

R cookbook for the casual dabbler (2nd edition)

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Introduction

G'day and welcome to *R cookbook for the casual dabbler (2nd edition)*.

RCCD 1st edition was originally published in 2020 as a side project during the COVID-19 pandemic in Melbourne.

As I wrote in the midst of lockdown:

I use R a lot for work and for side projects. Over the years I've collated a bunch of useful scripts, from macroeconomic analysis to quick hacks for making map legends format properly.

Historically my code has been stored in random Rpubs documents, medium articles, and a bunch of .Rmd files on my harddrive. Occasionally I feel like doing things properly - and upload code to a repository on github.

It doesn't take a genius to realize this isn't a very sustainable solution - and it also isn't very useful for sharing code with others. It turns out 2-years of lockdown in Melbourne was enough incentive to sit down and collate my best and most useful code into a single place. In the spirit of open source, a book seemed like the most logical format. The following is a very rough book written in **markdown** - R's very own publishing language.

RCCD1e had surprisingly good (and long-lasting reviews). Alas, five-years on, a lot has changed - in both the R community, and the world more broadly. As such, RCCD2e includes significant revisions. The most major of these is a restructure to make the chapters flow more logically. The Australian specific chapters have also been grouped together (e.g. election data and ABS economic indicators).

Usage

In each chapter I've written up the background, methodology and code for a separate piece of analysis.

Most of this code will not be extraordinary to the seasoned R aficionado. However I find that in classic Pareto style ~20% of my code contributes to the **vast** majority of my work output. Having this 20% on hand will hopefully be useful to both myself and others.

Additional resources

The R community is continually writing new packages and tools. Many of these are covered extensively in various free books available on the bookdown.org website.

The rise of LLM's over the past 2-years has also made it significantly easier to find, refine, and expand on R code. RCCD2e includes optimized (and better formated code) which has gone through the scrutiny of many of the different LLM's.

I encourage users to paste in code snippets to language models for deeper explanations or alternate examples.

Limitations

If you find a bug (along with spelling errors etc) please email me at charlesf-coverdale@gmail.com with the subject line 'RCCD2e'.

About the author

Charles Coverdale is an economist working across London and Melbourne. He is passionate about economics, climate science, and building talented teams. You can get in touch with Charles on twitter to hear more about his current projects.

Making maps beautiful

Why use a map

Maps are a great way to communicate data.

They're easily understandable, flexible, and more intuitive than a chart. There's been numerous studies showing that the average reader often struggles to interpret the units on a y-axis, let alone understand trends in scatter or line graphs.

Making maps in R takes some initial investment. However once you have some code you know and understand, spinning up new pieces of analysis can happen in minutes, rather than hours or days.

The aim of this chapter is to get you from 'I can make a map in R' to something more like 'I can conduct spatial analysis and produce a visual which is ready for publication'.

Getting started

First up, we need to load a bunch of mapping packages. The tidyverse package is a classic for just about everything data manipulation, while, the `sf` and `ggspatial` packages are essential for making maps.

```
# Load required packages
library(tidyverse) # Includes ggplot2, dplyr, tidyr, readxl, purrr
library(ggmap)
library(sf)
library(ggspatial)
library(rlang)
library(broom)
library(Census2016)
library(strayr)
library(absmapsdata)
library(officer)
```

Will Mackey's `absmapsdata` package contains all the ABS' ASGS shapefiles. The data is now also callable through the (thoroughly updated and expanded) `strayr` package. For example:

```
strayr::read_absmap("sa12016")
```

To get a basic demographic map up and running, we will splice together the shapefile (in this case the SA2 map of Australia) and some data from the 2016 Australian Census.

Hugh Parsonage put together a fantastic packaged called `Census2016` which makes downloading this data in a clean format easy.

```
#Get the shapefile form the absmapsdata package (predefined in the list above)

#Get the 2016 census dataset
census2016_wide <- Census2016_wide_by_SA2_year

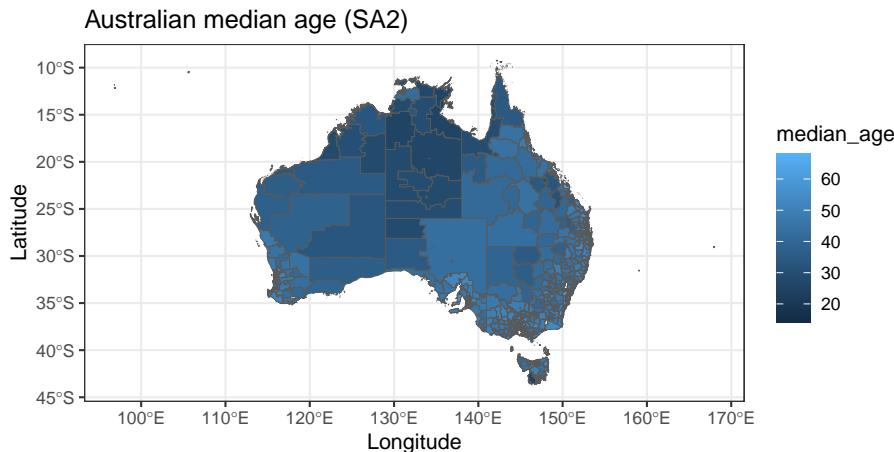
#Select the key demographic columns from the census data (i.e. the first 8 variables)
census_short <- census2016_wide[,1:8]

#Filter for a single year
census_short_2016 <- census_short %>%
  filter(year==2016)

#Use the inner_join function to get the shapefile and census wide data into a single data frame
SA2_shp_census_2016 <- inner_join(strayr::read_absmap("sa22016"),census_short_2016,
                                     by = c("sa2_name_2016" = "sa2_name"))

#Plot a map that uses census data
map1 <- ggplot() +
  geom_sf(data = SA2_shp_census_2016, aes(fill = median_age)) +
  ggtitle("Australian median age (SA2)") +
  xlab("Longitude") +
  ylab("Latitude") +
  theme_bw() +
  theme(legend.position = "right")

map1
```



There we go! A map. This looks ‘okay’... but it can be much better.

From okay to good

Heat maps don’t really show too much interesting data on such a large scale, so let’s filter down to Greater Melbourne.

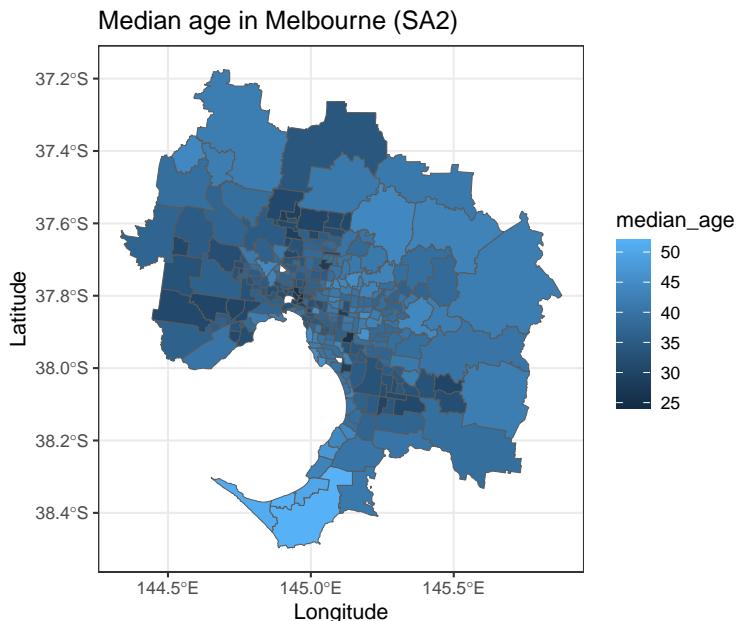
Seeing we have a bunch of census data in our dataframe, we can also do some basic analysis (e.g. population density).

```
#As a bit of an added extra, we can create a new population density column
SA2_shp_census_2016 <- SA2_shp_census_2016 %>%
  mutate(pop_density=persons/areasqkm_2016)

#Filter for Greater Melbourne
MEL_SA2_shp_census_2016 <- SA2_shp_census_2016 %>%
  filter(gcc_name_2016=="Greater Melbourne")

#Plot the new map just for Greater Melbourne
map2 <- ggplot() +
  geom_sf(data = MEL_SA2_shp_census_2016, aes(fill = median_age, border=NA)) +
  gtitle("Median age in Melbourne (SA2)") +
  xlab("Longitude") +
  ylab("Latitude") +
```

```
map2 <- ggplot() +
  theme_bw() +
  theme(legend.position = "right")
```



Much better. We can start to see some trends in this map. It looks like younger people tend to live closer to the city center. This seems logical.

From good to great

The map above is a good start! However, how do we turn this from something ‘good’, into something that is 100% ready to share?

We see our ‘ink to chart ratio’ (i.e. the amount of non-data stuff that is on the page) is still pretty high. Is the latitude of Melbourne useful for this analysis...? Not really. Let’s get rid of it and the axis labels. A few lines of code adjusting the axis, titles, and theme of the plot will go a long way. Because my geography Professor drilled it into me, I will also add a low-key scale bar.

```
map3 <- ggplot() +
  geom_sf(data = MEL_SA2_shp_census_2016, aes(fill = median_age)) +
  labs(title = "Melbourne's youth tend to live closer to the city centre",
       subtitle = "Analysis from the 2016 census",
       caption = "Data: Australian Bureau of Statistics 2016",
```

```

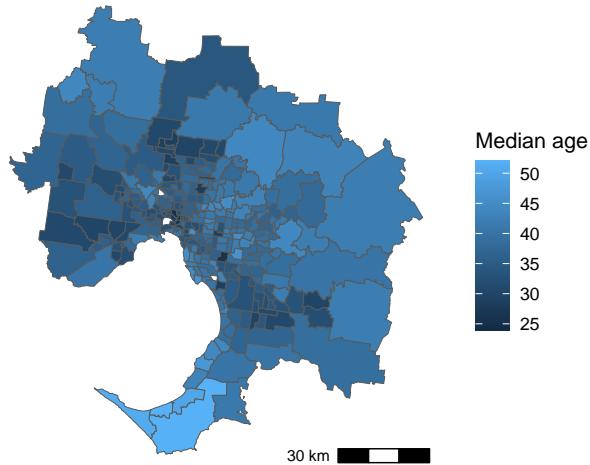
x="",
y="",
fill="Median age") +
ggspatial::annotation_scale(location="br") +
theme_minimal() +
theme(axis.ticks.x = element_blank(), axis.text.x = element_blank()) +
theme(axis.ticks.y = element_blank(), axis.text.y = element_blank()) +
theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank()) +
theme(legend.position = "right") +
theme(plot.title=element_text(face="bold",size=12)) +
theme(plot.subtitle=element_text(size=11)) +
theme(plot.caption=element_text(size=8))

```

map3

Melbourne's youth tend to live closer to the city centre

Analysis from the 2016 census



Data: Australian Bureau of Statistics 2016

From great to fantastic

The above is perfectly reasonable and looks professionally designed. However, this is where we can get really special.

Let's add a custom colour scheme, drop the boundary edges for the SA2's, and add in a dot and label for Melbourne CBD.

```

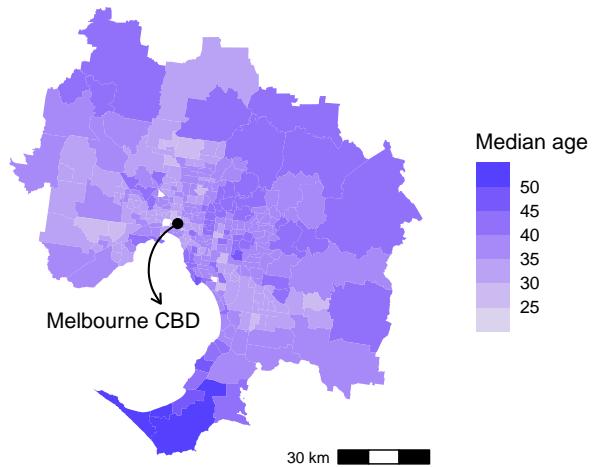
#Add in a point for the Melbourne CBD
MEL_location <- data.frame(town_name = c("Melbourne"),
                           x = c(144.9631),
                           y = c(-37.8136))

map4 <- ggplot() +
  geom_sf(data = MEL_SA2_shp_census_2016, aes(fill = median_age), color=NA) +
  geom_point(data=MEL_location,aes(x=x,y=y),size=2,color="black")+
  labs(title="Melbourne's youth tend to live closer to the city centre",
       subtitle = "Analysis from the 2016 census",
       caption = "Data: Australian Bureau of Statistics 2016",
       x="",
       y="",
       fill="Median age") +
  scale_fill_steps(low="#E2E0EB", high="#3C33FE")+
  annotate(geom='curve',
          x=144.9631,
          y=-37.8136,
          xend=144.9,
          yend=-38.05,
          curvature=0.5,
          arrow=arrow(length=unit(2, "mm")))+
  annotate(geom='text',x=144.76,y=-38.1,label="Melbourne CBD")+
  ggspatial::annotation_scale(location="br")+
  theme_minimal() +
  theme(axis.ticks.x = element_blank(),axis.text.x = element_blank())+
  theme(axis.ticks.y = element_blank(),axis.text.y = element_blank())+
  theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank)
  theme(legend.position = "right")+
  theme(plot.title=element_text(face="bold",size=12))+
  theme(plot.subtitle=element_text(size=11))+
  theme(plot.caption=element_text(size=8))

```

map4

Melbourne's youth tend to live closer to the city centre
Analysis from the 2016 census



Data: Australian Bureau of Statistics 2016

Now we're talking. A 'client-ready' looking map that can be added to a report, presentation, or with a few tweaks - a digital dashboard.

Make sure to export the map as a high quality PNG using the `ggplot2:ggsave()` function.

Charts

Packages matter

There's exceptional resources online for using the `ggplot2` package and the broader `tidyverse` suite to create production ready charts.

The R Graph Gallery is a great place to start, as is the visual storytelling blogs of The Economist and the BBC.

This chapter contains the code for some of my most used charts and visualization techniques.

```
# Load core packages
library(tidyverse) # Includes ggplot2, dplyr, tidyverse, purrr, and readr
library(lubridate)
library(readxl)
library(scales)

# Load additional visualization libraries
library(gggridges)
library(ggrepel)
library(viridis)
library(patchwork)

# Load additional data manipulation libraries
library(reshape2)
library(gapminder)
```

Make the data tidy

Before making a chart ensure the data is “tidy” - meaning there is a new row for every changed variable. It also doesn’t hurt to remove NA’s for consistency (particularly in time series).

```

#Read in data
url <-"https://raw.githubusercontent.com/charlescoverdale/ggridges/master/2019_MEL_maxTemp.csv"
MEL_temp_daily <- openxlsx::read.xlsx(url)

#Remove last 2 characters to just be left with the day number
MEL_temp_daily$Day=substr(MEL_temp_daily$Day,1,nchar(MEL_temp_daily$Day)-2)

#Make a wide format long using the gather function
MEL_temp_daily <- MEL_temp_daily %>%
  gather(Month,Temp,Jan:Dec)

MEL_temp_daily$Month<-factor(MEL_temp_daily$Month,levels=c("Jan", "Feb", "Mar", "Apr", "May", "Jun", "Jul", "Aug", "Sep", "Oct", "Nov", "Dec"))

#Add in a year
MEL_temp_daily["Year"] = 2019

#Reorder
MEL_temp_daily <- MEL_temp_daily[,c(1,2,4,3)]

#Make a single data field using lubridate
MEL_temp_daily <- MEL_temp_daily %>% mutate(Date = make_date(Year, Month, Day))

#Drop the original date columns
MEL_temp_daily <- MEL_temp_daily %>% dplyr::select(Date, Temp) %>% drop_na()

#Add on a 7-day rolling average
MEL_temp_daily <- MEL_temp_daily %>% dplyr::mutate(Seven_day_rolling =
  zoo::rollmean(Temp, k = 7, fill = NA,
  Mean = mean(Temp)))

#Drop NA's
#MEL_temp_daily <- MEL_temp_daily %>% drop_na()

```

Line plot

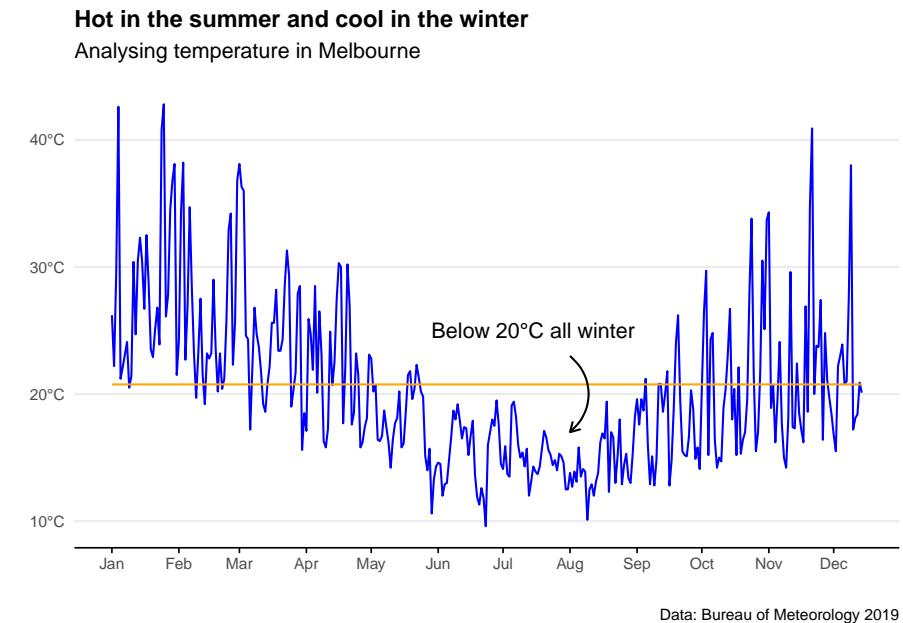
```

plot_MEL_temp <- ggplot(MEL_temp_daily, aes(x = Date)) +
  geom_line(aes(y = Temp), col = "blue") +
  geom_line(aes(y = Mean), col = "orange") +
  labs(
    title = "Hot in the summer and cool in the winter",
    subtitle = "Analysing temperature in Melbourne",
    x = "Date",
    y = "Temperature"
  )

```

```
caption = "Data: Bureau of Meteorology 2019",
x = "",
y = ""
) +
scale_x_date(
  date_breaks = "1 month",
  date_labels = "%b",
  limits = as.Date(c('2019-01-01', '2019-12-14'))
) +
scale_y_continuous(labels = unit_format(unit = "\u00b0C", sep = ""))
theme_minimal() +
theme(
  legend.position = "bottom",
  plot.title = element_text(face = "bold", size = 12),
  plot.subtitle = element_text(size = 11),
  plot.caption = element_text(size = 8),
  axis.text = element_text(size = 8),
  panel.grid.minor = element_blank(),
  panel.grid.major.x = element_blank(),
  axis.line.x = element_line(colour = "black", size = 0.4),
  axis.ticks.x = element_line(colour = "black", size = 0.4)
) +
annotate(
  geom = "curve",
  x = as.Date('2019-08-01'), y = 23,
  xend = as.Date('2019-08-01'), yend = 17,
  curvature = -0.5, arrow = arrow(length = unit(2, "mm")))
) +
annotate(
  geom = "text",
  x = as.Date('2019-07-15'), y = 25,
  label = "Below 20\u00b0C all winter"
)

plot_MEL_temp
```

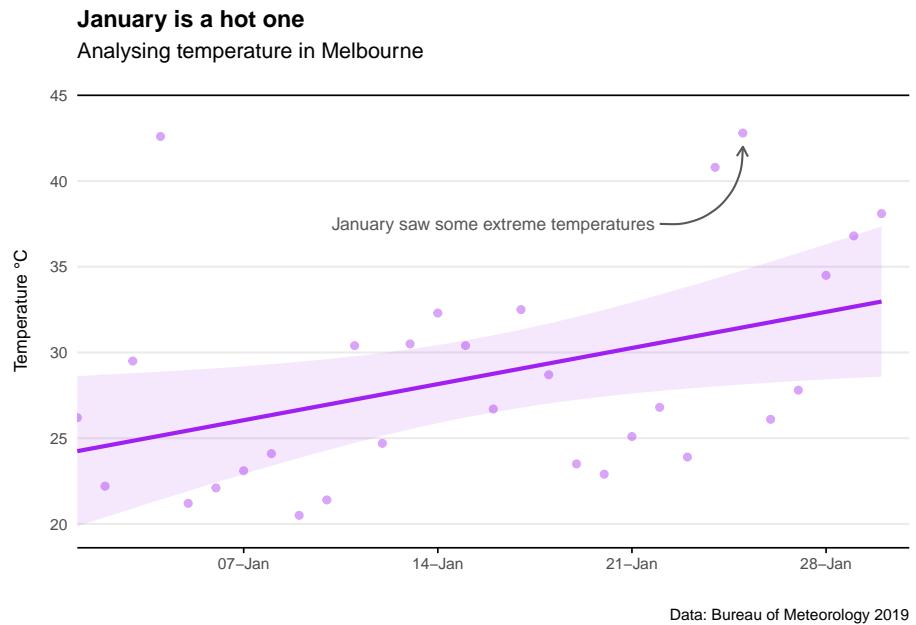


Scatter and trend plot

```
MEL_temp_Jan <- MEL_temp_daily %>% filter(Date < as.Date("2019-01-31"))

ggplot(MEL_temp_Jan, aes(x = Date, y = Temp)) +
  geom_point(col = "purple", alpha = 0.4) +
  geom_smooth(col = "purple", fill = "purple", alpha = 0.1, method = "lm") +
  labs(
    title = "January is a hot one",
    subtitle = "Analysing temperature in Melbourne",
    caption = "Data: Bureau of Meteorology 2019",
    x = "",
    y = "Temperature °C"
  ) +
  scale_x_date(
    date_breaks = "1 week",
    date_labels = "%d-%b",
    limits = as.Date(c('2019-01-01', '2019-01-31')),
    expand = c(0, 0)
  ) +
  geom_hline(yintercept = 45, colour = "black", size = 0.4) +
  annotate(
```

```
geom = "curve",
x = as.Date('2019-01-22'), y = 37.5,
xend = as.Date('2019-01-25'), yend = 42,
curvature = 0.5,
col = "#575757",
arrow = arrow(length = unit(2, "mm")))
) +
annotate(
  geom = "text",
  x = as.Date('2019-01-16'), y = 37.5,
  label = "January saw some extreme temperatures",
  size = 3.2, col = "#575757"
) +
theme_minimal() +
theme(
  plot.title = element_text(face = "bold", size = 12),
  plot.subtitle = element_text(size = 11),
  plot.caption = element_text(size = 8),
  axis.text = element_text(size = 8),
  axis.title.y = element_text(size = 9, margin = margin(r = 10)),
  panel.grid.minor = element_blank(),
  panel.grid.major.x = element_blank(),
  axis.line.x = element_line(colour = "black", size = 0.4),
  axis.ticks.x = element_line(colour = "black", size = 0.4)
)
```



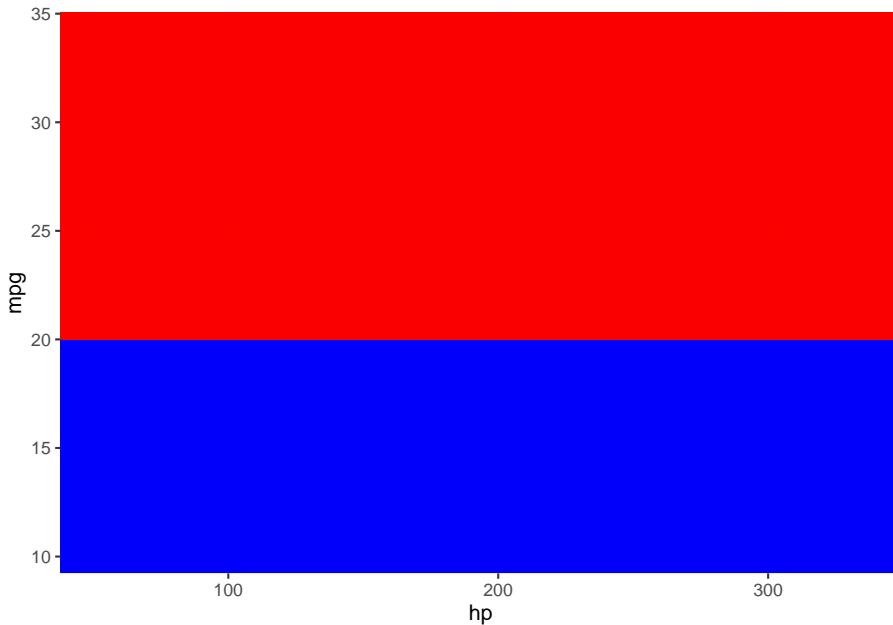
Shading areas on plots

Adding shading behind a plot area is simple using `geom_rect`.

Adding shading under a particular model line? A little trickier. See both example below.

```
# Example 1: Custom y-axis threshold shading
threshold <- 20

ggplot(mtcars, aes(x = hp, y = mpg)) +
  geom_point() +
  geom_hline(yintercept = threshold) +
  
  # Shade areas below and above threshold
  geom_rect(xmin = -Inf, xmax = Inf, ymin = -Inf, ymax = threshold,
            fill = "blue", alpha = 0.2) +
  geom_rect(xmin = -Inf, xmax = Inf, ymin = threshold, ymax = Inf,
            fill = "red", alpha = 0.2)
```



```
# Example 2: Model line with shaded areas
model <- lm(mpg ~ log(hp), data = mtcars)

# Generate predicted values for plotting
df_line <- data.frame(hp = seq(min(mtcars$hp), max(mtcars$hp), by = 1))
df_line$mpg <- predict(model, newdata = df_line)

# Define polygons above and below the model line
df_poly_under <- bind_rows(df_line, tibble(hp = c(max(df_line$hp), min(df_line$hp)), mpg = c(-Inf, Inf)))
df_poly_above <- bind_rows(df_line, tibble(hp = c(max(df_line$hp), min(df_line$hp)), mpg = c(Inf, -Inf)))

# Plot the data, model line, and shaded areas
ggplot(mtcars, aes(x = hp, y = mpg)) +
  geom_point(color = "grey", alpha = 0.5) +
  geom_line(data = df_line, aes(x = hp, y = mpg), color = "black") +
  # Shaded areas
  geom_polygon(data = df_poly_under, aes(x = hp, y = mpg), fill = "blue", alpha = 0.2) +
  geom_polygon(data = df_poly_above, aes(x = hp, y = mpg), fill = "red", alpha = 0.2) +
  scale_x_continuous(expand = c(0, 0)) +
  labs(
    title = "Look at that snazzy red/blue shaded area",
    subtitle = "Subtitle goes here",
```

```

caption = "Data: Made up from scratch",
x = "",
y = ""
) +
theme_minimal() +
theme(
  panel.grid.minor = element_blank(),
  panel.grid.major.x = element_blank(),
  axis.title = element_blank(),
  axis.text = element_blank(),
  axis.ticks = element_blank()
)

```

Look at that snazzy red/blue shaded area

Subtitle goes here



Data: Made up from scratch

Bar chart

```

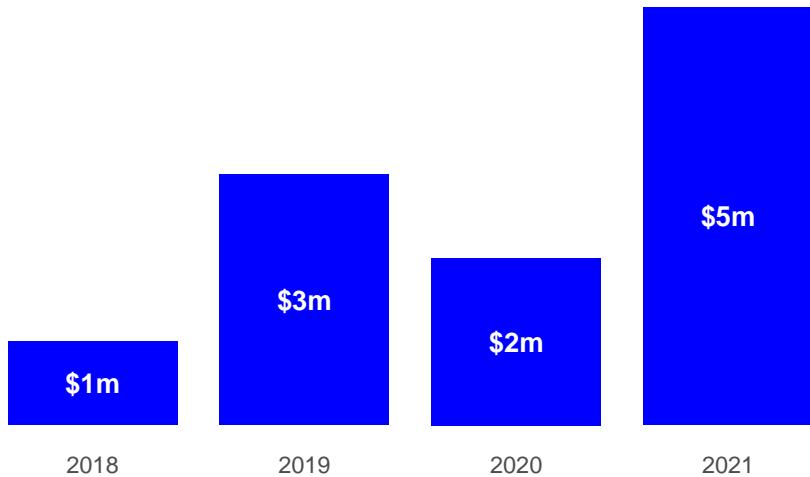
# Create data frame directly
bar_data_single <- data.frame(
  Year = c("2018", "2019", "2020", "2021"),
  Value = c(1000000, 3000000, 2000000, 5000000)
)

```

```
ggplot(bar_data_single, aes(x = Year, y = Value)) +
  geom_bar(stat = "identity", fill = "blue", width = 0.8) +
  # Labels in the middle of the bars
  geom_text(aes(y = Value / 2, label = scales::dollar(Value, scale = 1/1e6, suffix = "m")),
            size = 5, color = "white", fontface = "bold") +
  labs(
    title = "Bar chart example",
    subtitle = "Subtitle goes here",
    caption = "Data: Made up from scratch",
    x = "",
    y = ""
  ) +
  theme_minimal() +
  theme(
    plot.title = element_text(face = "bold", size = 12),
    plot.subtitle = element_text(size = 11),
    plot.caption = element_text(size = 12),
    axis.text = element_text(size = 12),
    panel.grid.minor = element_blank(),
    panel.grid.major = element_blank(),
    axis.title.y = element_blank(),
    axis.text.y = element_blank(),
    axis.ticks.y = element_blank()
  )
```

Bar chart example

Subtitle goes here



Data: Made up from scratch

```
# Save the plot
# ggsave("test.png", width = 10, height = 10, units = "cm", dpi = 600)
```

