NC STATE UNIVERSITY

R Basics, RMarkdown, & the Tidyverse

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Workshop Intention

- Introduce data wrangling and visualization using packages from the `tidyverse`
    - `readr`, `dplyr`, `ggplot2`
- Create reproducible work using `RMarkdown`
- Be introduced to `RShiny`
    - Create interactive documents that run R on the backend
- Only 4 total hours! Not going in depth… but we will provide resources for continued learning!

Schedule

- `RStudio` IDE (Integrated Development Environment)
- Vectors and Data frames/Tibbles
- Importing CSV files with `readr`
- Markdown basics
- Common data manipulation with `dplyr`
- Plotting with `ggplot2`
- Shiny basics

RStudio IDE

In RStudio, four main ‘areas’

- Console (& Terminal)
- Scripting and Viewing Window
- Plots/Help (& Files/Packages)
- Environment (& Connections/Git)

Console

- Type code directly into the **console** for evaluation

```
#simple math operations
# <-- is a comment - code not evaluated
3 + 7
```

```
## [1] 10
```

```
10 * exp(3) #exp is exponential function
```

```
## [1] 200.8554
```

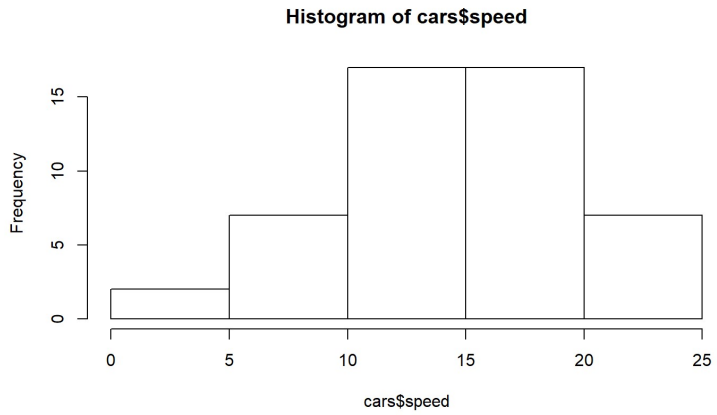
```
log(pi^2) #log is natural log by default
```

```
## [1] 2.28946
```

```
mean(cars$speed)
```

```
## [1] 15.4
```

```
hist(cars$speed)
```



Scripting and Viewing Window

- Usually want to keep code for later use!
- Write code in a ‘script’ and save script (or use markdown - covered later)
- From script can send code to console via:
  - “Run” button (runs current line)
  - CTRL+Enter (PC) or Command+Enter (MAC)
  - Highlight section and do above

Plots/Help

- Created plots stored in `Plots` tab
  - Cycle through past plots
  - Easily save
- Type `help(...)` into the console for documentation
  - `help(seq)`
  - `help(data.frame)`

Environment

- Store **data/info/function/etc.** in R objects
- Create an R object via <– (recommended) or =

```
#save for later
avg <- (5 + 7 + 6) / 3
#call avg object
avg
```

```
## [1] 6
```

```
#strings (text) can be saved as well
words <- c("Hello there!", "How are you?")
words
```

```
## [1] "Hello there!" "How are you?"
```

Environment

- Look at all current objects with `ls()`

```
ls()
```

```
## [1] "avg"   "words"
```

- `rm()` to remove

```
rm(avg)
ls()
```

```
## [1] "words"
```

```
#rm(list = ls()) cleans up environment
```

Environment

- Built-in objects exist like `letters` and `cars`

```
letters
```

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

```
head(cars, n = 3)
```

```
##   speed dist
## 1     4    2
## 2     4   10
## 3     7    4
```

- `data()` shows available built-in datasets

RStudio IDE

Four main ‘areas’

- Console (& Terminal)
- Scripting and Viewing Window
- Plots/Help (& Files/Packages)
- Environment (& Connections/Git)

Exercises

- Work through the part 1 exercises

https://jbpost2.github.io/TeachingWithR/exercises/TeachingR_Part_1_Exercises.html

- Introduce yourselves and get comfortable!

Solution
https://jbpost2.github.io/TeachingWithR/exercises/TeachingR_Part_1_Solutions.html

R Objects and Structure

- Create an R object via <– (recommended) or =
    - allocates memory to object

```
vec <- c(1, 4, 10)
vec
```

```
## [1]  1  4 10
```

R Objects and Structure

- Create an R object via <– (recommended) or =
    - allocates memory to object

```
fit <- lm(dist ~ speed, data = cars)
fit
```

```
##
## Call:
## lm(formula = dist ~ speed, data = cars)
##
## Coefficients:
## (Intercept)        speed
##     -17.579        3.932
```

Investigating Objects

Many functions to help understand an R Object

- `str()`
- compactly displays the internal structure of an R object

```
str(cars)
```

```
## 'data.frame':    50 obs. of  2 variables:
##  $ speed: num  4 4 7 7 8 9 10 10 10 11 ...
##  $ dist : num  2 10 4 22 16 10 18 26 34 17 ...
```

Data Objects

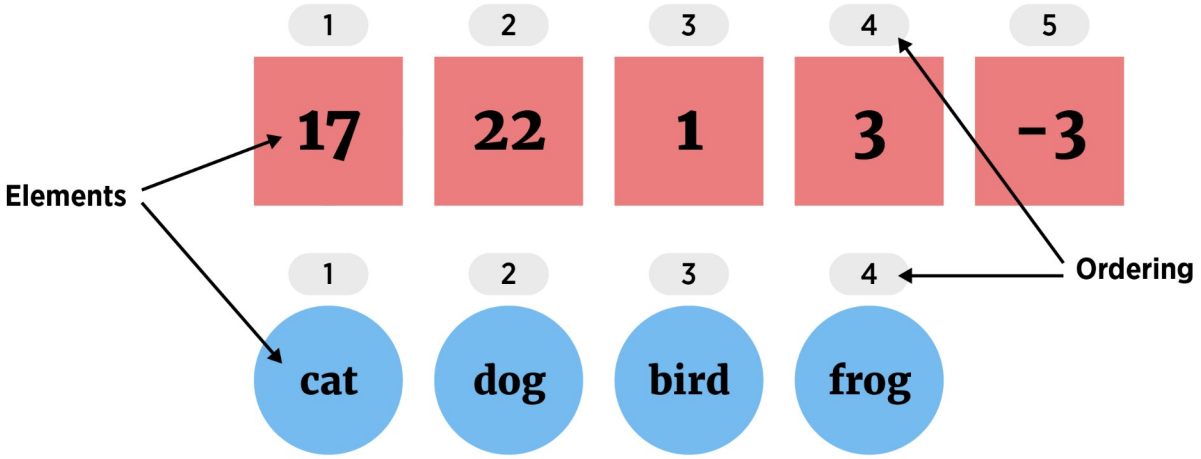
- Understand data structures first: Five major types

  1. Atomic Vector (1d)
  2. ~~Matrix (2d)~~
  3. ~~Array (nd)~~
  4. Data Frame (2d)
  5. ~~List (1d)~~

Dimension	Homogeneous	Heterogeneous
1d	Atomic Vector	List
2d	Matrix	Data Frame

Vector

1. Atomic Vector (1D group of elements with an ordering)



- Elements must be same ‘type’
    - numeric (integer or double), character, or logical

Vector

1. Atomic Vector (1D group of elements with an ordering)

- Create with `c()` function ('combine')

```
#vectors (1 dimensional) objects
x <- c(17, 22, 1, 3, -3)
y <- c("cat", "dog", "bird", "frog")
x
```

```
## [1] 17 22  1  3 -3
```

```
y
```

```
## [1] "cat"  "dog"  "bird" "frog"
```

Vector

- Many functions output a numeric vector

```
v <- seq(from = 1, to = 10, by = 2)
v
```

```
## [1] 1 3 5 7 9
```

```
1:10
```

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

Vector

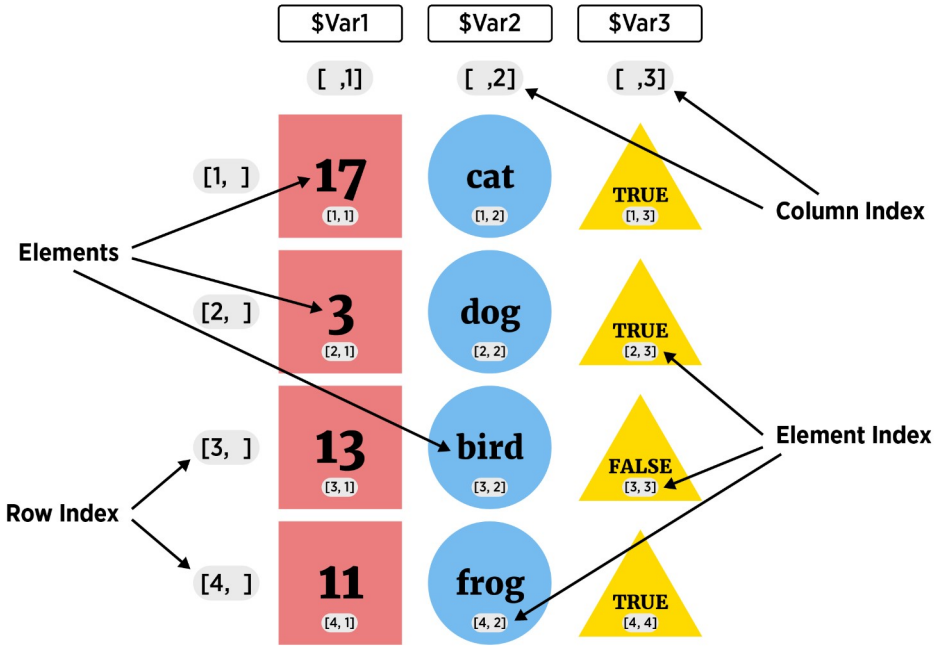
1. Atomic Vector (1D group of elements with an ordering)

- Vectors useful to know about
- Not usually useful for a dataset
- Often consider as ‘building blocks’ for other data types

Data Frame

4. Data Frame (2D data structure)

- collection (list) of *vectors* of the same **length**



Data Frame

4. Data Frame (2D data structure)

- collection (list) of *vectors* of the same **length**
- Create with `data.frame()` function

```
x <- c("a", "b", "c", "d", "e", "f")
y <- c(1, 3, 4, -1, 5, 6)
z <- 10:15
data.frame(x, y, z)
```

```
##   x  y  z
## 1 a  1 10
## 2 b  3 11
## 3 c  4 12
## 4 d -1 13
## 5 e  5 14
## 6 f  6 15
```

Data Frame

4. Data Frame (2D data structure)

- collection (list) of *vectors* of the same **length**
- Create with `data.frame()` function

```
data.frame(char = x, data1 = y, data2 = z)
```

```
##   char data1 data2
## 1    a     1    10
## 2    b     3    11
## 3    c     4    12
## 4    d    -1    13
## 5    e     5    14
## 6    f     6    15
```

- char, data1, and data2 become the variable names for the data frame

Data Frame

4. Data Frame (2D data structure)

- collection (list) of *vectors* of the same **length**
- Create with `data.frame()` function
- Perfect for most data sets!
- Most functions that read 2D data store it as a data frame
- `Tibbles` are special data frames used in the `tidyverse`

Schedule

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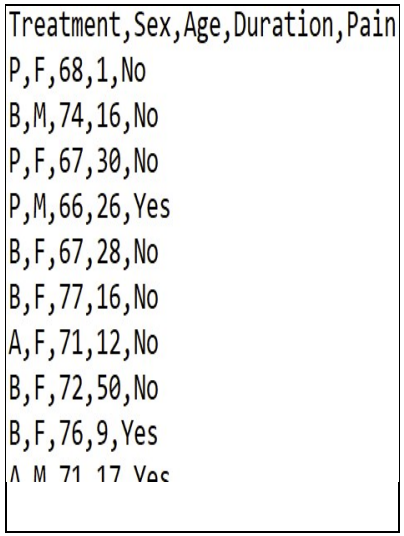
- Common data manipulation with `dplyr`
- Plotting with `ggplot2`
- Shiny basics

Importing Data

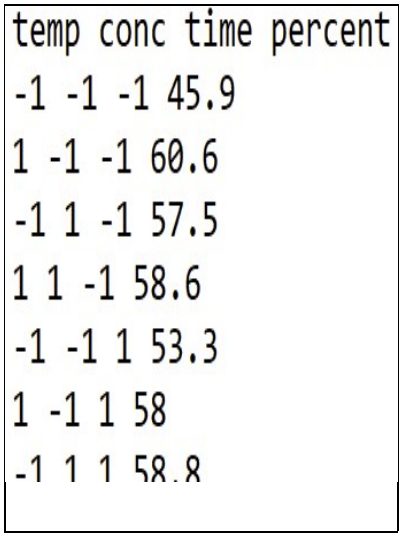
How to read in data depends on raw/external data type!

- Delimited data
  - Delimiter - Character (such as a ,) that separates data entries



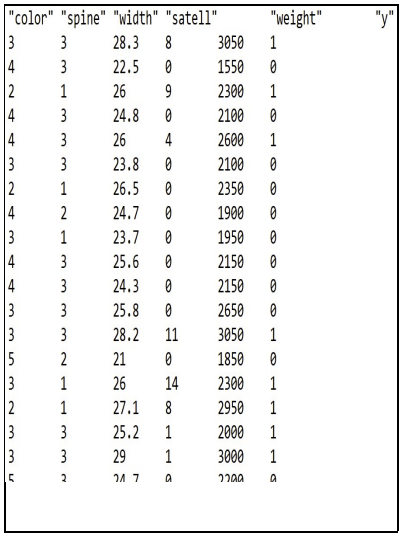
```
Treatment,Sex,Age,Duration,Pain
P,F,68,1,No
B,M,74,16,No
P,F,67,30,No
P,M,66,26,Yes
B,F,67,28,No
B,F,77,16,No
A,F,71,12,No
B,F,72,50,No
B,F,76,9,Yes
```

Comma: usually .csv



```
temp conc time percent
-1 -1 -1 45.9
1 -1 -1 60.6
-1 1 -1 57.5
1 1 -1 58.6
-1 -1 1 53.3
1 -1 1 58
```

Space: usually .txt or .dat



"color"	"spine"	"width"	"satell"	"weight"	"y"
3	3	28.3	8	3050	1
4	3	22.5	0	1550	0
2	1	26	9	2300	1
4	3	24.8	0	2100	0
4	3	26	4	2600	1
3	3	23.8	0	2100	0
2	1	26.5	0	2350	0
4	2	24.7	0	1900	0
3	1	23.7	0	1950	0
4	3	25.6	0	2150	0
4	3	24.3	0	2150	0
3	3	25.8	0	2650	0
3	3	28.2	11	3050	1
5	2	21	0	1850	0
3	1	26	14	2300	1
2	1	27.1	8	2950	1
3	3	25.2	1	2000	1
3	3	29	1	3000	1

Tab: usually .tsv or .txt

```
2012>4>12>MIN>LAA>D.J. Reyburn
2012>4>12>SD>ARI>Marty Foster
2012>4>12>WSH>CIN>Mike Everitt
2012>4>12>PHI>MIA>Jeff Nelson
2012>4>12>CHC>MIL>Fieldin Culbreth
2012>4>12>LAD>PIT>Wally Bell
2012>4>12>TEX>SEA>Doug Eddings
2012>4>12>COL>SF>Ron Kulpa
2012>4>12>DET>TB>Mark Carlson
2012>4>13>NYY>LAA>Mike DiMuro
```

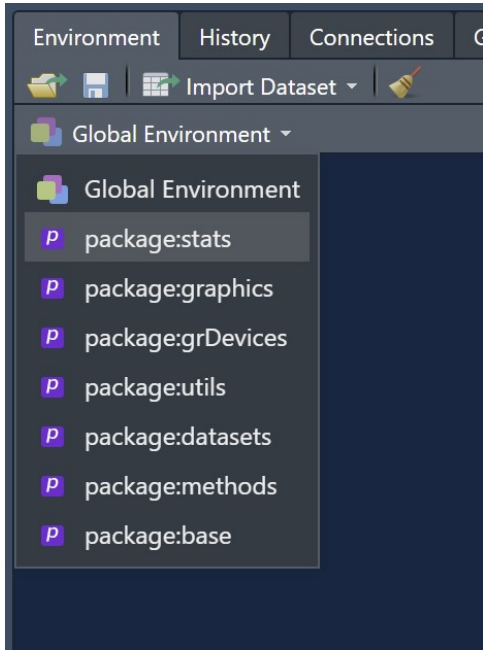
General: usually .txt or .dat

Importing Delimited Data

- When you open R a few `packages` are loaded
- R package
  - Collection of functions/datasets/etc. in one place
  - Packages exist to do almost anything
  - List of CRAN approved packages on R's website
  - Plenty of other packages on places like GitHub

Importing Delimited Data

- When you open R a few `packages` are loaded



- `utils` package has *family* of `read.` functions ready for use!

