

Data Visualization - 2.

Finding your way in R

Kieran Healy
Code Horizons

October 5, 2024

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

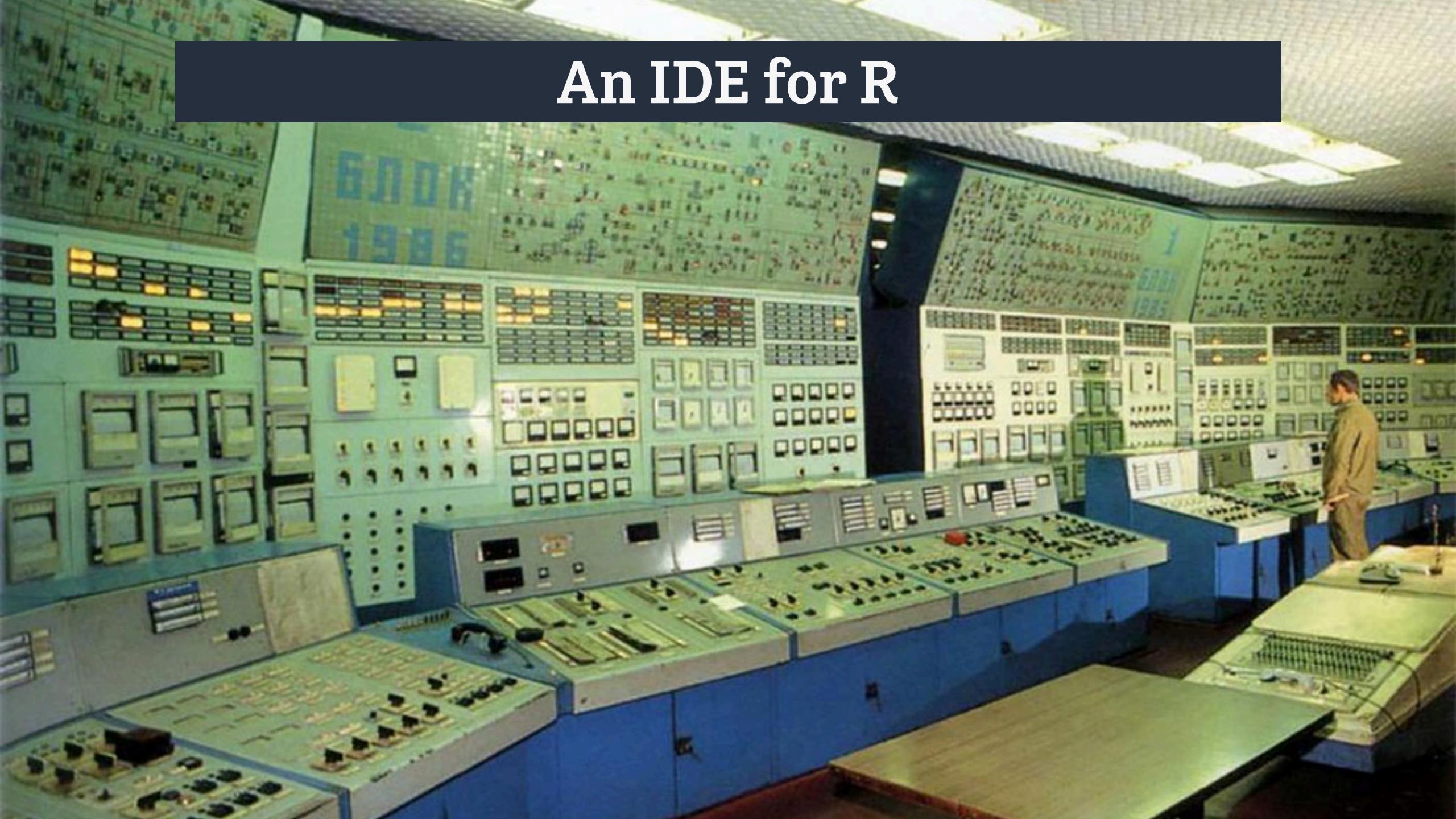
Raw data ▷ Read, Clean, Analyse ▷ Tidy table ▷ Make figures