Stacked bar chart

```
Year = c("2019", "2019", "2019", "2019", "2020", "2020", "2020", "2020")

Quarter = c("Q1", "Q2", "Q3", "Q4", "Q1", "Q2", "Q3", "Q4")

Value = (c(100, 300, 200, 500, 400, 700, 200, 300))

bar_data <- (cbind(Year, Quarter, Value))

bar_data <- as.data.frame(bar_data)

bar_data$Value = as.integer(bar_data$Value)

bar_data_totals <- bar_data %>%
  dplyr::group_by(Year) %>%
  dplyr::summarise(Total = sum(Value))
```

```
ggplot(bar_data, aes(x = Year, y = Value, fill = (Quarter), label=Value)) +
  geom_bar(position = position_stack(reverse=TRUE),stat='identity')+
  geom_text(size = 4,
            col="white",
            fontface="bold",
            position = position_stack(reverse=TRUE,vjust = 0.5),
            label=scales::dollar(Value))+

  geom_text(aes(Year, Total,
                label=scales::dollar(Total),
                fill = NULL,
                vjust=-0.5),
            fontface="bold",
            size=4,
            data = bar_data_totals)+

  scale_fill_brewer(palette = "Blues") +


  labs(title="Bar chart example",
        subtitle = "Subtitle goes here",
        caption = "Data: Made up from scratch",
        x="",
        y="Units") +


  theme_minimal() +


  theme(legend.position = "bottom")+
  theme(legend.title = element_blank())+


  theme(plot.title=element_text(face="bold",size=12))+ 
  theme(plot.subtitle=element_text(size=10))+ 
  theme(plot.caption=element_text(size=8))+

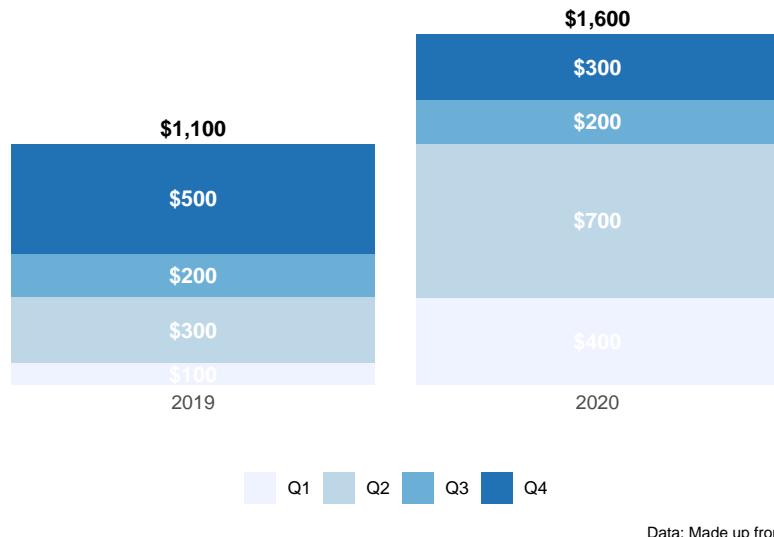

  theme(axis.text=element_text(size=10))+ 
  theme(panel.grid.minor = element_blank())+ 
  theme(panel.grid.major.x = element_blank())+ 
  theme(panel.grid.major.y = element_blank()) +


  scale_y_continuous(expand=c(0,0),limits=c(0,1800))+


  theme(axis.title.y=element_blank(),
        axis.text.y=element_blank(),
        axis.ticks.y=element_blank())
```

Bar chart example

Subtitle goes here



Histogram

Aka. a bar chart for a continuous variable where the bars are touching. Useful to show distribution of time series or ordinal variables.

```
c("0-20", "20-40", "40-60", "60-80", "80+")

## [1] "0-20"  "20-40"  "40-60"  "60-80"  "80+"

#Create a data set
hist_data <- data.frame(X1=sample(0:100,100,rep=TRUE))

ggplot(hist_data)+

  geom_histogram(aes(x=X1),binwidth=5,fill="blue",alpha=0.5) +
  geom_vline(xintercept=c(50,75,95),yintercept=0,linetype="longdash",col="orange")
  labs(title="Histogram example",
       subtitle = "Facet wraps are looking good",
       caption = "Data: Made up from scratch",
       x="")
```

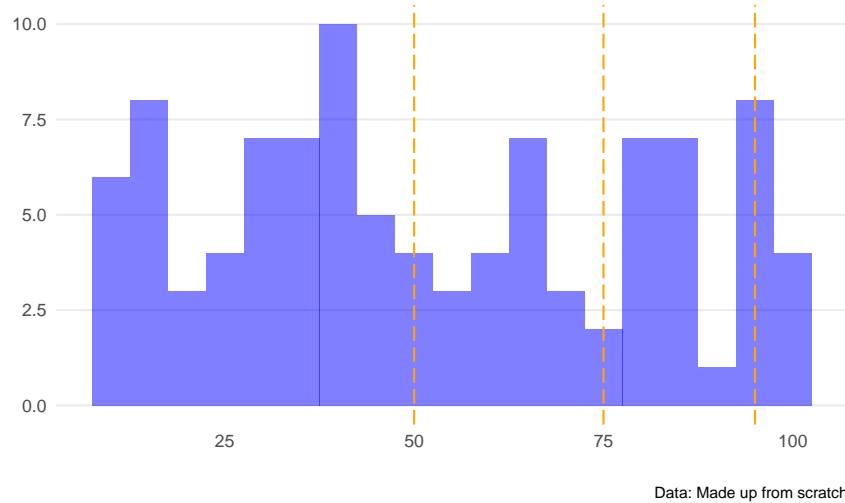
```

y=""") +
  theme_minimal() +
  theme(panel.spacing.x = unit(10, "mm")) +
  theme(legend.position="none") +
  theme(plot.title=element_text(face="bold",size=12)) +
  theme(plot.subtitle=element_text(size=11)) +
  theme(plot.caption=element_text(size=8)) +
  theme(axis.text=element_text(size=9)) +
  theme(panel.grid.minor = element_blank()) +
  theme(panel.grid.major.x = element_blank()) +
  theme(plot.subtitle = element_text(margin=margin(0,0,15,0))) +
  theme(plot.margin=unit(c(0.5,0.5,0.5,0.5), "cm"))

```

Histogram example

Facet wraps are looking good



Ridge chart

Handy when working with climate variables. Particularly useful at showing the difference in range of multiple series (e.g. temperature by month).

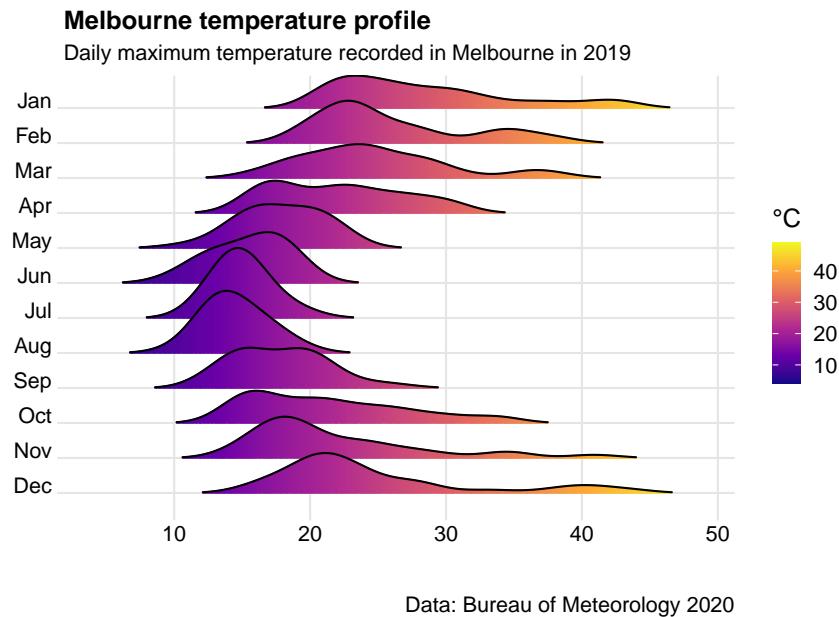
```
# Import data
url <-"https://raw.githubusercontent.com/charlescoverdale/ggridges/master/2019_MEL_max.xlsx"
MEL_temp_daily <- openxlsx::read.xlsx(url)

# Remove last 2 characters to just be left with the day number
MEL_temp_daily$Day=substr(MEL_temp_daily$Day,1,nchar(MEL_temp_daily$Day)-2)

# Make a wide format long using the gather function
MEL_temp_daily <- MEL_temp_daily %>%
  gather(Month,Temp,Jan:Dec)

MEL_temp_daily$Month<-factor(MEL_temp_daily$Month,levels=c("Jan", "Feb", "Mar", "Apr", "May", "Jun", "Jul", "Aug", "Sep", "Oct", "Nov", "Dec"))

# Plot
ggplot(MEL_temp_daily,
       aes(x = Temp, y = Month, fill = stat(x))) +
  geom_density_ridges_gradient(scale = 2,
                                size=0.3,
                                rel_min_height = 0.01,
                                gradient_lwd = 1.) +
  scale_y_discrete(limits = unique(rev(MEL_temp_daily$Month))) +
  scale_fill_viridis_c(name = "°C", option = "C") +
  labs(title = 'Melbourne temperature profile',
       subtitle = 'Daily maximum temperature recorded in Melbourne in 2019',
       caption = "Data: Bureau of Meteorology 2020") +
  xlab(" ") +
  ylab(" ") +
  theme_ridges(font_size = 13, grid = TRUE)
```



BBC style: Bar charts (categorical)

```
#devtools::install_github('bbc/bbplot')
library(gapminder)
library(bbplot)

# Prepare data
bar_df <- gapminder %>%
  filter(year == 2007 & continent == "Africa") %>%
  arrange(desc(lifeExp)) %>%
  head(5)

# Make plot
bars <- ggplot(bar_df, aes(x = reorder(country, lifeExp), y = lifeExp, fill = country == "Mauritius")) +
  geom_bar(stat="identity", position="identity") +
  geom_hline(yintercept = 0, size = 1, colour="#333333") +
  scale_fill_manual(values = c("TRUE" = "#1380A1", "FALSE" = "#dddddd")) +
  labs(title = "Mauritius has the highest life expectancy",
       subtitle = "Top 5 African countries by life expectancy, 2007") +
  coord_flip() +
  theme_minimal() +
  theme(panel.grid.major.x = element_line(color="#cbcbcb"),
```

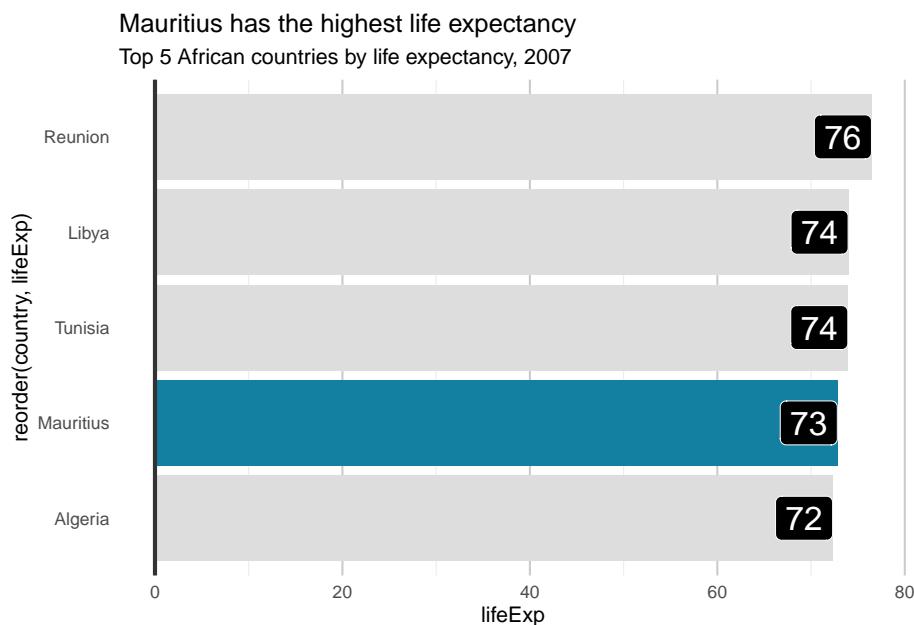
```

  panel.grid.major.y = element_blank(),
  legend.position = "none")

# Add labels
labelled_bars <- bars +
  geom_label(aes(label = round(lifeExp, 0)),
             hjust = 1, vjust = 0.5, colour = "white",
             fill = "black", label.size = 0.2,
             family = "Helvetica", size = 6)

labelled_bars

```



BBC style: Dumbbell charts

Dumbbell charts are handy instead of using clustered column charts with janky thinkcell labels and arrows to show the difference between the columns. Note it relies on having a 4 variable input (variable_name, value1, value2, and gap).

The `geom_dumbbell` function lives inside the `ggalt` package rather than the standard `ggplot2`.

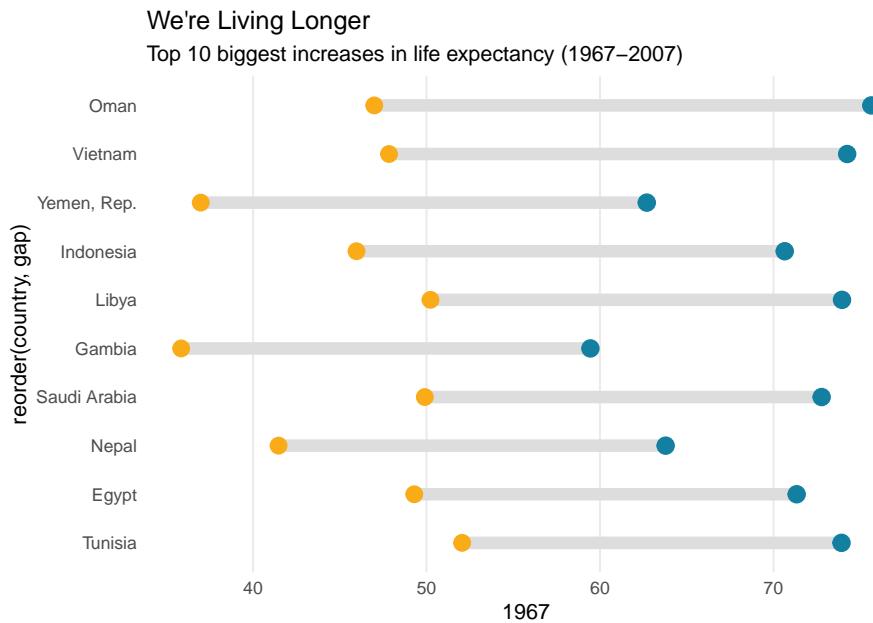
```

library(ggalt)    # For geom_dumbbell
library(gapminder)
library(bbplot)   # Uncomment if using bbc_style()

# Prepare data
dumbbell_df <- gapminder %>%
  filter(year %in% c(1967, 2007)) %>%
  select(country, year, lifeExp) %>%
  pivot_wider(names_from = year, values_from = lifeExp) %>%
  mutate(gap = `2007` - `1967`) %>%
  arrange(desc(gap)) %>%
  head(10)

# Make plot
ggplot(dumbbell_df, aes(x = `1967`, xend = `2007`, y = reorder(country, gap), group = country)) +
  geom_dumbbell(colour = "#dddddd",
                size = 3,
                colour_x = "#FAAB18",
                colour_xend = "#1380A1") +
  labs(title = "We're Living Longer",
       subtitle = "Top 10 biggest increases in life expectancy (1967–2007)") +
  theme_minimal() +
  theme(panel.grid.major.y = element_blank(),
        panel.grid.minor = element_blank())

```



Facet wraps

Handy rather than showing multiple lines on the same chart.

Top tips: `facet_wrap()` dataframes need to be in long form in order to be manipulated easily.

It also helps to add on separate columns for the start and end values (if you want to add data point labels).

```
#Create a data set
Year = c("2018", "2019", "2020", "2021")

QLD = (c(500,300, 500, 600))

NSW = (c(200,400, 500, 700))

VIC = (c(300,400, 500, 600))

#Combine the columns into a single dataframe
facet_data <- (cbind(Year, QLD,NSW,VIC))
facet_data <- as.data.frame(facet_data)

#Change formats to integers
facet_data$QLD = as.integer(facet_data$QLD)
facet_data$NSW = as.integer(facet_data$NSW)
facet_data$VIC = as.integer(facet_data$VIC)

#Make the wide data long
facet_data_long <- pivot_longer(facet_data, !Year, names_to="State", values_to="Value")

facet_data_long <- facet_data_long %>%
  dplyr::mutate(start_label =
    if_else(Year == min(Year),
           as.integer(Value), NA_integer_))

facet_data_long <- facet_data_long %>%
  dplyr::mutate(end_label =
    if_else(Year == max(Year),
           as.integer(Value), NA_integer_))

#Make the base line chart
base_chart <- ggplot() +
```

```
geom_line(data=facet_data_long,
aes(x = Year,
y = Value,
group = State,
colour = State)) +  
  
geom_point(data=facet_data_long,
aes(x = Year,
y = Value,
group = State,
colour = State)) +  
  
ggrepel::geom_text_repel(data=facet_data_long,
aes(x = Year,
y = Value,
label = end_label),
color = "black",
nudge_y = -10, size=3) +  
  
ggrepel::geom_text_repel(data=facet_data_long,
aes(x = Year,
y = Value,
label = start_label),
color = "black",
nudge_y = 10, size=3)  
  
base_chart +  
  
scale_x_discrete(  
breaks = seq(2018, 2021, 1),
labels = c("2018", "19", "20", "21"))+  
  
facet_wrap(State ~ .) +
#To control the grid arrangement, we can add in customer dimensions
#ncol = 2, nrow=2) +  
  
labs(title="State by state comparison",
subtitle = "Facet wraps are looking good",
caption = "Data: Made up from scratch",
x="",
y="") +  
  
theme_minimal() +
```

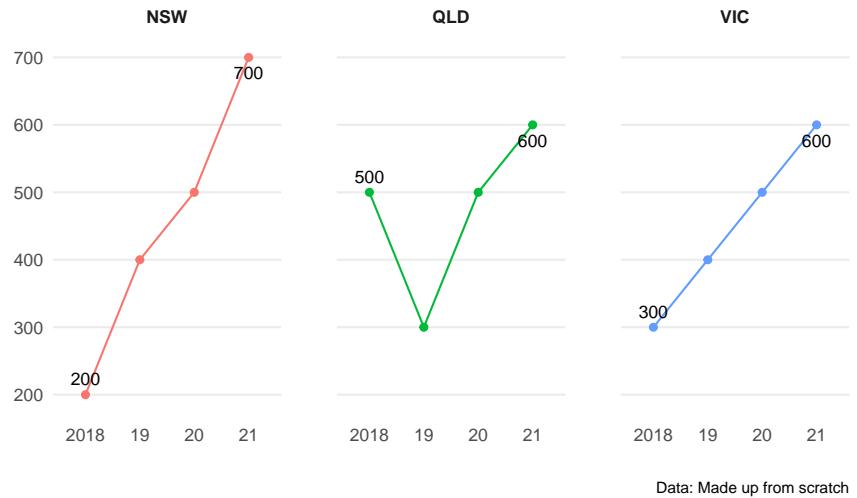
```

theme(strip.text.x = element_text(size = 9, face = "bold")) +
  theme(panel.spacing.x = unit(10, "mm")) +
  theme(legend.position="none") +
  theme(plot.title=element_text(face="bold",size=12)) +
  theme(plot.subtitle=element_text(size=11)) +
  theme(plot.caption=element_text(size=8)) +
  theme(axis.text=element_text(size=9)) +
  theme(panel.grid.minor = element_blank()) +
  theme(panel.grid.major.x = element_blank()) +
  theme(plot.subtitle = element_text(margin=margin(0,0,15,0))) +
  theme(plot.margin=unit(c(0.5,0.5,0.5,0.5), "cm"))

```

State by state comparison

Facet wraps are looking good



Pie chart

These should be used sparingly... but they are handy for showing proportions when the proportion of the whole is paramount (e.g. 45%) - rather than the

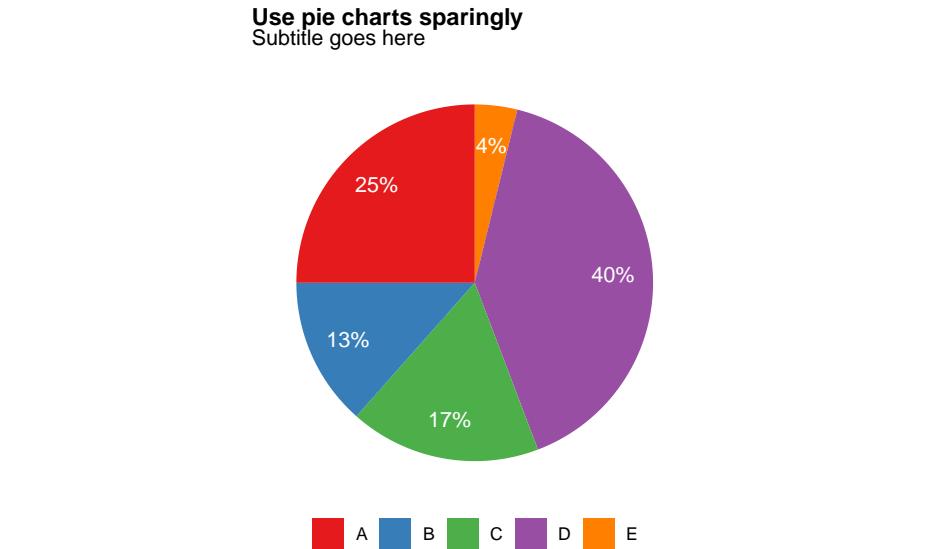
proportion in relation to another data point (e.g. 16% one year vs 18% the next).

```
# Create Data
pie_data <- data.frame(
  group=LETTERS[1:5],
  value=c(13,7,9,21,2))

# Compute the position of labels
pie_data <- pie_data %>%
  arrange(desc(group)) %>%
  mutate(proportion = value / sum(pie_data$value) *100) %>%
  mutate(ypos = cumsum(proportion)- 0.5*proportion )

# Basic piechart
ggplot(pie_data, aes(x="", y=proportion, fill=group)) +
  geom_bar(stat="identity")+
  coord_polar("y", start=0) +
  theme_void()+
  geom_text(aes(y = ypos,
                label = paste(round(proportion,digits=0),"%", sep = ""),
                color = "white",
                size=4) +
  scale_fill_brewer(palette="Set1")+
  labs(title="Use pie charts sparingly",
       subtitle = "Subtitle goes here",
       caption = "",
       x="",
       y="") +
  theme(legend.position = "bottom")+
  theme(legend.title = element_blank())+
  theme(plot.title=element_text(face="bold",size=12))+ 
  theme(plot.subtitle=element_text(size=11))+ 
  theme(plot.caption=element_text(size=8))+ 

  theme(plot.subtitle = element_text(margin=margin(0,0,5,0))) +
  theme(plot.margin=unit(c(0.5,0.5,0.5,0.5),"cm"))
```



```
# ggsave(plot=last_plot(),
#        width=10,
#        height=10,
#        units="cm",
#        dpi = 600,
#        filename = "/Users/charlescoverdale/Desktop/pietest.png")
```

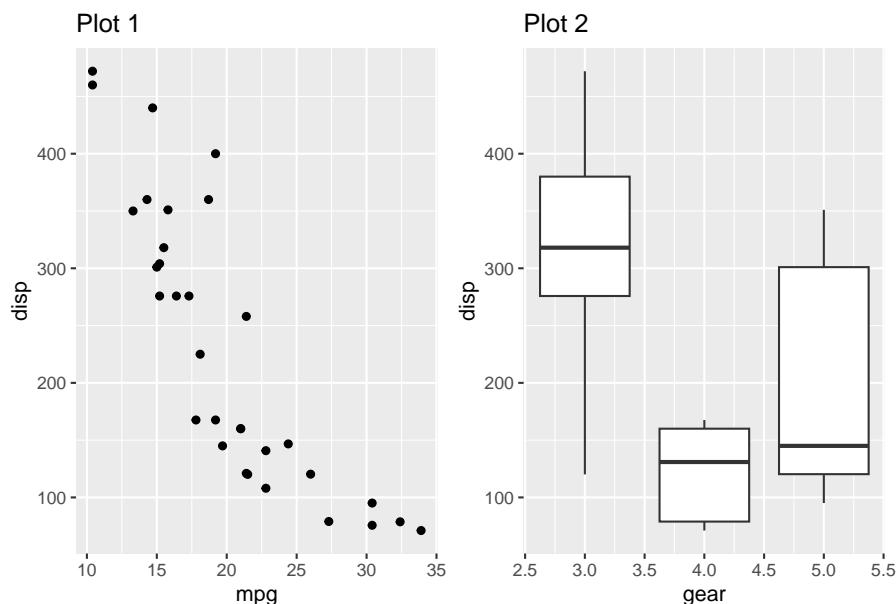
Patchwork

Patchwork is a nifty package for arranging plots and other graphic elements (text, tables etc) in different grid arrangements. The basic syntax is to use `plot1 | plot2` for side by side charts, and `plot1 / plot2` for top and bottom charts. You can also combine these two functions for a grid of different size columns (e.g. `plot3 / (plot1 | plot2)`)

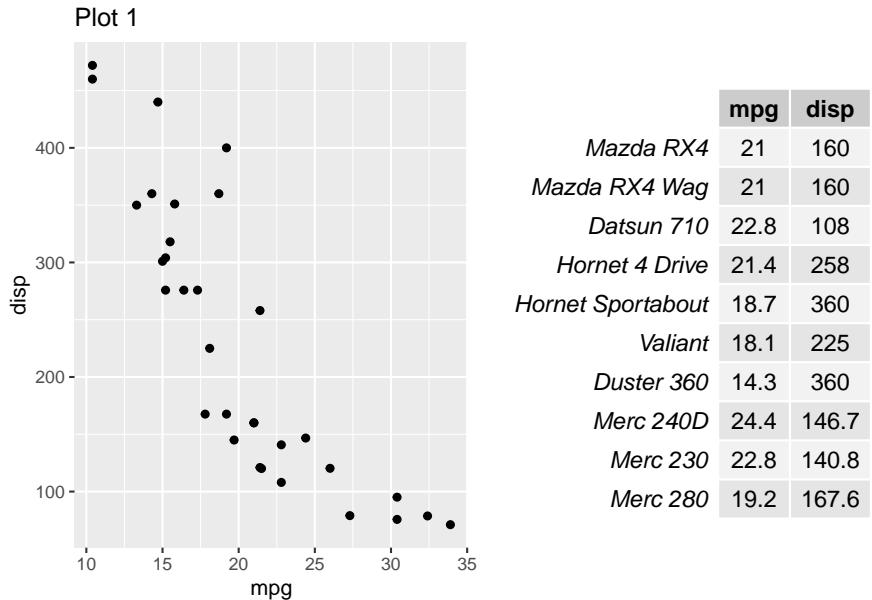
```
#Make some simply plots using the mtcars package
p1 <- ggplot(mtcars) +
  geom_point(aes(mpg, disp)) +
  ggtitle('Plot 1')

p2 <- ggplot(mtcars) +
  geom_boxplot(aes(gear, disp, group = gear)) +
  ggtitle('Plot 2')
```

```
#Example of side by side charts
library(patchwork)
p1 + p2
```



```
#Add in a table next to the plot
p1 + gridExtra::tableGrob(mtcars[1:10, c('mpg', 'disp')])
```



Saving to powerpoint

There's a bunch of ways to save ggplot graphics - but the way I find most useful is by exporting to pptx in a common 'charts' directory.

If you want to save as a png you can use the normal ggsave function - however it will not be editable (e.g. able to click and drag to rescale for a presentation).

Therefore instead we can use the grattantheme package to easily save to an editable pptx graphic.