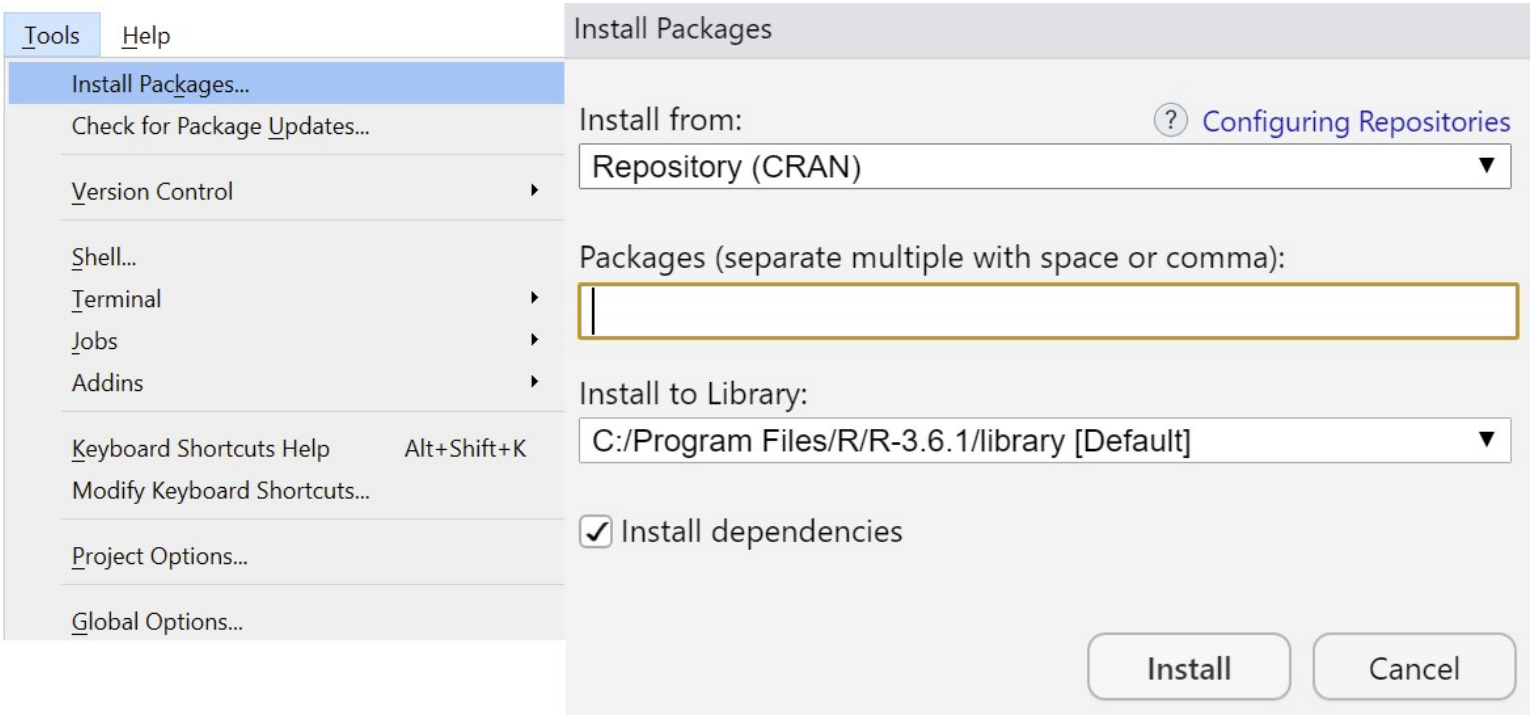
Reading Delimited Data

- Functions from `read.` family work well
- Concerns:
  - poor default function behavior
    - (formerly, prior to R 4.0) strings are read as `factors`
    - row & column names can be troublesome
  - (Slightly) different behavior on different computers
  - Want to have most of our functions we use 'feel' the same…
- "TidyVerse" - collection of R packages that share common philosophies and are designed to work together!

Aside: R Packages

- First time using a package
  - Must install package (download files)
  - Can use code or menus

```
install.packages("readr")
```



Aside: R Packages

- Only install once!
- **Each session**: read in package using `library()` or `require()`

```
library("readr")
```

Aside: R Packages

- Hopefully you've already installed the `tidyverse` package via:

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

Aside: R Packages

- Hopefully you've already installed the `tidyverse` package via:

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

- Now you can load the library

```
library(tidyverse)
```

- Once library loaded, check `help(filter)`

Aside: R Packages

- Can call functions without loading full library with `::`
- If not specified, most recently loaded package takes precedent

```
#stats::filter(...) calls time-series function from stats package
dplyr::filter(iris, Species == "virginica")
```

```
##    Sepal.Length Sepal.Width Petal.Length Petal.Width   Species
## 1           6.3         3.3          6.0         2.5 virginica
## 2           5.8         2.7          5.1         1.9 virginica
## 3           7.1         3.0          5.9         2.1 virginica
## 4           6.3         2.9          5.6         1.8 virginica
## 5           6.5         3.0          5.8         2.2 virginica
## 6           7.6         3.0          6.6         2.1 virginica
## 7           4.9         2.5          4.5         1.7 virginica
## 8           7.3         2.9          6.3         1.8 virginica
## 9           6.7         2.5          5.8         1.8 virginica
## 10          7.2         3.6          6.1         2.5 virginica
## 11          6.5         3.2          5.1         2.0 virginica
## 12          6.4         2.7          5.3         1.9 virginica
## 13          6.8         3.0          5.5         2.1 virginica
## 14          5.7         2.5          5.0         2.0 virginica
## 15          5.8         2.8          5.1         2.4 virginica
## 16          6.4         3.2          5.3         2.3 virginica
```

Reading Delimited Data

`baseR` and `tidyverse` (`readr` package does the heavy lifting) function and purpose:

Type of Delimeter	`utils` Function	`readr` Function
Comma	`read.csv()`	`read_csv()`
Semicolon (`,` for decimal)	`read.csv2()`	`read_csv2()`
Tab	`read.delim()`	`read_tsv()`
General	`read.table(sep = "")`	`read_delim()`
White Space	`read.table(sep = "")`	`read_table()` `read_table2()`

Reading a .csv File

- Let's read in the 'neuralgia.csv' file
- By default, R looks in the `working directory` for the file

```
getwd()
```

```
## [1] "C:/repos/TeachingWithR/slides"
```

```
#change with setwd()
#better to use R projects!
```

Reading a .csv File

- Let's read in the 'neuralgia.csv' file

```
neuralgiaData <- read_csv("neuralgia.csv")
```

- R can pull from URLs as well!

```
neuralgiaData <- read_csv("https://www4.stat.ncsu.edu/~online/datasets/neuralgia.csv")
neuralgiaData
```

```
## # A tibble: 60 x 5
##    Treatment Sex     Age Duration Pain
##    <chr>     <chr> <dbl>    <dbl> <chr>
##  1 P         F        68        1 No
##  2 B         M        74       16 No
##  3 P         F        67       30 No
##  4 P         M        66       26 Yes
##  5 B         F        67       28 No
##  6 B         F        77       16 No
##  7 A         F        71       12 No
##  8 B         F        72       50 No
##  9 B         F        76        9 Yes
## 10 A         M        71       17 Yes
## # ... with 50 more rows
```

Reading a .csv File

`read_csv()` function

- Other useful inputs:
    - `skip = 0`
    - `col_names = TRUE`
    - `na = c("", "NA")`

Reading Delimited Data

- May have noticed the fancy printing of the data!
- Checking column type is a basic data validation step
- `tidyverse` data frames are called `tibbles`

```
str(neuralgiaData)
```

```
## spec_tbl_df [60 x 5] (S3: spec_tbl_df/tbl_df/tbl/data.frame)
##  $ Treatment: chr [1:60] "P" "B" "P" "P" ...
##  $ Sex      : chr [1:60] "F" "M" "F" "M" ...
##  $ Age      : num [1:60] 68 74 67 66 67 77 71 72 76 71 ...
##  $ Duration : num [1:60] 1 16 30 26 28 16 12 50 9 17 ...
##  $ Pain     : chr [1:60] "No" "No" "No" "Yes" ...
##  - attr(*, "spec")=
##   .. cols(
##   ..   Treatment = col_character(),
##   ..   Sex = col_character(),
##   ..   Age = col_double(),
##   ..   Duration = col_double(),
##   ..   Pain = col_character()
##   .. )
```

tibbles

- Behavior slightly different than a standard `data frame`
- Use either `pull()` or `$` to return a column as a vector

```
pull(neuralgiaData, 1) #or pull(neuralgiaData, Treatment)
```

```
##  [1] "P" "B" "P" "P" "B" "B" "A" "B" "B" "A" "A" "A" "B" "A" "P" "A" "P" "A" "P"
## [20] "B" "B" "A" "A" "A" "B" "P" "B" "B" "P" "P" "A" "A" "B" "B" "B" "A" "P" "B"
## [39] "B" "P" "P" "P" "A" "B" "A" "P" "P" "A" "B" "P" "P" "P" "B" "A" "P" "A" "P"
## [58] "A" "B" "A"
```

```
neuralgiaData$Treatment
```

```
##  [1] "P" "B" "P" "P" "B" "B" "A" "B" "B" "A" "A" "A" "B" "A" "P" "A" "P" "A" "P"
## [20] "B" "B" "A" "A" "A" "B" "P" "B" "B" "P" "P" "A" "A" "B" "B" "B" "A" "P" "B"
## [39] "B" "P" "P" "P" "A" "B" "A" "P" "P" "A" "B" "P" "P" "P" "B" "A" "P" "A" "P"
## [58] "A" "B" "A"
```

Exercises

- Work through the part 2 exercises

https://jbpost2.github.io/TeachingWithR/exercises/TeachingR_Part_2_Exercises.html

Solution
https://jbpost2.github.io/TeachingWithR/exercises/TeachingR_Part_2_Solutions.html

Schedule

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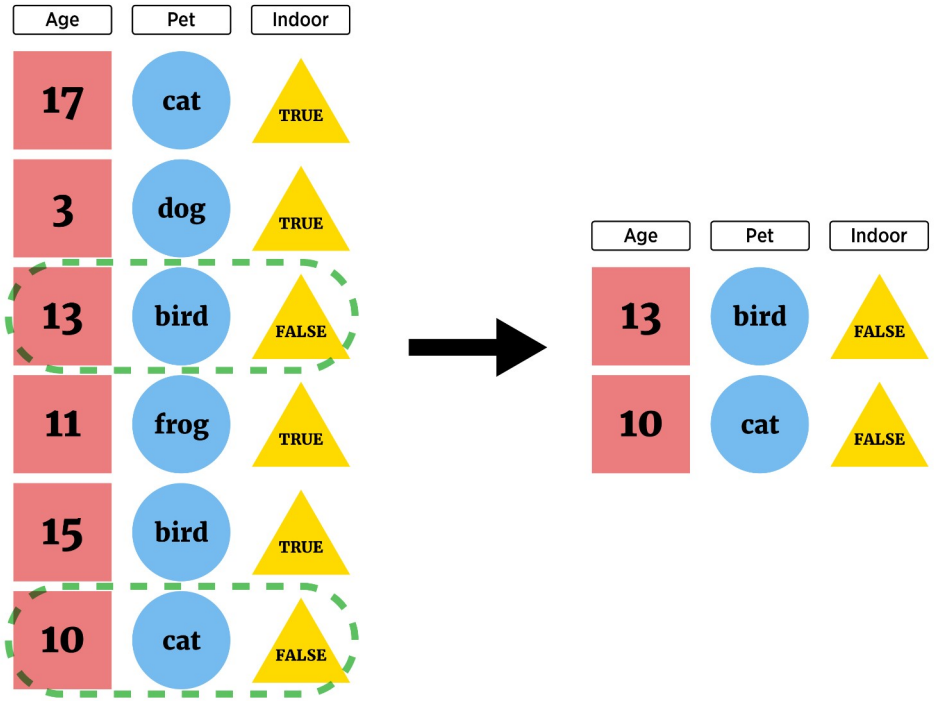
- Markdown basics
- Common data manipulation with `dplyr`
- Plotting with `ggplot2`
- Shiny basics

Data manipulation idea

We may want to subset our full data set or create new data

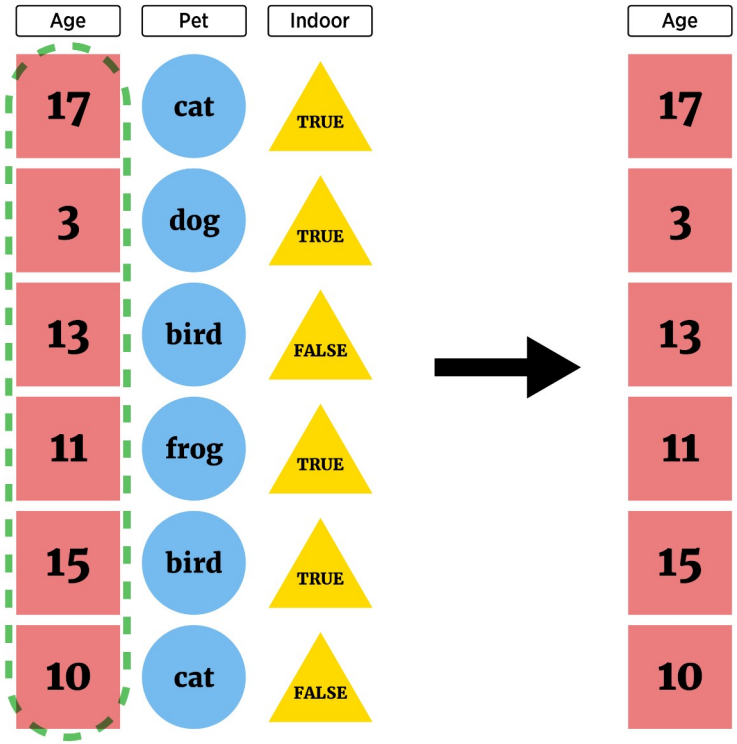
- Grab only certain types of observations (**filter rows**)



Data manipulation idea

We may want to subset our full data set or create new data

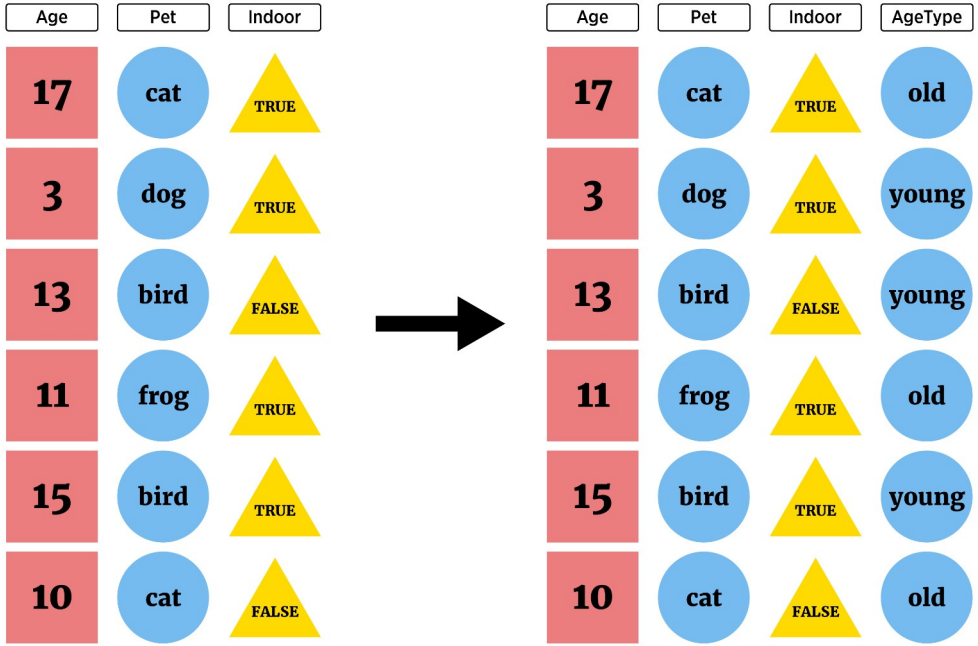
- Look at only certain variables (**select columns**)



Data manipulation idea

We may want to subset our full data set or create new data

- Create new variables



Data manipulation idea

We may want to subset our full data set or create new data

- Communication and reproducibility vital!
- Traditional documentation through comments (`#` in R) in script
- May have heard of JUPYTER notebooks
- R Markdown - built in notebook for RStudio

Documenting with Markdown

- R Markdown = Digital “Notebook”: Program that weaves word processing and code.
- Designed to be used in three ways (R for Data Science)

Documenting with Markdown

- R Markdown = Digital “Notebook”: Program that weaves word processing and code.
- Designed to be used in three ways (R for Data Science)
  - Communicating to decision makers (focus on conclusions not code)
  - Collaborating with other data scientists (including future you!)
  - As environment to do data science (documents what you did and what you were thinking)

Documenting with Markdown

Verbage

- May have heard of HTML (HyperText Mark-up Language)
    - Write plain text that the browser interprets and renders