2. Just hand ggplot a table of results

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

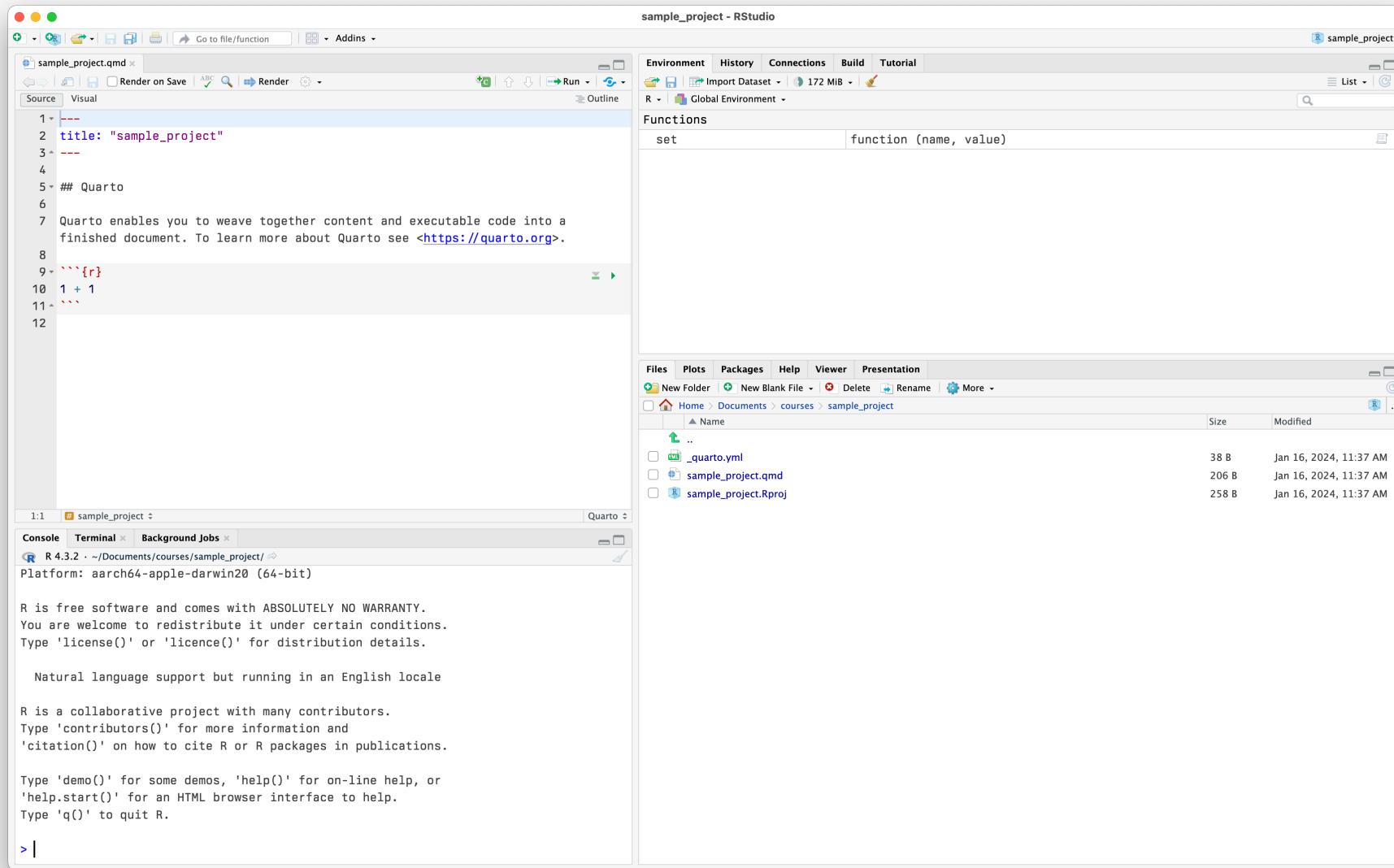
The RStudio IDE

An IDE for R

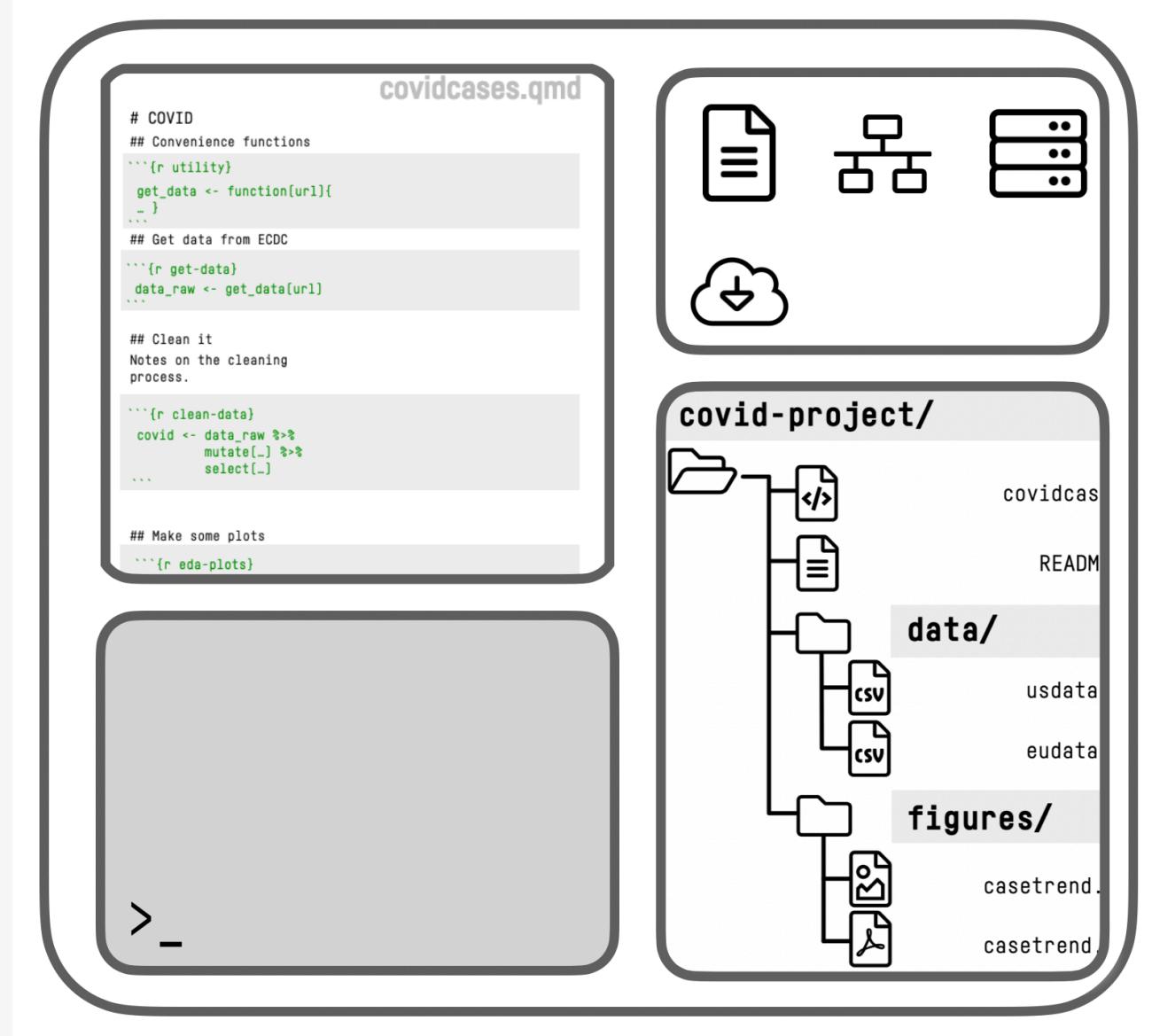


An IDE for Meals

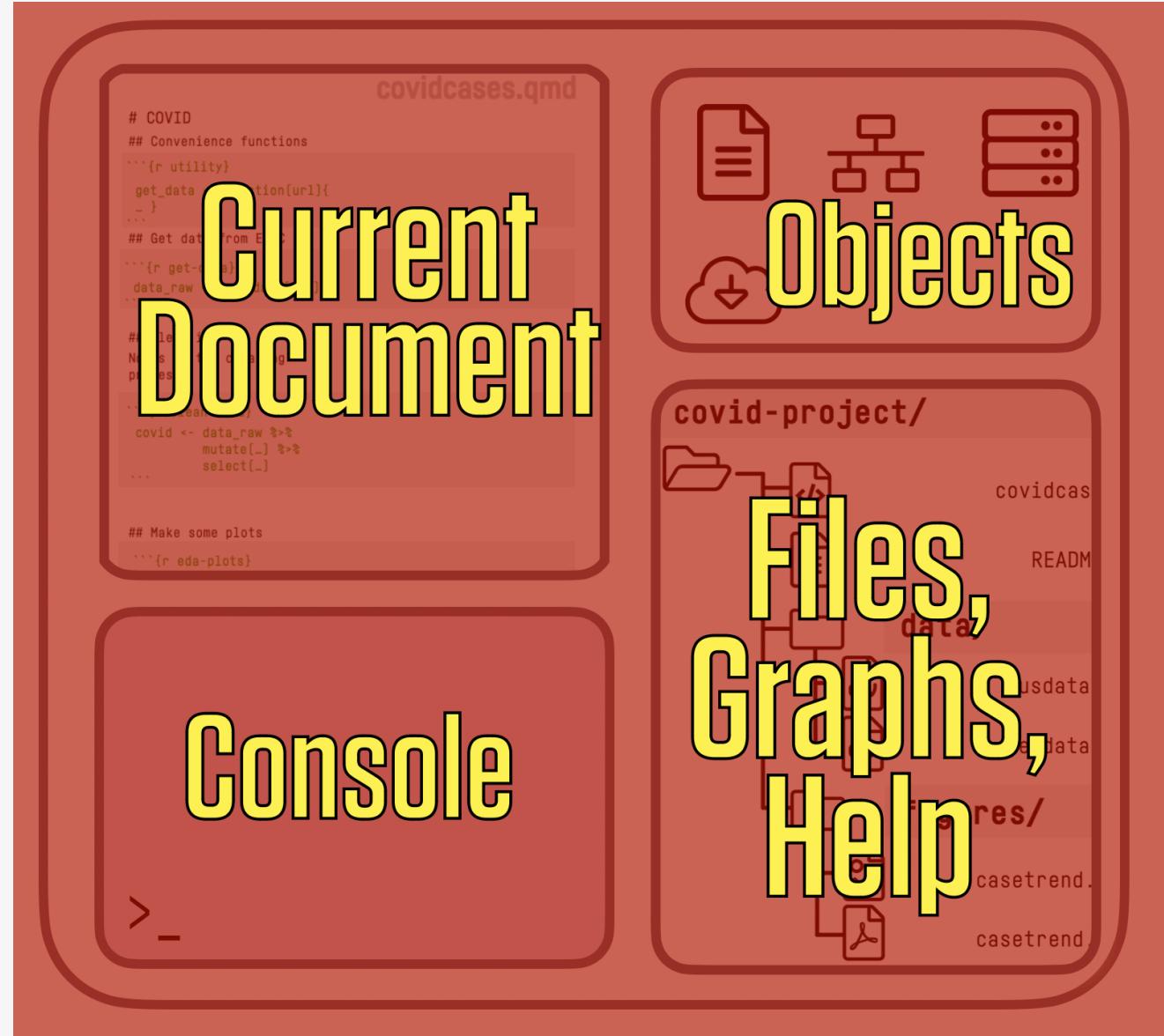




RStudio at startup



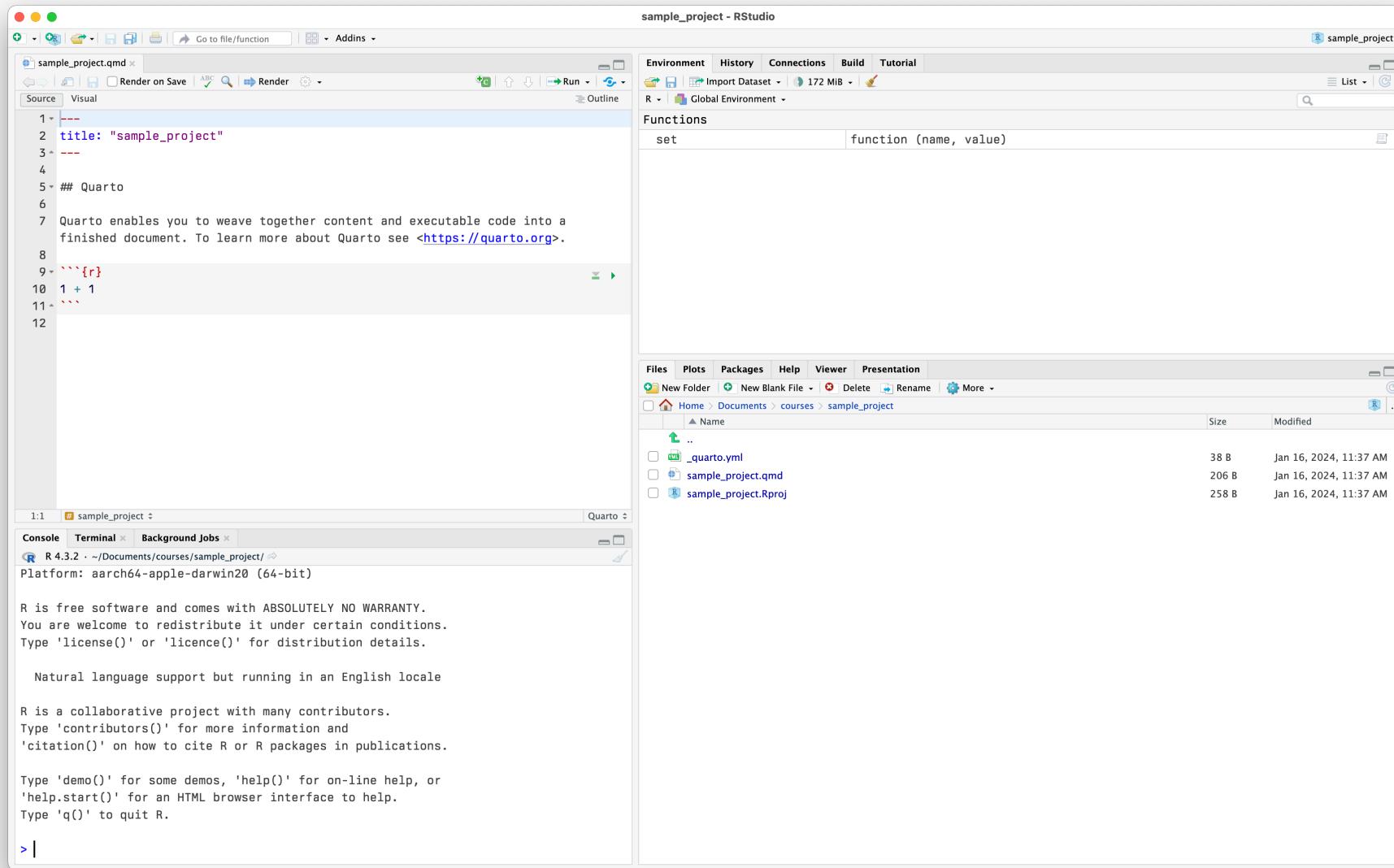
