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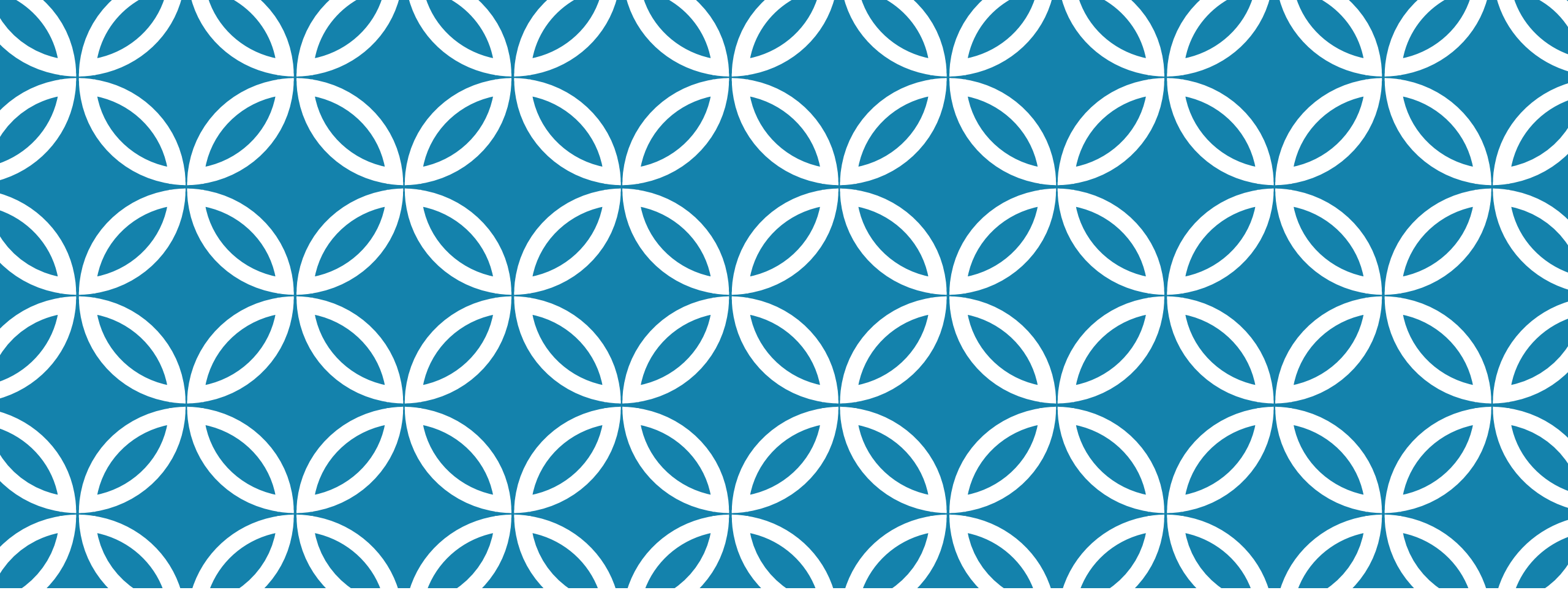
Introduction to R Workshop

August 16,23 2020



Introduction to R Workshop

Amrom Obstfeld

August 16, 2020

Course Introduction

Goals and Objectives

- Advocate for the use of R as a means of improving reproducibility in clinical data analysis
- Demonstrate how R is used to perform analyses of laboratory operational data
- Establish a basis of understanding in the 'tidy' approach to data analysis within the framework of R

Who are we?

Stephan Kadauke

Assistant Professor of Clinical Pathology and Laboratory Medicine

University of Pennsylvania Perelman School of Medicine

Assistant Director of the Cell and Gene Therapy Laboratory

Children's Hospital of Philadelphia

Daniel Herman

Assistant Professor of Pathology and Laboratory Medicine

University of Pennsylvania Perelman School of Medicine

Director, Endocrinology Laboratory

Hospital of the University of Pennsylvania

Amrom Obstfeld

Assistant Professor of Clinical Pathology and Laboratory Medicine

University of Pennsylvania Perelman School of Medicine

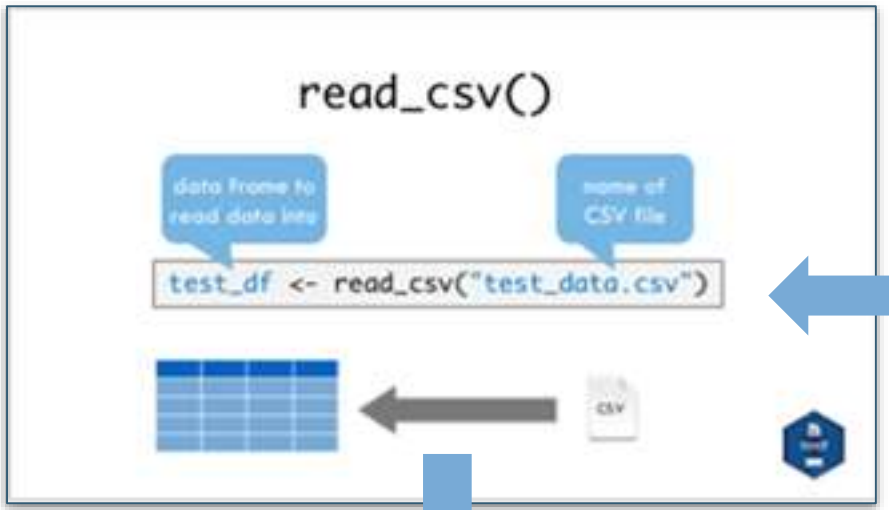
Director of Pathology Informatics

Children's Hospital of Philadelphia

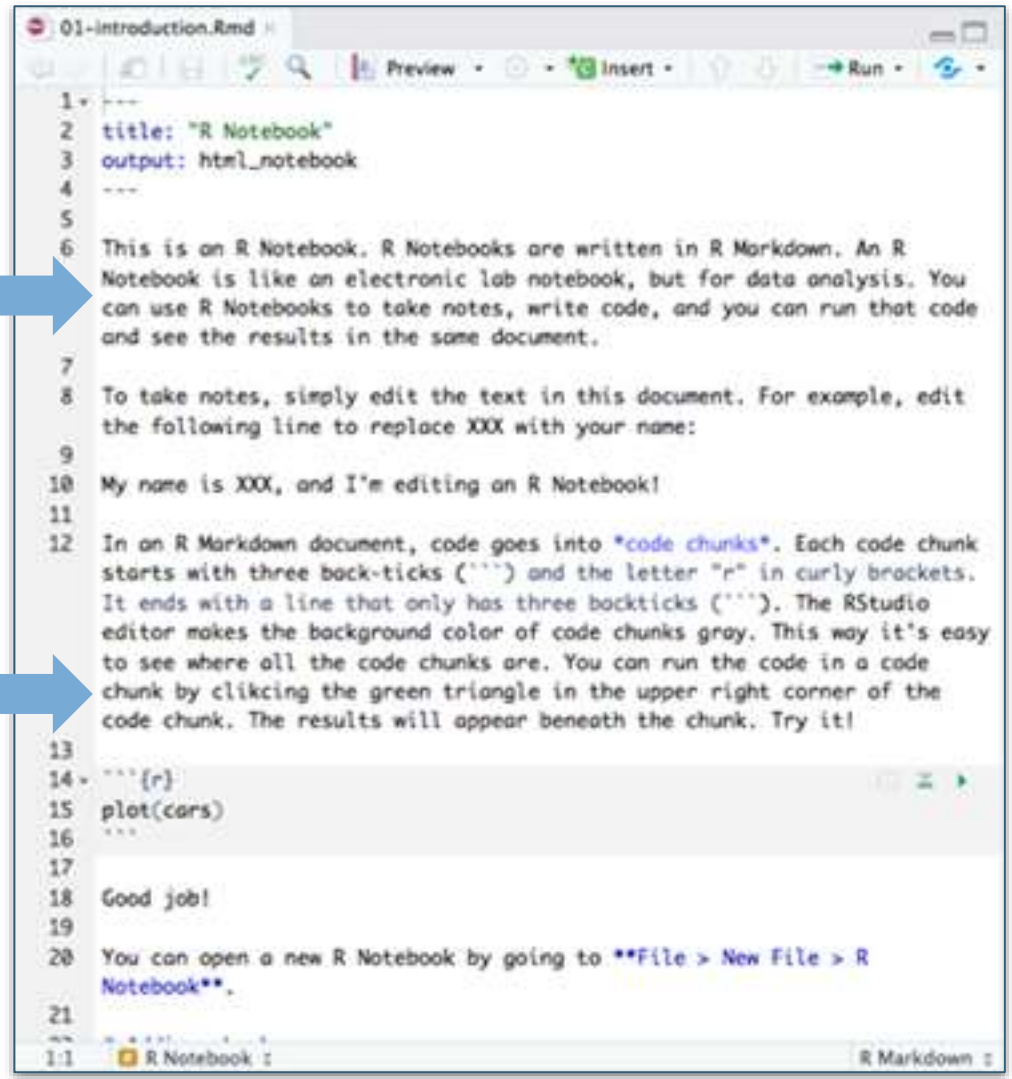
Workshop Workflow

August 16 2020	**Session**	**Instructor**
9:00 am - 9:30 am	Instructor Introductions, Introduction to technology	Amrom Obstfeld
9:30 am - 10:15 am	Introduction to R and RStudio	Amrom Obstfeld
10:30 pm - 11:15 am	Reproducible Reporting	Amrom Obstfeld
11:30 am - 1:00 am	Data Visualization	Stephan Kadauke
August 23 2020		
9:00 am - 10:30 pm	Data Transformation	Amrom Obstfeld
10:45 am - 12:15 pm	Statistical Analysis	Dan Herman
12:30 pm - 1:00 pm	Workshop Close out	Amrom Obstfeld

Sessions

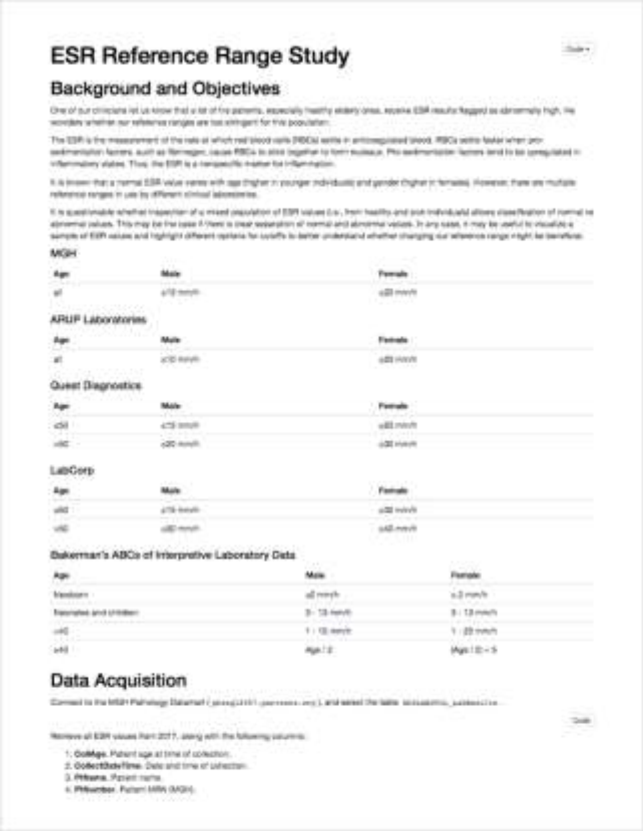

read_csv()
data frame to read data into
name of CSV file
test_df <- read_csv("test_data.csv")
csv

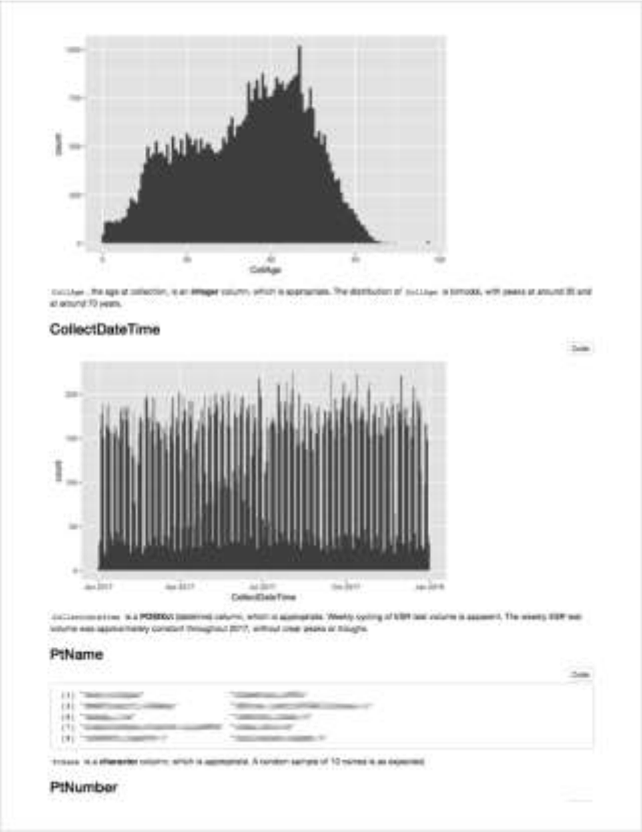

Your Turn
Introduce yourself to your neighbors
Who are you?
Where are you from?
What do you do with data?
Have you ever used R?
3:00


01-introduction.Rmd
Preview
Insert
Run
---
title: "R Notebook"
output: html_notebook

This is an R Notebook. R Notebooks are written in R Markdown. An R Notebook is like an electronic lab notebook, but for data analysis. You can use R Notebooks to take notes, write code, and you can run that code and see the results in the same document.
To take notes, simply edit the text in this document. For example, edit the following line to replace XXX with your name:
My name is XXX, and I'm editing an R Notebook!
In an R Markdown document, code goes into *code chunks*. Each code chunk starts with three back-ticks (```) and the letter "r" in curly brackets. It ends with a line that only has three backticks (```). The RStudio editor makes the background color of code chunks gray. This way it's easy to see where all the code chunks are. You can run the code in a code chunk by clikcing the green triangle in the upper right corner of the code chunk. The results will appear beneath the chunk. Try it!
```{r}
plot(cars)
```
Good job!
You can open a new R Notebook by going to **File > New File > R Notebook**.
R Notebook
R Markdown

Course Project



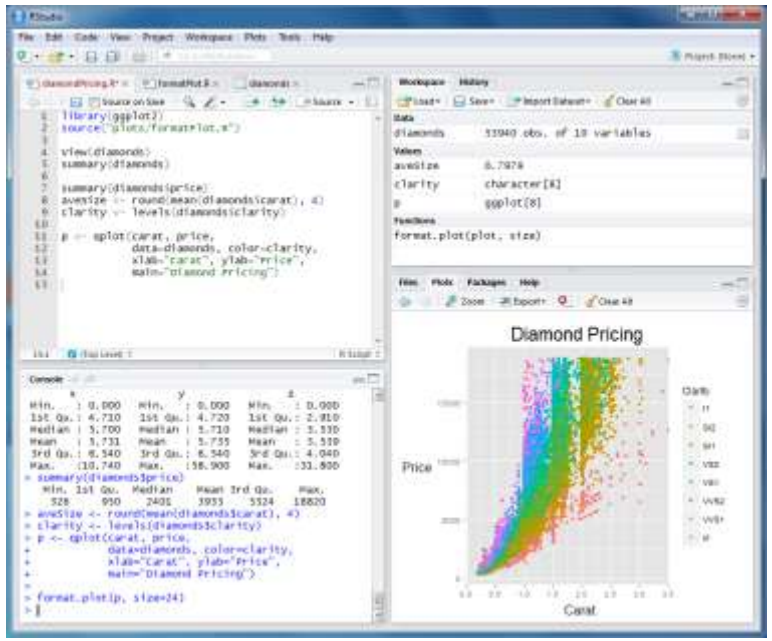


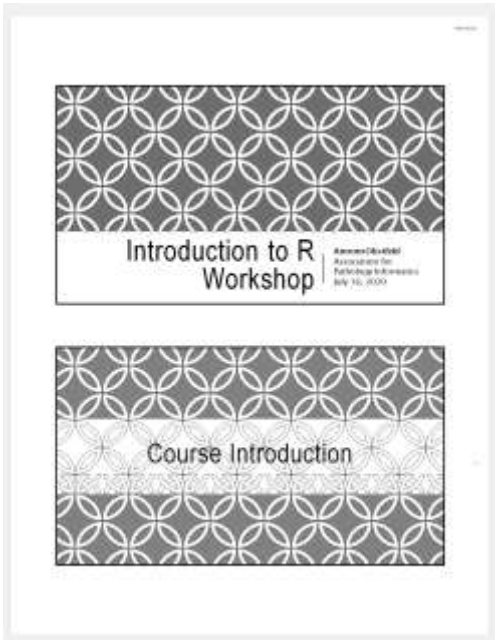
Hackathons

- Participants work with experienced R users on the course project
- Helps troubleshoot problems
- Practice collaborating on analytics projects

Your Setup


zoom


Diamond Pricing
Price
Carat


Introduction to R Workshop
Course Introduction


1


2

Workshop Coursebook

- Print out of all slides
- Appendix
  - Cheat sheets
  - Useful resources

Using Zoom

- Participants muted
- Chat window
- Non-verbal feedback
- Breakout sessions

Using Zoom

- Participants muted
- Chat window
- Non-verbal feedback
- Breakout sessions

om Meeting

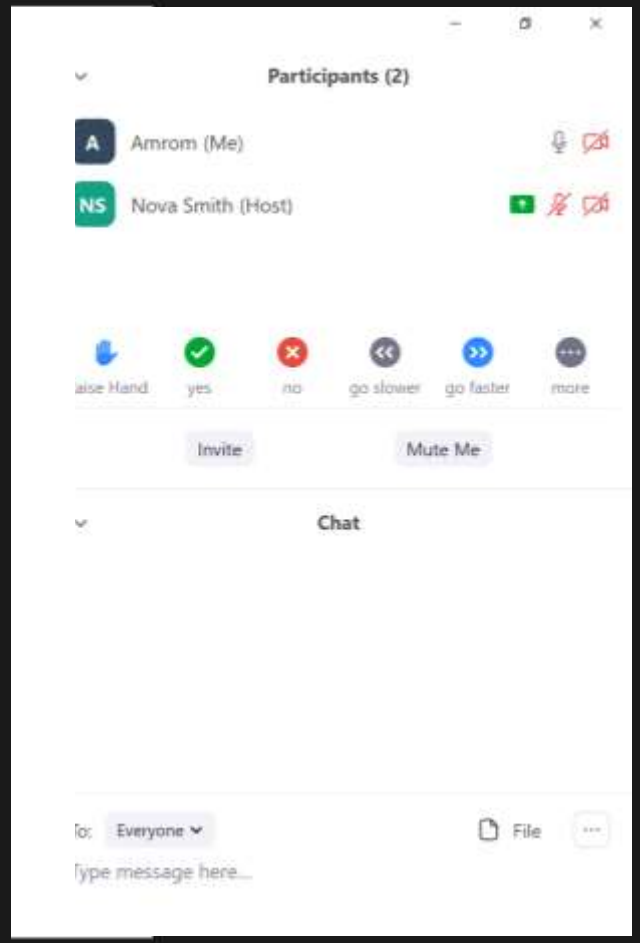
You are viewing Am Ob's screen

View Options

Amrom

Using Zoom

- Participants muted
- Chat window
- Non-verbal feedback
- Breakout sessions



mute

Start Video

2

Participants

Chat

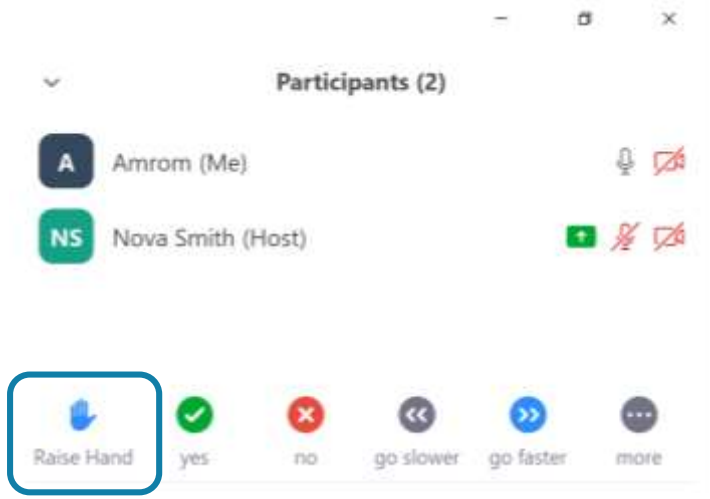
Share Screen

Record

Reactions

Leave

Getting Help



- During presentation – Raise hand, instructor will DM

- Break out sessions – Instructor available, unmuted

Who are you?

Your Turn

Introduce yourself!

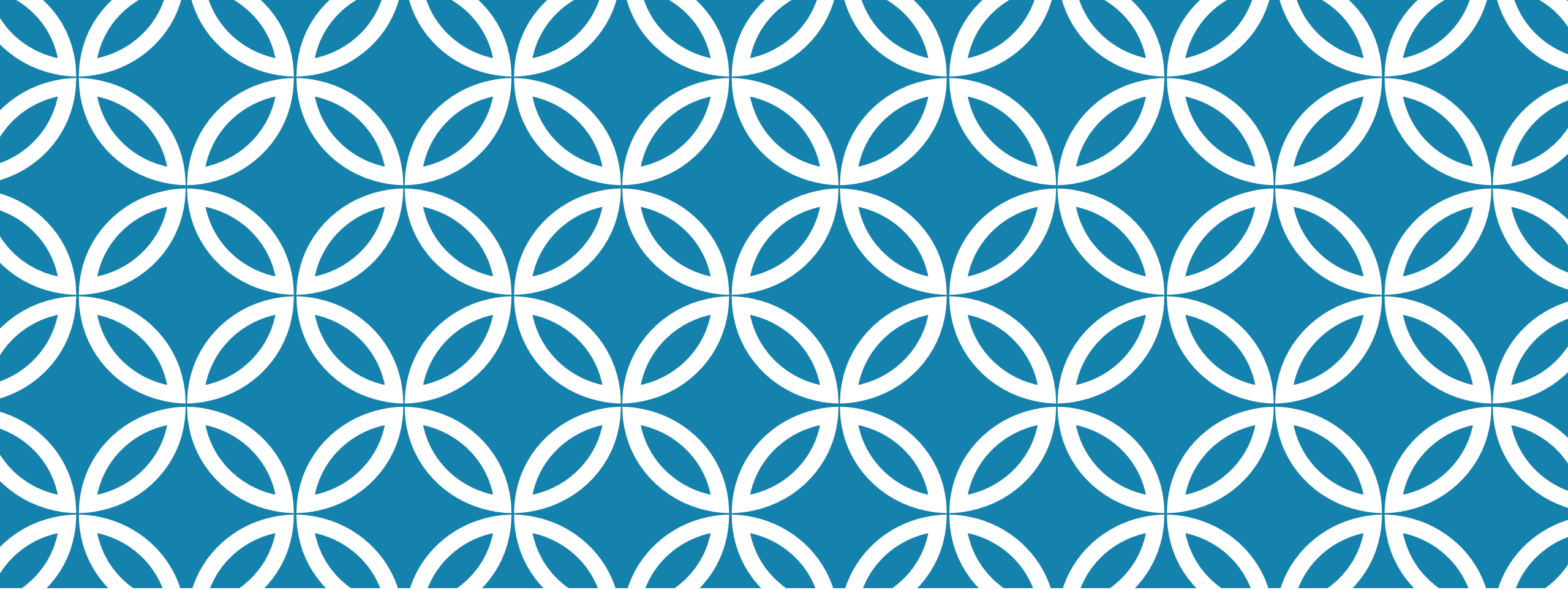
Who are you?
Where are you from?
Why are you here?
Have you ever used R?

When you need more help

- The Internet (Stack Overflow: https://stackoverflow.com/)
- Work Aids (RStudio Cheat Sheets: https://www.rstudio.com/resources/cheatsheets/)
- A Good Book (R for Data Science: http://r4ds.had.co.nz/)

Final Tips

- The best way to learn to code is by doing
- Practice is key!



Introduction to R and R Studio

Session 1
August 16, 2020
Amrom Obstfeld

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12:30 pm - 1:00 pm	Workshop Close out	Amrom Obstfeld

Lesson Goals

1. Get oriented to R and RStudio
2. Learn some fundamentals of coding

Lesson Objectives

1. Log in and tour RStudio Cloud
2. Execute code at the console
3. Define and use functions
4. Define and create objects in the environment
5. Load data into R and interact with a dataframe

Getting Oriented to R

What is R?

- R is a statistical programming language.
- Using R you can load, analyze, and visualize data.
- R also provides an environment in which we can conduct reproducible data analysis.
  - Documented
  - Revisable
  - Shareable

RStudio: The Portal to R

- RStudio is an integrated development environment (IDE)

- Using RStudio we can interact with the R programming language to:
  - Write and execute code interactively
  - View data
  - Debug and fix errors
  - Author our code

RStudio: In the Cloud… In Your Home

- RStudio Cloud: An online hosted version of RStudio that we will use for these course sessions

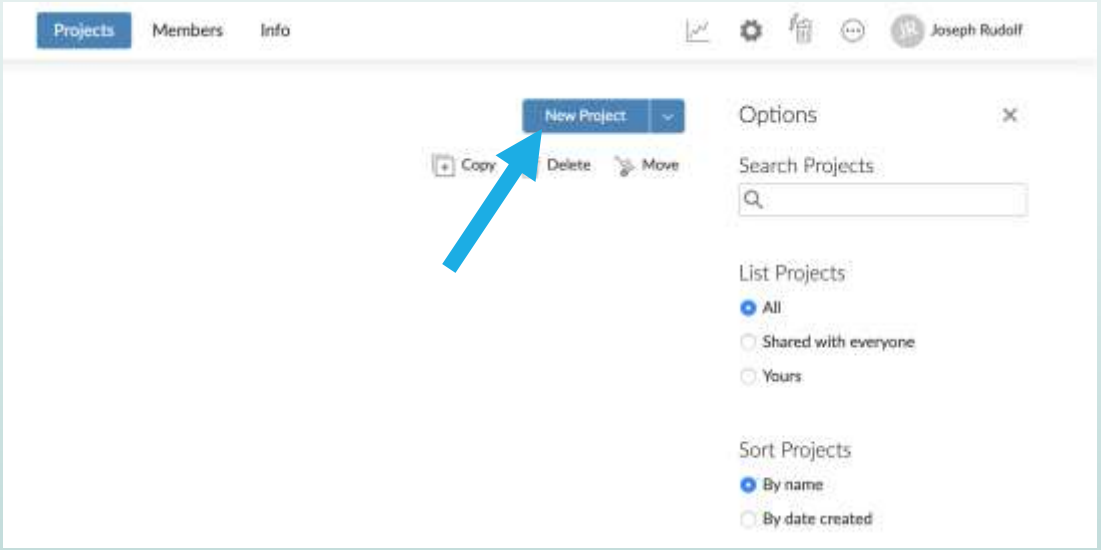
- RStudio Desktop: A locally installed version of RStudio that you will use when you get home to continue your learning

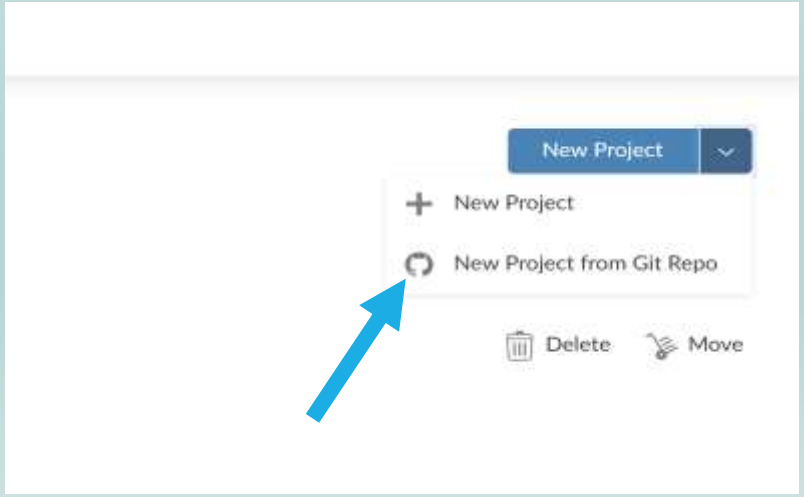
Note: Use Rstudio Cloud only for this course. Do not upload protected health information to the cloud!

Your Turn

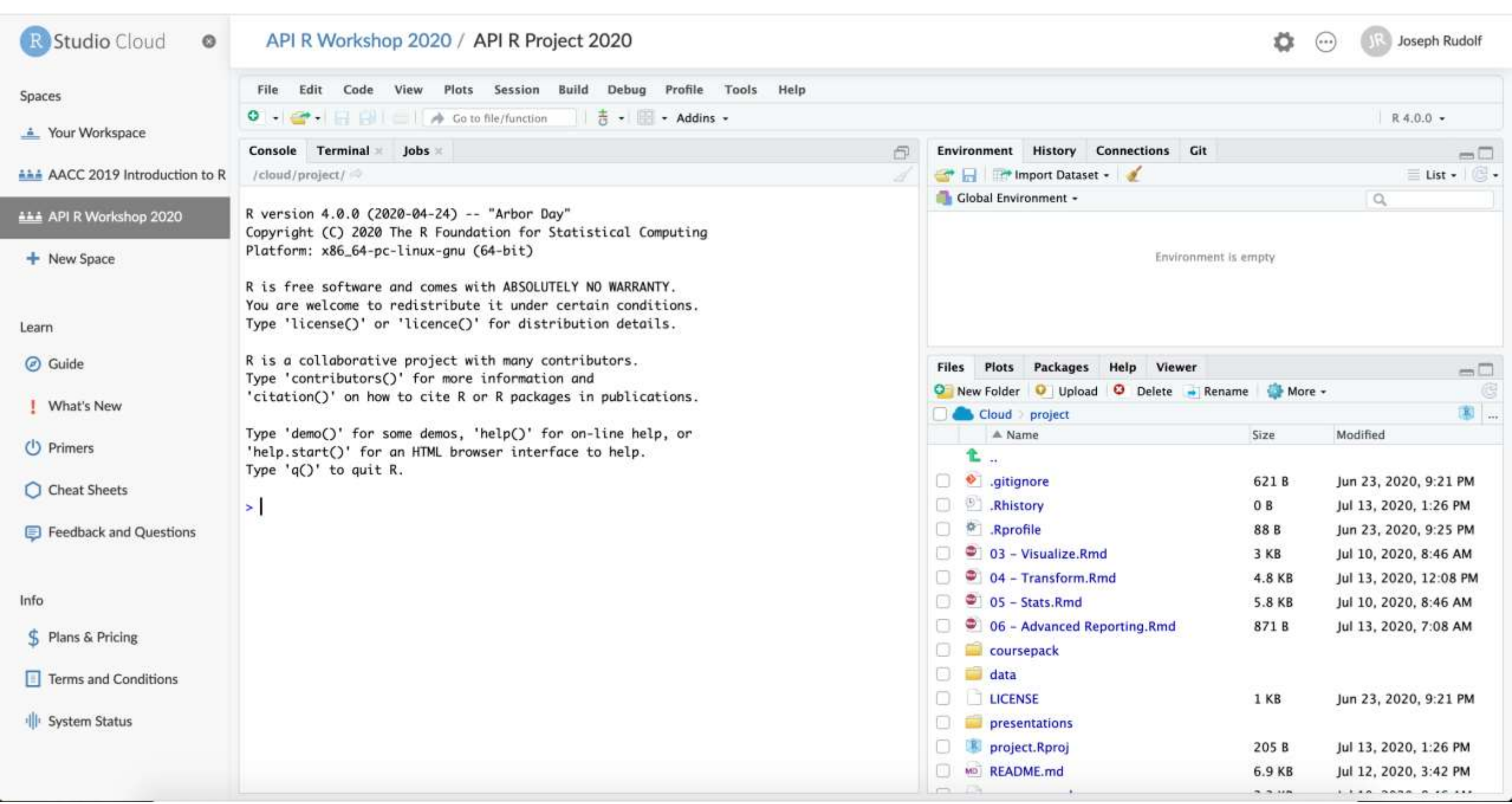
Navigate to:
rstudio.cloud

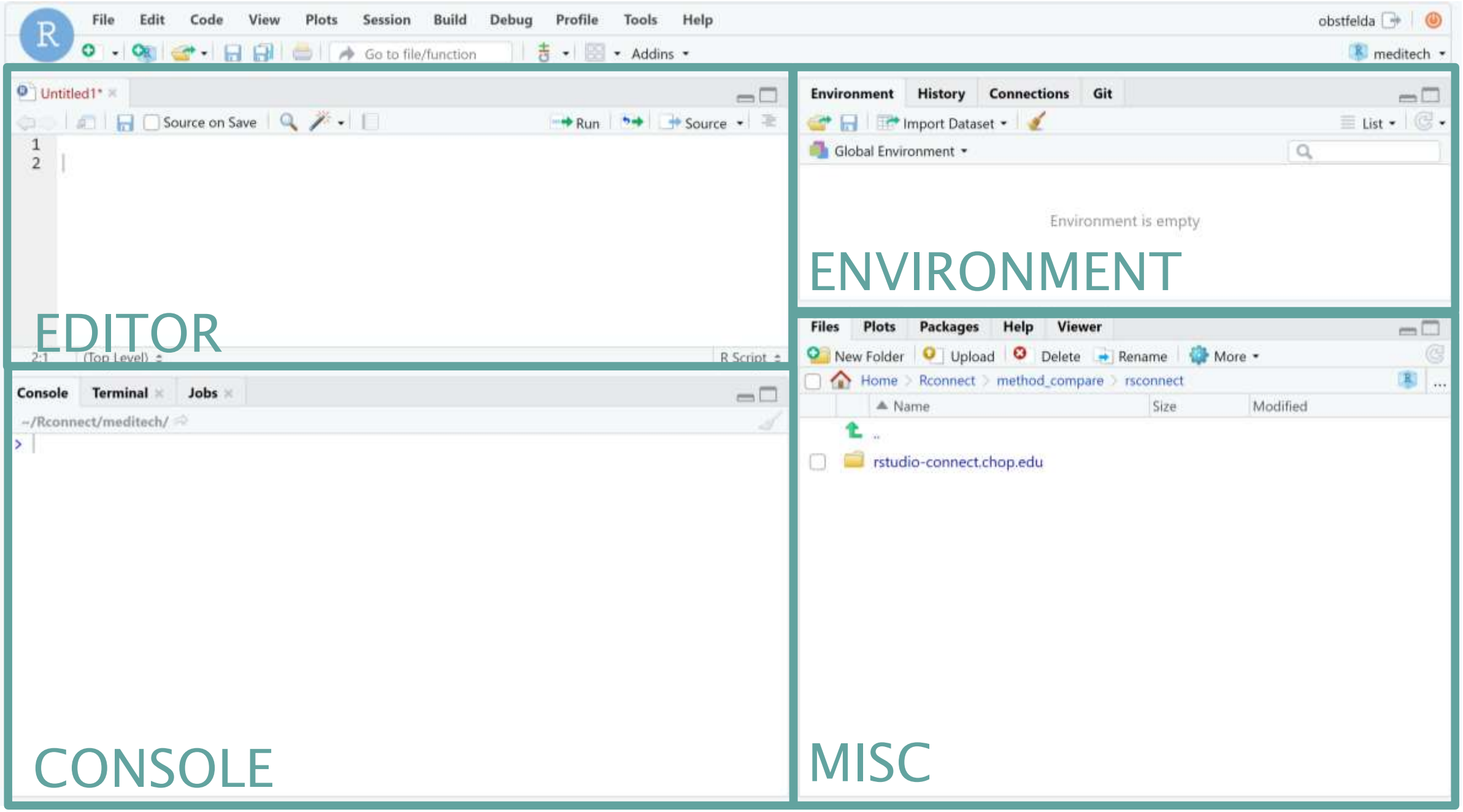
Register for an account





Type in this link at the prompt:
https://tinyurl.com/pennres2020

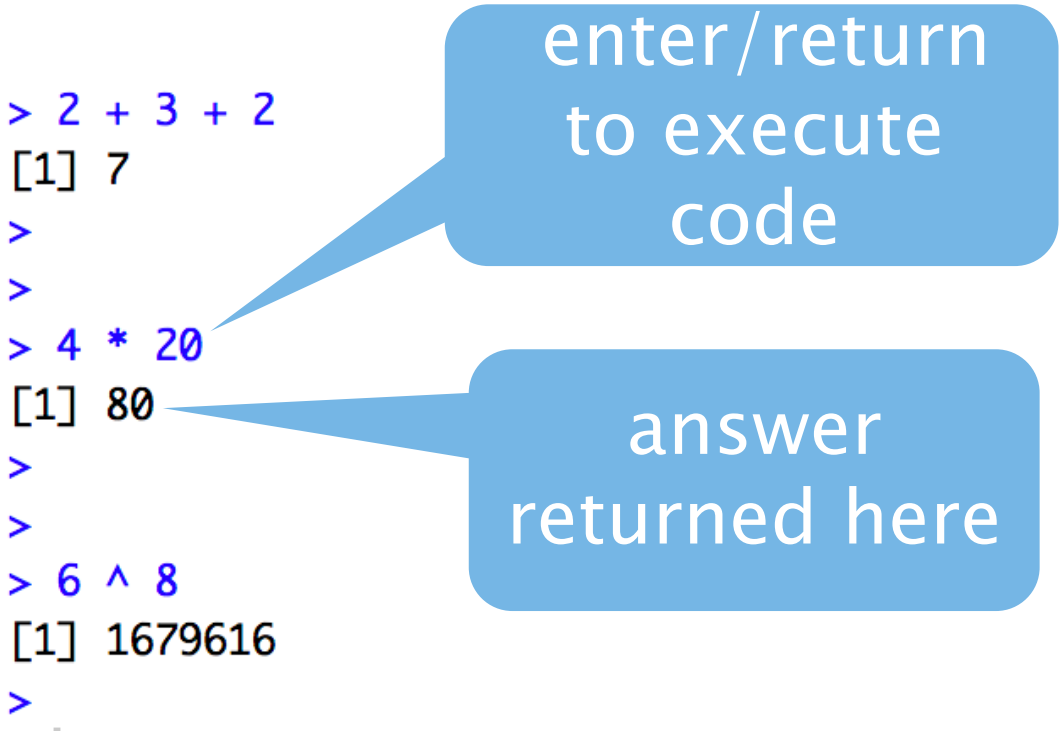

Studio Cloud
API R Workshop 2020 / API R Project 2020
Joseph Rudolf
Spaces
Your Workspace
AACC 2019 Introduction to R
API R Workshop 2020
New Space
Learn
Guide
What's New
Primers
Cheat Sheets
Feedback and Questions
Info
Plans & Pricing
Terms and Conditions
System Status
File Edit Code View Plots Session Build Debug Profile Tools Help
Go to file/function
Addins
R 4.0.0
Console Terminal Jobs
/cloud/project/
R version 4.0.0 (2020-04-24) -- "Arbor Day"
Copyright (C) 2020 The R Foundation for Statistical Computing
Platform: x86_64-pc-linux-gnu (64-bit)
R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.
R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.
Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.
>
Environment History Connections Git
Import Dataset
List
Global Environment
Environment is empty
Files Plots Packages Help Viewer
New Folder Upload Delete Rename More
Cloud project
Name Size Modified
..
.gitignore 621 B Jun 23, 2020, 9:21 PM
.Rhistory 0 B Jul 13, 2020, 1:26 PM
.Rprofile 88 B Jun 23, 2020, 9:25 PM
03 - Visualize.Rmd 3 KB Jul 10, 2020, 8:46 AM
04 - Transform.Rmd 4.8 KB Jul 13, 2020, 12:08 PM
05 - Stats.Rmd 5.8 KB Jul 10, 2020, 8:46 AM
06 - Advanced Reporting.Rmd 871 B Jul 13, 2020, 7:08 AM
coursepack
data
LICENSE 1 KB Jun 23, 2020, 9:21 PM
presentations
project.Rproj 205 B Jul 13, 2020, 1:26 PM
README.md 6.9 KB Jul 12, 2020, 3:42 PM


File Edit Code View Plots Session Build Debug Profile Tools Help
obstfelda
Go to file/function
Addins
meditech
Untitled1*
Source on Save
Run
Source
1
2
EDITOR
Environment History Connections Git
Import Dataset
List
Global Environment
Environment is empty
ENVIRONMENT
Console Terminal Jobs
~/Rconnect/meditech/
>
CONSOLE
Files Plots Packages Help Viewer
New Folder
Upload
Delete
Rename
More
Home > Rconnect > method_compare > rsconnect
Name
Size
Modified
..
rstudio-connect.chop.edu
MISC

The Basics of Coding

The Basics of Coding: Calculation

- R is a calculator!



Your Turn #1

Place your cursor at the console and click to enter the console.

Complete the following calculation:

-For the date 12-29-1974

-Take the four digit year

-Subtract the month then multiply by the day

What did you get?

- A four digit number? A five digit number?

```
> 1974 - 12 * 29
[1] 1626
>
>
> (1974 - 12) * 29
[1] 56898
```

- Order of operations matters!

The Basis of Coding: 3 Players

1. Functions
2. Arguments
3. Objects

The Basics of Coding: Functions

- Code that extends our reach beyond the basic operators

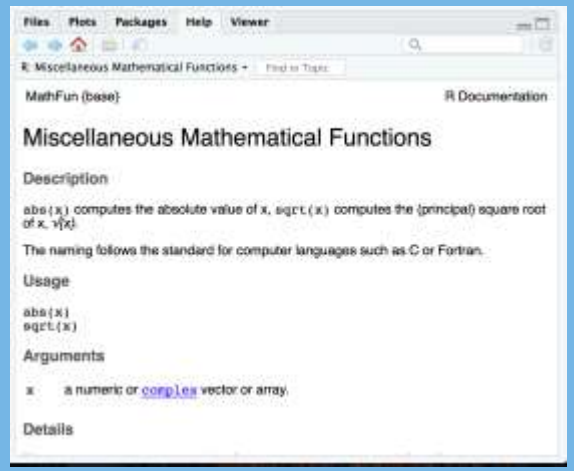
```
> abs(-77)
[1] 77
>
```

- What if I don't know what a function does?

```
> ?abs()
>
```

function
(does stuff)

abs(*-77*)



The Basics of Coding: Arguments

- The input that defines what the function should do

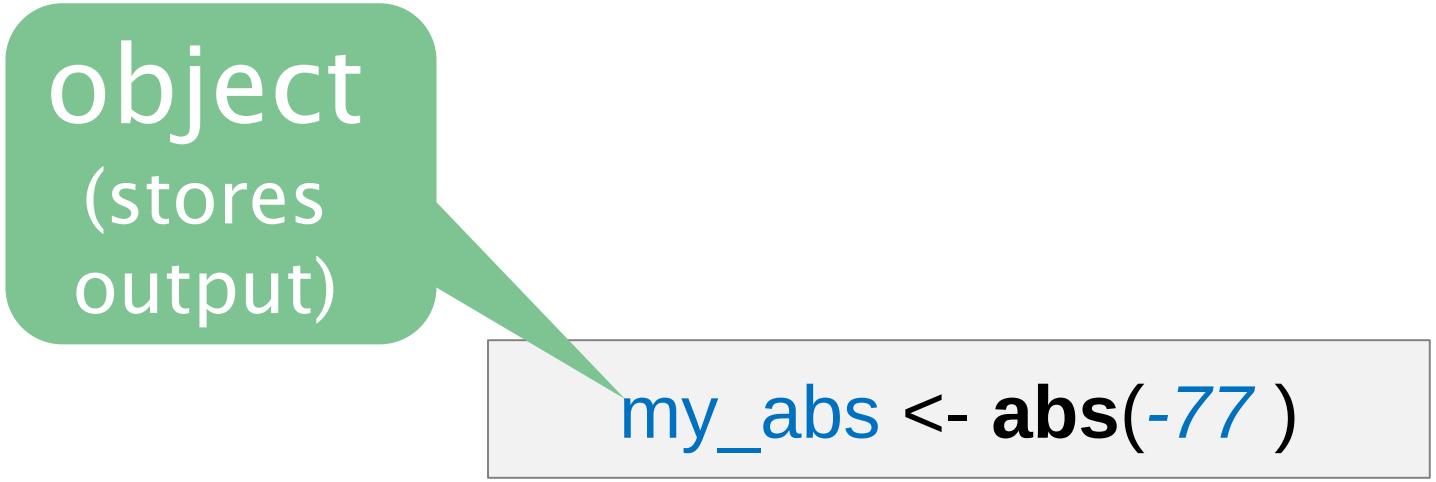
```
> abs(-77)
[1] 77
>
```

argument
(input)

abs(*-77*)

The Basics of Coding: Objects

- Objects are the container for your output



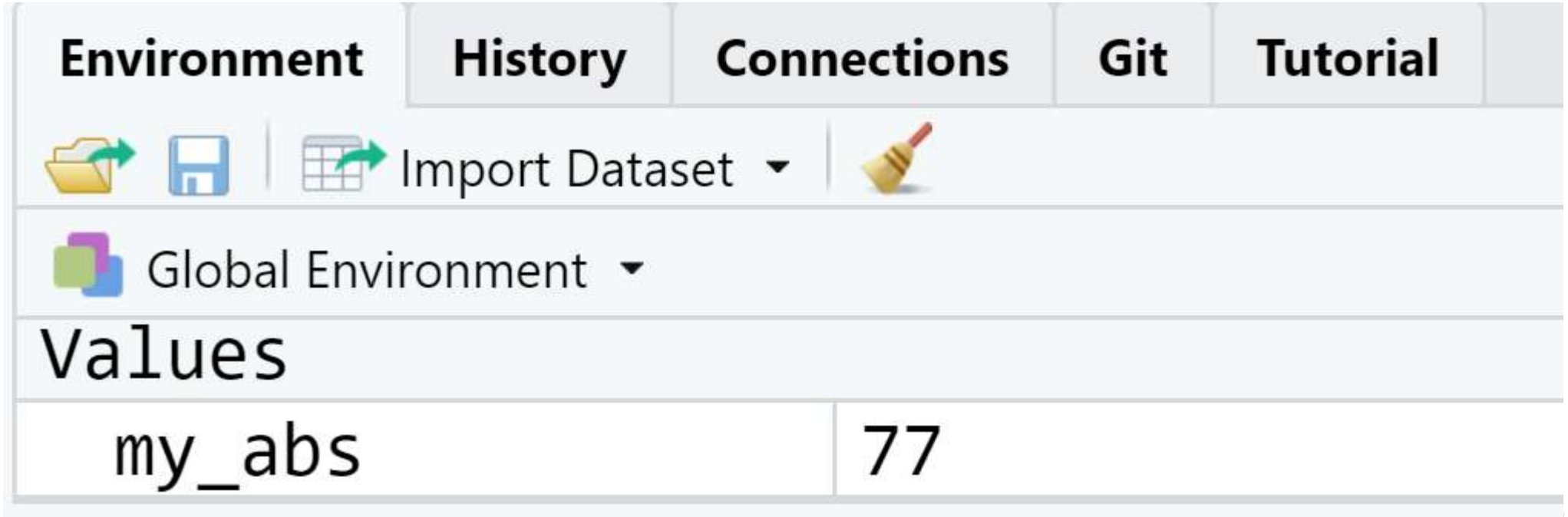
Checking the contents of an object

- Entering the object name at the console allows us to output the contents of an object.

```
> abs(-77)
[1] 77
> my_abs <- abs(-77)
> my_abs
[1] 77
> 
```

Checking the contents of an object

- The environment tab shows us the objects we have created.



Bending objects to your will

- Once we have created an object we can start to interact with it.
- This includes passing our objects to other functions… Whoa!

```
> log(my_abs,2)
[1] 6.266787
> 
```

Knowledge Check

Consider this code:.

```
mean_age <- mean(age, na.rm=TRUE)
```

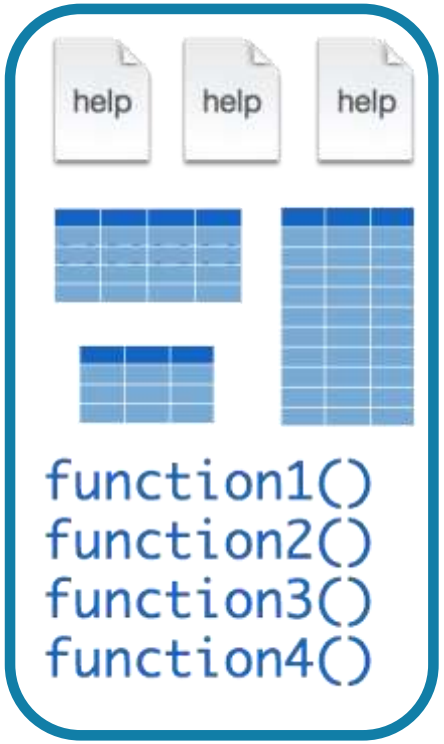
Which is the function?
Which is the argument?
Which is the objects?

The Basics of Coding: Packages

- A package is a collection of functions.
- Packages extend the capabilities of the base R programming language.
- The **tidyverse** includes functions for reading data into the R environment, cleaning and manipulating data, and plotting our results.