Documenting with Markdown

Verbage

- May have heard of HTML (HyperText Mark-up Language)
  - Write plain text that the browser interprets and renders
- Markdown is a specific markup language
  - Easier syntax
  - Not as powerful
- White space is important!
- Any plain text file can be used (.Rmd extension associates it with RStudio)

Documenting with Markdown

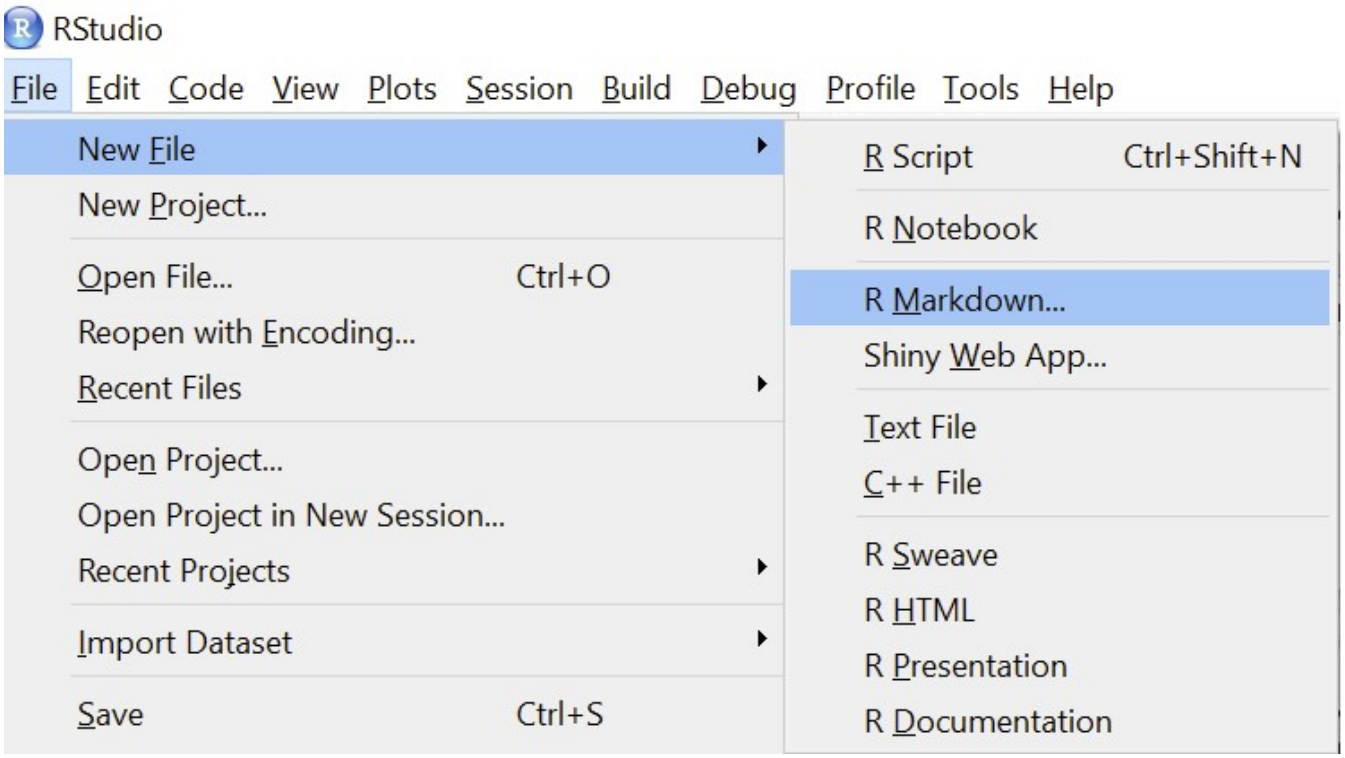
R Markdown file contains three important types of content:

1. (Optional) YAML header surrounded by ---s
2. Chunks of R code
3. Text mixed with simple text formatting instructions

Documenting with Markdown

Creating an R Markdown Document

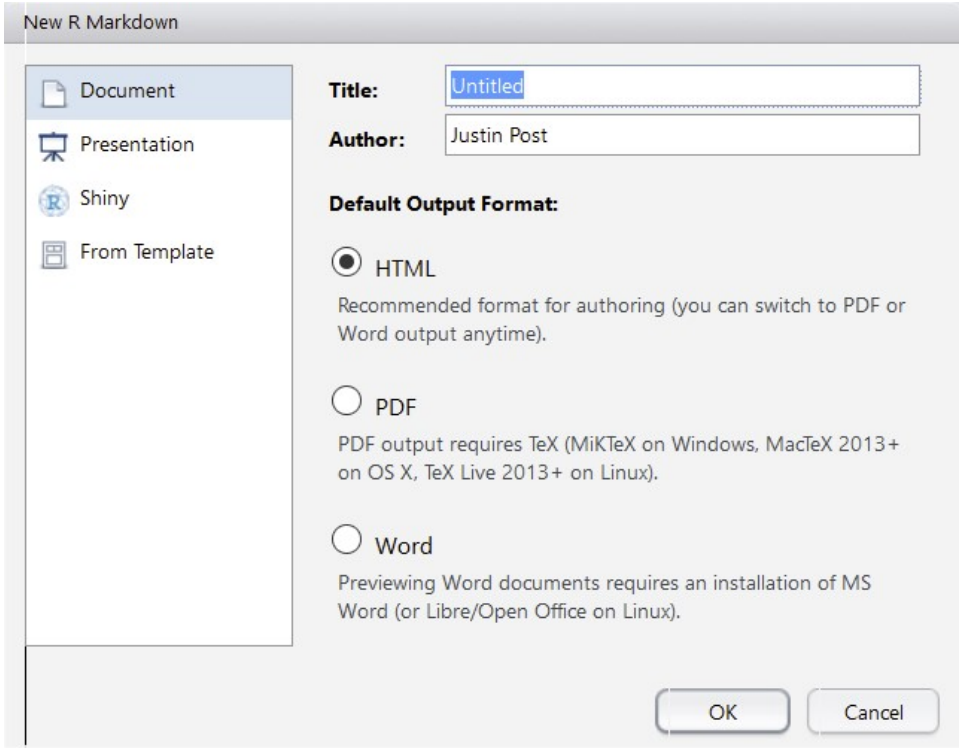
- RStudio makes it easy!



Documenting with Markdown

Creating an R Markdown Document

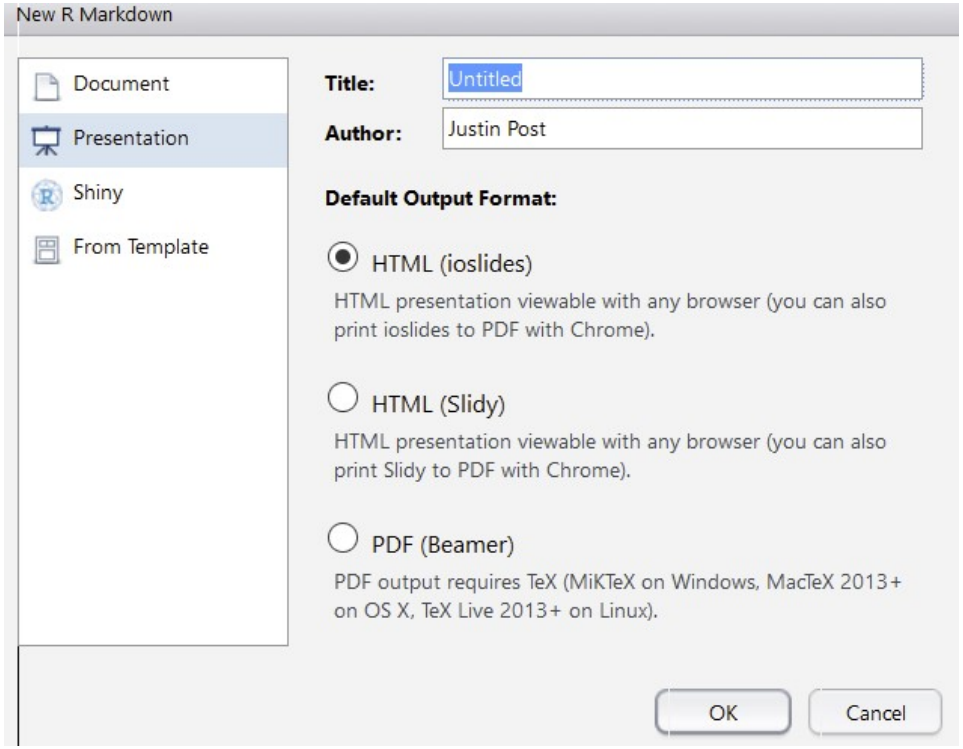
- Commonly used document types can be created



Documenting with Markdown

Creating an R Markdown Document

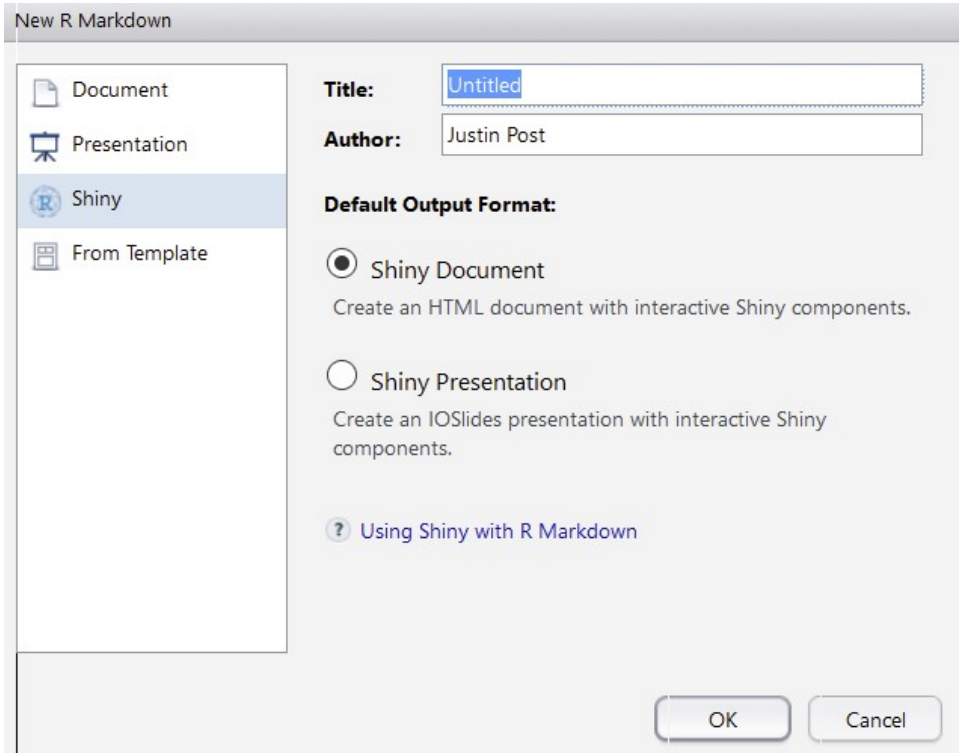
- Slide presentations



Documenting with Markdown

Creating an R Markdown Document

- Truly Interactive Documents/Pages (require R backend)



Documenting with Markdown

YAML Header

- Define settings for document

```
---
title: "Untitled"
author: "First Last"
date: "xxxx"
output: html_document
---
```

- CTRL/CMD + Shift + k **knits** via this info

Documenting with Markdown

Code Chunks

- Below YAML header: ‘r chunk’

````
```{r ggplot,eval=FALSE}
select(iris, Sepal.Width)
ggplot(iris, aes(x = Sepal.Width, y = Sepal.Length)) +
geom_point()
```
````

- Start code chunk by typing ```{r} out or with CTRL/CMD + Alt/Option + I
- Run and rerun code until you are happy
- Code will be executed when document is created

Documenting with Markdown

Markdown Syntax

- Below code chunk is plain text with markdown sytnax

```
## 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.
```

- When file created, “##” becomes a header, “<…>” a link, and `**Knit**` bold font

Documenting with Markdown

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.

Where do we go from here?

Briefly investigate:

- Markdown syntax
- Code chunks and their options
- Changing type of output

Documenting with Markdown

Markdown syntax

- `[Cheat Sheet link](https://www.rstudio.com/wp-content/uploads/2015/03/rmarkdown-reference.pdf)` becomes [Cheat Sheet link](https://www.rstudio.com/wp-content/uploads/2015/03/rmarkdown-reference.pdf)

Documenting with Markdown

Markdown syntax

- `[Cheat Sheet link](https://www.rstudio.com/wp-content/uploads/2015/03/rmarkdown-reference.pdf)` becomes Cheat Sheet link
- `# Header 1` becomes a large font header
- `## Header 2` becomes a slightly smaller font header
- Goes to 6 headers
    - Use of headers can automatically create a Table of Contents!

Documenting with Markdown

Markdown syntax

- `[Cheat Sheet link](https://www.rstudio.com/wp-content/uploads/2015/03/rmarkdown-reference.pdf)` becomes [Cheat Sheet link](https://www.rstudio.com/wp-content/uploads/2015/03/rmarkdown-reference.pdf)
- `# Header 1` becomes a large font header
- `## Header 2` becomes a slightly smaller font header
- Goes to 6 headers
    - Use of headers can automatically create a Table of Contents!
- `**bold**` **and** `__bold__`
- `` `code` `` becomes `code`

Documenting with Markdown

Markdown syntax

- Can do lists. Indent sub lists four spaces

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

1. ordered list
2. item 2
    + sub-item 1
    + sub-item 2
```

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

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

Documenting with Markdown

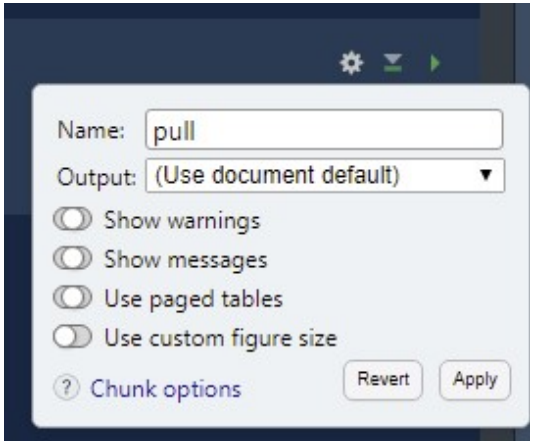
Code chunks and their options

- Any R code can go into the chunk
- Chunks evaluate sequentially (can use output from prior chunk)
- Code can be added in line: Ex: The Iris dataset has 150 observations
- Added by beginning with back-tick `r` and ending with a back-tick: Iris has `` `r length(iris$Sepal.Length)` ``

Documenting with Markdown

Code chunks and their options

- Can hide/show code with `echo = FALSE/TRUE`
- Can choose if code is evaluated with `eval = TRUE/FALSE`
- `message = TRUE/FALSE` and `warning = TRUE/FALSE` can turn on/off displaying messages/warnings



Documenting with Markdown

Code chunks and their options

- Many options depending on chunk purpose!
- Can hide/show code with `echo = FALSE/TRUE`
- Can choose if code is evaluated with `eval = TRUE/FALSE`
- `message = TRUE/FALSE` and `warning = TRUE/FALSE` can turn on/off displaying messages/warnings
- Can set global options for all chunks

```
opts_chunk$set(echo = FALSE, eval = TRUE, warning = FALSE)
```

- Allows for easy change of audience!

Documenting with Markdown

Changing type of output

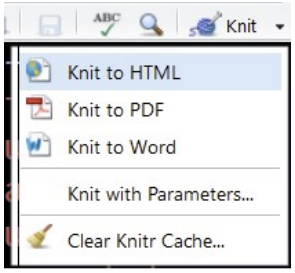
R Markdown really flexible!

Documenting with Markdown

Changing type of output

Change output type in the YAML header:

- Use CTRL/CMD + Shift + k or the Knit menu:



- Use code explicity:

```
rmarkdown::render("file.Rmd", output_format = "word_document")
```

Documenting with Markdown

Changing type of output

For HTML & PDF can include Table of Contents with options

```
output:
  html_document:
    toc: true
    toc_float: true
```

Documenting with Markdown

Changing type of output

For HTML & PDF can include Table of Contents with options

```
output:
  html_document:
    toc: true
    toc_float: true
```

For HTML another option is to make the code chunks hidden by default, but visible with a click:

```
output:
  html_document:
    code_folding: hide
```

Documenting with Markdown

Changing type of output

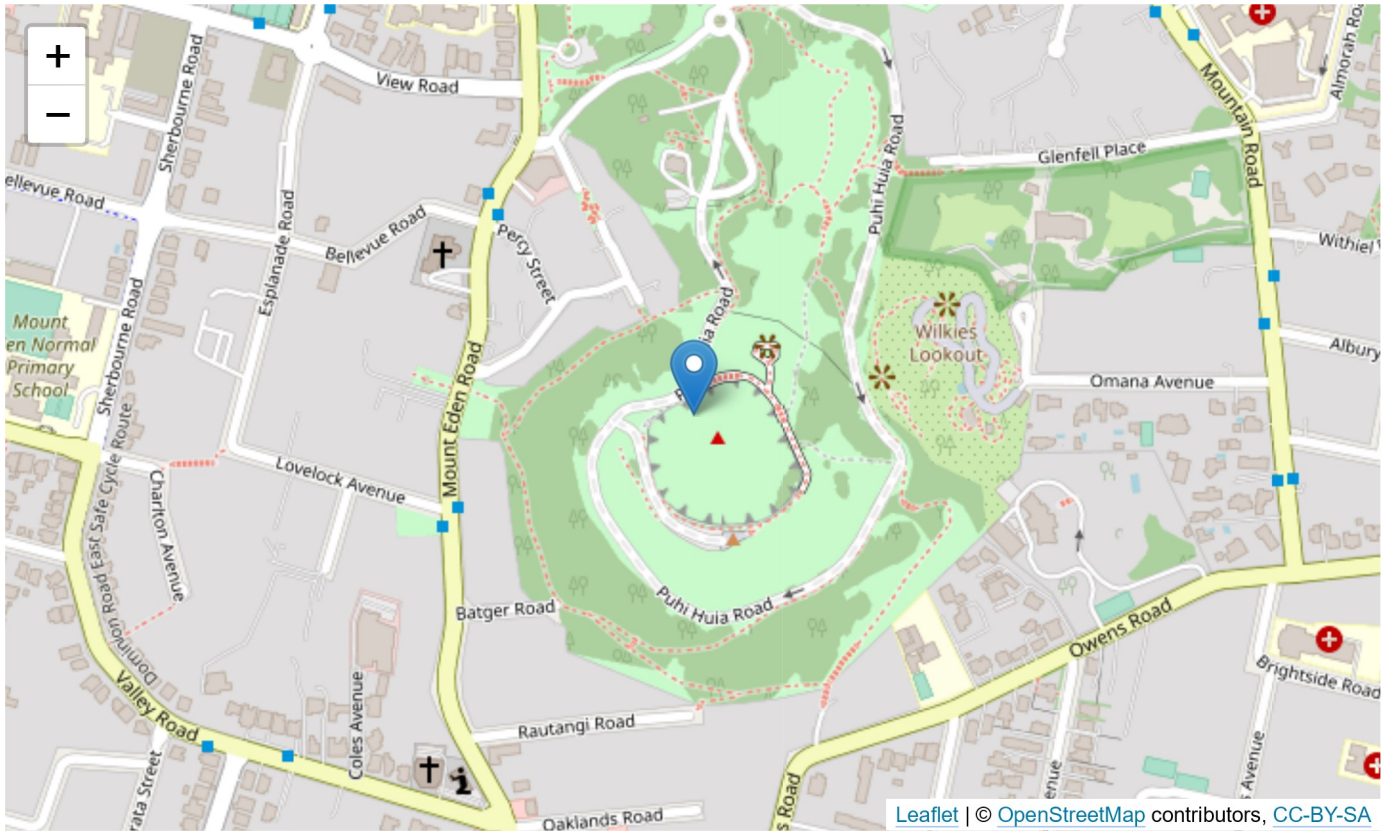
HTML documents inherently interactive

- Widgets can be included with appropriate **R package**

```
library(leaflet)
leaflet() %>%
  setView(174.764, -36.877, zoom = 16) %>%
  addTiles() %>%
  addMarkers(174.764, -36.877, popup = "Maungawhau")
```

Documenting with Markdown

Changing type of output



Documenting with Markdown

Changing type of output

- PDF
  - Install MikTex and update its packages or install a smaller version using the `tinytex` package: `tinytex::install_tinytex()`

```
output: pdf_document
```

Documenting with Markdown

Changing type of output

- PDF
    - Install MikTex and update its packages or install a smaller version using the `tinytex` package: `tinytex::install_tinytex()`

```
output: pdf_document
```

- Word

```
output: word_document
```

Documenting with Markdown

Changing type of output

- PDF
  - Install MikTex and update its packages or install a smaller version using the `tinytex` package: `tinytex::install_tinytex()`

```
output: pdf_document
```

- Word

```
output: word_document
```

- Slides (## for new slide)

```
output: ioslidespresentation
```

Exercises

- Work through the part 3 exercises

https://jbpost2.github.io/TeachingWithR/exercises/TeachingR_Part_3_Exercises.html

Partial Solution
https://jbpost2.github.io/TeachingWithR/exercises/TeachingR_Part_3_Solutions.html

`tidyverse` for data manipulations

Now we can document everything: let's manipulate some data!

Overview of dplyr and tidyr packages

- `dplyr` package made for most standard data manipulation tasks
- `tidyr` package reshapes data
- Both part of `tidyverse`
- Make sure `library(tidyverse)` has been run!

Tidyverse Syntax

- Reason to prefer `dplyr` and packages from the `tidyverse`
- Good defaults
- All packages have similar syntax! All work on `tibbles` (data frames)
- Syntax: `function(tibble, actions, ...)`

dplyr

- Basic commands
  - `as_tibble()` - convert data frame to one with better printing
  - `filter()` - subset **rows**
  - `arrange()` - reorder **rows**
  - `select()` - subset **columns**
  - `rename()` - rename **columns**
  - `mutate()` - add newly created **column**
  - `transmute()` - create new variable
  - `group_by()` - group **rows** by a variable
  - `summarise()` - apply basic function to data

`as_tibble()` - tidy data frame

`as_tibble()` - convert data frame to one with better printing and no simplification

```
#install.packages("Lahman")
library(Lahman)
head(Batting, n = 4) #look at just first 4 observations
```

```
##    playerID yearID stint teamID lgID  G  AB  R  H X2B X3B HR RBI SB CS BB SO
## 1 abercda01   1871     1    TRO   NA  1   4  0  0   0   0  0   0  0  0  0  0
## 2  addybo01   1871     1    RC1   NA 25 118 30 32   6   0  0  13  8  1  4  0
## 3 allisar01   1871     1    CL1   NA 29 137 28 40   4   5  0  19  3  1  2  5
## 4 allisdo01   1871     1    WS3   NA 27 133 28 44  10   2  2  27  1  1  0  2
##   IBB HBP SH SF GIDP
## 1  NA  NA NA NA    0
## 2  NA  NA NA NA    0
## 3  NA  NA NA NA    1
## 4  NA  NA NA NA    0
```

`as_tibble()` - tidy data frame

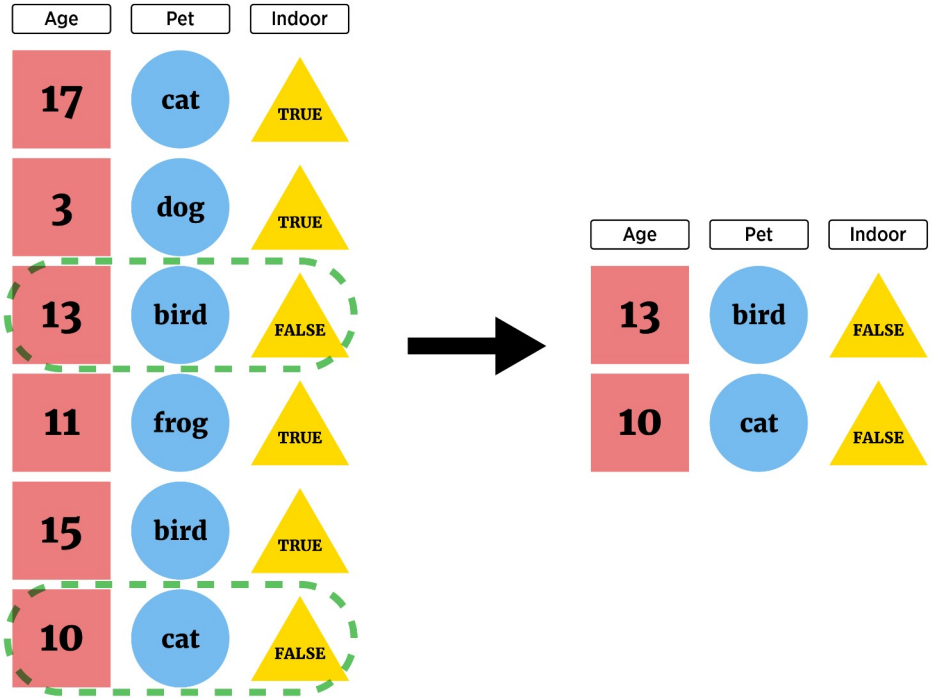
- Just 'wrap' a standard R data frame

```
myBatting <- as_tibble(Batting); myBatting
```

```
## # A tibble: 105,861 x 22
##    playerID  yearID stint teamID lgID      G    AB     R     H   X2B   X3B    HR
##    <chr>      <int> <int> <fct>  <fct> <int> <int> <int> <int> <int> <int> <int>
##  1 abercda01   1871     1 TRO    NA        1     4     0     0     0     0     0
##  2 addybo01    1871     1 RC1    NA       25   118    30    32     6     0     0
##  3 allisar01   1871     1 CL1    NA       29   137    28    40     4     5     0
##  4 allisdo01   1871     1 WS3    NA       27   133    28    44    10     2     2
##  5 ansonca01   1871     1 RC1    NA       25   120    29    39    11     3     0
##  6 armstbo01   1871     1 FW1    NA       12    49     9    11     2     1     0
##  7 barkeal01   1871     1 RC1    NA        1     4     0     1     0     0     0
##  8 barnero01   1871     1 BS1    NA       31   157    66    63    10     9     0
##  9 barrebi01   1871     1 FW1    NA        1     5     1     1     1     0     0
## 10 barrofr01   1871     1 BS1    NA       18    86    13    13     2     1     0
## # ... with 105,851 more rows, and 10 more variables: RBI <int>, SB <int>,
## #   CS <int>, BB <int>, SO <int>, IBB <int>, HBP <int>, SH <int>, SF <int>,
## #   GIDP <int>
```

`filter()` - subset rows or columns

- Grab only certain types of observations (**filter rows**)



Logical statements

Goal: Subset rows or columns

- **logical statement** - comparison that resolves as `TRUE` or `FALSE`

```
"hi" == " hi" #== is comparison
```

```
## [1] FALSE
```

```
"hi" == "hi"
```

```
## [1] TRUE
```

```
4 >= 1
```

```
## [1] TRUE
```

```
4 != 1
```

```
## [1] TRUE
```

```
sqrt(3)^2  == 3
```

```
## [1] FALSE
```

```
dplyr::near(sqrt(3)^2, 3)
```

```
## [1] TRUE
```

Logical statements

Goal: Subset rows or columns

- **logical statement** - comparison that resolves as `TRUE` or `FALSE`

```
#use of is. functions
is.numeric("Word")
```

```
## [1] FALSE
```

```
is.numeric(10)
```

```
## [1] TRUE
```

```
is.character("10")
```

```
## [1] TRUE
```

```
is.na(c(1:2, NA, 3))
```

```
## [1] FALSE FALSE  TRUE FALSE
```

```
is.matrix(c("hello", "world"))
```

```
## [1] FALSE
```

Logical statements

Goal: Subset rows or columns

- **logical statement** - useful for indexing an R object
- Syntax: `filter(tibble, vector-of-TRUE-FALSE)`
    - R returns elements where `TRUE`

```
myBatting$G > 20 #vector indicating Games > 20
```

```
##     [1] FALSE  TRUE  TRUE  TRUE  TRUE FALSE FALSE  TRUE FALSE FALSE  TRUE FALSE
##    [13] FALSE FALSE FALSE  TRUE FALSE FALSE FALSE FALSE  TRUE  TRUE  TRUE FALSE
##    [25] FALSE FALSE  TRUE FALSE FALSE  TRUE  TRUE FALSE FALSE  TRUE  TRUE FALSE
##    [37]  TRUE  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE  TRUE FALSE  TRUE FALSE
##    [49]  TRUE  TRUE FALSE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE
##    [61]  TRUE FALSE  TRUE FALSE FALSE  TRUE  TRUE  TRUE FALSE  TRUE  TRUE FALSE
##    [73]  TRUE  TRUE  TRUE  TRUE  TRUE  TRUE FALSE FALSE  TRUE  TRUE  TRUE FALSE
##    [85]  TRUE  TRUE  TRUE FALSE FALSE FALSE  TRUE  TRUE FALSE  TRUE FALSE  TRUE
##    [97]  TRUE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE FALSE
##   [109] FALSE  TRUE  TRUE FALSE  TRUE  TRUE  TRUE FALSE  TRUE FALSE FALSE  TRUE
##   [121] FALSE  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE FALSE  TRUE  TRUE
##   [133]  TRUE FALSE FALSE FALSE  TRUE FALSE  TRUE FALSE FALSE  TRUE FALSE  TRUE
##   [145] FALSE FALSE  TRUE FALSE FALSE FALSE  TRUE FALSE  TRUE  TRUE  TRUE  TRUE
##   [157] FALSE FALSE  TRUE  TRUE FALSE  TRUE  TRUE FALSE FALSE FALSE FALSE  TRUE
```

`filter()` - subset rows or columns

- **logical statement** - useful for indexing an R object

```
filter(myBatting, G > 20)
```

```
## # A tibble: 69,441 x 22
##    playerID  yearID stint teamID lgID      G    AB     R     H   X2B   X3B    HR
##    <chr>      <int> <int> <fct>  <fct> <int> <int> <int> <int> <int> <int> <int>
##  1 addybo01    1871     1 RC1    NA       25   118    30    32     6     0     0
##  2 allisar01   1871     1 CL1    NA       29   137    28    40     4     5     0
##  3 allisdo01   1871     1 WS3    NA       27   133    28    44    10     2     2
##  4 ansonca01   1871     1 RC1    NA       25   120    29    39    11     3     0
##  5 barnero01   1871     1 BS1    NA       31   157    66    63    10     9     0
##  6 bassjo01    1871     1 CL1    NA       22    89    18    27     1    10     3
##  7 bellast01   1871     1 TRO    NA       29   128    26    32     3     3     0
##  8 birdge01    1871     1 RC1    NA       25   106    19    28     2     5     0
##  9 birdsda01   1871     1 BS1    NA       29   152    51    46     3     3     0
## 10 brainas01   1871     1 WS3    NA       30   134    24    30     4     0     0
## # ... with 69,431 more rows, and 10 more variables: RBI <int>, SB <int>,
## #   CS <int>, BB <int>, SO <int>, IBB <int>, HBP <int>, SH <int>, SF <int>,
## #   GIDP <int>
```

Logical statements

Compound logicals via **Logical Operators**

- `&` ‘and’
- `|` ‘or’

Operator	A,B true	A true, B false	A,B false
&	`A & B = TRUE`	`A & B = FALSE`	`A & B = FALSE`
|	`A | B = TRUE`	`A | B = TRUE`	`A | B = FALSE`

Logical statements

- Pull out those that played more than 20 games and played in 2015

```
(myBatting$G > 20) & (myBatting$yearID == 2015)
```

```
##     [1] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##    [13] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##    [25] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##    [37] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##    [49] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##    [61] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##    [73] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##    [85] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##    [97] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [109] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [121] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [133] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [145] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [157] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [169] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [181] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [193] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [205] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [217] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
##   [229] FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE FALSE
```

`filter()` - subset rows or columns

- Pull out those that played more than 20 games and played in 2015

```
filter(myBatting, (G > 20) & (yearID == 2015))
```

```
## # A tibble: 949 x 22
##    playerID  yearID stint teamID lgID      G    AB     R     H   X2B   X3B    HR
##    <chr>      <int> <int> <fct>  <fct> <int> <int> <int> <int> <int> <int> <int>
##  1 aardsda01   2015     1 ATL    NL       33     1     0     0     0     0     0
##  2 abadfe01    2015     1 OAK    AL       62     0     0     0     0     0     0
##  3 abreujo02   2015     1 CHA    AL      154   613    88   178    34     3    30
##  4 ackledu01   2015     1 SEA    AL       85   186    22    40     8     1     6
##  5 ackledu01   2015     2 NYA    AL       23    52     6    15     3     2     4
##  6 adamecr01   2015     1 COL    NL       26    53     4    13     1     1     0
##  7 adamsau01   2015     1 CLE    AL       28     1     0     0     0     0     0
##  8 adamsma01   2015     1 SLN    NL       60   175    14    42     9     0     5
##  9 adriaeh01   2015     1 SFN    NL       52   113    11    21     7     1     0
## 10 affelje01   2015     1 SFN    NL       52     2     0     0     0     0     0
## # ... with 939 more rows, and 10 more variables: RBI <int>, SB <int>, CS <int>,
## #   BB <int>, SO <int>, IBB <int>, HBP <int>, SH <int>, SF <int>, GIDP <int>
```

`arrange()` - reorder rows

- Syntax: `arrange(tibble, column1, column2, ...)`