Note: The code below has been commented out so that is will upload to bookdown.org without an error.

```
#The classic save function to png

#      ggsave(plot = ggplot2::last_plot(),
#      width = 8,
#      height = 12,
#      dpi = 600,
#      filename = "/Users/charlescoverdale/Desktop/test.png")

#Using the grattantheme package to easily save to powerpoint

#      grattan_save_pptx(p = ggplot2::last_plot(),
```

```
#      "/Users/charlescoverdale/Desktop/test.pptx",
#      type = "wholecolumn")
```

Automating chart creation

Let's say we have a data frame of multiple variables. We want to produce simple charts of the same style for each variable (including formatting and titles etc). Sure we can change the `aes(x=)` and `aes(y=)` variables in `ggplot2` manually for each column - but this is time intensive especially for large data frames. Instead, we can write a function that will loop through the whole data frame and produce the same format of chart.

```
#Create a data set
Year = c("2018", "2019", "2020", "2021")

Variable1 = (c(500,300, 200, 400))

Variable2 = (c(200,400, 200, 700))

Variable3 = (c(300,500, 800, 1000))

#Combine the columns into a single data frame
bar_data_multiple <- (cbind(Year, Variable1, Variable2, Variable3))
bar_data_multiple <- as.data.frame(bar_data_multiple)

#Change formats to integers
bar_data_multiple$Variable1 = as.integer(bar_data_multiple$Variable1)
bar_data_multiple$Variable2 = as.integer(bar_data_multiple$Variable2)
bar_data_multiple$Variable3 = as.integer(bar_data_multiple$Variable3)

#Define a function
loop <- function(chart_variable) {

  ggplot(bar_data_multiple, aes(x = Year,
                                y = .data[[chart_variable]],
                                label = .data[[chart_variable]])) +

    geom_bar(stat='identity', fill="blue") +

    geom_text(aes(
      label = scales::dollar(.data[[chart_variable]]),
      size = 5,
      col="white",
```

```

    fontface="bold",
    position = position_stack(vjust = 0.5)) +  
  

  labs(title=paste("Company X: ",
                  chart_variable,
                  " (",head(Year,n=1),
                  " - ",
                  tail(Year,n=1),
                  ")",
                  sep=""),
       subtitle = "Subtitle goes here",
       caption = "Data: Made up from scratch",
       x="",
       y="") +  
  

  theme_minimal() +  
  

  theme(plot.title=element_text(face="bold",size=12)) +
  theme(plot.subtitle=element_text(size=11)) +
  theme(plot.caption=element_text(size=12)) +  
  

  theme(axis.text=element_text(size=12)) +
  theme(panel.grid.minor = element_blank()) +
  theme(panel.grid.major.x = element_blank()) +
  theme(panel.grid.major.y = element_blank()) +  
  

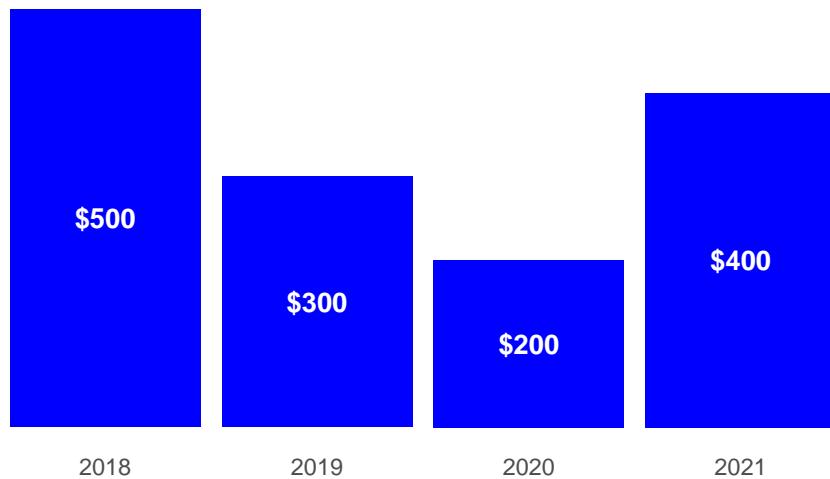
  theme(axis.title.y=element_blank(),
        axis.text.y=element_blank(),
        axis.ticks.y=element_blank())
}  
  

plots <- purrr::map(colnames(bar_data_multiple)[colnames(bar_data_multiple) != "Year"]
plots

```

Company X: Variable1 (2018 – 2021)

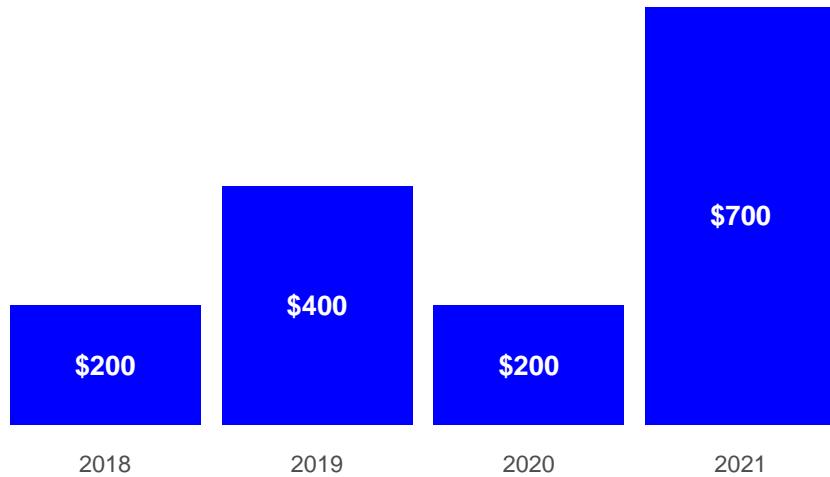
Subtitle goes here



Data: Made up from scratch

Company X: Variable2 (2018 – 2021)

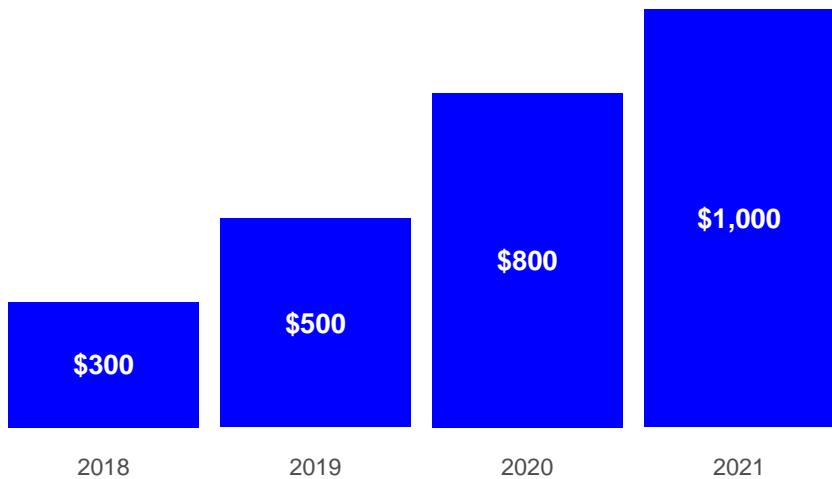
Subtitle goes here



Data: Made up from scratch

Company X: Variable3 (2018 – 2021)

Subtitle goes here



Data: Made up from scratch

```
#cowplot::plot_grid(plotlist = plots)
```

Basic modelling

Creating a model is an essential part of forecasting and data analysis.

I've put together a quick guide on my process for modelling data and checking model fit.

The source data I use in this example is Melbourne's weather record over a 12 month period. Daily temperature is based on macroscale weather and climate systems, however many observable measurements are correlated (i.e. hot days tend to have lots of sunshine). This makes using weather data great for model building.

Source, format, and plot data

Before we get started, it is useful to have some packages up and running.

```
#Useful packages for regression
library(readr)
library(readxl)
library(ggplot2)
library(tidyverse)
library(lubridate)
library(modelr)
library(cowplot)
```

I've put together a csv file of weather observations in Melbourne in 2019. We begin our model by downloading the data from Github.

```
#Input data
link <- "data/MEL_weather_2019.csv"

# We'll read this data in as a dataframe
# The 'check.names' function set to false means the funny units that the BOM use for column names
```

```
MEL_weather_2019 <- read.csv(link, check.names = F)

head(MEL_weather_2019)
```

This data is relatively clean. One handy change to make is to make the date into a dynamic format (to easily switch between months, years, etc).

```
#Add a proper date column
MEL_weather_2019 <- MEL_weather_2019 %>%
  mutate(Date = make_date(Year, Month, Day))
```

We also notice that some of the column names have symbols in them. This can be tricky to work with, so let's rename some columns into something more manageable.

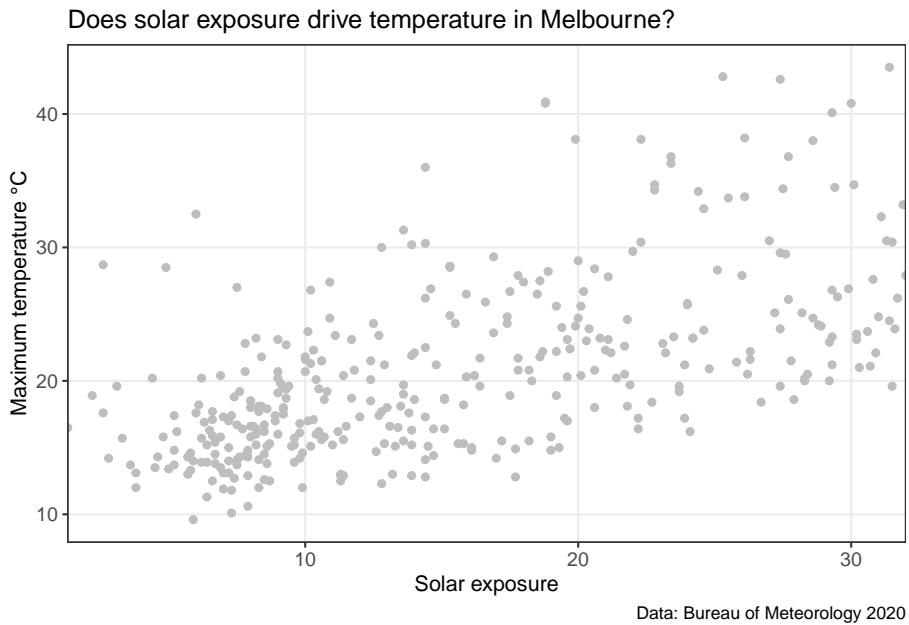
```
#Rename key df variables
names(MEL_weather_2019)[4] <- "Solar_exposure"
names(MEL_weather_2019)[5] <- "Rainfall"
names(MEL_weather_2019)[6] <- "Max_temp"

head(MEL_weather_2019)
```

We're aiming to investigate if other weather variables can predict maximum temperatures. Solar exposure seems like a plausible place to start. We start by plotting the two variables to see if there is a trend.

```
#Plot the data
MEL_temp_investigate <- ggplot(MEL_weather_2019) +
  geom_point(aes(y=Max_temp, x=Solar_exposure), col="grey") +
  labs(title = "Does solar exposure drive temperature in Melbourne?", caption = "Data: Bureau of Meteorology 2020") +
  xlab("Solar exposure") +
  ylab("Maximum temperature °C") +
  scale_x_continuous(expand=c(0,0)) +
  theme_bw() +
  theme(axis.text=element_text(size=10)) +
  theme(panel.grid.minor = element_blank())

MEL_temp_investigate
```



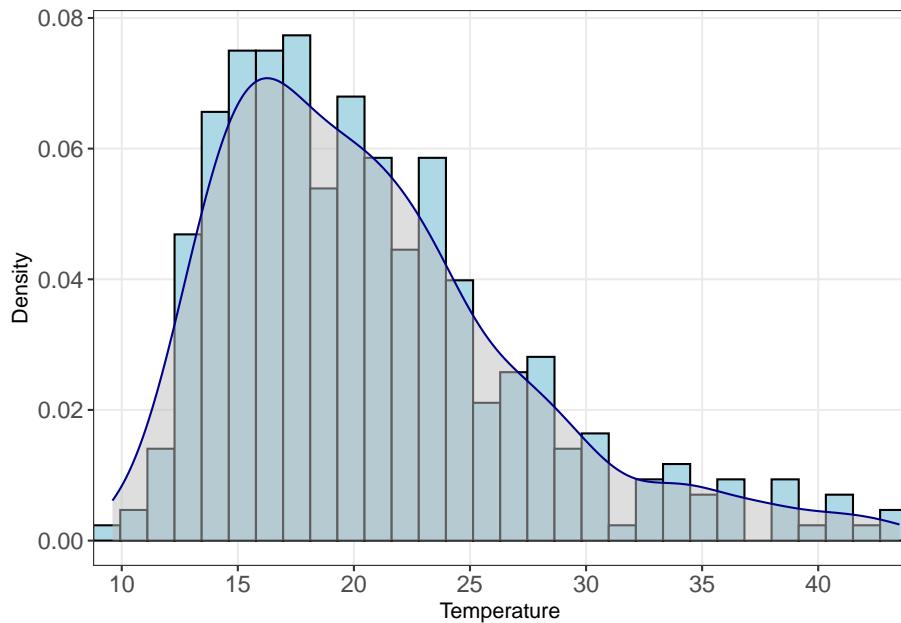
Eyeballing the chart above, there seems to be a correlation between the two data sets. We'll do one more quick plot to analyse the data. What is the distribution of temperature?

```
ggplot(MEL_weather_2019, aes(x=Max_temp)) +
  geom_histogram(aes(y=..density..), colour="black", fill="lightblue")+
  geom_density(alpha=.5, fill="grey", colour="darkblue")+

  scale_x_continuous(breaks=c(5,10,15,20,25,30,35,40,45),
                     expand=c(0,0))+

  xlab("Temperature")+
  ylab("Density")+

  theme_bw()+
  theme(axis.text=element_text(size=12))+
  theme(panel.grid.minor = element_blank())
```



We can see here the data is right skewed (i.e. the mean will be greater than the median). We'll need to keep this in mind. Let's start building a model.

Build a linear model

We start by looking whether a simple linear regression of solar exposure seems to be correlated with temperature. In R, we can use the linear model (`lm`) function.

```
#Create a straight line estimate to fit the data
temp_model <- lm(Max_temp~Solar_exposure, data=MEL_weather_2019)
```

Analyse the model fit

Let's see how well solar exposure explains changes in temperature

```
#Call a summary of the model
summary(temp_model)
```

The adjusted R squared value (one measure of model fit) is 0.3596. Furthermore the coefficient of our `solar_exposure` variable is statistically significant.

Compare the predicted values with the actual values

We can use this lm function to predict values of temperature based on the level of solar exposure. We can then compare this to the actual temperature record, and see how well the model fits the data set.

```
#Use this lm model to predict the values
MEL_weather_2019 <- MEL_weather_2019 %>%
  mutate(predicted_temp=predict(temp_model,newdata=MEL_weather_2019))

#Calculate the prediction interval
prediction_interval <- predict(temp_model,
                                newdata=MEL_weather_2019,
                                interval = "prediction")
summary(prediction_interval)

#Bind this prediction interval data back to the main set
MEL_weather_2019 <- cbind(MEL_weather_2019,prediction_interval)
MEL_weather_2019
```

Model fit is easier to interpret graphically. Let's plot the data with the model overlaid.

```
#Plot a chart with data and model on it
MEL_temp_predicted <-
ggplot(MEL_weather_2019)+ 
  geom_point(aes(y=Max_temp, x=Solar_exposure),
             col="grey")+
  geom_line(aes(y=predicted_temp,x=Solar_exposure),
            col="blue")+
  geom_smooth(aes(y=Max_temp, x= Solar_exposure),
              method=lm)+
  geom_line(aes(y=lwr,x=Solar_exposure),
            colour="red", linetype="dashed")+
  geom_line(aes(y=upr,x=Solar_exposure),
            colour="red", linetype="dashed")+
  labs(title =
        "Does solar exposure drive temperature in Melbourne?",
        subtitle = 'Investigation using linear regression',
        caption = "Data: Bureau of Meteorology 2020") +
  xlab("Solar exposure")+
  ylab("Maximum temperature °C")+
  scale_x_continuous(expand=c(0,0),
```

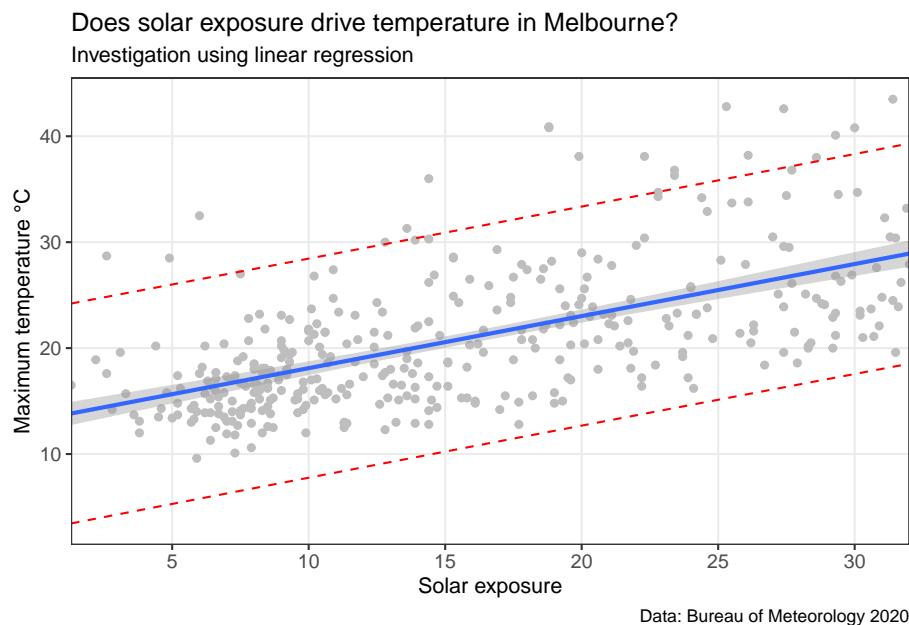
```

  breaks=c(0,5,10,15,20,25,30,35,40))+

  theme_bw()+
  theme(axis.text=element_text(size=10))+
  theme(panel.grid.minor = element_blank())

MEL_temp_predicted

```



This chart includes the model (blue line), confidence interval (grey band around the blue line), and a prediction interval (red dotted line). A prediction interval reflects the uncertainty around a single value (put simple: what is the reasonable upper and lower bound that this data point could be estimated at?). A confidence interval reflects the uncertainty around the mean prediction values (put simply: what is a reasonable upper and lower bound for the blue line at this x value?). Therefore, a prediction interval will be generally much wider than a confidence interval for the same value.

Analyse the residuals

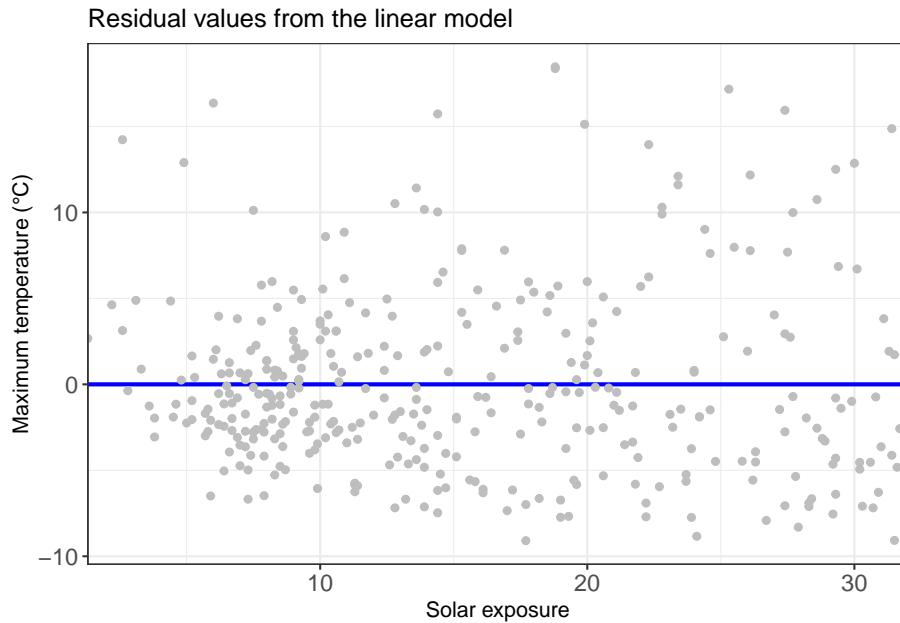
```

#Add the residuals to the series
residuals_temp_predict <- MEL_weather_2019 %>%
  add_residuals(temp_model)

```

Plot these residuals in a chart.

```
residuals_temp_predict_chart <-
  ggplot(data=residuals_temp_predict,
         aes(x=Solar_exposure, y=resid), col="grey") +
    geom_ref_line(h=0, colour="blue", size=1) +
    geom_point(col="grey") +
    xlab("Solar exposure") +
    ylab("Maximum temperature (°C)") +
    theme_bw() +
    labs(title = "Residual values from the linear model") +
    theme(axis.text=element_text(size=12)) +
    scale_x_continuous(expand=c(0,0))
residuals_temp_predict_chart
```



Linear regression with more than one variable

The linear model above is *okay*, but can we make it better? Let's start by adding in some more variables into the linear regression.

Rainfall data might assist our model in predicting temperature. Let's add in that variable and analyse the results.

```
temp_model_2 <-  
lm(Max_temp ~ Solar_exposure + Rainfall, data=MEL_weather_2019)  
summary(temp_model_2)
```

We can see that adding in rainfall made the model better (R squared value has increased to 0.4338).

Next, we consider whether solar exposure and rainfall might be related to each other, as well as to temperature. For our third temperature model, we add an interaction variable between solar exposure and rainfall.

```
temp_model_3 <- lm(Max_temp ~ Solar_exposure +  
                    Rainfall +  
                    Solar_exposure:Rainfall,  
                    data=MEL_weather_2019)  
summary(temp_model_3)
```

We now see this variable is significant, and improves the model slightly (seen by an adjusted R squared of 0.4529).

Fitting a polynomial regression

When analysing the above data set, we see the issue is the sheer variance of temperatures associated with every other variable (it turns out weather forecasting is notoriously difficult).

However we can expect that temperature follows a non-linear pattern throughout the year (in Australia it is hot in January-March, cold in June-August, then starts to warm up again). A linear model (e.g. a straight line) will be a very bad model for temperature — we need to introduce polynomials.

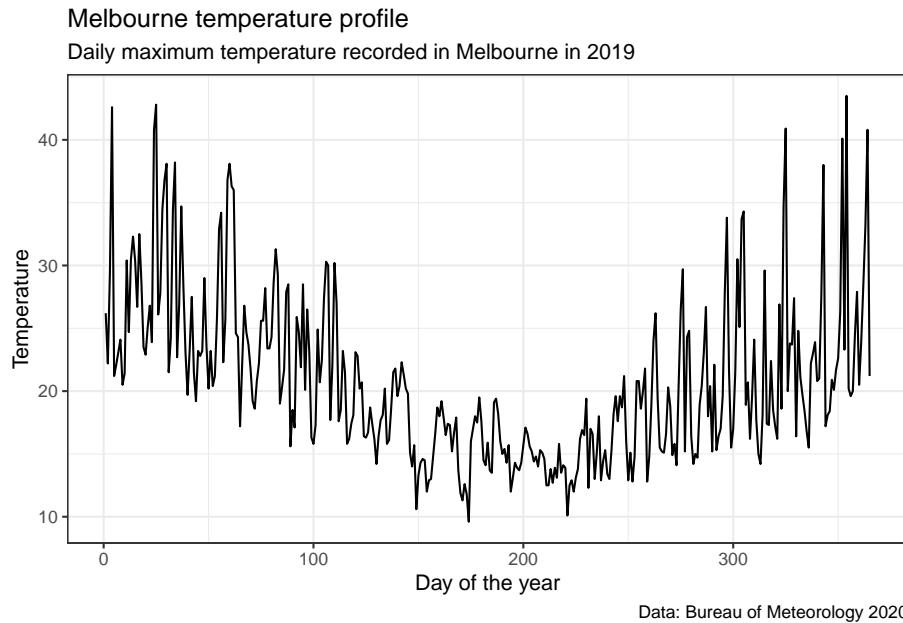
For simplicity, we will introduce a new variable (Day_number) which is the day of the year (e.g. 1 January is #1, 31 December is #366).

```
MEL_weather_2019 <- MEL_weather_2019 %>%  
  mutate(Day_number=row_number())  
head(MEL_weather_2019)
```

Using the same dataset as above, let's plot temperature in Melbourne in 2019.

```
MEL_temp_chart <-
ggplot(MEL_weather_2019) +
  geom_line(aes(x = Day_number, y = Max_temp)) +
  labs(title = 'Melbourne temperature profile',
       subtitle = 'Daily maximum temperature recorded in Melbourne in 2019',
       caption = "Data: Bureau of Meteorology 2020") +
  xlab("Day of the year") +
  ylab("Temperature") +
  theme_bw()

MEL_temp_chart
```



We can see we'll need a non-linear model to fit this data.

Below we create a few different models. We start with a normal straight line model, then add an x^2 and x^3 model. We then use these models and the 'predict' function to see what temperatures they forecast based on the input data.

```
#Create a straight line estimate to fit the data
poly1 <- lm(Max_temp ~ poly(Day_number, 1, raw=TRUE),
             data=MEL_weather_2019)
summary(poly1)

#Create a polynomial of order 2 to fit this data
poly2 <- lm(Max_temp ~ poly(Day_number, 2, raw=TRUE),
             data=MEL_weather_2019)
```

```

summary(poly2)
#Create a polynomial of order 3 to fit this data
poly3 <- lm(Max_temp ~ poly(Day_number,3,raw=TRUE),
             data=MEL_weather_2019)
summary(poly3)

#Use these models to predict
MEL_weather_2019 <- MEL_weather_2019 %>%
  mutate(poly1values=predict(poly1,newdata=MEL_weather_2019))%>%
  mutate(poly2values=predict(poly2,newdata=MEL_weather_2019))%>%
  mutate(poly3values=predict(poly3,newdata=MEL_weather_2019))

head(MEL_weather_2019)

```

In the table above we can see the estimates for that data point from the various models.

To see how well the models did graphically, we can plot the original data series with the polynominal models overlaid.

```

#Plot a chart with all models on it
MEL_weather_model_chart <-
ggplot(MEL_weather_2019)+ 
  geom_line(aes(x=Day_number, y= Max_temp),col="grey")+
  geom_line(aes(x=Day_number, y= poly1values),col="red") +
  geom_line(aes(x=Day_number, y= poly2values),col="green")+
  geom_line(aes(x=Day_number, y= poly3values),col="blue")+
  
  #Add text annotations
  geom_text(x=10,y=18,label="data series",col="grey",hjust=0)+
  geom_text(x=10,y=16,label="linear",col="red",hjust=0)+
  geom_text(x=10,y=13,label=parse(text="x^2"),col="green",hjust=0)+
  geom_text(x=10,y=10,label=parse(text="x^3"),col="blue",hjust=0)+

  labs(title = "Estimating Melbourne's temperature",
       subtitle = 'Daily maximum temperature recorded in Melbourne in 2019',
       caption = "Data: Bureau of Meteorology 2020") +
  
  xlim(0,366) +
  ylim(10,45) +
  scale_x_continuous(breaks=
    c(15,45,75,105,135,165,195,225,255,285,315,345),
    labels=c("Jan", "Feb", "Mar", "Apr", "May", "Jun", "Jul", "Aug", "Sep", "Oct", "Nov"),
    expand=c(0,0),
    limits=c(0,366)) +

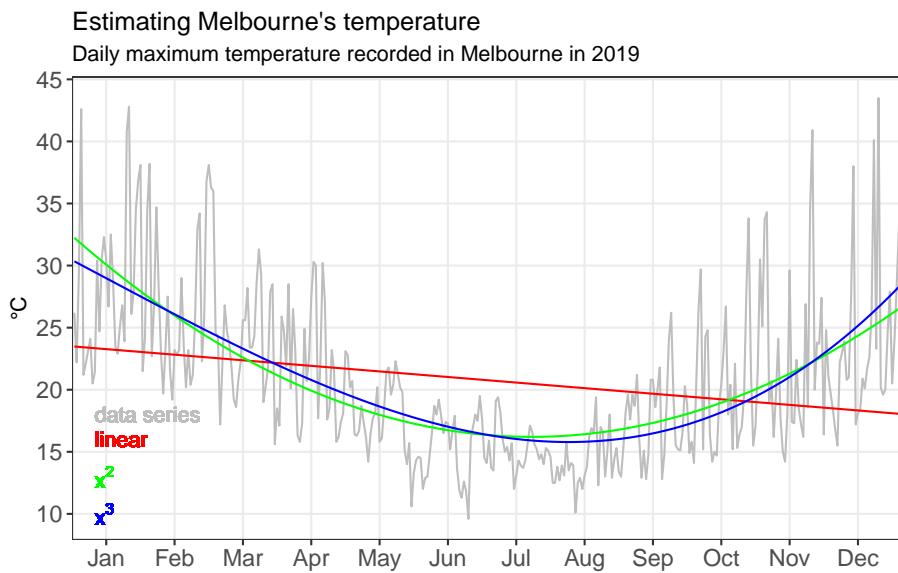
```

```

scale_y_continuous(breaks=c(10,15,20,25,30,35,40,45)) +
xlab("")+
ylab("°C")+
theme_bw()+
theme(axis.text=element_text(size=12))+ 
theme(panel.grid.minor = element_blank())

```

MEL_weather_model_chart



We can see in the chart above the polynomial models do much better at fitting the data. However, they are still highly variant.