RStudio schematic overview



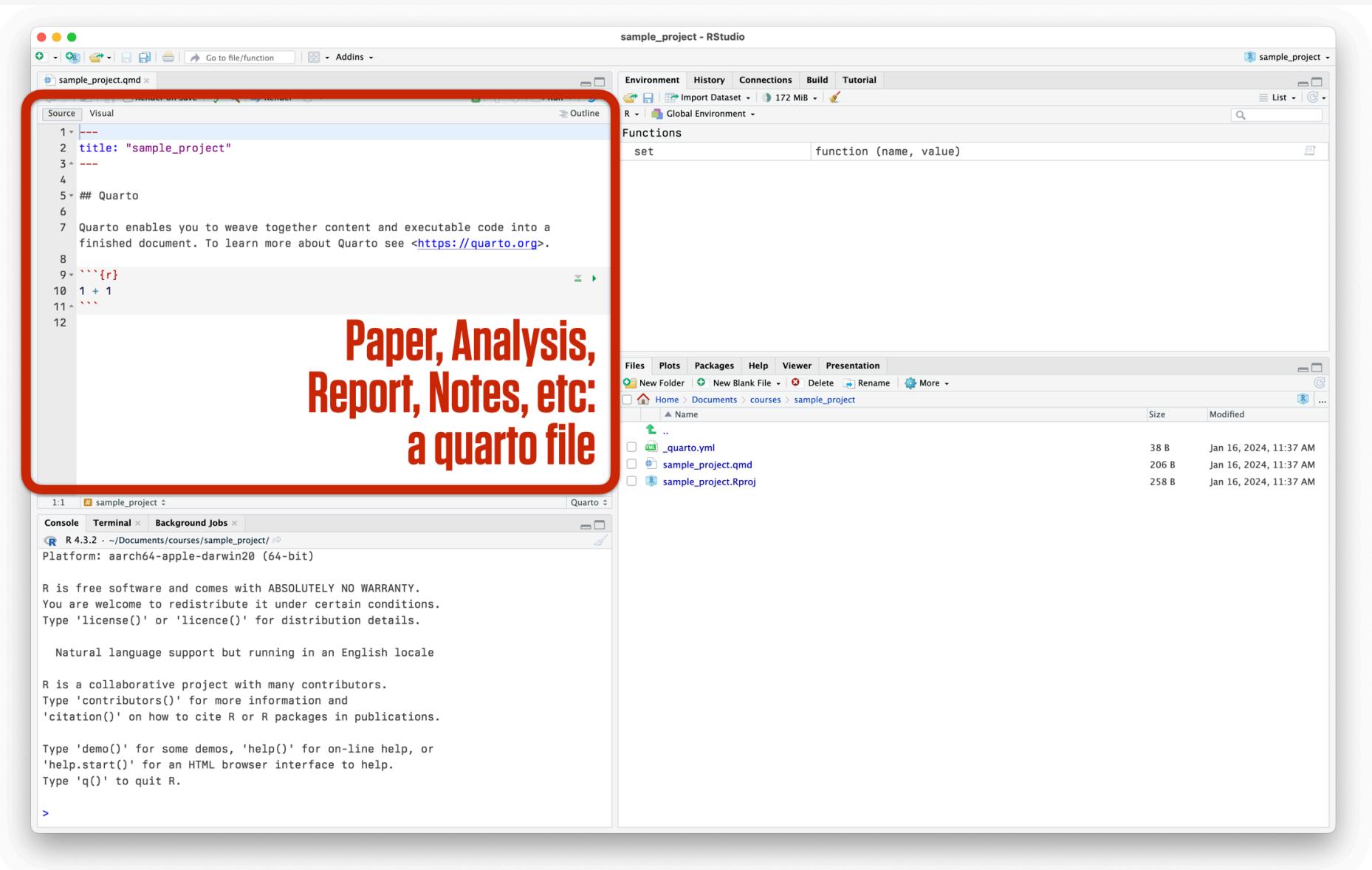
RStudio schematic overview

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

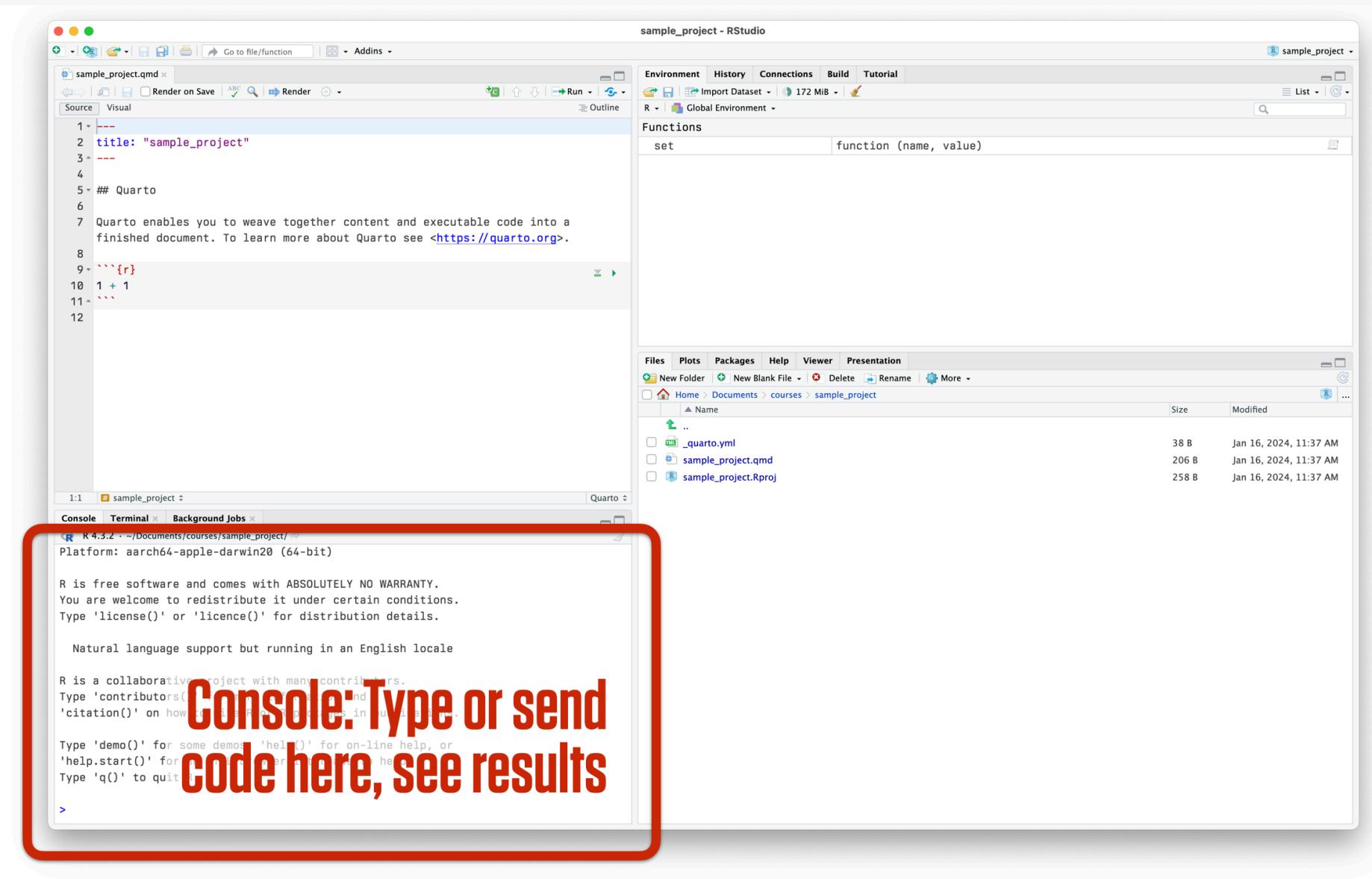
Our starting **data** + our **code** is what's “real”
in our projects, not the final output or any
intermediate objects