A Word About Packages

tidyverse



1

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

Downloads files to computer

1 x per computer

2

```
library("tidyverse")
```

Loads package

1 x per R Session

Your Turn #2

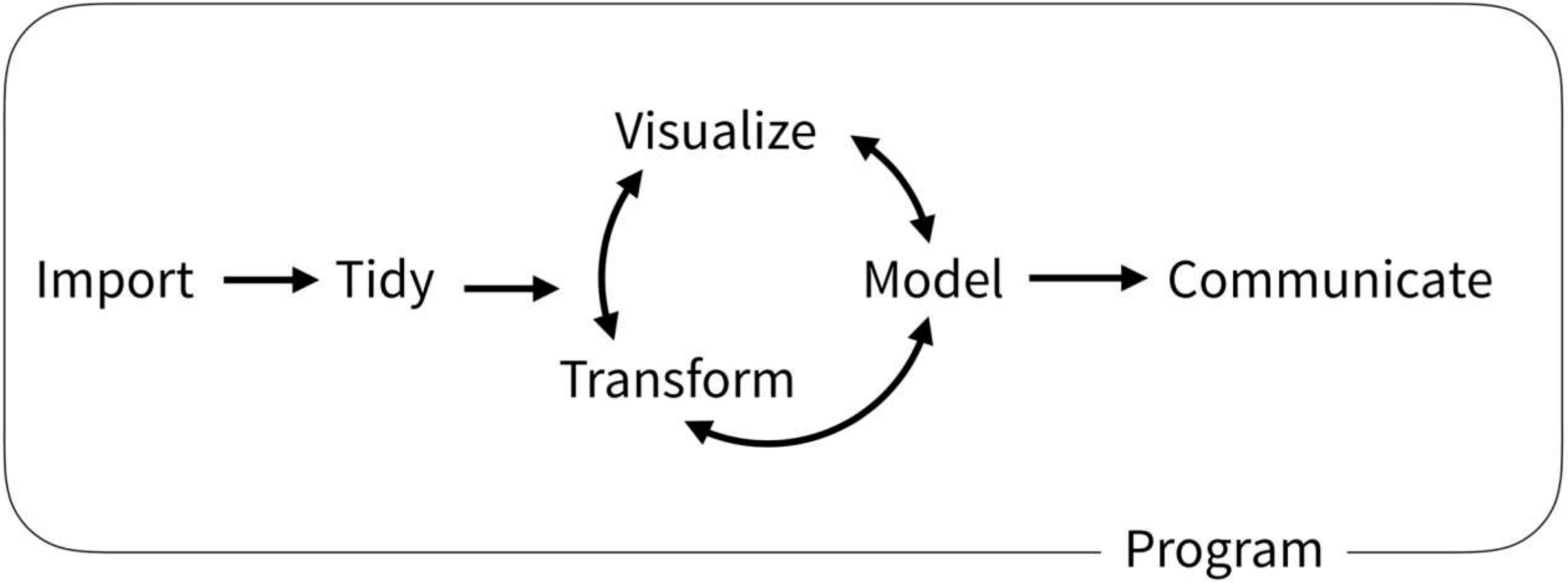
Run the following in the console:

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

```
library("tidyverse")
```

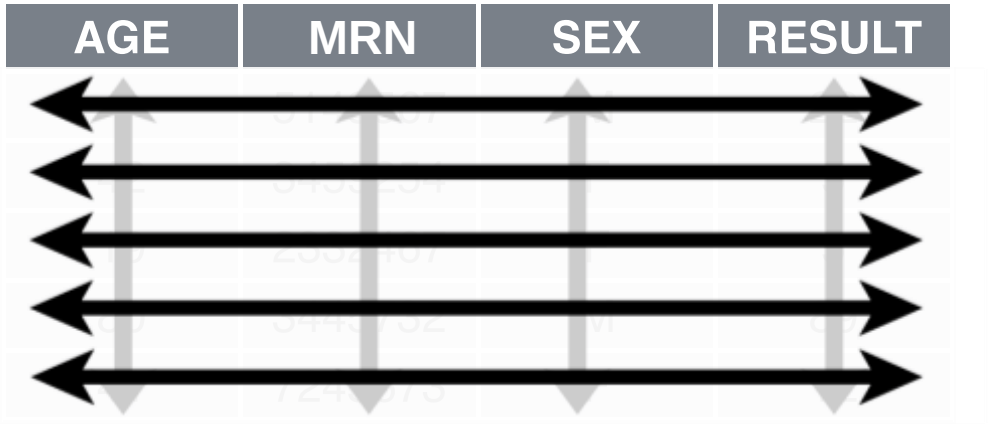
The Data Analysis Process

Typical Data Analysis Pipeline



From *R for Data Science*

What is a “Tidy” Data Frame

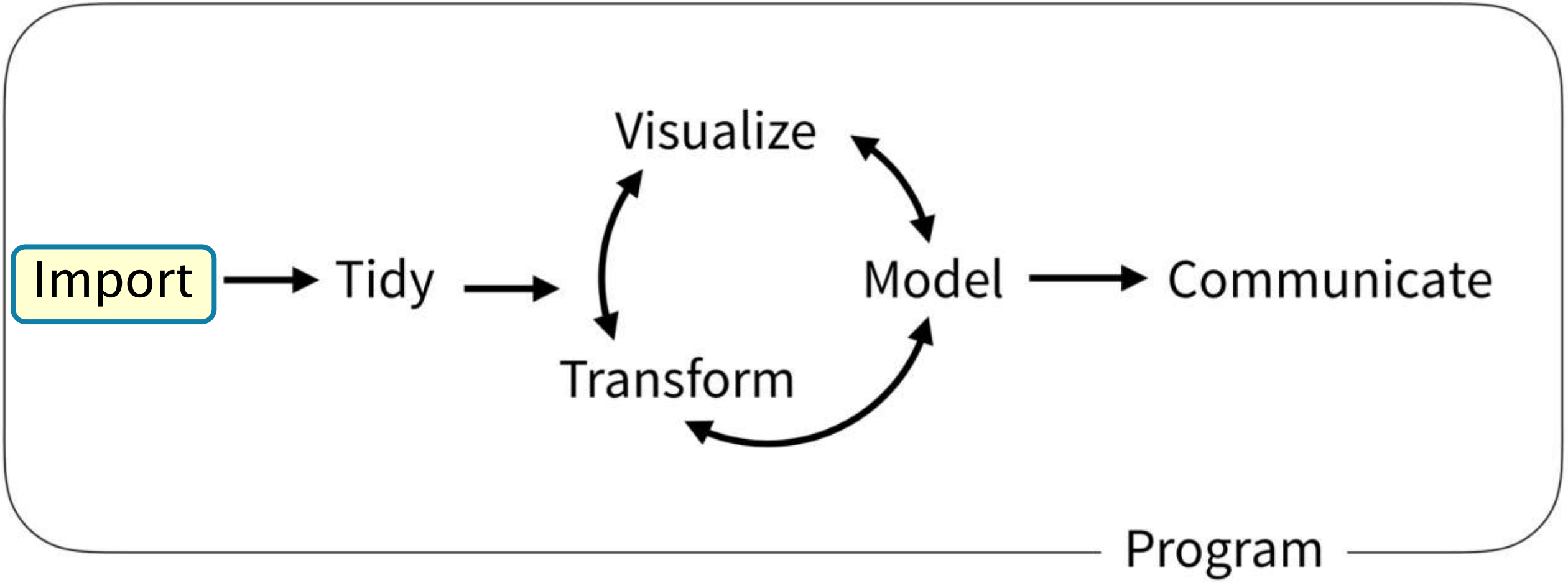


A data set is **tidy** if:

1. Each variable is in its own column
2. Each observation is in its own row
3. Each value is in its own cell

Importing Data

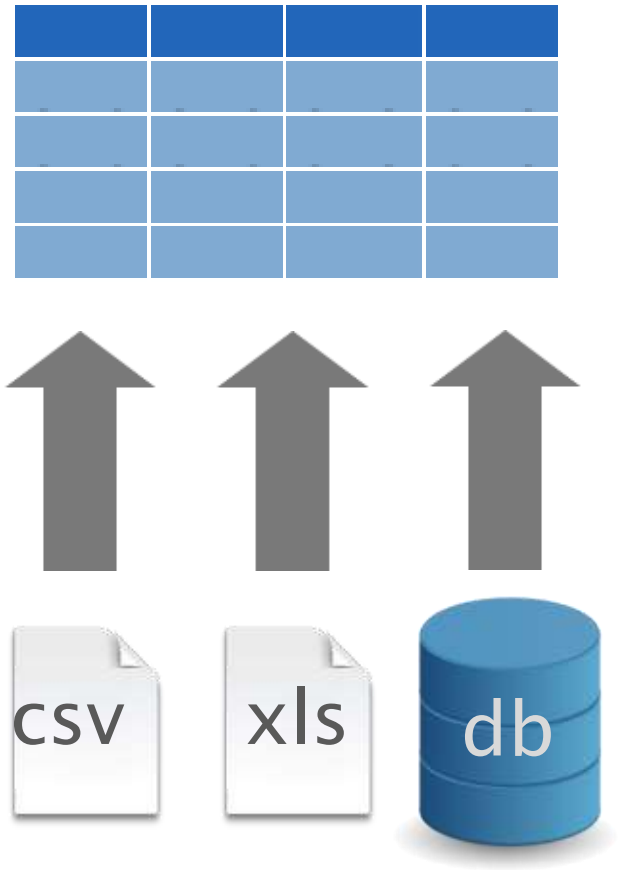
Typical Data Analysis Pipeline



From *R for Data Science*

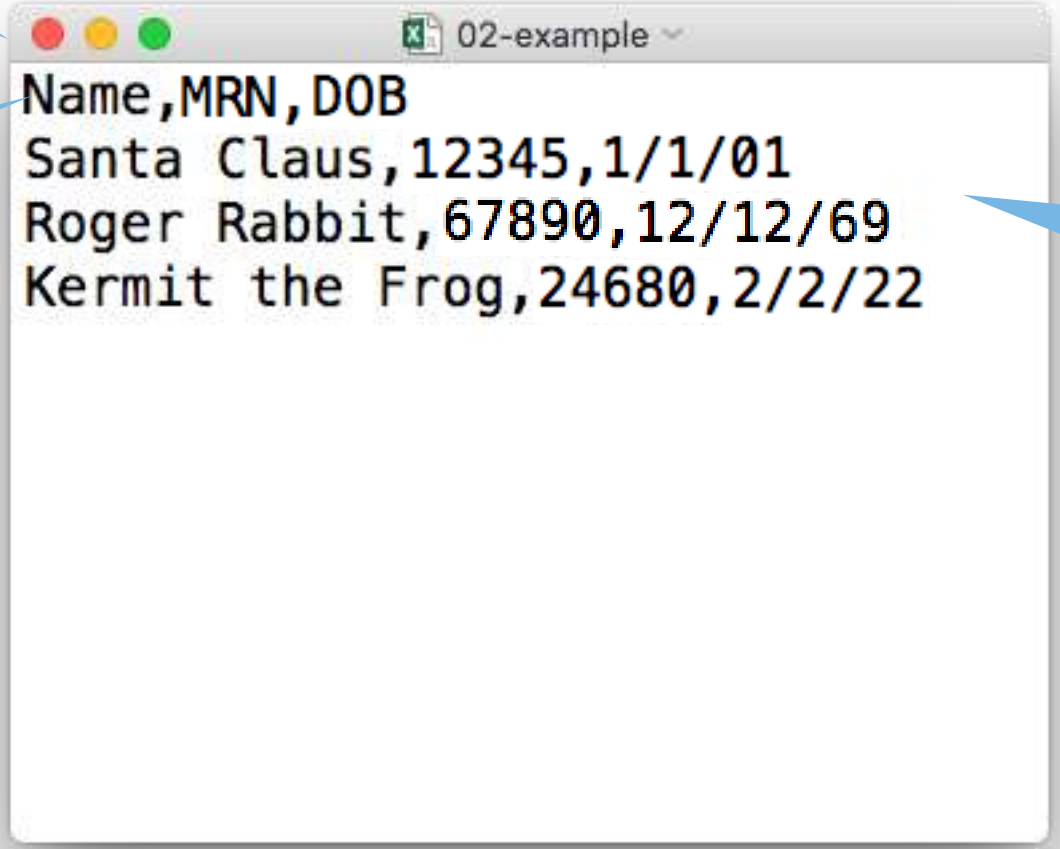
Dataframes: Beyond the Vector

- Dataframe is the term for a table
- Dataframes are composed:
  Columns (Variables)
  Rows (Observations)
- Dataframes are objects and can be acted on like other objects



plain text ("flat") file

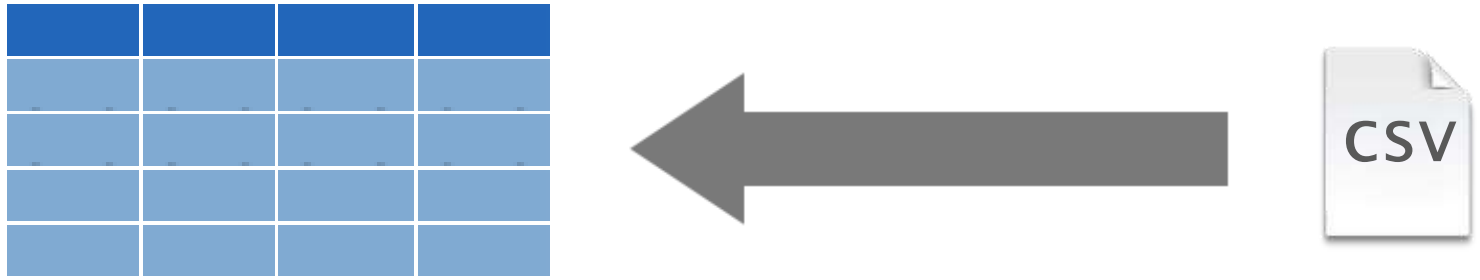
header row



rectangular structure

Loading Data to Create a Dataframe

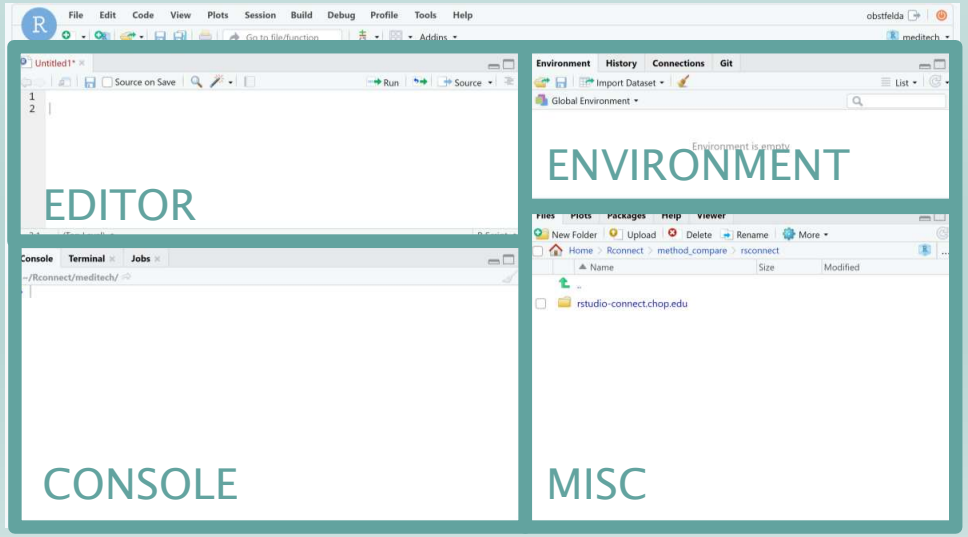
```
data_frame <- read_csv("file_name")
```



Memory Check

After reading in data using code such as this, where will you the data appear?

```
data_frame <- read_csv("file_name")
```

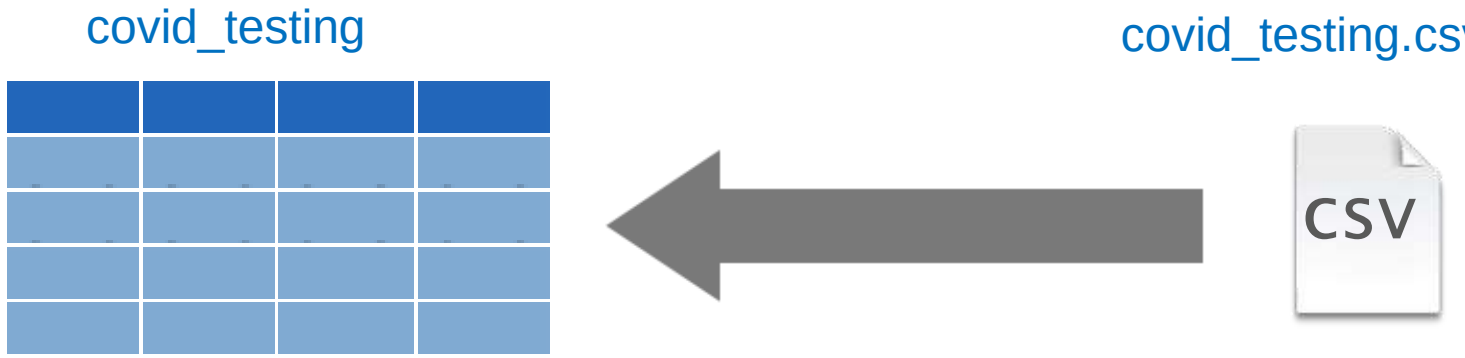


read_csv()

data frame to read data into

name of CSV file

```
covid_testing <- read_csv("data/covid_testing.csv")
```



Your Turn #3

Configure environment and load the Covid Testing CSV:

Load the tidyverse library using library(tidyverse)

Use the **read_csv()** function to load the data

-File_name argument: "data/covid_testing.csv"

-Object name: covid_testing

What's in a name?

- Capitalization matters

`covid_testing` ≠ `Covid_testing` ≠ `COVID_TESTING`

- Strive for names that are concise and meaningful (not easy!)

Bad	Still not great	Good
`p`	`name`	`patient_name`

Viewing the Contents of a Dataframe

single click to explore the data

Viewing the Contents of a Dataframe

covid_testing

Filter

	mrn	first_name	last_name	gender	pan_day	test_id	clinic_name	re
1	5001412	jhezane	westerling	female	4	covid	inpatient ward	
2	5000533	penny	targaryen	female	7	covid	clinical lab	
3	5009134	grunt	rivers	male	7	covid	clinical lab	
4	5008518	melisandre	swyft	female	8	covid	clinical lab	
5	5008967	rolley	karstark	male	8	covid	emergency dept	
6	5011048	megga	karstark	female	8	covid	oncology day hosp	negat
7	5000663	ithoke	targaryen	male	9	covid	clinical lab	negat
8	[illegible]2158	ravella	frey	female	9	covid	emergency dept	negat
9	5003794	styr	tyrell	male	9	covid	clinical lab	negat
10	5004706	wvnafrvd	seaworth	male	9	covid	clinical lab	negat

owing 1 to 11 of 15,524 entries, 17 total columns

17 Attributes (Columns)

15,524 Observations (Rows)

Data Import : : CHEAT SHEET

R's **tidyverse** is built around **tidy data** stored in **tibbles**, which are enhanced data frames.

The front side of this sheet shows how to read text files into R with **readr**.

The reverse side shows how to create tibbles with **tibble** and to layout tidy data with **tidyr**.

OTHER TYPES OF DATA

Try one of the following packages to import other types of files

- **haven** - SPSS, Stata, and SAS files
- **readxl** - excel files (.xls and .xlsx)
- **DBI** - databases
- **jsonlite** - json
- **xml2** - XML
- **httr** - Web APIs
- **rvest** - HTML (Web Scraping)

Save Data

Save x, an R object, to path, a file path, as:

Comma delimited file
write_csv(x, path, na = "NA", append = FALSE, col_names = !append)

File with arbitrary delimiter
write_delim(x, path, delim = " ", na = "NA", append = FALSE, col_names = !append)

CSV for excel
write_excel_csv(x, path, na = "NA", append = FALSE, col_names = !append)

String to file
write_file(x, path, append = FALSE)

String vector to file, one element per line
write_lines(x,path, na = "NA", append = FALSE)

Object to RDS file
write_rds(x, path, compress = c("none", "gz", "bz2", "xz"), ...)

Tab delimited files
write_tsv(x, path, na = "NA", append = FALSE, col_names = !append)

RStudio

Read Tabular Data - These functions share the common arguments:

read_*(file, col_names = TRUE, col_types = NULL, locale = default_locale(), na = c("", "NA"), quoted_na = TRUE, comment = "", trim_ws = TRUE, skip = 0, n_max = Inf, guess_max = min(1000, n_max), progress = interactive()**)**

Comma Delimited Files
read_csv("file.csv")
To make file.csv run:
write_file(x = "a,b,c\n1,2,3\n4,5,NA", path = "file.csv")

Semi-colon Delimited Files
read_csv2("file2.csv")
write_file(x = "a;b;c\n1;2;3\n4;5;NA", path = "file2.csv")

Files with Any Delimiter
read_delim("file.txt", delim = "|")
write_file(x = "a|b|c\n1|2|3\n4|5|NA", path = "file.txt")

Fixed Width Files
read_fwf("file.fwf", col_positions = c(1, 3, 5))
write_file(x = "a b c\n1 2 3\n4 5 NA", path = "file.fwf")

Tab Delimited Files
read_tsv("file.tsv") Also **read_table()**.
write_file(x = "a\tb\tc\n1\t2\t3\n4\t5\tNA", path = "file.tsv")

USEFUL ARGUMENTS

Example file
write_file("a,b,c\n1,2,3\n4,5,NA","file.csv")
f <- "file.csv"

Skip lines
read_csv(f, **skip = 1**)

No header
read_csv(f, **col_names = FALSE**)

Read in a subset
read_csv(f, **n_max = 1**)

Provide header
read_csv(f, **col_names = c("x", "y", "z")**)

Missing Values
read_csv(f, **na = c("1", ".")**)

Read Non-Tabular Data

Read a file into a single string
read_file(file, locale = default_locale())

Read each line into its own string
read_lines(file, skip = 0, n_max = -1L, na = character(), locale = default_locale(), progress = interactive())

Read Apache style log files
read_log(file, col_names = FALSE, col_types = NULL, skip = 0, n_max = -1, progress = interactive())

Read a file into a raw vector
read_file_raw(file)

Read each line into a raw vector
read_lines_raw(file, skip = 0, n_max = -1L, progress = interactive())

Data types

readr functions guess the types of each column and convert types when appropriate (but will NOT convert strings to factors automatically).

A message shows the type of each column in the result.

```
## Parsed with column specification:
## cols(
##   age = col_integer(),
##   sex = col_character(),
##   earn = col_double()
## )
```

age is an integer
sex is a character
earn is a double (numeric)

1. Use **problems()** to diagnose problems
x <- read_csv("file.csv"); problems(x)

2. Use a col_ function to guide parsing
- **col_guess()** - the default
- **col_character()**
- **col_double()**, **col_euro_double()**
- **col_datetime**(format = "") Also **col_date**(format = ""), **col_time**(format = "")
- **col_factor**(levels, ordered = FALSE)
- **col_integer()**
- **col_logical()**
- **col_number()**, **col_numeric()**
- **col_skip()**

x <- read_csv("file.csv", col_types = cols(
A = col_double(),
B = col_logical(),
C = col_factor()))

3. Else, read in as character vectors then parse with a parse_ function.
- **parse_guess()**
- **parse_character()**
- **parse_datetime()** Also **parse_date()** and **parse_time()**
- **parse_double()**
- **parse_factor()**
- **parse_integer()**
- **parse_logical()**
- **parse_number()**

x$A <- parse_number(x$A)

What Else?

Import Excel files (.xls, .xlsx)

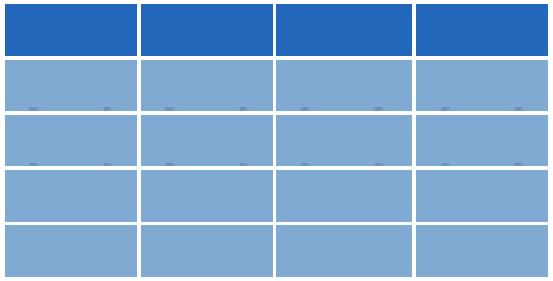
```
library(readxl)
```

read_excel()

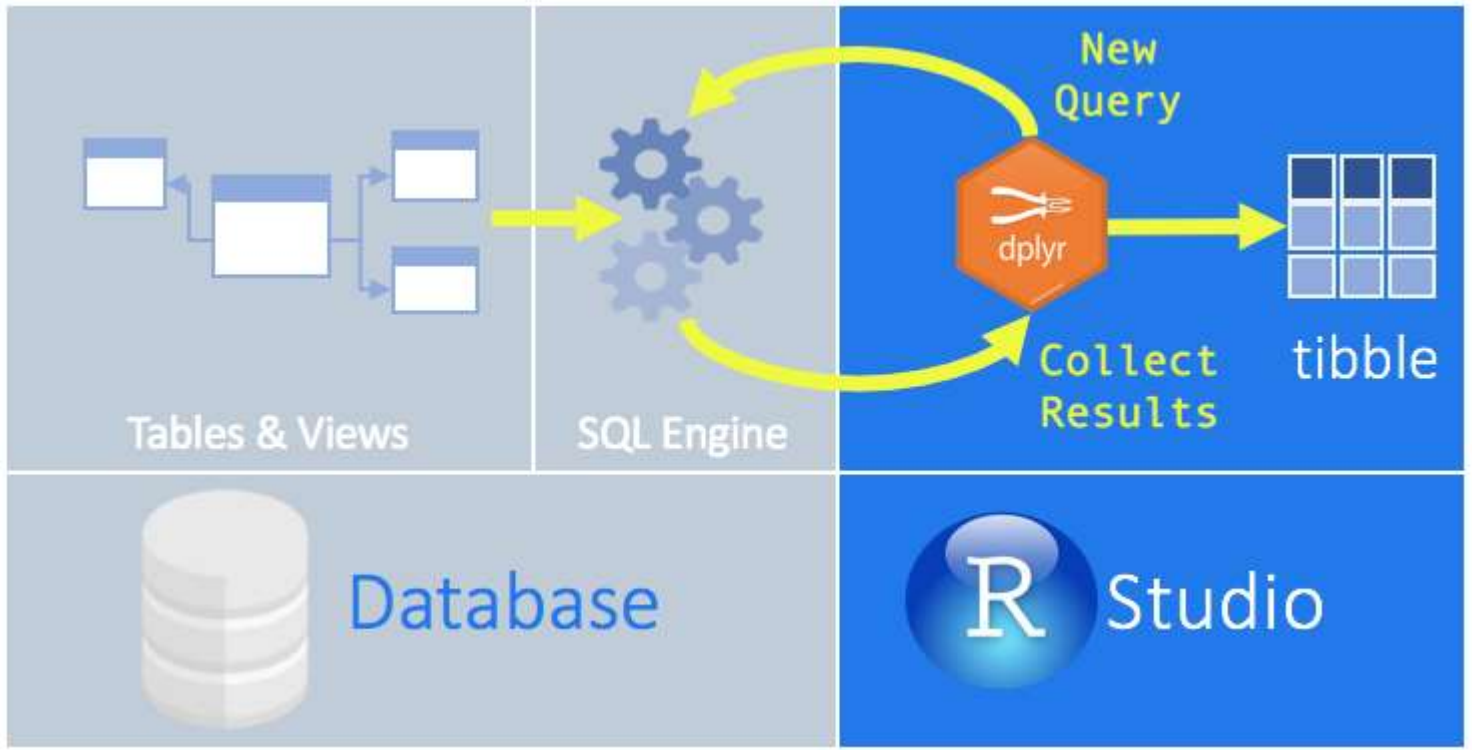
data frame to read data into

name of Excel file

```
data_frame <- read_excel(file_name)
```



Read Directly From Database



Reads SPSS, Stata, and SAS files

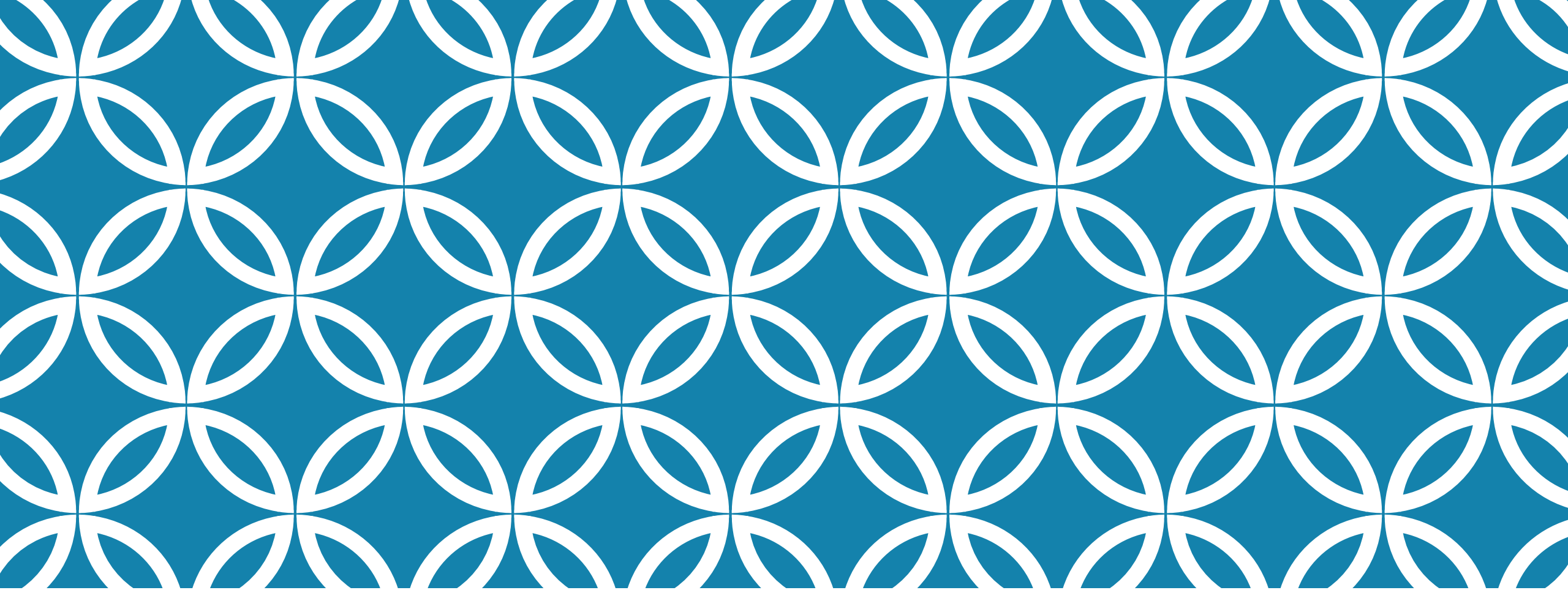
Format	Typical Extension	Import Package	Export Package	Installed by Default
Comma-separated data	.csv	data.table	data.table	Yes
Pipe-separated data	.psv	data.table	data.table	Yes
Tab-separated data	.tsv	data.table	data.table	Yes
CSVY (CSV + YAML metadata header)	.csvy	data.table	data.table	Yes
SAS	.sas7bdat	haven	haven	Yes
SPSS	.sav	haven	haven	Yes
Stata	.dta	haven	haven	Yes
SAS XPORT	.xpt	haven	haven	Yes
SPSS Portable	.por	haven		Yes
Excel	.xls	readxl		Yes
Excel	.xlsx	readxl	openxlsx	Yes
R syntax	.R	base	base	Yes
Saved R objects	.RData, .rda	base	base	Yes
Serialized R objects	.rds	base	base	Yes

Lesson Goals

1. Get oriented to R and RStudio
2. Learn some fundamentals of coding

Lesson Objectives

1. Log in and tour RStudio Cloud
2. Execute code at the console
3. Define and use functions
4. Define and create objects in the environment
5. Load data into R and interact with a dataframe



Reproducible Reporting

Session 2
August 16, 2020
Amrom Obstfeld

August 16 2020	**Session**	**Instructor**
9:00 am - 9:30 am	Instructor Introductions, Introduction to technology	Amrom Obstfeld
9:30 am - 10:15 am	Introduction to R and RStudio	Amrom Obstfeld
10:30 pm - 11:15 am	Reproducible Reporting	Amrom Obstfeld
11:30 am - 1:00 am	Data Visualization	Stephan Kadauke
August 23 2020		
9:00 am - 10:30 pm	Data Transformation	Amrom Obstfeld
10:45 am - 12:15 pm	Statistical Analysis	Dan Herman
12:30 pm - 1:00 pm	Workshop Close out	Amrom Obstfeld

Goals

1. Understand why reproducible reporting is important
2. Learn to work within R Markdown for reproducible reports

Objectives

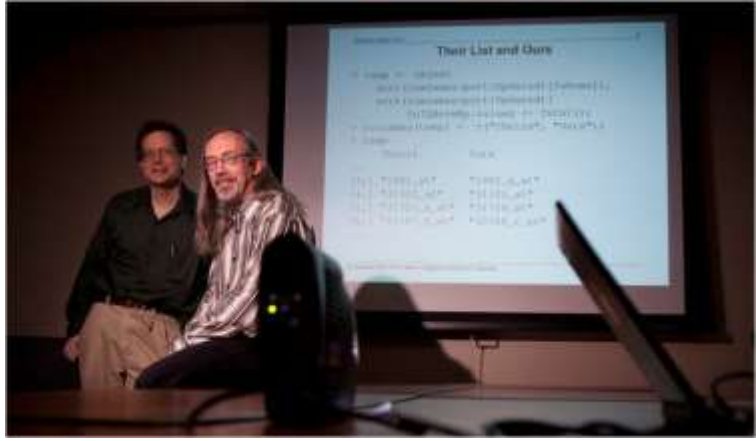
1. Create an R Markdown document and generate different types of output files
2. Practice modifying each component of a R Markdown file

Why Analyze Data with Code?

The Duke Cancer Scandal

- Chemo sensitivity from microarrays
- Errors first, then misconduct
- Clinical trials based on flawed models
- Papers retracted, lawsuits settled

“Common errors are simple, Simple errors are common”



Theirs	Ours
"1881_at"	"1882_g_at"
"31321_at"	"31322_at"
"31725_s_at"	"31726_at"
"32307_r_at"	"32308_r_at"
...	

https://youtu.be/tN31vZj0LZY

Point-and-Click Is Not Reproducible

- Interactive tools do not record user actions
- Manual documentation is error-prone
- Manual analyses cannot be repeated on new data sets or shared with collaborators

Computer code can precisely document each step of the analysis

Why YOU Should Do Data Analysis Reproducibly

"Can we redo the analysis with this month's data?"

"Why do the data in Table 1 not seem to agree with Figure 2?"

"Why did I decide to omit these six samples?"

YOUR CLOSEST COLLABORATOR IS **YOU** FROM 6 MONTHS AGO
(BUT YOU DON'T ANSWER E-MAILS)

Replication vs Reproduction

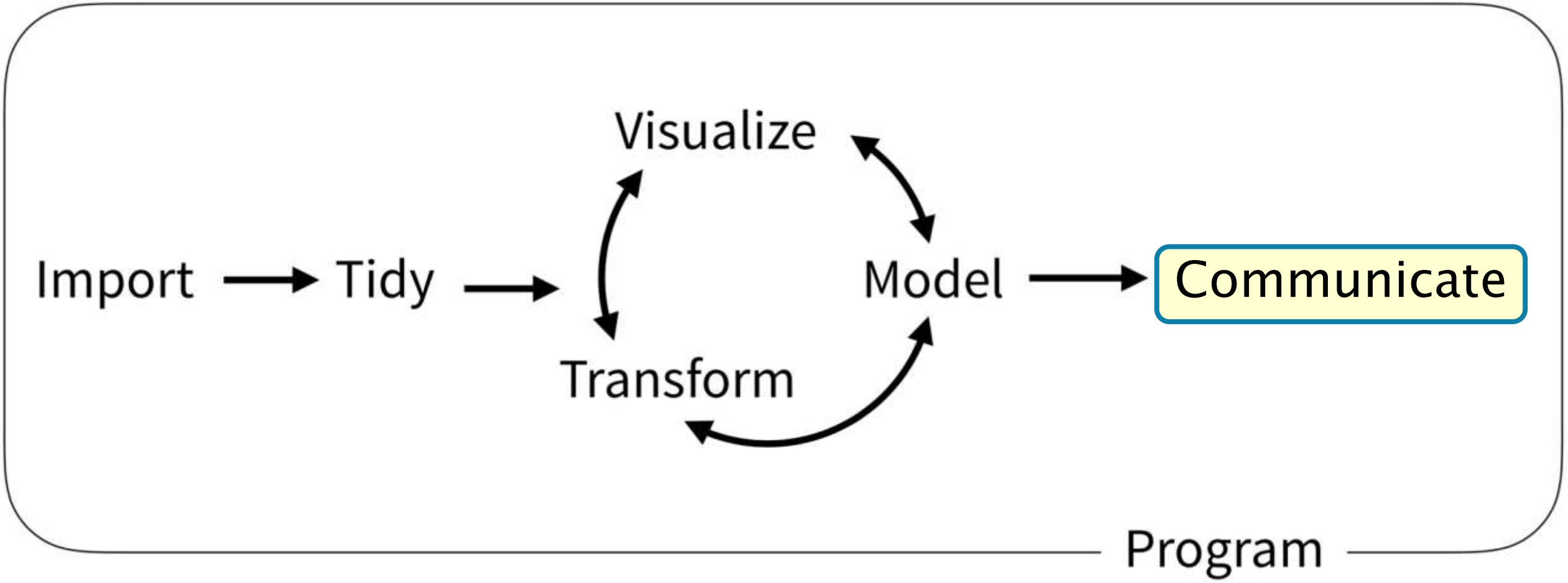
- Replication: other people collect new data
  - Scientific gold standard
  - Difficult and time-consuming

- Reproduction: other people analyze the same data
  - Does not by itself validate the analysis …
  - Has been proposed as a minimal standard

Your Turn #1

Spend one minute writing down as many reasons as you can think of for why you might want your **own** data analyses to be reproducible.

Typical Data Analysis Pipeline



From *R for Data Science*

Using R/R Markdown to Support Reproducibility

Using R for Reproducibility

Programming in R (or another language) allows one to reproduce analysis steps exactly or perform same analysis on new data

Better practice is to create documentation about analysis to accompany and explain code

Best practice is include documentation and code in one place

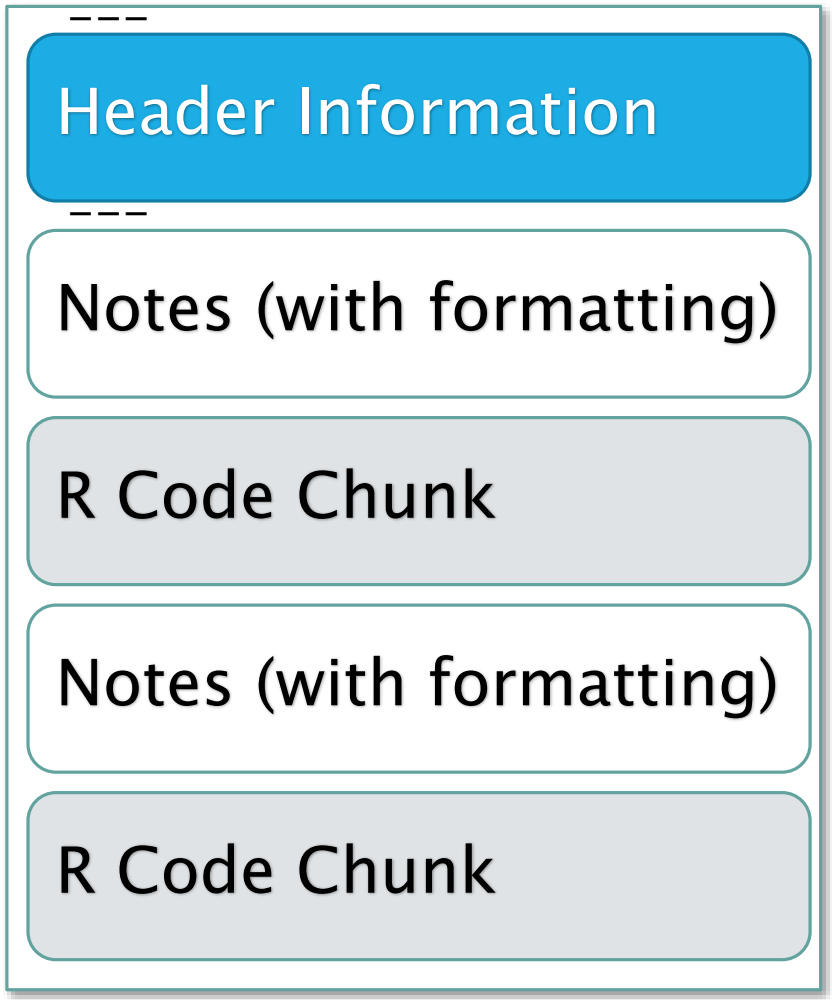
R Markdown for Reproducible Reports

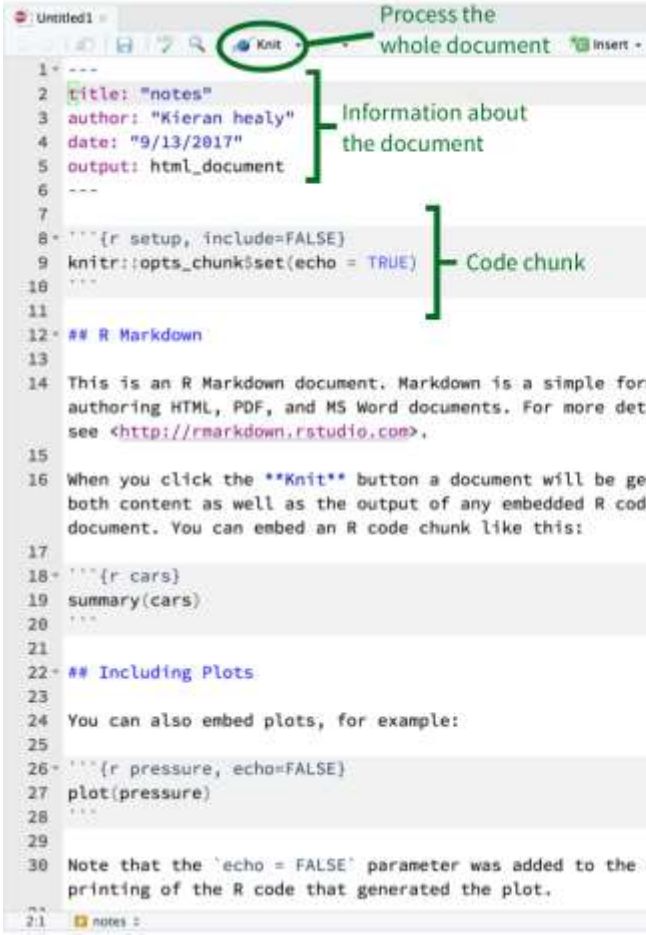
- Code remains attached to its documentation and output

- Text and code compile into a single HTML or PDF document that can be shared

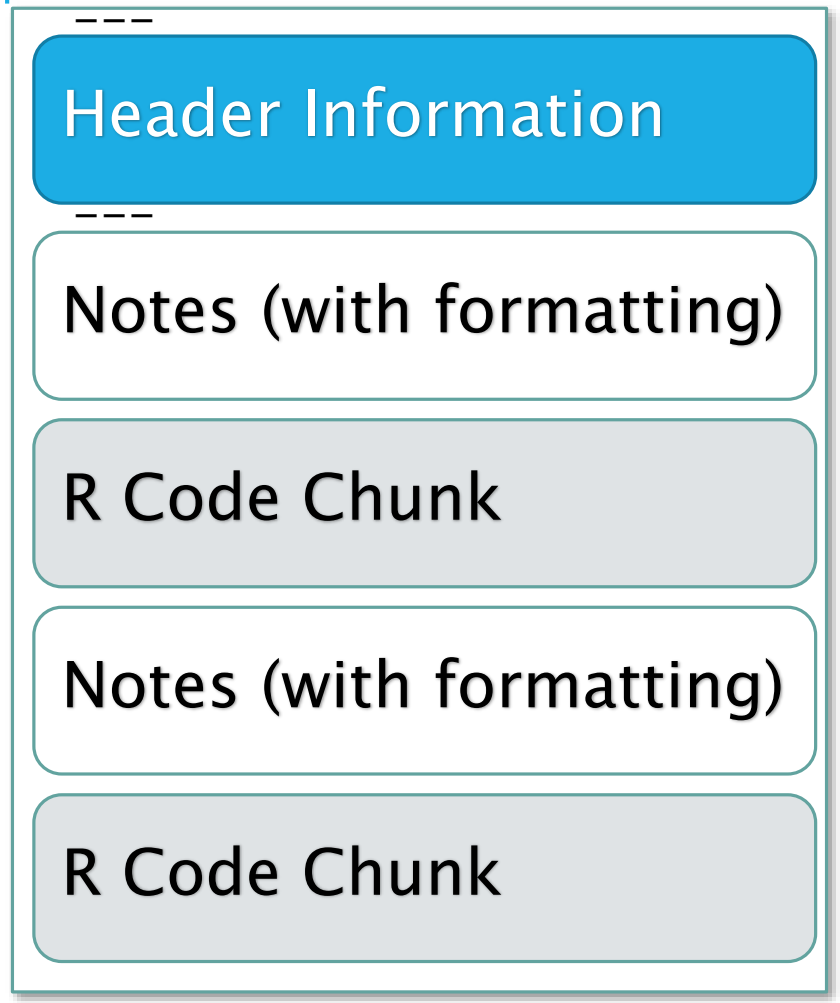
- Reproducible reports can be automated and turned into analytic dashboards

R Markdown Block Diagram





R Markdown Block Diagram




```
1  ---
2  title: "My Project"
3  author: "Julie"
4  date: "11/21/2017"
5  output: html_document
6  ---
13
14 This is an R Markdown document. Markdown is a simple formatting syntax for autho
   documents. For more details on using R Markdown see <http://rmarkdown.rstudio.co
15
16 When you click the **Knit** button a document will be generated that includes bo
   output of any embedded R code chunks within the document. You can embed an R cod
17
18 ```{r cars}
19 summary(cars)
20 ```
21
22 ## Including Plots
23
24 You can also embed plots, for example:
25
26 ```{r pressure, echo=FALSE}
27 plot(pressure)
28 ```
29
```

```
# One Hashtag = Large Header

## Two Hashtags = Smaller Header

Here is some text.

* It's easy to make a list.
* Here's how you style text *cursive* or **bold**.
* Let's add a [link](https://www.massgeneral.org).

```{r}
x <- rnorm(100)
summary(x)
```

Including plots

```{r, echo = FALSE}
hist(x)
```
```

One Hashtag = Large Header

Two Hashtags = Smaller Header

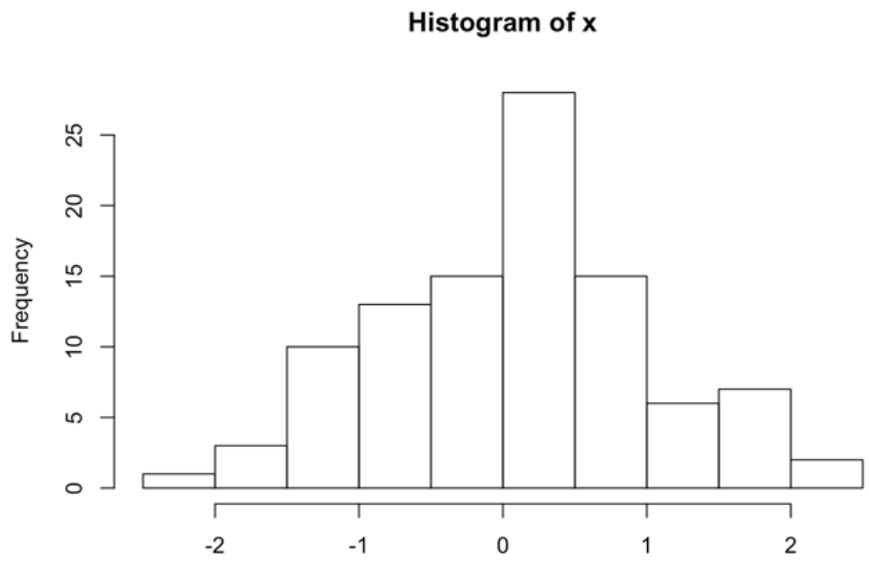
Here is some text.