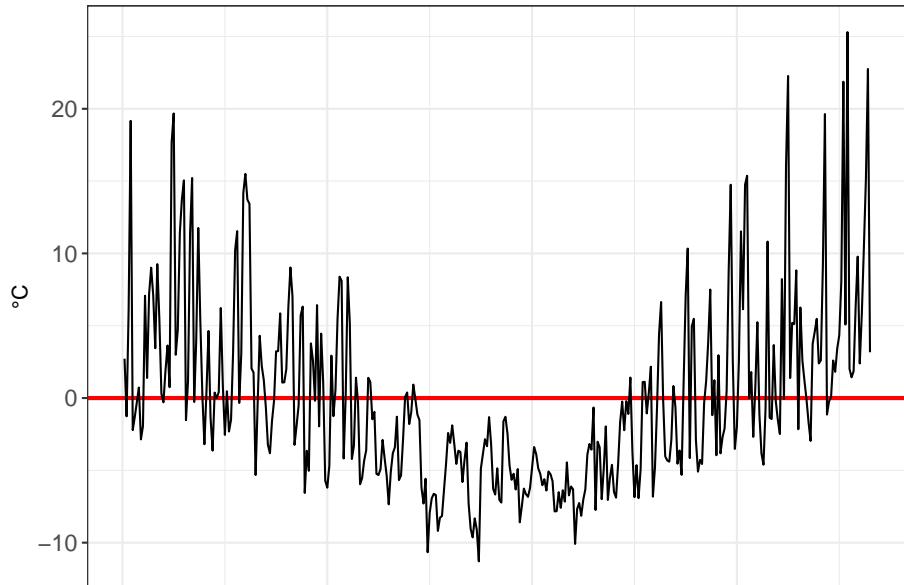
Just how variant are they? We can look at the residuals to find out. The residuals is the gap between the observed data point (i.e. the grey line) and our model.

```

#Get the residuals for poly1
residuals_poly1 <- MEL_weather_2019 %>%
  add_residuals(poly1)
residuals_poly1_chart <-
ggplot(data=residuals_poly1,aes(x=Day_number, y=resid))+
  geom_ref_line(h=0,colour="red", size=1)+ 
  geom_line()+
  xlab("")+
  ylab("°C")+

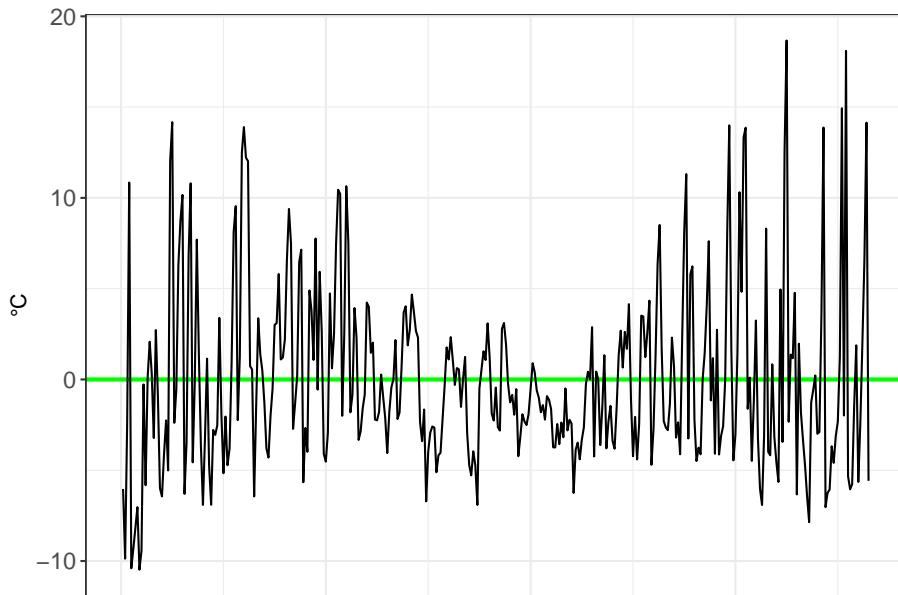
```

```
theme_bw()+
  theme(axis.text=element_text(size=12))+
  theme(axis.ticks.x=element_blank(),
        axis.text.x=element_blank())
residuals_poly1_chart
```



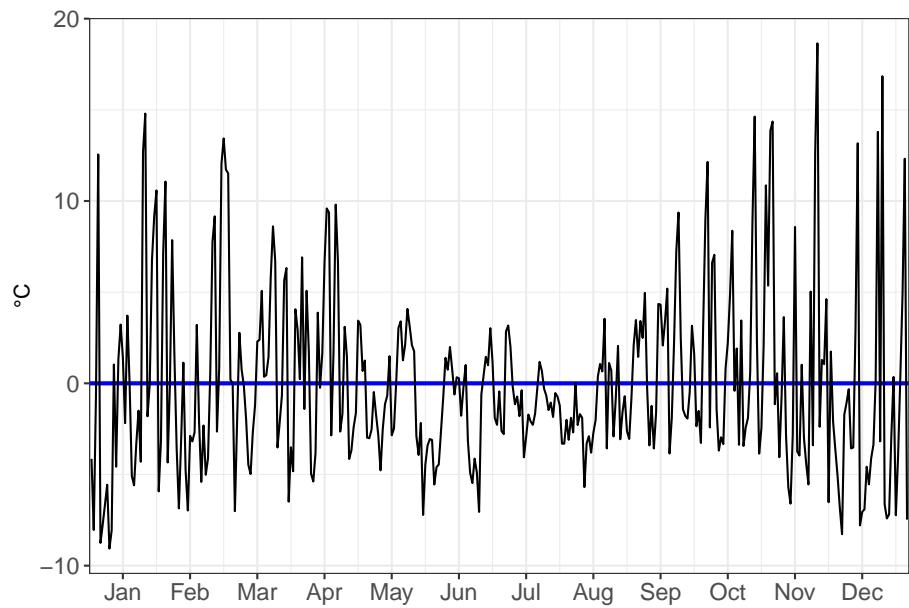
```
#Get the residuals for poly2
residuals_poly2 <- MEL_weather_2019%>%
  add_residuals(poly2)
residuals_poly2_chart <- ggplot(data=residuals_poly2,aes(x=Day_number, y=resid))+
  geom_ref_line(h=0,colour="green", size=1)+
  geom_line()+
  xlab("")+
  ylab("°C")+
  theme_bw()+
  theme(axis.text=element_text(size=12))+
  theme(axis.ticks.x=element_blank(),
        axis.text.x=element_blank())

residuals_poly2_chart
```

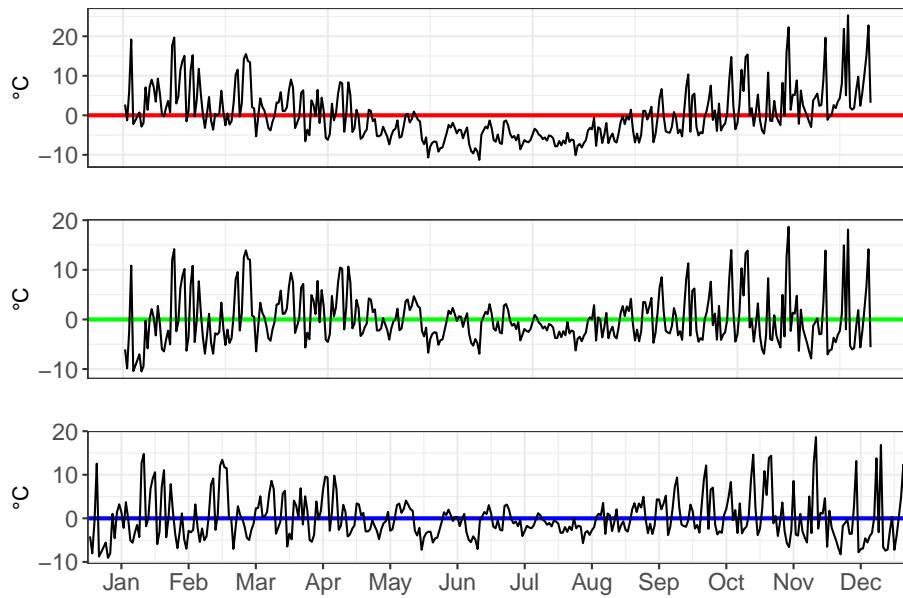


```
#Get the residuals for poly3
residuals_poly3 <- MEL_weather_2019 %>%
  add_residuals(poly3)
residuals_poly3_chart <- ggplot(data=residuals_poly3,aes(x=Day_number, y=resid))+
  geom_ref_line(h=0,colour="blue", size=1)+
  geom_line()+
  theme_bw()+
  theme(axis.text=element_text(size=12))+
  scale_x_continuous(breaks=
  c(15,45,75,105,135,165,195,225,255,285,315,345),
  labels=c("Jan", "Feb", "Mar", "Apr", "May", "Jun", "Jul", "Aug", "Sep", "Oct", "Nov", "Dec"),
  expand=c(0,0),
  limits=c(0,366))+ 
  xlab("")+
  ylab("°C")

residuals_poly3_chart
```



```
three_charts_single_page <- plot_grid(  
  residuals_poly1_chart,  
  residuals_poly2_chart,  
  residuals_poly3_chart,  
  ncol=1, nrow=3, label_size=16)  
three_charts_single_page
```



As we move from a linear, to a x^2 , to a x^3 model, we see the residuals decrease in volatility.

Hypothesis testing

A quick refresher

Hypothesis testing is a way of validating if a claim about a population (e.g. a data set) is correct. Getting data on a whole population (e.g. everyone in Australia) is hard. So, to validate a hypothesis, we use random samples from a population instead.

The language when dealing with hypothesis testing is purposefully janky.

When looking at the outputs of our hypothesis test, we consider p-values. Note: There's *lots wrong with p-values* that we won't bother getting into right now. The long story short is if you make your null hypothesis ultra specific and only report when your p-value on your millionth iteration of a test is below 0.05... bad science is likely to get published and cited.

What we need to know:

- A small p-value (typically less than or equal to 0.05) indicates strong evidence *against* the null hypothesis, so we *reject* it.
- A large p-value (greater than 0.05) indicates weak evidence *against* the null hypothesis, so you *fail to reject* it.

Let's load in some packages and get started.

```
# Load necessary packages
library(ggrrides)
library(ggplot2)
library(ggrepel)      # Avoid overlapping text in plots
library(viridis)      # Color scales
library(readxl)       # Read Excel files
library(dplyr)        # Data manipulation
library(stringr)      # String operations
library(tidyr)        # Data tidying (replaces reshape)
```

```

library(lubridate)      # Work with dates
library(gapminder)     # Gapminder dataset
library(ggalt)          # Extensions to ggplot (dumbbell plots, etc.)
library(purrr)          # Functional programming
library(scales)         # Scaling tools for ggplot
library(aTSA)           # Time series analysis
library(readrba)         # For working with Reserve Bank of Australia data

```

T-testing our first hypothesis

We'll start by creating a normally distributed random dataset using `rnorm`.

By default the `rnorm` function will generate a dataset that has a mean of 0 and a standard deviation of 1, but let's state it explicitly to keep things simple.

```

set.seed(40)
dataset1 <- data.frame(variable1=rnorm(1000,mean=0,sd=1))

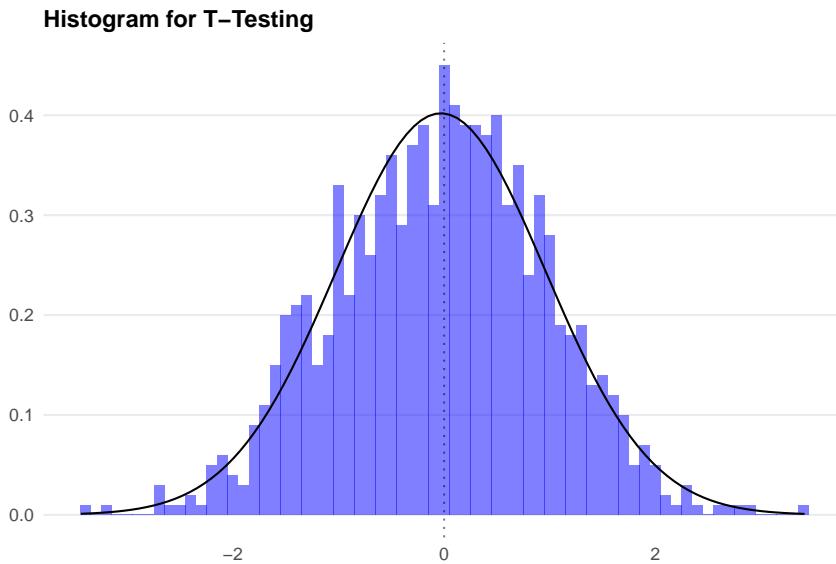
```

Let's chart the distribution.

```

ggplot() +
  geom_histogram(aes(x = dataset1$variable1, y = ..density..),
                 binwidth = 0.1, fill = "blue", alpha = 0.5) +
  stat_function(fun = dnorm, args = list(mean = mean(dataset1$variable1),
                                         sd = sd(dataset1$variable1))) +
  geom_vline(xintercept = 0, linetype = "dotted", alpha = 0.5) +
  labs(title = "Histogram for T-Testing", x = "", y = "") +
  theme_minimal() +
  theme(plot.title=element_text(face="bold",size=12))+
  theme(plot.subtitle=element_text(size=11))+ 
  theme(plot.caption=element_text(size=8))+ 
  theme(axis.text=element_text(size=9))+ 
  theme(panel.grid.minor = element_blank())+ 
  theme(panel.grid.major.x = element_blank()) + 
  theme(plot.subtitle = element_text(margin=ggplot2::margin(0,0,15,0))) +
  theme(plot.margin=unit(c(0.5,0.5,0.5,0.5), "cm"))

```



We know that the mean of dataset1 will be approximately zero (because we set it)... but let's check anyway.

```
# Find the mean of dataset1
mean(dataset1$variable1)
```

Now let's run our first hypothesis test. We'll use the `t.test` function. This is in the format of `t.test(data, null_hypothesis)`.

We'll start with the null hypothesis that the mean for `dataset1$variable1` is 5. This is a two tailed t-test, as we will reject the null if we're confident the mean is *either* above or below 5.

```
# Hypothesis test
t.test(dataset1$variable1, mu = 5)
```

We see the p-value here is tiny, meaning we reject the null hypothesis. That is to say, the mean for `dataset1$variable1` is not 5.

Understanding tailed tests

By default, `t.test` assumes a two-tailed test with a 95% confidence level. However, sometimes we need to test if one variable is greater or smaller than another (rather than just different from the null). This is when we use one-tailed tests.

Next, we test whether the mean is -0.03 using a one-tailed test:

```
# Hypothesis test
t.test(dataset1$variable1, mu = -0.03, alternative="greater")
```

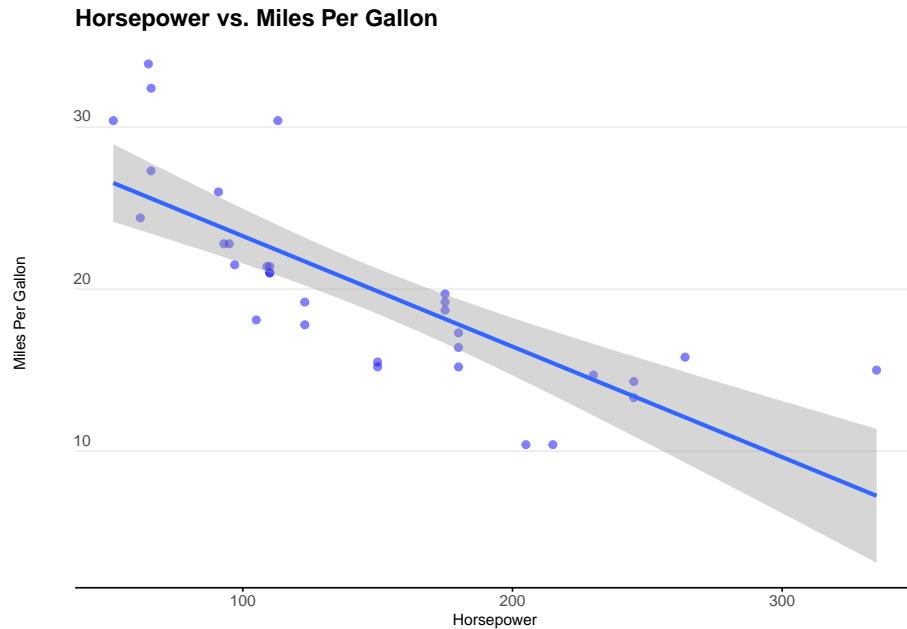
We see here the p-value is greater than 0.05, leading us to *fail to reject* the null hypothesis. In a sentence, we cannot say that the mean of dataset1\$variable1 is different to 0.01.

Correlation

A correlation coefficient measures the direction and strength of the relationship between two variables. However, correlation calculations assume normal distributions.

Let's examine the relationship between mpg and hp in the mtcars dataset.

```
ggplot2::ggplot(mtcars, aes(x = hp, y = mpg)) +
  geom_point(color = "blue", alpha = 0.5) +
  geom_smooth(method = 'lm') +
  labs(
    title = "Horsepower vs. Miles Per Gallon",
    x = "Horsepower",
    y = "Miles Per Gallon"
  ) +
  theme_minimal(base_size = 8) +
  theme(
    legend.position = "bottom",
    plot.title = element_text(face = "bold", size = 12),
    plot.subtitle = element_text(size = 11, margin = margin(0, 0, 25, 0)),
    plot.caption = element_text(size = 8),
    axis.text = element_text(size = 8),
    axis.title.y = element_text(margin = margin(r = 3)),
    axis.text.y = element_text(vjust = -0.5, margin = margin(l = 20, r = -10)),
    panel.grid.minor = element_blank(),
    panel.grid.major.x = element_blank(),
    axis.line.x = element_line(colour = "black", size = 0.4),
    axis.ticks.x = element_line(colour = "black", size = 0.4)
  )
```



We see that miles per gallon is correlated with horsepower. It's a negative relationship, meaning the more horsepower in a car, the less miles per gallon the car exhibits.

We can use the `cor.test` to tell us the correlation coefficient and the p-value of the correlation.

We specify the method as 'pearson' for the Pearson correlation coefficient.

```
cor.test(mtcars$hp, mtcars$mpg, method="pearson")
```

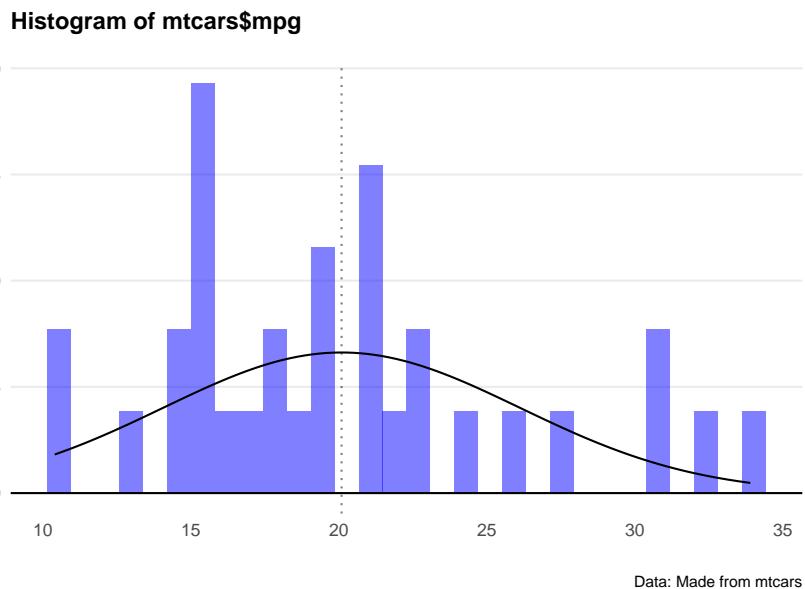
Since Pearson's method assumes normality, we check the distributions. Let's plot a histogram for both hp and mpg.

```
ggplot()+
  geom_histogram(aes(x=mtcars$mpg,y=..density..),fill="blue",alpha=0.5) +
  stat_function(fun = dnorm,
               args = list(mean = mean(mtcars$mpg), sd = sd(mtcars$mpg)))+
  geom_hline(yintercept = 0) +
  geom_vline(xintercept = mean(mtcars$mpg), linetype="dotted",alpha=0.5) +
  labs(title="Histogram of mtcars$mpg",
       caption = "Data: Made from mtcars",
       x="",
       y="") +
  theme_minimal() +
  theme(panel.spacing.x = unit(10, "mm"))+
```

```

theme(legend.position="none")+
theme(plot.title=element_text(face="bold",size=12))+
theme(plot.subtitle=element_text(size=11))+
theme(plot.caption=element_text(size=8))+
theme(axis.text=element_text(size=9))+
theme(panel.grid.minor = element_blank())+
theme(panel.grid.major.x = element_blank()) +
theme(plot.title = element_text(margin=ggplot2::margin(0,0,15,0))) +
theme(plot.margin=unit(c(0.5,0.5,0.5,0.5),"cm"))

```



```

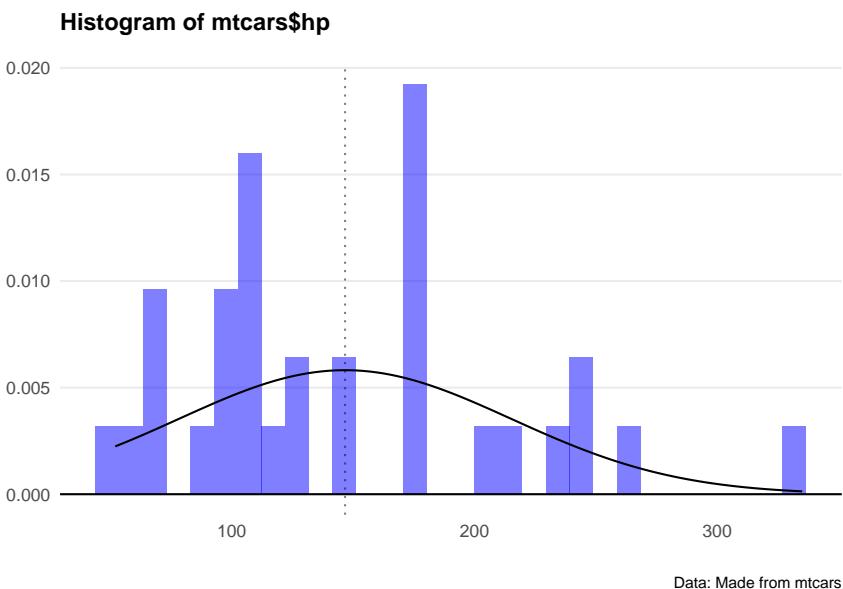
ggpplot()+
  geom_histogram(aes(x=mtcars$hp,y=..density..),fill="blue",alpha=0.5) +
  stat_function(fun = dnorm,
                args = list(mean = mean(mtcars$hp), sd = sd(mtcars$hp))) +
  geom_hline(yintercept = 0) +
  geom_vline(xintercept = mean(mtcars$hp), linetype="dotted",alpha=0.5) +
  labs(title="Histogram of mtcars$hp",
        caption = "Data: Made from mtcars",
        x="",
        y="") +
  theme_minimal() +
  theme(panel.spacing.x = unit(10, "mm"))

```

```

theme(legend.position="none")+
theme(plot.title=element_text(face="bold",size=12))+
theme(plot.subtitle=element_text(size=11))+
theme(plot.caption=element_text(size=8))+
theme(axis.text=element_text(size=9))+
theme(panel.grid.minor = element_blank())+
theme(panel.grid.major.x = element_blank()) +
theme(plot.title = element_text(margin=ggplot2::margin(0,0,15,0))) +
theme(plot.margin=unit(c(0.5,0.5,0.5,0.5),"cm"))

```



Crikey... they don't look very normal at all.

Let's plot QQ plots of our variables and see what's going on.

```

ggplot(mtcars, aes(sample = mpg)) +
  geom_qq()+
  geom_qq_line()+
  labs(title="QQ plot of mtcars$mpg",
       caption = "Data: Made from mtcars",
       x="",
       y="") +
  theme_minimal() +
  theme(panel.spacing.x = unit(10, "mm"))+
  theme(legend.position="none")+
  theme(plot.title=element_text(face="bold",size=12))+
```

```

theme(plot.subtitle=element_text(size=11))+  

theme(plot.caption=element_text(size=8))+  

theme(axis.text=element_text(size=9))+  

theme(panel.grid.minor = element_blank())+  

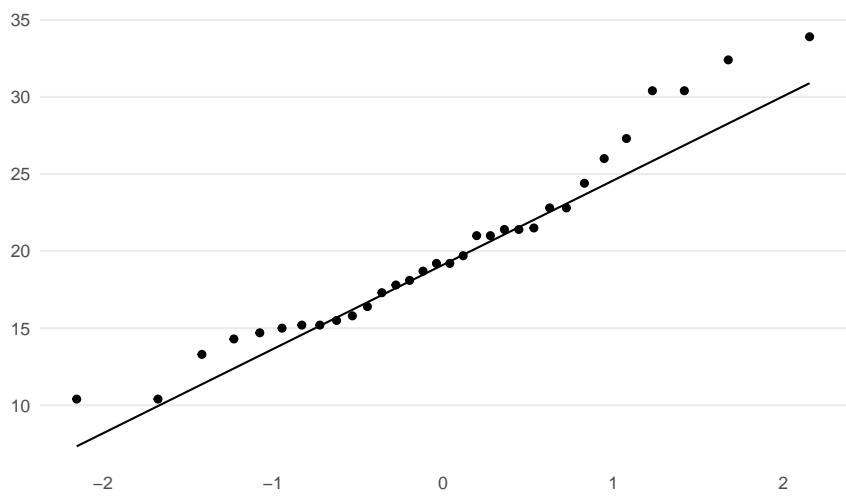
theme(panel.grid.major.x = element_blank()) +  

theme(plot.title = element_text(margin=ggplot2::margin(0,0,15,0))) +  

theme(plot.margin=unit(c(0.5,0.5,0.5,0.5), "cm"))

```

QQ plot of mtcars\$mpg



Data: Made from mtcars

```

ggplot(mtcars, aes(sample = hp)) +  

  geom_qq() +  

  geom_qq_line() +  

  labs(title="QQ plot of mtcars$hp",  

       caption = "Data: Made from mtcars",  

       x="",  

       y="") +  

  theme_minimal() +  

  theme(panel.spacing.x = unit(10, "mm")) +  

  theme(legend.position="none") +  

  theme(plot.title=element_text(face="bold",size=12)) +  

  theme(plot.subtitle=element_text(size=11)) +  

  theme(plot.caption=element_text(size=8)) +  

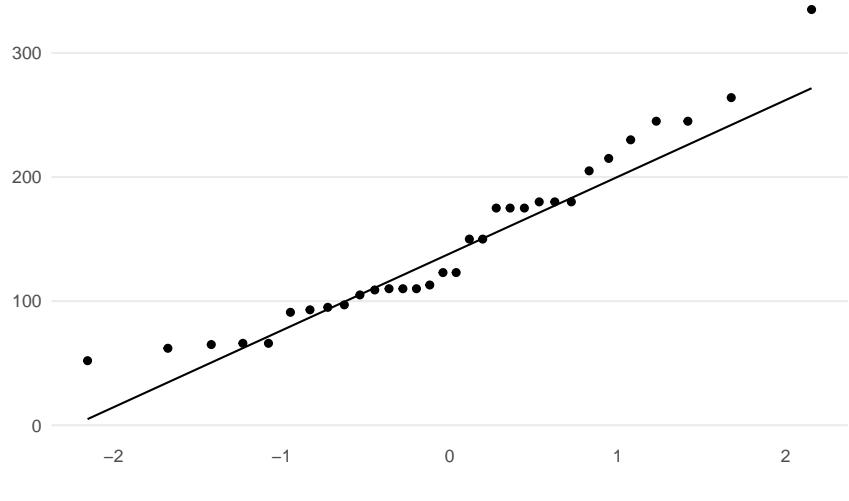
  theme(axis.text=element_text(size=9)) +  

  theme(panel.grid.minor = element_blank()) +  

  theme(panel.grid.major.x = element_blank())

```

```
theme(plot.title = element_text(margin=ggplot2::margin(0,0,15,0))) +
  theme(plot.margin=unit(c(0.5,0.5,0.5,0.5),"cm"))
```

QQ plot of mtcars\$hp

Data: Made from mtcars

Hmm okay, both series are a bit all over the shop. Let's do a statistical test to confirm.

The Shapiro-Wilk's method is widely used for normality testing. The null hypothesis of this tests is that the sample distribution is normal. If the test is significant, the distribution is non-normal.

```
shapiro.test(mtcars$mpg)
shapiro.test(mtcars$hp)
```

Confidence intervals for the mean

We can calculate the confidence interval for the mean. This measures the variance of the normal distribution, and gives us an idea of how 'clustered' the values are to the mean.

There are 4 steps to do this:

1. Calculate the mean
2. Calculate the standard error of the mean

3. Find the t-score that corresponds to the confidence level
4. Calculate the margin of error and construct the confidence interval

```

mpg.mean <- mean(mtcars$mpg)
print(mpg.mean)

mpg.n <- length(mtcars$mpg)
mpg.sd <- sd(mtcars$mpg)
mpg.se <- mpg.sd/sqrt(mpg.n)
print(mpg.se)

alpha = 0.05
degrees.freedom = mpg.n - 1
t.score = qt(p=alpha/2, df=degrees.freedom, lower.tail=F)
print(t.score)

mpg.error <- t.score * mpg.se

lower.bound <- mpg.mean - mpg.error
upper.bound <- mpg.mean + mpg.error
print(c(lower.bound, upper.bound))

```

For the lazy folks among us - there's also this quick and dirty way of doing it.

```

# Calculate the mean and standard error
mpg.model <- lm(mpg ~ 1, mtcars)

# Calculate the confidence interval
confint(mpg.model, level=0.95)

```

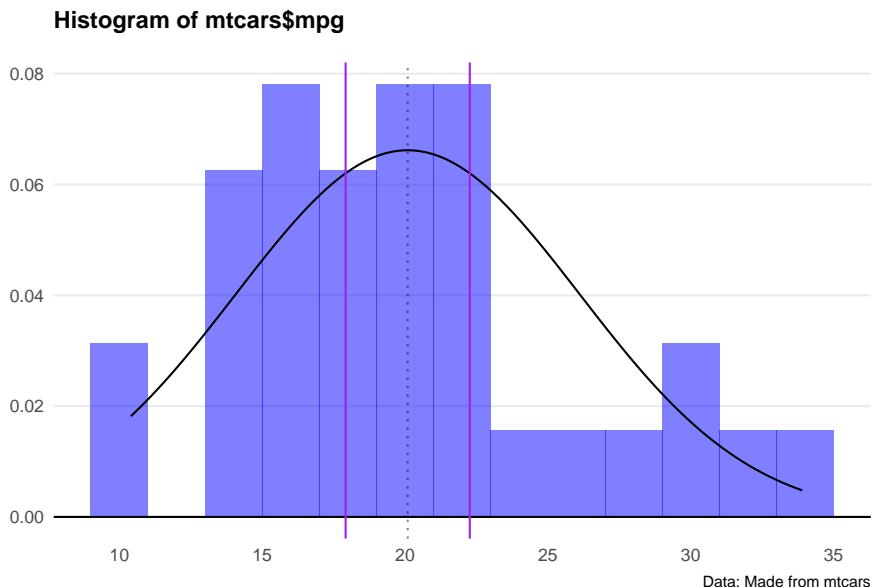
Great. Let's plot this interval on the distribution.

```

ggplot(mtcars, aes(x = mpg)) +
  geom_histogram(aes(y = ..density..), binwidth = 2, fill = "blue", alpha = 0.5) +
  stat_function(fun = dnorm, args = list(mean = mean(mtcars$mpg), sd = sd(mtcars$mpg)))
  geom_hline(yintercept = 0) +
  geom_vline(xintercept = mean(mtcars$mpg), linetype = "dotted", alpha = 0.5) +
  geom_vline(xintercept = c(lower.bound, upper.bound), col = "purple") +
  labs(
    title = "Histogram of mtcars$mpg",
    caption = "Data: Made from mtcars",
    x = NULL,
    y = NULL
  )

```

```
theme_minimal() +
  theme(
    panel.spacing.x = unit(10, "mm"),
    legend.position = "none",
    plot.title = element_text(face = "bold", size = 12, margin = margin(0, 0, 15, 0)),
    plot.subtitle = element_text(size = 11),
    plot.caption = element_text(size = 8),
    axis.text = element_text(size = 9),
    panel.grid.minor = element_blank(),
    panel.grid.major.x = element_blank(),
    plot.margin = unit(c(0.5, 0.5, 0.5, 0.5), "cm")
  )
```



Two things we note here: Firstly, the distribution doesn't look *that* normal. Secondly, the 95% confidence interval looks narrow as a result.