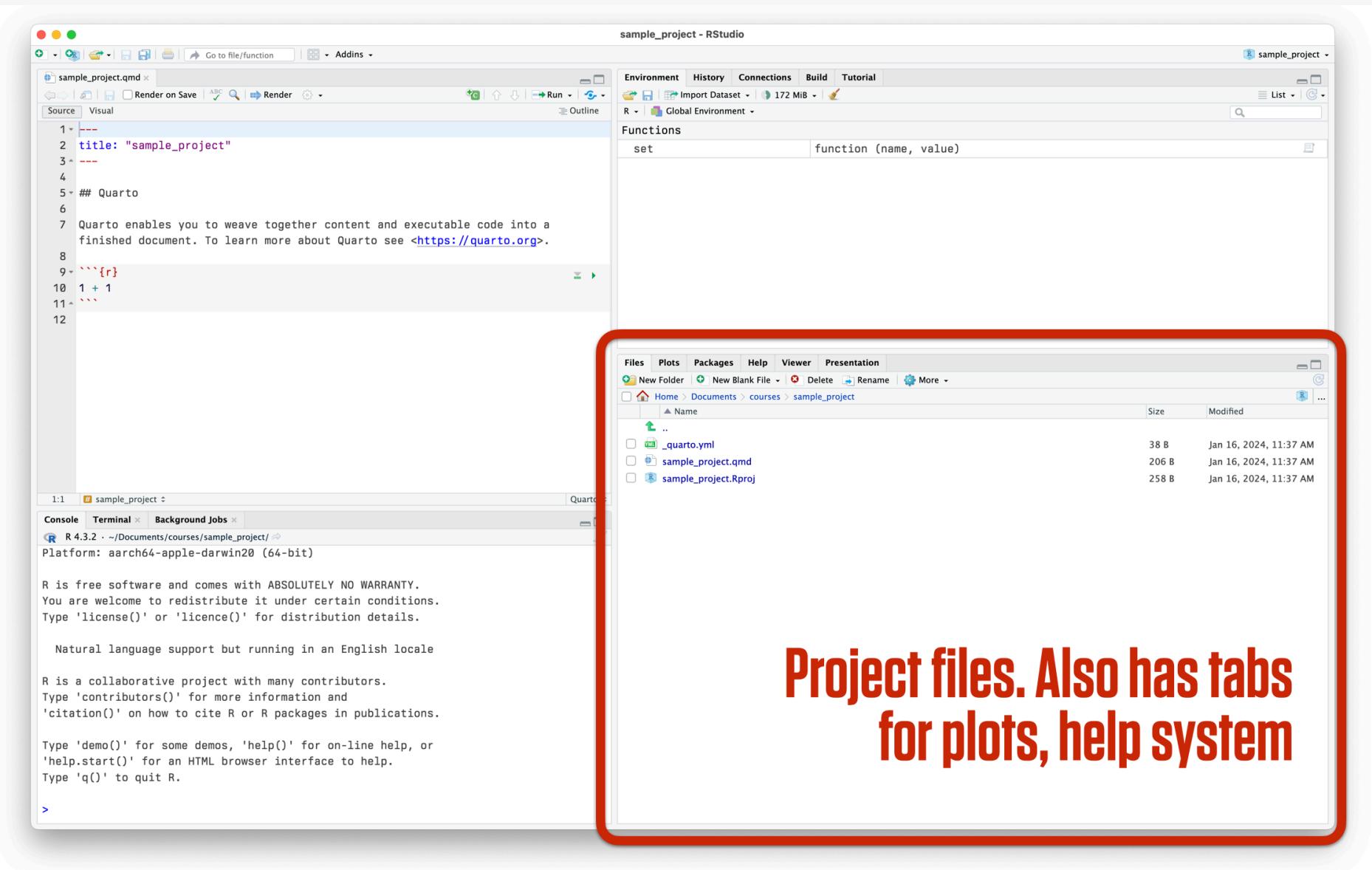
RStudio at startup



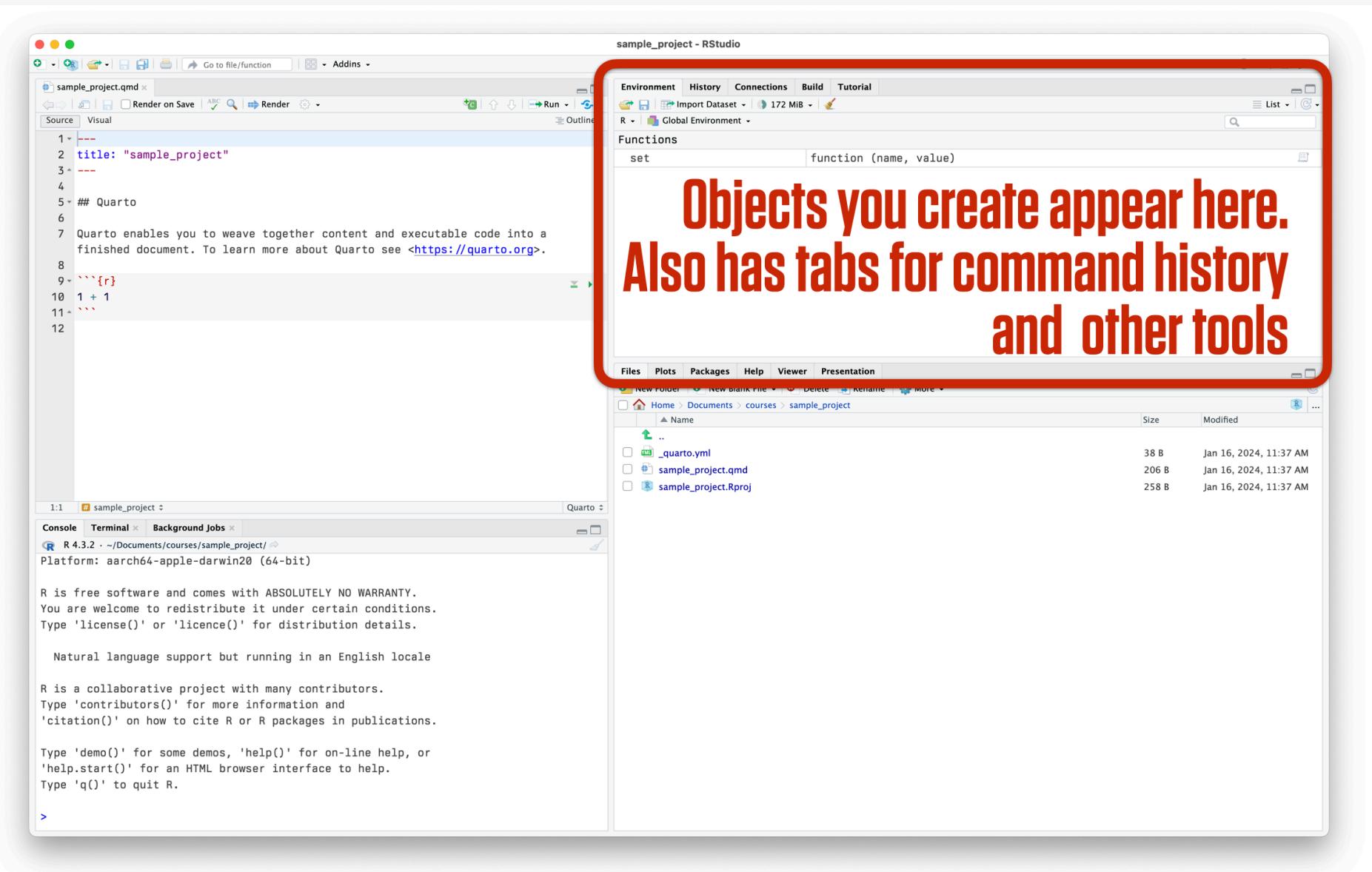
RStudio at startup



RStudio at startup

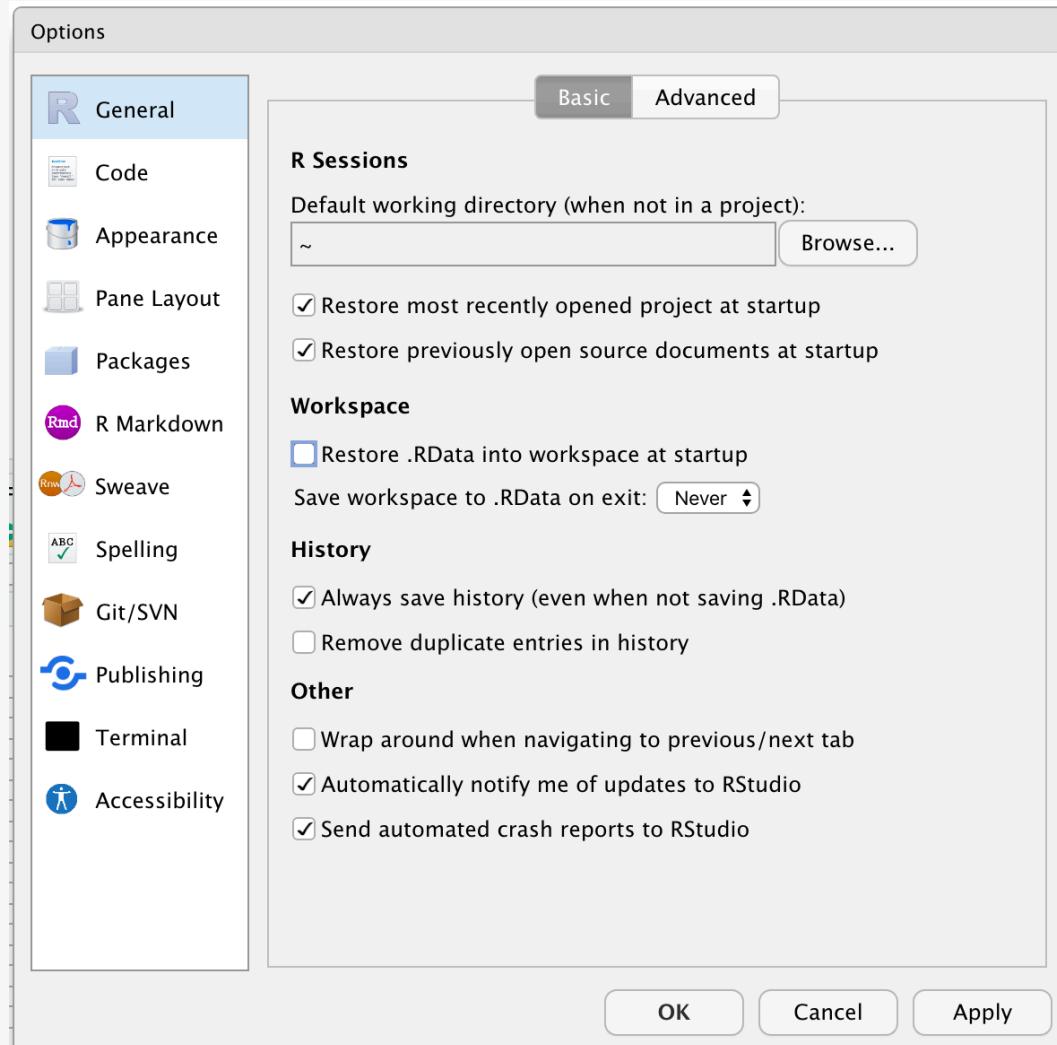


RStudio at startup

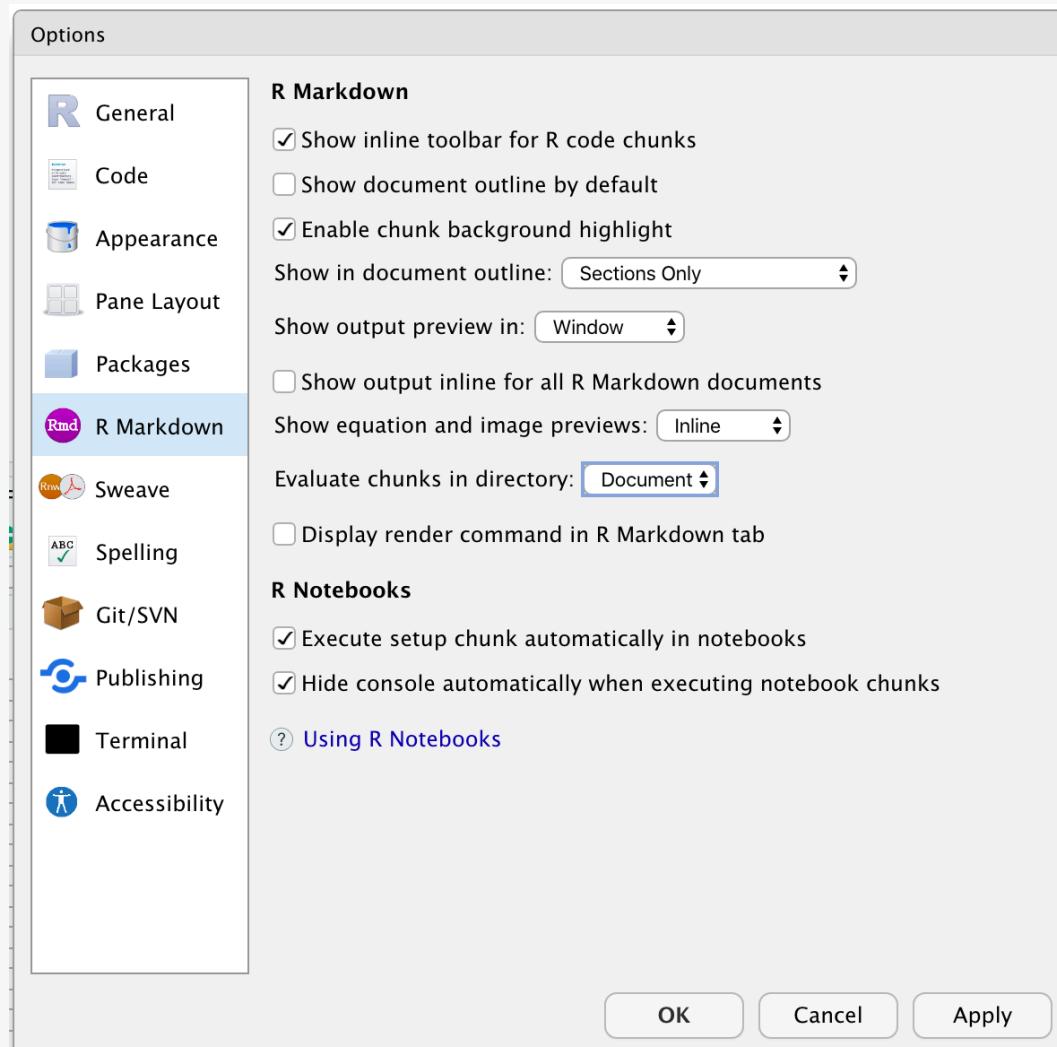


RStudio at startup

Your code is what's real in your project



Consider not showing output inline



Writing documents

Use Quarto to
produce and
reproduce your
work

Where we want to end up

Where we want to end up

Covid Cases

Kieran Healy

Introduction

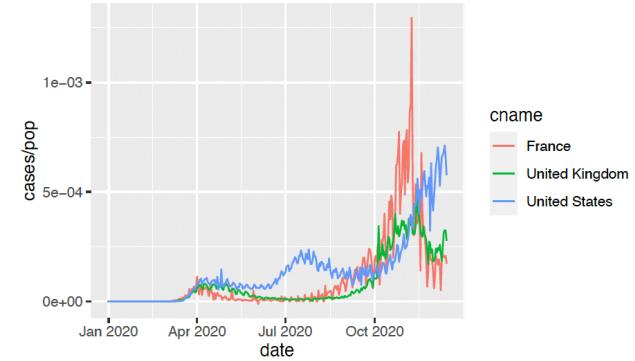
We will look at some data from the `covdata` package.

cname	cases
France	2376852
United Kingdom	1849403
United States	16256754

A little graph

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.

Daily COVID cases in 2020 for three countries



PDF out

Where we want to end up

Covid Cases

AUTHOR
Kieran Healy