```
#reorder by teamID
arrange(myBatting, teamID)
```

```
## # A tibble: 105,861 x 22
##    playerID  yearID stint teamID lgID      G    AB     R     H   X2B   X3B    HR
##    <chr>      <int> <int> <fct>  <fct> <int> <int> <int> <int> <int> <int> <int>
##  1 berrych01   1884     1 ALT    UA        7    25     2     6     0     0     0
##  2 brownji01   1884     1 ALT    UA       21    88    12    22     2     2     1
##  3 carropa01   1884     1 ALT    UA       11    49     4    13     1     0     0
##  4 connojo01   1884     1 ALT    UA        3    11     0     1     0     0     0
##  5 crosscl01   1884     1 ALT    UA        2     7     1     4     1     0     0
##  6 daisege01   1884     1 ALT    UA        1     4     0     0     0     0     0
##  7 doughch01   1884     1 ALT    UA       23    85     6    22     5     0     0
##  8 gradyjo01   1884     1 ALT    UA        9    36     5    11     3     0     0
##  9 harrifr01   1884     1 ALT    UA       24    95    10    25     2     1     0
## 10 koonsha01   1884     1 ALT    UA       21    78     8    18     2     1     0
## # ... with 105,851 more rows, and 10 more variables: RBI <int>, SB <int>,
## #   CS <int>, BB <int>, SO <int>, IBB <int>, HBP <int>, SH <int>, SF <int>,
## #   GIDP <int>
```

`arrange()` - reorder rows

```
#get secondary arrangement as well
arrange(myBatting, teamID, G)
```

```
## # A tibble: 105,861 x 22
##    playerID  yearID stint teamID lgID      G    AB     R     H   X2B   X3B    HR
##    <chr>      <int> <int> <fct>  <fct> <int> <int> <int> <int> <int> <int> <int>
##  1 daisege01   1884     1 ALT    UA        1     4     0     0     0     0     0
##  2 crosscl01   1884     1 ALT    UA        2     7     1     4     1     0     0
##  3 manloch01   1884     1 ALT    UA        2     7     1     3     0     0     0
##  4 connojo01   1884     1 ALT    UA        3    11     0     1     0     0     0
##  5 shafff01    1884     1 ALT    UA        6    19     1     3     0     0     0
##  6 berrych01   1884     1 ALT    UA        7    25     2     6     0     0     0
##  7 noftsge01   1884     1 ALT    UA        7    25     0     1     0     0     0
##  8 learyja01   1884     1 ALT    UA        8    33     1     3     0     0     0
##  9 gradyjo01   1884     1 ALT    UA        9    36     5    11     3     0     0
## 10 carropa01   1884     1 ALT    UA       11    49     4    13     1     0     0
## # ... with 105,851 more rows, and 10 more variables: RBI <int>, SB <int>,
## #   CS <int>, BB <int>, SO <int>, IBB <int>, HBP <int>, SH <int>, SF <int>,
## #   GIDP <int>
```

`arrange()` - reorder rows

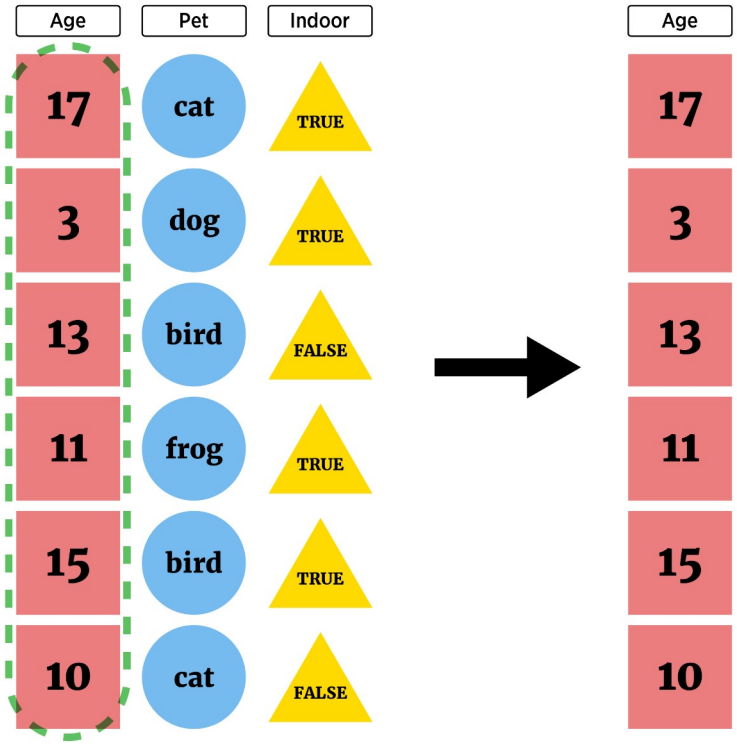
```
#descending instead
arrange(myBatting, teamID, desc(G))
```

```
## # A tibble: 105,861 x 22
##    playerID  yearID stint teamID lgID      G    AB     R     H   X2B   X3B    HR
##    <chr>      <int> <int> <fct>  <fct> <int> <int> <int> <int> <int> <int> <int>
##  1 smithge01   1884     1 ALT    UA       25   108     9    34     8     1     0
##  2 harrifr01   1884     1 ALT    UA       24    95    10    25     2     1     0
##  3 doughch01   1884     1 ALT    UA       23    85     6    22     5     0     0
##  4 murphjo01   1884     1 ALT    UA       23    94    10    14     1     0     0
##  5 brownji01   1884     1 ALT    UA       21    88    12    22     2     2     1
##  6 koonsha01   1884     1 ALT    UA       21    78     8    18     2     1     0
##  7 mooreje01   1884     1 ALT    UA       20    80    10    25     3     1     1
##  8 shaffta01   1884     1 ALT    UA       13    55    10    18     2     0     0
##  9 carropa01   1884     1 ALT    UA       11    49     4    13     1     0     0
## 10 gradyjo01   1884     1 ALT    UA        9    36     5    11     3     0     0
## # ... with 105,851 more rows, and 10 more variables: RBI <int>, SB <int>,
## #   CS <int>, BB <int>, SO <int>, IBB <int>, HBP <int>, SH <int>, SF <int>,
## #   GIDP <int>
```

Data manipulation idea

We may want to subset our full data set or create new data

- Look at only certain variables (**select columns**)



`select()` - subset columns

- May only want certain variables
- `select(tibble, column1, column2,...)`

```
#Choose a single column by name
select(myBatting, X2B)
```

```
## # A tibble: 105,861 x 1
##      X2B
##    <int>
##  1     0
##  2     6
##  3     4
##  4    10
##  5    11
##  6     2
##  7     0
##  8    10
##  9     1
## 10     2
## # ... with 105,851 more rows
```

`select()` - subset columns

```
#Choose more than one column by name
select(myBatting, playerID, X2B)
```

```
## # A tibble: 105,861 x 2
##    playerID    X2B
##    <chr>     <int>
##  1 abercda01     0
##  2 addybo01      6
##  3 allisar01     4
##  4 allisdo01    10
##  5 ansonca01    11
##  6 armstbo01     2
##  7 barkeal01     0
##  8 barnero01    10
##  9 barrebi01     1
## 10 barrofr01     2
## # ... with 105,851 more rows
```

Aside: Piping or Chaining

- Applying multiple functions: nesting hard to parse!
- Piping or Chaining with `%>%` operator helps

```
arrange(select(filter(myBatting, teamID == "PIT"), playerID, G, X2B), desc(X2B))
```

```
## # A tibble: 4,817 x 3
##    playerID      G   X2B
##    <chr>     <int> <int>
##  1 wanerpa01   154    62
##  2 wanerpa01   148    53
##  3 sanchfr01   157    53
##  4 wanerpa01   152    50
##  5 comorad01   152    47
##  6 mclouna01   152    46
##  7 wagneho01   135    45
##  8 parkeda01   158    45
##  9 vanslan01   154    45
## 10 wagneho01   132    44
## # ... with 4,807 more rows
```

Aside: Piping or Chaining

- Applying multiple functions: nesting hard to parse!
- Piping or Chaining with `%>%` operator helps

```
myBatting %>%
  filter(teamID == "PIT") %>%
  select(playerID, G, X2B) %>%
  arrange(desc(X2B))
```

```
## # A tibble: 4,817 x 3
##    playerID      G   X2B
##    <chr>     <int> <int>
##  1 wanerpa01   154    62
##  2 wanerpa01   148    53
##  3 sanchfr01   157    53
##  4 wanerpa01   152    50
##  5 comorad01   152    47
##  6 mclouna01   152    46
##  7 wagneho01   135    45
##  8 parkeda01   158    45
##  9 vanslan01   154    45
## 10 wagneho01   132    44
## # ... with 4,807 more rows
```

Aside: Piping or Chaining

- Generically, pipe does the following

`x %>% f(y)` turns into `f(x,y)`

`x %>% f(y) %>% g(z)` turns into `g(f(x, y), z)`

- Can be used with functions outside the tidyverse if this structure works!

`select()` - subset columns

- Great functionality for choosing variables

```
#all columns between
myBatting %>%
  select(X2B:HR)
```

```
## # A tibble: 105,861 x 3
##      X2B   X3B    HR
##    <int> <int> <int>
##  1     0     0     0
##  2     6     0     0
##  3     4     5     0
##  4    10     2     2
##  5    11     3     0
##  6     2     1     0
##  7     0     0     0
##  8    10     9     0
##  9     1     0     0
## 10     2     1     0
## # ... with 105,851 more rows
```

`select()` - subset columns

- Great functionality for choosing variables

```
#all columns containing
myBatting %>%
  select(contains("X"))
```

```
## # A tibble: 105,861 x 2
##      X2B   X3B
##    <int> <int>
##  1     0     0
##  2     6     0
##  3     4     5
##  4    10     2
##  5    11     3
##  6     2     1
##  7     0     0
##  8    10     9
##  9     1     0
## 10     2     1
## # ... with 105,851 more rows
```

`select()` - subset columns

- Great functionality for choosing variables

```
#all columns starting with
myBatting %>%
  select(starts_with("X"))
```

```
## # A tibble: 105,861 x 2
##      X2B   X3B
##    <int> <int>
##  1     0     0
##  2     6     0
##  3     4     5
##  4    10     2
##  5    11     3
##  6     2     1
##  7     0     0
##  8    10     9
##  9     1     0
## 10     2     1
## # ... with 105,851 more rows
```

`select()` - subset columns

- Great functionality for choosing variables

```
#multiple selections
myBatting %>%
  select(starts_with("X"), ends_with("ID"), G)
```

```
## # A tibble: 105,861 x 7
##      X2B   X3B playerID  yearID teamID lgID      G
##    <int> <int> <chr>      <int> <fct>  <fct> <int>
##  1     0     0 abercda01   1871 TRO    NA        1
##  2     6     0 addybo01    1871 RC1    NA       25
##  3     4     5 allisar01   1871 CL1    NA       29
##  4    10     2 allisdo01   1871 WS3    NA       27
##  5    11     3 ansonca01   1871 RC1    NA       25
##  6     2     1 armstbo01   1871 FW1    NA       12
##  7     0     0 barkeal01   1871 RC1    NA        1
##  8    10     9 barnero01   1871 BS1    NA       31
##  9     1     0 barrebi01   1871 FW1    NA        1
## 10     2     1 barrofr01   1871 BS1    NA       18
## # ... with 105,851 more rows
```

`select()` - subset columns

- Can reorder variables

```
#reorder
myBatting %>%
  select(playerID, HR, everything())
```

```
## # A tibble: 105,861 x 22
##    playerID     HR yearID stint teamID lgID      G    AB     R     H   X2B   X3B
##    <chr>     <int>  <int> <int> <fct>  <fct> <int> <int> <int> <int> <int> <int>
##  1 abercda01     0   1871     1 TRO    NA        1     4     0     0     0     0
##  2 addybo01      0   1871     1 RC1    NA       25   118    30    32     6     0
##  3 allisar01     0   1871     1 CL1    NA       29   137    28    40     4     5
##  4 allisdo01     2   1871     1 WS3    NA       27   133    28    44    10     2
##  5 ansonca01     0   1871     1 RC1    NA       25   120    29    39    11     3
##  6 armstbo01     0   1871     1 FW1    NA       12    49     9    11     2     1
##  7 barkeal01     0   1871     1 RC1    NA        1     4     0     1     0     0
##  8 barnero01     0   1871     1 BS1    NA       31   157    66    63    10     9
##  9 barrebi01     0   1871     1 FW1    NA        1     5     1     1     1     0
## 10 barrofr01     0   1871     1 BS1    NA       18    86    13    13     2     1
## # ... with 105,851 more rows, and 10 more variables: RBI <int>, SB <int>,
## #   CS <int>, BB <int>, SO <int>, IBB <int>, HBP <int>, SH <int>, SF <int>,
## #   GIDP <int>
```

`rename()` - rename variables

- Syntax: `rename(tibble, "new-name" = column, ...)`

```
#rename our previous
myBatting %>%
  select(starts_with("X"), ends_with("ID"), G) %>%
  rename("Doubles" = X2B, "Triples" = X3B)
```

```
## # A tibble: 105,861 x 7
##    Doubles Triples playerID  yearID teamID lgID      G
##      <int>   <int> <chr>      <int> <fct>  <fct> <int>
##  1       0       0 abercda01   1871 TRO    NA        1
##  2       6       0 addybo01    1871 RC1    NA       25
##  3       4       5 allisar01   1871 CL1    NA       29
##  4      10       2 allisdo01   1871 WS3    NA       27
##  5      11       3 ansonca01   1871 RC1    NA       25
##  6       2       1 armstbo01   1871 FW1    NA       12
##  7       0       0 barkeal01   1871 RC1    NA        1
##  8      10       9 barnero01   1871 BS1    NA       31
##  9       1       0 barrebi01   1871 FW1    NA        1
## 10       2       1 barrofr01   1871 BS1    NA       18
## # ... with 105,851 more rows
```

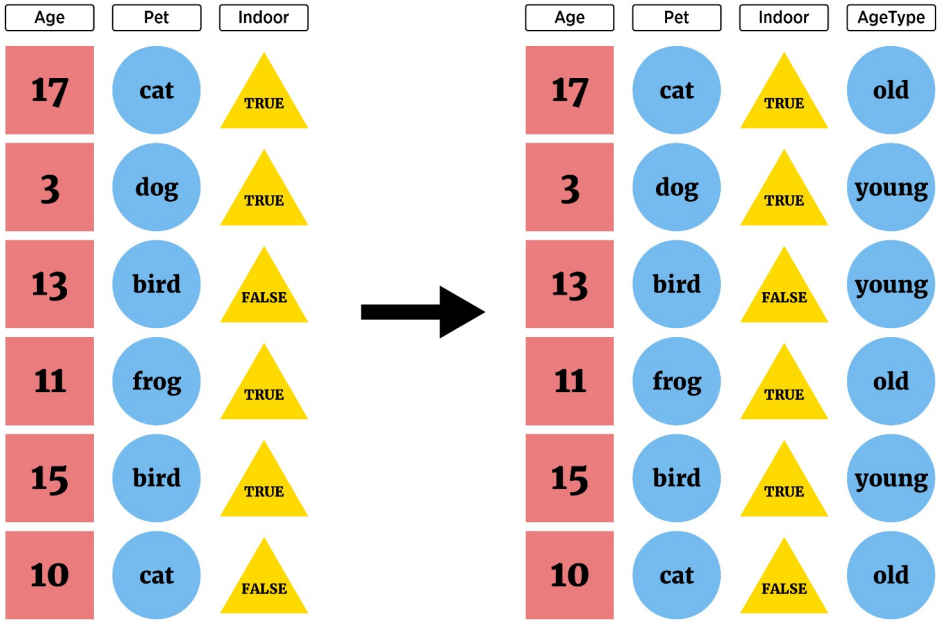
dplyr

Cheat sheet

- Common syntax and piping make code easy to use and read
- Basic commands
  - `as_tibble()` - convert data frame to one with better printing
  - `filter()` - subset **rows**
  - `arrange()` - reorder **rows**
  - `select()` - subset **columns**
- Many `joins` to combine tibbles too! (Similar to SQL)

Data manipulation idea

- Create new variables



Creating New Variables

- `mutate()` - add newly created **column(s)** to current data frame (doesn't overwrite the data frame)
- `transmute()` - create new data frame with created variable(s) only
- Syntax:

```
mutate(data, newVarName = functionOfData, newVarName2 =
functionOfData, ...)
```

Creating New Variables

- Consider a data set on movie ratings