- It's easy to make a list.
- Here's how you style text *cursive* or **bold**.
- Let's add a link.

```
x <- rnorm(100)
summary(x)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
## -2.0053 -0.6084  0.1125  0.0747  0.6100  2.1437
```

Including plots



R Markdown Reference Guide

Learn more about R Markdown at rmarkdown.rstudio.com
Learn more about Interactive Docs at shiny.rstudio.com/articles

Contents:

Syntax

```
Plain text

End a line with two spaces
to start a new paragraph.

*italics* and _italics_

**bold** and __bold__

superscript^2^

~~strikethrough~~

[link](www.rstudio.com)

# Header 1

## Header 2

### Header 3

#### Header 4
```

Becomes

Plain text

End a line with two spaces to start a new paragraph.

italics and *italics*

bold and **bold**

superscript^2

~~strikethrough~~

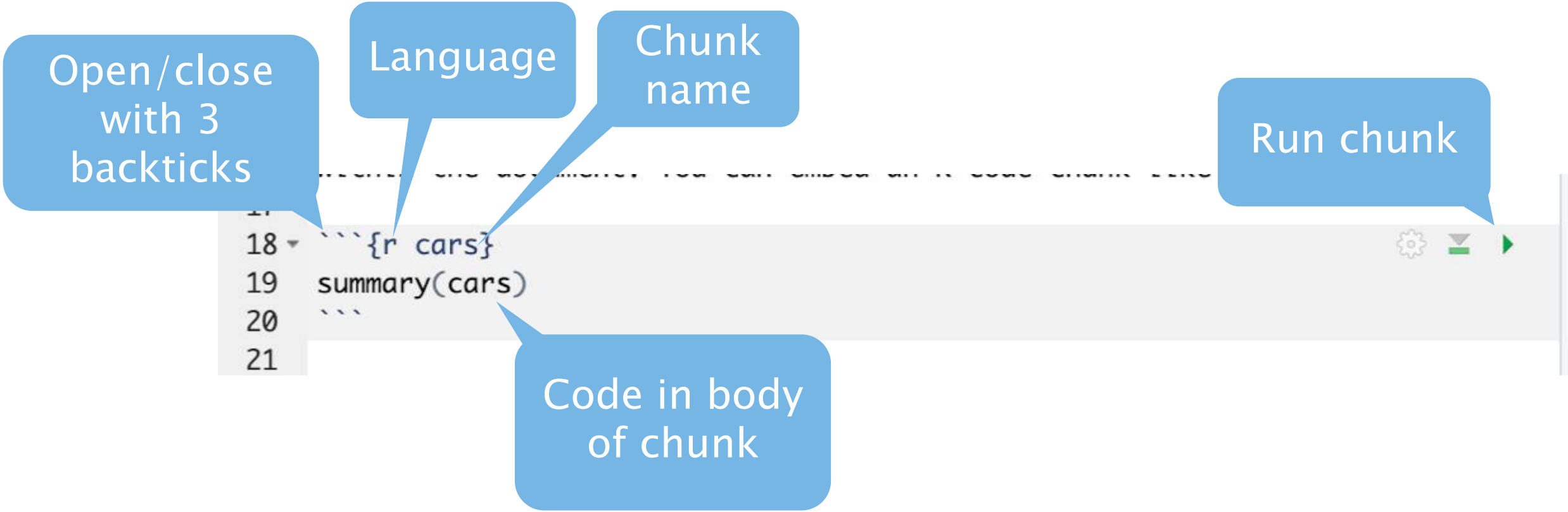
link

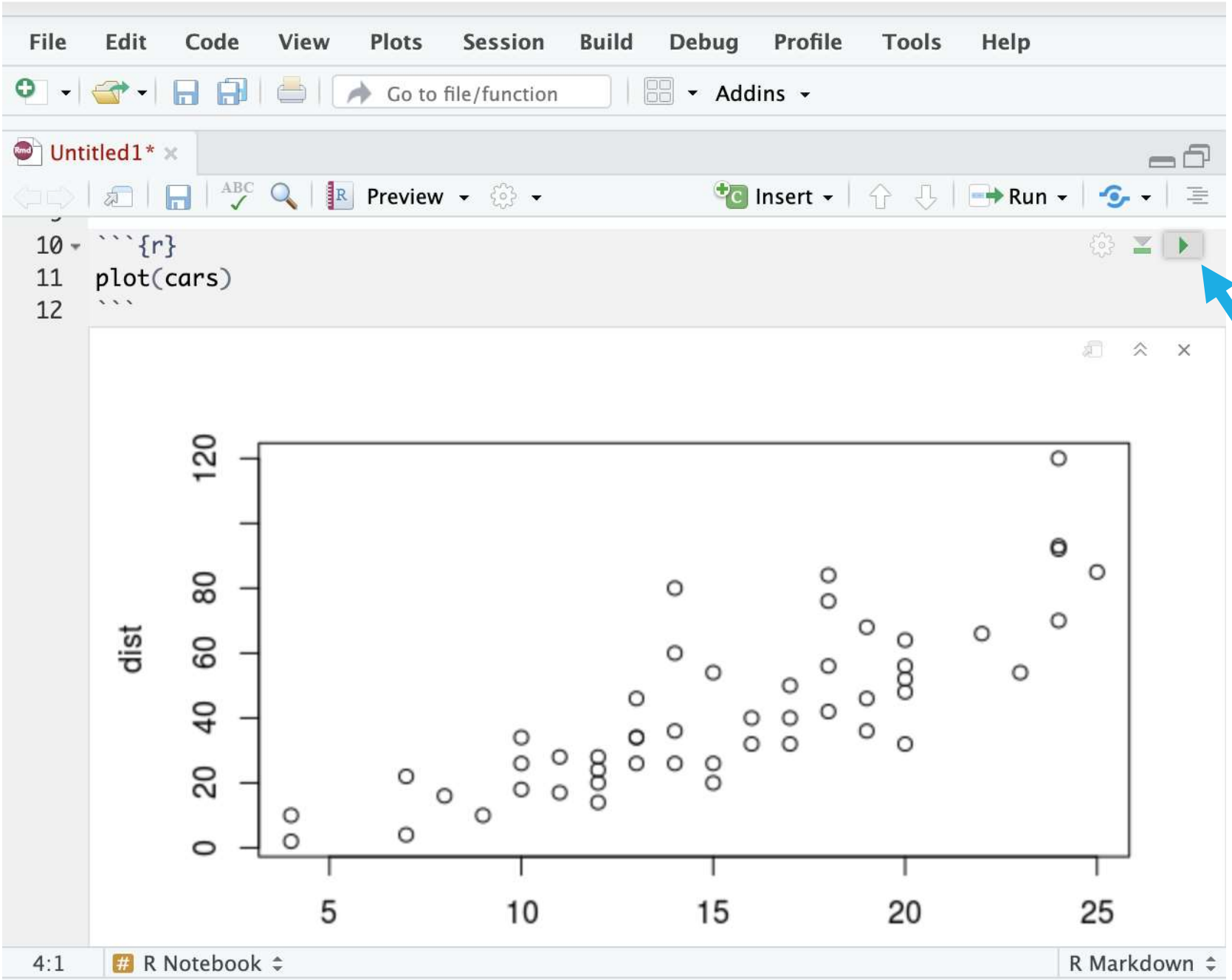
Header 1

Header 2

Header 3

Code chunks


Open/close with 3 backticks
Language
Chunk name
Run chunk
18 ```{r cars}
19 summary(cars)
20 ```
21
Code in body of chunk



Run code chunk

Your Turn #2

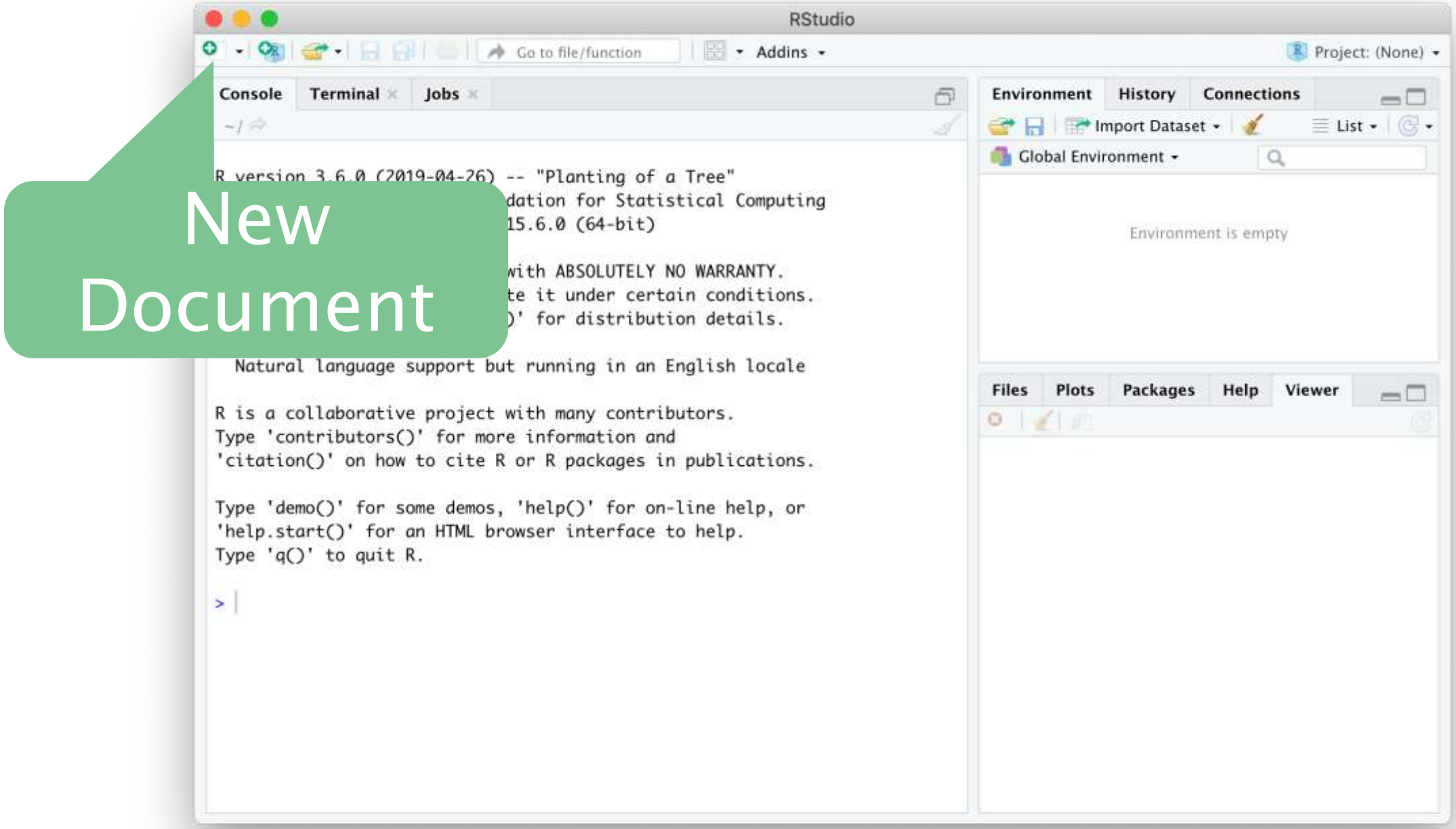
Open Rstudio.Cloud

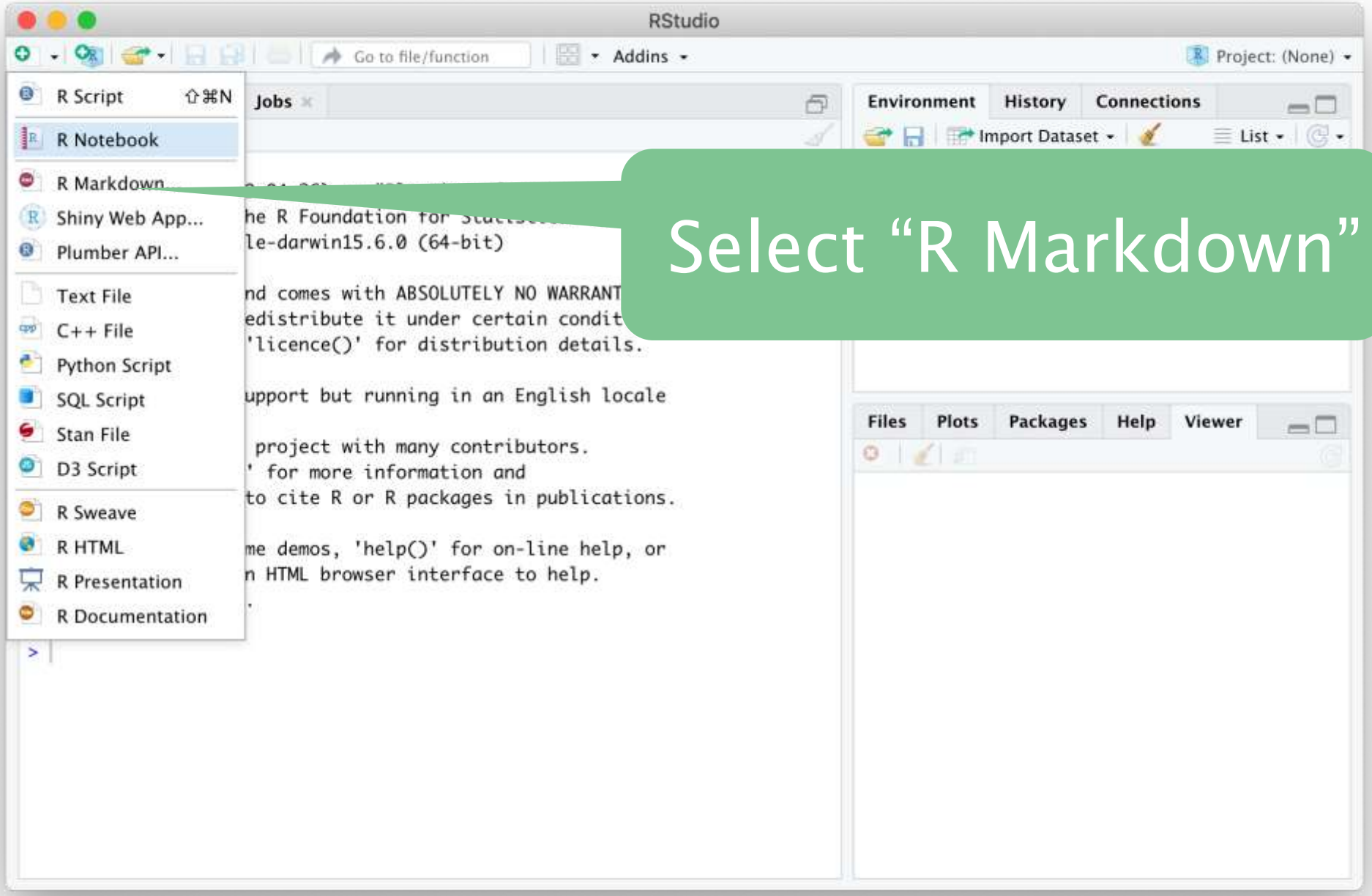
In the lower right MISC pane

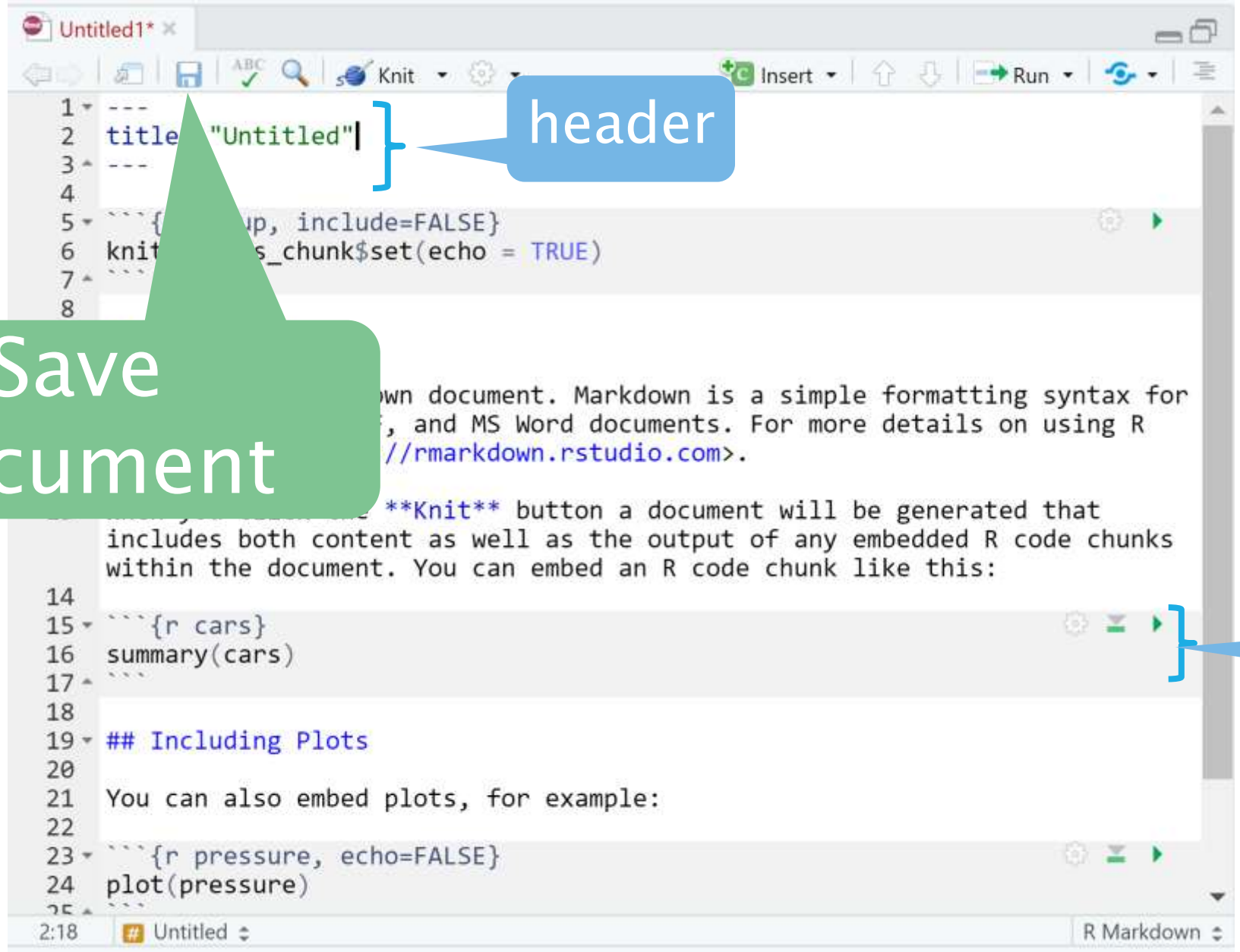
Open 02 - Reproducible Reporting.

Read through the R Notebook and do everything it asks you to do.

Creating a New R Notebook


New
Document
RStudio
Go to file/function
Addins
Project: (None)
Console
Terminal
Jobs
R version 3.6.0 (2019-04-26) -- "Planting of a Tree"
dation for Statistical Computing
15.6.0 (64-bit)
with ABSOLUTELY NO WARRANTY.
te it under certain conditions.
)' for distribution details.
Natural language support but running in an English locale
R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.
Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.
>
Environment
History
Connections
Import Dataset
List
Global Environment
Environment is empty
Files
Plots
Packages
Help
Viewer

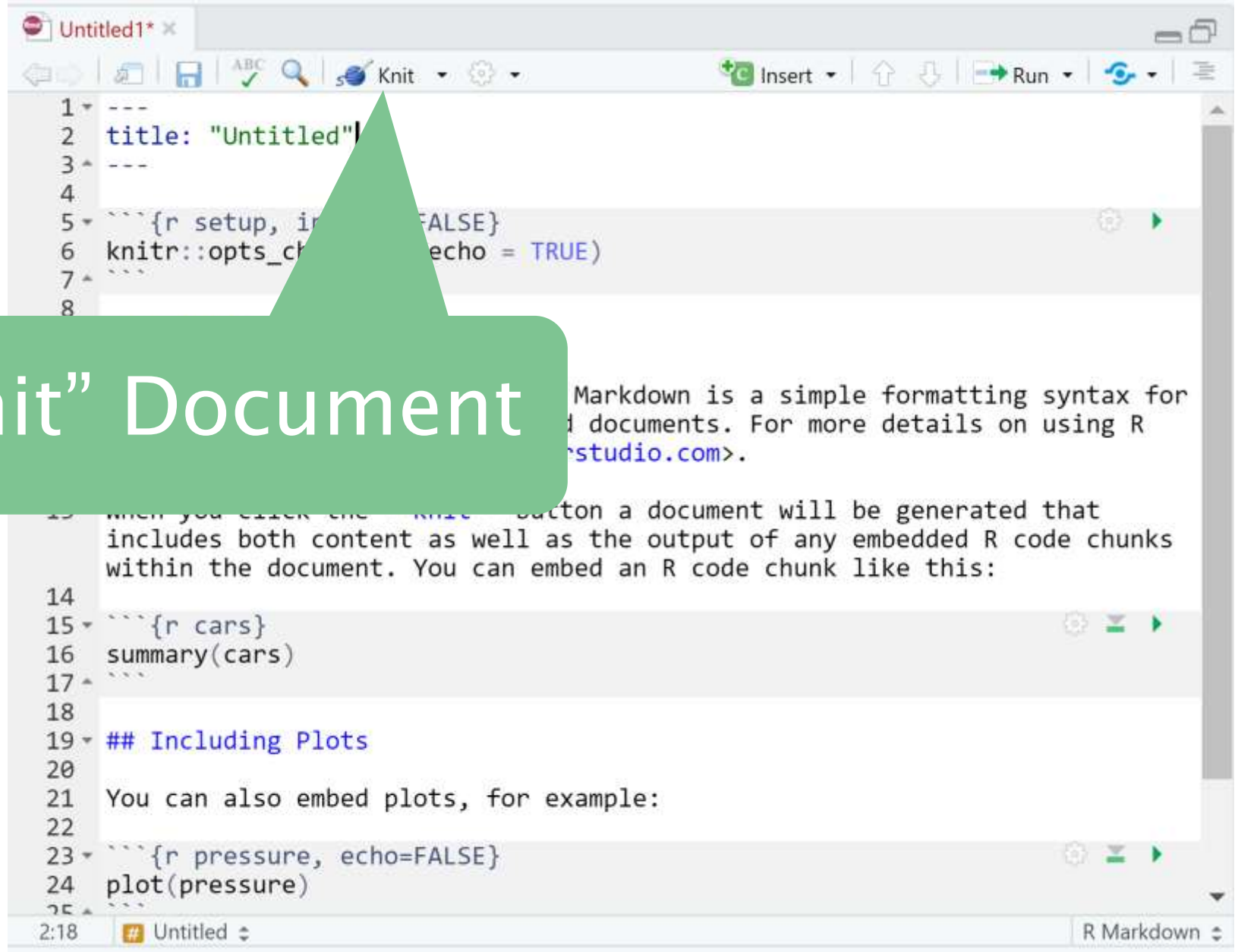

RStudio
Go to file/function
Addins
Project: (None)
R Script ⇧⌘N
R Notebook
R Markdown...
Shiny Web App...
Plumber API...
Text File
C++ File
Python Script
SQL Script
Stan File
D3 Script
R Sweave
R HTML
R Presentation
R Documentation
Jobs
Environment
History
Connections
Import Dataset
List
Files
Plots
Packages
Help
Viewer
he R Foundation for
le-darwin15.6.0 (64-bit)
nd comes with ABSOLUTELY NO WARRANT
edistribute it under certain condit
'licence()' for distribution details.
upport but running in an English locale
project with many contributors.
' for more information and
to cite R or R packages in publications.
me demos, 'help()' for on-line help, or
n HTML browser interface to help.
Select “R Markdown”



header

Save Document

code chunk



“Knit” Document

Untitled

R Markdown

This is an R Markdown document. 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.

When you click the **Knit** button a document will be generated that includes both content as well as the output of any embedded R code chunks within the document. You can embed an R code chunk like this:

```
summary(cars)
```

```
##      speed           dist       
##  Min.   : 4.0   Min.   :  2.00  
##  1st Qu.:12.0   1st Qu.: 26.00  
##  Median :15.0   Median : 36.00  
##  Mean   :15.4   Mean   : 42.98  
##  3rd Qu.:19.0   3rd Qu.: 56.00  
##  Max.   :25.0   Max.   :120.00
```

Including Plots

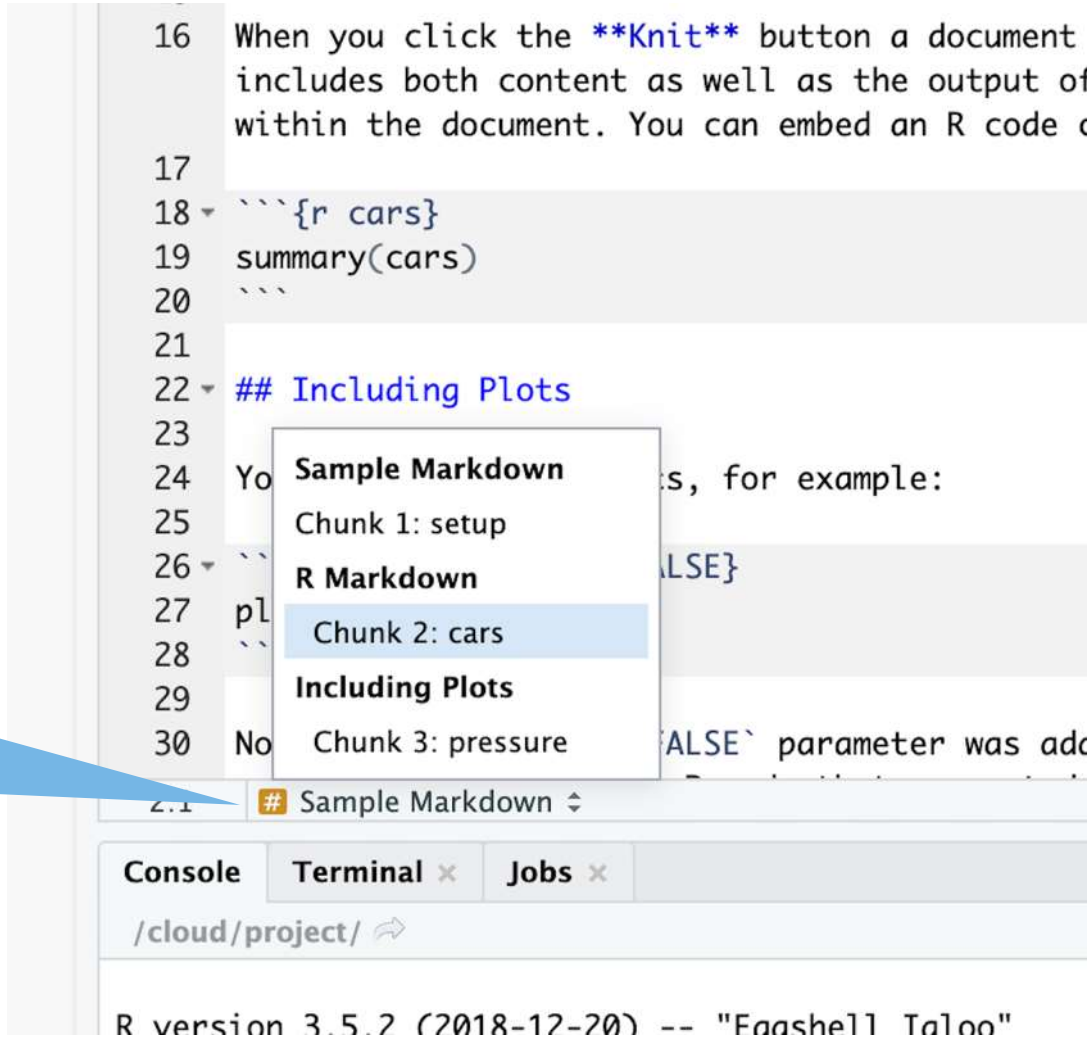
You can also embed plots, for example:

Your Turn #2

Try to reproduce this markdown document starting with the file you just created as a template.

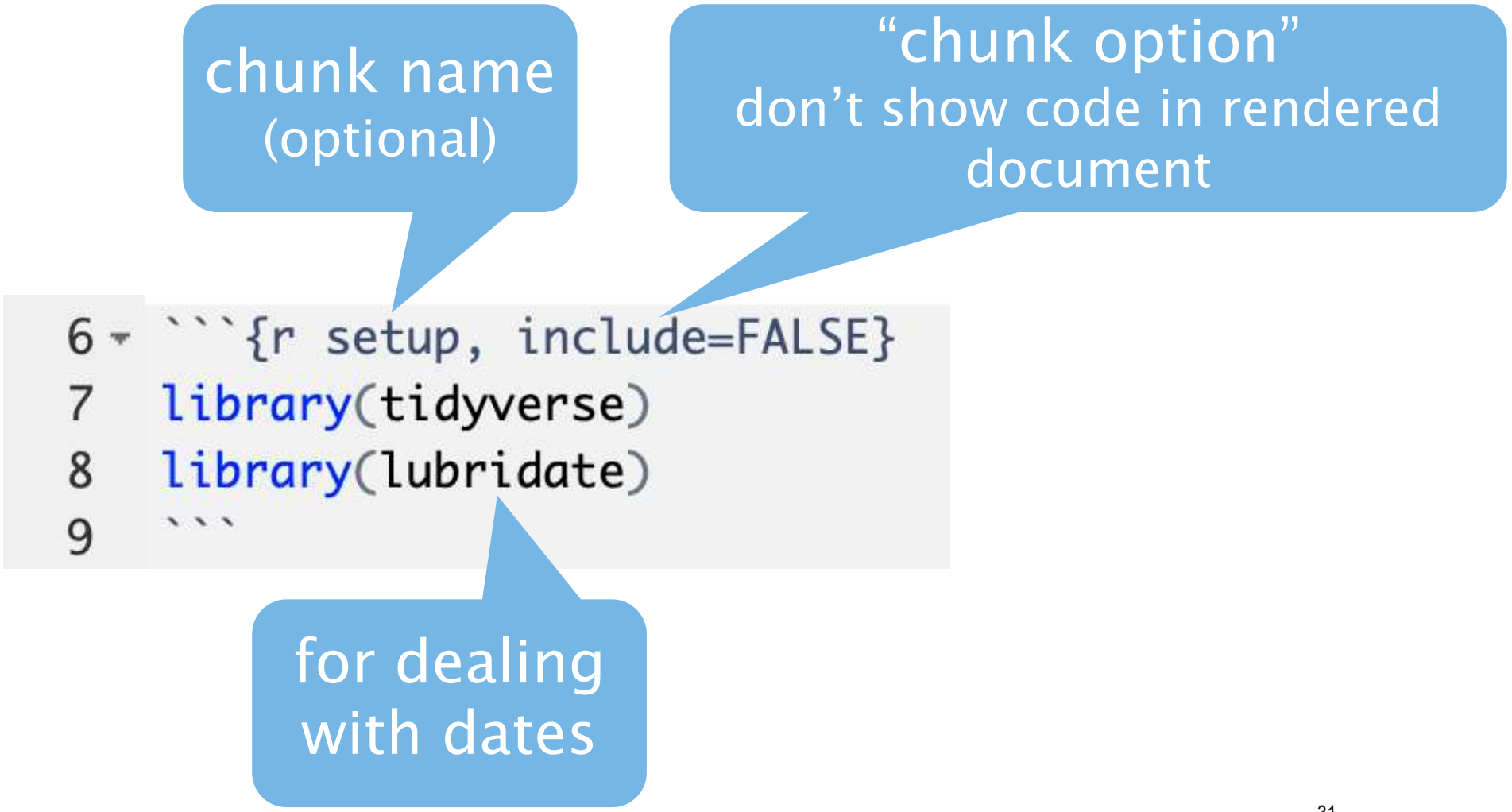
What Else?

Why name Code Chunks?



Jump between chunks

“Setup” Chunk & Chunk Options



Chunk options

option	default	effect
eval	TRUE	Whether to evaluate the code and include its results
echo	TRUE	Whether to display code along with its results
warning	TRUE	Whether to display warnings
error	FALSE	Whether to display errors
message	TRUE	Whether to display messages
tidy	FALSE	Whether to reformat code in a tidy way when displaying it
results	"markup"	"markup", "asis", "hold", or "hide"
cache	FALSE	Whether to cache results for future renders
comment	"##"	Comment character to preface results with
fig.width	7	Width in inches for plots created in chunk
fig.height	7	Height in inches for plots created in chunk

For more details visit yihui.name/knitr/

Keyboard Shortcuts

Insert a code chunk into white space within your open R Markdown document using:

- Windows: CTRL+ALT+i
- Mac: COMMAND+OPTION+I

Execute using shortcuts:

- Windows: CTRL+SHIFT+ENTER
- Mac: COMMMAND+SHIFT+ENTER

Multiple Output Formats are Available

Pandoc universal document converter can create multiple document types:

- html
- pdf
- docx

Can also create presentations and dashboards

- Including Powerpoint (most recent version of RStudio)

Creating a pdf report

R & RStudio require additional packages to create a nicely formatted pdf report

Behind the scenes, R will use a markup language called LaTeX to turn your markdown into the pdf

Install the tinytex package with the following commands:

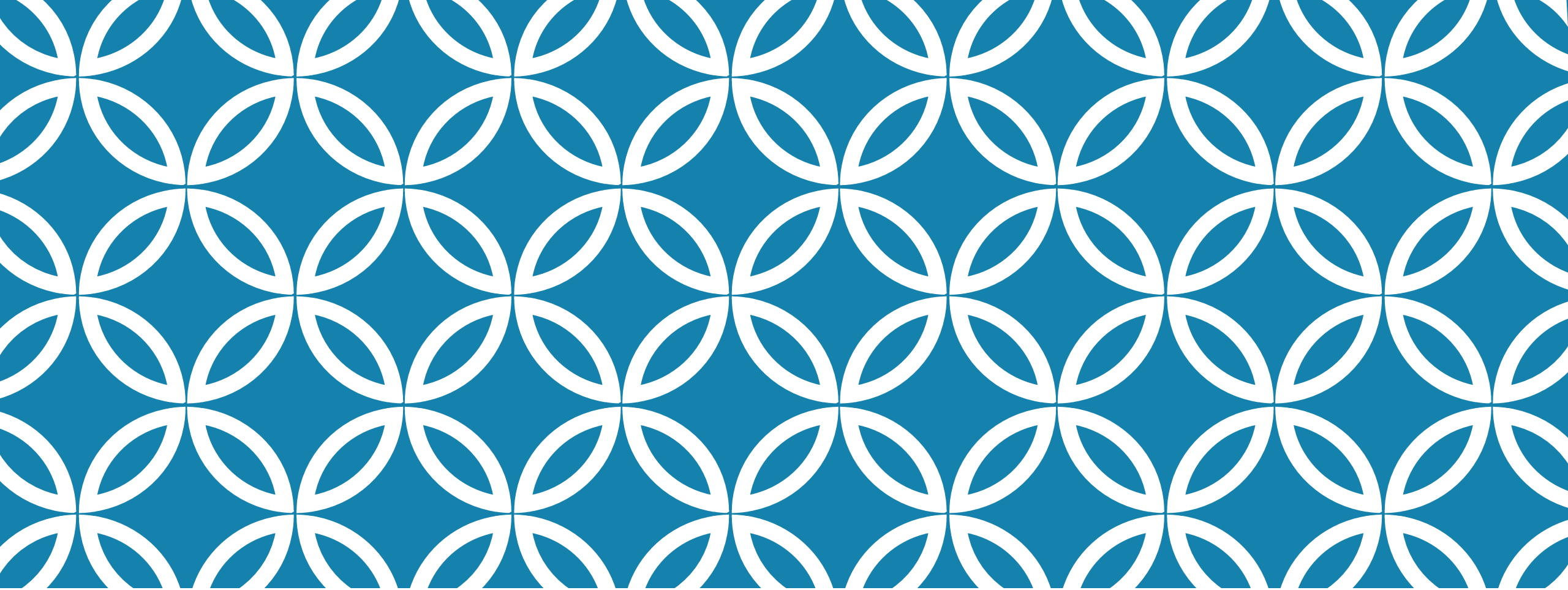
- install.packages('tinytex')
- tinytex::install_tinytex()

Goals

1. Understand why reproducible reporting is important
2. Learn to work within R Markdown for reproducible reports

Objectives

1. Create an R Markdown document and generate different types of output files
2. Practice modifying each component of a R Markdown file



Data Visualization

Session 3

Stephan Kadauke

July 16, 2020

July 16 2020	**Session**	**Instructor**
1:00 pm - 1:30 pm	Instructor Introductions, Introduction to technology	Amrom Obstfeld
1:30 pm - 2:15 pm	Introduction to R and RStudio	Joe Rudolf
2:30 pm - 3:15 pm	Reproducible Reporting	Patrick Mathias
3:30 pm - 5:00 pm	Data Visualization	Stephan Kadauke
July 17 2020		
1:00 pm - 2:30 pm	Data Transformation	Amrom Obstfeld
2:45 pm - 4:15 pm	Statistical Analysis	Dan Herman
4:30 pm - 5:00 pm	Advanced Reporting	Patrick Mathias

Goals

1. Appreciate the importance of visualization for understanding data
2. Learn how to use ggplot2 to visualize data

Objectives

1. Create a basic visualization using a simple template
2. Define “aesthetic mapping” and explain how aesthetic mappings relate variables of a data frame to features of graphic markings on a plot
3. Write the code to specify a type of plot and fine tune its appearance using “geom” functions
4. Explain how to add layers to a ggplot object to create complex and highly customized visualizations

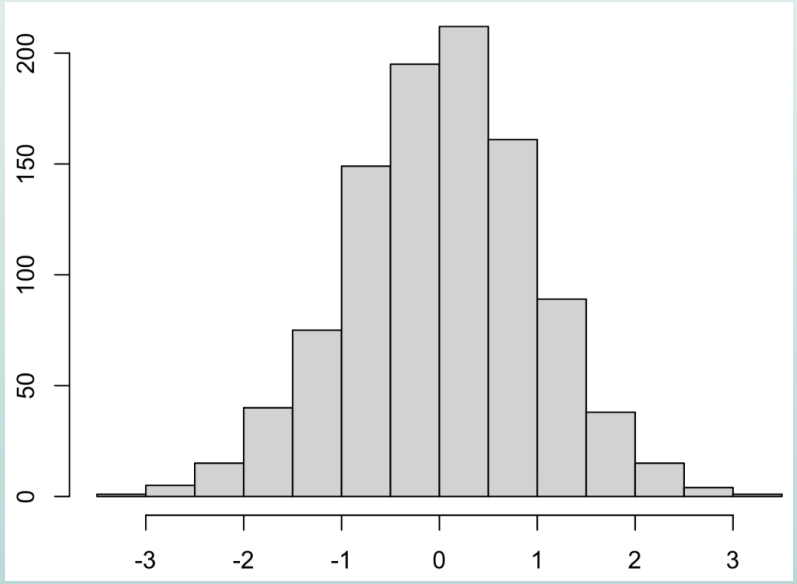
Your Turn 1

Consider the `covid_testing` data frame.

What do you think plot would look like in which:

- the x-axis represents `pan_day` (day of the pandemic), and
- the y-axis represents the number of tests that were performed on that day?

Your Turn 2



What is the name of this kind of plot?

Type the answer into the chat!

Your Turn 3

Type the following code in the RStudio console to make a graph.

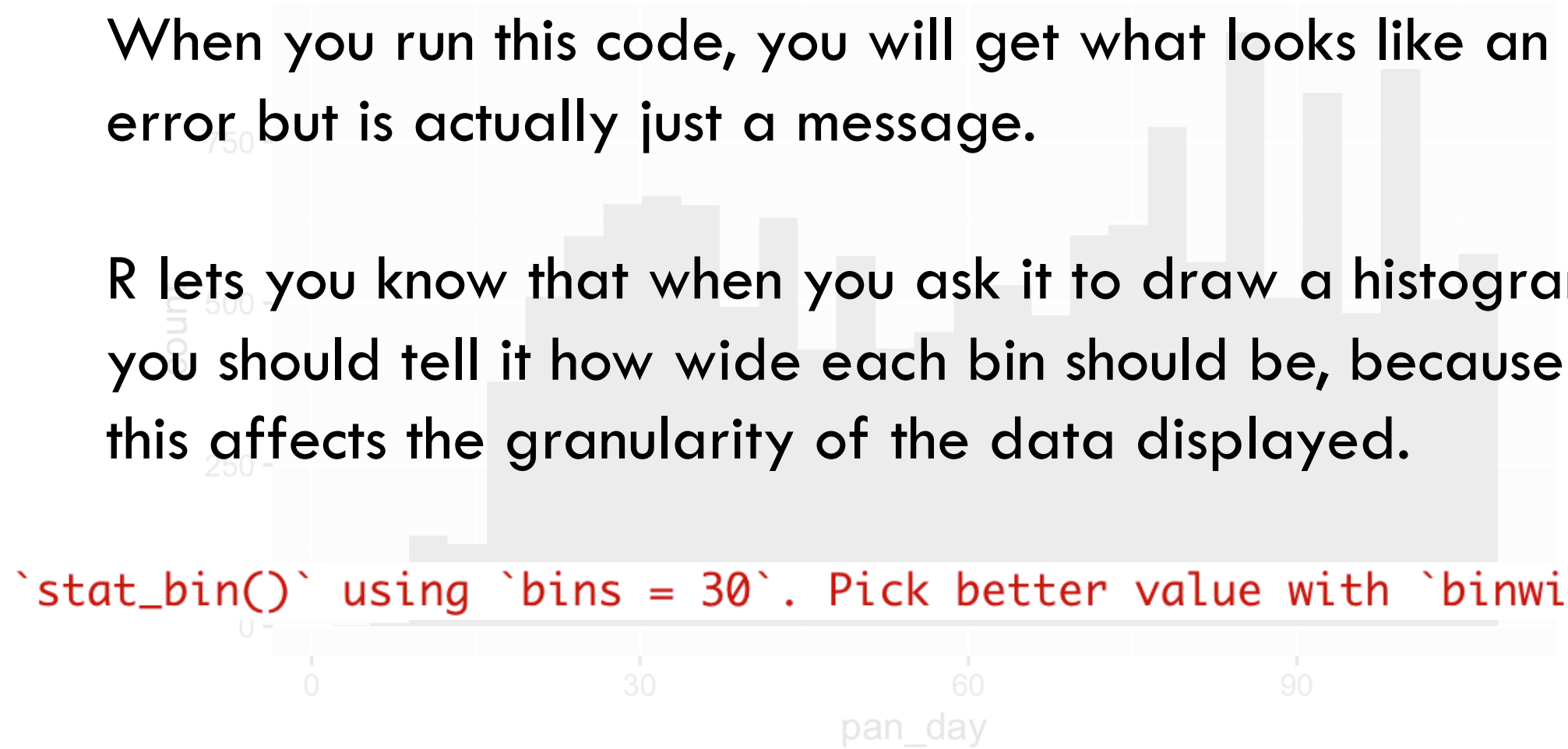
Pay attention to the spelling, capitalization, and parentheses!

```
ggplot(data = covid_testing) +
  geom_histogram(mapping = aes(x = pan_day))
```

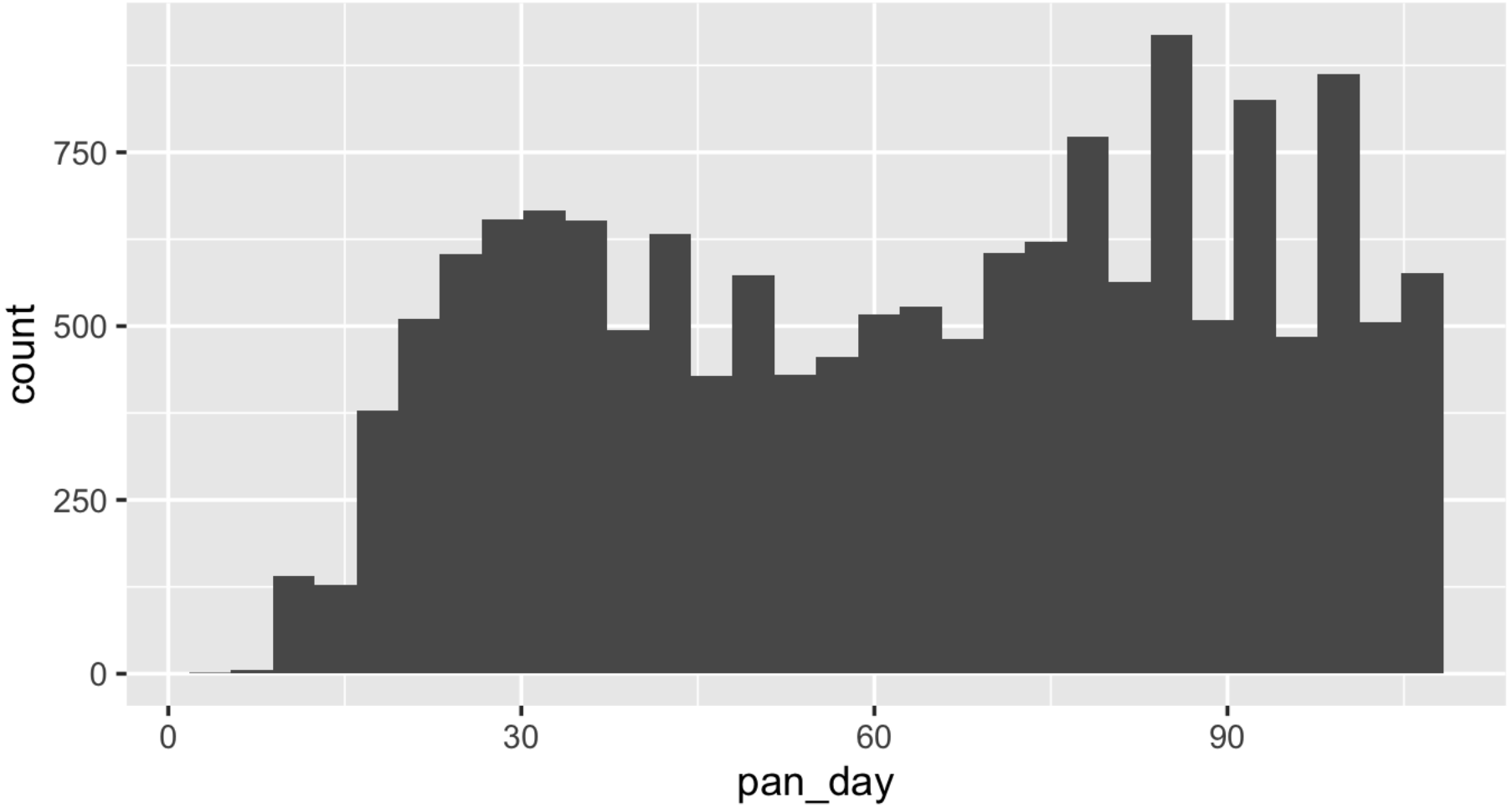
When you run this code, you will get what looks like an error but is actually just a message.

R lets you know that when you ask it to draw a histogram you should tell it how wide each bin should be, because this affects the granularity of the data displayed.

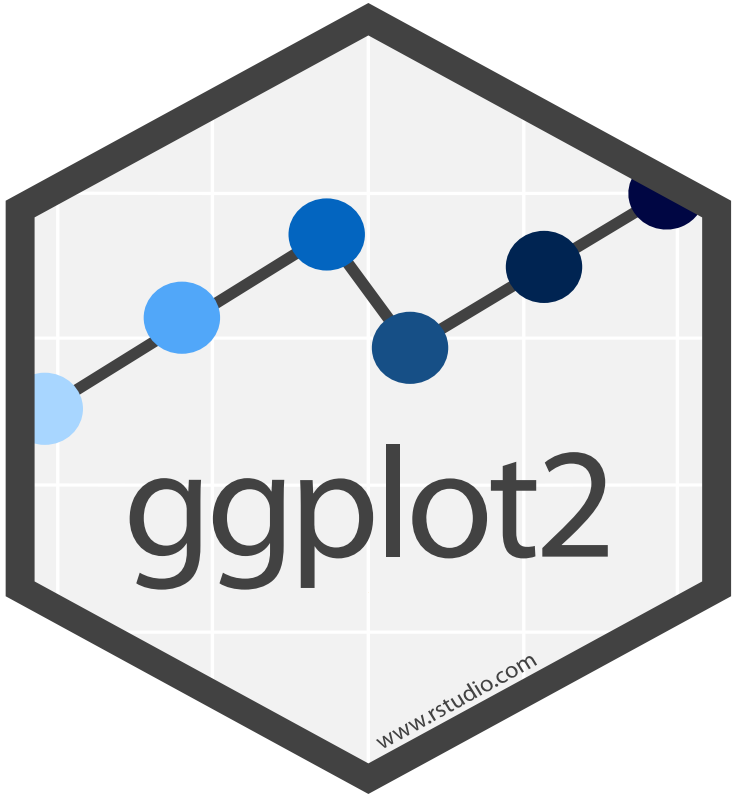
```
`stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```




```
ggplot(data = covid_testing) +
  geom_histogram(mapping = aes(x = pan_day))
```




```
ggplot(data = covid_testing) +
  geom_histogram(mapping = aes(x = pan_day))
```


ggplot2
www.rstudio.com

ggplot()

Always start with ggplot()

data frame

+ sign before new line

```
ggplot(data = covid_testing) +
  geom_histogram(mapping = aes(x = pan_day))
```

type of plot

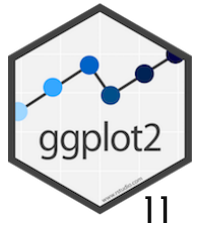
mappings inside aes() function

x axis mapping

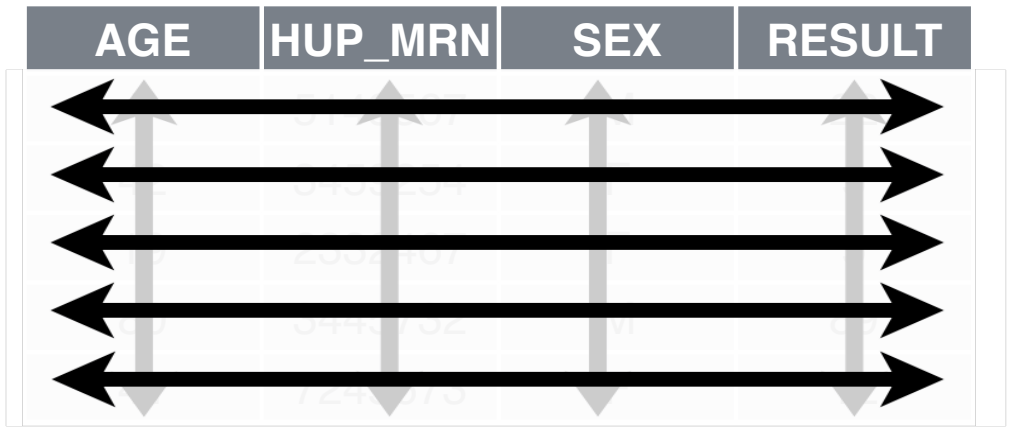
To make **any** kind of graph:

1. Choose a "tidy" **data** frame

```
ggplot(data = data_frame) +
  geom_function(mapping = aes(mappings))
```



1. Pick a "Tidy" Data Frame



A data set is **tidy** if:

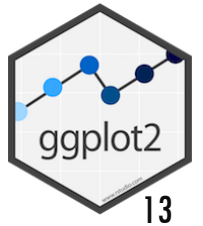
1. Each **variable** is in its own **column**
2. Each **observation** is in its own **row**
3. Each **value** is in its own **cell**

To make **any** kind of graph:

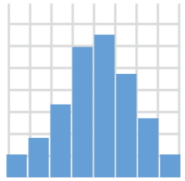
1. Choose a "tidy" **data** frame

```
ggplot(data = data_frame) +
  geom_function(mapping = aes(mappings))
```

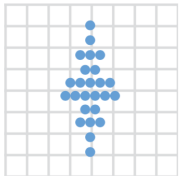
2. Pick a "**geom**" function



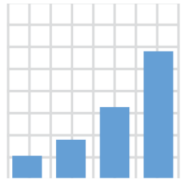
2. Choose a "Geom" Function



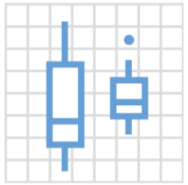
```
geom_histogram()
```



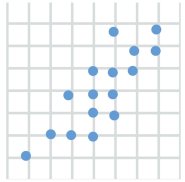
```
geom_dotplot()
```



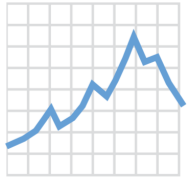
```
geom_bar()
```



```
geom_boxplot()
```



```
geom_point()
```



```
geom_line()
```

Data Visualization with ggplot2 : : CHEAT SHEET

Basics

ggplot2 is based on the **grammar of graphics**, the idea that you can build every graph from the same components: a **data** set, a **coordinate system**, and geoms—visual marks that represent data points.

To display values, map variables in the data to visual properties of the geom (**aesthetics**) like **size**, **color**, and **x** and **y** locations.

Complete the template below to build a graph.