Introduction

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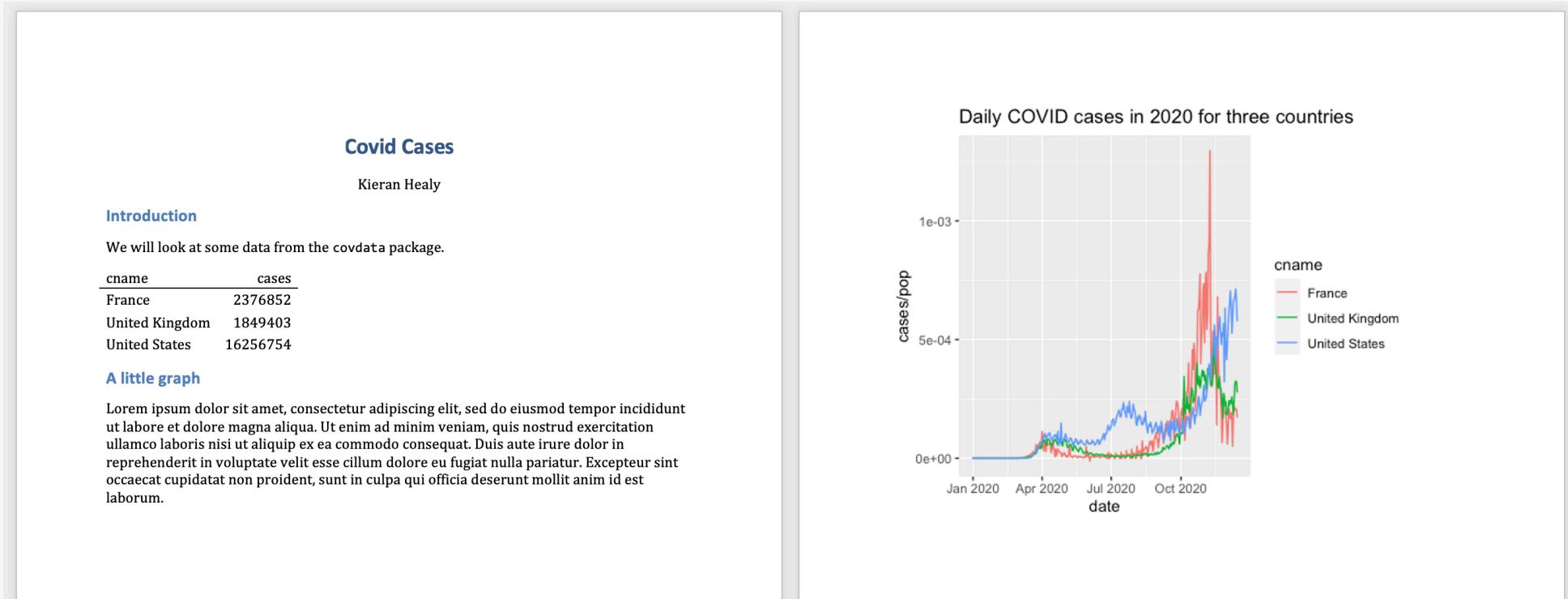
Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum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

Daily COVID cases in 2020 for three countries

The chart displays the daily COVID cases per capita for three countries in 2020. The y-axis represents 'cases/pop' on a logarithmic scale, ranging from 0e+00 to 1e-03. The x-axis represents the 'date' from January 2020 to October 2020. France (red line) shows a significant spike in late October, reaching approximately 1e-03 cases/pop. The United Kingdom (green line) and United States (blue line) also show a major increase in cases during the same period, with the US slightly higher than the UK. All three countries exhibit a general upward trend in cases throughout the year, with a notable peak in late 2020.