```
library(fivethirtyeight)
fandango
```

```
## # A tibble: 146 x 23
##    film    year rottentomatoes rottentomatoes_~ metacritic metacritic_user  imdb
##    <chr>  <dbl>          <int>            <int>      <int>           <dbl> <dbl>
##  1 Aveng~  2015             74               86         66             7.1   7.8
##  2 Cinde~  2015             85               80         67             7.5   7.1
##  3 Ant-M~  2015             80               90         64             8.1   7.8
##  4 Do Yo~  2015             18               84         22             4.7   5.4
##  5 Hot T~  2015             14               28         29             3.4   5.1
##  6 The W~  2015             63               62         50             6.8   7.2
##  7 Irrat~  2015             42               53         53             7.6   6.9
##  8 Top F~  2014             86               64         81             6.8   6.5
##  9 Shaun~  2015             99               82         81             8.8   7.4
## 10 Love ~  2015             89               87         80             8.5   7.8
## # ... with 136 more rows, and 16 more variables: fandango_stars <dbl>,
## #   fandango_ratingvalue <dbl>, rt_norm <dbl>, rt_user_norm <dbl>,
## #   metacritic_norm <dbl>, metacritic_user_nom <dbl>, imdb_norm <dbl>,
## #   rt_norm_round <dbl>, rt_user_norm_round <dbl>, metacritic_norm_round <dbl>,
## #   metacritic_user_norm_round <dbl>, imdb_norm_round <dbl>,
## #   metacritic_user_vote_count <int>, imdb_user_vote_count <int>,
```

`mutate()` - create new column(s)

```
##Create an average rottentomatoes score variable
fandango %>%
  mutate(avgRotten = (rottentomatoes + rottentomatoes_user)/2)
```

```
## # A tibble: 146 x 24
##    film    year rottentomatoes rottentomatoes_~ metacritic metacritic_user  imdb
##    <chr>  <dbl>          <int>            <int>      <int>           <dbl> <dbl>
##  1 Aveng~  2015             74               86         66             7.1   7.8
##  2 Cinde~  2015             85               80         67             7.5   7.1
##  3 Ant-M~  2015             80               90         64             8.1   7.8
##  4 Do Yo~  2015             18               84         22             4.7   5.4
##  5 Hot T~  2015             14               28         29             3.4   5.1
##  6 The W~  2015             63               62         50             6.8   7.2
##  7 Irrat~  2015             42               53         53             7.6   6.9
##  8 Top F~  2014             86               64         81             6.8   6.5
##  9 Shaun~  2015             99               82         81             8.8   7.4
## 10 Love ~  2015             89               87         80             8.5   7.8
## # ... with 136 more rows, and 17 more variables: fandango_stars <dbl>,
## #   fandango_ratingvalue <dbl>, rt_norm <dbl>, rt_user_norm <dbl>,
## #   metacritic_norm <dbl>, metacritic_user_nom <dbl>, imdb_norm <dbl>,
## #   rt_norm_round <dbl>, rt_user_norm_round <dbl>, metacritic_norm_round <dbl>,
## #   metacritic_user_norm_round <dbl>, imdb_norm_round <dbl>,
## #   metacritic_user_vote_count <int>, imdb_user_vote_count <int>,
## #   fandango_votes <int>, fandango_difference <dbl>, avgRotten <dbl>
```

`mutate()` - create new column(s)

```
#can't see it!
fandango %>%
  mutate(avgRotten = (rottentomatoes + rottentomatoes_user)/2) %>%
  select(film, year, avgRotten, everything())
```

```
## # A tibble: 146 x 24
##    film                year avgRotten rottentomatoes rottentomatoes_u~ metacritic
##    <chr>              <dbl>     <dbl>          <int>             <int>      <int>
##  1 Avengers: Age of~  2015      80               74                86         66
##  2 Cinderella         2015      82.5             85                80         67
##  3 Ant-Man            2015      85               80                90         64
##  4 Do You Believe?    2015      51               18                84         22
##  5 Hot Tub Time Mac~  2015      21               14                28         29
##  6 The Water Diviner  2015      62.5             63                62         50
##  7 Irrational Man     2015      47.5             42                53         53
##  8 Top Five           2014      75               86                64         81
##  9 Shaun the Sheep ~  2015      90.5             99                82         81
## 10 Love & Mercy       2015      88               89                87         80
## # ... with 136 more rows, and 18 more variables: metacritic_user <dbl>,
## #   imdb <dbl>, fandango_stars <dbl>, fandango_ratingvalue <dbl>,
## #   rt_norm <dbl>, rt_user_norm <dbl>, metacritic_norm <dbl>,
## #   metacritic_user_nom <dbl>, imdb_norm <dbl>, rt_norm_round <dbl>,
## #   rt_user_norm_round <dbl>, metacritic_norm_round <dbl>,
## #   metacritic_user_norm_round <dbl>, imdb_norm_round <dbl>,
```

`mutate()` - create new column(s)

- Add more than one variable

```
fandango %>%
  mutate(avgRotten = (rottentomatoes + rottentomatoes_user)/2,
         avgMeta = (metacritic_norm + metacritic_user_nom)/2) %>%
  select(film, year, avgRotten, avgMeta, everything())
```

```
## # A tibble: 146 x 25
##    film        year avgRotten avgMeta rottentomatoes rottentomatoes_~ metacritic
##    <chr>      <dbl>     <dbl>   <dbl>          <int>            <int>      <int>
##  1 Avengers:~  2015      80      3.42             74               86         66
##  2 Cinderella  2015      82.5    3.55             85               80         67
##  3 Ant-Man     2015      85      3.62             80               90         64
##  4 Do You Be~  2015      51      1.72             18               84         22
##  5 Hot Tub T~  2015      21      1.58             14               28         29
##  6 The Water~  2015      62.5    2.95             63               62         50
##  7 Irrationa~  2015      47.5    3.22             42               53         53
##  8 Top Five    2014      75      3.72             86               64         81
##  9 Shaun the~  2015      90.5    4.22             99               82         81
## 10 Love & Me~  2015      88      4.12             89               87         80
## # ... with 136 more rows, and 18 more variables: metacritic_user <dbl>,
## #   imdb <dbl>, fandango_stars <dbl>, fandango_ratingvalue <dbl>,
## #   rt_norm <dbl>, rt_user_norm <dbl>, metacritic_norm <dbl>,
## #   metacritic_user_nom <dbl>, imdb_norm <dbl>, rt_norm_round <dbl>,
```

Creating New Variables

`mutate()` and `transmute()` can also use some statistical functions

```
fandango %>%
  select(rottentomatoes) %>%
  mutate(avg = mean(rottentomatoes), sd = sd(rottentomatoes))
```

```
## # A tibble: 146 x 3
##    rottentomatoes   avg    sd
##             <int> <dbl> <dbl>
##  1             74  60.8  30.2
##  2             85  60.8  30.2
##  3             80  60.8  30.2
##  4             18  60.8  30.2
##  5             14  60.8  30.2
##  6             63  60.8  30.2
##  7             42  60.8  30.2
##  8             86  60.8  30.2
##  9             99  60.8  30.2
## 10             89  60.8  30.2
## # ... with 136 more rows
```

Creating New Variables

`mutate()` and `transmute()` can also use some statistical functions

- `group_by` to create summaries for groups

```
fandango %>%
  select(year, rottentomatoes) %>%
  group_by(year) %>%
  mutate(avg = mean(rottentomatoes), sd = sd(rottentomatoes))
```

```
## # A tibble: 146 x 4
## # Groups:   year [2]
##     year rottentomatoes   avg    sd
##    <dbl>          <int> <dbl> <dbl>
##  1  2015             74  58.4  30.3
##  2  2015             85  58.4  30.3
##  3  2015             80  58.4  30.3
##  4  2015             18  58.4  30.3
##  5  2015             14  58.4  30.3
##  6  2015             63  58.4  30.3
##  7  2015             42  58.4  30.3
##  8  2014             86  79.5  21.6
##  9  2015             99  58.4  30.3
## 10  2015             89  58.4  30.3
## # ... with 136 more rows
```

Other notes: Summarizing with `dplyr`

- `summarize()` is often used with `group_by()` to obtain summaries without adding to the dataset

```
fandango %>%
  select(year, rottentomatoes) %>%
  group_by(year) %>%
  summarize(avg = mean(rottentomatoes), sd = sd(rottentomatoes))
```

```
## # A tibble: 2 x 3
##    year   avg    sd
##   <dbl> <dbl> <dbl>
## 1  2014  79.5  21.6
## 2  2015  58.4  30.3
```

`if_else()` - conditional execution

- Often want to execute statements conditionally to create a variable
- `if_else()` syntax:
  - `if_else(condition, true, false)`
  - `condition` is a vector of TRUE/FALSE
  - `true` is what to do when TRUE occurs
  - `false` is what to do when FALSE occurs
- Works well with `mutate()`

Creating New Variables

Conditional Execution with If then, If then else

- Consider built-in data set `airquality`
    - daily air quality measurements in New York
    - from May (Day 1) to September (Day 153) in 1973

```
myAirquality <- as_tibble(airquality)
myAirquality
```

```
## # A tibble: 153 x 6
##    Ozone Solar.R  Wind  Temp Month   Day
##    <int>   <int> <dbl> <int> <int> <int>
##  1    41     190   7.4    67     5     1
##  2    36     118   8      72     5     2
##  3    12     149  12.6    74     5     3
##  4    18     313  11.5    62     5     4
##  5    NA      NA  14.3    56     5     5
##  6    28      NA  14.9    66     5     6
##  7    23     299   8.6    65     5     7
##  8    19      99  13.8    59     5     8
##  9     8      19  20.1    61     5     9
## 10    NA     194   8.6    69     5    10
```

if_else() with mutate()

```
myAirquality <- myAirquality %>%
  mutate(Status = if_else(Wind >= 15, "HighWind",
                          if_else(Wind >= 10, "Windy",
                                  if_else(Wind >= 6, "LightWind", "Calm"))))
myAirquality
```

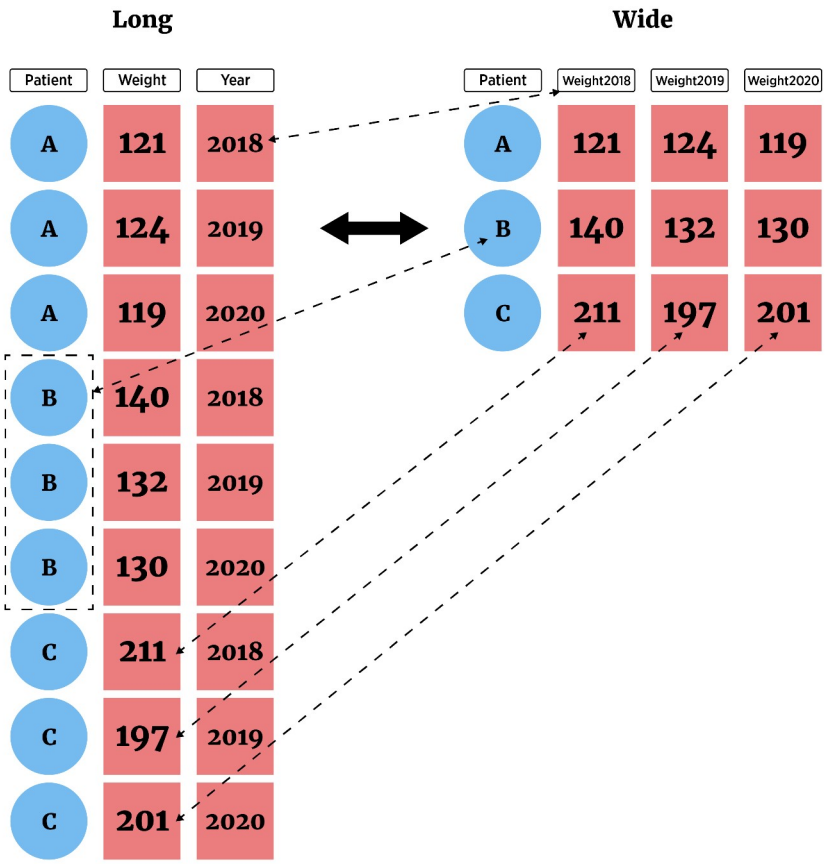
```
## # A tibble: 153 x 7
##    Ozone Solar.R  Wind  Temp Month   Day Status
##    <int>   <int> <dbl> <int> <int> <int> <chr>
##  1    41     190   7.4    67     5     1 LightWind
##  2    36     118   8      72     5     2 LightWind
##  3    12     149  12.6    74     5     3 Windy
##  4    18     313  11.5    62     5     4 Windy
##  5    NA      NA  14.3    56     5     5 Windy
##  6    28      NA  14.9    66     5     6 Windy
##  7    23     299   8.6    65     5     7 LightWind
##  8    19      99  13.8    59     5     8 Windy
##  9     8      19  20.1    61     5     9 HighWind
## 10    NA     194   8.6    69     5    10 LightWind
## # ... with 143 more rows
```

Creating New Variables Recap!

- `mutate()` - add newly created **column(s)** to current data frame
- `transmute()` - create new data frame with created variable(s)
  - Use `if_else()` to do conditional creation
  - Note: `cut()` can be used to categorize a numeric variable!

Other notes: Reshaping Data

Long vs Wide format data



Other notes: Reshaping Data

`tidyr` package

Easily allows for two very important actions

- `pivot_longer()` - lengthens data by increasing the number of rows and decreasing the number of columns
    - Most important as analysis methods often prefer this form
- `pivot_wider()` - widens data by increasing the number of columns and decreasing the number of rows
- Also, `unite()` and `separate()` to join and split columns
- All functions work with tibbles and have a similar syntax/philosophy

Exercises

- Work through the part 4 exercises

https://jbpost2.github.io/TeachingWithR/exercises/TeachingR_Part_4_Exercises.html

Partial Solution
https://jbpost2.github.io/TeachingWithR/exercises/TeachingR_Part_4_Solutions.html

Schedule

- `RStudio` IDE (Integrated Development Environment)
- Vectors and Data Frames/Tibbles
- Importing CSV files with `readr`
- Markdown basics
- Common data manipulation with `dplyr`
- Plotting with `ggplot2`
- Shiny basics

Graphical Summaries

Three major systems for plotting:

- Base R (built-in functions)
- Lattice
- ggplot2 (sort of part of the tidyverse - Cheat Sheet)
    - `ggplot(data = data_frame)` creates a plot instance
    - Add “layers” to the system (geoms or stats)

Great reference book here!

`ggplot2` Plotting

ggplot2 basics (Cheat Sheet)

- `ggplot(data = data_frame)` creates a plot instance
- Add “layers” to the system (geoms or stats)
    - Creates a visualization of the data

`ggplot2` Plotting

ggplot2 basics (Cheat Sheet)

- `ggplot(data = data_frame)` creates a plot instance
- Add “layers” to the system (geoms or stats)
  - Creates a visualization of the data
- Modify layer “mapping” args (aes)
  - Ex: size, color, and x, y location(s)
- Coordinate system (mostly use Cartesian plane)
- Optional: Titles, etc.

`factors`

- factor - special class of vector with a `levels` attribute
- Levels define all possible values for that variable
  - Great for variable like `Day` (Monday, Tuesday, …)
  - Not great for variable like `Name` where new values may come up
- Quite useful with plotting
  - Allows for easy labeling of subgroups

factors

- Consider data on titanic passengers in `titanic.csv`

```
titanicData <- read_csv("titanic.csv")
#convert survival status to a factor
titanicData$survived <- as.factor(titanicData$survived)
levels(titanicData$survived) #R knows it isn't numeric now
```

```
## [1] "0" "1"
```

- Can’t add value unless it is a level

```
titanicData$survived[1] <- "5"
```

```
## Warning in `[<-.factor`(`*tmp*`, 1, value = structure(c(NA, 2L, 1L, 1L, :
## invalid factor level, NA generated
```

`factor` levels

- Useful if you want to create better labels (or change the ordering)

```
levels(titanicData$survived) <- c("Died", "Survived")
levels(titanicData$survived)
```

```
## [1] "Died"     "Survived"
```

`ggplot2` Plotting: Categorical variables

Categorical variable - entries are a label or attribute

Generally, describe distriubtion using a barplot!

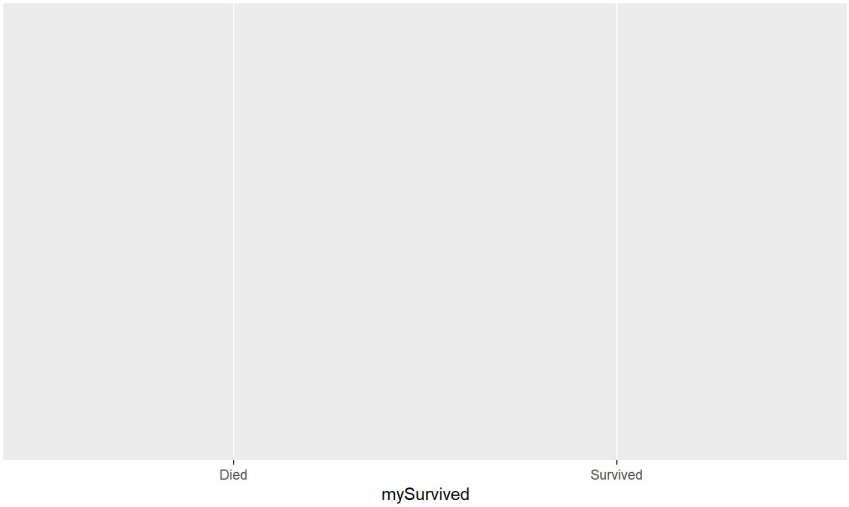
- Barplots via `ggplot + geom_bar`

```
titanicData <- read_csv("titanic.csv")
titanicData$mySurvived <- as.factor(titanicData$survived)
levels(titanicData$mySurvived) <- c("Died", "Survived")
titanicData$myEmbarked <- as.factor(titanicData$embarked)
levels(titanicData$myEmbarked) <- c("Cherbourg", "Queenstown", "Southampton")
titanicData <- titanicData %>% drop_na(mySurvived, sex, myEmbarked)
```

`ggplot2` barplots

- Barplots via `ggplot + geom_bar`
- Across x-axis we want our categories - specify with `aes(x = ...)`

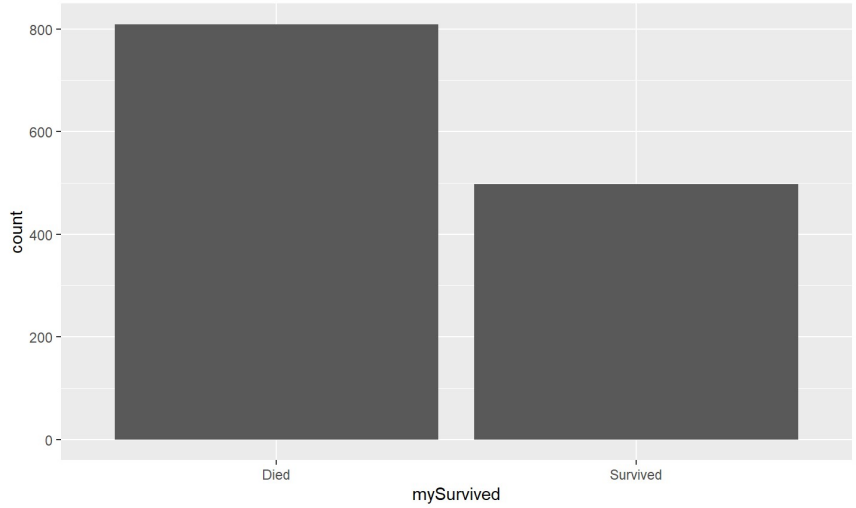
```
ggplot(data = titanicData, aes(x = mySurvived))
```



ggplot2 barplots

- Barplots via `ggplot + geom_bar`
- Must add geom (or stat) layer!