```
ggplot (data = <DATA>) +                                   ] required
<GEOM_FUNCTION>(mapping = aes(<MAPPINGS>),
 stat = <STAT> , position = <POSITION> ) +                 ] Not required, sensible defaults supplied
<COORDINATE_FUNCTION> +
<FACET_FUNCTION> +
<SCALE_FUNCTION> +
<THEME_FUNCTION>
```

ggplot(data = mpg, **aes**(x = cty, y = hwy)) Begins a plot that you finish by adding layers to. Add one geom function per layer.

aesthetic mappings | data | geom

```
qplot(x = cty, y = hwy, data = mpg, geom = "point")
```

Geoms

Use a geom function to represent data points, use the geom's aesthetic properties to represent variables. Each function returns a layer.

GRAPHICAL PRIMITIVES

```
a <- ggplot(economics, aes(date, unemploy))
b <- ggplot(seals, aes(x = long, y = lat))
```

a + geom_blank()
(Useful for expanding limits)

b + geom_curve(aes(yend = lat + 1, xend=long+1,curvature=z)) - x, xend, y, yend, alpha, angle, color, curvature, linetype, size

a + geom_path(lineend="butt", linejoin="round", linemitre=1)
x, y, alpha, color, group, linetype, size

a + geom_polygon(aes(group = group))
x, y, alpha, color, fill, group, linetype, size

b + geom_rect(aes(xmin = long, ymin=lat, xmax= long + 1, ymax = lat + 1)) - xmax, xmin, ymax, ymin, alpha, color, fill, linetype, size

a + geom_ribbon(aes(ymin=unemploy - 900, ymax=unemploy + 900)) - x, ymax, ymin, alpha, color, fill, group, linetype, size

LINE SEGMENTS

common aesthetics: x, y, alpha, color, linetype, size

b + geom_abline(aes(intercept=0, slope=1))
b + geom_hline(aes(yintercept = lat))
b + geom_vline(aes(xintercept = long))

b + geom_segment(aes(yend=lat+1, xend=long+1))
b + geom_spoke(aes(angle = 1:1155, radius = 1))

ONE VARIABLE continuous

```
c <- ggplot(mpg, aes(hwy)); c2 <- ggplot(mpg)
```

c + geom_area(stat = "bin")
x, y, alpha, color, fill, linetype, size

c + geom_density(kernel = "gaussian")
x, y, alpha, color, fill, group, linetype, size, weight

c + geom_dotplot()
x, y, alpha, color, fill

TWO VARIABLES

continuous x , continuous y

```
e <- ggplot(mpg, aes(cty, hwy))
```

e + geom_label(aes(label = cty), nudge_x = 1, nudge_y = 1, check_overlap = TRUE) x, y, label, alpha, angle, color, family, fontface, hjust, lineheight, size, vjust

e + geom_jitter(height = 2, width = 2)
x, y, alpha, color, fill, shape, size

e + geom_point(), x, y, alpha, color, fill, shape, size, stroke

e + geom_quantile(), x, y, alpha, color, group, linetype, size, weight

e + geom_rug(sides = "bl"), x, y, alpha, color, linetype, size

e + geom_smooth(method = lm), x, y, alpha, color, fill, group, linetype, size, weight

e + geom_text(aes(label = cty), nudge_x = 1, nudge_y = 1, check_overlap = TRUE), x, y, label, alpha, angle, color, family, fontface, hjust, lineheight, size, vjust

discrete x , continuous y

```
f <- ggplot(mpg, aes(class, hwy))
```

f + geom_col(), x, y, alpha, color, fill, group, linetype, size

f + geom_boxplot(), x, y, lower, middle, upper, ymax, ymin, alpha, color, fill, group, linetype, shape, size, weight

f + geom_dotplot(binaxis = "y", stackdir = "center"), x, y, alpha, color, fill, group

f + geom_violin(scale = "area"), x, y, alpha, color, fill, group, linetype, size, weight

continuous bivariate distribution

```
h <- ggplot(diamonds, aes(carat, price))
```

h + geom_bin2d(binwidth = c(0.25, 500))
x, y, alpha, color, fill, linetype, size, weight

h + geom_density2d()
x, y, alpha, colour, group, linetype, size

h + geom_hex()
x, y, alpha, colour, fill, size

continuous function

```
i <- ggplot(economics, aes(date, unemploy))
```

i + geom_area()
x, y, alpha, color, fill, linetype, size

i + geom_line()
x, y, alpha, color, group, linetype, size

i + geom_step(direction = "hv")
x, y, alpha, color, group, linetype, size

visualizing error

```
df <- data.frame(grp = c("A", "B"), fit = 4:5, se = 1:2)
j <- ggplot(df, aes(grp, fit, ymin = fit-se, ymax = fit+se))
```

j + geom_crossbar(fatten = 2)
x, y, ymax, ymin, alpha, color, fill, group, linetype, size

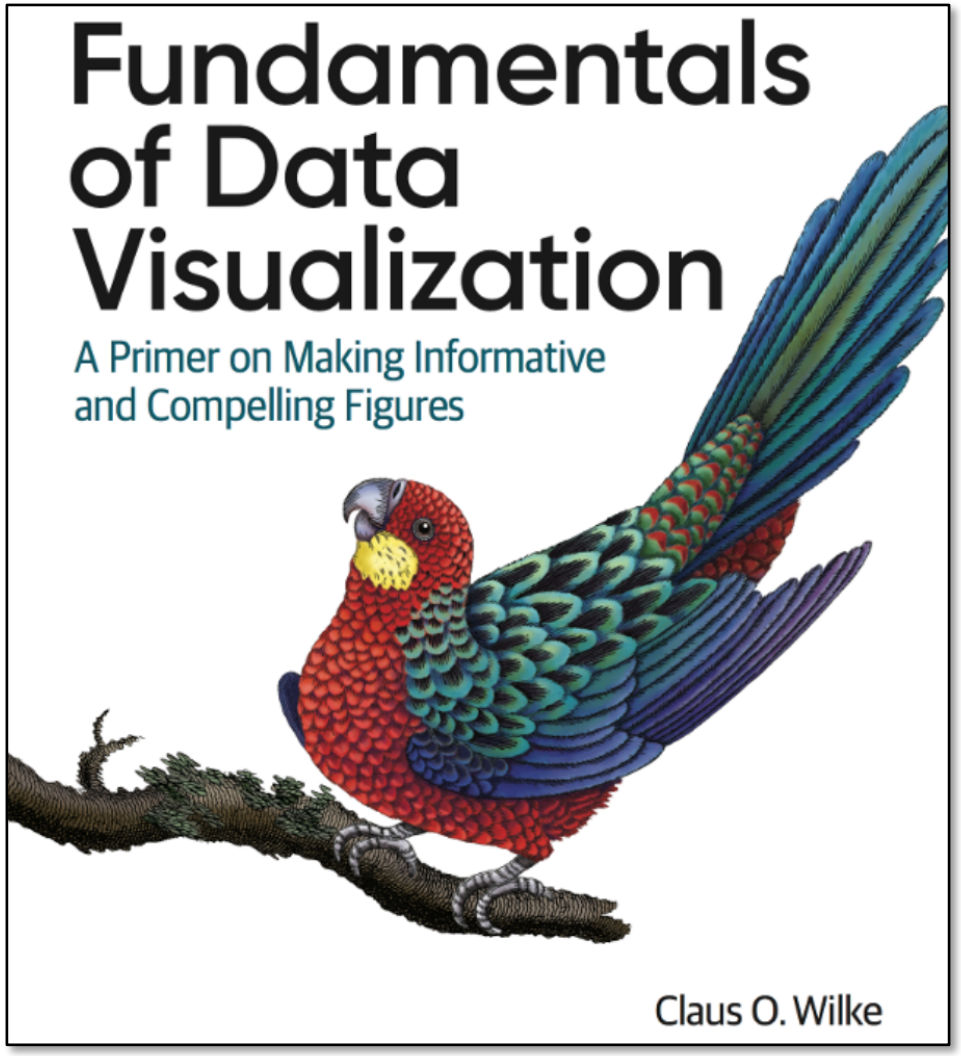
j + geom_errorbar(), x, ymax, ymin, alpha, color, group, linetype, size, width (also **geom_errorbarh()**)

j + geom_linerange()
x, ymin, ymax, alpha, color, group, linetype, size

j + geom_pointrange()
x, y, ymin, ymax, alpha, color, fill, group, linetype, shape, size

maps

```
data <- data.frame(murder = USArrests$Murder
```



https://serialmentor.com/dataviz

To make **any** kind of graph:

1. Choose a "tidy" **data** frame

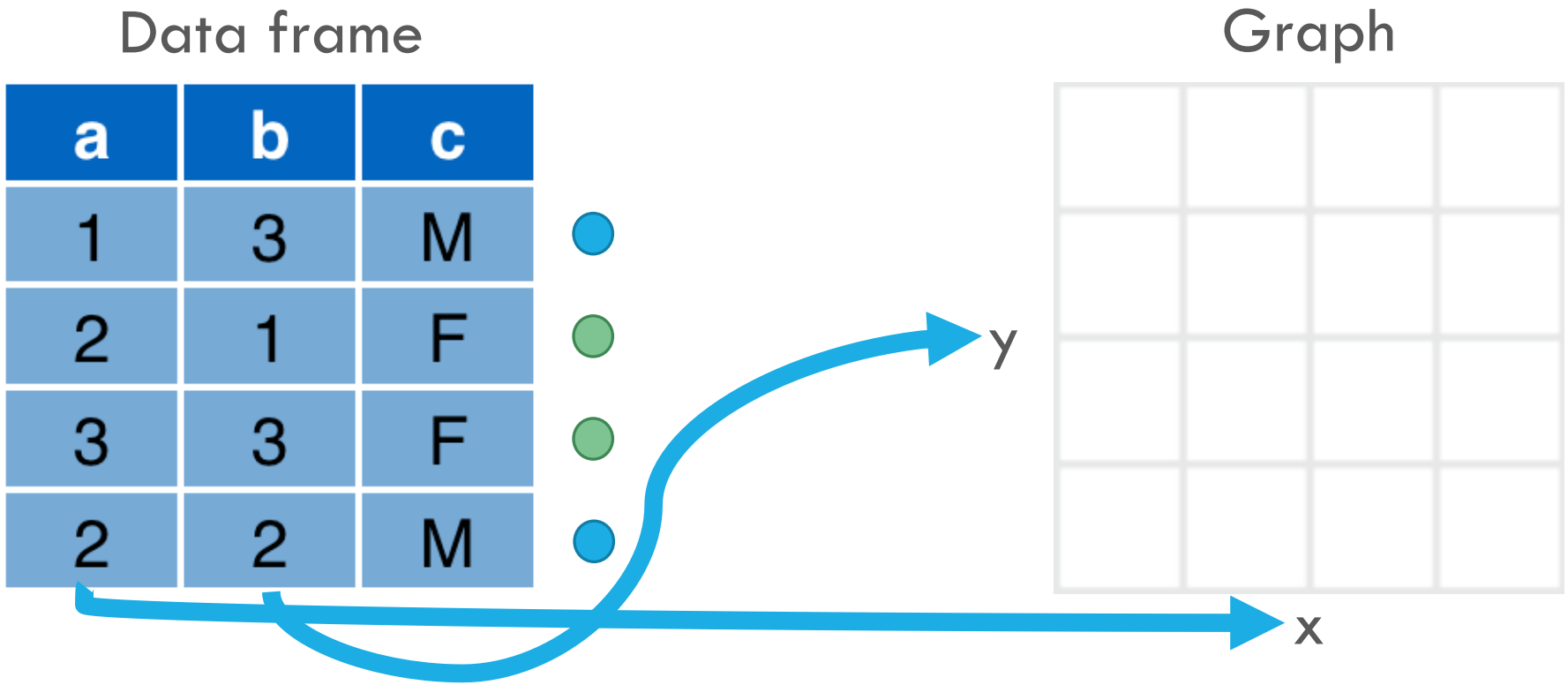
```
ggplot(data = data_frame) +
  geom_function(mapping = aes(mappings))
```

2. Pick a "**geom**" function

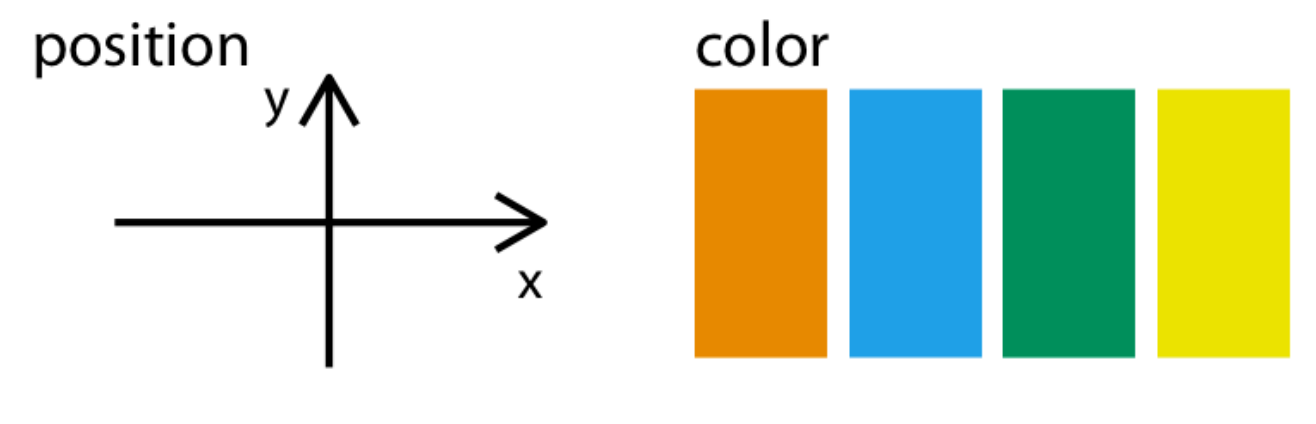
3. Write aesthetic **mappings**

3. Write Aesthetic Mappings

```
aes(x = a, y = b, color = c)
```



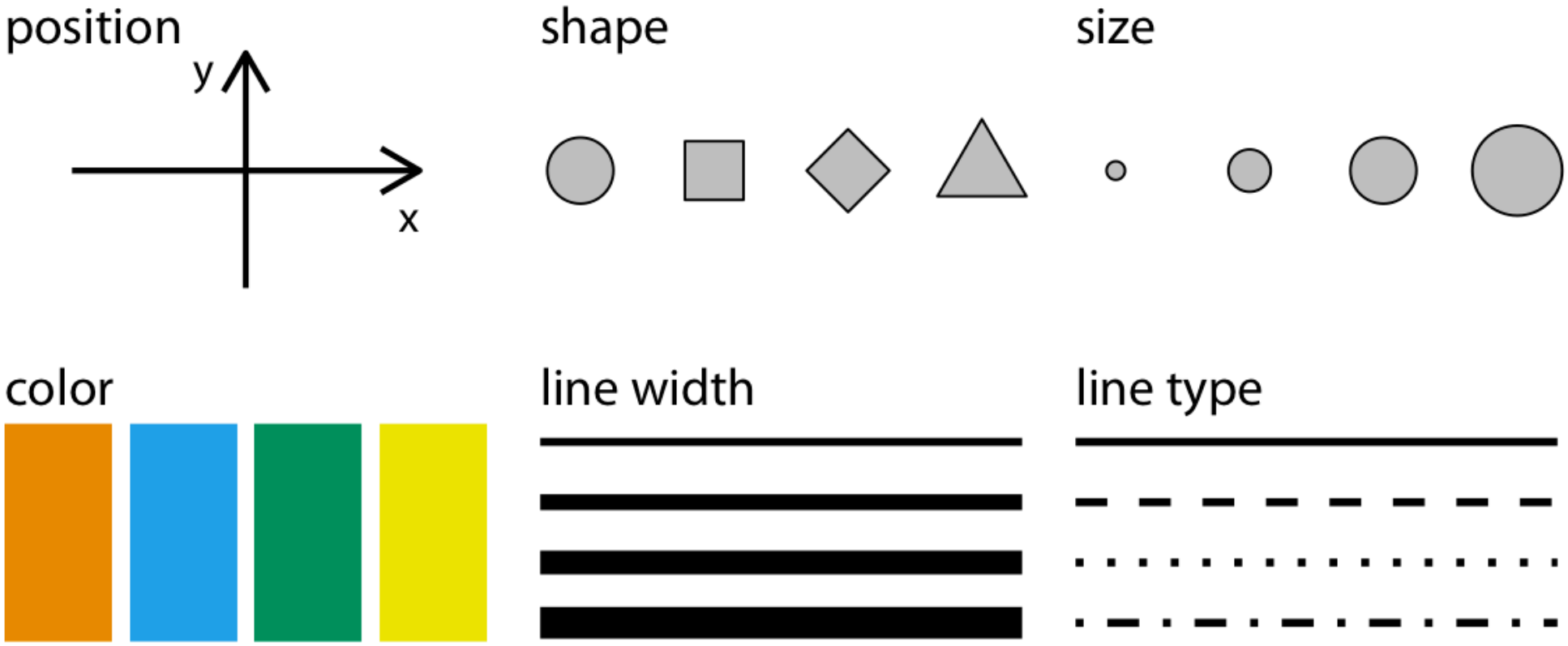
Your Turn 4



In addition to x/y position and color, what other aesthetics can you think of?

Type your answers in the chat!

Aesthetics



From Fundamentals of Data Visualization, by Claus Wilke, licensed under CC-BY-NC-ND

To make **any** kind of graph:

1. Choose a "tidy" **data** frame

```
ggplot(data = data_frame) +
  geom_function(mapping = aes(mappings))
```

2. Pick a "**geom**" function

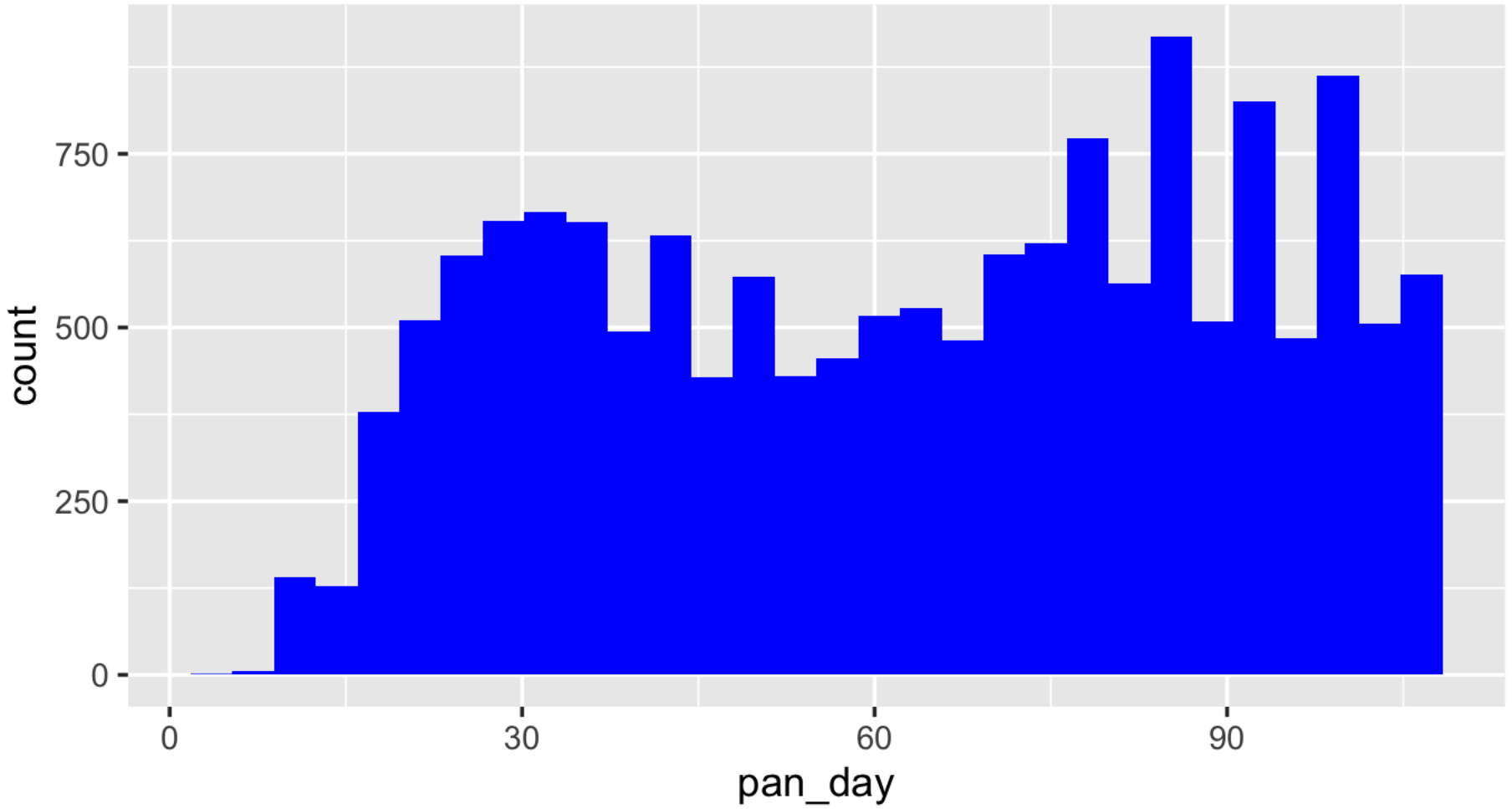
3. Write aesthetic **mappings**

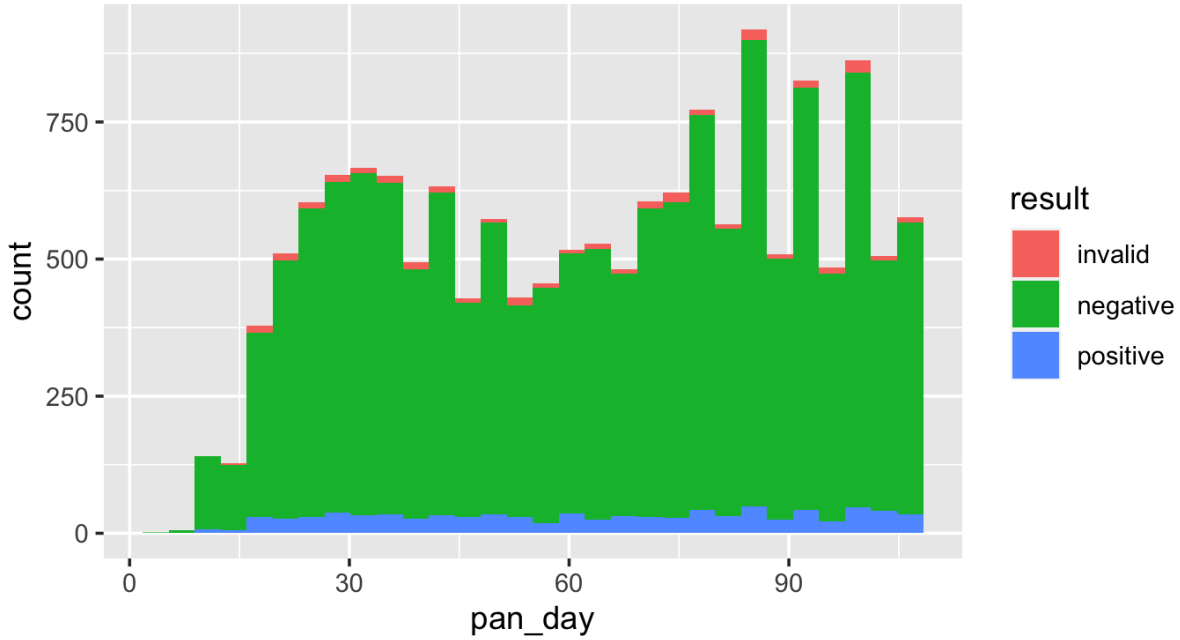
Your Turn 5

Open `03-Visualize.Rmd`. Work through the exercises of the section titled "Your Turn 5."

Setting vs Mapping Aesthetics

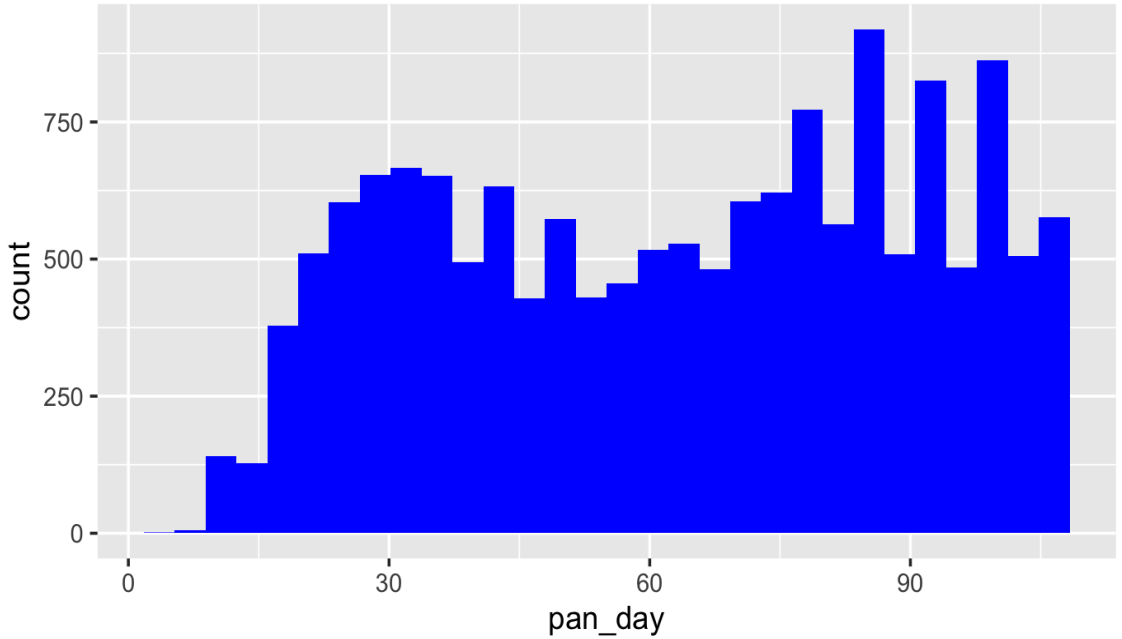
How would you make this plot?





Inside of aes():
map an aesthetic
to a variable

```
ggplot(data = covid_testing) +
  geom_histogram(mapping = aes(x = pan_day, fill = result))
```

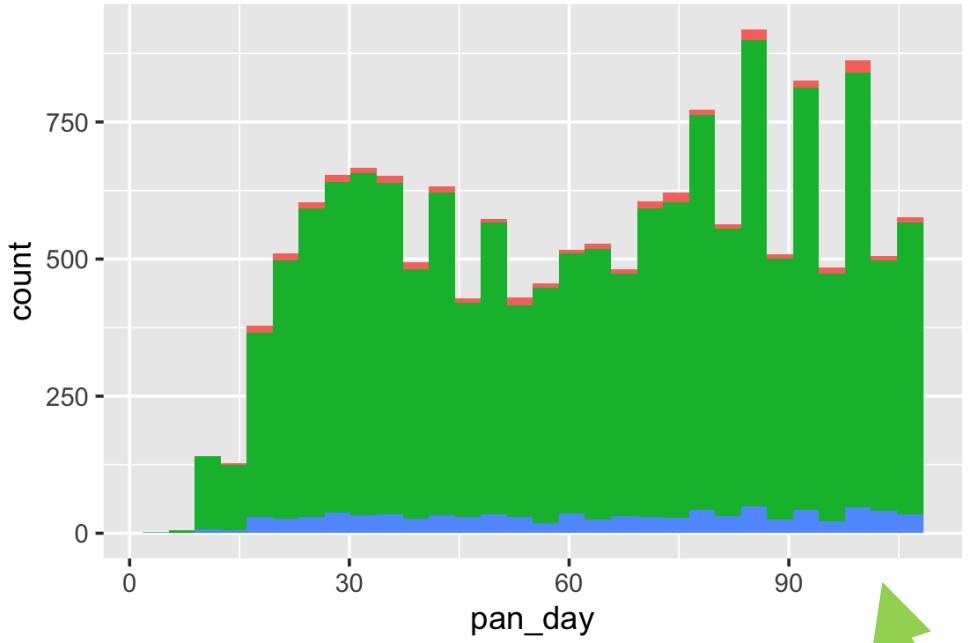


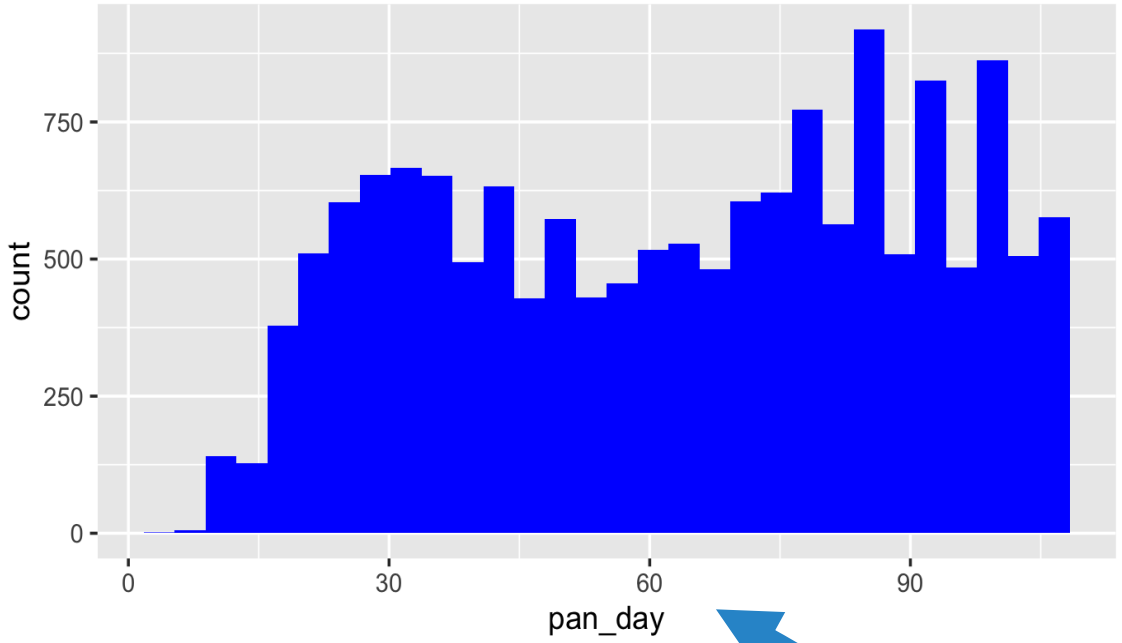
Outside of **aes()**:

set an aesthetic to a **value**

color name in "quotes"

```
ggplot(data = covid_testing) +
  geom_histogram(mapping = aes(x = pan_day), fill = "blue")
```



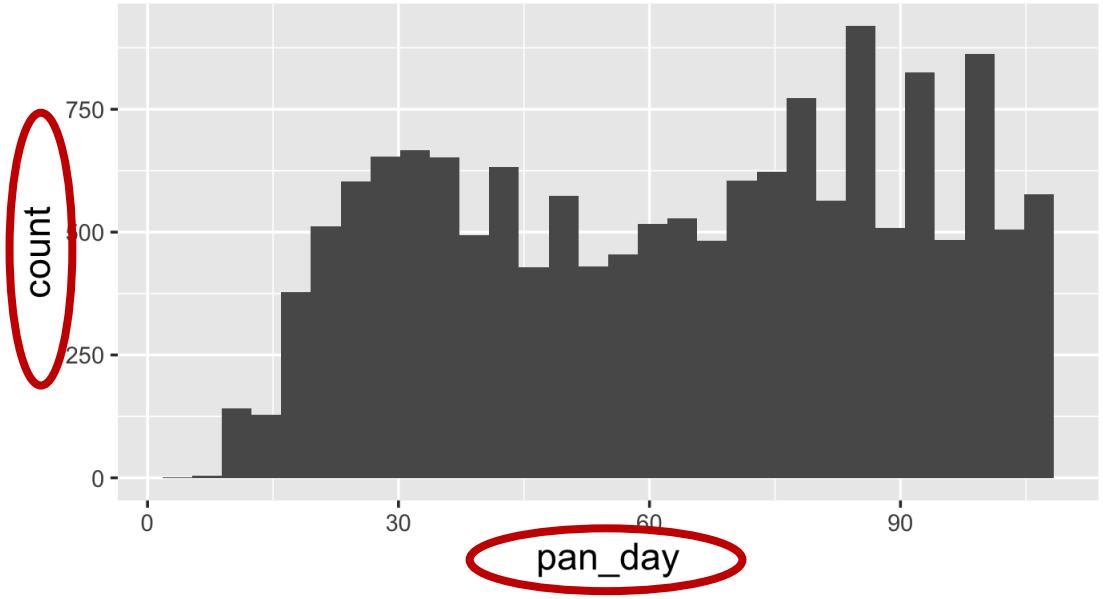


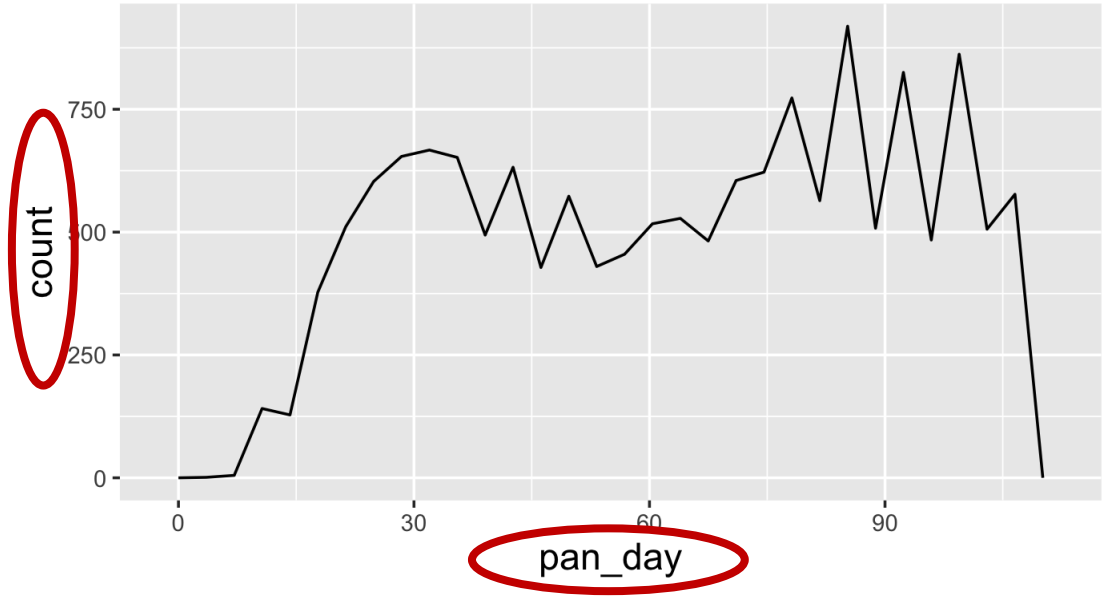

```
ggplot(data = covid_testing) +
  geom_histogram(mapping = aes(x = pan_day, fill = result))
```

```
ggplot(data = covid_testing) +
  geom_histogram(mapping = aes(x = pan_day), fill = "blue")
```

Geom Functions

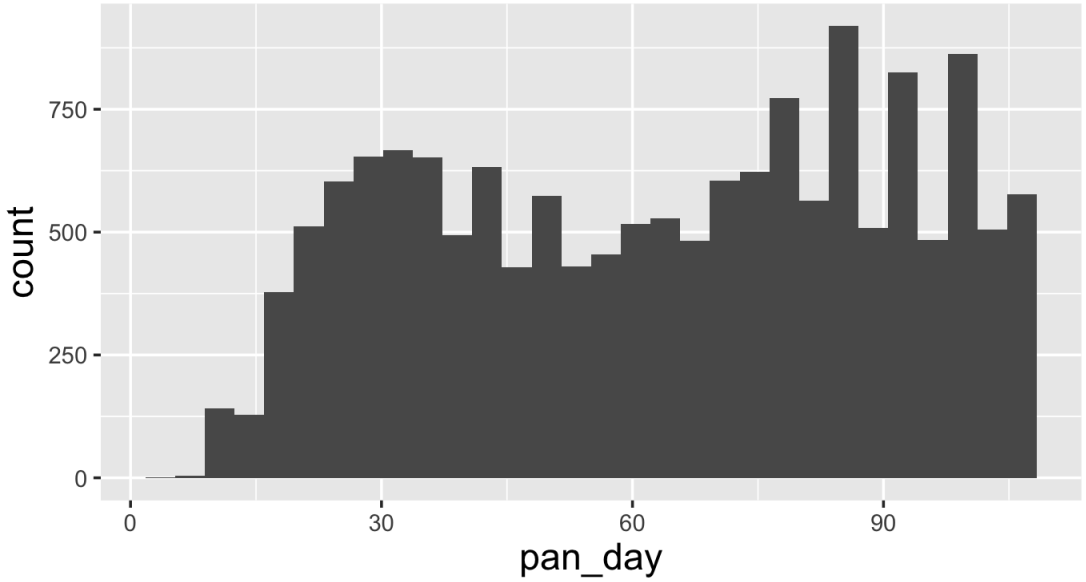
How are these plots similar?

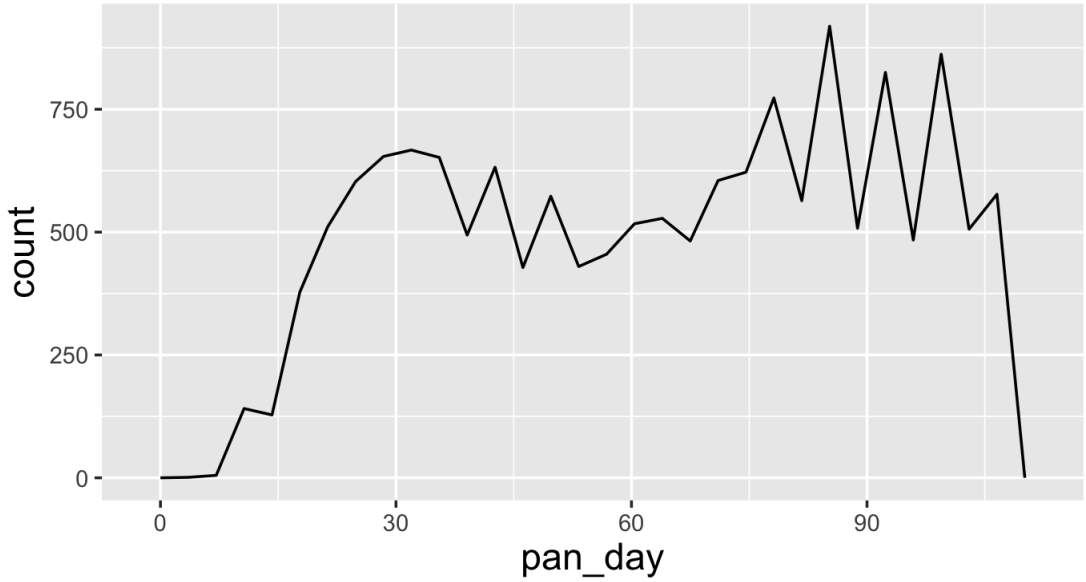




Same: x axis, y axis, data

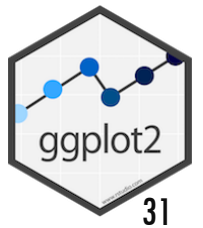
How are these plots different?





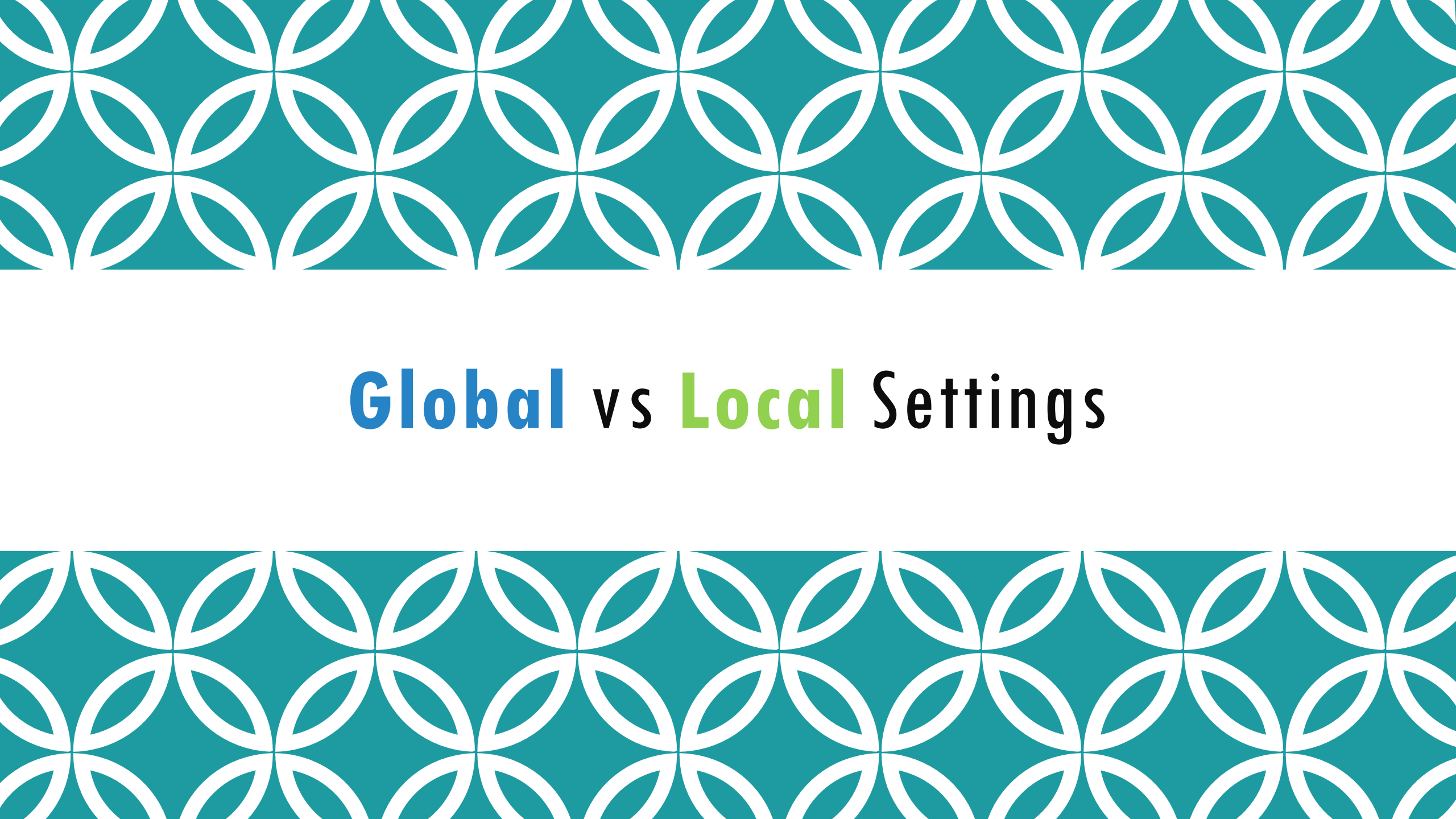
Different **geometric object** ("geom") used to represent the data

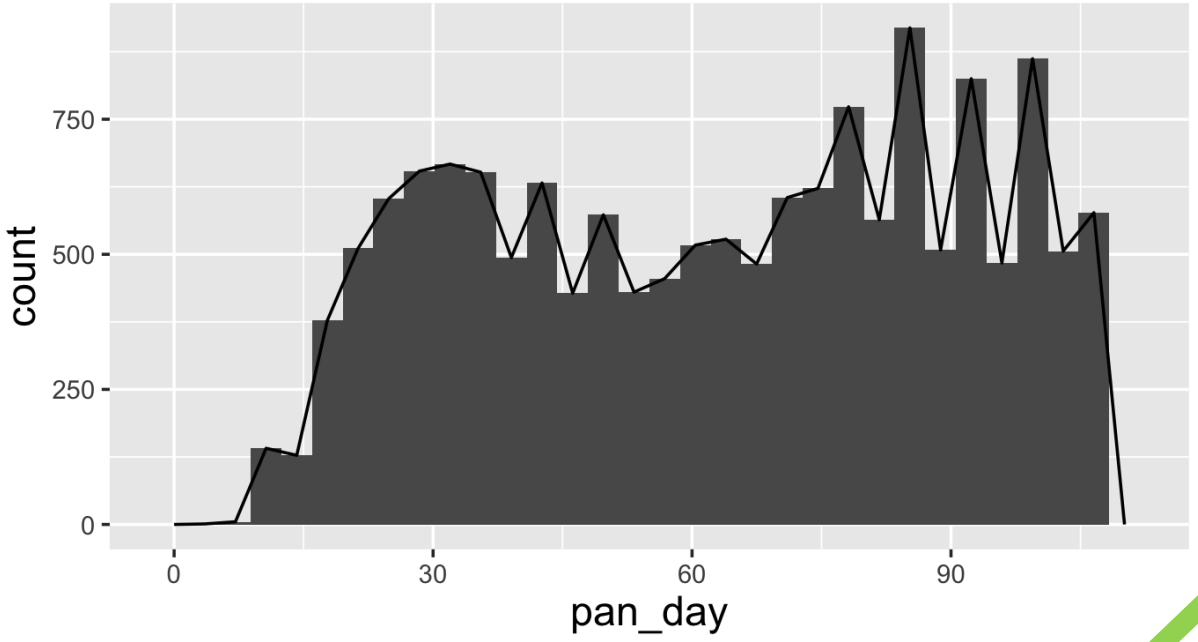
```
ggplot(data = data_frame) +
  geom_function(mapping = aes(mappings))
```



Your Turn 6

Open `03-Visualize.Rmd`. Work through the exercises of the section titled "Your Turn 6."


Global vs Local Settings



Inside of geom_ function: apply locally to only the current layer

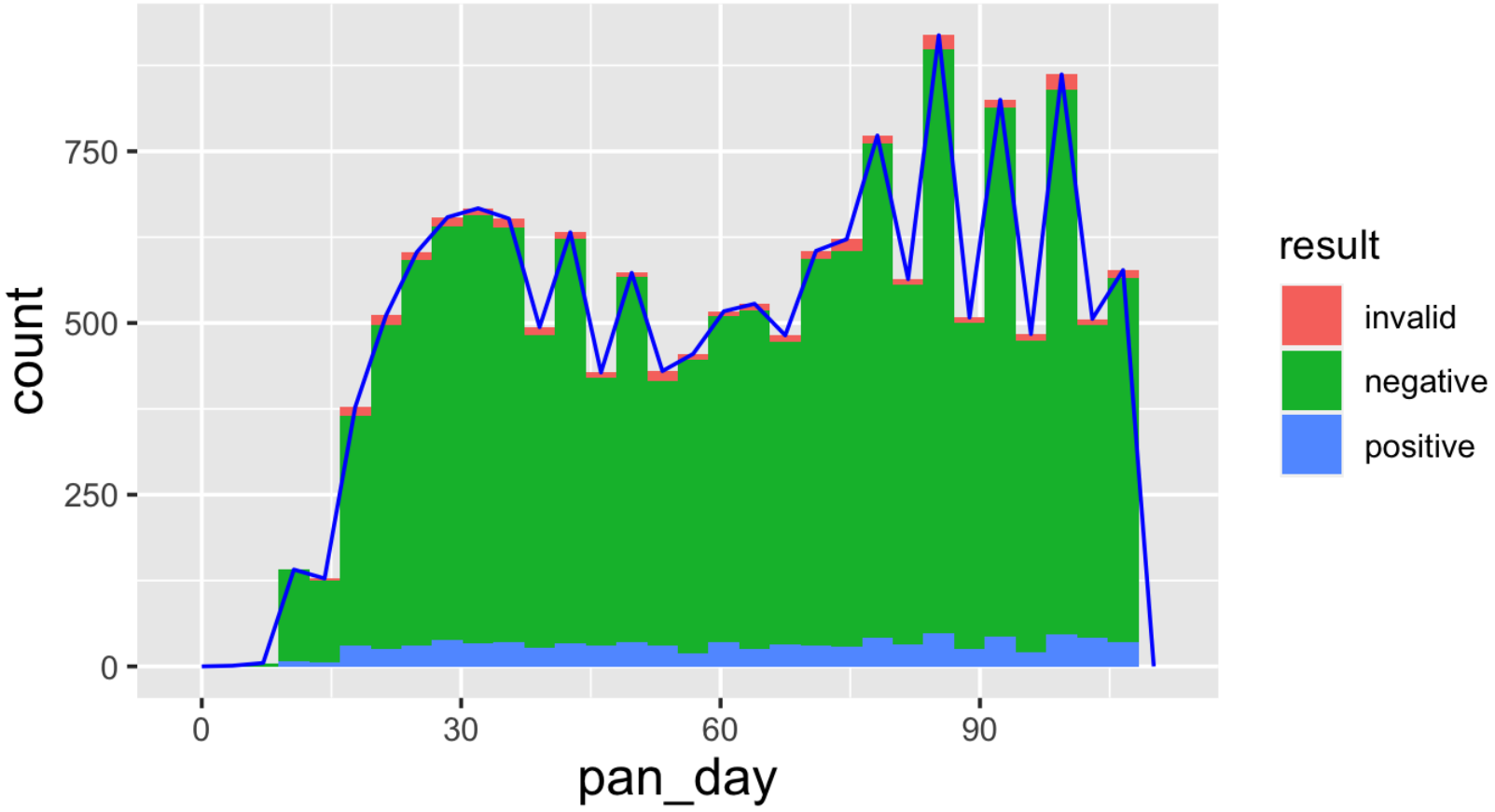
Inside of ggplot(): apply globally to every layer

```
ggplot(data = covid_testing) +
  geom_histogram(mapping = aes(x = pan_day)) +
  geom_freqpoly(mapping = aes(x = pan_day))
```

```
ggplot(data = covid_testing, mapping = aes(x = pan_day)) +
  geom_histogram() +
  geom_freqpoly()
```

empty ()

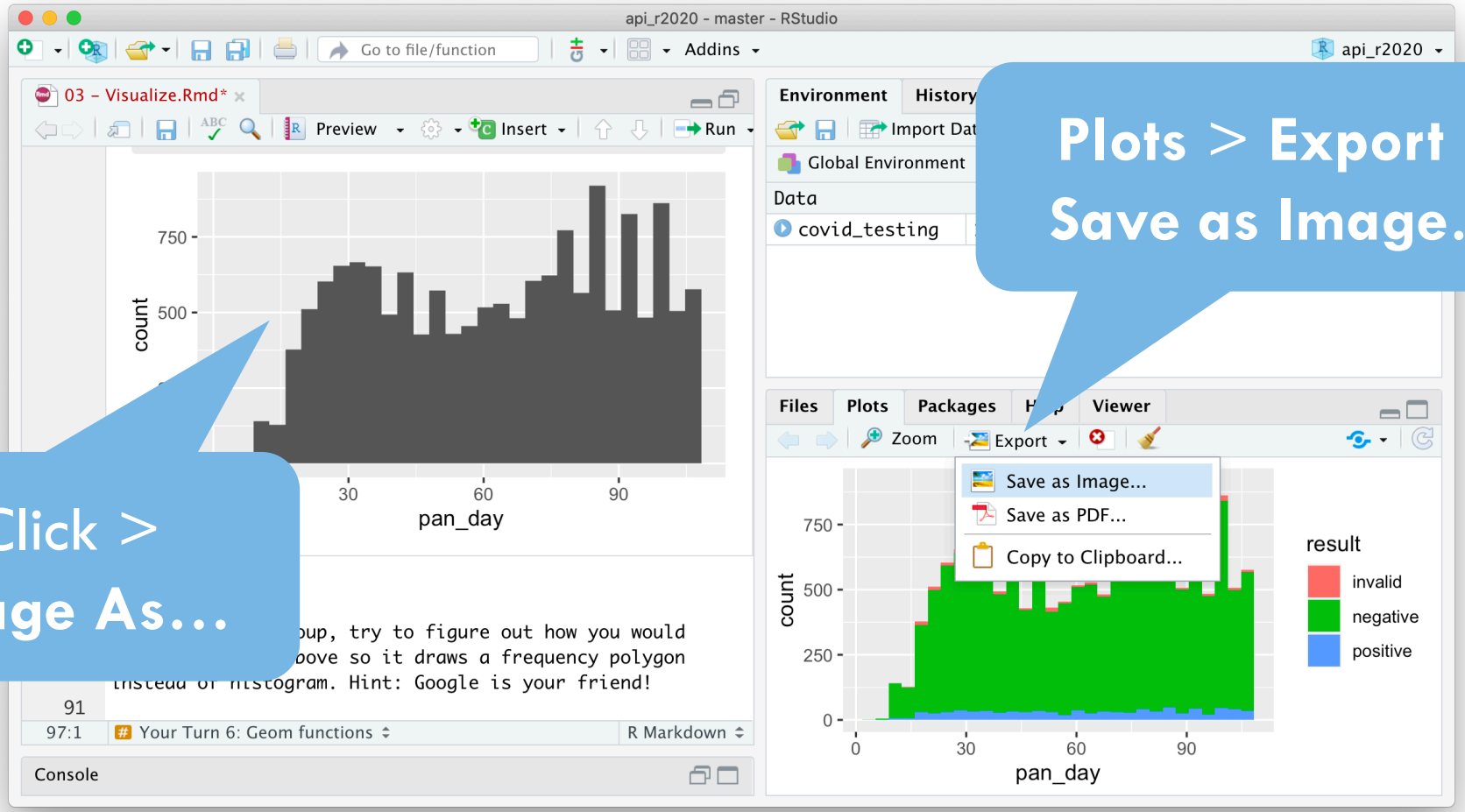
How would you make this plot?