HTML out

Where we want to end up



Word out

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(...) +  
  geom_line(...)
```

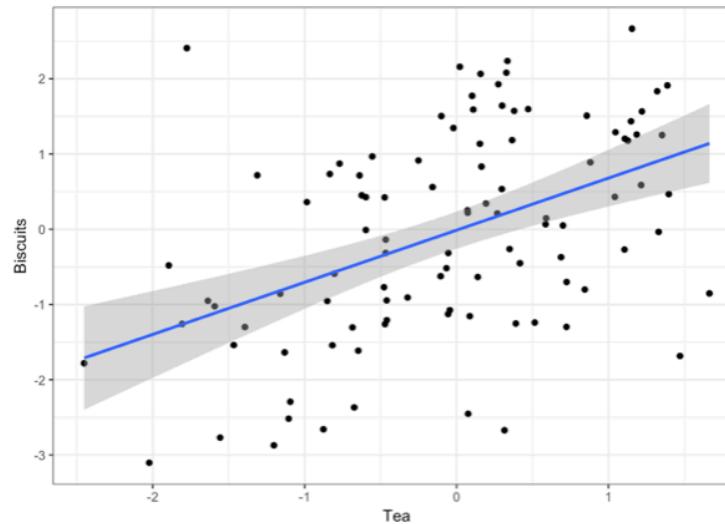
We could write an **R script** with some notes inside, using it to create some figures and tables, paste them into our document.

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.



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... by writing this

Lorem Ipsum

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 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)
```

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 cillum dolore eu fugiat nulla pariatur. Excepteur sint
 occaecat cupidatat non proident, sunt in culpa qui officia
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The code gets replaced by its output

Lorem Ipsum

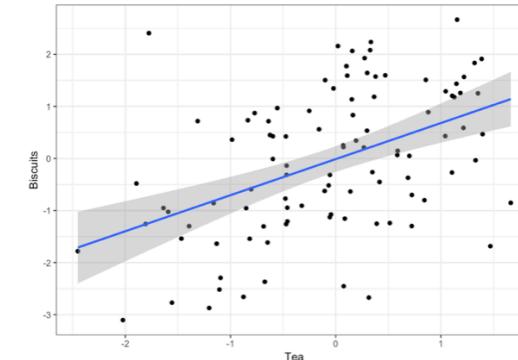
 Lorem ipsum dolor sit amet, consectetur adipisicing elit,
 sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enimad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat.

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```

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```
---
```

```
title: "Covid Cases"
author: "Kieran Healy"
format: html
```

```
---
```

```
```{r}
#| label: setup
#| echo: false
#| message: false

Don't include code chunks in the document
knitr::opts_chunk$set (echo = FALSE)

library(tidyverse)
library(covdata)

```
## Introduction

We will look at some data from the `covdata` package.
```

```
```{r}
#| label: data

covnat_daily %>
 filter(iso3 %in% c("USA", "GBR", "FRA")) %>
 group_by(cname) %>
 summarize(cases = sum(cases)) %>
 knitr::kable()
```
```

Markdown document

```
---  
title: "Covid Cases"  
author: "Kieran Healy"  
format: html  
---  
  
```{r}  
#| label: setup
#| echo: false
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Introduction

We will look at some data from the `covdata` package.

```{r}  
#| label: data  
  
covnat_daily %>  
  filter(iso3 %in% c("USA", "GBR", "FRA")) %>  
  group_by(cname) %>  
  summarize(cases = sum(cases)) %>  
  knitr::kable()  
```
```

Markdown document annotated

Header section with metadata

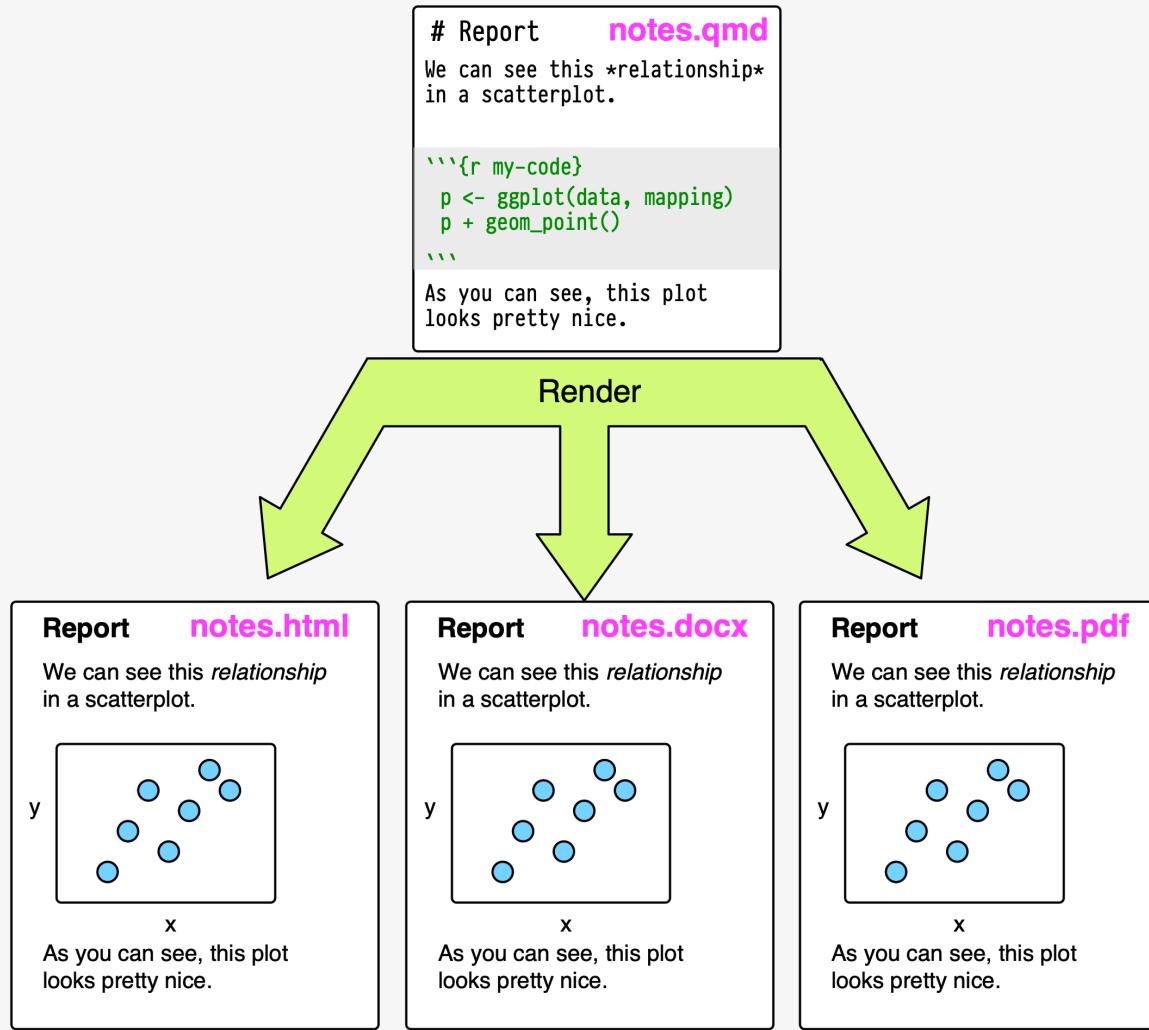
Chunks can have labels or options

Text with markdown formatting

When rendered, code chunks are replaced by their output

Code chunk (or cell)

Code chunks can be “played” one at a time



This approach has its limitations, but it's *very* useful and has many benefits.



