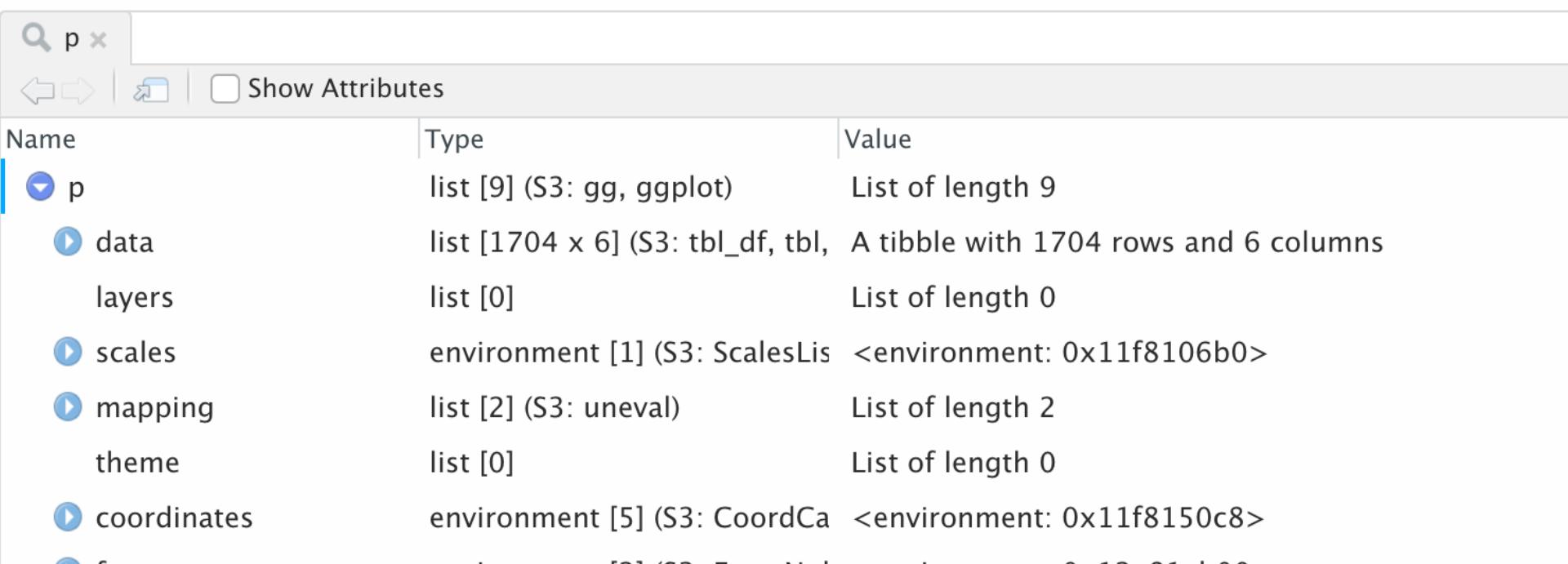
R |  Global Environment

Data

 p List of 9

Functions





A screenshot of a variable viewer or debugger interface. At the top, there is a search bar with the text "p" and a close button. Below the search bar are navigation icons: back, forward, and a refresh symbol, followed by a checkbox labeled "Show Attributes".

| Name        | Type                                   | Value                                 |
|-------------|----------------------------------------|---------------------------------------|
| p           | list [9] (S3: gg, ggplot)              | List of length 9                      |
| data        | list [1704 x 6] (S3: tbl_df, tbl, ...) | A tibble with 1704 rows and 6 columns |
| layers      | list [0]                               | List of length 0                      |
| scales      | environment [1] (S3: ScalesList)       | <environment: 0x11f8106b0>            |
| mapping     | list [2] (S3: uneval)                  | List of length 2                      |
| theme       | list [0]                               | List of length 0                      |
| coordinates | environment [5] (S3: CoordCatList)     | <environment: 0x11f8150c8>            |
| facet       | environment [2] (S3: FacetNullList)    | <environment: 0x12a81ab00>            |