```
ggplot(data = covid_testing, mapping = aes(x = pan_day)) +
  geom_histogram(mapping = aes(fill = result)) +
  geom_freqpoly(color = "blue")
```

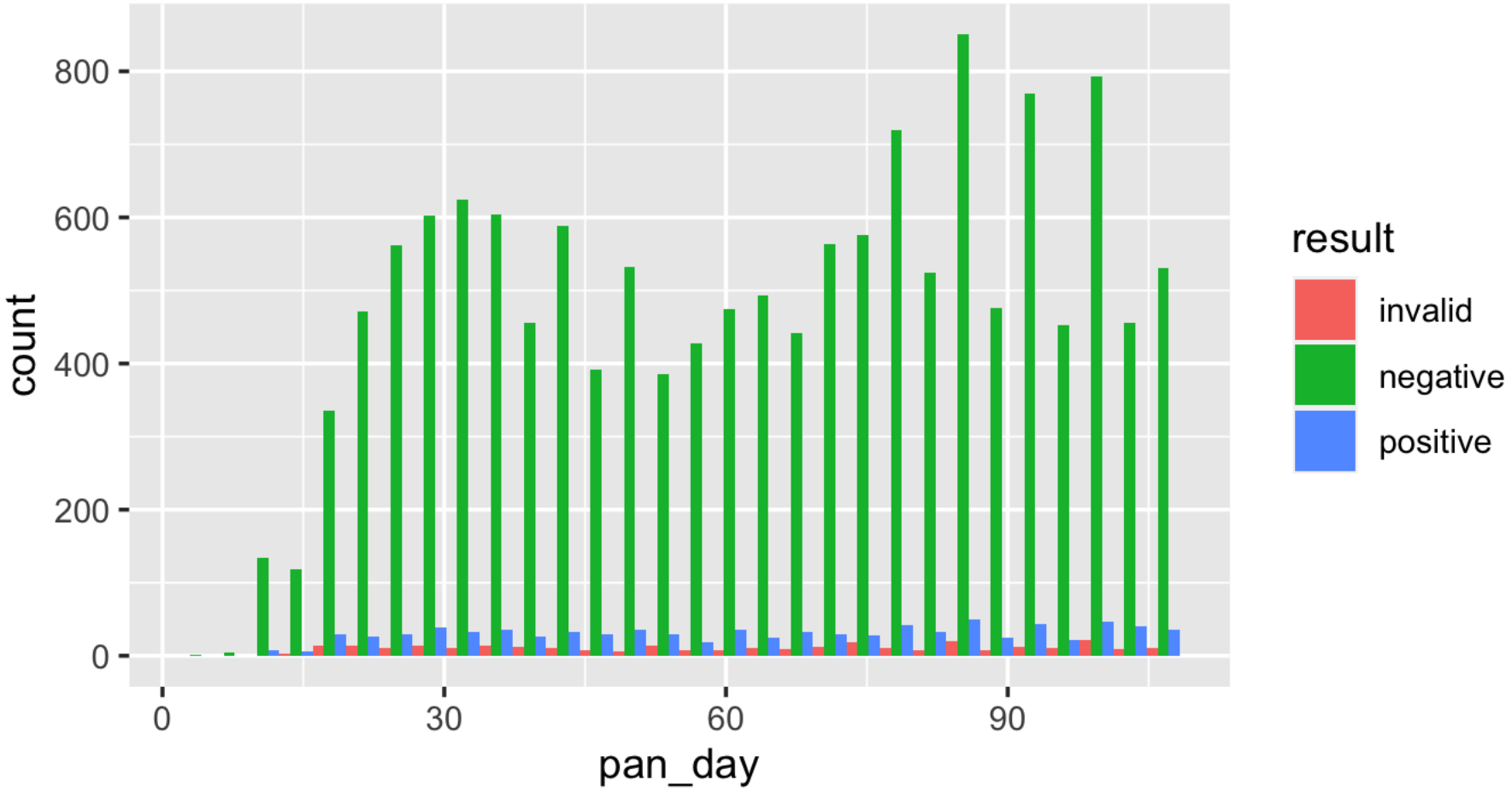
What Else?

Manually saving plots



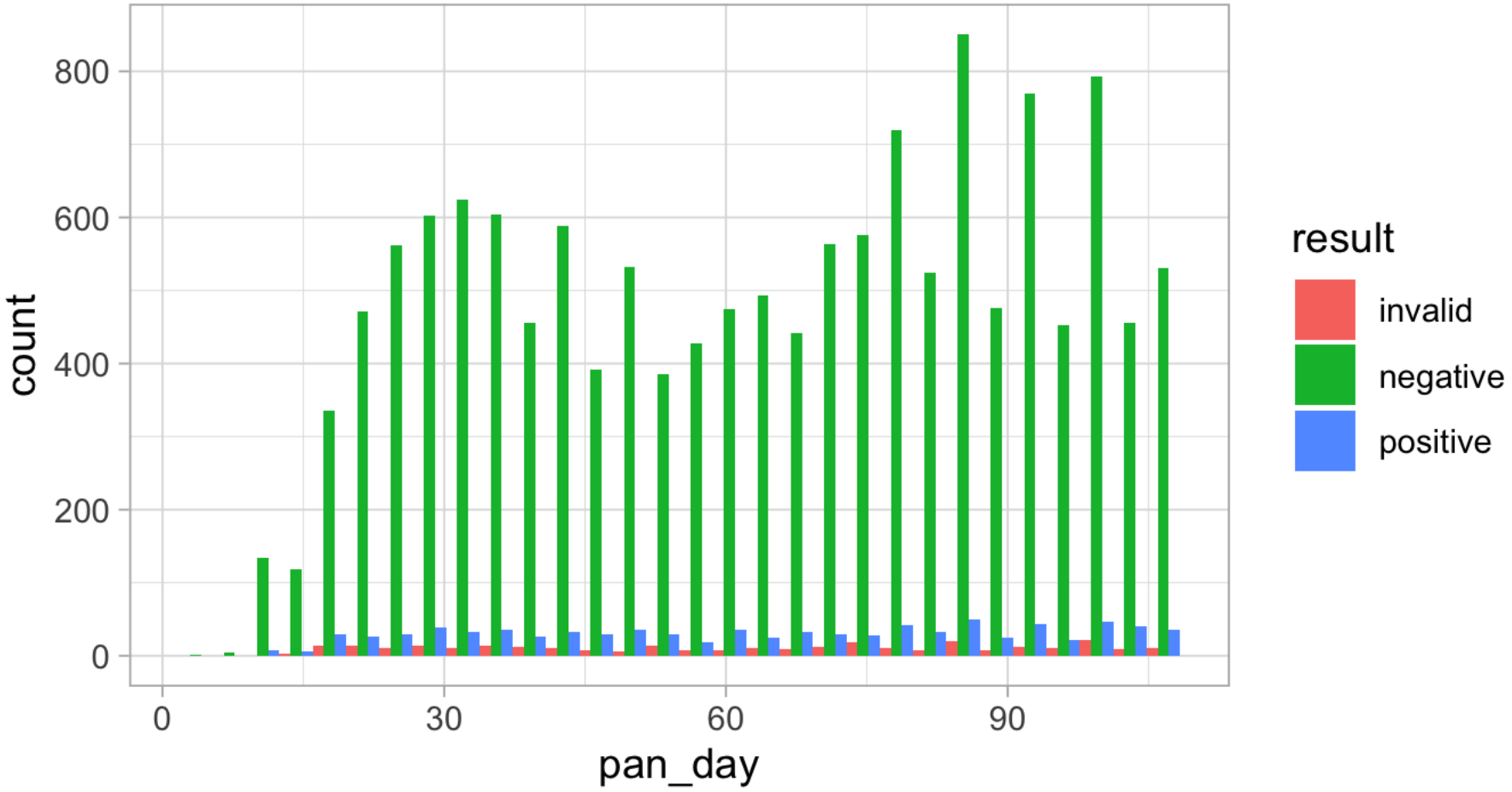
Position adjustments

How overlapping objects are arranged



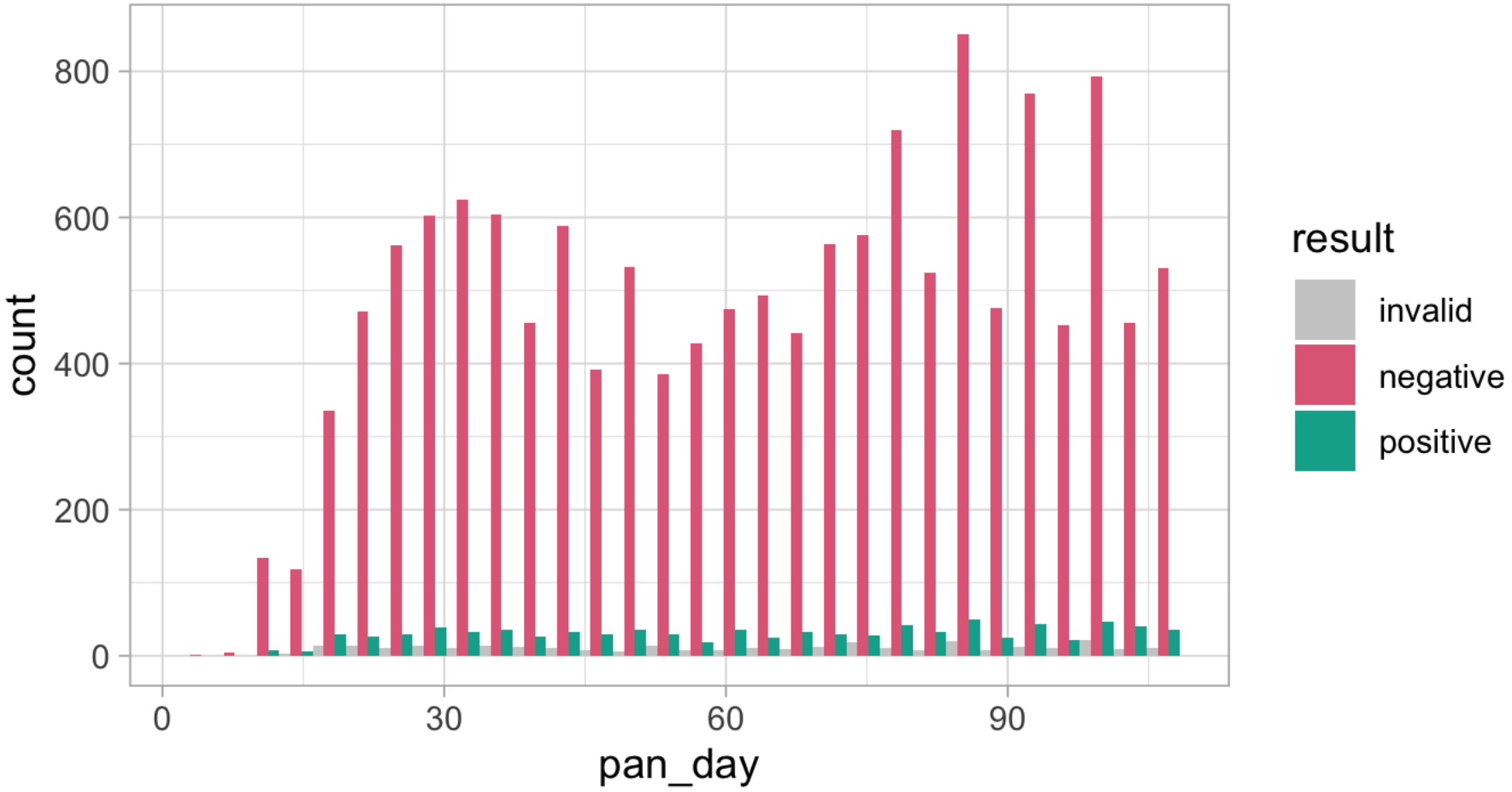
Themes

Visual appearance of non-data elements



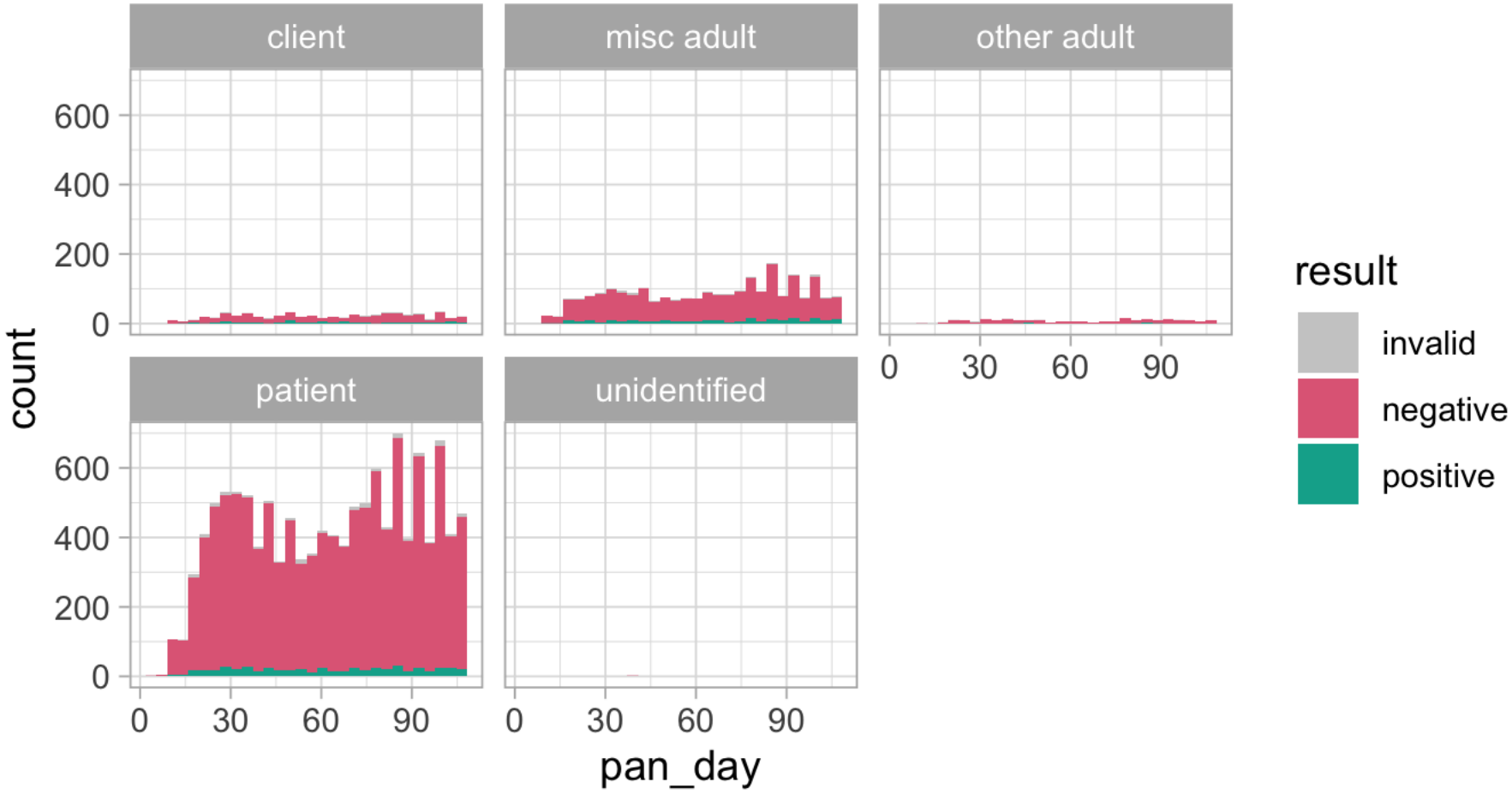
Scales

Customize color scales and other mappings

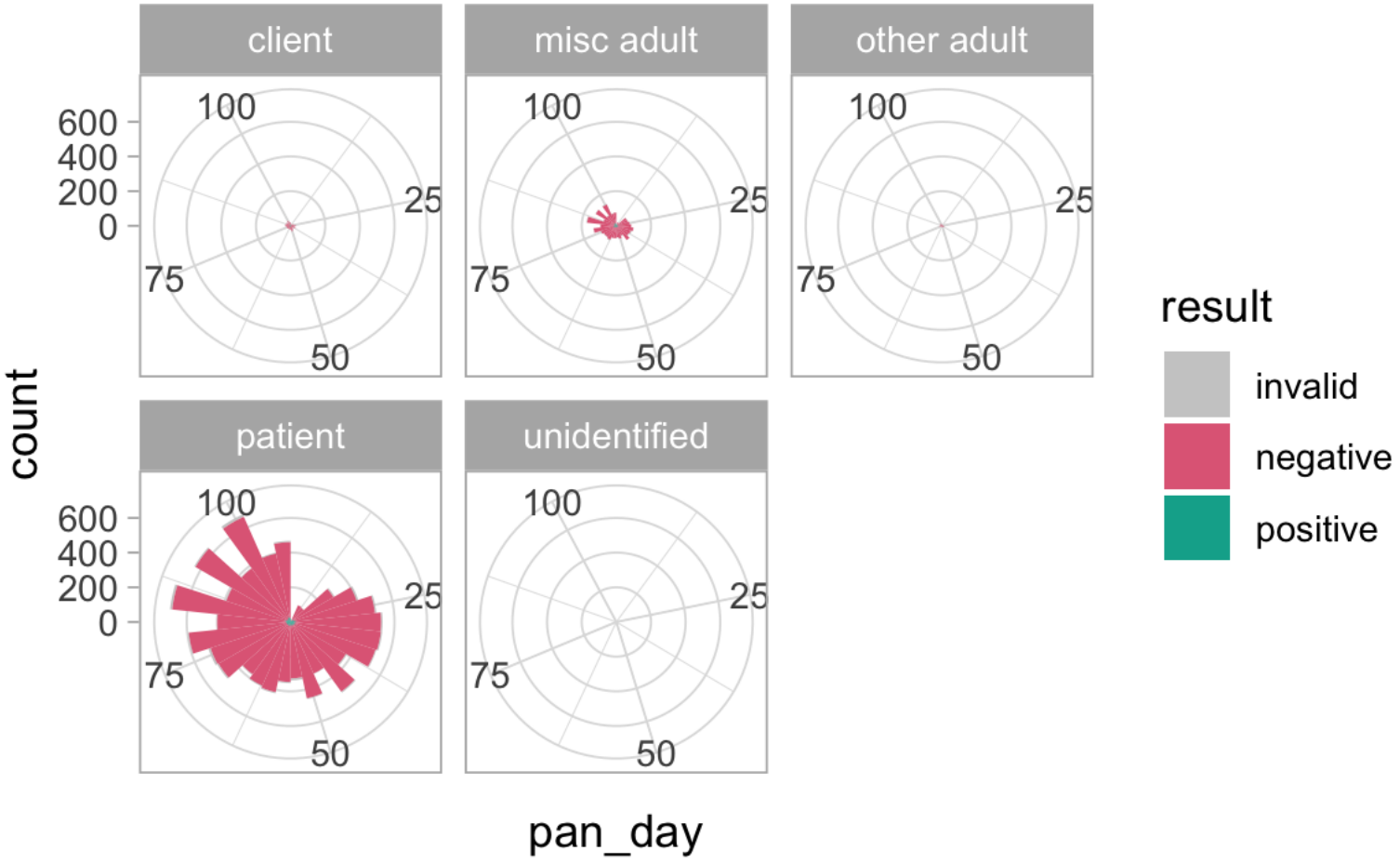


Facets

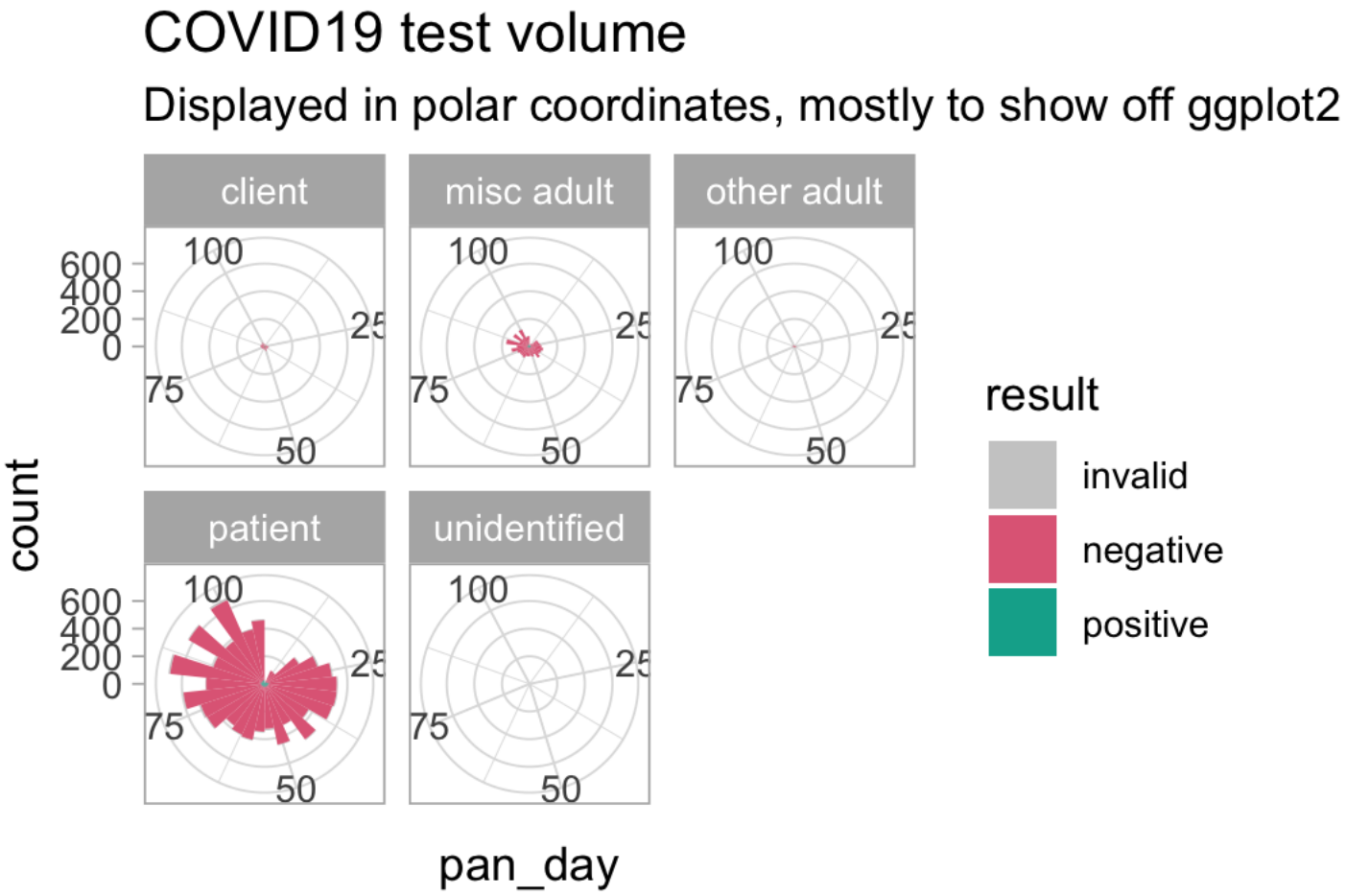
Subplots that display subsets of the data



Coordinate systems



Titles and captions



```
ggplot(data = data_frame) +
  geom_function(mapping = aes(mappings)) +
  theme_function +
  scale_function +
  facet_function +
  coordinate_function +
  ...
```

Required

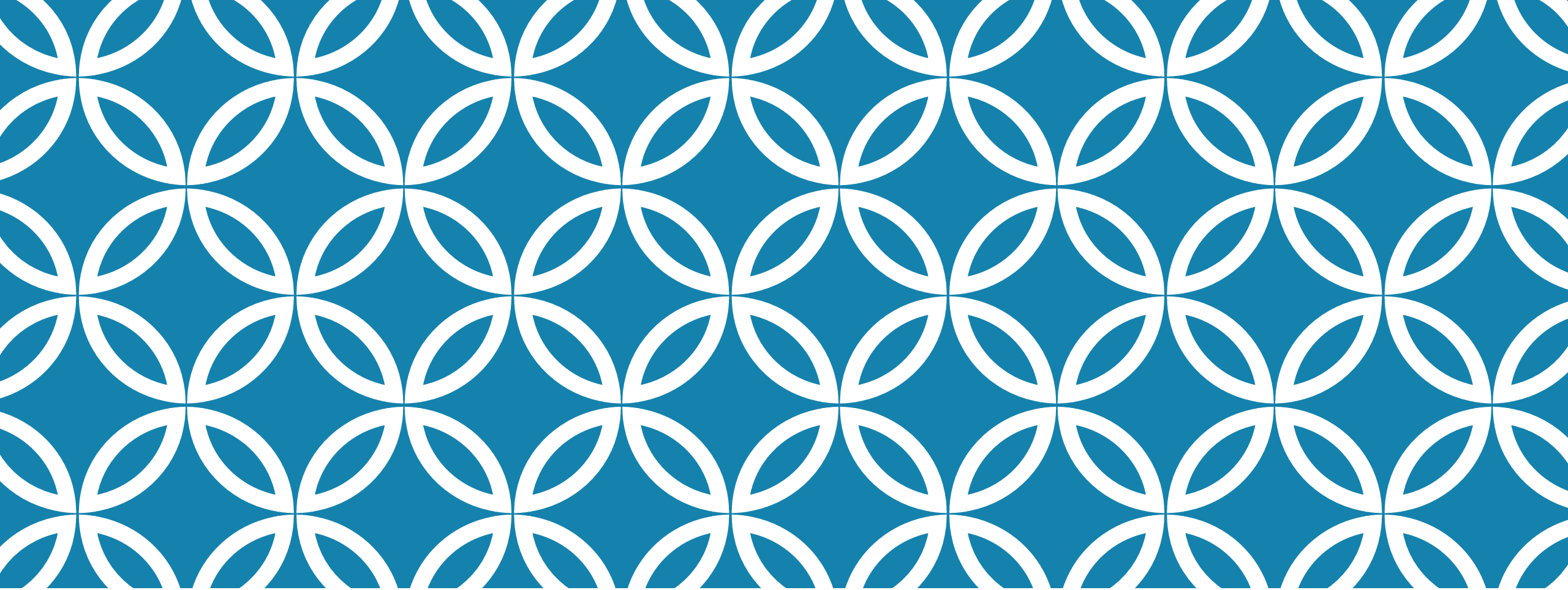
Optional

Goals

1. Appreciate the importance of visualization for understanding data
2. Learn how to use ggplot2 to visualize data

Objectives

1. Create a basic visualization using a simple template
2. Define “aesthetic mapping” and explain how aesthetic mappings relate variables of a data frame to features of graphic markings on a plot
3. Write the code to specify a type of plot and fine tune its appearance using “geom” functions
4. Explain how to add layers to a ggplot object to create complex and highly customized visualizations



Data Transformation

Session 4

Amrom Obstfeld

August 23, 2020

August 16 2020	**Session**	**Instructor**
9:00 am - 9:30 am	Instructor Introductions, Introduction to technology	Amrom Obstfeld
9:30 am - 10:15 am	Introduction to R and RStudio	Amrom Obstfeld
10:30 pm - 11:15 am	Reproducible Reporting	Amrom Obstfeld
11:30 am - 1:00 am	Data Visualization	Stephan Kadauke
August 23 2020		
9:00 am - 10:30 pm	Data Transformation	Amrom Obstfeld
10:45 am - 12:15 pm	Statistical Analysis	Dan Herman
12:30 pm - 1:00 pm	Workshop Close out	Amrom Obstfeld

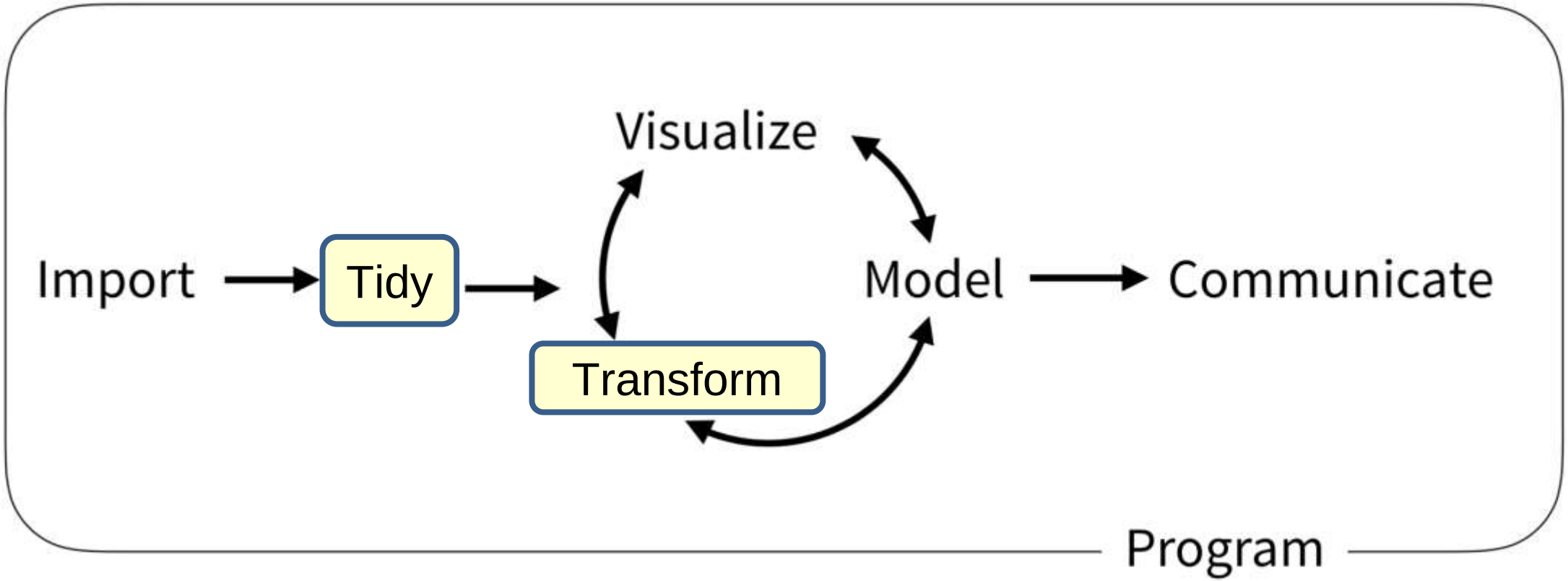
Goal

1. Learn how to use dplyr to transform data frames
2. Appreciate the role of piping in facilitating data transformation

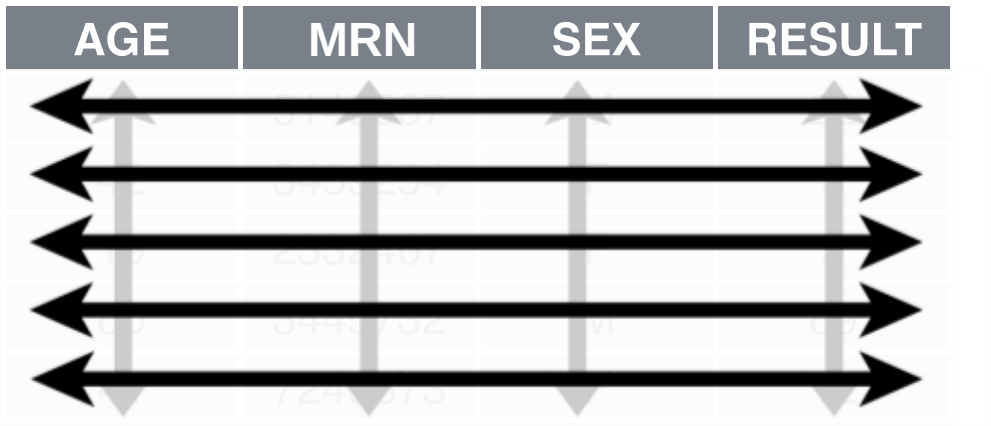
Objectives

1. List the major forms of data transformation implemented in dplyr
2. Use code templates with dplyr functions to tidy a raw data set
3. Use the pipe operator to pass the output of one function as an input to the next function
4. Create new calculated columns not found in the original data frame

Typical Data Science Pipeline



What is a “Tidy” Data Frame



A data set is **tidy** if:

1. Each **variable** is in its own **column**
2. Each **observation** is in its own **row**
3. Each **value** is in its own **cell**

Your Turn 1

Open "**04-Transform.Rmd**"

Run the setup chunk

Pop Quiz

How can you confirm that you have successfully loaded the data file into Rstudio?

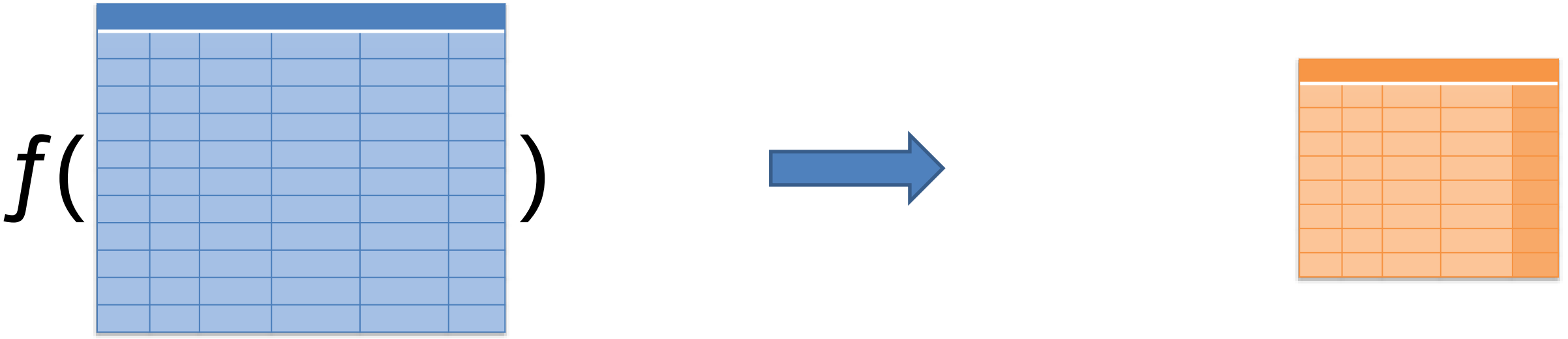
1. The code that imported the data did not yield an error
2. Code that references the `covid_testing` object runs without errors
3. The `covid_testing` object is present in the environment pane
4. All of the above

Transform Data with

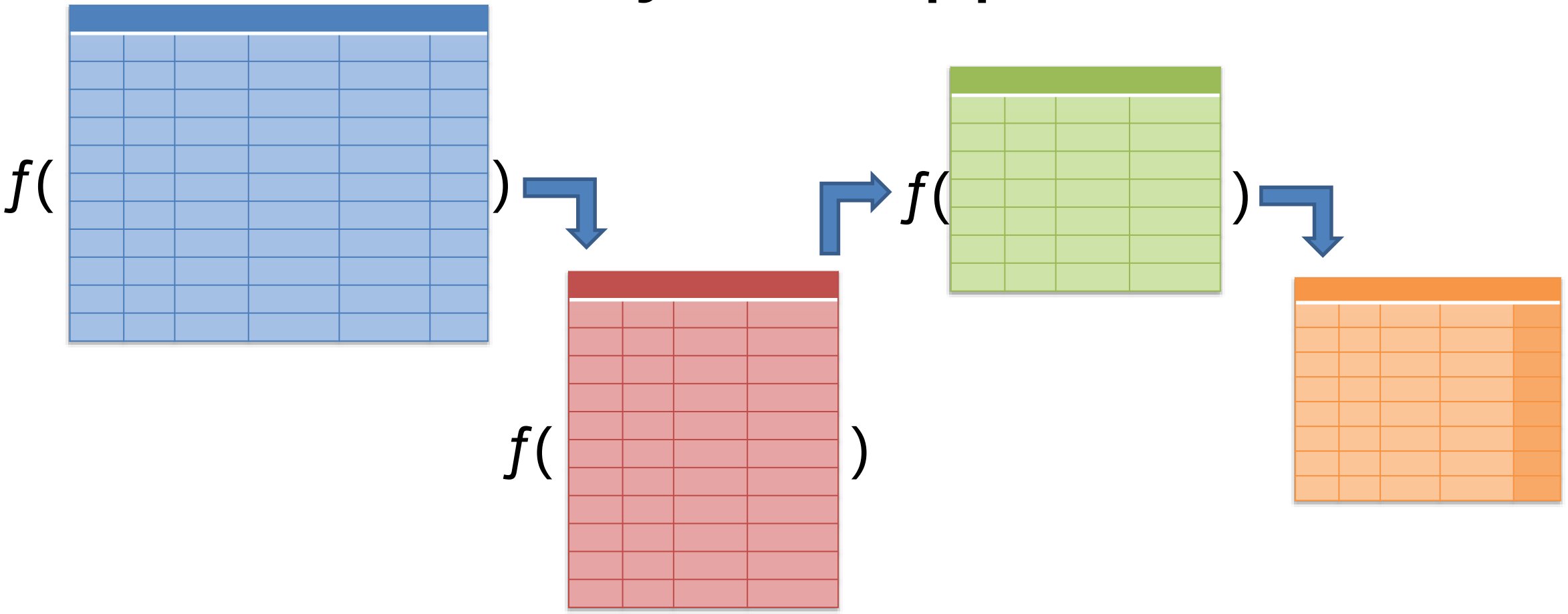
dplyr

dplyr implements a *grammar* for transforming tabular data.

Analytical Approach



Analytical Approach



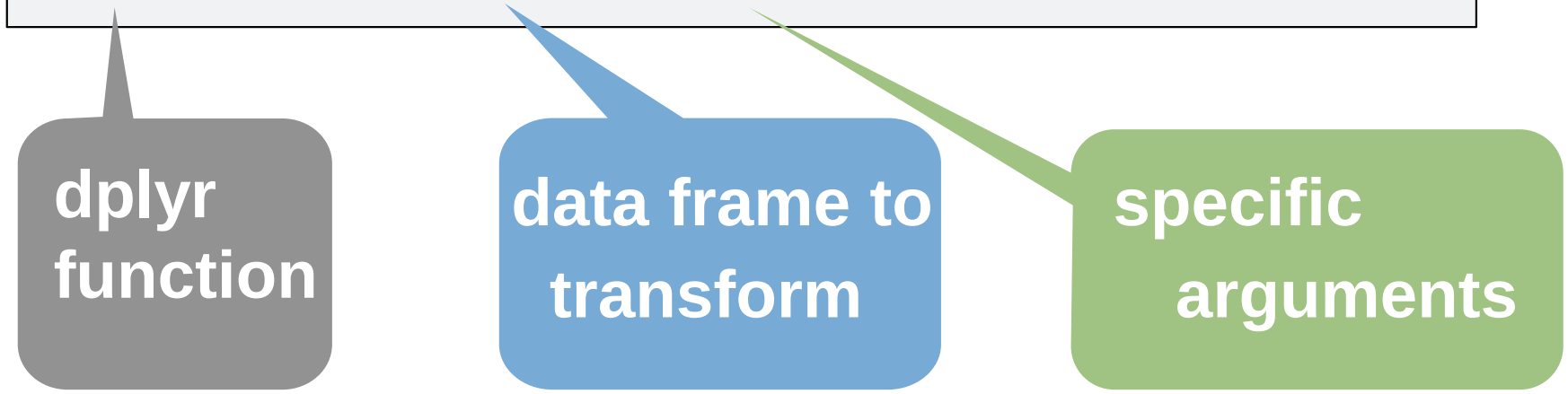
dplyr: a grammar for transforming data

1. **Choose** columns. — **select()**
2. **Extract** rows. — **filter()**
3. **Derive** new columns. — **mutate()**
4. **Change** the unit of analysis. — **summarize()**

Common syntax

Each function takes a data frame as its first argument and returns a data frame as its output.

```
function(data, ...)
```

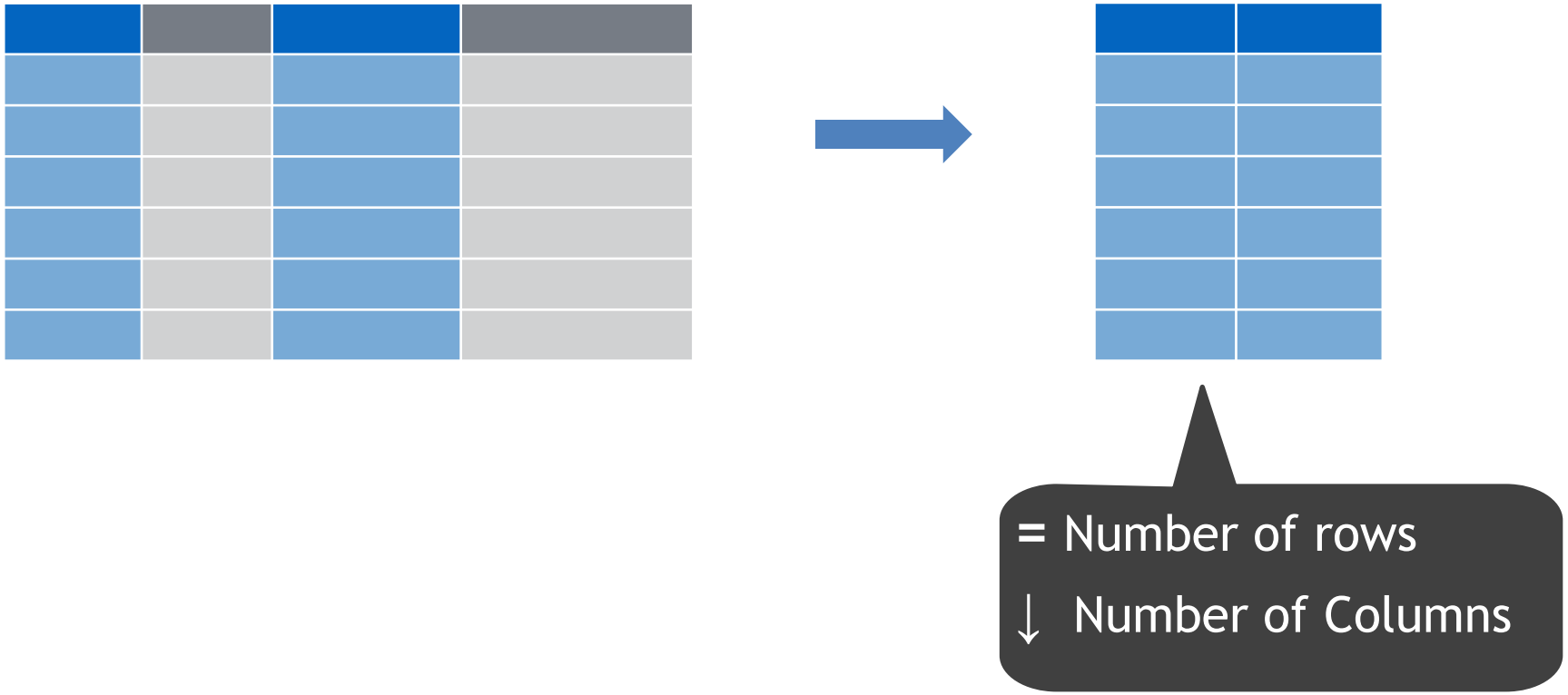


Isolating data

select()

select()

Extract columns from a data frame



select()

Extract columns from a data frame

```
select(covid_testing, mrn, last_name)
```

dplyr function

data frame to transform

name(s) of columns to extract
(or a select helper)

select()

Extract columns from a data frame **by name**

```
select(covid_testing, mrn, last_name)
```

covid_testing

mrn	first_name	last_name	gender
5000876	sarella	stark	female
5006017	alester	stark	male
5001412	jhezane	westerling	female
5000533	penny	targaryen	female
...			

mrn	last_name
5000876	stark
5006017	stark
5001412	westerling
5000533	targaryen

select()

Extract columns from a data frame **by name**

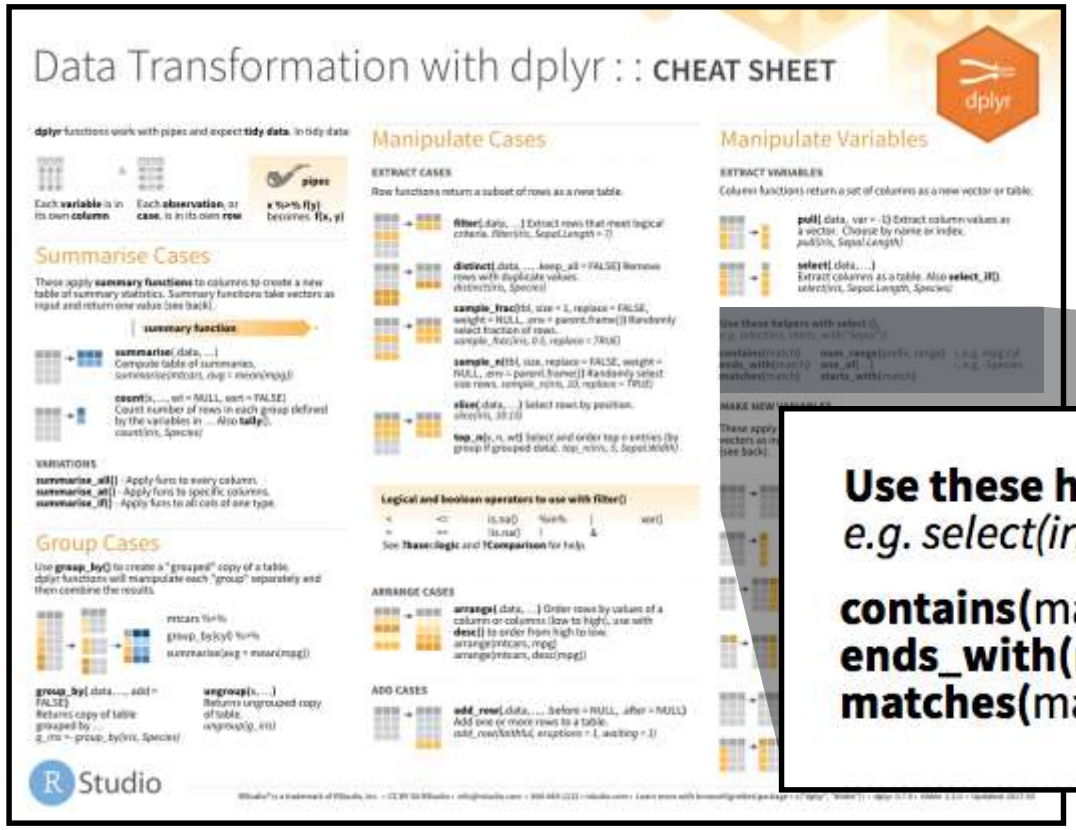
```
select(covid_testing, -mrn, -last_name)
```

covid_testing

mrn	first_name	last_name	gender
5000876	sarella	stark	female
5006017	alester	stark	male
5001412	jhezane	westerling	female
5000533	penny	targaryen	female
...			

first_name	gender
sarella	female
alester	male
jhezane	female
penny	female

select() helpers



Use these helpers with select (),
e.g. select(iris, starts_with("Sepal"))

contains(match)	**num_range**(prefix, range)	**:**, e.g. mpg:cyl
ends_with(match)	**one_of**(…)	**-**, e.g, -Species
matches(match)	**starts_with**(match)	

dplyr

Your Turn 2

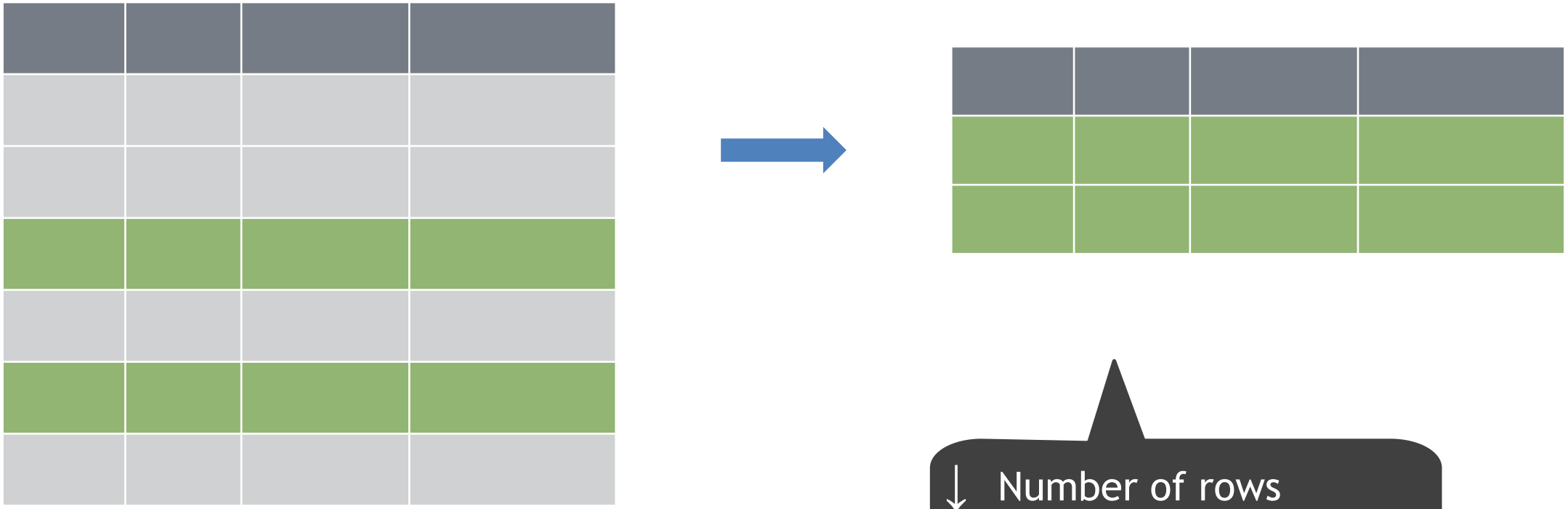
- Alter the code to select just the `first_name` column from `covid_testing`
- If you have time, try to remove the `first_name` column

```
covid_testing_2 <- select(covid_testing, _____)
```

filter()

filter()

Extract rows that meet logical criteria



↓ Number of rows

= Number of Columns

Common syntax

Each function takes a data frame as its first argument and returns a data frame as its output.

```
function(data, ...)
```

dplyr function

data frame to transform

specific arguments

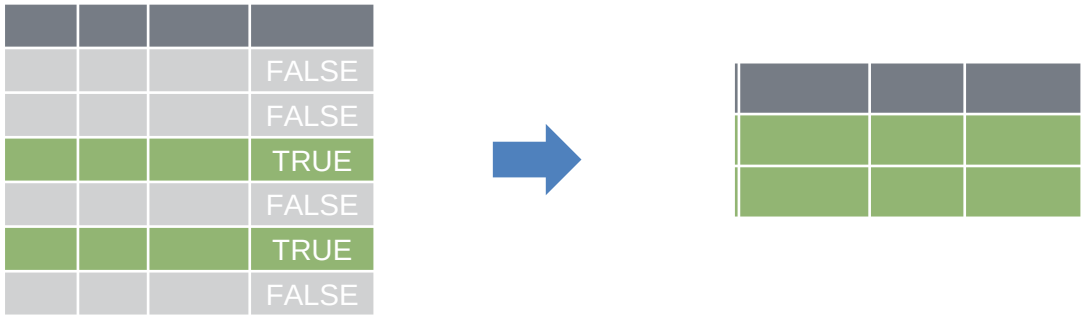
filter()

Extract rows that meet logical criteria

```
filter(data,... )
```

data frame to transform

one or more logical tests (filter returns each row for which the test is TRUE)

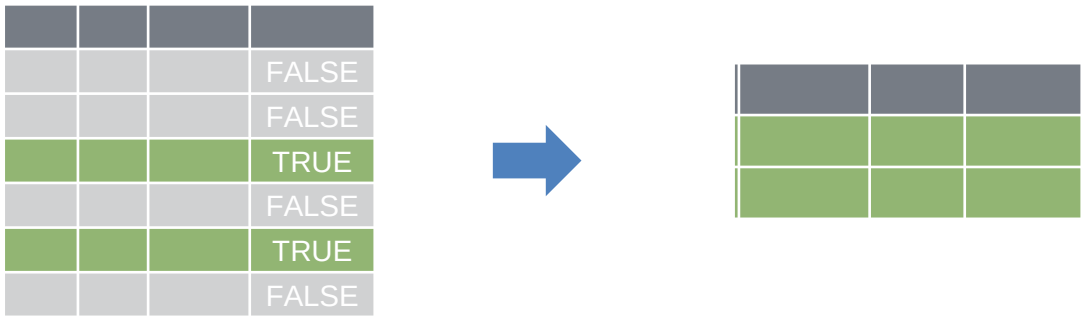


filter()

Extract rows that meet logical criteria

```
filter(data, column_name == criteria )
```

one or more logical tests
(filter returns each row for which the test is TRUE)



filter()

Extract rows that meet logical criteria

```
filter(covid_testing, mrn==5000083)
```

	mrn	first_name	last_name
FALSE	5000876	sarella	stark
FALSE	5006017	alester	stark
FALSE	5001412	jhezane	westerling
TRUE	5000083	lollys	clegane

mrn	first_name	last_name
5000083	lollys	clegane

filter()

Extract rows that meet logical criteria

```
filter(covid_testing, mrn==5000083)
```

mrn	first_name	last_name
5000876	sarella	stark
5006017	alester	stark
5001412	jhezane	westerling
5000083	lollys	clegane

= sets

(returns nothing)

== tests if equal

(returns TRUE or FALSE)

filter()

Values coded as character strings must be surrounded by quotes

Extract rows that meet logical criteria.