# 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.                 |

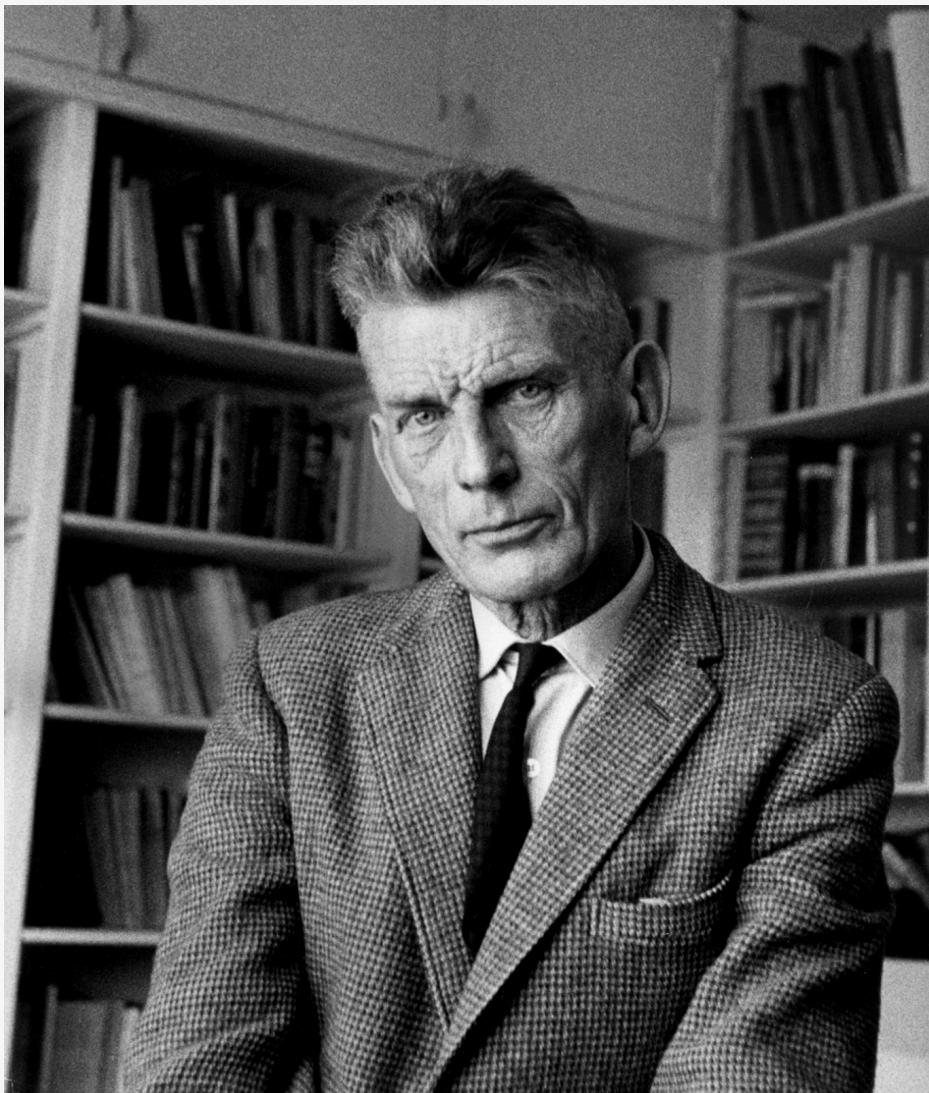
# The right frame of mind

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**



Samuel Beckett

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

Samuel Beckett,  
early data analyst

# GETTING ORIENTED

# Loading the tidyverse libraries

```
library(tidyverse)
-- Attaching core tidyverse packages ━━━━━━━━━━━━━━━━ tidyverse 2.0.0
✓ dplyr 1.1.4 ✓ readr 2.1.5
✓ forcats 1.0.0 ✓ stringr 1.5.1
✓ ggplot2 3.5.1 ✓ tibble 3.2.1
✓ lubridate 1.9.3 ✓ tidyr 1.3.1
✓ purrr 1.0.2
-- Conflicts ━━━━━━━━━━━━━━━━ tidyverse_conflicts()
✖ dplyr::filter() masks stats::filter()
✖ dplyr::lag() masks stats::lag()
ℹ Use the conflicted package to force all conflicts to become errors
```

The tidyverse has several components.

We'll return to this message about Conflicts later.

# Tidyverse components

```
library(tidyverse)
```

Call the package and ...

```
Loading tidyverse: ggplot2
```

◁ Draw graphs

```
Loading tidyverse: tibble
```

◁ Nicer data tables

```
Loading tidyverse: tidyr
```

◁ Tidy your data

```
Loading tidyverse: readr
```

◁ Get data into R

```
Loading tidyverse: purrr
```

◁ Fancy Iteration

```
Loading tidyverse: dplyr
```

◁ 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
```

```
log10(100)
```

```
[1] 2
```

# 0. It's a calculator

## Arithmetic

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(31 * 12) / 2^4
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[1] 5
```

```
log(100)
```

```
[1] 4.60517
```

```
log10(100)
```

```
[1] 2
```

## 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
```

```
4 < 2 | 1 < 0.5
```

```
[1] FALSE
```

# 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
```

# 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

# 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.

# 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 ::

```
A little glimpse of what we'll do soon
penguins %>
 count(species, sex, year) %>
 pivot_wider(names_from = year, values_from = n) %>
 tinytable::tt()
```

| species   | sex    | 2007 | 2008 | 2009 |
|-----------|--------|------|------|------|
| Adelie    | female | 22   | 25   | 26   |
| Adelie    | male   | 22   | 25   | 26   |
| Adelie    | NA     | 6    | NA   | NA   |
| Chinstrap | female | 13   | 9    | 12   |
| Chinstrap | male   | 13   | 9    | 12   |
| Gentoo    | female | 16   | 22   | 20   |
| Gentoo    | male   | 17   | 23   | 21   |
| Gentoo    | NA     | 1    | 1    | 3    |

# Remember those conflicts?

```
library(tidyverse)

— Attaching packages ————— tidyverse 1.3.0 —

✓ ggplot2 3.3.3 ✓ purrr 0.3.4
✓ tibble 3.1.0 ✓ dplyr 1.0.5
✓ tidyr 1.1.3 ✓ stringr 1.4.0
✓ readr 1.4.0 ✓forcats 0.5.1

— Conflicts ————— tidyverse_conflicts() —
x dplyr::filter() masks stats::filter()
x purrr::is_null() masks testthat::is_null()
x dplyr::lag() masks stats::lag()
x dplyr::matches() masks tidyR::matches(), testthat::matches()
```

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. Vector **types**; Object **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. Vector **types**; Object **classes**

Objects are made of one or more vectors. A vector can, in effect, have a single type: integer, double, logical, character, factor, date, etc. That is, vectors are “atomic”. Complex objects are mostly lists of vectors of different sorts, or nested lists of other simpler objects that are themselves ultimately made up of vectors of

# 5. Vector **types**; Object **classes**

The object inspector in RStudio is your friend.

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

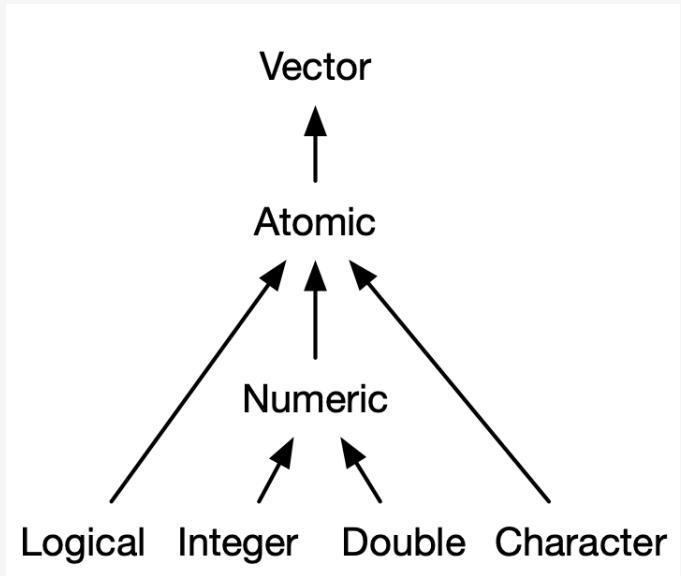
```
class(my_numbers)
```

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

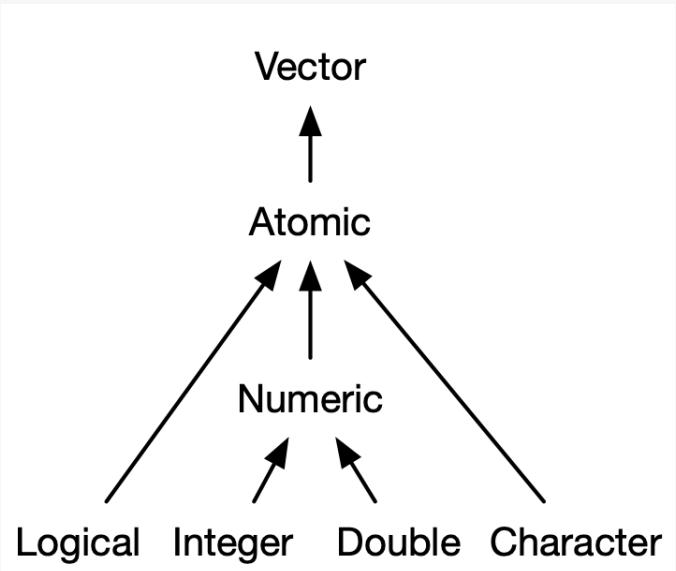
```
typeof(my_numbers)
```

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

# Types of vector



# Types 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
```

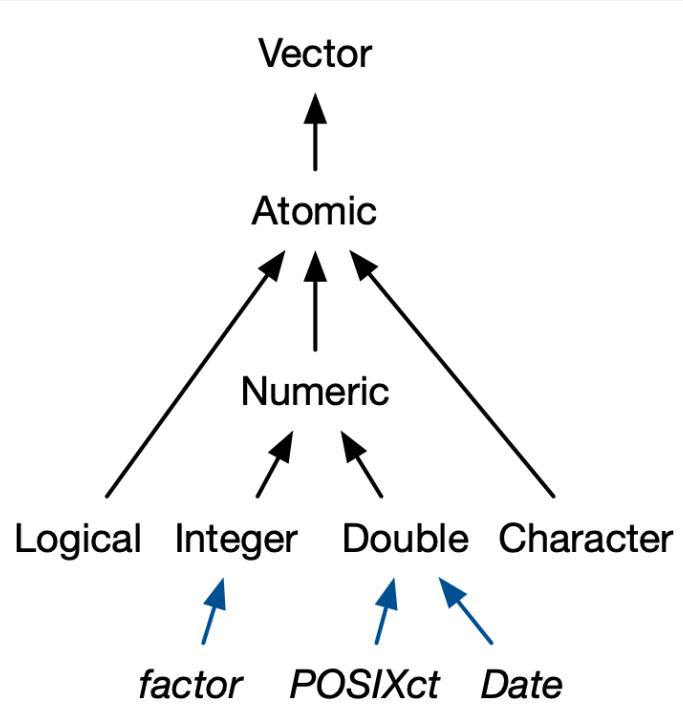
```
my_chr <- c("Mary", "had", "a", "little", "lamb")
is.character(my_chr)
```