Let's do the same analysis with an actual normal distribution and see what happens.

```
set.seed(404)
dataset2 <- data.frame(variable1 = rnorm(1000, mean = 0, sd = 1))

df2.mean <- mean(dataset2$variable1)
df2.n <- length(dataset2$variable1)
df2.sd <- sd(dataset2$variable1)
```

```

df2.se <- df2.sd / sqrt(df2.n) # Fixed variable name typo

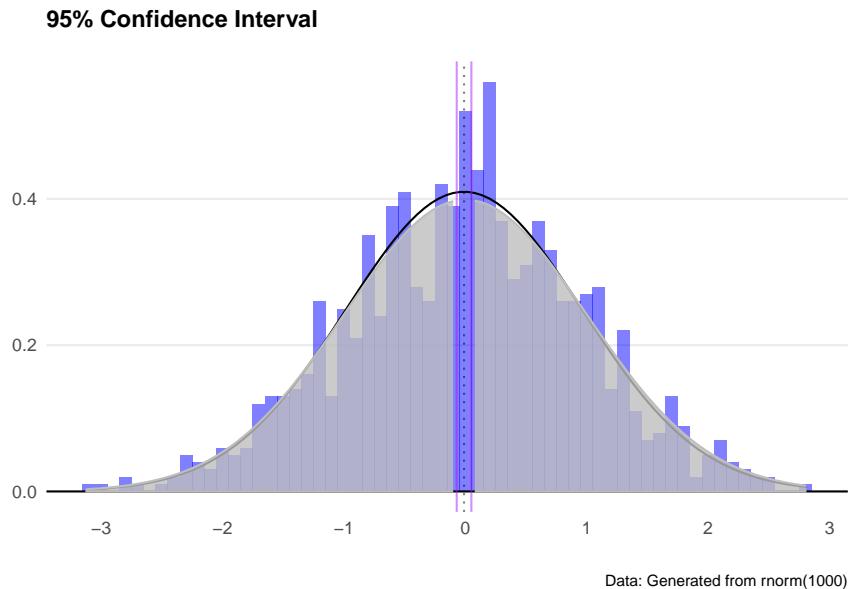
alpha <- 0.05
t.score <- qt(p = alpha / 2, df = df2.n - 1, lower.tail = FALSE)

df2.error <- t.score * df2.se
lower.bound.df2 <- df2.mean - df2.error
upper.bound.df2 <- df2.mean + df2.error

# Functions to shade the tails
shade_tail <- function(x, bound, direction) {
  y <- dnorm(x, mean = 0, sd = 1)
  y[(direction == "upper" & x < bound) | (direction == "lower" & x > bound)] <- NA
  return(y)
}

# Plot
ggplot(dataset2, aes(x = variable1)) +
  geom_histogram(aes(y = ..density..), binwidth = 0.1, fill = "blue", alpha = 0.5) +
  stat_function(fun = dnorm, args = list(mean = df2.mean, sd = df2.sd)) +
  geom_hline(yintercept = 0) +
  geom_vline(xintercept = c(df2.mean, lower.bound.df2, upper.bound.df2),
             linetype = c("dotted", "solid", "solid"), col = c("black", "purple", "purple"),
             stat_function(fun = function(x) shade_tail(x, upper.bound.df2, "upper"),
                           geom = "area", fill = "grey", col = "grey", alpha = 0.8) +
             stat_function(fun = function(x) shade_tail(x, lower.bound.df2, "lower"),
                           geom = "area", fill = "grey", col = "grey", alpha = 0.8) +
  labs(
    title = "95% Confidence Interval",
    caption = "Data: Generated from rnorm(1000)",
    x = "", y = ""
  ) +
  theme_minimal() +
  scale_x_continuous(breaks = seq(-3, 3, by = 1)) +
  theme(
    panel.spacing.x = unit(10, "mm"),
    legend.position = "none",
    plot.title = element_text(face = "bold", size = 12, margin = margin(0, 0, 15, 0)),
    plot.subtitle = element_text(size = 11),
    plot.caption = element_text(size = 8),
    axis.text = element_text(size = 9),
    panel.grid.minor = element_blank(),
    panel.grid.major.x = element_blank(),
    plot.margin = unit(c(0.5, 0.5, 0.5, 0.5), "cm")
  )

```



Great - we've got a more sensible looking plot, and greyed out the tails where our confidence interval excludes. We expect our observation to fall somewhere between the two purple lines (or more exactly between -2.1 and 2.1)

Confidence intervals for a model

We can also calculate the confidence interval around a linear model. This process shows how confident we can be about any single point in the linear estimate. If the confidence interval is wide, the estimate at that point is likely unreliable.

We'll create a linear model of mpg on the y-axis and horsepower on the x-axis.

```
mtcars.lm <- lm(mpg ~ hp, data = mtcars)
summary(mtcars.lm)

predict(mtcars.lm, newdata = mtcars, interval = 'confidence')
```

The `geom_smooth()` function presents an easy way to plot a confidence interval on a chart.

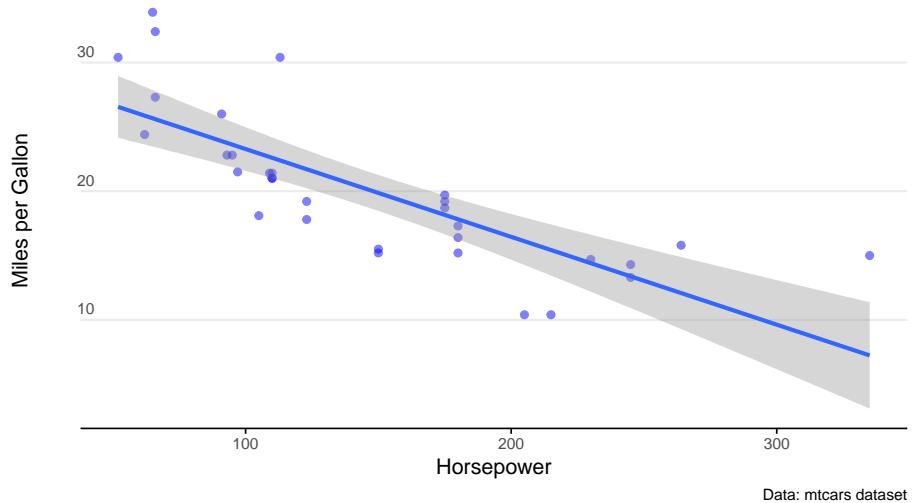
The syntax in this example is:

```
geom_smooth(aes(x = hp, y = mpg), method='lm', level=0.95)
```

```
ggplot(mtcars, aes(x = hp, y = mpg)) +
  geom_point(col = "blue", alpha = 0.5) +
  geom_smooth(method = "lm", level = 0.95) +
  labs(
    title = "Building a Regression Model",
    subtitle = "Higher horsepower cars get fewer miles per gallon",
    caption = "Data: mtcars dataset",
    x = "Horsepower",
    y = "Miles per Gallon"
  ) +
  theme_minimal() +
  theme(
    legend.position = "bottom",
    plot.title = element_text(face = "bold", size = 12),
    plot.subtitle = element_text(size = 11, margin = margin(0, 0, 25, 0)),
    plot.caption = element_text(size = 8),
    axis.text = element_text(size = 8),
    panel.grid.minor = element_blank(),
    panel.grid.major.x = element_blank(),
    axis.title.y = element_text(margin = margin(r = 3)),
    axis.text.y = element_text(vjust = -0.5, margin = margin(l = 20, r = -10)),
    axis.line.x = element_line(colour = "black", size = 0.4),
    axis.ticks.x = element_line(colour = "black", size = 0.4)
  )
)
```

Building a Regression Model

Higher horsepower cars get fewer miles per gallon



Data: mtcars dataset

For a sanity check, let's crank up the confidence level to 0.999 (meaning our interval should capture just about all the observations). We see the confidence interval band increases... but not by *that* much. Why?

Well remember how the data isn't a very good normal distribution? That means the confidence interval function won't be super accurate - especially at the extremes.

Forecasting

So, we've got a time series dataset... but what is a reasonable forecast for how it might behave in the future?

Sure we can build a confidence interval (as we learned in the previous chapter) and figure out a reasonable value - but what about forecasting for multiple periods into the future?

That's where we need to build models. Let's load in some packages.

```
# Load in required packages
library(tidyverse)    # Includes ggplot2, dplyr, purrr, stringr, etc.
library(gggridges)     # For ridge plots
library(forecast)      # Time series forecasting
library(ggrepel)       # For better text label placement
library(viridis)        # Color scales
library(readxl)         # Excel file reading
library(lubridate)      # Date and time manipulation
library(gapminder)      # Gapminder data for examples
library(ggalt)          # Additional ggplot2 geoms
library(scales)         # Scale functions for ggplot2
```

We'll start with some pre-loaded time series data. The `ggplot2` package includes a data set called 'economics' that contains US economic indicators from the 1960's to 2015.

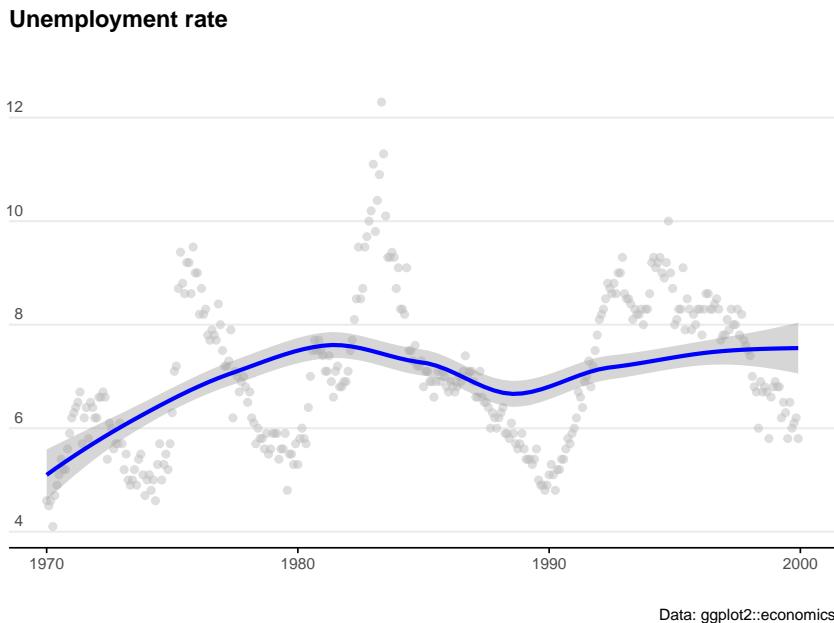
```
econ_data <- economics %>% dplyr::select(c("date", "uempmed"))
econ_data <- econ_data %>% dplyr::filter((date >= as.Date("1970-01-01")
                                             & date <= as.Date("1999-12-31")))
```

As a side note: We can also get Australian unemployment rate data using the `readrba` function.

```
aus_unemp_rate <- read_rba(series_id = "GLFSURSA")
head(aus_unemp_rate)
```

Let's plot the US data to see what we are working with.

```
ggplot(econ_data) +
  geom_point(aes(x = date, y = uempmed), col = "grey", alpha = 0.5) +
  geom_smooth(aes(x = date, y = uempmed), col = "blue") +
  labs(title = "Unemployment rate",
       caption = "Data: ggplot2::economics",
       x = "",
       y = "") +
  theme_minimal() +
  theme(
    plot.title = element_text(face = "bold", size = 12, margin = margin(0, 0, 25, 0)),
    plot.subtitle = element_text(size = 11),
    plot.caption = element_text(size = 8),
    axis.text = element_text(size = 8),
    axis.title.y = element_text(margin = margin(t = 0, r = 3, b = 0, l = 0)),
    axis.text.y = element_text(vjust = -0.5, margin = margin(l = 20, r = -10)),
    axis.line.x = element_line(colour = "black", size = 0.4),
    axis.ticks.x = element_line(colour = "black", size = 0.4),
    panel.grid.minor = element_blank(),
    panel.grid.major.x = element_blank(),
    legend.position = "bottom"
  )
```



ARIMA models

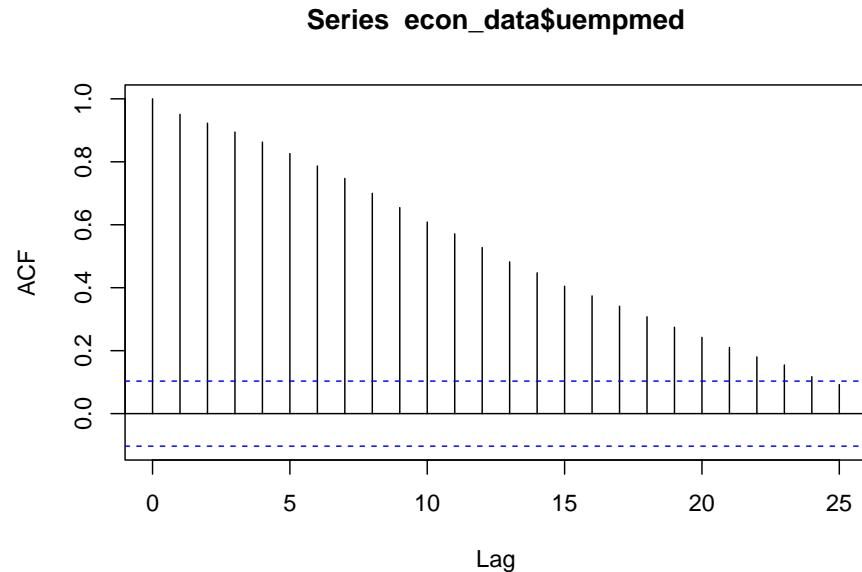
AutoRegressive Integrated Moving Average (ARIMA) models are a handy tool to have in the toolbox. An ARIMA model describes where Y_t depends on its own lags. A moving average (MA only) model is one where Y_t depends only on the lagged forecast errors. We combine these together (technically we integrate them) and get ARIMA.

When working with ARIMAs, we need to ‘difference’ our series to make it stationary.

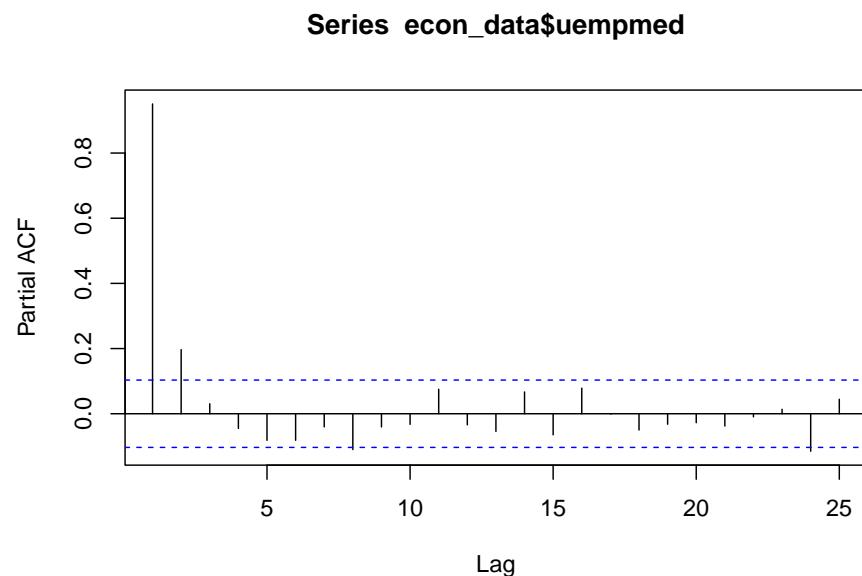
We check if it is stationary using the augmented Dickey-Fuller test. The null hypothesis assumes that the series is non-stationary. A series is said to be stationary when its mean, variance, and autocovariance don’t change much over time.

```
# Test for stationarity
aTSA::adf.test(econ_data$uempmed)

# See the auto correlation
acf(econ_data$uempmed)
```

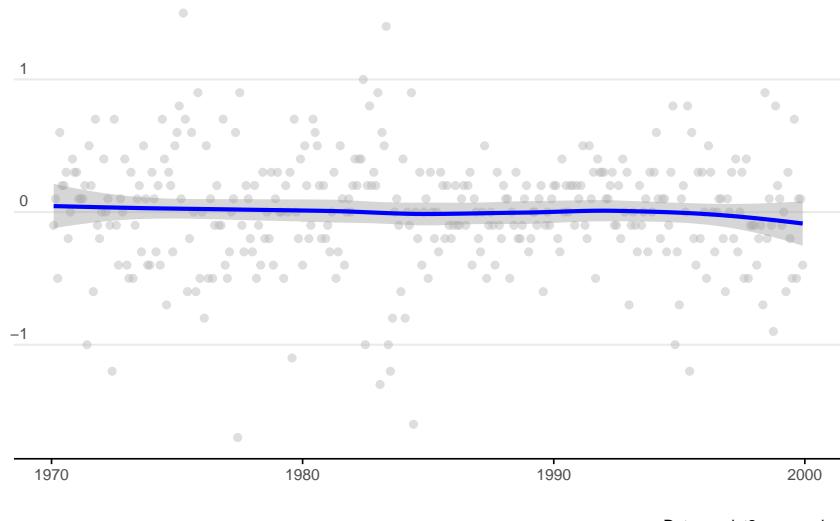


```
# Identify partial auto correlation  
pacf(econ_data$uempmed)
```



```
# Take the first differences of the series
econ_data <- econ_data %>% mutate(diff = uempmed - lag(uempmed))

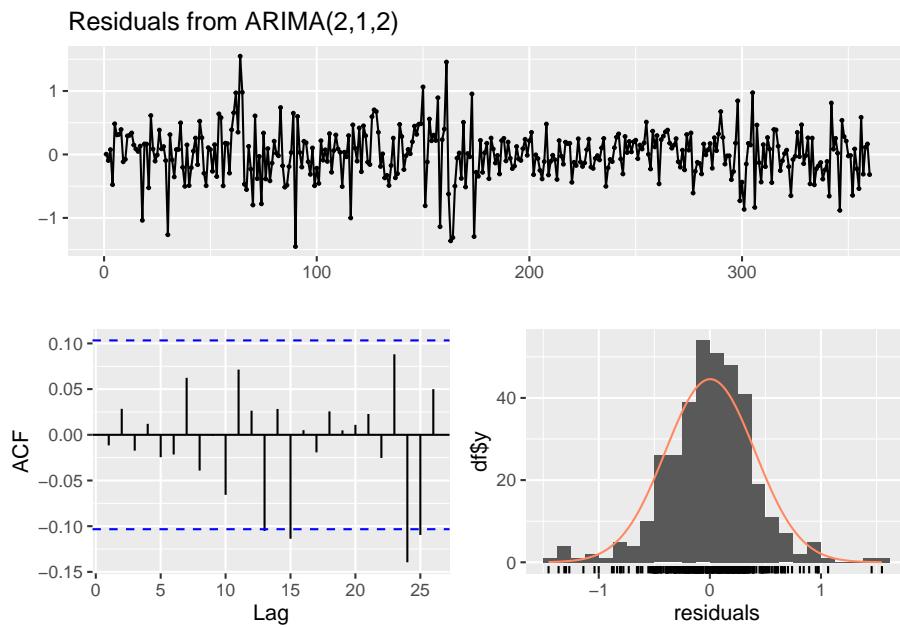
# Plot the first differences
ggplot(econ_data, aes(x = date, y = diff)) +
  geom_point(col = "grey", alpha = 0.5) +
  geom_smooth(col = "blue") +
  labs(
    title = "1st Difference (Unemployment Rate)",
    caption = "Data: ggplot2::economics",
    x = "",
    y = ""
  ) +
  theme_minimal() +
  theme(
    legend.position = "bottom",
    plot.title = element_text(face = "bold", size = 12, margin = margin(0, 0, 25, 0)),
    plot.subtitle = element_text(size = 11),
    plot.caption = element_text(size = 8),
    axis.text = element_text(size = 8),
    axis.title.y = element_text(margin = margin(t = 0, r = 3, b = 0, l = 0)),
    axis.text.y = element_text(vjust = -0.5, margin = margin(l = 20, r = -10)),
    axis.line.x = element_line(colour = "black", size = 0.4),
    axis.ticks.x = element_line(colour = "black", size = 0.4),
    panel.grid.minor = element_blank(),
    panel.grid.major.x = element_blank()
  )
)
```

1st Difference (Unemployment Rate)

Data: ggplot2::economics

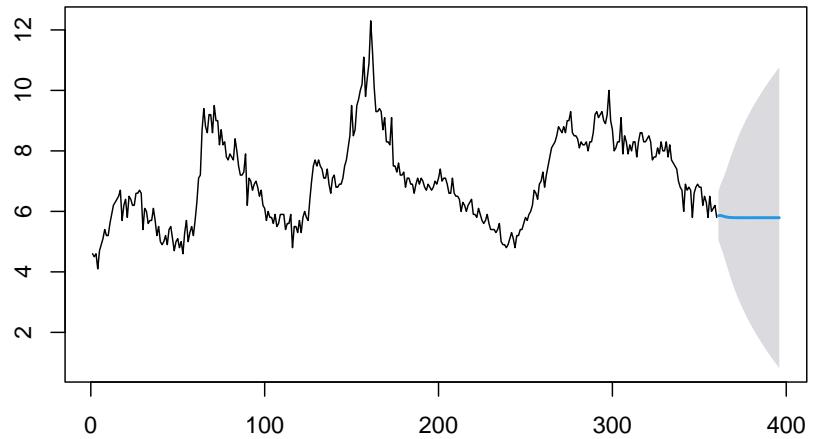
```
# Fit an ARIMA model
ARIMA_model <- forecast::auto.arima(econ_data$uempmed)

# Display model summary and residual diagnostics
summary(ARIMA_model)
forecast::checkresiduals(ARIMA_model)
```



```
# Forecast for the next 36 time periods
ARIMA_forecast <- forecast::forecast(ARIMA_model, h = 36, level = c(95))

# Plot the forecast
plot(ARIMA_forecast)
```

Forecasts from ARIMA(2,1,2)

Web scraping

Why it matters

Collecting data off websites can be a nightmare. The worst case is manually typing data from a web-page into spreadsheets... but there are *many* steps we can do before resorting to that.

This chapter will outline the process for pulling data off the web, and particularly for understanding the exact web-page element we want to extract.

The notes and code loosely follow the fabulous data tutorial by Grant R. McDermott in his *Data Science for Economists* series. It has been updated to scrape the most recent version and structure of the relevant Wikipedia pages.

First up, let's load some packages.

```
# Install development version of rvest if necessary
if (numeric_version(packageVersion("rvest")) < numeric_version('0.99.0')) {
  remotes::install_github('tidyverse/rvest')
}

# Load and install the packages that we'll be using today
if (!require("pacman")) install.packages("pacman")
pacman::p_load(tidyverse, rvest, lubridate, janitor, data.table, hrbrthemes)

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

Anatomy of a webpage

Web pages can be categorized as either *server-side rendered* (where content is embedded in the HTML) or *client-side rendered* (where content loads dynami-

cally using JavaScript). When scraping server-side rendered pages, locating the correct CSS or XPath selectors is crucial.

Trawling through CSS code on a webpage is a bit of a nightmare - so we'll use a chrome extension called SelectGadget to help.

The R package that's going to do the heavy lifting is called `rvest` and is based on the python package called Beauty Soup.

Scraping a table

Let's use this wikipedia page as a starting example. It contains various entries for the men's 100m running record.

We can start by pulling all the data from the webpage.

```
m100 <- rvest::: read_html(
  "http://en.wikipedia.org/wiki/Men%27s_100_metres_world_record_progression"
m100

## {html_document}
## <html class="client-nojs vector-feature-language-in-header-enabled vector-feature-la
## [1] <head>\n<meta http-equiv="Content-Type" content="text/html; charset=UTF-8 ...
## [2] <body class="skin--responsive skin-vector skin-vector-search-vue mediawik ...
```

... and we get a whole heap of mumbo jumbo.

To get the table of 'Unofficial progression before the IAAF' we're going to have to be more specific.

Using the SelectGadget tool we can click around and identify that that specific table.

```
pre_iaaf =
  m100 %>%
    html_element("div+ .wikitable :nth-child(1)") %>% ## select table element
    html_table()                                     ## convert to data frame

pre_iaaf

## # A tibble: 21 x 5
##       Time Athlete      Nationality `Location of races` Date
##     <dbl> <chr>        <chr>          <chr>           <chr>
## 1   10.8 Luther Cary United States Paris, France July 4, 1-
## 2   10.8 Cecil Lee  United Kingdom Brussels, Belgium September~
```

```

## 3 10.8 Étienne De Ré          Belgium      Brussels, Belgium    August 4, ~
## 4 10.8 L. Atcherley         United Kingdom Frankfurt/Main, Germany April 13, ~
## 5 10.8 Harry Beaton        United Kingdom Rotterdam, Netherlands August 28-
## 6 10.8 Harald Anderson-Arbin Sweden      Helsingborg, Sweden    August 9, ~
## 7 10.8 Isaac Westergren     Sweden      Gävle, Sweden       September-
## 8 10.8 Isaac Westergren     Sweden      Gävle, Sweden       September-
## 9 10.8 Frank Jarvis        United States Paris, France     July 14, ~
## 10 10.8 Walter Tewksbury   United States Paris, France     July 14, ~
## # i 11 more rows

```

Niiiiice - now that's better. Let's do some quick data cleaning.

```

pre_iaaf <- pre_iaaf %>%
  clean_names() %>%
  mutate(date = mdy(date))

pre_iaaf

## # A tibble: 21 x 5
##       time athlete      nationality location_of_races   date
##     <dbl> <chr>        <chr>           <chr>           <date>
## 1 10.8 Luther Cary   United States Paris, France 1891-07-04
## 2 10.8 Cecil Lee    United Kingdom Brussels, Belgium 1892-09-25
## 3 10.8 Étienne De Ré Belgium      Brussels, Belgium 1893-08-04
## 4 10.8 L. Atcherley United Kingdom Frankfurt/Main, Germany 1895-04-13
## 5 10.8 Harry Beaton   United Kingdom Rotterdam, Netherlands 1895-08-28
## 6 10.8 Harald Anderson-Arbin Sweden      Helsingborg, Sweden 1896-08-09
## 7 10.8 Isaac Westergren Sweden      Gävle, Sweden   1898-09-11
## 8 10.8 Isaac Westergren Sweden      Gävle, Sweden   1899-09-10
## 9 10.8 Frank Jarvis    United States Paris, France 1900-07-14
## 10 10.8 Walter Tewksbury United States Paris, France 1900-07-14
## # i 11 more rows

```

Let's also scrape the data for the more recent running records. That's the tables named 'Records (1912-1976)' and 'Records since 1977'.

For the second table:

```

iaaf_76 = m100 %>%
  html_element("#mw-content-text > div > table:nth-child(17)") %>%
  html_table()

iaaf_76 <-iaaf_76 %>%
  clean_names() %>%
  mutate(date = mdy(date))

```

```
iaaf_76
```

```
## # A tibble: 54 x 8
##   time wind  auto athlete      nationality location_of_race date     ref
##   <dbl> <chr> <dbl> <chr>      <chr>        <chr>       <date>    <chr>
## 1 10.6   ""    NA  Donald Lippi~ United Sta~ Stockholm, Swed~ 1912-07-06 [2]
## 2 10.6   ""    NA  Jackson Scho~ United Sta~ Stockholm, Swed~ 1920-09-16 [2]
## 3 10.4   ""    NA  Charley Padd~ United Sta~ Redlands, USA   1921-04-23 [2]
## 4 10.4   "0.0" NA  Eddie Tolan   United Sta~ Stockholm, Swed~ 1929-08-08 [2]
## 5 10.4   ""    NA  Eddie Tolan   United Sta~ Copenhagen, Den~ 1929-08-25 [2]
## 6 10.3   ""    NA  Percy Willia~ Canada       Toronto, Canada 1930-08-09 [2]
## 7 10.3   "0.4" 10.4 Eddie Tolan   United Sta~ Los Angeles, USA 1932-08-01 [2]
## 8 10.3   ""    NA  Ralph Metcal~ United Sta~ Budapest, Hunga~ 1933-08-12 [2]
## 9 10.3   ""    NA  Eulace Peaco~ United Sta~ Oslo, Norway   1934-08-06 [2]
## 10 10.3  ""    NA  Chris Berger Netherlands Amsterdam, Neth~ 1934-08-26 [2]
## # i 44 more rows
```

And now for the third table:

```
iaaf <- m100 %>%
  html_element("#mw-content-text > div.mw-parser-output > table:nth-child(23)")
  html_table() %>%
  clean_names() %>%
  mutate(date = mdy(date))
iaaf

## # A tibble: 24 x 9
##   time wind  auto athlete      nationality location_of_race date
##   <dbl> <chr> <dbl> <chr>      <chr>        <chr>       <date>
## 1 10.1  1.3    NA Bob Hayes   United States Tokyo, Japan 1964-10-15
## 2 10.0  0.8    NA Jim Hines   United States Sacramento, USA 1968-06-20
## 3 10.0  2.0    NA Charles Greene United States Mexico City, Mexico 1968-10-13
## 4 9.95  0.3    NA Jim Hines   United States Mexico City, Mexico 1968-10-14
## 5 9.93  1.4    NA Calvin Smith United States Colorado Springs, ~ 1983-07-03
## 6 9.83  1.0    NA Ben Johnson Canada       Rome, Italy   1987-08-30
## 7 9.93  1.0    NA Carl Lewis   United States Rome, Italy   1987-08-30
## 8 9.93  1.1    NA Carl Lewis   United States Zürich, Switzerland 1988-08-17
## 9 9.79  1.1    NA Ben Johnson Canada       Seoul, South Korea 1988-09-24
## 10 9.92 1.1    NA Carl Lewis   United States Seoul, South Korea 1988-09-24
## # i 14 more rows
## # i 2 more variables: notes_note_2 <chr>, duration_of_record <chr>
```

How good. Now let's bind the rows together to make a master data set.