```
ggplot(data = titanicData, aes(x = mySurvived)) + geom_bar()
```



ggplot2 barplots

- Generally: Save base object, then “add layers”

```
g <- ggplot(data = titanicData, aes(x = mySurvived))
g + geom_bar()
```

`ggplot2` barplots

- Generally: Save base object, then “add layers”

```
g <- ggplot(data = titanicData, aes(x = mySurvived))
g + geom_bar()
```

- `aes()` defines visual properties of objects in the plot

  `x = , y = , size = , shape = , color = , alpha = , ...`

- Cheat Sheet gives most common properties for a given `geom`

ggplot2 barplots

- Generally: Save base object, then “add layers”

```
g <- ggplot(data = titanicData, aes(x = mySurvived))
g + geom_bar()
```

- `aes()` defines visual properties of objects in the plot

  `x = , y = , size = , shape = , color = , alpha = , ...`

- Cheat Sheet gives most common properties for a given `geom`

  `d + geom_bar()`

  `x, alpha, color, fill, linetype, size, weight`

`ggplot2` global and local aesthetics

`data` and `aes` can be set in two ways;

- 'globally' (for all layers) via the `ggplot` statement
- 'locally' (for just that layer) via the `geom`, `stat`, etc. layer

`ggplot2` global and local aesthetics

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```
#global
ggplot(data = titanicData, aes(x = mySurvived)) + geom_bar()
#local
ggplot() + geom_bar(data = titanicData, aes(x = mySurvived))
```

`ggplot2` global and local aesthetics

`data` and `aes` can be set in two ways;

- 'globally' (for all layers) via the `ggplot` statement
- 'locally' (for just that layer) via the `geom`, `stat`, etc. layer

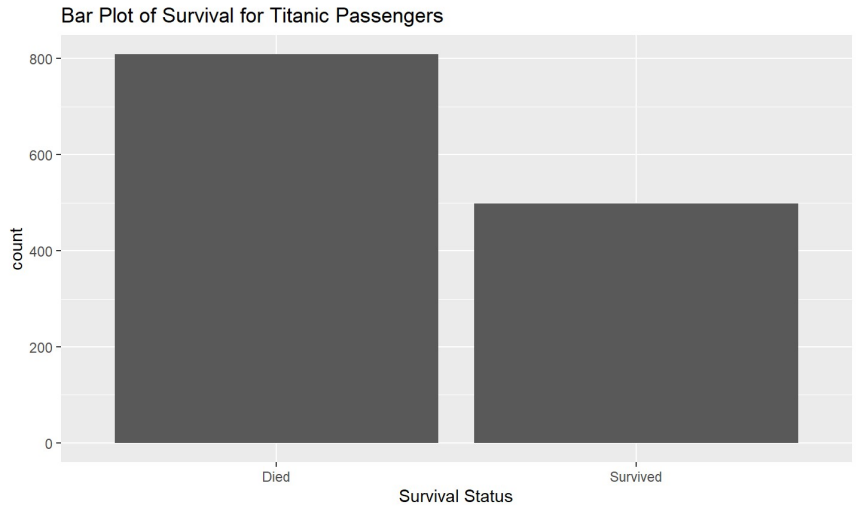
```
#global
ggplot(data = titanicData, aes(x = mySurvived)) + geom_bar()
#local
ggplot() + geom_bar(data = titanicData, aes(x = mySurvived))
```

- To set an attribute that doesn't depend on the data (i.e. `color = 'blue'`), generally place these outside of the `aes`

ggplot2 barplots

- Add better labels and a title (new layers, see cheat sheet!)

```
ggplot(data = titanicData, aes(x = mySurvived)) +
  geom_bar() +
  labs(x = "Survival Status", title = "Bar Plot of Survival for Titanic Passengers")
```



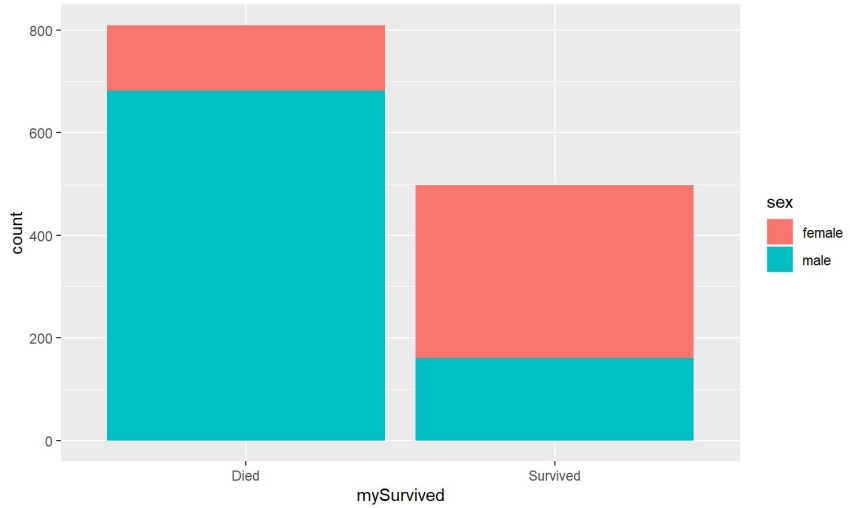
`ggplot2` stacked barplots

- **Stacked barplot** created by via `fill` aesthetic and same process
  - Create base object
  - Add geoms
  - Use aes to specify aspects of the plot

`ggplot2` stacked barplots

- **Stacked barplot** created by via `fill` aesthetic
- Automatic assignment of colors, creation of legends, etc. for `aes` elements (except with `group`)

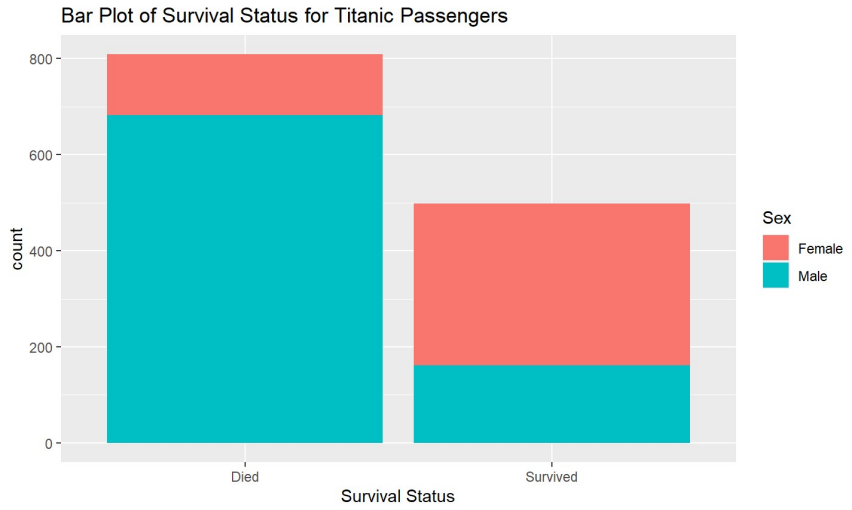
```
ggplot(data = titanicData, aes(x = mySurvived, fill = sex)) + geom_bar()
```



ggplot2 labeling

- Add custom labels by adding more layers

```
ggplot(data = titanicData, aes(x = mySurvived, fill = sex)) +
  geom_bar() +
  labs(x = "Survival Status",
       title = "Bar Plot of Survival Status for Titanic Passengers") +
  scale_fill_discrete(name = "Sex", labels = c("Female", "Male"))
```



ggplot2 labeling

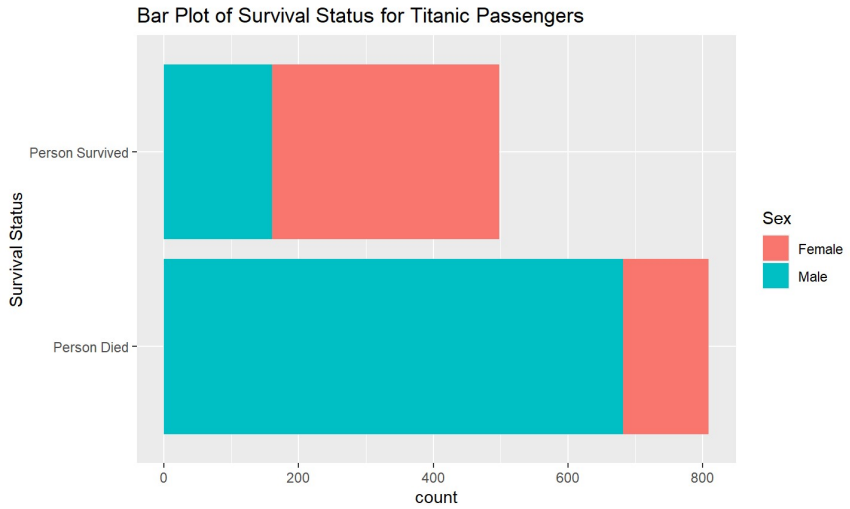
- Adjusting appropriate labeling via `scale_*_discrete`

```
aes(x = survived, fill = sex)

scale_x_discrete(labels = c("Person Died", "Person Survived"))

scale_fill_discrete(name = "Sex", labels = c("Female","Male"))
```

ggplot2 horizontal barplots

- Easy to rotate a plot with `coord_flip`

```
ggplot(data = titanicData, aes(x = mySurvived, fill = sex)) + geom_bar() +
  labs(x = "Survival Status",
       title = "Bar Plot of Survival Status for Titanic Passengers") +
  scale_x_discrete(labels = c("Person Died", "Person Survived")) +
  scale_fill_discrete(name = "Sex", labels = c("Female", "Male")) +
  coord_flip()
```



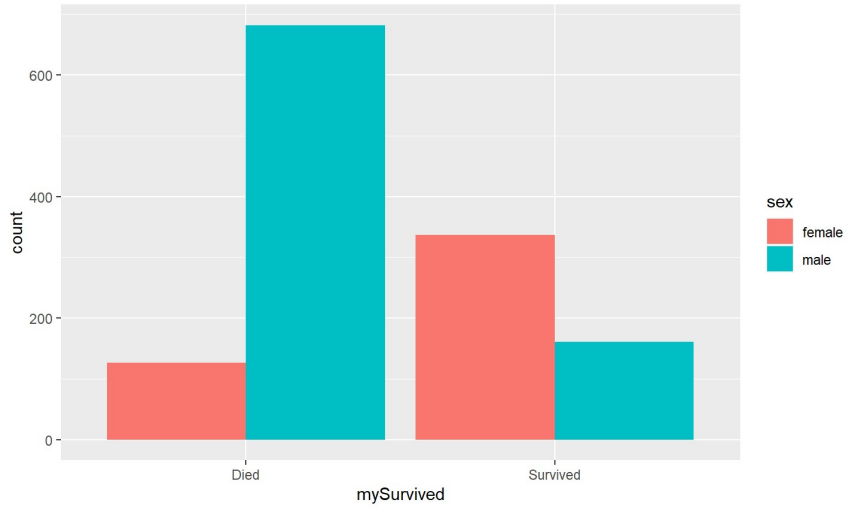
`ggplot2` side-by-side barplots

- **Side-by-side barplot** created by via `position` aesthetic
  - `dodge` for side-by-side bar plot
  - `jitter` for continuous data with many points at same values
  - `fill` stacks bars and standardises each stack to have constant height
  - `stack` stacks bars on top of each other

`ggplot2` side-by-side barplots

- **Side-by-side barplot** created by via `position` aesthetic

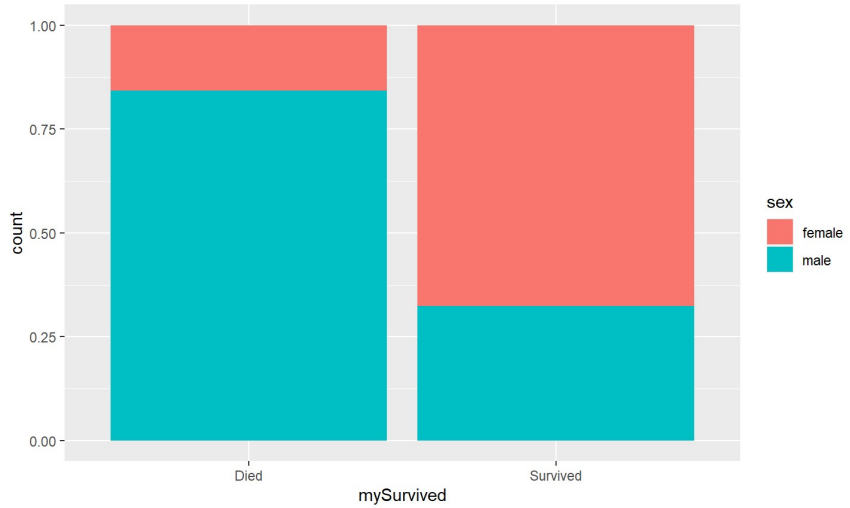
```
ggplot(data = titanicData, aes(x = mySurvived, fill = sex)) +
  geom_bar(position = "dodge")
```



ggplot2 filled barplots

- `position = fill` stacks bars and standardises each stack to have constant height (especially useful with equal group sizes)

```
ggplot(data = titanicData, aes(x = mySurvived, fill = sex)) +
  geom_bar(position = "fill")
```



`ggplot2` faceting

How to create same plot for each `myEmbarked` value? Use **faceting**!

`ggplot2` faceting

How to create same plot for each `myEmbarked` value? Use **faceting**!

`facet_wrap(~ var)` - creates a plot for each setting of `var`

- Can specify `nrow` and `ncol` or let R figure it out

ggplot2 faceting

How to create same plot for each `myEmbarked` value? Use **faceting**!

`facet_wrap(~ var)` - creates a plot for each setting of `var`

- Can specify `nrow` and `ncol` or let R figure it out

`facet_grid(var1 ~ var2)` - creats a plot for each combination of `var1` and `var2`

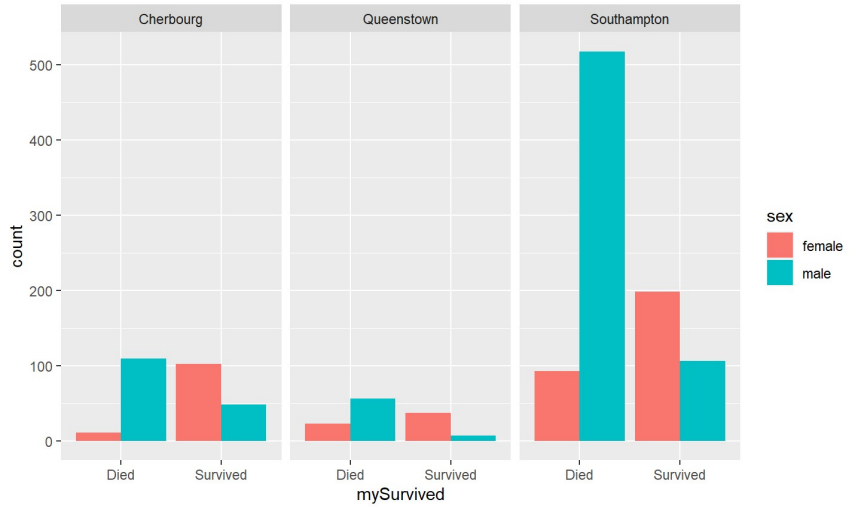
- `var1` values across rows
- `var2` values across columns
- Use `. ~ var2` or `var1 ~ .` to have only one row or column

ggplot2 faceting

How to create same plot for each `myEmbarked` value? Use **faceting**!