```
[1] TRUE
```

```
my_lgl <- c(TRUE, FALSE, TRUE)
is.logical(my_lgl)
```

```
[1] TRUE
```

# Types 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"
$levels
[1] "Maybe" "No" "Yes"

$class
[1] "factor"
```

```
levels(x)
[1] "Maybe" "No" "Yes"
```

```
is.ordered(x)
[1] FALSE
```

# Vectors 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"
```

# Vectors 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 are collections of vectors of possibly different types and lengths, or collections of more complex objects that are themselves ultimately made out of vectors. Underneath, most complex R objects are some kind of list with different components that can be accessed by some function that knows the names of the things inside the list.

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 data frame is a natural representation of what most real tables of data look like. Having it be a basic sort of entity in the programming language **IS ONE OF R's BEST IDEAS AND EASILY UNDERRATED!**

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
```

```
[1] 62.0 5.7 16.7 15.6
```

# 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
```

```
[1] 62.0 5.7 16.7 15.6
```

## 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"
```

A data frame and a tibble are both fundamentally a list of vectors of the same length, where the vectors can be of different types (e.g. numeric, character, logical, etc)

# 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 Bach... 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 Bach... 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>,
bigregion <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
 40 ,
 41 mapping = aes(x = gdpPercap,
 42 y = lifeExp))
 43 |
```

```
39 p <- ggplot(data = gapminder,
40 mapping = aes(x = gdpPercap,
41 y = lifeExp)))
42 | unexpected token ')'
43 | \\\|
```

**Let's Go!**

# Time to make a plot

Like before:

```
gapminder
```

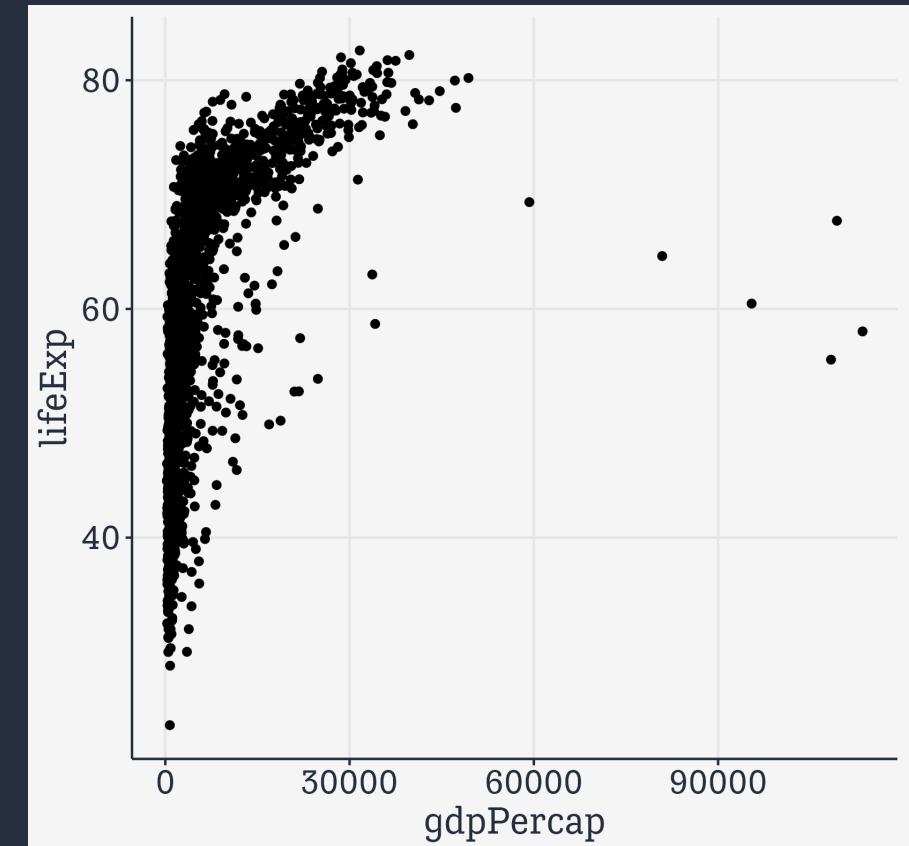
```
A tibble: 1,704 × 6
 country continent year lifeExp pop gdpPerCap
 <fct> <fct> <int> <dbl> <int> <dbl>
1 Afghanistan Asia 1952 28.8 8425333 779.
2 Afghanistan Asia 1957 30.3 9240934 821.
3 Afghanistan Asia 1962 32.0 10267083 853.
4 Afghanistan Asia 1967 34.0 11537966 836.
5 Afghanistan Asia 1972 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(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

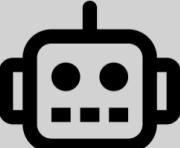
— Represent or Map

“continent” using colors

Just deal with these for me  
automatically for now, robot

scales coordinates  
plot\_env theme

bleep bloop



## Labels

— Label the x axis “GDP per Capita”

— Label the y axis “Life Expectancy”

— Label the color key “Continent”

The **p** object

Environment History Connections Git Tutorial

 Import Dataset |  297 MiB | 

R |  Global Environment

Data

 p List of 9

Functions

Peek in with the object inspector

The screenshot shows the RStudio object inspector for an object named 'p'. The top bar includes search, previous/next, and show attributes buttons. The table lists the components of 'p':

| 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: CoordCa...        | <environment: 0x11f8150c8>            |
| facet       | environment [2] (S3: FacetNul...       | <environment: 0x12a81ab00>            |
| plot_env    | environment [6]                        | <environment: R_GlobalEnv>            |
| labels      | list [2]                               | List of length 2                      |

Peek in with the object inspector

# Appendix: A Few More R Details

# Logic: 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!

# Logic: 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,

# Logic: 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.

# Assignment with =

You can use = as well as ← for assignment.

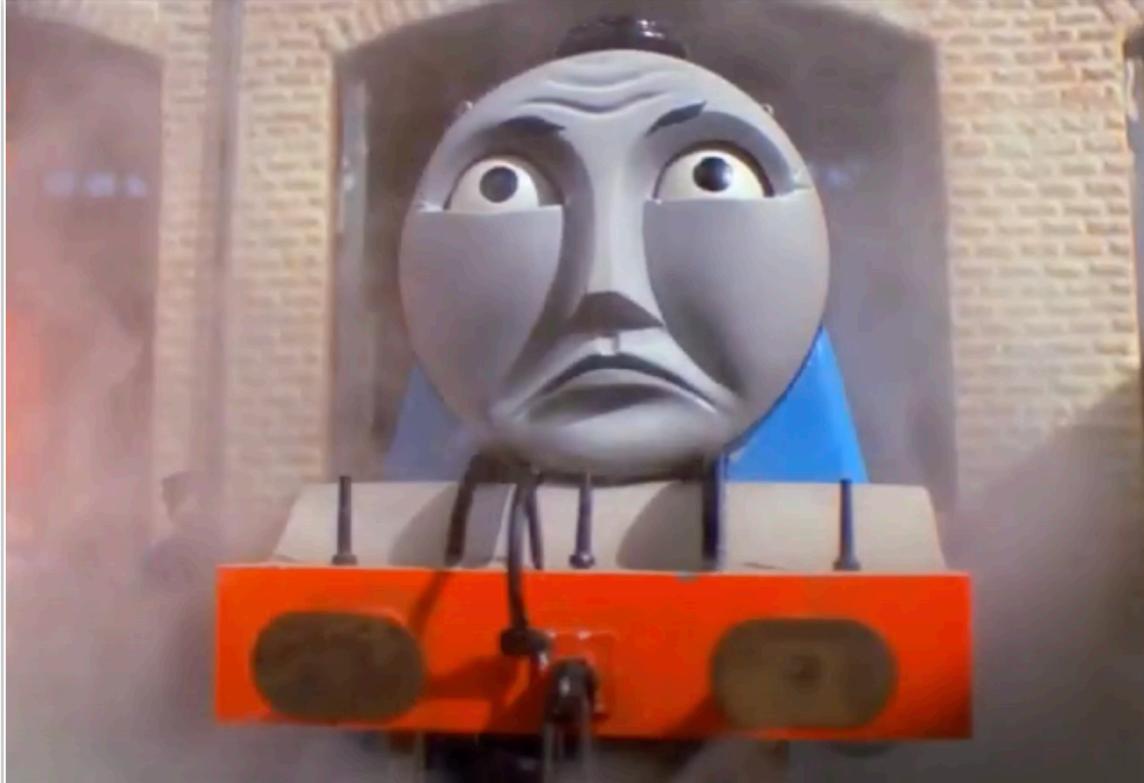
```
my_numbers = c(1, 2, 3, 1, 3, 5, 25)
my_numbers
[1] 1 2 3 1 3 5 25
```

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

# 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: %>%

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.

# 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. 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

# Object classes

Objects can have more than one (nested) class:

```
summary(my_numbers)
```

| Min.  | 1st Qu. | Median | Mean  | 3rd Qu. | Max.   |
|-------|---------|--------|-------|---------|--------|
| 1.000 | 1.500   | 3.000  | 5.714 | 4.000   | 25.000 |

```
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"
```

# Object 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."
```