```

wr100 <- rbind(
  pre_iaaf %>% dplyr::select(time, athlete, nationality, date) %>%
  mutate(era = "Pre-IIAAF"),
  iaaf_76 %>% dplyr::select(time, athlete, nationality, date) %>%
  mutate(era = "Pre-automatic"),
  iaaf %>% dplyr::select(time, athlete, nationality, date) %>%
  mutate(era = "Modern")
)

wr100

## # A tibble: 99 x 5
##   time      athlete      nationality      date      era
##   <dbl>     <chr>        <chr>        <date>    <chr>
## 1 10.8 Luther Cary United States 1891-07-04 Pre-IIAAF
## 2 10.8 Cecil Lee   United Kingdom 1892-09-25 Pre-IIAAF
## 3 10.8 Étienne De Ré Belgium       1893-08-04 Pre-IIAAF
## 4 10.8 L. Atcherley United Kingdom 1895-04-13 Pre-IIAAF
## 5 10.8 Harry Beaton United Kingdom 1895-08-28 Pre-IIAAF
## 6 10.8 Harald Anderson-Arbin Sweden       1896-08-09 Pre-IIAAF
## 7 10.8 Isaac Westergren Sweden       1898-09-11 Pre-IIAAF
## 8 10.8 Isaac Westergren Sweden       1899-09-10 Pre-IIAAF
## 9 10.8 Frank Jarvis  United States 1900-07-14 Pre-IIAAF
## 10 10.8 Walter Tewksbury United States 1900-07-14 Pre-IIAAF
## # i 89 more rows

```

Excellent. Let's plot the results.

```

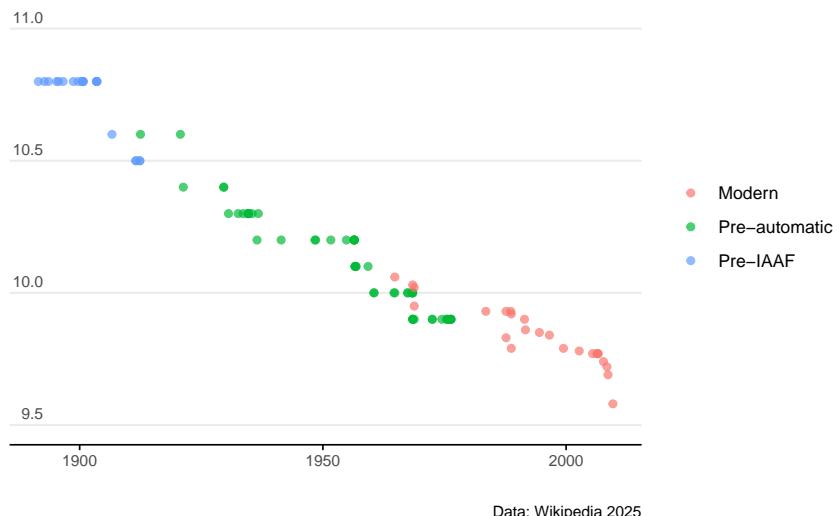
ggplot(wr100) +
  geom_point(aes(x = date, y = time, col = era), alpha = 0.7) +
  labs(
    title = "Men's 100m World Record Progression",
    subtitle = "Analysing how times have improved over the past 130 years",
    caption = "Data: Wikipedia 2025",
    x = "",
    y = ""
  ) +
  theme_minimal() +
  scale_y_continuous(limits = c(9.5, 11), breaks = c(9.5, 10, 10.5, 11)) +
  theme(
    axis.text.y = element_text(vjust = -0.5, margin = margin(l = 20, r = -20)),

```

```
plot.subtitle = element_text(margin = margin(0, 0, 25, 0), size=11),
legend.title = element_blank(),
plot.title = element_text(face = "bold", size = 12),
plot.caption = element_text(size = 8),
axis.text = element_text(size = 8),
panel.grid.minor = element_blank(),
panel.grid.major.x = element_blank(),
axis.line.x = element_line(colour = "black", size = 0.4),
axis.ticks.x = element_line(colour = "black", size = 0.4)
)
```

Men's 100m World Record Progression

Analysing how times have improved over the past 130 years



Text mining

Numbers are great... but words literally tell a story. Analysing text (e.g. books, tweets, survey responses) in a quantitative format is naturally challenging - however there's a few tricks which can simplify the process.

This chapter outlines the process for inputting text data, and running some simple analysis. The notes and code loosely follow the fabulous book *Text Mining with R* by Julia Silge and David Robinson.

First up, let's load some packages.

```
library(ggplot2)
library(dplyr)
library(tidyverse)
library(tidytext)
library(textdata)
```

Frequency analysis

There's a online depository called Project Gutenberg which catalogue texts that have lost their copyright.

It just so happens that The Bible is on this list. Let's check out the most frequent words.

```
library(tidyverse)
library(tidytext)

# Correct URL for the raw text file
bible_url <- "https://raw.githubusercontent.com/charlescoverdale/casualdabbler2e/main/data/bible.txt"

# Read the text file directly from the URL
bible <- read_lines(bible_url)
```

```
# Convert to a tibble
bible_df <- tibble(text = bible)

# Tokenize words and remove stop words
bible_tidy <- bible_df %>%
  unnest_tokens(word, text) %>%
  anti_join(stop_words, by = "word")

# Find and display the most common words
common_words <- bible_tidy %>%
  count(word, sort = TRUE) %>%
  head(20) # Show the top 20 words

print(common_words)
```

```
## # A tibble: 20 x 2
##   word     n
##   <chr> <int>
## 1 lord    7830
## 2 thou    5474
## 3 thy     4600
## 4 god     4446
## 5 ye      3983
## 6 thee    3827
## 7 1       2830
## 8 2       2724
## 9 3       2570
## 10 israel 2565
## 11 4       2476
## 12 son    2370
## 13 7       2351
## 14 5       2308
## 15 6       2297
## 16 hath   2264
## 17 king   2264
## 18 9       2210
## 19 8       2193
## 20 people  2142
```

Somewhat unsurprisingly - “lord” wins it by a country mile.

Sentiment analysis

Just like a frequency analysis, we can do a ‘vibe’ analysis (i.e. sentiment of a text) using a clever thesaurus matching technique.

In the `tidytext` package are lexicons which include the general sentiment of words (e.g. the emotion you can use to describe that word).

Let’s see the count of words most associated with ‘joy’ in the bible.

```
# Tokenize words
bible_tidy <- bible_df %>%
  unnest_tokens(word, text) %>%
  mutate(word = tolower(word)) # Ensure lowercase matching

# Get NRC lexicon & filter for "joy"
nrcjoy <- tidytext::get_sentiments("nrc") %>%
  filter(sentiment == "joy")

# Join words with NRC joy sentiment list & count occurrences
bible_joy_words <- bible_tidy %>%
  inner_join(nrcjoy, by = "word") %>%
  count(word, sort = TRUE)

# View top joyful words
print(bible_joy_words)

## # A tibble: 264 x 2
##   word      n
##   <chr>    <int>
## 1 god      4446
## 2 good     720
## 3 art      494
## 4 peace    429
## 5 found    404
## 6 glory    402
## 7 daughter 324
## 8 pray     313
## 9 love     310
## 10 blessed 302
## # i 254 more rows
```


Geocoding

Drivetime analysis

Raster data

Raster data (sometimes referred to as gridded data) is a type of spatial data that is stored in a grid rather than a polygon. Imagine a chessboard of individual squares covering the Australian landmass compared to 8 different shapes covering each state and territory.

The nice thing about gridded data is that all the cells in the grid are the same size - making calculations much easier. The tricky part is those squares are overlaid on a (very roughly) spherical earth. We'll have to think about mapping projections along the way.

Let's get started. First up we need to load some spatial and data crunching packages.

```
# Core tidyverse packages (includes ggplot2, dplyr, tidyverse, etc.)
library(tidyverse)

# Spatial data handling
library(sf)          # Modern replacement for sp + rgdal
library(raster)       # Working with raster data
library(ncdf4)        # NetCDF file handling
library(leaflet)      # Interactive maps

# Mapping & Visualization
library(ggspatial)   # Adds scale bars, north arrows, etc.
#library(tmap)         # Thematic mapping
library(ggmap)        # Google Maps integration
library(rasterVis)    # Raster visualization
library(viridis)       # Color scales for ggplot2 and rasterVis
library(RColorBrewer)  # Color palettes

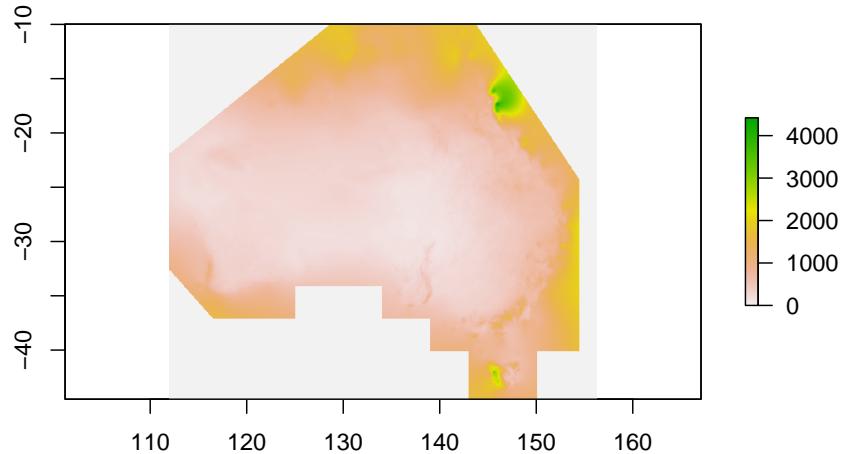
# Other Utilities
library(absmapsdata) # Australian Bureau of Statistics map data
```

Import raster

Next, we want to import annual rainfall data from github (original source available from the Bureau of Meteorology)

```
rainfall <- raster("https://raw.github.com/charlescoverdale/ERF/master/rainan.txt")

plot(rainfall)
```



Straight away we see this is for the whole of Australia (and then some). We're only interested in what's going on in QLD... so let's crop the data down to scale. For this we'll need to import a shapefile for QLD.

The easiest way to do this is using the absmapsdata package - importing a shapefile of Australia then filtering for only Queensland.

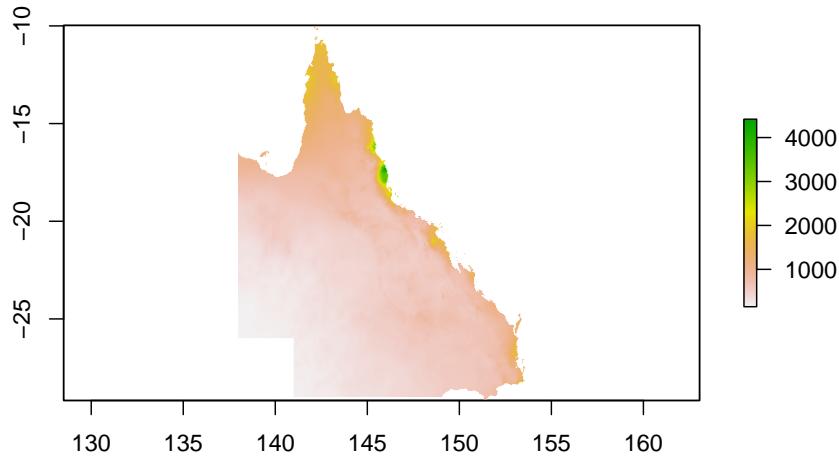
```
# Import a polygon for the state of Queensland
QLD_shape <- absmapsdata::state2016 %>%
  filter(state_name_2016 == "Queensland")
```

Choosing geographies

We have raster data for the entirety of Australia (and then some as it's pulled from one of the BOMs satellites). This is a bit messy to work with - so let's

crop the rainfall data from the entire Australian continent to just Queensland.

```
#Crop data
r2 <- crop(rainfall,extent(QLD_shape))
r3 <- mask(r2,QLD_shape)
plot(r3)
```



]Next up, let's transform the cropped raster into a data frame that we can use in the ggplot package.

```
r3_df <- as.data.frame(r3,xy=TRUE)

r3_df <- r3_df %>%
  filter(rainan!="NA")

ggplot() +
  geom_tile(data=r3_df, aes(x=x, y=y, fill=rainan)) +
  scale_fill_viridis() +
  coord_equal() +
  theme(legend.position="bottom") +
  theme(legend.key.width=unit(1.2, "cm"))+
  labs(title="Rainfall in QLD",
       subtitle = "Analysis from the Bureau of Meteorology",
       caption = "Data: BOM 2021",
       x="",
       y="")
```

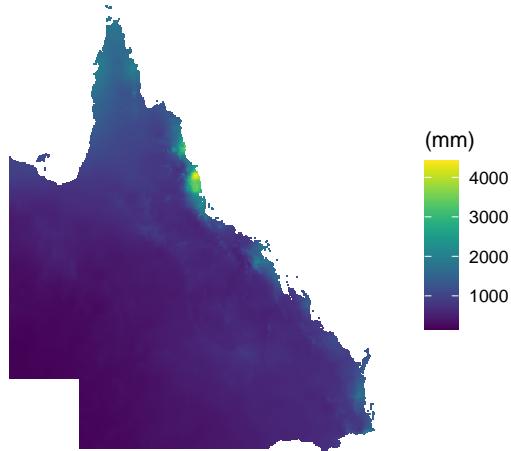
```

y="",
fill="(mm)" +
theme_minimal() +
theme(axis.ticks.x = element_blank(), axis.text.x = element_blank()) +
theme(axis.ticks.y = element_blank(), axis.text.y = element_blank()) +
theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank())
#theme(legend.position = "bottom") +
theme(plot.title=element_text(face="bold",size=12)) +
theme(plot.subtitle=element_text(size=11)) +
theme(plot.caption=element_text(size=8))

```

Rainfall in QLD

Analysis from the Bureau of Meteorology



Data: BOM 2021

Excellent, we've got a working map of rainfall in Queensland using the `ggplot` package. We'll tidy up the map also and add a title and some better colours.

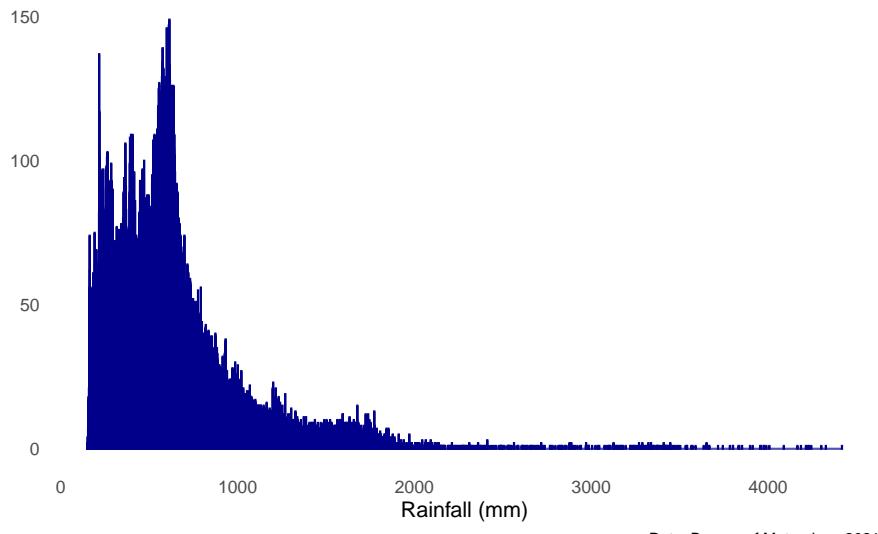
Analysis with raster data

For our first piece of data analysis, we're going to look at areas with less than 600mm of annual rainfall. How many of our data points will have less than 600mm of rain? Let's take a look at the data distribution and find out.

```
ggplot(r3_df) +
  geom_histogram(aes(rainan), binwidth=1, col="darkblue") +
  labs(title="Distribution of annual rainfall in QLD",
       subtitle = "Data using a 5x5km grid",
       caption = "Data: Bureau of Meterology 2021",
       x="Rainfall (mm)",
       y="",
       fill="(mm)") +
  theme_minimal() +
  theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank()) +
  theme(legend.position = "none") +
  theme(plot.title=element_text(face="bold", size=12)) +
  theme(plot.subtitle=element_text(size=11)) +
  theme(plot.caption=element_text(size=8))
```

Distribution of annual rainfall in QLD

Data using a 5x5km grid



Data: Bureau of Meterology 2021

Interesting. The data is heavily right tailed skewed (the mean will be much higher than the median)... and most of the data looks to be between 0-1000mm (this makes sense).

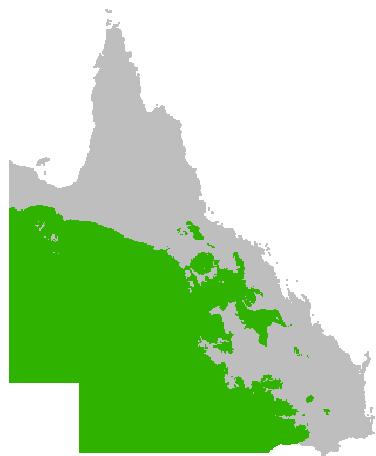
Let's create a 'flag' column of 0's and 1's that shows when a data point is less than 600mm.

```
# Define flag column and colors
r3_df <- r3_df %>%
  mutate(flag_600mm = as.factor(ifelse(rainan <= 600, 1, 0)))
```

```
flag_colours <- c("grey", "#2FB300")

# Plot
ggplot(r3_df, aes(x = x, y = y, fill = flag_600mm)) +
  geom_tile() +
  scale_fill_manual(values = flag_colours) +
  coord_equal() +
  theme_minimal() +
  labs(
    title = "Areas with Less than 600mm of Annual Rainfall in QLD",
    subtitle = "Identifying Suitable Land Parcels for ERF Plantings",
    caption = "Data: Bureau of Meteorology 2021",
    x = "",
    y = "",
    fill = "(mm)"
  ) +
  theme(
    axis.ticks = element_blank(),
    axis.text = element_blank(),
    panel.grid = element_blank(),
    legend.position = "none",
    plot.title = element_text(face = "bold", size = 12),
    plot.subtitle = element_text(size = 11),
    plot.caption = element_text(size = 8)
  )
```

Areas with Less than 600mm of Annual Rainfall in QLD
Identifying Suitable Land Parcels for ERF Plantings



Data: Bureau of Meteorology 2021

Making an interactive map

The static map above is good... but an interactive visual (ideally with place names below) is better. The `leaflet` package is exceptional here.

```
# This code creates an interactive leaflet map. It is commented out to allow the html version of
# leaflet() %>%
#   addTiles() %>%
#   addRasterImage(r5, opacity = 0.5) %>%
#   addLegend(pal = colorNumeric("viridis", values(r5)), values = values(r5))
```

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RASTER DATA

Australian economic data

Australia has exceptional financial and economic institutions. Three of these institutions release periodic data useful for economic analysis:

- Australian Bureau of Statistics
- Reserve Bank of Australia
- Treasury

As usual, there are catches. Most of this data is in inconsistent formats (the reasons for which continue to baffle me). What's more, it's currently not possible to ping databases or API's for access to this data... it is mainly accessed through spreadsheets.

The scripts below run through some of the main ways to import, clean, and analyse Australian macroeconomic data in R.

Some of the key packages we'll use are `readabs` and `readrba`.

To get started, let's install and load packages.

```
# Loads the required packages
pacman::p_load(
  ggmap, tmaptools, RCurl, jsonlite, tidyverse,
  leaflet, writexl, readr, readxl, readabs, readrba, lubridate,
  zoo, scales
)

## 
## There are binary versions available but the source versions are later:
##           binary source needs_compilation
## sf        1.0-15 1.0-19          TRUE
## stars     0.5-5  0.6-8          FALSE
## tmaptools 3.1-1   3.2          FALSE
```

GDP

To get GDP data from the ABS, we'll use the `read_abs` function from the `readrba` package.

```
#For simplicity, we keep the download function seperate to the analysis
all_gdp <- read_abs("5206.0")

#Select the seasonally adjusted data and filter for data and value columns
gdp_level <- all_gdp %>%
  filter(series == "Gross domestic product: Chain volume measures ;",
         !is.na(value)) %>%
  filter(series_type == "Seasonally Adjusted") %>%
  dplyr::select(date,value) %>%
  dplyr::rename(quarterly_output=value)

gdp_level <- gdp_level %>%
  mutate(quarterly_growth_rate =
    ((quarterly_output / lag(quarterly_output,1)-1))*100) %>%
  mutate(annual_gdp =
    rollapply(quarterly_output,
              4,
              sum,
              na.rm=TRUE,
              fill = NA,
              align = "right")) %>%
  mutate(annual_gdp_trillions=annual_gdp/1000000)%>%
  mutate(annual_growth_rate =
    ((annual_gdp / lag(annual_gdp, 4) - 1))*100)%>%
  mutate(Quarter_of_year =
    lubridate::quarter(date,
                        with_year = FALSE,
                        fiscal_start = 1))

#Set a baseline value
gdp_level$baseline_value <- gdp_level$quarterly_output[
  which(gdp_level$date == "2022-03-01")]

gdp_level <- gdp_level %>%
  mutate(baseline_comparison =
    (quarterly_output/baseline_value)*100)

tail(gdp_level)
```

```
## # A tibble: 6 x 9
##   date      quarterly_output quarterly_growth_rate annual_gdp
##   <date>           <dbl>                  <dbl>        <dbl>
## 1 2023-06-01       646331                 0.334     2567511
## 2 2023-09-01       649432                 0.480     2581019
## 3 2023-12-01       650532                 0.169     2590477
## 4 2024-03-01       651554                 0.157     2597849
## 5 2024-06-01       652734                 0.181     2604252
## 6 2024-09-01       654912                 0.334     2609732
## # i 5 more variables: annual_gdp_trillions <dbl>, annual_growth_rate <dbl>,
## # Quarter_of_year <int>, baseline_value <dbl>, baseline_comparison <dbl>
```

Now we can plot the GDP data for Australia.

```

  theme(axis.line.x = element_line(colour ="black", size=0.4))+  

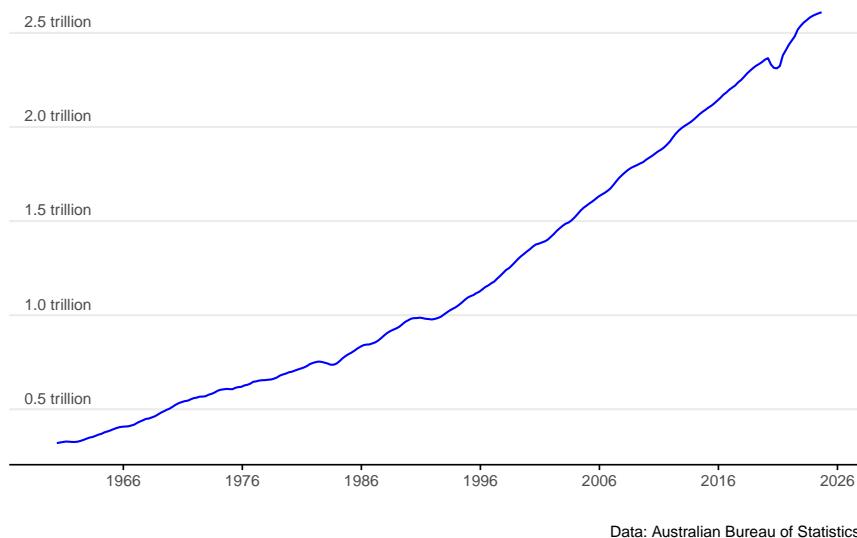
  theme(axis.ticks.x = element_line(colour ="black", size=0.4))  
  

plot_gdp

```

Australian GDP (\$AUD)

Annualised figures



Data: Australian Bureau of Statistics

Unemployment rate

Download the data

```

#Download the time series  

all_unemployment <- read_abs("6202.0")

```

Clean and analyse the data

```

unemployment_rate <- all_unemployment %>%  

  filter(series == "Unemployment rate ; Persons ;", !is.na(value)) %>%  

  filter(table_title=="Table 1. Labour force status by Sex, Australia - Tr  

  filter(series_type =="Seasonally Adjusted") %>%  

  mutate(mean_unemployment_rate=mean(value)) %>%  

  mutate(percentile_25=quantile(value,0.25))%>%  

  mutate(percentile_75=quantile(value,0.75)) %>%

```

```
dplyr::select(date,value,mean_unemployment_rate,percentile_25,percentile_75)

tail(unemployment_rate)

## # A tibble: 6 x 5
##   date      value mean_unemployment_rate percentile_25 percentile_75
##   <date>    <dbl>          <dbl>            <dbl>            <dbl>
## 1 2024-07-01  4.22           6.58            5.27            7.92
## 2 2024-08-01  4.13           6.58            5.27            7.92
## 3 2024-09-01  4.07           6.58            5.27            7.92
## 4 2024-10-01  4.11           6.58            5.27            7.92
## 5 2024-11-01  3.93           6.58            5.27            7.92
## 6 2024-12-01  3.98           6.58            5.27            7.92
```

Plot the data

```
plot_unemployment_rate <- ggplot(data=unemployment_rate)+  
  geom_line(aes(x = date, y = value), col = "blue") +  
  
  labs(title = "Unemployment rate",  
        subtitle = "Subtitle goes here",  
        caption = "Data: Australian Bureau of Statistics",  
        y = "Unemployment rate (%)",  
        x = " ") +  
  
  scale_y_continuous(labels = scales::comma) +  
  scale_x_date(date_breaks = "10 years", date_labels="%Y") +  
  
  theme_minimal() +  
  theme(legend.position="bottom") +  
  
  theme(plot.title=element_text(face="bold", size=12)) +  
  theme(plot.subtitle=element_text(size=11)) +  
  theme(plot.caption=element_text(size=8)) +  
  
  theme(axis.text=element_text(size=8)) +  
  theme(panel.grid.minor = element_blank()) +  
  theme(panel.grid.major.x = element_blank()) +  
  
  theme(axis.title.y =  
        element_text(margin = margin(t = 0, r = 0, b = 0, l = 0))) +  
  
  theme(axis.text.y = element_text(vjust = -0.5,
```

```

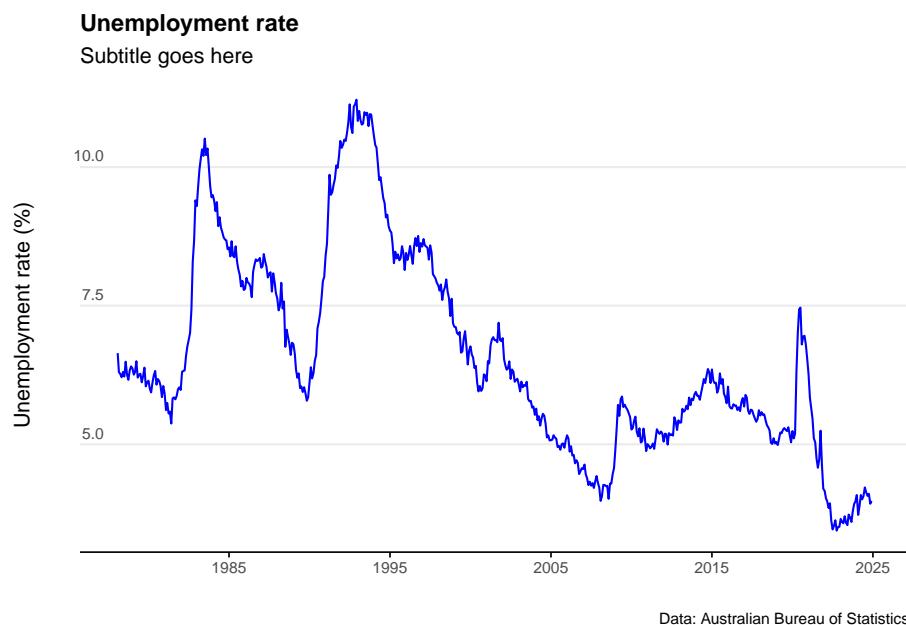
margin = margin(l = 20, r = -15)))+

theme(axis.line.x = element_line(colour ="black", size=0.4))+

theme(axis.ticks.x = element_line(colour ="black", size=0.4))

plot_unemployment_rate

```



Inflation (CPI)

Download the data

```
all_CPI <- read_abs("6401.0")
```

Clean and analyse the data

```

Australia_CPI <- all_CPI %>%
  filter(series == "Percentage Change from Corresponding Quarter of Previous Year") %>%
  mutate(mean_CPI=mean(value)) %>%
  mutate(percentile_25=quantile(value,0.25))%>%
  mutate(percentile_75=quantile(value,0.75)) %>%
  dplyr::select(date, value,mean_CPI,percentile_25,percentile_75)

```