```
filter(covid_testing, last_name=="stark")
```

mrn	first_name	last_name	
5000876	sarella	stark	TRUE
5006017	alester	stark	TRUE
5001412	jhezane	westerling	FALSE
5000083	lollys	clegane	FALSE

→

mrn	first_name	last_name
5000876	sarella	stark
5006017	alester	stark

filter()

Extract rows that meet logical criteria

```
filter(data, ...)
```

data frame to transform

one or more logical tests (filter returns each row for which the test is TRUE)

Logical tests

`x < y`	Less than
`x > y`	Greater than
`x == y`	Equal to
`x <= y`	Less than or equal to
`x >= y`	Greater than or equal to
`x != y`	Not equal to
`x %in% y`	Group membership
`is.na(x)`	Is NA
`!is.na(x)`	Is not NA

Pop Quiz

What is the result?

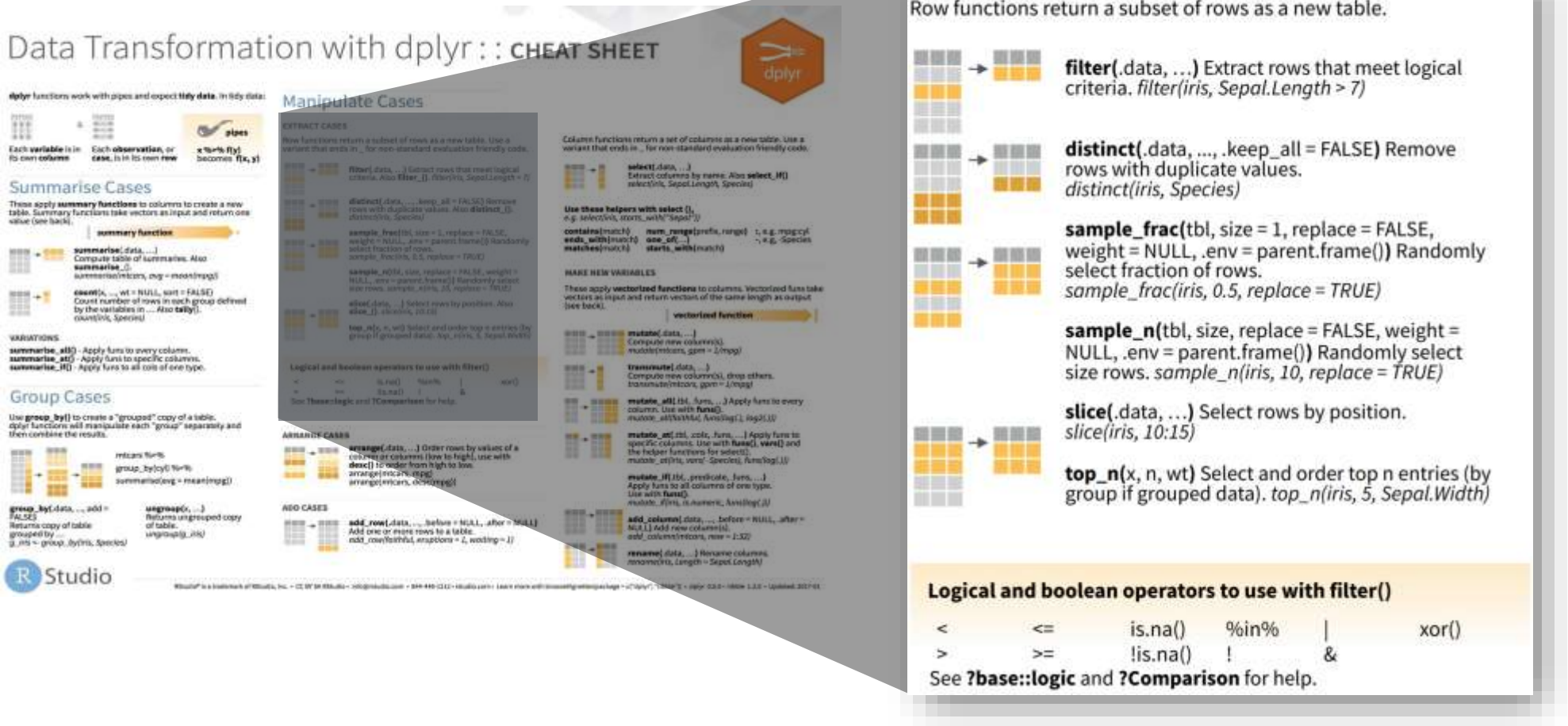
```
1 == 1
```

Pop Quiz

What is the result?

```
3 != 1
```

filter() variants



Your Turn 3

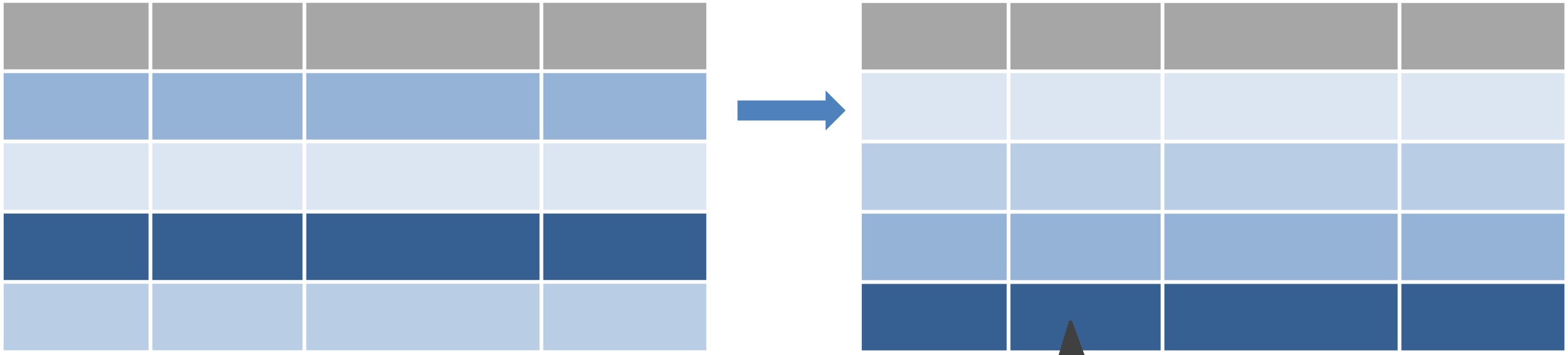
Use filter() with the logical operators to find:

- Every test for patients **over age 80**
- All of the covid testing where the demographic group (demo_group) is **equal to "client"**
- CHALLENGE:
  - All of the covid testing where the patient class (patient_class) **is NA** [Hint: See slide titled "Logical Tests"]

arrange()

arrange()

Order rows by values in a column



= Number of rows

= Number of Columns

arrange()

Order rows by values in a column

```
arrange(data, ... )
```

data frame to transform

name(s) of columns to arrange by

arrange()

Order rows by values in a column

```
arrange(covid_testing, first_name)
```

mrn	first_name	last_name
5000876	sarella	stark
5006017	alester	stark
5001412	jhezane	targaryen
5000533	penny	targaryen

mrn	first_name	last_name
5006017	alester	stark
5001412	jhezane	targaryen
5000533	penny	targaryen
5000876	sarella	stark

arrange()

Order rows by values in a column

```
arrange(covid_testing, desc(mrn))
```

mrn	first_name	last_name
5000876	sarella	stark
5006017	alester	stark
5001412	jhezane	targaryen
5000533	penny	targaryen

mrn	first_name	last_name
5006017	alester	stark
5001412	jhezane	targaryen
5000876	sarella	stark
5000533	penny	targaryen

Your Turn 4

The column `ct_value` contains the cycle threshold (Ct) for the real-time PCR that generated the final result.

How might you use `arrange()` to determine the highest and lowest Ct result in the dataset?

Pop Quiz

The default behavior of arrange() is to order from lower to higher values.

When might arrange() place "1000" before "50"?

%>%

Data Analysis Steps

```
day_10 <- filter(covid_testing, pan_day <= 10)

day_10 <- select(day_10, clinic_name)

day_10 <- arrange(day_10 , clinic_name)
```

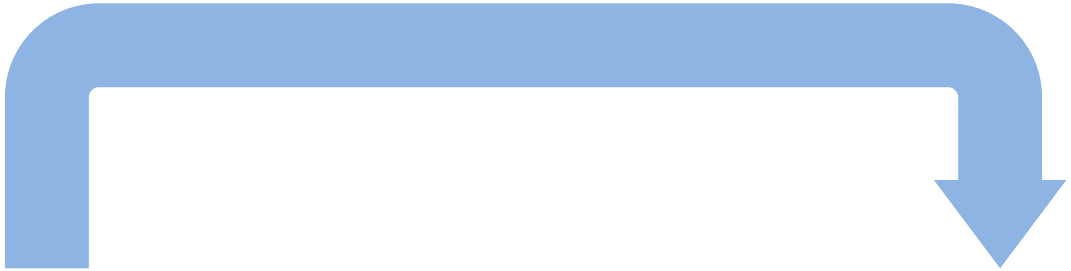
1. Filter tests to those on pandemic day less than 10
2. Select the column that contains ordering location
3. Arrange those columns by location

Data Analysis Steps

```
day_10 <- arrange(
            select(
              filter(
                covid_testing,
                pan_day <= 10
              ),
              clinic_name
            ),
            clinic_name
          )
```

The Pipe Operator %>%

Passes result on left into first argument of function on right.



```
covid_testing %>% filter(____, pan_day <= 10)
```

```
filter(covid_tesing, pan_day <= 10)
covid_tesing %>% filter(pan_day <= 10)
```

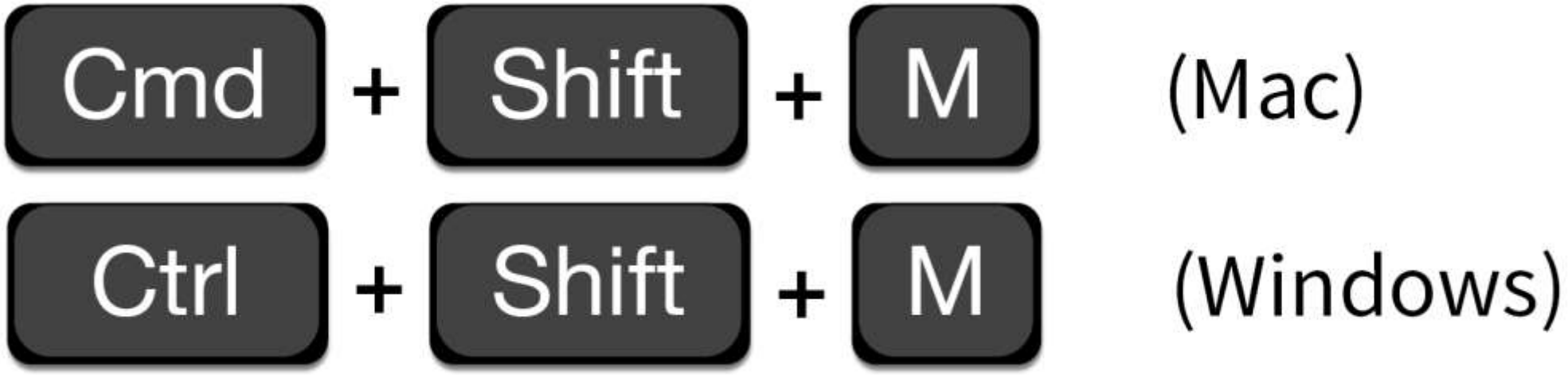
Data Analysis Steps

```
day_10 <- arrange(
            select(
              filter(
                covid_testing,
                pan_day <= 10
              ),
              clinic_name
            ),
            clinic_name
          )
```

Data Analysis Steps

```
covid_testing %>%
    filter(pan_day <= 10) %>%
    select(clinic_name) %>%
    arrange(clinic_name)
```

Shortcut to type %>%



Scene

The PICU would like a word with you because of a recent incident involving a delay in results for a patient who required a AGP

They had to wait over 10 hours before the procedure could begin

You decide to investigate… WITH DATA

Question

Was the TAT so high in this situation because:

A. Your lab has long TAT's and you need to find a way to get the results to certain priority areas faster
B. Something was missed in this one case and the workflow just needs to be reviewed and tweaked so things aren't missed

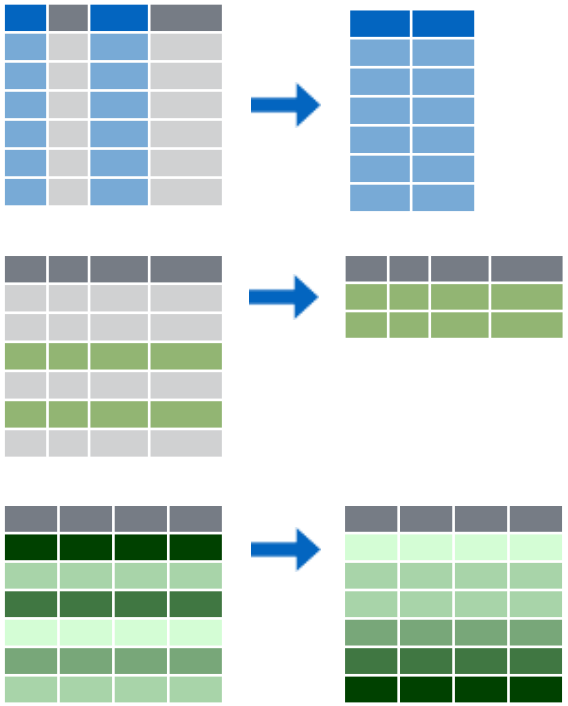
Your Turn 5

Use %>% to write a sequence of three functions that:

1. Filters to tests from the clinic (**`clinic_name`**) of "picu"
2. Selects the column with the receive to verify turnaround time (**`rec_ver_tat`**) as well as the day from start of the pandemic (**`pan_day`**)
3. Arrange the **`pan_day`** from highest to lowest

Using <-, assign the result to a new variable, call it whatever you want.

Isolating data



Extract variables with **select()**

Extract rows with **filter()**

Arrange rows, with **arrange()**.

Deriving Data

What is the average and SD in total turnaround time by clinic?

Breaking down the analytical question

1. Total TAT for each test
2. Group tests by clinic
3. Calculate average and SD for each clinic

Deriving data

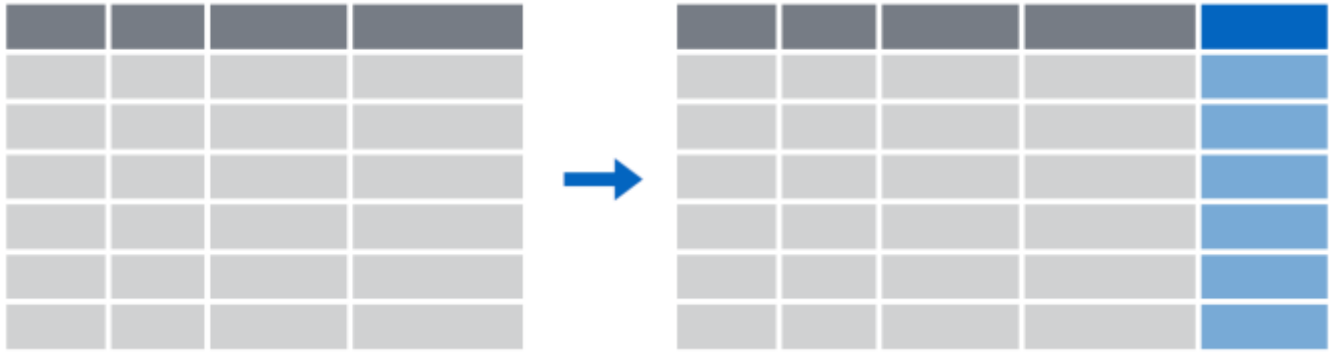
Make new variables with **mutate()**

Make summaries of data with **summarize()**

mutate()

mutate()

Creating new calculated columns



= Number of rows

↑ Number of Columns

mutate()

Creating new calculated columns

```
covid_testing %>%
    mutate(new_column = calculation)
```

name for new column

equals

function whose results will populate columns

mutate()

Creating new calculated columns

```
covid_testing %>%
    mutate(c_r_tat_mins = col_rec_tat * 60)
```

mrn	col_rec_tat	rec_ver_tat
5000876	29.5	11.5
5006017	3.6	5
5001412	1.4	5.2
5000533	2.3	5.8

mrn	col_rec_tat	rec_ver_tat	c_r_tat_mins
5000876	29.5	11.5	1770
5006017	3.6	5	216
5001412	1.4	5.2	84
5000533	2.3	5.8	138

Your Turn 6

Create a new column using the mutate() function that contains the total TAT (sum of **`col_rec_tat`** and **`rec_ver_tat`**)

mutate()

Replacing columns

Function to "coerce" one type of data into another type of data

```
covid_testing %>%
    mutate(mrn = as.character(mrn))
```

mrn <dbl>	first_name <chr>	last_name <chr>
5000876	sarella	stark
5006017	alester	stark
5001412	jhezane	westerling
5000533	penny	targaryen

mrn <chr>	first_name <chr>	last_name <chr>
5000876	sarella	stark
5006017	alester	stark
5001412	jhezane	westerling
5000533	penny	targaryen

Functions to use in mutate()

Vector Functions

TO USE WITH MUTATE ()

mutate() and **transmute()** apply vectorized functions to columns to create new columns. Vectorized functions take vectors as input and return vectors of the same length as output.

vectorized function

OFFSETS

dplyr::**lag()** - Offset elements by 1
dplyr::**lead()** - Offset elements by -1

CUMULATIVE AGGREGATES

dplyr::**cumall()** - Cumulative all()
dplyr::**cumany()** - Cumulative any()
cummax() - Cumulative max()
dplyr::**cummean()** - Cumulative mean()
cummin() - Cumulative min()
cumprod() - Cumulative prod()
cumsum() - Cumulative sum()

RANKINGS

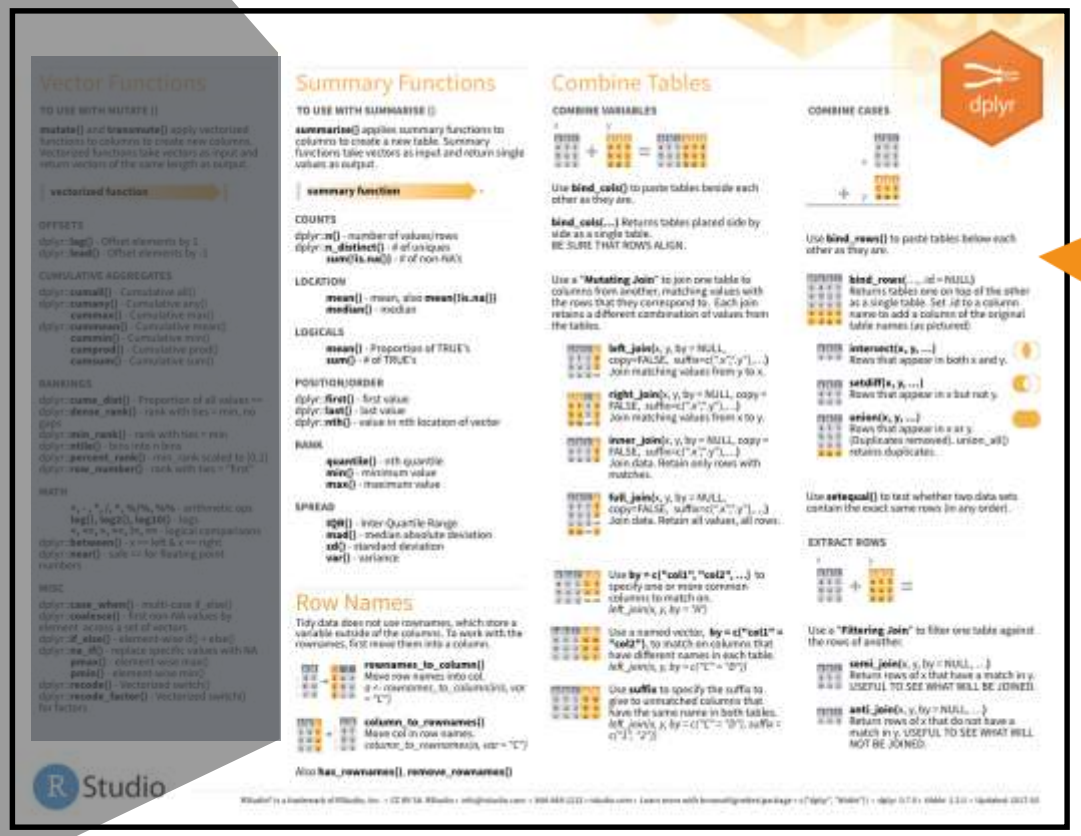
dplyr::**cume_dist()** - Proportion of all values <=
dplyr::**dense_rank()** - rank with ties = min, no gaps
dplyr::**min_rank()** - rank with ties = min
dplyr::**ntile()** - bins into n bins
dplyr::**percent_rank()** - min_rank scaled to [0,1]
dplyr::**row_number()** - rank with ties = "first"

MATH

+, -, *, /, ^, %/%, %% - arithmetic ops
log(), log2(), log10() - logs
<, <=, >, >=, !=, == - logical comparisons
dplyr::**between()** - x >= left & x <= right
dplyr::**near()** - safe == for floating point numbers

MISC

dplyr::**case_when()** - multi-case if_else()
dplyr::**coalesce()** - first non-NA values by element across a set of vectors
dplyr::**if_else()** - element-wise if() + else()
dplyr::**na_if()** - replace specific values with NA
pmax() - element-wise max()
pmin() - element-wise min()
dplyr::**recode()** - Vectorized switch()
dplyr::**recode_factor()** - Vectorized switch() for factors



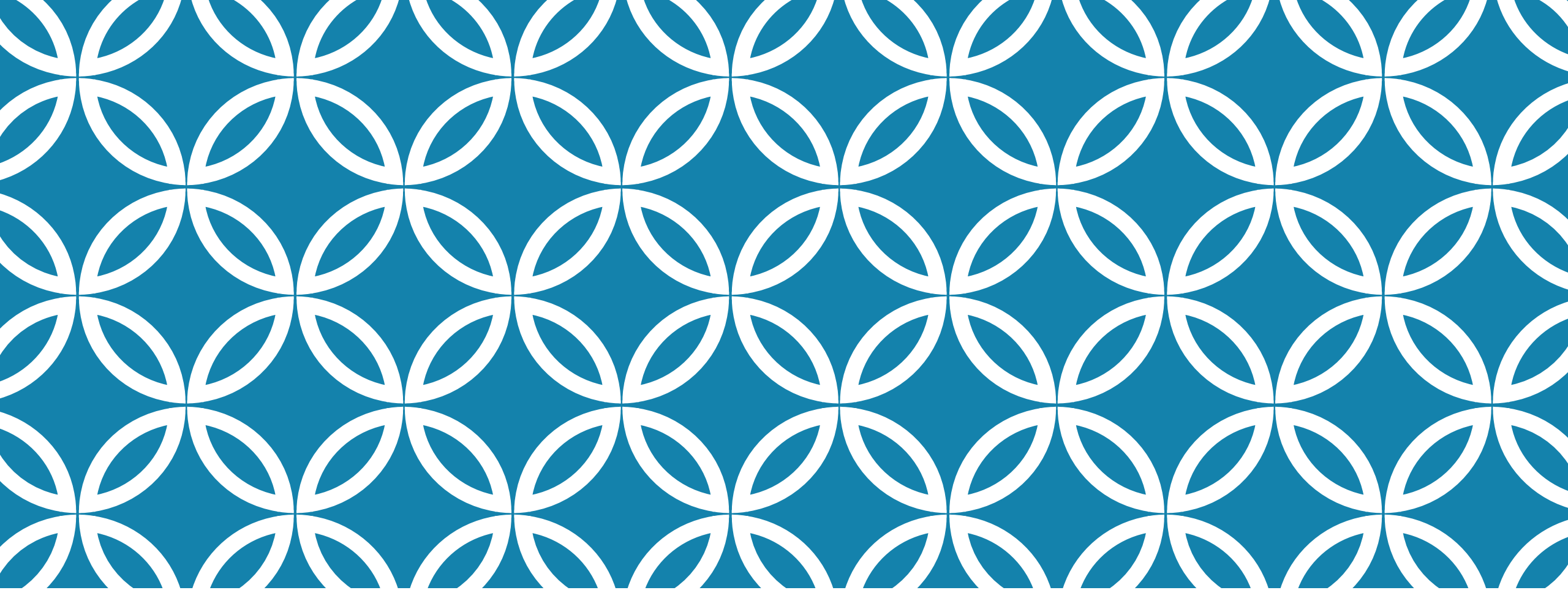
on back

Goal

1. Learn how to use dplyr to transform data frames
2. Appreciate the role of piping in facilitating data transformation

Objectives

1. List the major forms of data transformation implemented in dplyr
2. Use code templates containing dplyr functions to tidy a raw data set
3. Use the pipe operator to pass the output of one function as an input to the next function
4. Create new calculated columns not found in the original data frame



Summary and Stats

Session 5

Dan Herman

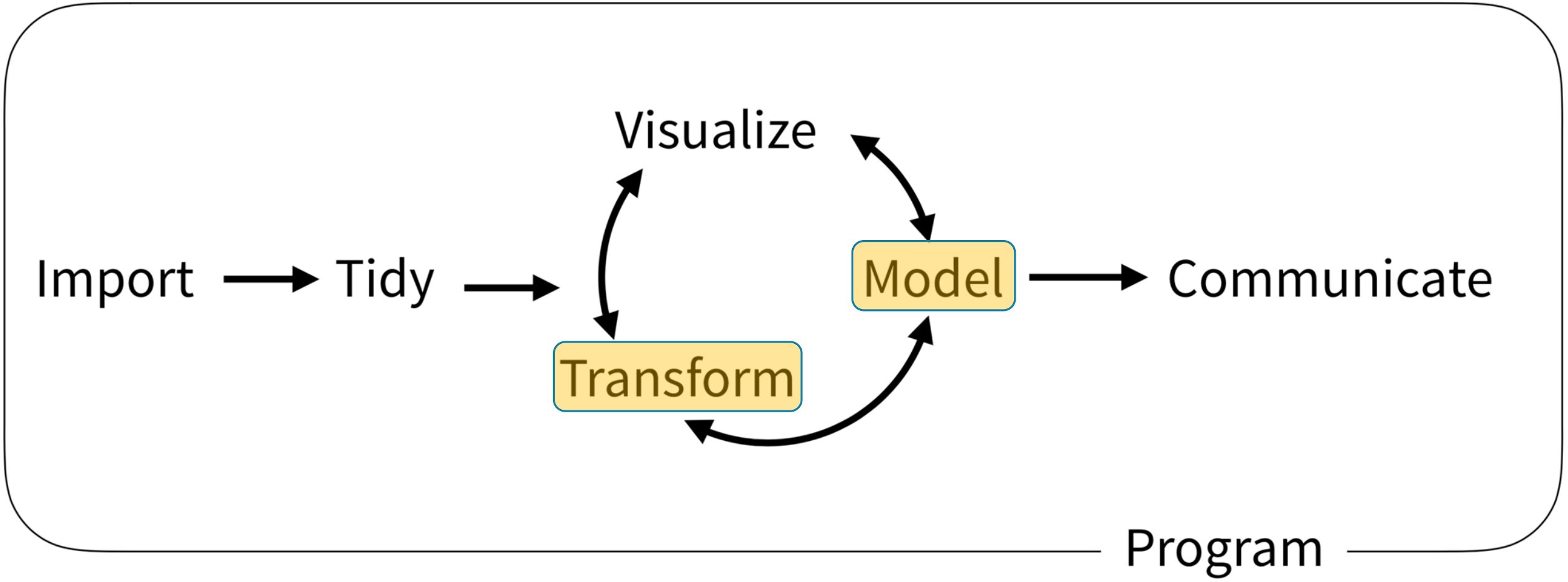
Goals

1. Learn how to summarize data
2. Appreciate how to perform hypothesis testing

Objectives

1. Calculate a summary statistic for a variable using `summarize`
2. Calculate summary statistics for a variable separately for a group of observations, using `group_by` and `summarize`
3. Describe the process of performing a simple test for association

Typical Data Science Pipeline



From *R for Data Science*

Summarize()

summarize()

- Make summaries of your data

summarize()

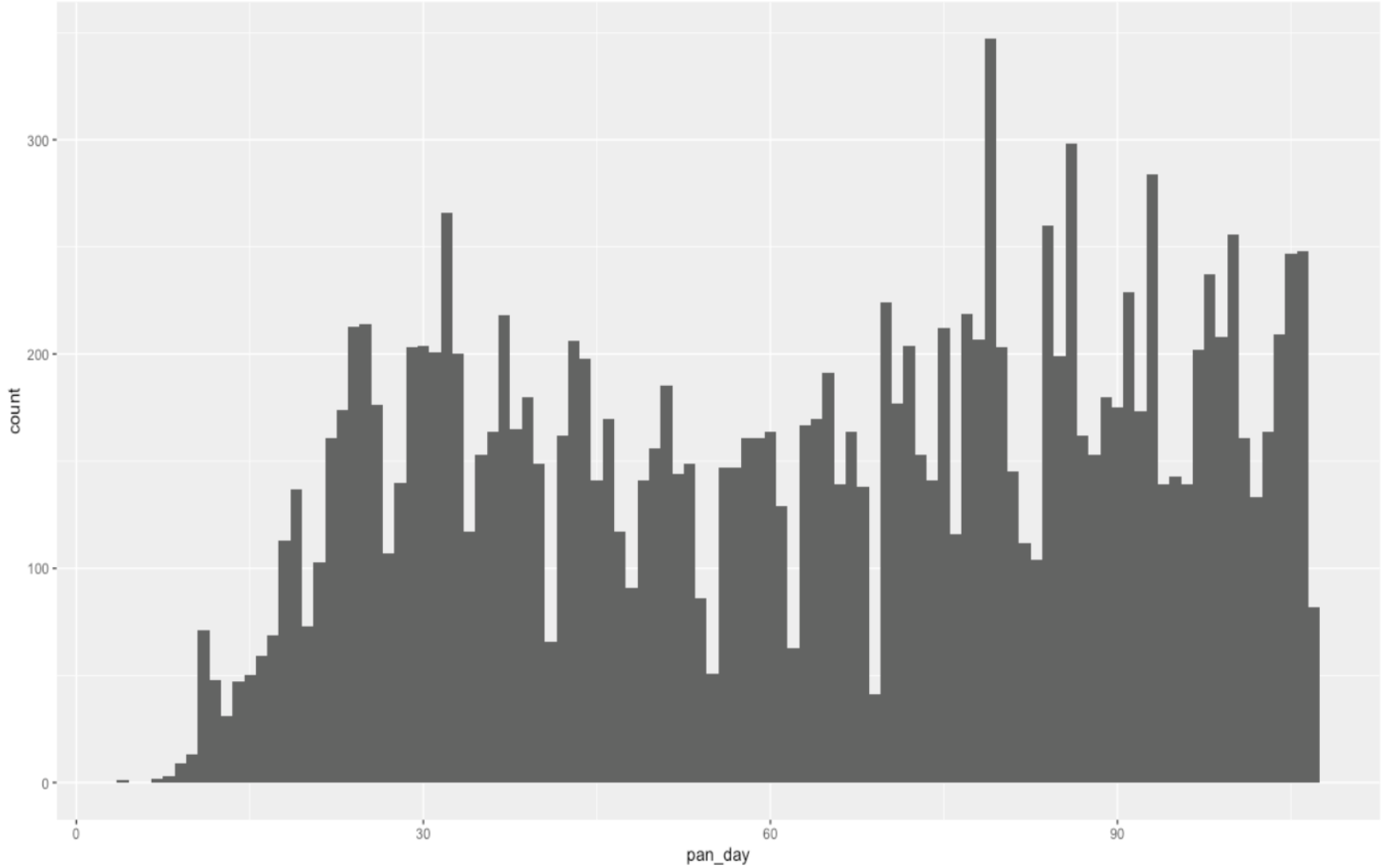
- Make summaries of your data

```
covid_testing %>%
    summarize(new_variable = calculation)
```

name for new variable

Value or function

Q: How many tests are ordered per day?



summarize()

- Make summaries of your data

```
covid_testing %>%
      select(mrn, pan_day)  %>%
      head(4) %>%
      summarize(order_count = n())
```

function that returns number of observations

mrn	pan_day
5001412	4
5000533	7
5009134	7
5008518	8

→

order_count
4

summarize()

- Make summaries of your data

```
covid_testing %>%
      select(mrn, pan_day)  %>%
      head(4) %>%
      summarize(order_count = n(),
                day_count = n_distinct(pan_day))
```

function that returns number of distinct values

mrn	pan_day
5001412	4
5000533	7
5009134	7
5008518	8

→

order_count	day_count
4	3

Your Turn 1

- Open “05 - Stats.Rmd”
- Run the setup chunk
- Fill-in gaps to calculate:

  a) Mean count of orders per `pan_day`

  b) Mean count of orders per clinic

Vector Functions

TO USE WITH MUTATE ()

COUNTS

dplyr::**n()** - number of values/rows
dplyr::**n_distinct()** - # of uniques
sum(!is.na()) - # of non-NA's

LOCATION

mean() - mean, also **mean(!is.na())**
median() - median

LOGICALS

mean() - Proportion of TRUE's
sum() - # of TRUE's

POSITION/ORDER

dplyr::**first()** - first value
dplyr::**last()** - last value
dplyr::**nth()** - value in nth location of vector

RANK

quantile() - nth quantile
min() - minimum value
max() - maximum value

SPREAD

IQR() - Inter-Quartile Range
mad() - median absolute deviation
sd() - standard deviation
var() - variance

Summary Functions

TO USE WITH SUMMARISE ()

summarise() applies summary functions to columns to create a new table. Summary functions take vectors as input and return single values as output.

summary function

COUNTS

dplyr::**n()** - number of values/rows
dplyr::**n_distinct()** - # of uniques
sum(!is.na()) - # of non-NA's

LOCATION

mean() - mean, also **mean(!is.na())**
median() - median

LOGICALS

mean() - Proportion of TRUE's
sum() - # of TRUE's

POSITION/ORDER

dplyr::**first()** - first value
dplyr::last() - last value
dplyr::nth() - value in nth location of vector

RANK

quantile() - nth quantile
min() - minimum value
max() - maximum value

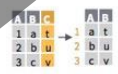
SPREAD

IQR() - Inter-Quartile Range
mad() - median absolute deviation
sd() - standard deviation
var() - variance

Row Names

Tidy data does not use rownames, which store a variable outside of the columns. To work with the rownames, first move them into a column.

rownames_to_column()
Move row names into col.
a <- rownames_to_column(iris, var = "C")

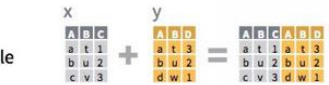


column_to_rownames()
Move col in row names.
column_to_rownames(a, var = "C")

Also **has_rownames()**, **remove_rownames()**

Combine Tables

COMBINE VARIABLES



Use **bind_cols()** to paste tables beside each other as they are.

bind_cols(…) Returns tables placed side by side as a single table.
BE SURE THAT ROWS ALIGN.

Use a "**Mutating Join**" to join one table to columns from another, matching values with the rows that they correspond to. Each join retains a different combination of values from the tables.

left_join(x, y, by = NULL, copy=FALSE, suffix=c(".x",".y"),…)
Join matching values from y to x.

right_join(x, y, by = NULL, copy = FALSE, suffix=c(".x",".y"),…)
Join matching values from x to y.

inner_join(x, y, by = NULL, copy = FALSE, suffix=c(".x",".y"),…)
Join data. Retain only rows with matches.

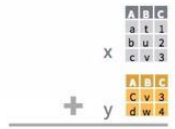
full_join(x, y, by = NULL, copy=FALSE, suffix=c(".x",".y"),…)
Join data. Retain all values, all rows.

Use **by = c("col1", "col2")** to specify the column(s) to match on.
left_join(x, y, by = "A")

Use a named vector, **by = c("col1" = "col2")**, to match on columns with different names in each data set.
left_join(x, y, by = c("C" = "D"))

Use **suffix** to specify suffix to give to duplicate column names.
left_join(x, y, by = c("C" = "D"), suffix = c("1", "2"))

COMBINE CASES



Use **bind_rows()** to paste tables below each other as they are.

bind_rows(…, .id = NULL)
Returns tables one on top of the other as a single table. Set .id to a column name to add a column of the original table names (as pictured)

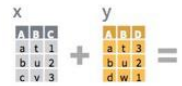
intersect(x, y, …)
Rows that appear in both x and y.

setdiff(x, y, …)
Rows that appear in x but not y.

union(x, y, …)
Rows that appear in x or y.
(Duplicates removed). union_all() retains duplicates.

Use **setequal()** to test whether two data sets contain the exact same rows (in any order).

EXTRACT ROWS



Use a "**Filtering Join**" to filter one table against the rows of another.

semi_join(x, y, by = NULL, …)
Return rows of x that have a match in y.
USEFUL TO SEE WHAT WILL BE JOINED.

anti_join(x, y, by = NULL, …)
Return rows of x that do not have a match in y. USEFUL TO SEE WHAT WILL NOT BE JOINED.

summarize() examples

- Last pandemic day (in data)
- Median turnaround time

Your Turn 2

Consider:

How would you calculate the median number of orders per day?

group_by()

group_by()

group_by()

- *Grouping observations based on a specific variable's values*

```
covid_testing %>%
    group_by(variable)
```

name of variable to group by

group_by()

- *Group observations by pan_day*

```
covid_testing %>%
    group_by(pan_day)
```

```
# A tibble: 15,524 x 17
# Groups:   pan_day [102]
      mrn first_name last_name gender pan_day
    <dbl> <chr>      <chr>     <chr>     <dbl>
 1 5.00e6 jhezane    westerli… female        4
 2 5.00e6 penny      targaryen female        7
 3 5.01e6 grunt      rivers    male          7
 4 5.01e6 melisandre swyft     female        8
 5 5.01e6 rolley     karstark  male          8
```

group_by()

- *Group observations by `pan_day` and `clinic_name`*

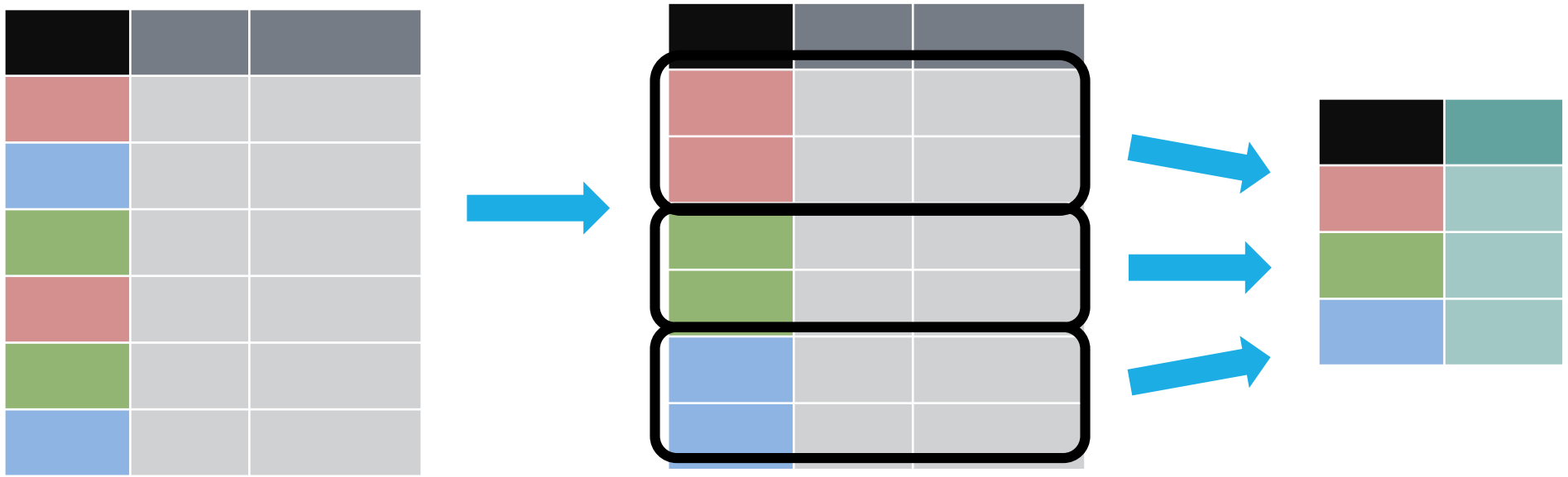
```
covid_testing %>%
    select(mrn, pan_day, clinic_name) %>%
    group_by(pan_day, clinic_name)
```

```
# A tibble: 15,524 x 3
# Groups:   pan_day, clinic_name [2,526]
       mrn pan_day clinic_name
     <dbl>   <dbl> <chr>
 1 5001412       4 inpatient ward a
 2 5000533       7 clinical lab
 3 5009134       7 clinical lab
 4 5008518       8 clinical lab
 5 5008967       8 emergency dept
```

group_by() %>% summarize()

group_by() %>% summarize()

Make summaries of your data *by group*



group_by() %>% summarize()

- Make summaries of your data

```
covid_testing %>%

    summarize(order_count = n())
```

mrn	pan_day
5001412	4
5000533	7
5009134	7
5008518	8

→

order_count
15524

group_by() %>% summarize()

- Make summaries of your data

```
covid_testing %>%
      group_by(pan_day) %>%
      summarize(order_count = n())
```

mrn	pan_day
5001412	4
5000533	7
5009134	7
5008518	8

→

pan_day	order_count
4	1
7	2
8	3
9	9

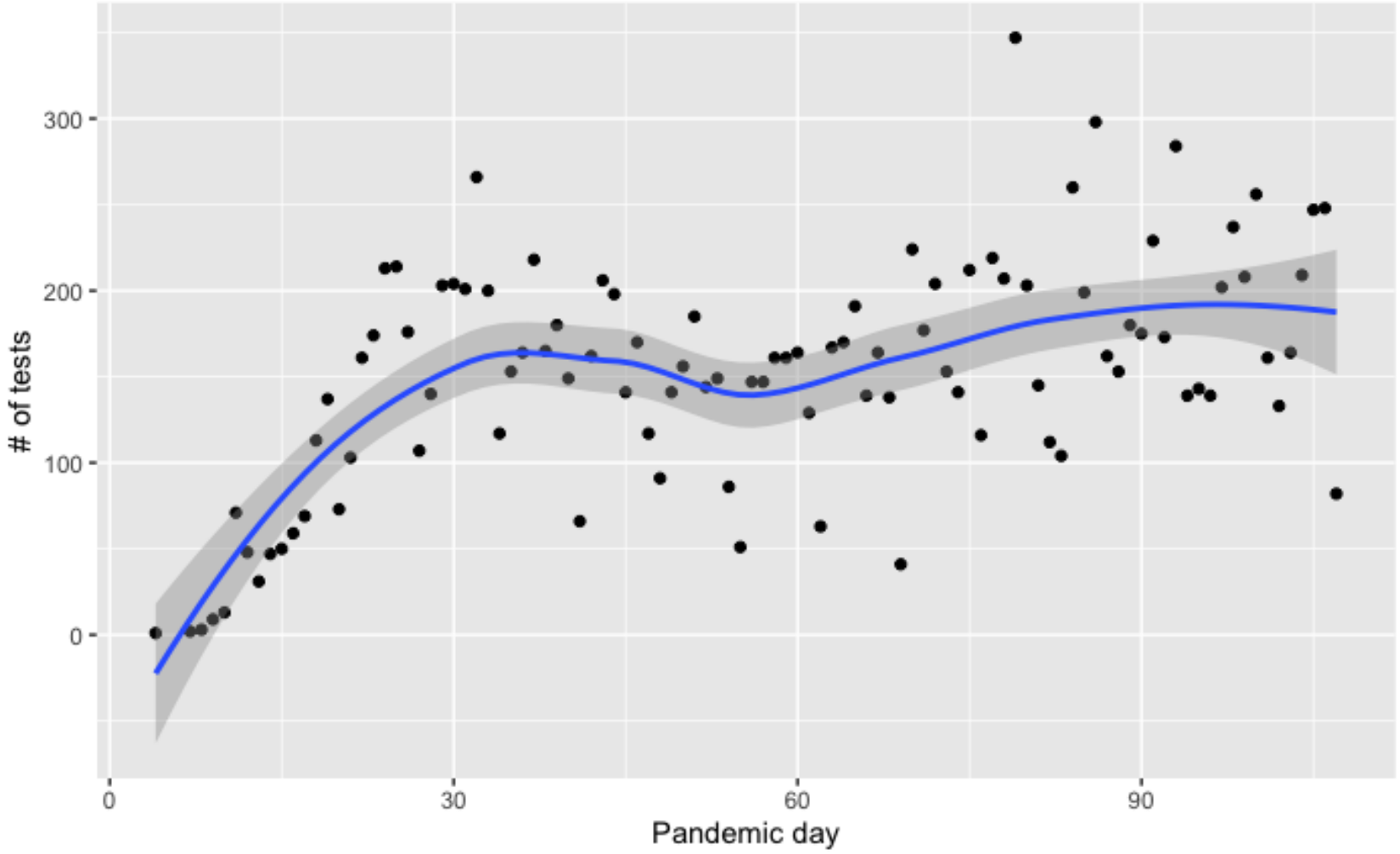
Your Turn 3

Calculate:

a) The median turnaround time for each day

b) (**Extra**) The median number of orders per day

group_by() %>% summarize(): Example



Stats: Tests for association

Q: Is there an association between insurance and SARS-CoV-2 RT-PCR positivity?

payor_group_fac <chr>	negative <int>	positive <int>
commercial	3549	86
government	3318	242
other	309	17
unassigned	7182	520

4 rows

```
data %>%
  fisher.test(simulate.p.value = T)
```

Data wrangling - 1

function that flexibly assigns values

```
covid_testing_2 <- covid_testing %>%
  mutate(payor_group_fac = case_when(
                            is.na(payor_group)                          ~ "unassigned",
                            payor_group %in% c("charity care",
                                               "medical assistance",
                                               "self pay",
                                               "other")                 ~ "other",
                                                                    TRUE ~ payor_group)
  ) %>%
  filter(result %in% c("positive", "negative"))
```

Data wrangling - 2

```
# Generate counts
tmp_table_tall <- covid_testing_2 %>%
  group_by(payor_group_fac, result) %>%
  summarize(n = n()) %>%
  ungroup()
tmp_table_tall

# Pivot from tall to wide table
tmp_table_wide <- tmp_table_tall %>%
  spread(key = "result", value = "n")
tmp_table_wide
```

Remove groupings

Maps key values to separate columns

Testing for association

payor_group_fac <chr>	negative <int>	positive <int>
commercial	3549	86
government	3318	242
other	309	17
unassigned	7182	520

4 rows

```
data %>%
  fisher.test(simulate.p.value = T)
```

```
        Fisher's Exact Test for Count Data with simulated p-value (based on 2000 replicates)

data:  .
p-value = 0.0004998
alternative hypothesis: two.sided
```

Testing for association: Example

Use fisher.test() to estimate the relative odds of a positive test result for patients with government insurance compared to commercial insurance?

What Else?

Logistic regression

```
tmp_fit <- glm(result_fac ~ payor_group_fac + age,  # model formula
               data = tmp,                          # dataset
               family = "binomial")                 # type of model