- `facet_wrap(~ var)` - creates a plot for each setting of `var`

```
ggplot(data = titanicData, aes(x = mySurvived)) +
  geom_bar(aes(fill =sex), position = "dodge") +
  facet_wrap(~ myEmbarked)
```



`ggplot2` Plotting Recap

General `ggplot` things:

- Can set local or global `aes`
- Modify titles/labels by adding more layers
- Faceting (multiple plots) via `facet_grid` or `facet_wrap`
- Only need `aes` if setting a mapping value that is dependent on the data (or you want to create a custom legend!)

`ggplot2` Plotting: Numeric Variables

Numeric variables - generally, describe distribution via a histogram or boxplot!

Same process:

- Create base object
- Add geoms
- Use aes to specify aspects of the plot

`ggplot2` smoothed histogram

- **Kernel Smoother** - Smoothed version of a histogram
- Common `aes` values (from cheat sheet):

```
c + geom_density(kernel = "gaussian")
```

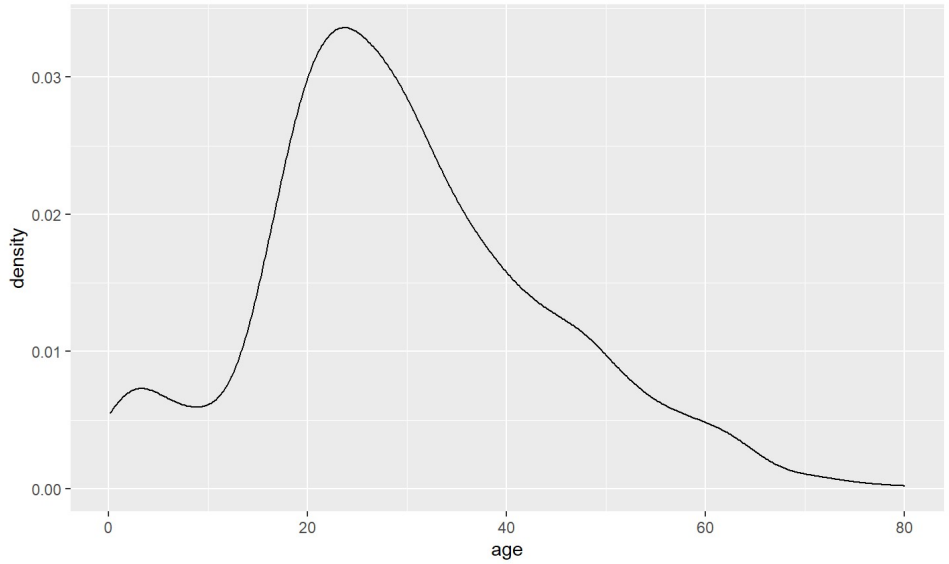
```
x, y, alpha, color, fill, group, linetype, size, weight
```

- Only `x =` is really needed

ggplot2 smoothed histogram

- **Kernel Smoother** - Smoothed version of a histogram

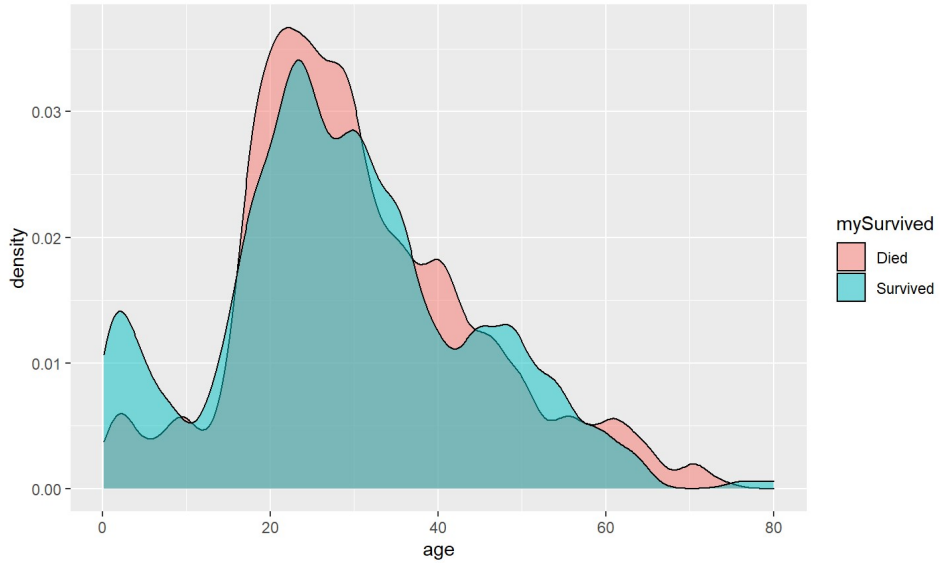
```
g <- ggplot(titanicData, aes(x = age))
g + geom_density()
```



ggplot2 smoothed histogram

- **Kernel Smoother** - Smoothed version of a histogram
- `fill` a useful aesthetic!

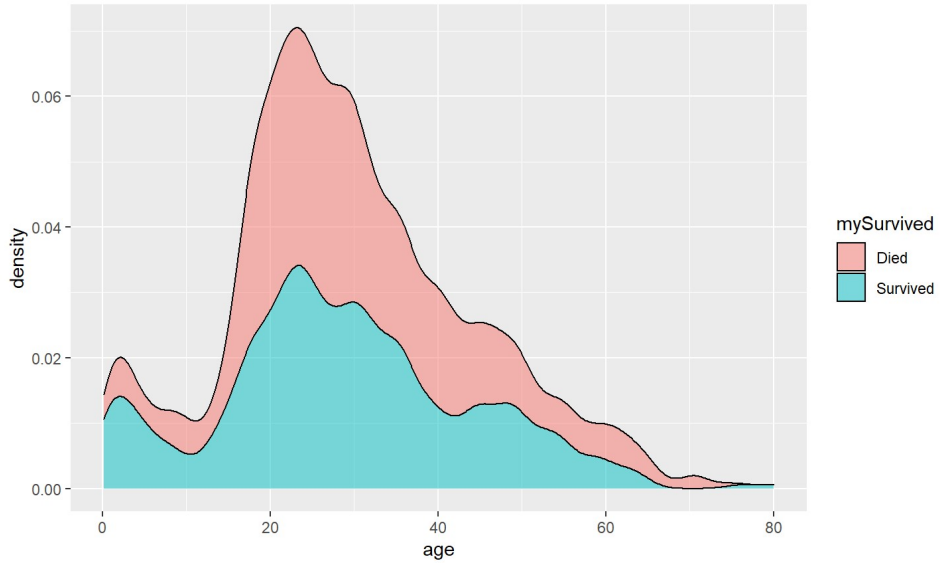
```
g + geom_density(adjust = 0.5, alpha = 0.5, aes(fill = mySurvived))
```



ggplot2 smoothed histogram

- **Kernel Smoother** - Smoothed version of a histogram
- recall `position` choices of `dodge`, `jitter`, `fill`, and `stack`

```
g + geom_density(adjust = 0.5, alpha = 0.5, position = "stack", aes(fill = mySurvived))
```



`ggplot2` boxplots

- **Boxplot** - Provides the five number summary in a graph
- Common `aes` values (from cheat sheet):

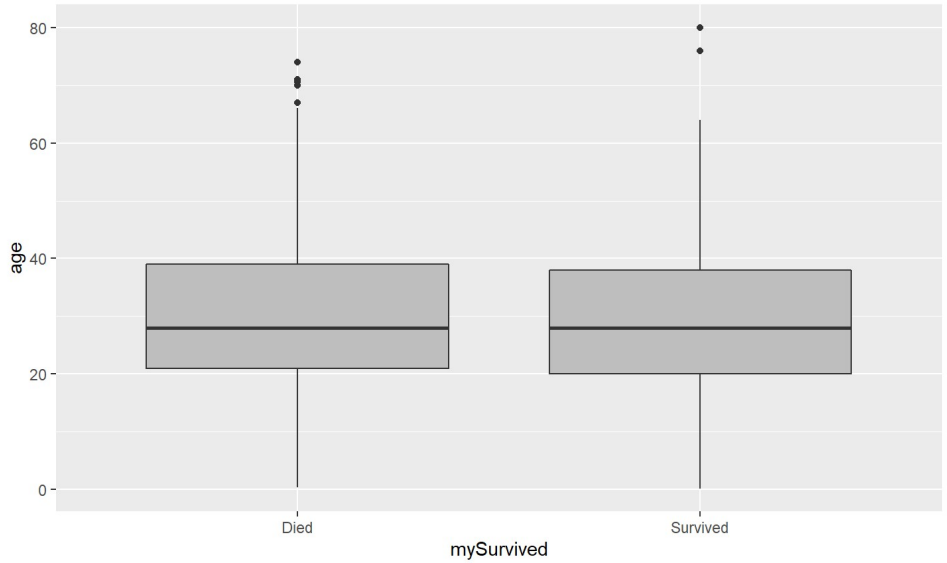
```
f + geom_boxplot()
```

```
x, y, lower, middle, upper, ymax, ymin, alpha, color, fill,
group, linetype, shape, size, weight
```

- Only `x =, y =` are really needed

ggplot2 boxplots

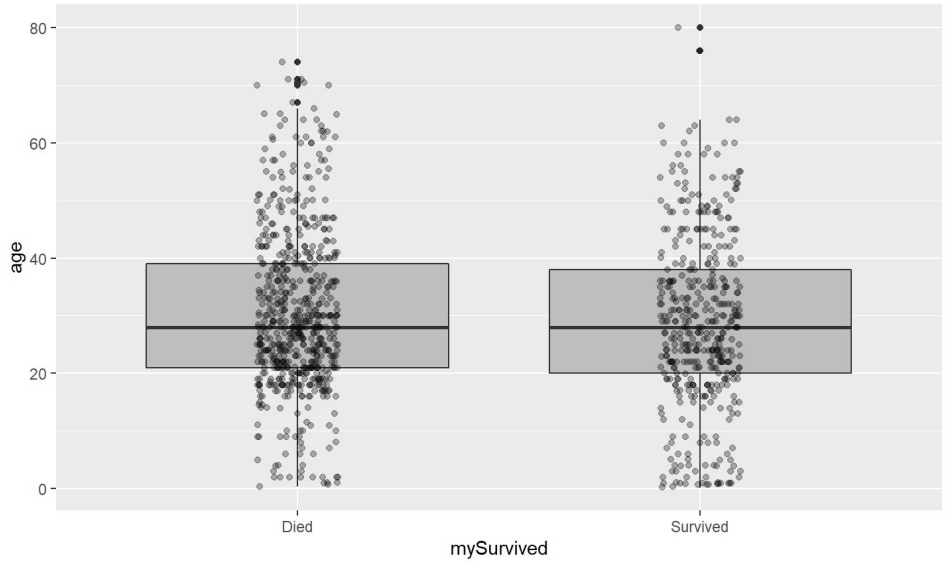
```
g <- ggplot(titanicData, aes(x = mySurvived, y = age))
g + geom_boxplot(fill = "grey")
```



ggplot2 boxplots with points

- Can add data points (jittered) to see shape of data better (or use violin plot)

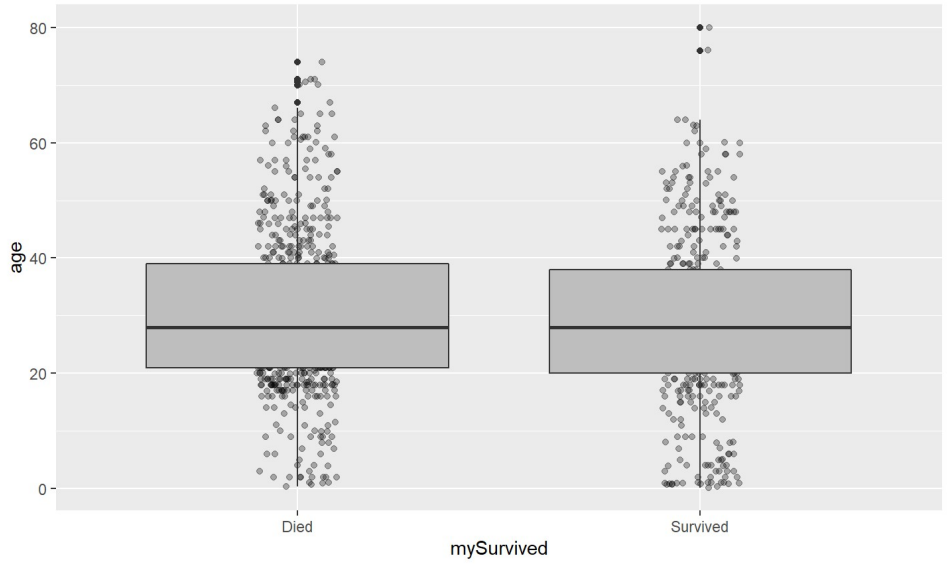
```
g +
  geom_boxplot(fill = "grey") +
  geom_jitter(width = 0.1, alpha = 0.3)
```



ggplot2 boxplots with points

- Order of layers important!

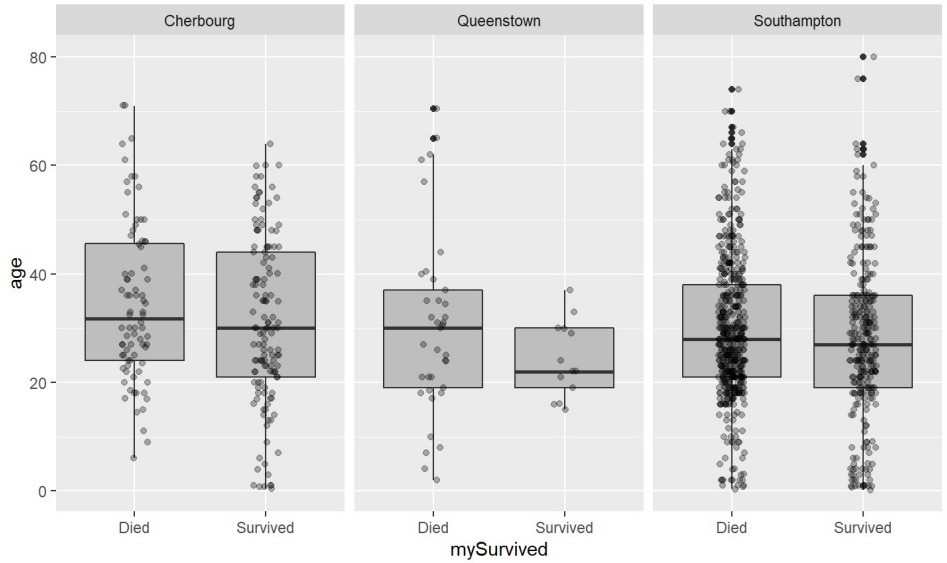
```
g +
  geom_jitter(width = 0.1, alpha = 0.3) +
  geom_boxplot(fill = "grey")
```



ggplot2 faceting

- Can `facet` easily!

```
g + geom_boxplot(fill = "grey") +
  geom_jitter(width = 0.1, alpha = 0.3) +
  facet_wrap(~ myEmbarked)
```



`ggplot2` Plotting: Numeric variables

Recap!

Numeric variable - entries are a numerical value where math can be performed

Most common plots:

- Histogram (`geom_hist`), Density (`geom_density`)
- Boxplot (`geom_boxplot`), Violin plot (`geom_violin`)
- Scatter plot (`geom_point`), Smoothers (`geom_smooth`)
- Jittered points (`geom_jitter`)
- Text on plot (`geom_text`)

`ggplot2` Plotting Recap

General `ggplot` things:

- Can set local or global `aes`
- Modify titles/labels by adding more layers
- Use either stat or geom layer
- Faceting (multiple plots) via `facet_grid` or `facet_wrap`
- Only need `aes` if setting a mapping value that is dependent on the data (or you want to create a custom legend!)
- `esquisse` is a great package for exploring ggplot2!

Exercises

- Work through the part 5 exercises

https://jbpost2.github.io/TeachingWithR/exercises/TeachingR_Part_5_Exercises.html

Partial Solution
https://jbpost2.github.io/TeachingWithR/exercises/TeachingR_Part_5_Solutions.html