```

tail(Australia_CPI)

## # A tibble: 6 x 5
##   date      value mean_CPI percentile_25 percentile_75
##   <date>    <dbl>    <dbl>        <dbl>        <dbl>
## 1 2023-09-01  5.4     4.95       1.9         7.3
## 2 2023-12-01  4.1     4.95       1.9         7.3
## 3 2024-03-01  3.6     4.95       1.9         7.3
## 4 2024-06-01  3.8     4.95       1.9         7.3
## 5 2024-09-01  2.8     4.95       1.9         7.3
## 6 2024-12-01  2.4     4.95       1.9         7.3

#Can add in the below line to filter
#filter(date > "2010-01-01") %>%

```

Plot the data

```

plot_CPI <- ggplot(data = Australia_CPI %>%
                      filter(date > as.Date("2000-01-01"))) +
  geom_rect(aes(xmin = as.Date("2000-01-01"),
                xmax = as.Date("2025-03-01"),
                ymin = 2,
                ymax = 3),
            alpha = 0.1, # Adjusted alpha for better visibility
            fill = "lightgrey") +
  geom_line(aes(x = date, y = value), col = "blue") +
  scale_x_date(date_breaks = "2 years", date_labels = "%Y") +
  labs(title = "Inflation (as measured by the CPI)",
       subtitle = "Subtitle goes here",
       caption = "Data: Australian Bureau of Statistics",
       y = "(%)",
       x = "") +
  scale_y_continuous(labels = scales::comma) +
  theme_minimal() +
  theme(legend.position = "bottom") +
  theme(plot.title = element_text(face = "bold", size = 12)) +
  theme(plot.subtitle = element_text(size = 11)) +
  theme(plot.caption = element_text(size = 8)) +

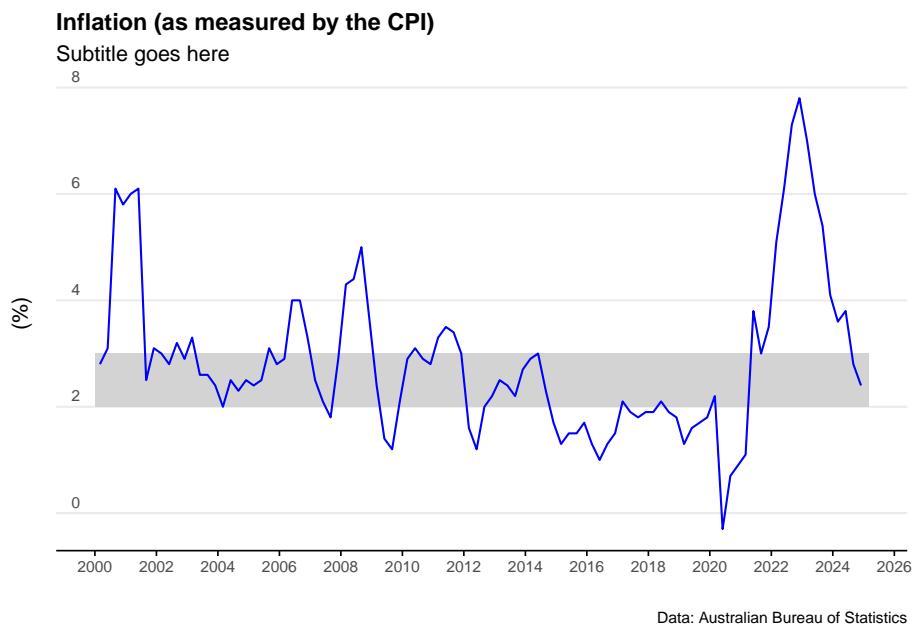
```

```

theme(axis.text = element_text(size = 8)) +
  theme(panel.grid.minor = element_blank()) +
  theme(panel.grid.major.x = element_blank()) +
  theme(axis.title.y = element_text(margin = margin(t = 0, r = 0, b = 0, l = 0))) +
  theme(axis.text.y = element_text(vjust = -0.5,
                                    margin = margin(l = 20, r = -15))) +
  theme(axis.line.x = element_line(colour = "black", size = 0.4)) +
  theme(axis.ticks.x = element_line(colour = "black", size = 0.4))

plot_CPI

```



Plot a histogram of the data

```

plot_CPI_hist <- ggplot(Australia_CPI, aes(x = value)) +
  geom_histogram(aes(y = ..density..),
                 colour = "black", fill = "lightblue") +
  geom_density(alpha = .5, fill = "grey", colour = "darkblue") +
  scale_x_continuous(expand = c(0, 0)) # Remove extra space on the x-axis

  labs(title = "Consumer Price Index: Histogram",
       subtitle = "Subtitle goes here",

```

```

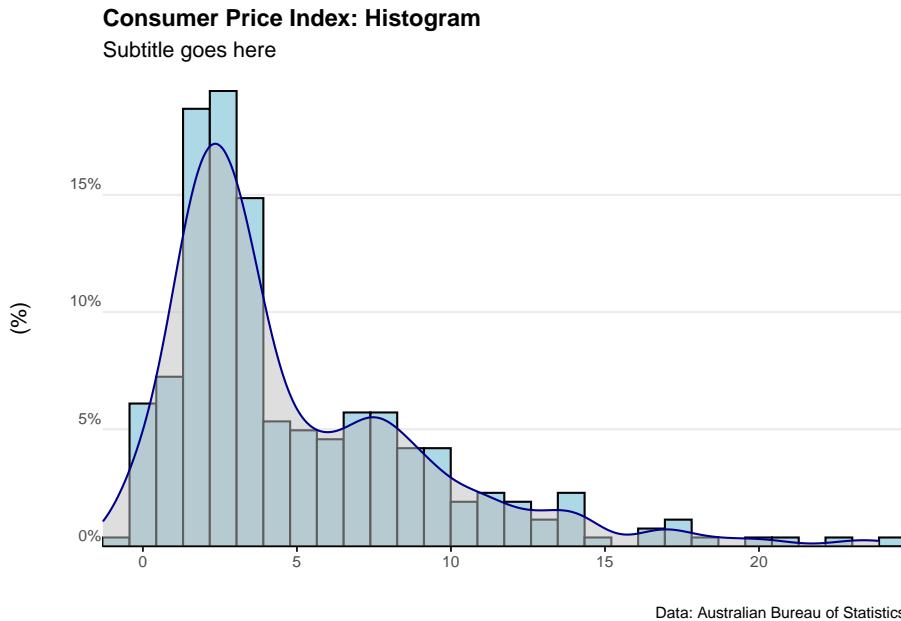
caption = "Data: Australian Bureau of Statistics",
y = "(%)",
x = "") + 

scale_y_continuous(labels = scales::percent, expand = c(0, 0)) + # Ensure no space on y-axis

theme_minimal() +
theme(
  legend.position = "bottom",
  plot.title = element_text(face = "bold", size = 12),
  plot.subtitle = element_text(size = 11, margin = margin(b = 15)),
  plot.caption = element_text(size = 8),
  axis.text = element_text(size = 8),
  panel.grid.minor = element_blank(),
  panel.grid.major.x = element_blank(),
  axis.title.y = element_text(margin = margin(t = 0, r = 0, b = 20, l = 0)),
  axis.text.y = element_text(vjust = -0.5, margin = margin(l = 20, r = -2)),
  axis.line.x = element_line(colour = "black", size = 0.4),
  axis.ticks.x = element_line(colour = "black", size = 0.4)
)
)

plot_CPI_hist

```



Wage Price Index

Download the data

```
all_wpi <- read_abs("6345.0")
```

Clean and analyse the data

```
Australia_WPI <- all_wpi %>%
  filter(series == "Percentage Change From Corresponding Quarter of Previous Year" &
         !is.na(value)) %>%
  filter(series_type=="Seasonally Adjusted") %>%
  mutate(mean_WPI=mean(value)) %>%
  dplyr::select(date, value,mean_WPI)

tail(Australia_WPI)

## # A tibble: 6 x 3
##   date      value mean_WPI
##   <date>    <dbl>    <dbl>
## 1 2023-06-01    3.6    3.12
## 2 2023-09-01     4     3.12
## 3 2023-12-01    4.3    3.12
## 4 2024-03-01    4.1    3.12
## 5 2024-06-01    4.1    3.12
## 6 2024-09-01    3.5    3.12
```

Plot the data

```
plot_WPI <- ggplot(data=Australia_WPI) +
  geom_line(aes(x = date, y = value), col = "blue") +
  labs(title = "Wage Price Index",
       subtitle = "Subtitle goes here",
       caption = "Data: Australian Bureau of Statistics",
       y = "(%)",
       x = " ") +
  scale_y_continuous(labels = scales::comma) +
  scale_x_date(date_breaks = "5 years", date_labels = "%Y") +
  theme_minimal() +
  theme(legend.position = "bottom") +
```

```

theme(plot.title=element_text(face="bold", size=12))+  

theme(plot.subtitle=element_text(size=11))+  

theme(plot.caption=element_text(size=8))+  

theme(axis.text=element_text(size=8))+  

theme(panel.grid.minor = element_blank())+  

theme(panel.grid.major.x = element_blank()) +  

theme(axis.title.y =  

element_text(margin = margin(t = 0, r = 0, b = 0, l = 0)))+  

theme(axis.text.y = element_text(vjust = -0.5,  

margin = margin(l = 20, r = -15)))+  

theme(axis.line.x = element_line(colour ="black", size=0.4))+  

theme(axis.ticks.x = element_line(colour ="black", size=0.4))

```

plot_WPI



AUD exchange rate

God knows why - but there are super quirky names for the official exchange rate tables

Download the data

```
exchange_rate_all <- readrba::read_rba(table_no = (c("ex_daily_8386",
                                                    "ex_daily_8790",
                                                    "ex_daily_9194",
                                                    "ex_daily_9598",
                                                    "ex_daily_9902",
                                                    "ex_daily_0306",
                                                    "ex_daily_0709",
                                                    "ex_daily_1013",
                                                    "ex_daily_1417",
                                                    "ex_daily_18cur")),
                                         cur_hist = "historical")
```

Clean and analyse the data

```
exchange_rate_AUD <- exchange_rate_all %>%
  filter(series == "A$1=USD") %>%
  dplyr::select(date, value)

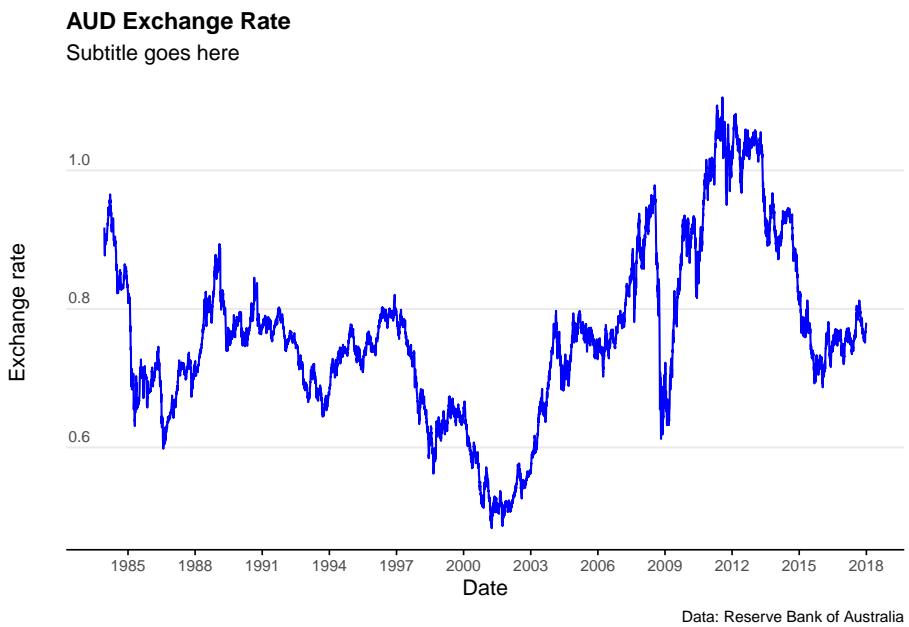
tail(exchange_rate_AUD)
```

```
## # A tibble: 6 x 2
##   date      value
##   <date>    <dbl>
## 1 2017-12-20 0.766
## 2 2017-12-21 0.767
## 3 2017-12-22 0.771
## 4 2017-12-27 0.774
## 5 2017-12-28 0.779
## 6 2017-12-29 0.78
```

Plot the data

```
plot_exchange_rate_AUD <- ggplot(data = exchange_rate_AUD) +
  geom_line(aes(x = date, y = value), col = "blue") +
  labs(
```

```
title = "AUD Exchange Rate",
subtitle = "Subtitle goes here",
caption = "Data: Reserve Bank of Australia",
y = "Exchange rate", # Adding a Y-axis label
x = "Date"
) +  
  
scale_y_continuous(labels = scales::comma) +
scale_x_date(date_breaks = "3 years", date_labels = "%Y") +  
  
theme_minimal() +  
  
theme(
  plot.title = element_text(face = "bold", size = 12),
  plot.subtitle = element_text(size = 11),
  plot.caption = element_text(size = 8),
  axis.text = element_text(size = 8),
  axis.title.y = element_text(margin = margin(t = 0, r = 0, b = 0, l = 0)),
  axis.text.y = element_text(vjust = -0.5, margin = margin(l = 20, r = -15)),
  axis.line.x = element_line(colour = "black", size = 0.4),
  axis.ticks.x = element_line(colour = "black", size = 0.4),
  panel.grid.minor = element_blank(),
  panel.grid.major.x = element_blank(),
  legend.position = "bottom"
)  
  
plot_exchange_rate_AUD
```



Australian election data

Elections tend to create fascinating data sets. They are spatial in nature, comparable over time (i.e. the number of electorates roughly stays the same) - and more importantly they are **consequential** for all Australians.

Australia's compulsory voting system is a remarkable feature of our Federation. Every three-ish years we all turn out at over 7,000 polling booths our local schools, churches, and community centres to cast a ballot and pick up an obligatory election day sausage. The byproduct is a fascinating longitudinal and spatial data set.

The following code explores different R packages, election data sets, and statistical processes aimed at exploring and modelling federal elections in Australia.

One word of warning: I use the term electorates, divisions, and seats interchangeably throughout this chapter.

Let's start by loading up some packages

```
library(ggparliament)    # If working with parliamentary data
library(tidyverse)        # Includes dplyr, ggplot2, tidyv, purrr, and more
library(ggthemes)
library(readxl)           # Reading Excel files
library(sf)                # Spatial data handling
library(DT)
library(eechidna)
library(absmapsdata)
```

Some phenomenal Australian economists and statisticians have put together a handy election package called eechidna. It includes three main data sets for the most recent Australia federal election (2022).

- **fp22:** first preference votes for candidates at each electorate
- **tpp22:** two party preferred votes for candidates at each electorate
- **tcp22:** two candidate preferred votes for candidates at each electorate

They've also gone to the trouble of aggregating some census data to the electorate level. This can be found with the **abs2022** function.

```
data(fp22)
data(tpp22)
data(tcp22)
data(abs2022)

# Show the first few rows
head(tpp22)

## # A tibble: 6 x 9
##   DivisionNm DivisionID StateAb LNP_Votes LNP_Percent ALP_Votes ALP_Percent
##   <chr>        <dbl> <chr>      <dbl>       <dbl>      <dbl>       <dbl>
## 1 CANBERRA     101 ACT       25424      27.5      66898      72.5
## 2 FENNER        102 ACT       31315      34.3      59966      65.7
## 3 BANKS         103 NSW       48969      53.2      43076      46.8
## 4 BARTON        104 NSW       31569      34.5      60054      65.5
## 5 BENNELONG     105 NSW       48847      49.0      50801      51.0
## 6 BEROWRA       106 NSW       55771      59.8      37535      40.2
## # i 2 more variables: TotalVotes <dbl>, Swing <dbl>

head(tcp22)

## # A tibble: 6 x 13
##   StateAb DivisionID DivisionNm BallotPosition CandidateID Surname GivenNm
##   <chr>        <dbl> <chr>          <dbl>       <dbl> <chr>    <chr>
## 1 ACT           318 BEAN            3       36231 SMITH   DAVID
## 2 ACT           318 BEAN            6       37198 HIATT   JANE
## 3 ACT           101 CANBERRA       5       36241 HOLLO   TIM
## 4 ACT           101 CANBERRA       6       36228 PAYNE   ALICIA
## 5 ACT           102 FENNER          1       36234 LEIGH   ANDREW
## 6 ACT           102 FENNER          2       37203 KUSTER  NATHAN
## # i 6 more variables: PartyAb <chr>, PartyNm <chr>, Elected <chr>,
## #   HistoricElected <chr>, OrdinaryVotes <dbl>, Percent <dbl>
```

Election maps

As noted in the introduction, elections are *spatial* in nature.

Not only does geography largely determine policy decisions, we see that many electorates vote for the same party (or even the same candidate) for decades. How electorate boundaries are drawn is a long story (see [here](#), [here](#), and [here](#)).

The summary version is the AEC carves up the population by state and territory, uses a wacky formula to decide how many seats each state and territory should be allocated, then draws maps to try and get a *roughly* equal number of people in each electorate.

Oh... and did I mention for reasons that aren't worth explaining that Tasmania has to have at least 5 seats? Our Federation is a funny thing. Anyhow, at time of writing this is how the breakdown of seats looks.

State/Territory	Number of members of the House of Representatives (2022)
New South Wales	47
Victoria	39
Queensland	30
Western Australia	15
South Australia	10
Tasmania	5
Australian Capital Territory	3
Northern Territory	2
TOTAL	151

Note: The NT doesn't have the population to justify its second seat . The AEC scheduled to dissolve it after the 2019 election but Parliament intervened in late 2020 and a bill was passed to make sure both seats were kept (creating 151 nationally).

How variant are these 151 electorates in size? Massive.

Durack in Western Australia (1.63 million square kilometres) is by far the largest and the smallest is Grayndler in New South Wales (32 square kilometres).

Let's make a map to make things easier.

```
CED_map <- absmapsdata::ced2021 %>%
  ggplot() +
  geom_sf() +
  labs(title = "Electoral divisions in Australia",
       subtitle = "It turns out we divide the country in very non-standard blocks",
       caption = "Data: Australian Bureau of Statistics 2016",
       x = "",
       y = "") +
  theme_minimal() +
  theme(axis.ticks.x = element_blank(), axis.text.x = element_blank()) +
  theme(axis.ticks.y = element_blank(), axis.text.y = element_blank()) +
  theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank()) +
```

```

theme(legend.position = "right")+
theme(plot.title=element_text(face="bold",size=12))+
theme(plot.subtitle=element_text(size=11))+  

theme(plot.caption=element_text(size=8))

CED_map_remove_6 <- ced2021 %>%
  dplyr::filter(!ced_code_2021 %in% c(506,701,404,511,321,317)) %>%
  ggplot()+
  geom_sf()+
  labs(title="194 electoral divisions in Australia",
       subtitle = "Turns out removing the largest 6 electorates makes a difference",
       caption = "Data: Australian Bureau of Statistics 2016",
       x="",
       y="") +
  theme_minimal() +
  theme(axis.ticks.x = element_blank(),axis.text.x = element_blank())+
  theme(axis.ticks.y = element_blank(),axis.text.y = element_blank())+
  theme(panel.grid.major = element_blank(), panel.grid.minor = element_blank)
  theme(legend.position = "right")+
  theme(plot.title=element_text(face="bold",size=12))+
  theme(plot.subtitle=element_text(size=11))+  

  theme(plot.caption=element_text(size=8))

CED_map
CED_map_remove_6

```

Electoral divisions in Australia
It turns out we divide the country in very non-standard blocks



Data: Australian Bureau of Statistics 2016

194 electoral divisions in Australia
Turns out removing the largest 6 electorates makes a difference



Data: Australian Bureau of Statistics 2016

Next let's look at what party/candidate is currently the sitting member for each electorate. To do this on a map we're going to need to join our tcp22 data and the ced2021 spatial data.

In the first data set, the electorate column in called 'DivisionNm' and in the second 'ced_name_2021'.

We see the data in our DivisionNm variable is in UPPERCASE while our

ced_name_2021 variable is in Titlecase. Let's change the first variable to Titlecase to match.

We can then join the two dataframes using the left_join function.

```
#Pull in the electorate shapefiles from the absmapsdata package
electorates <- ced2021

#Make the DivisionNm Titlecase
tcp22$DivisionNm=str_to_title(tcp22$DivisionNm)

tcp22_edit <- tcp22 %>% distinct() %>% filter(Elected == "Y")

#Make the column names the same
electorates <- dplyr::rename(electorates, DivisionNm = ced_name_2021)

ced_map_data <- left_join(tcp22_edit, electorates, by = "DivisionNm")

ced_map_data <- as.data.frame(ced_map_data)

head(ced_map_data, n=151)
```

Analysis

Let's start by answering a simple question: who won the election? For this we'll need to use the two-candidate preferred data set (to make sure we capture all the minor parties that won seats).

Note in the table above, the PartyNm variable is a mess. Some candidates noted their party by it's abbreviation rather than full name, others put in a state specific prefix. For this analysis, the PartyAb variable is cleaner to use.

```
who_won <- tcp22 %>%
  filter(Elected == "Y") %>%
  group_by(PartyAb) %>%
  tally() %>%
  arrange(desc(n))

head(who_won, n=10)

## # A tibble: 7 x 2
##   PartyAb     n
##   <chr>    <int>
## 1 ALP        77
```

```
## 2 LP      48
## 3 IND     10
## 4 NP      10
## 5 GRN     4
## 6 KAP     1
## 7 XEN     1
```

Next up let's see which candidates won with the smallest percentage of first preference votes. Australia's preferential voting system normally makes these numbers quite interesting.

```
who_won_least_votes_prop <- fp22 %>%
  filter(Elected == "Y") %>%
  arrange(Percent) %>%
  mutate(candidate_full_name = paste0(GivenNm, " ", Surname, " (", CandidateID, ")"))
  dplyr::select(candidate_full_name, PartyNm, DivisionNm, Percent)

head(who_won_least_votes_prop, n=10)

## # A tibble: 10 x 4
##   candidate_full_name       PartyNm    DivisionNm  Percent
##   <chr>                  <chr>      <chr>        <dbl>
## 1 KYLEA JANE TINK (37452) INDEPENDENT NORTH SYDNEY 25.2
## 2 SAM BIRRELL (36061)    NATIONAL PARTY NICHOLLS 26.1
## 3 STEPHEN BATES (37338) QUEENSLAND GREENS BRISBANE 27.2
## 4 MICHELLE ANANDA-RAJAH (36433) AUSTRALIAN LABOR PARTY HIGGINS 28.5
## 5 JUSTINE ELLIOT (36802) AUSTRALIAN LABOR PARTY RICHMOND 28.8
## 6 BRIAN MITCHELL (37276) AUSTRALIAN LABOR PARTY LYONS 29.0
## 7 KATE CHANEY (36589)    INDEPENDENT CURTIN 29.5
## 8 DAI LE (36240)         INDEPENDENT FOWLER 29.5
## 9 ELIZABETH WATSON-BROWN (37370) QUEENSLAND GREENS RYAN 30.2
## 10 REBEKHA SHARKIE (37710) CENTRE ALLIANCE MAYO 31.4
```

This is really something.

The relationship we're seeing here seems to be these are *many* the seats that are won with barely 30% of the first preference vote.

The electorate I grew up in is listed here (Richmond) - let's look at how the votes were allocated.

```
Richmond_fp <- fp22 %>%
  filter(DivisionNm == "RICHMOND") %>%
  arrange(-Percent) %>%
  mutate(candidate_full_name = paste0(GivenNm, " ", Surname, " (", CandidateID, ")"))
```

```
dplyr::select(candidate_full_name, PartyNm, DivisionNm, Percent, OrdinaryVotes)
head(Richmond_fp, n=10)

## # A tibble: 10 x 5
##   candidate_full_name     PartyNm    DivisionNm Percent OrdinaryVotes
##   <chr>          <chr>        <chr>      <dbl>       <dbl>
## 1 JUSTINE ELLIOT (36802) AUSTRALIAN L~ RICHMOND  28.8      28733
## 2 MANDY NOLAN (36361)   THE GREENS   RICHMOND  25.3      25216
## 3 KIMBERLY HONE (36351) NATIONAL PAR~ RICHMOND  23.4      23299
## 4 GARY BIGGS (36648)    LIBERAL DEMO~ RICHMOND  7.7       7681
## 5 TRACEY BELL-HENSELIN (37831) ONE NATION   RICHMOND  4.08      4073
## 6 ROBERT JAMES MARKS (37084) UNITED AUSTR~ RICHMOND  2.93      2922
## 7 DAVID WARTH (37813)    INDEPENDENT RICHMOND  2.35      2341
## 8 MONICA SHEPHERD (36408) INFORMED MED~ RICHMOND  2.28      2271
## 9 NATHAN JONES (37721)   INDEPENDENT RICHMOND  1.98      1974
## 10 TERRY PATRICK SHARPLES (37823) INDEPENDENT RICHMOND 1.28      1274
```

Sure enough - the Greens certainly helped get the ALP across the line.

The interpretation that these seats are the ‘most marginal’ is incorrect under a preferential voting system (e.g. imagine if ALP win 30% and the Greens win 30% - that is a pretty safe 10% margin assuming traditional preference flows).

But - let’s investigate which seats are the most marginal.

```
who_won_smallest_margin <- tcp22 %>%
  filter(Elected == "Y") %>%
  mutate(percent_margin = 2*(Percent - 50), vote_margin = round(percent_margin * OrdinaryVotes / 100))
  arrange(Percent) %>%
  mutate(candidate_full_name = paste0(GivenNm, " ", Surname, " (", CandidateID, ")")) %>%
  dplyr::select(candidate_full_name, PartyNm, DivisionNm, Percent, OrdinaryVotes, percent_margin)

head(who_won_smallest_margin, n=20)

## # A tibble: 20 x 7
##   candidate_full_name     PartyNm DivisionNm Percent OrdinaryVotes percent_margin
##   <chr>          <chr>        <chr>      <dbl>       <dbl>       <dbl>
## 1 FIONA PHILLIPS (3677~ AUSTRALIAN LIBERA~ Gilmore  50.2      56039      0.340
## 2 MICHAEL SUKKAR (3671~ LIBERAL Deakin  50.2      50322      0.380
## 3 JAMES STEVENS (37067) LIBERAL Sturt   50.4      56813      0.900
## 4 IAN GOODENOUGH (3659~ LIBERAL Moore   50.7      52958      1.32
## 5 KEITH WOLAHAN (36733) LIBERAL Menzies  50.7      51198      1.36
## 6 BRIAN MITCHELL (3727~ AUSTRALIAN Lyons  50.9      37341      1.84
## 7 MARION SCRIMGOUR (37~ A.L.P. Lingiari 51.0      23339      1.90
```

```

##  8 JEROME LAXALE (36827) AUSTRALIAN LIBERAL Bennelong    51.0    50801   1.96
##  9 KATE CHANEY (36589) INDEPENDENT Curtin            51.3    53847   2.52
## 10 BRIDGET KATHLEEN ARC LIBERAL Bass                 51.4    35288   2.86
## 11 AARON VIOLI (36711) LIBERAL Casey                51.5    51283   2.96
## 12 DAI LE (36240) INDEPENDENT Fowler               51.6    44348   3.26
## 13 PETER DUTTON (37493) LIBERAL Dickson             51.7    51196   3.40
## 14 MICHELLE ANANDA-RAJA AUSTRALIAN LIBERAL Higgins  52.1    49726   4.12
## 15 GORDON REID (36801) AUSTRALIAN LIBERAL Robertson 52.3    50277   4.52
## 16 PAT CONAGHAN (36342) NATIONAL Cowper              52.3    58204   4.64
## 17 SAM LIM (37337) AUSTRALIAN LIBERAL Tangney         52.4    56331   4.76
## 18 SOPHIE SCAMPS (37450) INDEPENDENT Mackellar        52.5    51973   5
## 19 ELIZABETH WATSON-BROWN QUEENSLAND Liberal Ryan   52.6    52286   5.3
## 20 ALAN TUDGE (36704) LIBERAL Aston                 52.8    51840   5.62
## # i 1 more variable: vote_margin <dbl>

```

Crikey. We see Fiona Phillips in Gilmore got in with a 0.17% margin (just 380 votes!)

While we're at it, we better do the opposite and see who romped it in by the largest margin.