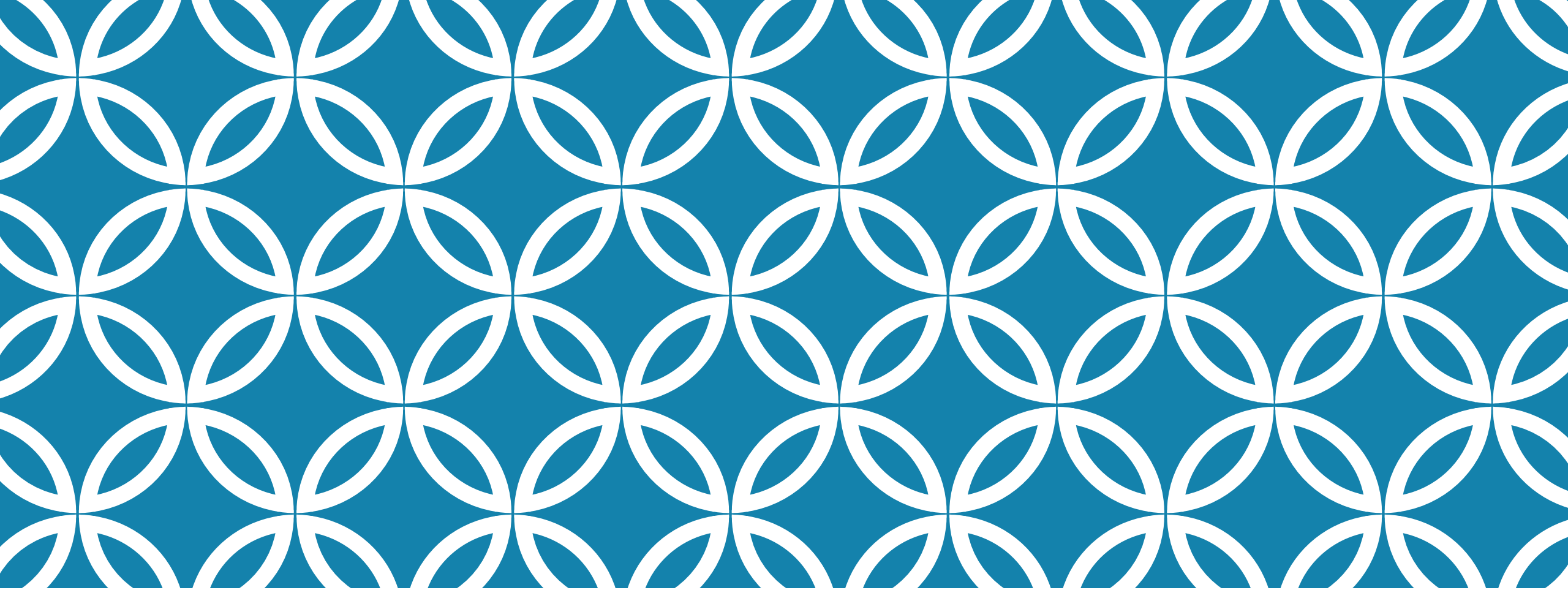
summary(tmp_fit)
```

Goals

1. Learn how to summarize data
2. Appreciate how to perform statistical analyses

Objectives

1. Calculate a summary statistic for a variable using `summarize`
2. Calculate of summary statistic for a variable separately for a group of observations, using `group_by` and `summarize`
3. Describe the process of performing a simple test for association



Advanced Reporting

Session 7

Patrick Mathias

July 16 2020	**Session**	**Instructor**
1:00 pm - 1:30 pm	Instructor Introductions, Introduction to technology	Amrom Obstfeld
1:30 pm - 2:15 pm	Introduction to R and RStudio	Joe Rudolf
2:30 pm - 3:15 pm	Reproducible Reporting	Patrick Mathias
3:30 pm - 5:00 pm	Data Visualization	Stephan Kadauke
July 17 2020		
1:00 pm - 2:30 pm	Data Transformation	Amrom Obstfeld
2:45 pm - 4:15 pm	Statistical Analysis	Dan Herman
4:30 pm - 5:00 pm	Advanced Reporting	Patrick Mathias

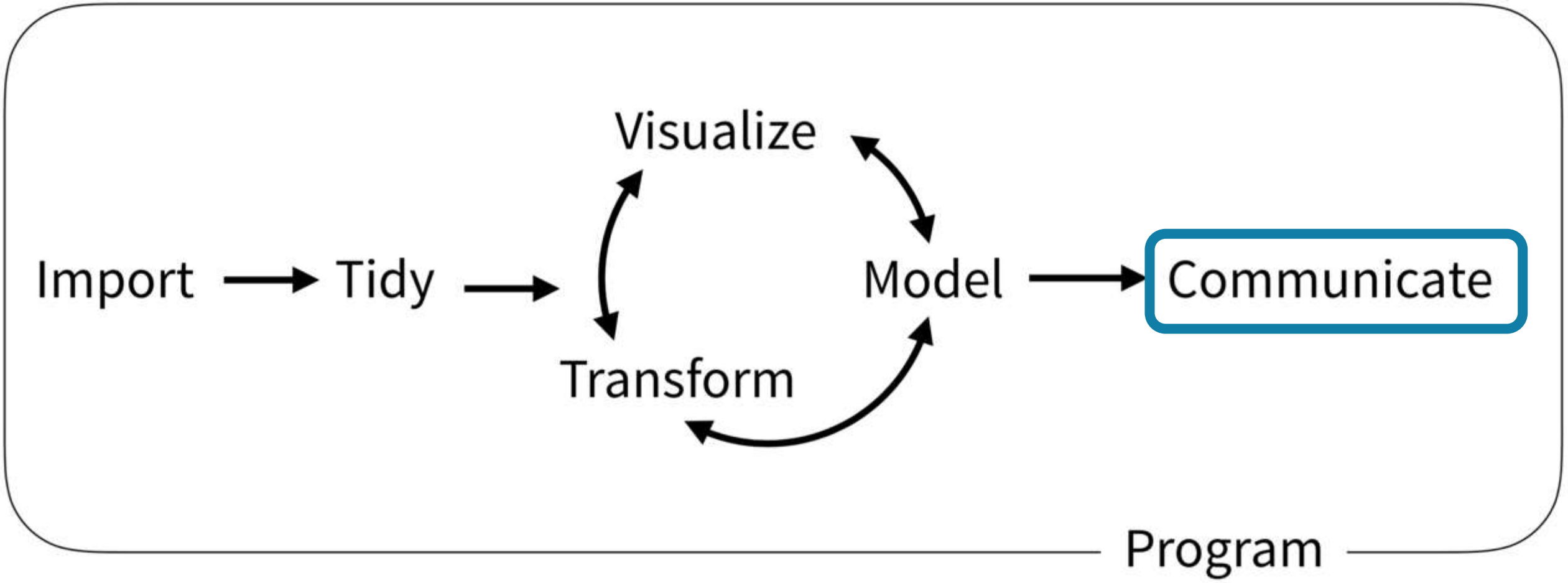
Goals

1. Build R Markdown reports using formatting outputs beyond standard document formats

Objectives

1. Format a flexdashboard to improve display of multiple plots
2. Convert a static plot into an interactive plot

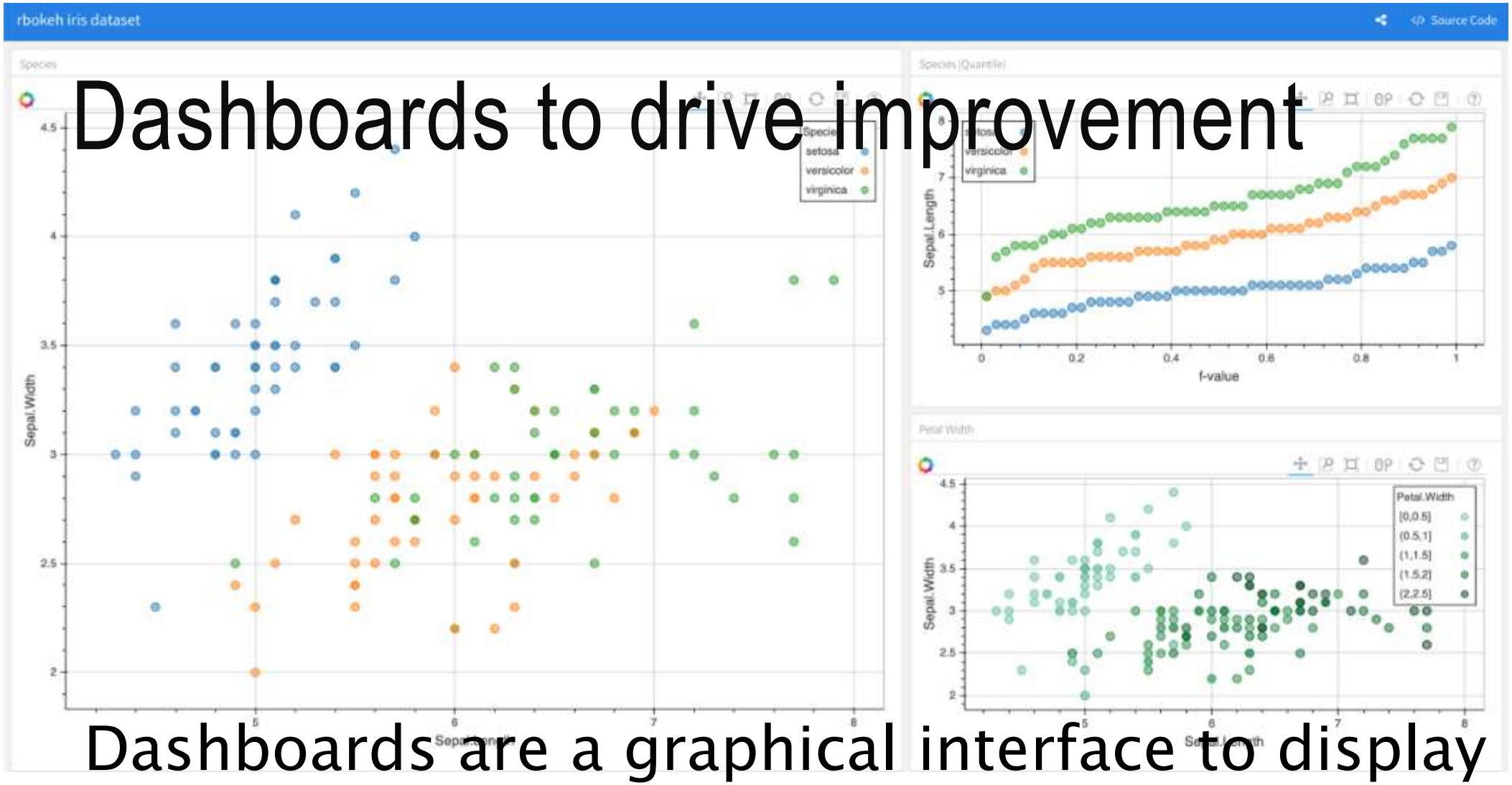
Typical Data Science Pipeline



From *R for Data Science*

From R Markdown to Quick and Painless Dashboards

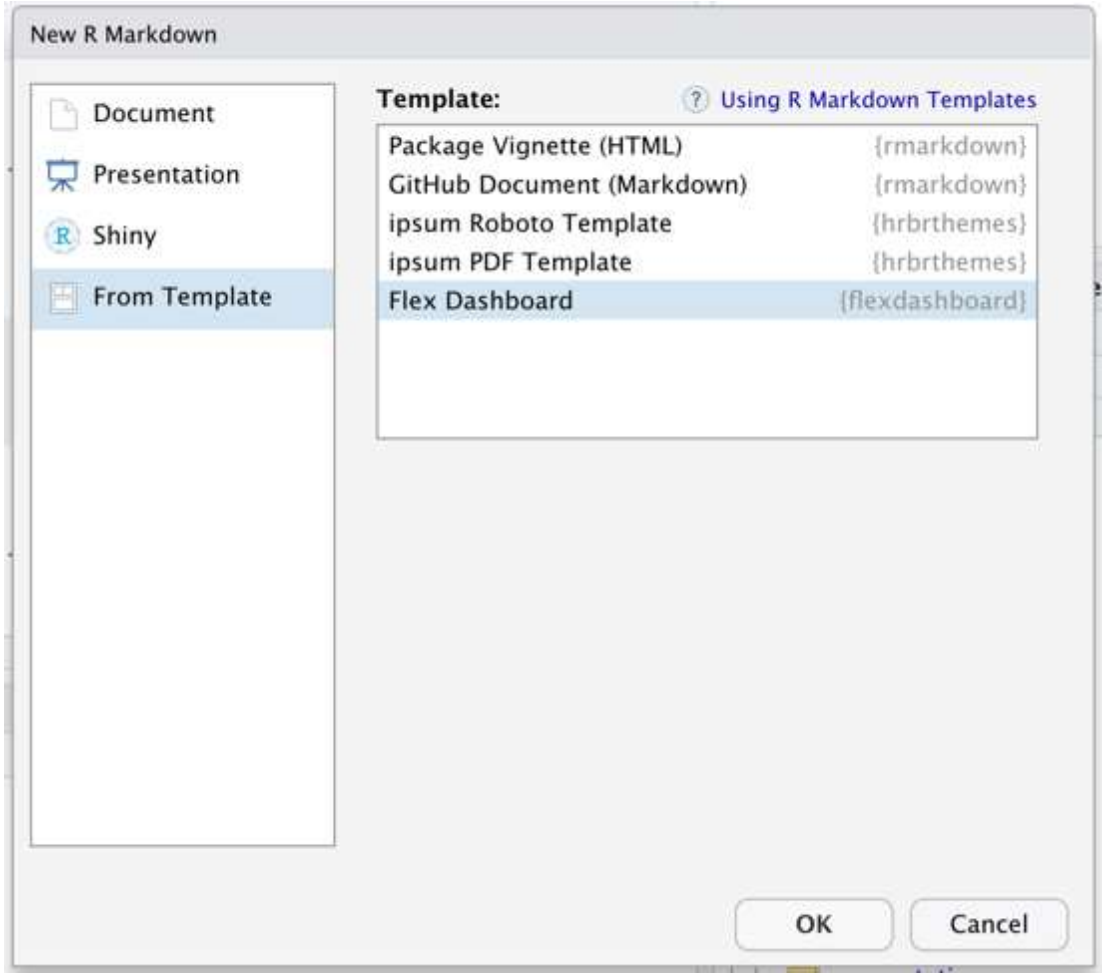
Dashboards to drive improvement



Dashboards are a graphical interface to display key performance indicators or other metrics

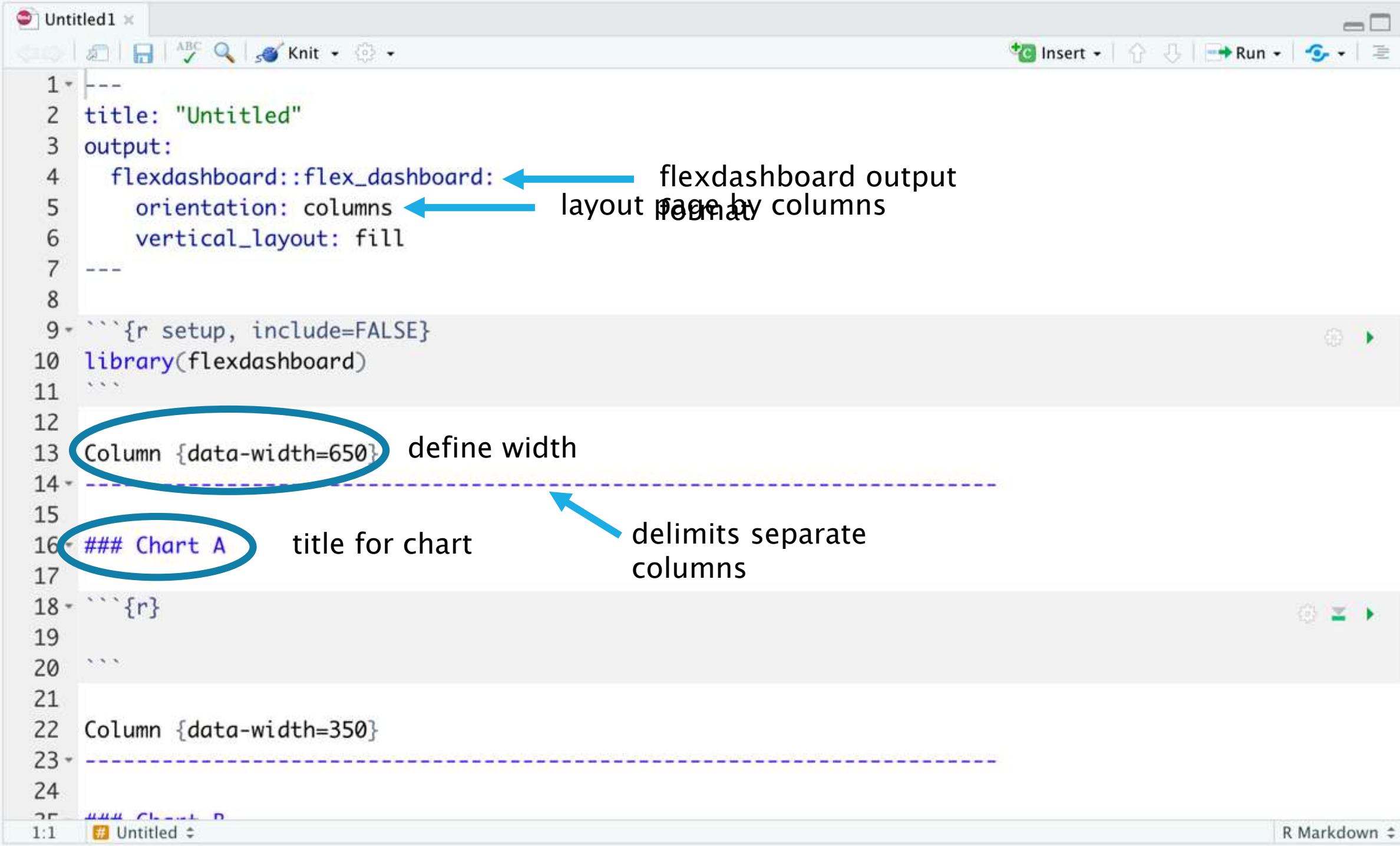
Intended to represent multiple pieces of information at a glance

flexdashboard provides easy dashboard templates for reporting



- Produces HTML file that can be opened on web browsers
- Or deployed on existing web server
- Provides row or column based layouts
- Get started by running: install.packages("flexdashboard")

https://rmarkdown.rstudio.com/flexdashboard/


Untitled1
Knit
Insert
Run
1 ---
2 title: "Untitled"
3 output:
4 flexdashboard::flex_dashboard:
5 orientation: columns
6 vertical_layout: fill
7 ---
8
9 ```{r setup, include=FALSE}
10 library(flexdashboard)
11 ```
12
13 Column {data-width=650}
14 ---
15
16 ### Chart A
17
18 ```{r}
19
20 ```
21
22 Column {data-width=350}
23 ---
24
flexdashboard output format
layout page by columns
define width
delimits separate columns
title for chart
1:1
Untitled
R Markdown

```
---
title: "Column Orientation"
output: flexdashboard::flex_dashboard
---

Column
-------------------------------------

### Chart 1

```{r}
```

Column

Chart 2

```{r}
```

Chart 3

```{r}
```
```

```
---
title: "Row Orientation"
output:
  flexdashboard::flex_dashboard:
    orientation: rows
---

Row
-------------------------------------

### Chart 1

```{r}
```

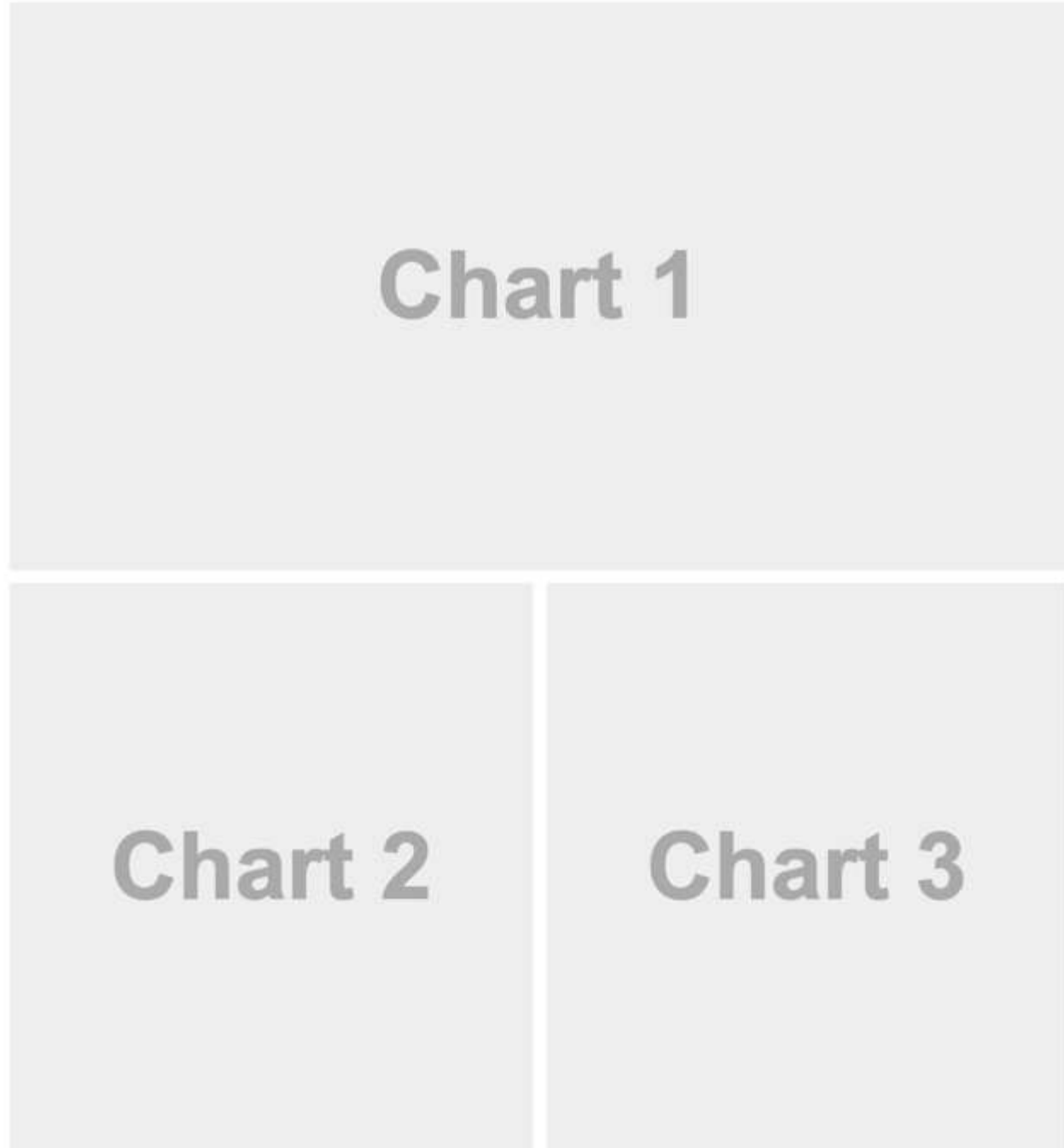
Row

Chart 2

```{r}
```

Chart 3

```{r}
```
```



```
---
title: "Chart Stack (Scrolling)"
output:
  flexdashboard::flex_dashboard:
    vertical_layout: scroll
---

### Chart 1

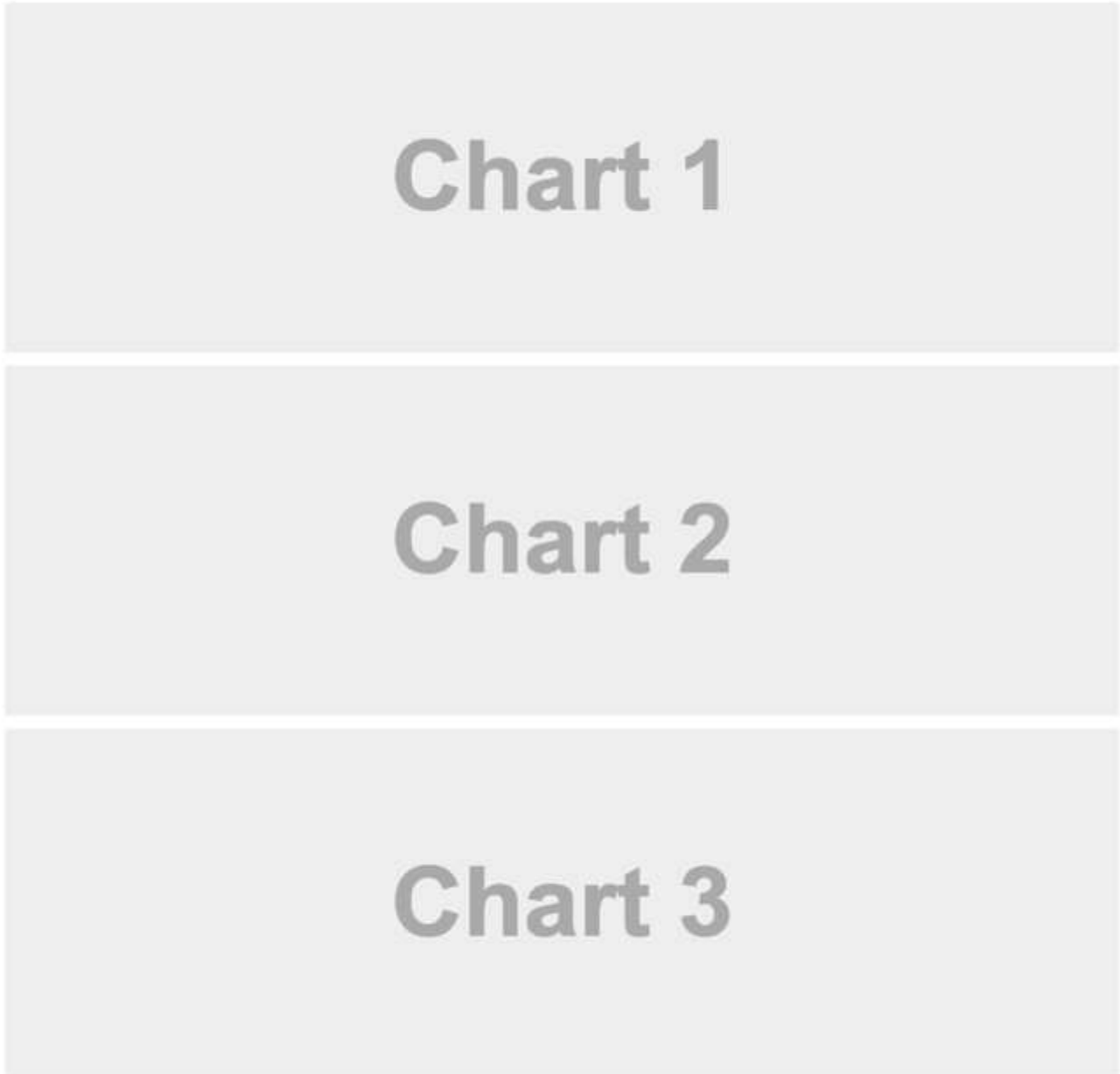
```{r}
```

Chart 2

```{r}
```

Chart 3

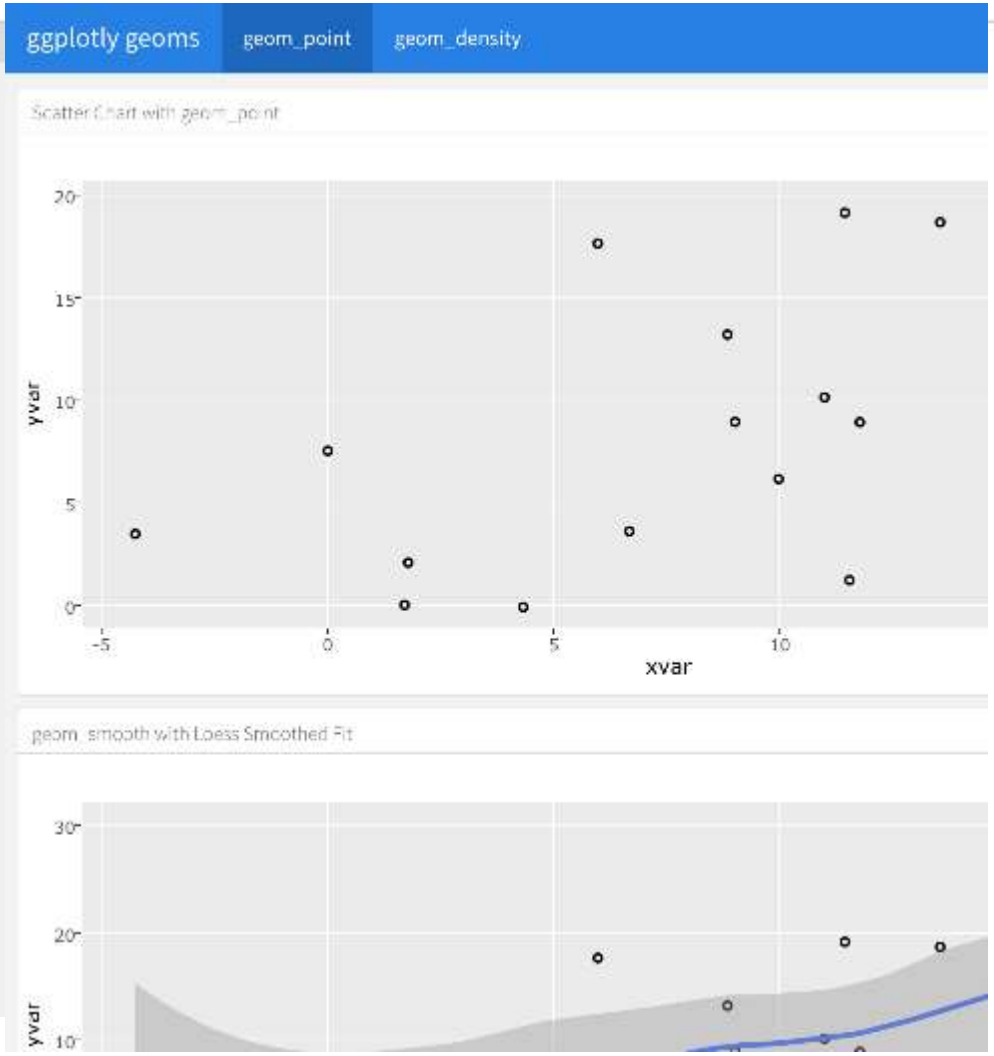
```{r}
```
```

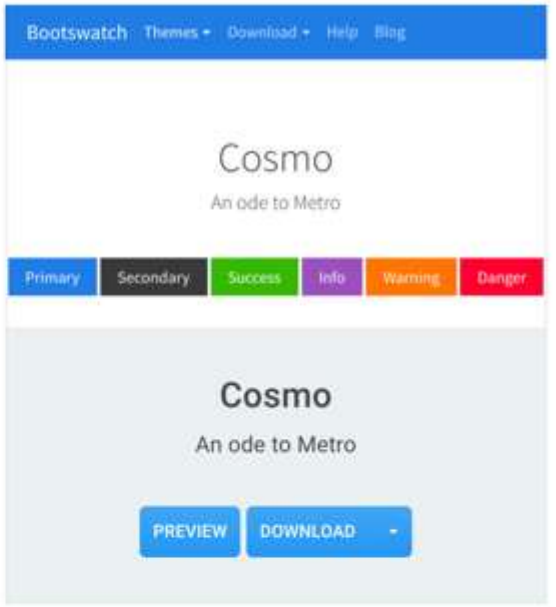


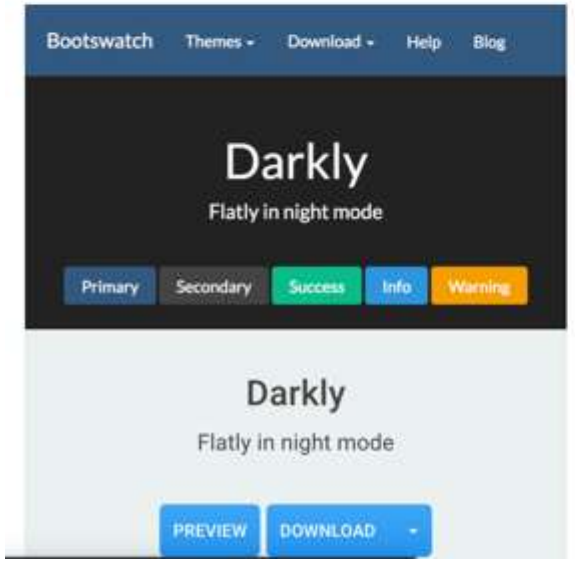
Your Turn #1

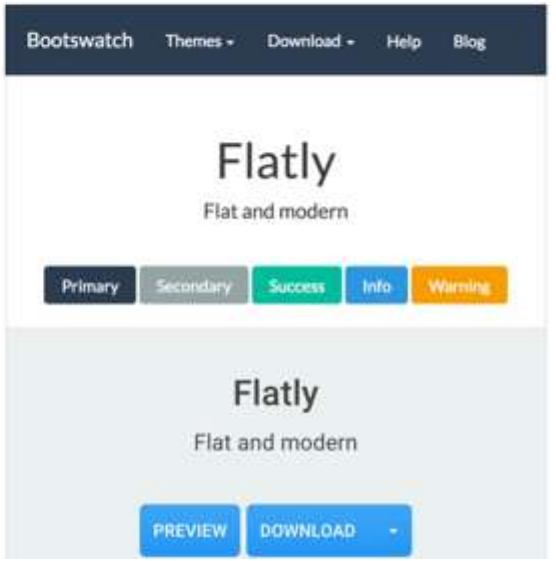
1. Open “07 - Advanced Reporting.Rmd” to work with a draft COVID-19 flexdashboard and run the setup chunk. Knit the document to see the dashboard output.
2. The ”Test Volumes Over Time” plot could show additional information regarding positive tests. Add fill to your barplot to show the result field in addition to overall test volume by day. Run that code chunk to see the output.
3. Too much information is crunched on the right side. Change the layout from columns to a row orientation. The 2nd and 3rd plots (Turnaround Times and Cycle Thresholds) should appear on the 2nd row.

Customization









Making plots interactive

htmlwidgets for R support interactive visuals

Packages using htmlwidgets use R code to call Javascript visualization libraries (http://www.htmlwidgets.org/)

Use one line of code to convert a static plot into an interactive one

Plotly package converts ggplot with a simple command

To use Plotly install the plotly package using the following command:

```
install.packages("plotly")
```

Examples of visualizations at Plotly website: https://plotly.com/r/

Store plot as object and add one line to make interactive

```
plot_name <- ggplot(data = data_frame) +
  geom_function(mapping = aes(mappings))
ggplotly(plot_name)
```

Your Turn #2

1. Load the plotly package in your setup chunk
2. Convert each of the plots into an interactive plot by storing the ggplot in an object and using the ggplotly() function.
3. Knit the dashboard and hover over the interactive plots.

Other options for interactive plots

Other interactive plot packages:

- rbokeh
- Highcharter

Time series graphs with dygraphs package

Maps with leaflet package

Interactive tables with one line

DataTables library quickly converts tables into interactive element

DT package in R

Use `datatable()` function on a data frame

- Filter number of entries
- Search entries
- Sort by column

datatable example

```
datatable(head(iris), class = 'cell-border stripe')
```

Show 10 entries

Search:

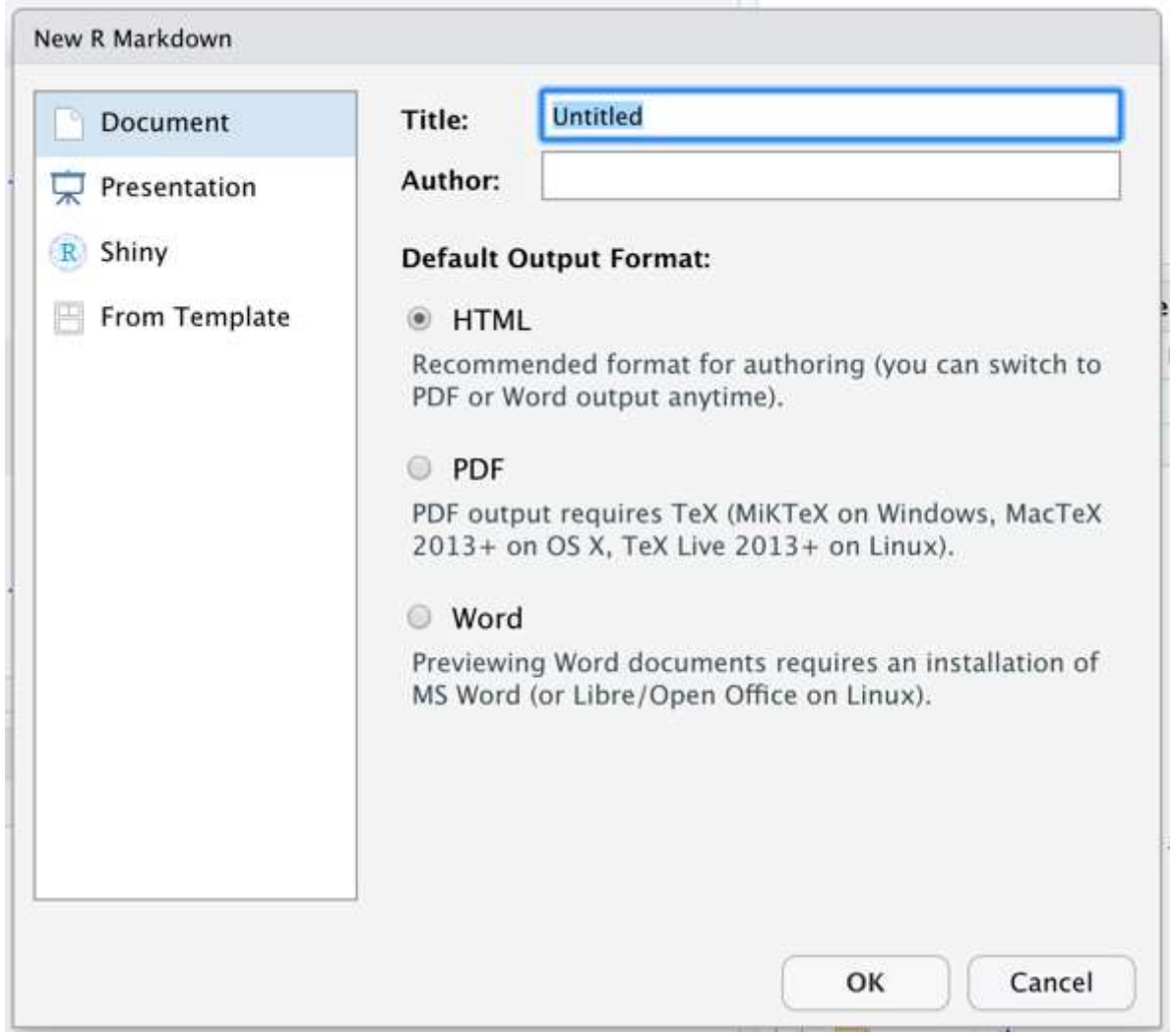
	Sepal.Length	Sepal.Width	Petal.Length	Petal.Width	Species
1	5.1	3.5	1.4	0.2	setosa
2	4.9	3	1.4	0.2	setosa
3	4.7	3.2	1.3	0.2	setosa
4	4.6	3.1	1.5	0.2	setosa
5	5	3.6	1.4	0.2	setosa
6	5.4	3.9	1.7	0.4	setosa

Showing 1 to 6 of 6 entries

Previous 1 Next

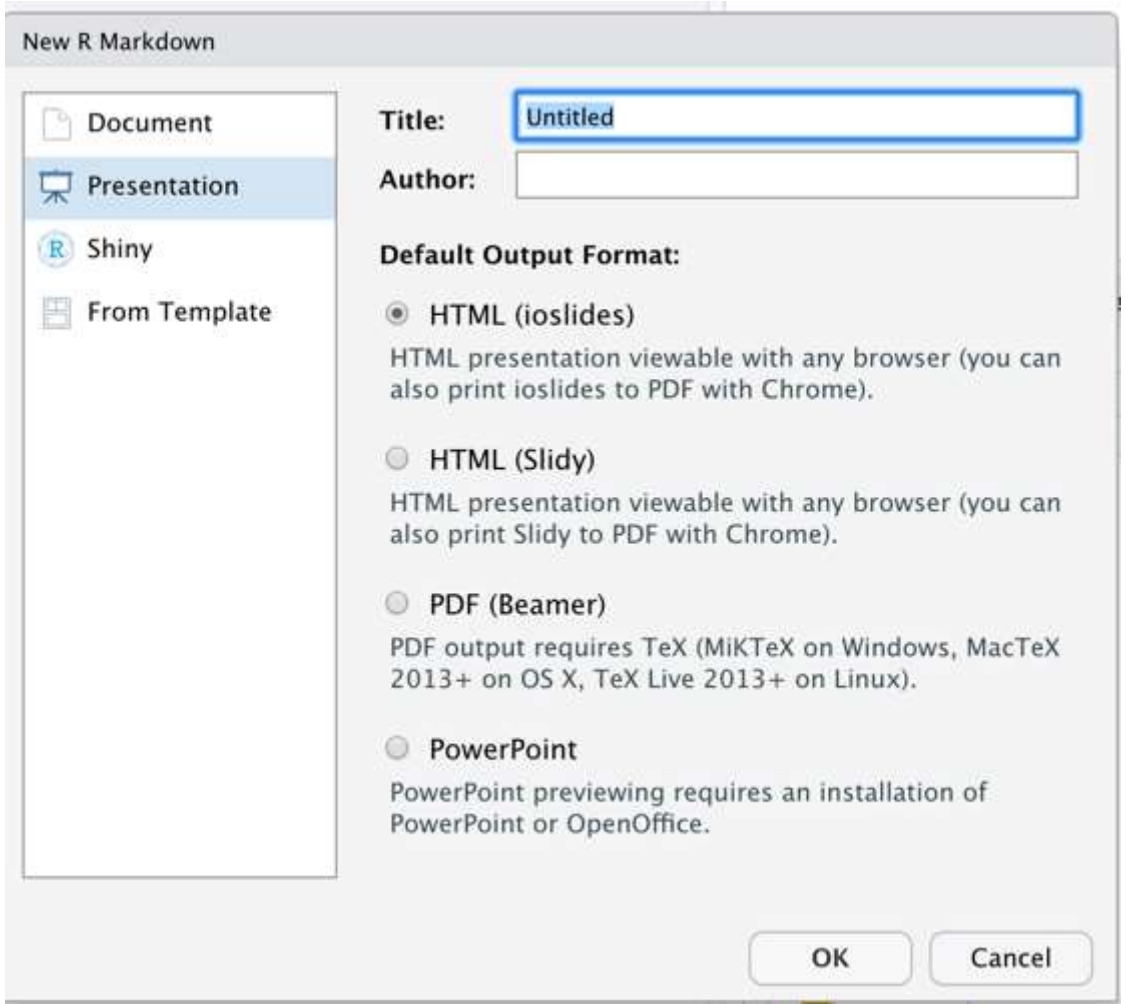
What Else?

Standard Markdown Reporting Formats



- HTML file – open with any web browser
- PDF – requires LaTeX dependencies
  - install.packages('tinytex')
  - tinytex::install_tinytex()
- Word – default format for collaborating with those who aren't familiar with R

Formats to go straight from code to slides



- Multiple HTML formats create webpage that's advanceable like slides
- PDF presentation uses LaTeX in the background
- Powerpoint produces simple slides

README.md | Untitled1

Knit | Insert | Run

```
---
title: "Untitled"
output: powerpoint_presentation
---

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

R Markdown

This is an R Markdown presentation. 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>.

When you click the **Knit** button a document will be generated that includes both content as well as the output of any embedded R code chunks within the document.

Slide with Bullets

- Bullet 1
- Bullet 2
- Bullet 3

Slide with R Output

```{r cars, echo = TRUE}
summary(cars)
```

Slide with Plot

```{r pressure}
plot(pressure)
```
```

Output format

Each slide has its own header

R Markdown

This is an R Markdown presentation. 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.

When you click the **Knit** button a document will be generated that includes both content as well as the output of any embedded R code chunks within the document.

Example output slide

Slide with Bullets

- Bullet 1
- Bullet 2
- Bullet 3

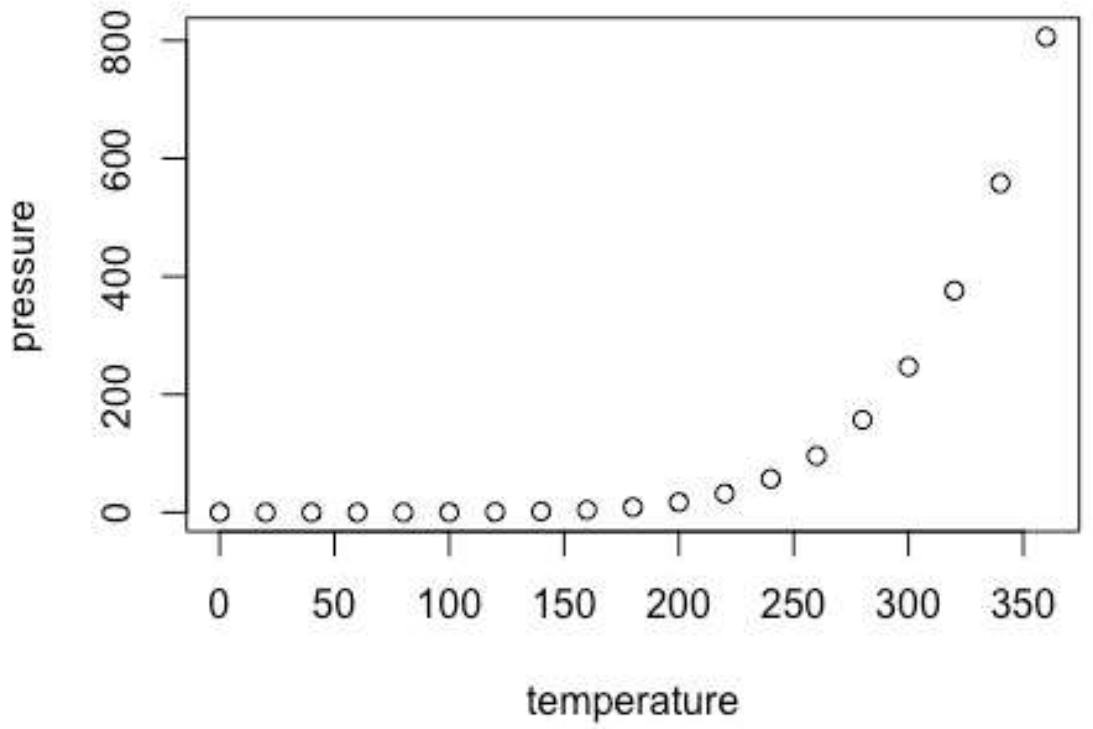
Example output slide

Slide with R Output

```
summary(cars)
##      speed           dist       
##  Min.   : 4.0   Min.   :  2.00  
##  1st Qu.:12.0   1st Qu.: 26.00  
##  Median :15.0   Median : 36.00  
##  Mean   :15.4   Mean   : 42.98  
##  3rd Qu.:19.0   3rd Qu.: 56.00  
##  Max.   :25.0   Max.   :120.00
```

Example output slide

Slide with Plot



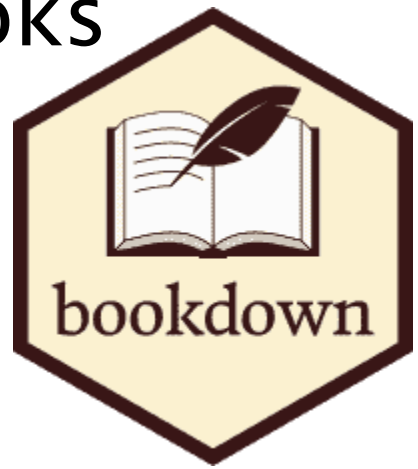
Example output slide

Books and longer documents also generated from R Markdown

Can generate printer ready books and ebooks

Supports LaTeX features such as equations

Generates blog formatted websites



https://github.com/rstudio/bookdown

https://bookdown.org/yihui/bookdown/

https://bookdown.org/yihui/blogdown/

Goals

1. Build R Markdown reports using formatting outputs beyond standard document formats

Objectives

1. Format a flexdashboard to improve display of multiple plots
2. Convert a static plot into an interactive plot

z

Appendix

Data Import : : CHEAT SHEET

R's **tidyverse** is built around **tidy data** stored in **tibbles**, which are enhanced data frames.

The front side of this sheet shows how to read text files into R with **readr**.

The reverse side shows how to create tibbles with **tibble** and to layout tidy data with **tidyr**.

OTHER TYPES OF DATA

Try one of the following packages to import other types of files

- **haven** - SPSS, Stata, and SAS files
- **readxl** - excel files (.xls and .xlsx)
- **DBI** - databases
- **jsonlite** - json
- **xml2** - XML
- **httr** - Web APIs
- **rvest** - HTML (Web Scraping)

Save Data

Save **x**, an R object, to **path**, a file path, as:

Comma delimited file
write_csv(x, path, na = "NA", append = FALSE, col_names = !append**)**

File with arbitrary delimiter
write_delim(x, path, delim = " ", na = "NA", append = FALSE, col_names = !append**)**

CSV for excel
write_excel_csv(x, path, na = "NA", append = FALSE, col_names = !append**)**

String to file
write_file(x, path, append = FALSE**)**

String vector to file, one element per line
write_lines(x,path, na = "NA", append = FALSE**)**

Object to RDS file
write_rds(x, path, compress = c("none", "gz", "bz2", "xz"), ...**)**

Tab delimited files
write_tsv(x, path, na = "NA", append = FALSE, col_names = !append**)**

Read Tabular Data - These functions share the common arguments:

read_*(file, col_names = TRUE, col_types = NULL, locale = default_locale(), na = c("", "NA"), quoted_na = TRUE, comment = "", trim_ws = TRUE, skip = 0, n_max = Inf, guess_max = min(1000, n_max), progress = interactive()**)**

a,b,c
1,2,3
4,5,NA

A	B	C
1	2	3
4	5	NA

Comma Delimited Files
read_csv("file.csv"**)**
To make file.csv run:
write_file(x = "a,b,c\n1,2,3\n4,5,NA", path = "file.csv")

a;b;c
1;2;3
4;5;NA

A	B	C
1	2	3
4	5	NA

Semi-colon Delimited Files
read_csv2("file2.csv"**)**
write_file(x = "a;b;c\n1;2;3\n4;5;NA", path = "file2.csv")

a|b|c
1|2|3
4|5|NA

A	B	C
1	2	3
4	5	NA

Files with Any Delimiter
read_delim("file.txt", delim = "|"**)**
write_file(x = "a|b|c\n1|2|3\n4|5|NA", path = "file.txt")

a b c
1 2 3
4 5 NA

A	B	C
1	2	3
4	5	NA

Fixed Width Files
read_fwf("file.fwf", col_positions = c(1, 3, 5)**)**
write_file(x = "a b c\n1 2 3\n4 5 NA", path = "file.fwf")

Tab Delimited Files
read_tsv("file.tsv"**)** Also **read_table().**
write_file(x = "a\tb\tc\n1\t2\t3\n4\t5\tNA", path = "file.tsv")

USEFUL ARGUMENTS

a,b,c
1,2,3
4,5,NA

Example file
write_file("a,b,c\n1,2,3\n4,5,NA","file.csv")
f <- "file.csv"

A	B	C
1	2	3
4	5	NA

No header
read_csv(f, **col_names = FALSE**)

x	y	z
A	B	C
1	2	3
4	5	NA

Provide header
read_csv(f, **col_names = c("x", "y", "z")**)

1	2	3
4	5	NA

Skip lines
read_csv(f, **skip = 1**)

A	B	C
1	2	3

Read in a subset
read_csv(f, **n_max = 1**)

A	B	C
NA	2	3
4	5	NA

Missing Values
read_csv(f, **na = c("1", ".")**)

Read Non-Tabular Data

Read a file into a single string
read_file(file, locale = default_locale()**)**

Read each line into its own string
read_lines(file, skip = 0, n_max = -1L, na = character(), locale = default_locale(), progress = interactive()**)**

Read Apache style log files
read_log(file, col_names = FALSE, col_types = NULL, skip = 0, n_max = -1, progress = interactive()**)**

Read a file into a raw vector
read_file_raw(file**)**

Read each line into a raw vector
read_lines_raw(file, skip = 0, n_max = -1L, progress = interactive()**)**

Data types

readr functions guess the types of each column and convert types when appropriate (but will NOT convert strings to factors automatically).

A message shows the type of each column in the result.

```
## Parsed with column specification:
## cols(
##   age = col_integer(),
##   sex = col_character(),
##   earn = col_double()
## )
```

age is an integer
sex is a character
earn is a double (numeric)

1. Use **problems()** to diagnose problems.
x <- read_csv("file.csv"); problems(x)

2. Use a col_ function to guide parsing.
- **col_guess()** - the default
- **col_character()**
- **col_double()**, **col_euro_double()**
- **col_datetime(**format = ""**)** Also **col_date(**format = ""**)**, **col_time(**format = ""**)**
- **col_factor(**levels, ordered = FALSE**)**
- **col_integer()**
- **col_logical()**
- **col_number()**, **col_numeric()**
- **col_skip()**

```
x <- read_csv("file.csv", col_types = cols(
  A = col_double(),
  B = col_logical(),
  C = col_factor()))
```

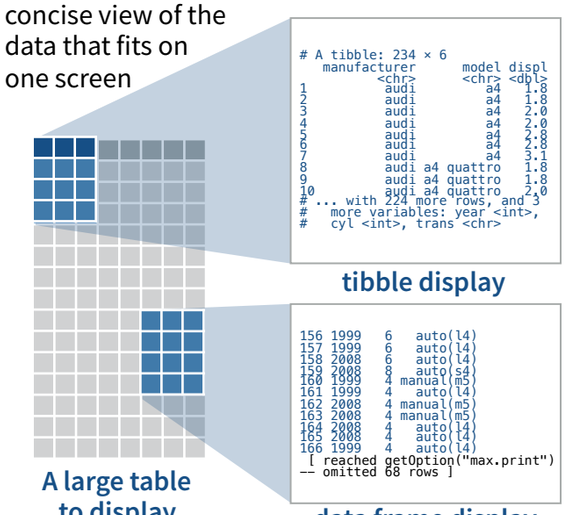
3. Else, read in as character vectors then parse with a parse_ function.
- **parse_guess()**
- **parse_character()**
- **parse_datetime()** Also **parse_date()** and **parse_time()**
- **parse_double()**
- **parse_factor()**
- **parse_integer()**
- **parse_logical()**
- **parse_number()**

```
x$A <- parse_number(x$A)
```

Tibbles - an enhanced data frame

The **tibble** package provides a new S3 class for storing tabular data, the tibble. Tibbles inherit the data frame class, but improve three behaviors:

- **Subsetting** - [always returns a new tibble, [[and $ always return a vector.
- **No partial matching** - You must use full column names when subsetting
- **Display** - When you print a tibble, R provides a concise view of the data that fits on one screen



- Control the default appearance with options:

  options(tibble.print_max = n, tibble.print_min = m, tibble.width = Inf**)**

- View full data set with **View()** or **glimpse()**
- Revert to data frame with **as.data.frame()**

CONSTRUCT A TIBBLE IN TWO WAYS

tibble(…)
Construct by columns.
tibble(x = 1:3, y = c("a", "b", "c"))

tribble(…)
Construct by rows.
tribble(~x, ~y, 1, "a", 2, "b", 3, "c")

Both make this tibble

```
A tibble: 3 × 2
      x     y
  <int> <chr>
1     1     a
2     2     b
3     3     c
```

as_tibble(x, …) Convert data frame to tibble.

enframe(x, name = "name", value = "value")
Convert named vector to a tibble

is_tibble(x) Test whether x is a tibble.

Tidy Data with tidyr

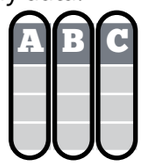
Tidy data is a way to organize tabular data. It provides a consistent data structure across packages.

A table is tidy if:

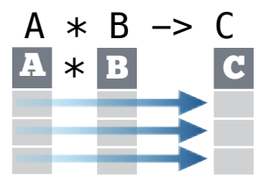
Each **variable** is in its own **column**

Each **observation**, or **case**, is in its own **row**

Tidy data:



Makes variables easy to access as vectors



Preserves cases during vectorized operations

Reshape Data - change the layout of values in a table

Use **gather()** and **spread()** to reorganize the values of a table into a new layout.

gather(data, key, value, ..., na.rm = FALSE, convert = FALSE, factor_key = FALSE**)**

gather() moves column names into a **key** column, gathering the column values into a single **value** column.

table4a

country	1999	2000
A	0.7K	2K
B	37K	80K
C	212K	213K

→

country	year	cases
A	1999	0.7K
B	1999	37K
C	1999	212K
A	2000	2K
B	2000	80K
C	2000	213K

key value

gather(table4a, `1999`, `2000`, key = "year", value = "cases")

spread(data, key, value, fill = NA, convert = FALSE, drop = TRUE, sep = NULL**)**

spread() moves the unique values of a **key** column into the column names, spreading the values of a **value** column across the new columns.

table2

country	year	type	count
A	1999	cases	0.7K
A	1999	pop	19M
A	2000	cases	2K
A	2000	pop	20M
B	1999	cases	37K
B	1999	pop	172M
B	2000	cases	80K
B	2000	pop	174M
C	1999	cases	212K
C	1999	pop	1T
C	2000	cases	213K
C	2000	pop	1T

key value

→

country	year	cases	pop
A	1999	0.7K	19M
A	2000	2K	20M
B	1999	37K	172M
B	2000	80K	174M
C	1999	212K	1T
C	2000	213K	1T

spread(table2, type, count)

Handle Missing Values

drop_na(data, ...**)**
Drop rows containing NA's in … columns.

x

x1	x2
A	1
B	NA
C	NA
D	3
E	NA

→

x1	x2
A	1
D	3

drop_na(x, x2)

fill(data, ..., .direction = c("down", "up")**)**
Fill in NA's in … columns with most recent non-NA values.

x

x1	x2
A	1
B	NA
C	NA
D	3
E	NA

→

x1	x2
A	1
B	1
C	1
D	3
E	3

fill(x, x2)

replace_na(data, replace = list(), ...**)**
Replace NA's by column.

x

x1	x2
A	1
B	NA
C	NA
D	3
E	NA

→

x1	x2
A	1
B	2
C	2
D	3
E	2

replace_na(x, list(x2 = 2))

Expand Tables - quickly create tables with combinations of values

complete(data, ..., fill = list()**)**
Adds to the data missing combinations of the values of the variables listed in …
complete(mtcars, cyl, gear, carb)

expand(data, ...**)**
Create new tibble with all possible combinations of the values of the variables listed in …
expand(mtcars, cyl, gear, carb)

Split Cells

Use these functions to split or combine cells into individual, isolated values.

separate(data, col, into, sep = "[^[:alnum:]]+", remove = TRUE, convert = FALSE, extra = "warn", fill = "warn", ...**)**

Separate each cell in a column to make several columns.

table3

country	year	rate
A	1999	0.7K/19M
A	2000	2K/20M
B	1999	37K/172M
B	2000	80K/174M
C	1999	212K/1T
C	2000	213K/1T

→

country	year	cases	pop
A	1999	0.7K	19M
A	2000	2K	20M
B	1999	37K	172
B	2000	80K	174
C	1999	212K	1T
C	2000	213K	1T

separate(table3, rate, sep = "/", into = c("cases", "pop"))

separate_rows(data, ..., sep = "[^[:alnum:].]+", convert = FALSE**)**

Separate each cell in a column to make several rows.

table3

country	year	rate
A	1999	0.7K/19M
A	2000	2K/20M
B	1999	37K/172M
B	2000	80K/174M
C	1999	212K/1T
C	2000	213K/1T

→

country	year	rate
A	1999	0.7K
A	1999	19M
A	2000	2K
A	2000	20M
B	1999	37K
B	1999	172M
B	2000	80K
B	2000	174M
C	1999	212K
C	1999	1T
C	2000	213K
C	2000	1T

separate_rows(table3, rate, sep = "/")

unite(data, col, ..., sep = "_", remove = TRUE**)**

Collapse cells across several columns to make a single column.

table5

country	century	year
Afghan	19	99
Afghan	20	00
Brazil	19	99
Brazil	20	00
China	19	99
China	20	00

→

country	year
Afghan	1999
Afghan	2000
Brazil	1999
Brazil	2000
China	1999
China	2000

unite(table5, century, year, col = "year", sep = "")

Data Transformation with dplyr : : CHEAT SHEET

dplyr functions work with pipes and expect **tidy data**. In tidy data:

Each **variable** is in its own **column**

&

Each **observation**, or **case**, is in its own **row**

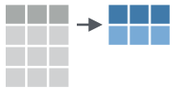
pipes

x %>% f(y) becomes **f(x, y)**

Summarise Cases

These apply **summary functions** to columns to create a new table of summary statistics. Summary functions take vectors as input and return one value (see back).

summary function



summarise(.data, …)
Compute table of summaries.
summarise(mtcars, avg = mean(mpg))

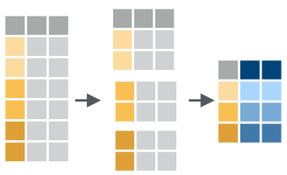
count(x, ..., wt = NULL, sort = FALSE)
Count number of rows in each group defined by the variables in … Also **tally**().
count(iris, Species)

VARIATIONS

summarise_all() - Apply funs to every column.
summarise_at() - Apply funs to specific columns.
summarise_if() - Apply funs to all cols of one type.

Group Cases

Use **group_by()** to create a "grouped" copy of a table. dplyr functions will manipulate each "group" separately and then combine the results.



```
mtcars %>%
group_by(cyl) %>%
summarise(avg = mean(mpg))
```

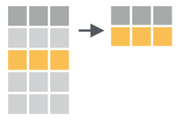
group_by(.data, ..., add = FALSE)
Returns copy of table grouped by …
g_iris <- group_by(iris, Species)

ungroup(x, …)
Returns ungrouped copy of table.
ungroup(g_iris)

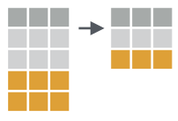
Manipulate Cases

EXTRACT CASES

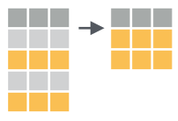
Row functions return a subset of rows as a new table.



filter(.data, …**)** Extract rows that meet logical criteria. *filter(iris, Sepal.Length > 7)*

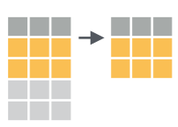


distinct(.data, ..., .keep_all = FALSE**)** Remove rows with duplicate values.
distinct(iris, Species)



sample_frac(tbl, size = 1, replace = FALSE, weight = NULL, .env = parent.frame()**)** Randomly select fraction of rows.
sample_frac(iris, 0.5, replace = TRUE)

sample_n(tbl, size, replace = FALSE, weight = NULL, .env = parent.frame()**)** Randomly select size rows. *sample_n(iris, 10, replace = TRUE)*



slice(.data, …**)** Select rows by position.
slice(iris, 10:15)

top_n(x, n, wt**)** Select and order top n entries (by group if grouped data). *top_n(iris, 5, Sepal.Width)*

Logical and boolean operators to use with filter()

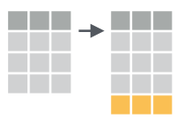
<	<=	is.na()	%in%	|	xor()
>	>=	!is.na()	!	&	

See **?base::Logic** and **?Comparison** for help.

ARRANGE CASES

arrange(.data, …**)** Order rows by values of a column or columns (low to high), use with **desc()** to order from high to low.
arrange(mtcars, mpg)
arrange(mtcars, desc(mpg))

ADD CASES



add_row(.data, ..., .before = NULL, .after = NULL**)**
Add one or more rows to a table.
add_row(faithful, eruptions = 1, waiting = 1)

Manipulate Variables

EXTRACT VARIABLES

Column functions return a set of columns as a new vector or table.

pull(.data, var = -1**)** Extract column values as a vector. Choose by name or index.
pull(iris, Sepal.Length)

select(.data, …**)**
Extract columns as a table. Also **select_if()**.
select(iris, Sepal.Length, Species)

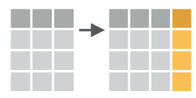
Use these helpers with select (),
e.g. select(iris, starts_with("Sepal"))

contains(match**)**	**num_range(**prefix, range**)**	**:**, e.g. mpg:cyl
ends_with(match**)**	**one_of(**…**)**	**-**, e.g, -Species
matches(match**)**	**starts_with(**match**)**	

MAKE NEW VARIABLES

These apply **vectorized functions** to columns. Vectorized funs take vectors as input and return vectors of the same length as output (see back).

vectorized function

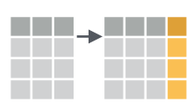


mutate(.data, …**)**
Compute new column(s).
mutate(mtcars, gpm = 1/mpg)

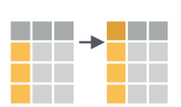
transmute(.data, …**)**
Compute new column(s), drop others.
transmute(mtcars, gpm = 1/mpg)

mutate_all(.tbl, .funs, …**)** Apply funs to every column. Use with **funs()**. Also **mutate_if()**.
mutate_all(faithful, funs(log(.), log2(.)))
mutate_if(iris, is.numeric, funs(log(.)))

mutate_at(.tbl, .cols, .funs, …**)** Apply funs to specific columns. Use with **funs()**, **vars()** and the helper functions for select().
mutate_at(iris, vars(-Species), funs(log(.)))



add_column(.data, ..., .before = NULL, .after = NULL**)** Add new column(s). Also **add_count()**, **add_tally()**. *add_column(mtcars, new = 1:32)*



rename(.data, …**)** Rename columns.
rename(iris, Length = Sepal.Length)

Vector Functions

TO USE WITH MUTATE ()

mutate() and **transmute()** apply vectorized functions to columns to create new columns. Vectorized functions take vectors as input and return vectors of the same length as output.

vectorized function

OFFSETS

dplyr::**lag()** - Offset elements by 1
dplyr::**lead()** - Offset elements by -1

CUMULATIVE AGGREGATES

dplyr::**cumall()** - Cumulative all()
dplyr::**cumany()** - Cumulative any()
cummax() - Cumulative max()
dplyr::**cummean()** - Cumulative mean()
cummin() - Cumulative min()
cumprod() - Cumulative prod()
cumsum() - Cumulative sum()

RANKINGS

dplyr::**cume_dist()** - Proportion of all values <=
dplyr::**dense_rank()** - rank w ties = min, no gaps
dplyr::**min_rank()** - rank with ties = min
dplyr::**ntile()** - bins into n bins
dplyr::**percent_rank()** - min_rank scaled to [0,1]
dplyr::**row_number()** - rank with ties = "first"

MATH

+, - , *, /, ^, %/%, %% - arithmetic ops
log(), log2(), log10() - logs
<, <=, >, >=, !=, == - logical comparisons
dplyr::**between()** - x >= left & x <= right
dplyr::**near()** - safe == for floating point numbers

MISC

dplyr::**case_when()** - multi-case if_else()

```
iris %>% mutate(Species = case_when(
                Species == "versicolor" ~ "versi",
                Species == "virginica"  ~ "virgi",
                           TRUE ~ Species))
```

dplyr::**coalesce()** - first non-NA values by element across a set of vectors
dplyr::**if_else()** - element-wise if() + else()
dplyr::**na_if()** - replace specific values with NA
pmax() - element-wise max()
pmin() - element-wise min()
dplyr::**recode()** - Vectorized switch()
dplyr::**recode_factor()** - Vectorized switch() for factors

Summary Functions

TO USE WITH SUMMARISE ()

summarise() applies summary functions to columns to create a new table. Summary functions take vectors as input and return single values as output.

summary function

COUNTS

dplyr::**n()** - number of values/rows
dplyr::**n_distinct()** - # of uniques
sum(!is.na()) - # of non-NA's

LOCATION

mean() - mean, also **mean(!is.na())**
median() - median

LOGICALS

mean() - Proportion of TRUE's
sum() - # of TRUE's

POSITION/ORDER

dplyr::**first()** - first value
dplyr::**last()** - last value
dplyr::**nth()** - value in nth location of vector

RANK

quantile() - nth quantile
min() - minimum value
max() - maximum value

SPREAD

IQR() - Inter-Quartile Range
mad() - median absolute deviation
sd() - standard deviation
var() - variance

Row Names

Tidy data does not use rownames, which store a variable outside of the columns. To work with the rownames, first move them into a column.

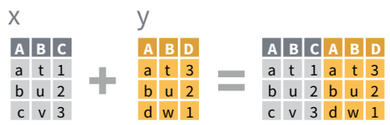
rownames_to_column()
Move row names into col.
a <- rownames_to_column(iris, var = "C")

column_to_rownames()
Move col in row names.
column_to_rownames(a, var = "C")

Also **has_rownames()**, **remove_rownames()**

Combine Tables

COMBINE VARIABLES



Use **bind_cols()** to paste tables beside each other as they are.

bind_cols(...) Returns tables placed side by side as a single table.
BE SURE THAT ROWS ALIGN.

Use a "**Mutating Join**" to join one table to columns from another, matching values with the rows that they correspond to. Each join retains a different combination of values from the tables.

left_join(x, y, by = NULL, copy=FALSE, suffix=c(".x",".y"),…**)**
Join matching values from y to x.

right_join(x, y, by = NULL, copy = FALSE, suffix=c(".x",".y"),…**)**
Join matching values from x to y.

inner_join(x, y, by = NULL, copy = FALSE, suffix=c(".x",".y"),…**)**
Join data. Retain only rows with matches.

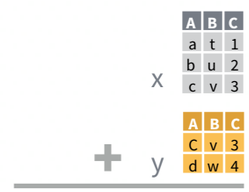
full_join(x, y, by = NULL, copy=FALSE, suffix=c(".x",".y"),…**)**
Join data. Retain all values, all rows.

Use **by = c("col1", "col2", ...)** to specify one or more common columns to match on.
left_join(x, y, by = "A")

Use a named vector, **by = c("col1" = "col2")**, to match on columns that have different names in each table.
left_join(x, y, by = c("C" = "D"))

Use **suffix** to specify the suffix to give to unmatched columns that have the same name in both tables.
left_join(x, y, by = c("C" = "D"), suffix = c("1", "2"))

COMBINE CASES



Use **bind_rows()** to paste tables below each other as they are.

bind_rows(…, .id = NULL**)**
Returns tables one on top of the other as a single table. Set .id to a column name to add a column of the original table names (as pictured)

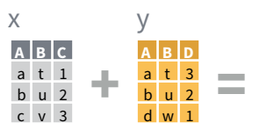
intersect(x, y, ...)
Rows that appear in both x and y.

setdiff(x, y, ...)
Rows that appear in x but not y.

union(x, y, ...)
Rows that appear in x or y. (Duplicates removed). union_all() retains duplicates.

Use **setequal()** to test whether two data sets contain the exact same rows (in any order).

EXTRACT ROWS



Use a "**Filtering Join**" to filter one table against the rows of another.

semi_join(x, y, by = NULL, …**)**
Return rows of x that have a match in y. USEFUL TO SEE WHAT WILL BE JOINED.

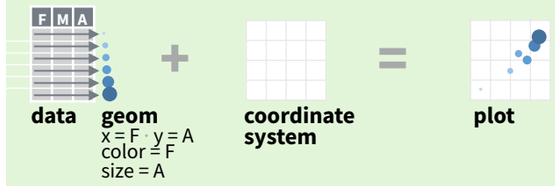
anti_join(x, y, by = NULL, …**)**
Return rows of x that do not have a match in y. USEFUL TO SEE WHAT WILL NOT BE JOINED.

Data Visualization with ggplot2 : : CHEAT SHEET

Basics

ggplot2 is based on the **grammar of graphics**, the idea that you can build every graph from the same components: a **data** set, a **coordinate system**, and geoms—visual marks that represent data points.

To display values, map variables in the data to visual properties of the geom (**aesthetics**) like **size**, **color**, and **x** and **y** locations.



Complete the template below to build a graph.

```
ggplot (data = <DATA>) +                                  required
<GEOM_FUNCTION>(mapping = aes(<MAPPINGS>),
 stat = <STAT>, position = <POSITION> ) +                 Not required, sensible defaults supplied
<COORDINATE_FUNCTION> +
<FACET_FUNCTION> +
<SCALE_FUNCTION> +
<THEME_FUNCTION>
```

ggplot(data = mpg, **aes(**x = cty, y = hwy**))** Begins a plot that you finish by adding layers to. Add one geom function per layer.

aesthetic mappings · data · geom

qplot(x = cty, y = hwy, data = mpg, geom = "point"**)** Creates a complete plot with given data, geom, and mappings. Supplies many useful defaults.

last_plot() Returns the last plot

ggsave("plot.png", width = 5, height = 5) Saves last plot as 5' x 5' file named "plot.png" in working directory. Matches file type to file extension.

Geoms

Use a geom function to represent data points, use the geom's aesthetic properties to represent variables. Each function returns a layer.

GRAPHICAL PRIMITIVES

a <- ggplot(economics, aes(date, unemploy))
b <- ggplot(seals, aes(x = long, y = lat))

a + geom_blank()
(Useful for expanding limits)

b + geom_curve(aes(yend = lat + 1, xend=long+1),curvature=1**)** - x, xend, y, yend, alpha, angle, color, curvature, linetype, size

a + geom_path(lineend="butt", linejoin="round", linemitre=1**)**
x, y, alpha, color, group, linetype, size

a + geom_polygon(aes(group = group)**)**
x, y, alpha, color, fill, group, linetype, size

b + geom_rect(aes(xmin = long, ymin=lat, xmax= long + 1, ymax = lat + 1)**)** - xmax, xmin, ymax, ymin, alpha, color, fill, linetype, size

a + geom_ribbon(aes(ymin=unemploy - 900, ymax=unemploy + 900)**)** - x, ymax, ymin, alpha, color, fill, group, linetype, size

LINE SEGMENTS

common aesthetics: x, y, alpha, color, linetype, size

b + geom_abline(aes(intercept=0, slope=1)**)**
b + geom_hline(aes(yintercept = lat)**)**
b + geom_vline(aes(xintercept = long)**)**

b + geom_segment(aes(yend=lat+1, xend=long+1)**)**
b + geom_spoke(aes(angle = 1:1155, radius = 1)**)**

ONE VARIABLE continuous

c <- ggplot(mpg, aes(hwy)); c2 <- ggplot(mpg)

c + geom_area(stat = "bin")
x, y, alpha, color, fill, linetype, size

c + geom_density(kernel = "gaussian"**)**
x, y, alpha, color, fill, group, linetype, size, weight

c + geom_dotplot()
x, y, alpha, color, fill

c + geom_freqpoly() x, y, alpha, color, group, linetype, size

c + geom_histogram(binwidth = 5**)** x, y, alpha, color, fill, linetype, size, weight

c2 + geom_qq(aes(sample = hwy)**)** x, y, alpha, color, fill, linetype, size, weight

discrete

d <- ggplot(mpg, aes(fl))

d + geom_bar()
x, alpha, color, fill, linetype, size, weight

TWO VARIABLES

continuous x , continuous y

e <- ggplot(mpg, aes(cty, hwy))

e + geom_label(aes(label = cty), nudge_x = 1, nudge_y = 1, check_overlap = TRUE**)** x, y, label, alpha, angle, color, family, fontface, hjust, lineheight, size, vjust

e + geom_jitter(height = 2, width = 2**)**
x, y, alpha, color, fill, shape, size

e + geom_point(), x, y, alpha, color, fill, shape, size, stroke

e + geom_quantile(), x, y, alpha, color, group, linetype, size, weight

e + geom_rug(sides = "bl"**)**, x, y, alpha, color, linetype, size

e + geom_smooth(method = lm**)**, x, y, alpha, color, fill, group, linetype, size, weight

e + geom_text(aes(label = cty), nudge_x = 1, nudge_y = 1, check_overlap = TRUE**)**, x, y, label, alpha, angle, color, family, fontface, hjust, lineheight, size, vjust

discrete x , continuous y

f <- ggplot(mpg, aes(class, hwy))

f + geom_col(), x, y, alpha, color, fill, group, linetype, size

f + geom_boxplot(), x, y, lower, middle, upper, ymax, ymin, alpha, color, fill, group, linetype, shape, size, weight

f + geom_dotplot(binaxis = "y", stackdir = "center"**)**, x, y, alpha, color, fill, group

f + geom_violin(scale = "area"**)**, x, y, alpha, color, fill, group, linetype, size, weight

discrete x , discrete y

g <- ggplot(diamonds, aes(cut, color))

g + geom_count(), x, y, alpha, color, fill, shape, size, stroke

continuous bivariate distribution

h <- ggplot(diamonds, aes(carat, price))

h + geom_bin2d(binwidth = c(0.25, 500)**)**
x, y, alpha, color, fill, linetype, size, weight

h + geom_density2d()
x, y, alpha, colour, group, linetype, size

h + geom_hex()
x, y, alpha, colour, fill, size

continuous function

i <- ggplot(economics, aes(date, unemploy))

i + geom_area()
x, y, alpha, color, fill, linetype, size

i + geom_line()
x, y, alpha, color, group, linetype, size

i + geom_step(direction = "hv")
x, y, alpha, color, group, linetype, size

visualizing error

df <- data.frame(grp = c("A", "B"), fit = 4:5, se = 1:2)
j <- ggplot(df, aes(grp, fit, ymin = fit-se, ymax = fit+se))

j + geom_crossbar(fatten = 2**)**
x, y, ymax, ymin, alpha, color, fill, group, linetype, size

j + geom_errorbar(), x, ymax, ymin, alpha, color, group, linetype, size, width (also **geom_errorbarh()**)

j + geom_linerange()
x, ymin, ymax, alpha, color, group, linetype, size

j + geom_pointrange()
x, y, ymin, ymax, alpha, color, fill, group, linetype, shape, size

maps

data <- data.frame(murder = USArrests$Murder, state = tolower(rownames(USArrests)))
map <- map_data("state")
k <- ggplot(data, aes(fill = murder))

k + geom_map(aes(map_id = state), map = map**)**
+ expand_limits(x = map$long, y = map$lat**)**,
map_id, alpha, color, fill, linetype, size

THREE VARIABLES

seals$z <- with(seals, sqrt(delta_long^2 + delta_lat^2)); l <- ggplot(seals, aes(long, lat))

l + geom_contour(aes(z = z))
x, y, z, alpha, colour, group, linetype, size, weight

l + geom_raster(aes(fill = z), hjust=0.5, vjust=0.5, interpolate=FALSE**)**
x, y, alpha, fill

l + geom_tile(aes(fill = z)), x, y, alpha, color, fill, linetype, size, width

Stats An alternative way to build a layer

A stat builds new variables to plot (e.g., count, prop).

Visualize a stat by changing the default stat of a geom function, **geom_bar(stat="count")** or by using a stat function, **stat_count(geom="bar")**, which calls a default geom to make a layer (equivalent to a geom function). Use **..name..** syntax to map stat variables to aesthetics.

c + stat_bin(binwidth = 1, origin = 10**)**
x, y | ..count.., ..ncount.., ..density.., ..ndensity..

c + stat_count(width = 1**) x, y,** | ..count.., ..prop..

c + stat_density(adjust = 1, kernel = "gaussian"**)**
x, y, | ..count.., ..density.., ..scaled..

e + stat_bin_2d(bins = 30, drop = T**)**
x, y, fill | ..count.., ..density..

e + stat_bin_hex(bins=30**) x, y, fill** | ..count.., ..density..

e + stat_density_2d(contour = TRUE, n = 100**)**
x, y, color, size | ..level..

e + stat_ellipse(level = 0.95, segments = 51, type = "t"**)**

l + stat_contour(aes(z = z)**) x, y, z, order** | ..level..

l + stat_summary_hex(aes(z = z), bins = 30, fun = max**)**
x, y, z, fill | ..value..

l + stat_summary_2d(aes(z = z), bins = 30, fun = mean**)**
x, y, z, fill | ..value..

f + stat_boxplot(coef = 1.5**) x, y** | ..lower.., ..middle.., ..upper.., ..width.. , ..ymin.., ..ymax..

f + stat_ydensity(kernel = "gaussian", scale = "area"**) x, y** | ..density.., ..scaled.., ..count.., ..n.., ..violinwidth.., ..width..

e + stat_ecdf(n = 40**) x, y** | ..x.., ..y..

e + stat_quantile(quantiles = c(0.1, 0.9), formula = y ~ log(x), method = "rq"**) x, y** | ..quantile..

e + stat_smooth(method = "lm", formula = y ~ x, se=T, level=0.95**) x, y** | ..se.., ..x.., ..y.., ..ymin.., ..ymax..

ggplot() + stat_function(aes(x = -3:3), n = 99, fun = dnorm, args = list(sd=0.5)**) x** | ..x.., ..y..

e + stat_identity(na.rm = TRUE**)**

ggplot() + stat_qq(aes(sample=1:100), dist = qt, dparam=list(df=5)**) sample, x, y** | ..sample.., ..theoretical..

e + stat_sum() x, y, size | ..n.., ..prop..

e + stat_summary(fun.data = "mean_cl_boot"**)**

h + stat_summary_bin(fun.y = "mean", geom = "bar"**)**

e + stat_unique()

Scales

Scales map data values to the visual values of an aesthetic. To change a mapping, add a new scale.

(n <- d + geom_bar(aes(fill = fl)))

GENERAL PURPOSE SCALES

Use with most aesthetics

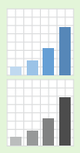
scale_*_continuous() - map cont' values to visual ones
scale_*_discrete() - map discrete values to visual ones
scale_*_identity() - use data values **as** visual ones
scale_*_manual(values = c()**)** - map discrete values to manually chosen visual ones
scale_*_date(date_labels = "%m/%d"), date_breaks = "2 weeks"**)** - treat data values as dates.
scale_*_datetime() - treat data x values as date times. Use same arguments as scale_x_date(). See ?strptime for label formats.

X & Y LOCATION SCALES

Use with x or y aesthetics (x shown here)

scale_x_log10() - Plot x on log10 scale
scale_x_reverse() - Reverse direction of x axis
scale_x_sqrt() - Plot x on square root scale

COLOR AND FILL SCALES (DISCRETE)

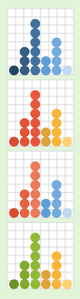


n <- d + geom_bar(aes(fill = fl)**)**

n + scale_fill_brewer(palette = "Blues"**)**
For palette choices:
RColorBrewer::display.brewer.all()

n + scale_fill_grey(start = 0.2, end = 0.8, na.value = "red"**)**

COLOR AND FILL SCALES (CONTINUOUS)



o <- c + geom_dotplot(aes(fill = ..x..))

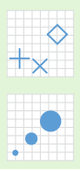
o + scale_fill_distiller(palette = "Blues"**)**

o + scale_fill_gradient(low="red", high="yellow"**)**

o + scale_fill_gradient2(low="red", high="blue", mid = "white", midpoint = 25)

o + scale_fill_gradientn(colours=topo.colors(6)**)**
Also: rainbow(), heat.colors(), terrain.colors(), cm.colors(), RColorBrewer::brewer.pal()

SHAPE AND SIZE SCALES



p <- e + geom_point(aes(shape = fl, size = cyl))
p + scale_shape() + scale_size()
p + scale_shape_manual(values = c(3:7)**)**

p + scale_radius(range = c(1,6)**)**
p + scale_size_area(max_size = 6**)**

Coordinate Systems

r <- d + geom_bar()

r + coord_cartesian(xlim = c(0, 5)**)**
xlim, ylim
The default cartesian coordinate system

r + coord_fixed(ratio = 1/2**)**
ratio, xlim, ylim
Cartesian coordinates with fixed aspect ratio between x and y units

r + coord_flip()
xlim, ylim
Flipped Cartesian coordinates

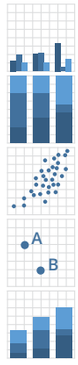
r + coord_polar(theta = "x", direction=1 **)**
theta, start, direction
Polar coordinates

r + coord_trans(ytrans = "sqrt"**)**
xtrans, ytrans, limx, limy
Transformed cartesian coordinates. Set xtrans and ytrans to the name of a window function.

π + coord_quickmap()
π + coord_map(projection = "ortho", orientation=c(41, -74, 0)**)**projection, xlim, ylim
Map projections from the mapproj package (mercator (default), azequalarea, lagrange, etc.)

Position Adjustments

Position adjustments determine how to arrange geoms that would otherwise occupy the same space.



s <- ggplot(mpg, aes(fl, fill = drv))

s + geom_bar(position = "dodge")
Arrange elements side by side

s + geom_bar(position = "fill")
Stack elements on top of one another, normalize height

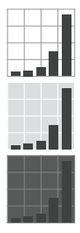
e + geom_point(position = "jitter")
Add random noise to X and Y position of each element to avoid overplotting

e + geom_label(position = "nudge")
Nudge labels away from points

s + geom_bar(position = "stack")
Stack elements on top of one another

Each position adjustment can be recast as a function with manual **width** and **height** arguments
s + geom_bar(position = position_dodge(width = 1))

Themes



r + theme_bw()
White background with grid lines

r + theme_gray()
Grey background (default theme)

r + theme_dark()
dark for contrast

r + theme_classic()

r + theme_light()

r + theme_linedraw()

r + theme_minimal()
Minimal themes

r + theme_void()
Empty theme

Faceting

Facets divide a plot into subplots based on the values of one or more discrete variables.

t <- ggplot(mpg, aes(cty, hwy)) + geom_point()

t + facet_grid(cols = vars(fl))
facet into columns based on fl

t + facet_grid(rows = vars(year))
facet into rows based on year

t + facet_grid(rows = vars(year), cols = vars(fl))
facet into both rows and columns

t + facet_wrap(vars(fl))
wrap facets into a rectangular layout

Set **scales** to let axis limits vary across facets

t + facet_grid(rows = vars(drv), cols = vars(fl), scales = "free")
x and y axis limits adjust to individual facets
"free_x" - x axis limits adjust
"free_y" - y axis limits adjust

Set **labeller** to adjust facet labels

t + facet_grid(cols = vars(fl), labeller = label_both)

fl: c	fl: d	fl: e	fl: p	fl: r

t + facet_grid(rows = vars(fl), labeller = label_bquote(alpha ^ .(fl)**))**

α^c	α^d	α^e	α^p	α^r

Labels

t + labs(**x** = "New x axis label", **y** = "New y axis label",
title ="Add a title above the plot",
subtitle = "Add a subtitle below title",
caption = "Add a caption below plot",
<AES> = "New **<AES>** legend title")

Use scale functions to update legend labels

t + annotate(geom = "text", x = 8, y = 9, label = "A")

geom to place
manual values for geom's aesthetics

Legends

n + theme(legend.position = "bottom"**)**
Place legend at "bottom", "top", "left", or "right"

n + guides(fill = "none"**)**
Set legend type for each aesthetic: colorbar, legend, or none (no legend)

n + scale_fill_discrete(name = "Title", labels = c("A", "B", "C", "D", "E")**)**
Set legend title and labels with a scale function.

Zooming

Without clipping (preferred)

t + coord_cartesian(xlim = c(0, 100), ylim = c(10, 20)**)**

With clipping (removes unseen data points)

t + xlim(0, 100**) + ylim(**10, 20**)**

t + scale_x_continuous(limits = c(0, 100)**) + scale_y_continuous(**limits = c(0, 100)**)**

R Markdown : : CHEAT SHEET

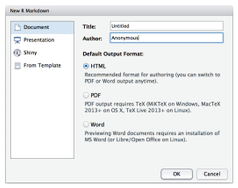
What is R Markdown?

.Rmd files • An R Markdown (.Rmd) file is a record of your research. It contains the code that a scientist needs to reproduce your work along with the narration that a reader needs to understand your work.

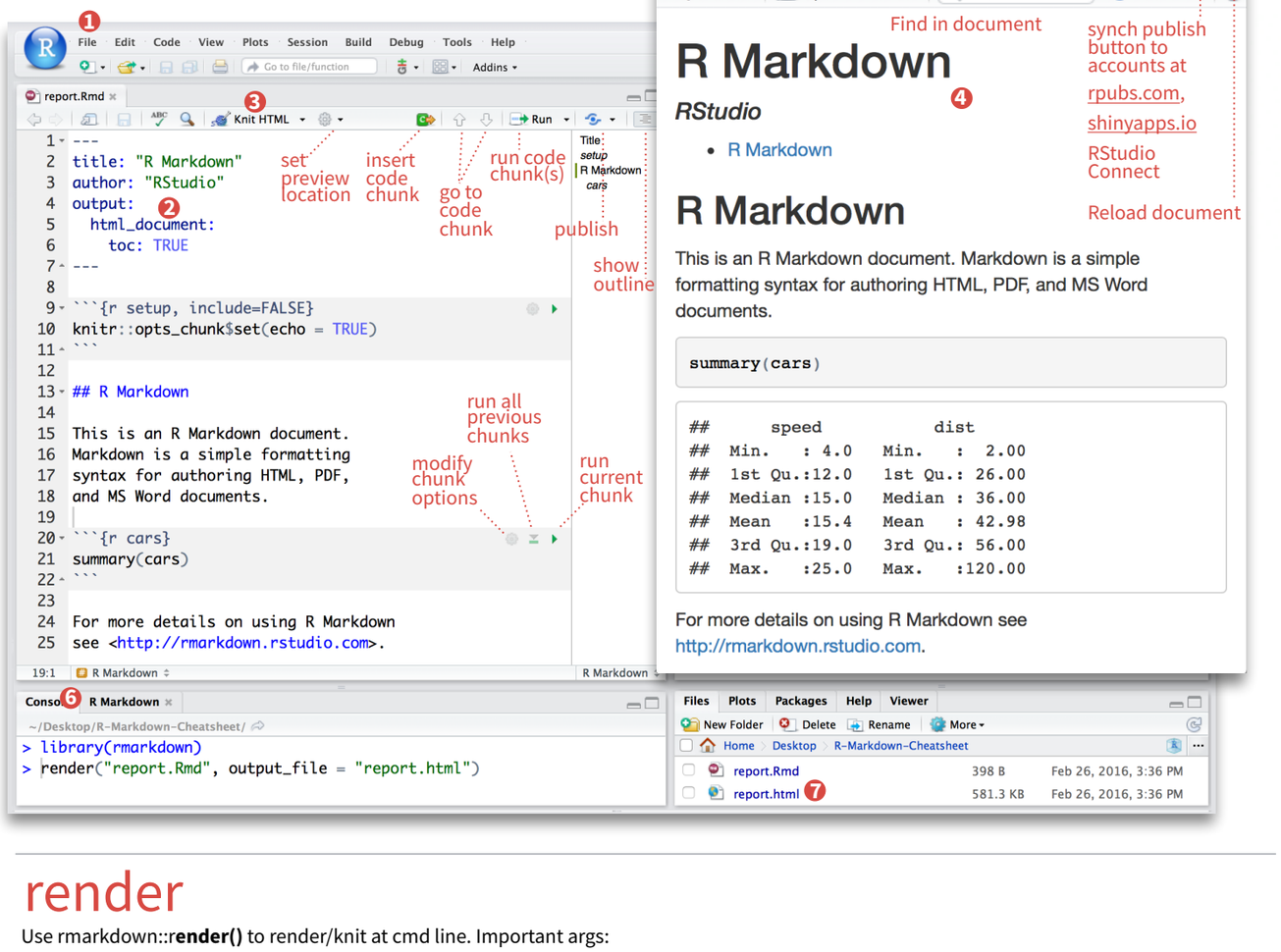
Reproducible Research • At the click of a button, or the type of a command, you can rerun the code in an R Markdown file to reproduce your work and export the results as a finished report.

Dynamic Documents • You can choose to export the finished report in a variety of formats, including html, pdf, MS Word, or RTF documents; html or pdf based slides, Notebooks, and more.

Workflow



1. **Open a new .Rmd file** at File ▶ New File ▶ R Markdown. Use the wizard that opens to pre-populate the file with a template
2. **Write document** by editing template
3. **Knit document to create report**; use knit button or **render()** to knit
4. **Preview Output** in IDE window
5. **Publish** (optional) to web server
6. **Examine build log** in R Markdown console
7. **Use output file** that is saved along side .Rmd



render

Use rmarkdown::**render()** to render/knit at cmd line. Important args:

input - file to render **output_format**	**output_options** - List of render options (as in YAML)	**output_file** **output_dir**	**params** - list of params to use	**envir** - environment to evaluate code chunks in	**encoding** - of input file

Embed code with knitr syntax

INLINE CODE

Insert with **`r <code>`**. Results appear as text without code.

Built with `` `r getRversion()` `` ➡ Built with 3.2.3

CODE CHUNKS

One or more lines surrounded with **```{r}** and **```**. Place chunk options within curly braces, after **r**. Insert with

```
```{r echo=TRUE}
getRversion()
```
```

➡

```
getRversion()
## [1] '3.2.3'
```

GLOBAL OPTIONS

Set with knitr::**opts_chunk$set()**, e.g.

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

IMPORTANT CHUNK OPTIONS

cache - cache results for future knits (default = FALSE)

cache.path - directory to save cached results in (default = "cache/")

child - file(s) to knit and then include (default = NULL)

collapse - collapse all output into single block (default = FALSE)

comment - prefix for each line of results (default = '##')

dependson - chunk dependencies for caching (default = NULL)

echo - Display code in output document (default = TRUE)

engine - code language used in chunk (default = 'R')

error - Display error messages in doc (TRUE) or stop render when errors occur (FALSE) (default = FALSE)

eval - Run code in chunk (default = TRUE)

fig.align - 'left', 'right', or 'center' (default = 'default')

fig.cap - figure caption as character string (default = NULL)

fig.height, fig.width - Dimensions of plots in inches

highlight - highlight source code (default = TRUE)

include - Include chunk in doc after running (default = TRUE)

message - display code messages in document (default = TRUE)

results (default = 'markup')
'asis' - passthrough results
'hide' - do not display results
'hold' - put all results below all code

tidy - tidy code for display (default = FALSE)

warning - display code warnings in document (default = TRUE)

Options not listed above: R.options, aniopts, autodep, background, cache.comments, cache.lazy, cache.rebuild, cache.vars, dev, dev.args, dpi, engine.opts, engine.path, fig.asp, fig.env, fig.ext, fig.keep, fig.lp, fig.path, fig.pos, fig.process, fig.retina, fig.scap, fig.show, fig.showtext, fig.subcap, interval, out.extra, out.height, out.width, prompt, purl, ref.label, render, size, split, tidy.opts

.rmd Structure

YAML Header
Optional section of render (e.g. pandoc) options written as key:value pairs (YAML).

At start of file

Between lines of `---`

Text
Narration formatted with markdown, mixed with:

Code Chunks
Chunks of embedded code. Each chunk:

Begins with **```{r}**

ends with **```**

R Markdown will run the code and append the results to the doc.

It will use the location of the .Rmd file as the **working directory**

Parameters

Parameterize your documents to reuse with new inputs (e.g., data, values, etc.)

1. **Add parameters** • Create and set parameters in the header as sub-values of params

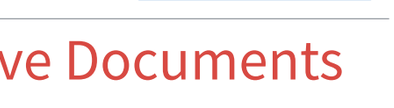
2. **Call parameters** • Call parameter values in code as params$<name>

3. **Set parameters** • Set values wth Knit with parameters or the params argument of render():

render("doc.Rmd", params = list(n = 1, d = as.Date("2015-01-01"))

```
---
params:
  n: 100
  d: !r Sys.Date()
---
```

```
Today's date
is `r params$d`
```



Interactive Documents

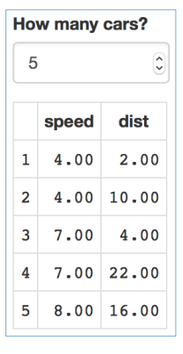
Turn your report into an interactive Shiny document in 4 steps

1. Add runtime: shiny to the YAML header.
2. Call Shiny input functions to embed input objects.
3. Call Shiny render functions to embed reactive output.
4. Render w rmarkdown::run or click Run Document in RStudio IDE

```
---
output: html_document
runtime: shiny
---

```{r, echo = FALSE}
numericInput("n",
  "How many cars?", 5)

renderTable({
  head(cars, input$n)
})
```
```



Embed a complete app into your document with shiny::**shinyAppDir()**

Publish on RStudio Connect, to share R Markdown documents securely, schedule automatic updates, and interact with parameters in real time. www.rstudio.com/products/connect/

RStudio

Pandoc's Markdown

Write with syntax on the left to create effect on right (after render)

```
Plain text
End a line with two spaces
to start a new paragraph.
*italics* and **bold**
`verbatim code`
sub/superscript^2^~2~
~~strikethrough~~
escaped: \* \_ \\
endash: --, emdash: ---
equation: $A = \pi*r^{2}$
equation block:

$$E = mc^{2}$$

> block quote

# Header1  {#anchor}

## Header 2  {#css_id}

### Header 3  {.css_class}

#### Header 4

##### Header 5

###### Header 6

<!--Text comment-->

\textbf{Tex ignored in HTML}
<em>HTML ignored in pdfs</em>

<http://www.rstudio.com>
[link](www.rstudio.com)
Jump to [Header 1](#anchor)
image:

![Caption](smallorb.png)

* unordered list
  + sub-item 1
  + sub-item 2
    - sub-sub-item 1

* item 2

  Continued (indent 4 spaces)

1. ordered list
2. item 2
   i) sub-item 1
      A. sub-sub-item 1

(@)  A list whose numbering

continues after

(@)  an interruption

Term 1

:  Definition 1

| Right | Left | Default | Center |
|------:|:-----|---------|:------:|
|  12 |  12 |  12 |  12 |
| 123 | 123 | 123 | 123 |
|   1 |   1 |   1 |   1 |

- slide bullet 1
- slide bullet 2

(>- to have bullets appear on click)

horizontal rule/slide break:

***

A footnote [^1]

[^1]: Here is the footnote.
```

Plain text
End a line with two spaces
to start a new paragraph.
italics and **bold**
`verbatim code`
sub/superscript$^2_2$
~~strikethrough~~
escaped: * _ \
endash: –, emdash: —
equation: $A = \pi * r^2$
equation block:

$$E = mc^2$$

> block quote

Header1

Header 2

Header 3

Header 4

Header 5

Header 6

HTML ignored in pdfs

http://www.rstudio.com
link
Jump to Header 1
image:

Caption

- unordered list
  - sub-item 1
  - sub-item 2
    - sub-sub-item 1
- item 2

  Continued (indent 4 spaces)

1. ordered list
2. item 2
   i. sub-item 1
      A. sub-sub-item 1

1. A list whose numbering

continues after

2. an interruption

Term 1

Definition 1

Right	Left	Default	Center
12	12	12	12
123	123	123	123
1	1	1	1

- slide bullet 1
- slide bullet 2

(>- to have bullets appear on click)

horizontal rule/slide break:

A footnote [1]

1. Here is the footnote. ↩

Set render options with YAML

When you render, R Markdown

1. runs the R code, embeds results and text into .md file with knitr
2. then converts the .md file into the finished format with pandoc

Set a document's default output format in the YAML header:

```
---
output: html_document
---
# Body
```

output value	creates
html_document	html
pdf_document	pdf (requires Tex)
word_document	Microsoft Word (.docx)
odt_document	OpenDocument Text
rtf_document	Rich Text Format
md_document	Markdown
github_document	Github compatible markdown
ioslides_presentation	ioslides HTML slides
slidy_presentation	slidy HTML slides
beamer_presentation	Beamer pdf slides (requires Tex)

Customize output with sub-options (listed to the right):

Indent 2 spaces — Indent 4 spaces

```
---
output: html_document:
  code_folding: hide
  toc_float: TRUE
---
# Body
```

html tabsets

Use tablet css class to place sub-headers into tabs

```
# Tabset {.tabset .tabset-fade .tabset-pills}
## Tab 1
text 1
## Tab 2
text 2
### End tabset
```

Tabset

Tab 1 | Tab 2

text 1

End tabset

sub-option	description	html	pdf	word	odt	rtf	md	github	ioslides	slidy	beamer
citation_package	The LaTeX package to process citations, natbib, biblatex or none		X				X				X
code_folding	Let readers to toggle the display of R code, "none", "hide", or "show"	X									
colortheme	Beamer color theme to use										X
css	CSS file to use to style document	X							X	X	
dev	Graphics device to use for figure output (e.g. "png")	X	X				X	X	X	X	X
duration	Add a countdown timer (in minutes) to footer of slides									X	
fig_caption	Should figures be rendered with captions?	X	X	X	X				X	X	X
fig_height, fig_width	Default figure height and width (in inches) for document	X	X	X	X	X	X	X	X	X	X
highlight	Syntax highlighting: "tango", "pygments", "kate","zenburn", "textmate"	X	X	X						X	X
includes	File of content to place in document (in_header, before_body, after_body)	X	X		X		X	X	X	X	X
incremental	Should bullets appear one at a time (on presenter mouse clicks)?								X	X	X
keep_md	Save a copy of .md file that contains knitr output	X		X	X	X			X	X	
keep_tex	Save a copy of .tex file that contains knitr output		X								X
latex_engine	Engine to render latex, "pdflatex", "xelatex", or "lualatex"		X								X
lib_dir	Directory of dependency files to use (Bootstrap, MathJax, etc.)	X							X	X	
mathjax	Set to local or a URL to use a local/URL version of MathJax to render equations	X							X	X	
md_extensions	Markdown extensions to add to default definition or R Markdown	X	X	X	X	X	X	X	X	X	X
number_sections	Add section numbering to headers	X	X								
pandoc_args	Additional arguments to pass to Pandoc	X	X	X	X	X	X	X	X	X	X
preserve_yaml	Preserve YAML front matter in final document?						X				
reference_docx	docx file whose styles should be copied when producing docx output			X							
self_contained	Embed dependencies into the doc	X							X	X	
slide_level	The lowest heading level that defines individual slides										X
smaller	Use the smaller font size in the presentation?								X		
smart	Convert straight quotes to curly, dashes to em-dashes, … to ellipses, etc.	X							X	X	
template	Pandoc template to use when rendering file quarterly_report.html).	X	X		X					X	X
theme	Bootswatch or Beamer theme to use for page	X									X
toc	Add a table of contents at start of document	X	X	X		X	X	X			X
toc_depth	The lowest level of headings to add to table of contents	X	X	X		X	X	X			
toc_float	Float the table of contents to the left of the main content	X									

Create a Reusable Template

1. **Create a new package** with a inst/rmarkdown/templates directory
2. In the directory, **Place a folder** that contains:
   template.yaml (see below)
   skeleton.Rmd (contents of the template)
   any supporting files
3. **Install the package**
4. **Access template** in wizard at File ▶ New File ▶ R Markdown

template.yaml

```
---
name: My Template
—
```

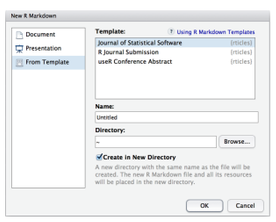


Table Suggestions

Several functions format R data into tables

Table with kable

eruptions	waiting
3.600	79
1.800	54
3.333	74
2.283	62

	eruptions	waiting
1	3.60	79.00
2	1.80	54.00
3	3.33	74.00
4	2.28	62.00

Table with xtable

Table with stargazer

	eruptions	waiting
1	3.600	79
2	1.800	54
3	3.333	74
4	2.283	62

```
data <- faithful[1:4, ]
```{r results = 'asis'}
knitr::kable(data, caption = "Table with kable")
```
```{r results = "asis"}
print(xtable::xtable(data, caption = "Table with xtable"),
      type = "html", html.table.attributes = "border=0"))
```
```{r results = "asis"}
stargazer::stargazer(data, type = "html", title = "Table
                     with stargazer")
```
```

Learn more in the **stargazer, xtable**, and **knitr** packages.

Citations and Bibliographies

Create citations with .bib, .bibtex, .copac, .enl, .json, .medline, .mods, .ris, .wos, and .xml files

1. **Set bibliography file** and CSL 1.0 Style file (optional) in the YAML header

```
---
bibliography: refs.bib
csl: style.csl
---
```

2. **Use citation keys in text**

```
Smith cited [@smith04].
Smith cited without author [-@smith04].
@smith04 cited in line.
```

3. **Render.** Bibliography will be added to end of document

```
Smith cited (Joe Smith 2004).
Smith cited without author (2004).
Joe Smith (2004) cited in line.
```

Resources for Future Learning

After this workshop you will have a foundation for building future knowledge and skills in R and data analysis. However, we have barely scratched the surface in terms of what R is, what R can do, and more generally how to code or do data analysis. Below are our favorite resources for learning R.

The most comprehensive inventory of R related resources and educational material can be found on RStudio's website. Check out the huge inventory of guidelines, workshop material, videos, and other useful content.

RStudio Cheatsheets

Very well-designed (if somewhat dense) two-page overview cards for specific R packages or topics. We recommend:

Data Import Cheatsheet: https://github.com/rstudio/cheatsheets/raw/master/data-import.pdf

Data Visualization Cheatsheet: https://github.com/rstudio/cheatsheets/raw/master/data-visualization-2.1.pdf

Data Transformation Cheatsheet: https://github.com/rstudio/cheatsheets/raw/master/data-transformation.pdf

R Markdown Cheatsheet: https://github.com/rstudio/cheatsheets/raw/master/rmarkdown-2.0.pdf

---

Massive Open Online Courses (MOOCs)/online courses

The Johns Hopkins University Data Science Specialization

- An excellent series of lessons teaching the A to Z of data science from some of the earliest and best team of R educators.

Harvard Data Science Specialization

- A fantastic data science course with a leading biostatistician and data scientist.

stat545

- Data wrangling, exploration, and analysis with R, one of best courses teaching data munging and all things R, initially taught by statistician Jenny Bryan at UBC.

Online/Free Textbooks

R for Data Science by Hadley Wickham and Garrett Grolemund

- The definitive text on data science via the tidyverse by the leading R developer Hadley Wickham.

Introduction to Data Science by Rafael Irizarry

- Raf Irizarry, Harvard Professor and fantastic teacher has published a wonderful introductory Data Science Book.

An Introduction to Statistical and Data Sciences via R byChester Ismay and Albert Y. Kim

- A fantastic introduction to R via statistical inference.

Fundamentals of Data Visualization by Clause Wilke

- Claus Wilke, a professor from UT Austin has written a highly useful ggplot add-on package and now has a new book on data visualization.

Youtube videos

Anything with Hadley Wickham, including:

- Hadley Wickham's "dplyr" tutorial at useR 2014
- Stanford Seminar - Expressing yourself in R

As well as Garrett Grolemund's Data Wrangling Series

Websites/Blogs

R Bloggers is a blog aggregator which captures a lot of the most prominent R bloggers on the internet

Rweekly.org is a weekly manual review of the latest and greatest in R internet content.

Rviews is the RStudio blog devoted to the R Community and the R Language.