```

who_won_largest_margin <- tcp22 %>%
  filter(Elected == "Y") %>%
  mutate(percent_margin = 2*(Percent - 50), vote_margin = round(percent_margin * OrdinaryVotes))
  arrange(desc(Percent)) %>%
  mutate(candidate_full_name = paste0(GivenNm, " ", Surname, " (", CandidateID, ")"))
  dplyr::select(candidate_full_name, PartyNm, DivisionNm, Percent, OrdinaryVotes, percent_margin)

head(who_won_largest_margin, n=20)

## # A tibble: 20 x 7
##   candidate_full_name   PartyNm DivisionNm Percent OrdinaryVotes percent_margin
##   <chr>          <chr>     <chr>      <dbl>       <dbl>           <dbl>
## 1 DAVID LITTLEPROUD (3~ LIBERAL Maranoa    72.1      67153           44.2
## 2 ANDREW WILKIE (33553) INDEPENDENT Clark    70.8      46668           41.6
## 3 DARREN CHESTER (3604~ NATIONAL Gippsland   70.6      71205           41.1
## 4 ANNE WEBSTER (36060) NATIONAL Mallee     69.0      70523           38.0
## 5 SHARON CLAYDON (3680~ AUSTRALIAN Newcastle 68.0      71807           36.0
## 6 MARK COULTON (36363) NATIONAL Parkes     67.8      60433           35.7
## 7 ANTHONY ALBANESE (36~ AUSTRALIAN Grayndler 67.0      63413           34.1
## 8 JOSH WILSON (37314) AUSTRALIAN Fremantle  66.9      65585           33.8
## 9 MADELEINE KING (3718~ AUSTRALIAN Brand     66.7      63829           33.4
## 10 TANYA PLIBERSEK (368~ AUSTRALIAN Sydney    66.7      68770           33.4
## 11 TONY PASIN (37083) LIBERAL Barker       66.6      70483           33.2
## 12 DANIEL MULINO (36385) AUSTRALIAN Fraser    66.5      61251           33

```

```
## 13 BARNABY JOYCE (36335) NATION~ New Engla~ 66.4 64622 32.9
## 14 SUSSAN LEY (37032) LIBERA~ Farrer 66.4 66739 32.7
## 15 AMANDA RISHWORTH (36~ AUSTRA~ Kingston 66.4 72564 32.7
## 16 ANDREW LEIGH (36234) AUSTRA~ Fenner 65.7 59966 31.4
## 17 ANDREW GILES (36447) AUSTRA~ Scullin 65.6 59761 31.2
## 18 LINDA BURNEY (36820) AUSTRA~ Barton 65.5 60054 31.1
## 19 MATT KEOGH (37195) AUSTRA~ Burt 65.2 59704 30.4
## 20 TONY BURKE (36809) AUSTRA~ Watson 65.1 55810 30.2
## # i 1 more variable: vote_margin <dbl>
```

Wowza. That's really something. Some candidates won seats with a 40-45 percent margin - scooping up 70% of the two candidate preferred vote in the process!

We can also cut the seats by state for a look at where the ‘strongholds’ are across the country.

```
who_won <- tpp22 %>%
  filter(Elected == "Y") %>%
  group_by(PartyAb, StateAb) %>%
  tally() %>%
  arrange(desc(n))

who_won_by_state <- spread(who_won, StateAb, n) %>% arrange(desc(NSW))

head(who_won_by_state, n=10)
```

Trends

Now we've figured out how to work with election data - let's link it up to some Australian demographic data. The eechidna package includes a cleaned set of census data from 2022 that has already been adjusted from ASGS boundaries to Commonwealth Electoral Divisions.

```
# Import the census data from the eechidna package
data(eechidna::abs2021)
head(abs2021)

# Join with two-party preferred voting data
data(tpp10)
election2022 <- left_join(abs2021, tpp10, by = "DivisionNm")
```

That's what we want to see. 151 rows of data (one for each electorate) and over 80 columns of census variables.

A starting exploratory exercise is to see which of these variables are correlated with voting for one party or another. There's some old narrative around LNP voters being rich, old, white, and somehow 'upper class' compared to the population at large. Let's pick a few variables that roughly match with this criteria (Income, Age, English language speakers, and Bachelor educated) and chart it compared to LNP percentage of the vote.

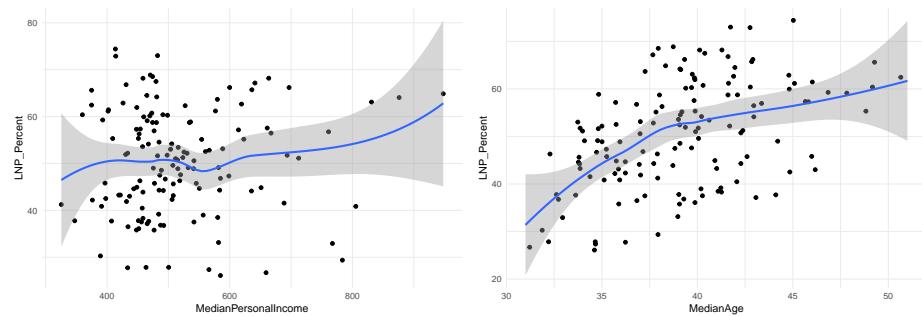
```
# See relationship between personal income and Liberal/National support

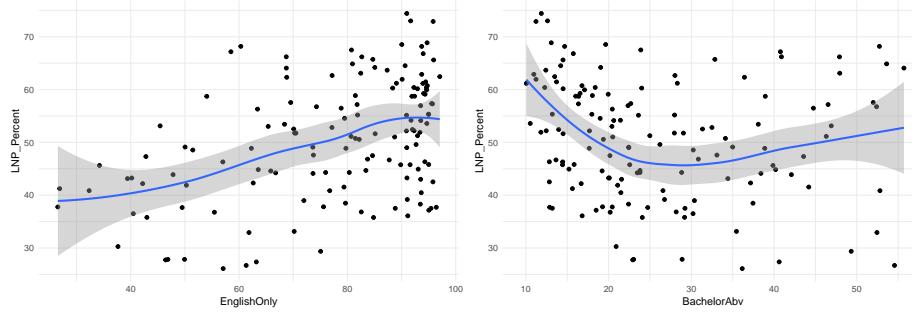
ggplot(election2022, aes(x = MedianPersonalIncome, y = LNP_Percent)) +
  geom_point() +
  geom_smooth() +
  theme_minimal()

ggplot(election2022, aes(x = MedianAge, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()

ggplot(election2022, aes(x = EnglishOnly, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()

ggplot(election2022, aes(x = BachelorAbv, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()
```





First impressions: Geez this data looks messy.

Second impression: Maybe there's a bit of a trend with age and income?

Let's build a regression model to run all the 80 odd census variables in the abs2022 data set against the LNP_percent variable.

```
# We can use colnames(election2022) to get a big list of all the variables available

# Now we build the model
election_model <- lm(LNP_Percent ~
  Population +
  Area +
  Age00_04 +
  Age05_14 +
  Age15_19 +
  Age20_24 +
  Age25_34 +
  Age35_44 +
  Age45_54 +
  Age55_64 +
  Age65_74 +
  Age75_84 +
  Age85plus +
  Anglican +
  AusCitizen +
  AverageHouseholdSize +
  BachelorAbv + Born_Asia +
  Born_MidEast + Born_SE_Europe +
  Born_UK +
  BornElsewhere +
  Buddhism +
  Catholic +
  Christianity +
  Couple_NoChild_House + Couple_WChild_House +
  CurrentlyStudying + DeFacto)
```

```

DiffAddress+
DipCert+
EnglishOnly+
FamilyRatio+
Finance+
HighSchool+
Indigenous+
InternetUse+
Islam+
Judaism+
Laborer+
LFParticipation+
Married+
MedianAge+
MedianFamilyIncome+
MedianHouseholdIncome+
MedianLoanPay+
MedianPersonalIncome+
MedianRent+
Mortgage+
NoReligion+
OneParent_House+
Owned+
Professional+
PublicHousing+
Renting+
SocialServ+
SP_House+
Tradesperson+
Unemployed+
Volunteer,
data=election2022)

summary(election_model)

##
## Call:
## lm(formula = LNP_Percent ~ Population + Area + Age00_04 + Age05_14 +
##     Age15_19 + Age20_24 + Age25_34 + Age35_44 + Age45_54 + Age55_64 +
##     Age65_74 + Age75_84 + Age85plus + Anglican + AusCitizen +
##     AverageHouseholdSize + BachelorAbv + Born_Asia + Born_MidEast +
##     Born_SE_Europe + Born_UK + BornElsewhere + Buddhism + Catholic +
##     Christianity + Couple_NoChild_House + Couple_WChild_House +
##     CurrentlyStudying + DeFacto + DiffAddress + DipCert + EnglishOnly +
##     FamilyRatio + Finance + HighSchool + Indigenous + InternetUse +
##     Islam +
##     Judaism +
##     Laborer +
##     LFParticipation +
##     Married +
##     MedianAge +
##     MedianFamilyIncome +
##     MedianHouseholdIncome +
##     MedianLoanPay +
##     MedianPersonalIncome +
##     MedianRent +
##     Mortgage +
##     NoReligion +
##     OneParent_House +
##     Owned +
##     Professional +
##     PublicHousing +
##     Renting +
##     SocialServ +
##     SP_House +
##     Tradesperson +
##     Unemployed +
##     Volunteer,
##     data = election2022)

```

```

## Islam + Judaism + Laborer + LFParticipation + Married + MedianAge +
## MedianFamilyIncome + MedianHouseholdIncome + MedianLoanPay +
## MedianPersonalIncome + MedianRent + Mortgage + NoReligion +
## OneParent_House + Owned + Professional + PublicHousing +
## Renting + SocialServ + SP_House + Tradesperson + Unemployed +
## Volunteer, data = election2022)
##
## Residuals:
##      Min       1Q     Median      3Q      Max
## -11.9358 -2.0714 -0.1947  2.1152  8.1823
##
## Coefficients: (1 not defined because of singularities)
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 2.973e+04 1.408e+04 2.111 0.037912 *
## Population  8.911e-05 4.885e-05 1.824 0.071865 .
## Area        7.945e-06 5.069e-06 1.567 0.120957
## Age00_04   -2.830e+02 1.402e+02 -2.018 0.046910 *
## Age05_14   -2.923e+02 1.403e+02 -2.084 0.040367 *
## Age15_19   -2.793e+02 1.401e+02 -1.993 0.049677 *
## Age20_24   -2.989e+02 1.402e+02 -2.132 0.036042 *
## Age25_34   -2.921e+02 1.404e+02 -2.080 0.040715 *
## Age35_44   -2.942e+02 1.401e+02 -2.100 0.038900 *
## Age45_54   -2.921e+02 1.404e+02 -2.080 0.040689 *
## Age55_64   -2.903e+02 1.400e+02 -2.073 0.041402 *
## Age65_74   -2.888e+02 1.401e+02 -2.062 0.042477 *
## Age75_84   -2.844e+02 1.404e+02 -2.025 0.046152 *
## Age85plus  -3.014e+02 1.398e+02 -2.156 0.034123 *
## Anglican    8.452e-01 4.518e-01 1.871 0.065057 .
## AusCitizen  4.673e-01 7.032e-01 0.664 0.508282
## AverageHouseholdSize -2.556e+01 1.684e+01 -1.518 0.133076
## BachelorAbv -3.068e+00 8.049e-01 -3.812 0.000270 ***
## Born_Asia   3.963e-01 3.771e-01 1.051 0.296516
## Born_MidEast 1.091e+00 1.029e+00 1.060 0.292396
## Born_SE_Europe -1.628e+00 2.119e+00 -0.768 0.444585
## Born_UK      1.487e-01 4.886e-01 0.304 0.761591
## BornElsewhere 7.110e-01 5.618e-01 1.266 0.209346
## Buddhism     -1.097e+00 7.070e-01 -1.551 0.124835
## Catholic     -6.257e-01 4.202e-01 -1.489 0.140356
## Christianity 5.736e-01 5.095e-01 1.126 0.263605
## Couple_NoChild_House -1.581e+00 3.747e+00 -0.422 0.674192
## Couple_WChild_House -3.264e-01 4.061e+00 -0.080 0.936150
## CurrentlyStudying -4.117e-01 1.241e+00 -0.332 0.740988
## DeFacto      -6.600e+00 1.931e+00 -3.417 0.000997 ***
## DiffAddress   9.427e-01 3.174e-01 2.970 0.003935 **
## DipCert      -9.857e-01 6.871e-01 -1.435 0.155319
## EnglishOnly  -3.977e-01 4.103e-01 -0.969 0.335365

```

```

## FamilyRatio      -2.873e+01  4.547e+01  -0.632  0.529296
## Finance         1.399e+00  8.717e-01   1.605  0.112372
## HighSchool      7.160e-01  4.161e-01   1.721  0.089173 .
## Indigenous     3.919e-01  4.572e-01   0.857  0.393876
## InternetUse    NA          NA          NA      NA
## Islam            -4.161e-01  5.624e-01  -0.740  0.461601
## Judaism          4.377e-01  6.511e-01   0.672  0.503385
## Laborer          -8.258e-01  7.283e-01  -1.134  0.260251
## LFParticipation 6.822e-01  6.359e-01   1.073  0.286562
## Married          -5.852e+00  1.734e+00  -3.375  0.001141 **
## MedianAge        -9.926e-01  1.036e+00  -0.958  0.340782
## MedianFamilyIncome -3.456e-02  2.524e-02  -1.369  0.174711
## MedianHouseholdIncome 6.410e-02  2.756e-02   2.326  0.022568 *
## MedianLoanPay    -1.889e-02  1.143e-02  -1.653  0.102290
## MedianPersonalIncome 2.957e-02  5.171e-02   0.572  0.569043
## MedianRent        6.781e-03  5.786e-02   0.117  0.906997
## Mortgage          2.021e-02  1.406e+00   0.014  0.988568
## NoReligion        6.649e-01  4.779e-01   1.391  0.167983
## OneParent_House  -6.243e+00  3.876e+00  -1.611  0.111150
## Owned             1.168e-02  1.334e+00   0.009  0.993036
## Professional      1.314e+00  8.840e-01   1.487  0.141064
## PublicHousing     -8.154e-01  5.754e-01  -1.417  0.160350
## Renting            -2.602e-02  1.463e+00  -0.018  0.985859
## SocialServ         -5.254e-02  4.674e-01  -0.112  0.910776
## SP_House           -2.021e-01  8.735e-01  -0.231  0.817658
## Tradesperson       -1.299e-01  7.929e-01  -0.164  0.870301
## Unemployed         -4.229e+00  1.503e+00  -2.814  0.006160 **
## Volunteer          4.773e-01  6.417e-01   0.744  0.459120
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.729 on 80 degrees of freedom
##   (11 observations deleted due to missingness)
## Multiple R-squared:  0.8975, Adjusted R-squared:  0.822
## F-statistic: 11.88 on 59 and 80 DF,  p-value: < 2.2e-16

```

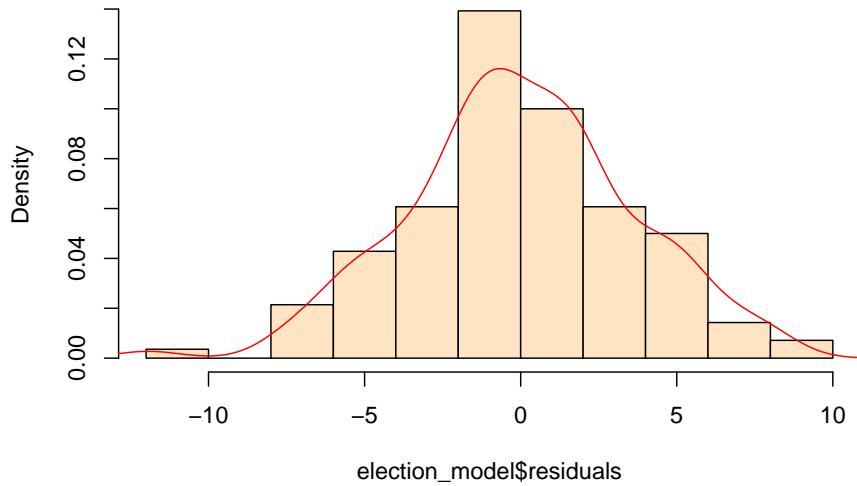
For the people that care about statistical fit and endogenous variables, you may have concerns (and rightly so) with the above approach.

It's pretty rough. Let's run a basic check to see if the residuals are normally distributed.

```

hist(election_model$residuals, col="bisque", freq=FALSE, main=NA)
lines(density(election_model$residuals), col="red")

```



Hmm... that's actually not too bad. Onwards.

We see now that only a handful of these variables in the table above are statistically significant. Running an updated (and leaner) model gives:

```
election_model_lean <- lm(LNP_Percent ~
  BachelorAbv +
  CurrentlyStudying +
  DeFacto +
  DiffAddress +
  Finance + HighSchool +
  Indigenous +
  LFParticipation +
  Married +
  NoReligion,
  data = election2022)

summary(election_model_lean)

ggplot(election2022, aes(x = BachelorAbv, y = LNP_Percent)) +
  geom_point() +
  geom_smooth() +
  theme_minimal()

ggplot(election2022, aes(x = CurrentlyStudying, y = LNP_Percent)) +
  geom_point() +
  geom_smooth() +
  theme_minimal()
```

```
geom_jitter() +
geom_smooth() +
theme_minimal()

ggplot(election2022, aes(x = DeFacto, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()

ggplot(election2022, aes(x = DiffAddress, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()

ggplot(election2022, aes(x = Finance, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()

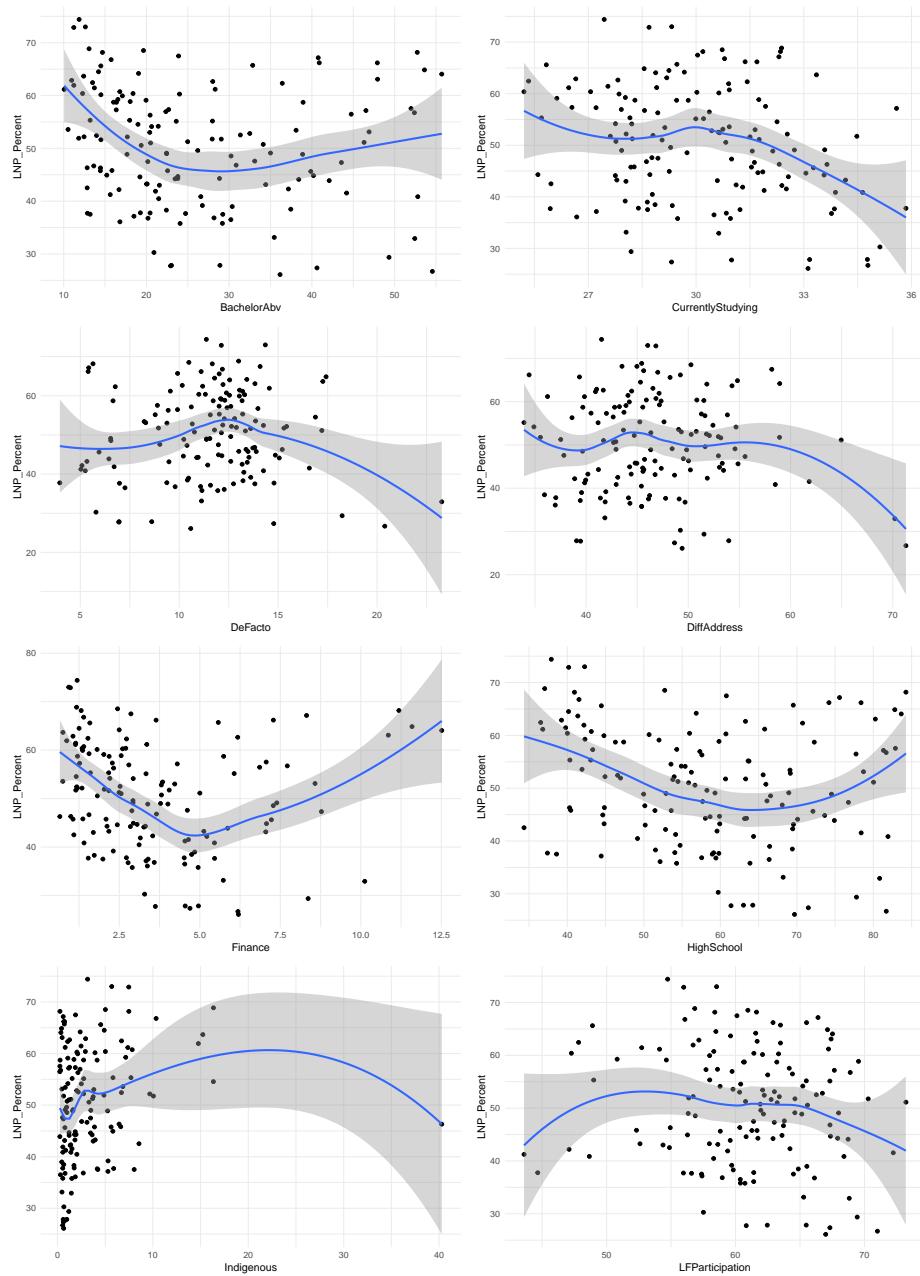
ggplot(election2022, aes(x = HighSchool, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()

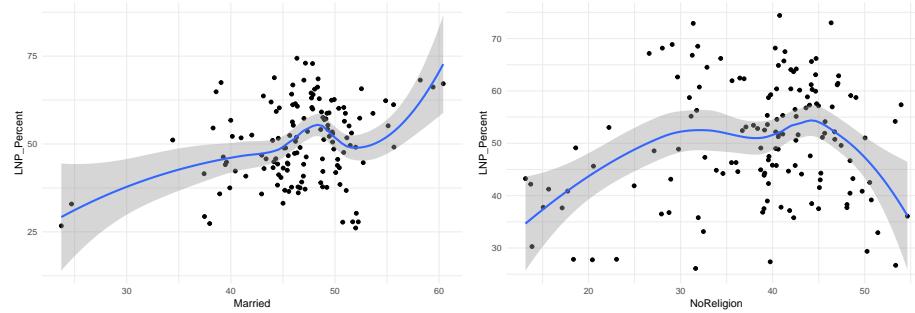
ggplot(election2022, aes(x = Indigenous, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()

ggplot(election2022, aes(x = LFParticipation, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()

ggplot(election2022, aes(x = Married, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()

ggplot(election2022, aes(x = NoReligion, y = LNP_Percent)) +
  geom_jitter() +
  geom_smooth() +
  theme_minimal()
```





One of the more novel issues with the above analysis is that it's done on the electorate level, however electorates vary dramatically in size (google the Modifiable Area Unit Problem if this piques your interest)

Instead of using one data point for a whole electorate (regardless of how big it is), we can fetch data from all 7,000 voting booths, the match it up with the corresponding local demographic data.

Booth data

The AEC maintains a handy spreadsheet of booth locations for recent federal elections. You can search for your local booth location (probably a school, church, or community center) in the table below.

```
## # A tibble: 10 x 15
##   State DivisionID DivisionNm PollingPlaceID PollingPlaceTypeID PollingPlaceNm
##   <chr>      <dbl> <chr>           <dbl>          <dbl> <chr>
## 1 ACT         101  Canberra        8829            1 Barton
## 2 ACT         101  Canberra       64583           5 Belconnen CANB-
## 3 ACT         101  Canberra      65504           5 BLV Canberra P-
## 4 ACT         101  Canberra     11877            1 Bonython
## 5 ACT         101  Canberra     8802             1 Braddon (Canbe-
## 6 ACT         101  Canberra    11452            1 Calwell
## 7 ACT         101  Canberra    8806            1 Campbell
## 8 ACT         101  Canberra    8761            1 Chapman
## 9 ACT         101  Canberra    8763            1 Chisholm
## 10 ACT        101  Canberra   8808            1 City (Canberra)
## # i 9 more variables: PremisesNm <chr>, PremisesAddress1 <chr>,
## #   PremisesAddress2 <chr>, PremisesAddress3 <chr>, PremisesSuburb <chr>,
## #   PremisesStateAb <chr>, PremisesPostCode <chr>, Latitude <dbl>,
## #   Longitude <dbl>
```

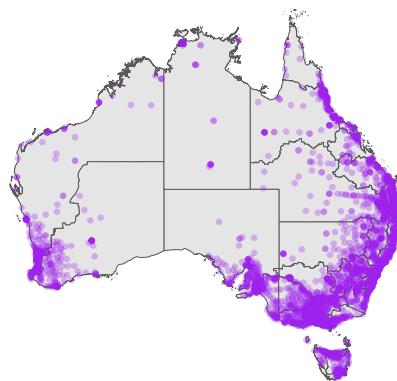
What do these booths look like on a map? Let's reuse the CED map above and plot a point for each booth location.

```

ggplot() +
  geom_sf(data = ced2021) +
  geom_point(data = booths, aes(x = Longitude, y = Latitude),
             colour = "purple", size = 1, alpha = 0.3, inherit.aes = FALSE) +
  labs(
    title = "Polling booths in Australia",
    subtitle = " ",
    caption = "Data: Australian Electoral Commission 2016",
    x = "",
    y = ""
  ) +
  theme_minimal() +
  theme(
    axis.ticks.x = element_blank(),
    axis.text.x = element_blank(),
    axis.ticks.y = element_blank(),
    axis.text.y = element_blank(),
    panel.grid.major = element_blank(),
    panel.grid.minor = element_blank(),
    legend.position = "right",
    plot.title = element_text(size = 12),
    plot.subtitle = element_text(size = 11),
    plot.caption = element_text(size = 8)
  ) +
  xlim(c(112, 157)) +
  ylim(c(-44, -11))

```

Polling booths in Australia



Data: Australian Electoral Commission 2016

Figuring out where a candidates votes come from *within* an electorate is funda-

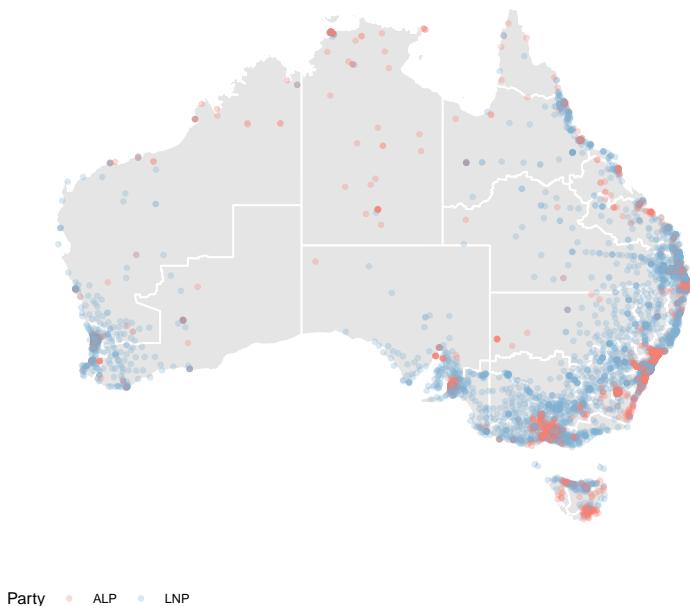
mental to developing a campaign strategy. Even in small electorates (e.g. Wentworth), there are pockets of right leaning and left leaning districts. Once you factor in preference flows, this multi-variate calculus becomes important to winning or maintaining a seat.

In the `eechidnapackage`, election results are provided at the resolution of polling place. Unfortunately, these are yet to be updated for elections after 2016.

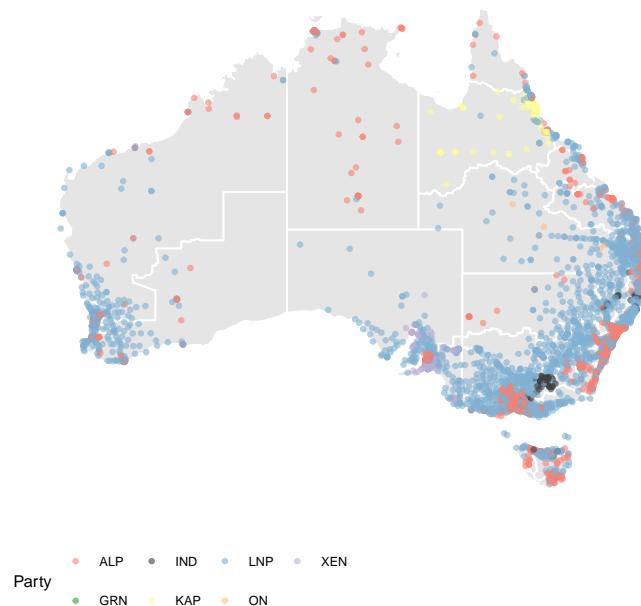
The data sets must be downloaded using the functions `firstpref_pollingbooth_download`, `twoparty_pollingbooth_download` or `twocand_pollingbooth_download` (depending on the vote type).

The two files need to be merged to be useful for analysis. Both have a unique ID for the polling place that can be used to match the records. The two party preferred vote, a measure of preference between only the Australian Labor Party (ALP) and the Liberal/National Coalition (LNP), is downloaded using `twoparty_pollingbooth_download`. The preferred party is the one with the higher percentage, and we use this to colour the points indicating polling places.

We see that within some big rural electorates (e.g. in Western NSW), there are pockets of ALP preference despite the seat going to the LNP. Note that this data set is on a tpp basis - so we can't see the booths that were won by minor parties (although it would be fascinating). We see that within some big rural electorates (e.g. in Western NSW), there are pockets of ALP preference despite the seat going to the LNP. Note that this data set is on a tpp basis - so we can't see the booths that were won by minor parties (although it would be fascinating).



The two candidate preferred vote (downloaded with `twocand_pollingbooth_download`) is a measure of preference between the two candidates who received the most votes through the division of preferences, where the winner has the higher percentage.



Informal votes

Over 700,000 people (around 5% of all votes cast) vote informally each election. Of these, over have ‘no clear first preference’, meaning their vote did not contribute to the campaign of any candidate.

I’ll be honest, informal votes absolutely *fascinate* me. Not only are there 8 types of informal votes (you can read all about the Australian Electoral Commission’s analysis here), but the rate of informal voting varies a tremendous amount by electorate.

Broadly, we can think of informal votes in two main buckets.

1. Protest votes
2. Stuff-ups

If we want to get particular about it, I like to subcategorise these buckets into:

1. Protest votes (i.e. a person that thinks they are voting against):
 - the democratic system,
 - their local selection of candidates on the ballot, or
 - the two most likely candidates for PM.
2. Stuff ups (people who):
 - filled in the form wrong but a clear preference was still made
 - stuffed up the form entirely and it didn't contribute towards the tally for any candidate

The AEC works tirelessly to reduce stuff-ups on ballot papers (clear instructions and UI etc), but there isn't much of a solution for protest votes.

Bayesian for the common man

