R Without Statistics

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# About the Book

This is the in-progress version of *R Without Statistics*, a forthcoming book from [No Starch Press](https://www.nostarch.com/).

Since R was invented in 1993, it has become a widely used programming language for statistical analysis. From academia to the tech world and beyond, R is used for a wide range of statistical analysis.

R’s ubiquity in the world of statistics leads many to assume that it is only useful to those who do complex statistical work. But as R has grown in popularity, the number of ways it can be used has grown as well. Today, R is used for:

* Data visualization
* Map making
* Sharing results through reports, slides, and websites
* Automating processes
* And much more!

The idea that R is only for statistical analysis is outdated and inaccurate. But, without a single book that demonstrates the power of R for non-statistical purposes, this perception persists.

**Enter R Without Statistics.**

R Without Statistics will show ways that R can be used beyond complex statistical analysis. Readers will learn about a range of uses for R, many of which they have likely never even considered.

Each chapter will, using a consistent format, cover one novel way of using R.

1. Readers will first be introduced to an R user who has done something novel and learn how using R in this way transformed their work.
2. Following this, there will be code samples that demonstrate exactly how the R user did the thing they are being profiled for.
3. Finally, there will be a summary, with lessons learned from this novel way of using R.

Written by David Keyes, Founder and CEO of [R for the Rest of Us](https://rfortherestofus.com/), R Without Statistics will be published by [No Starch Press](https://nostarch.com/).

# 1 Why R Without Statistics?

In early 2020, as COVID spread across the world, the government of New Zealand began planning their response. New Zealand had one major advantage that other countries lacked: being a remote island. This bought the country some time, but those working in the government knew that this head start would not last forever. Unless they quickly developed a plan to tackle COVID, New Zealand faced the same bleak future that other countries were already beginning to experience.

Of course, New Zealand did develop a plan to tackle COVID. As one of the few countries to largely keep COVID out in 2020 and 2021, New Zealand came to be seen as a model for how to respond to a global pandemic. While other countries were forced into repeated lockdowns due out of control COVID spread, life in New Zealand remained largely normal.

There are many reasons why New Zealand was so successful in tackling COVID. One of these was its use of R. Yes, R.

To understand how R helped New Zealand tackle COVID, let’s go back a bit before the pandemic. In the years leading up to 2020, the Ministry of Health had begun to transition from SAS to R. So when COVID finally arrived on the shores of New Zealand in February 2020, they had the knowledge of R to use it as their main analysis and reporting tool.

But while people at Ministry of Health had R skills, they did not have a reporting system in place for a virus like COVID. Government officials and the general public needed to know how many cases there were in New Zealand and whether these cases were the result of international arrivals or community spread. And they didn’t need to know just once. They needed to know every day. As Chris Knox, who led a team at the Ministry of Health focused on the COVID response in 2021 and 2022 told me,

Our general infectious disease reporting was not designed to be day to day. There were systems in place for reporting at the end of the year after everything had been tidied up.

Creating a system to report daily on COVID data was no small feat. But because the Ministry of Health was already using R, they were able to leverage its power to make their reporting efficient.

The work did involve complex analysis. Case reports from across New Zealand would go into a database. The Ministry of Health team would then pull data to generate reports on cases throughout the country. But the reporting requirements were high. The team had to produce three daily reports:

1. A 9:00am summary of cases for high-level government officials.
2. An 11:00am situation report, complete with charts and tables, sent out to a wide range of government officials.
3. A 1:00pm public release of data on a Ministry of Health website.

There were a few tricky steps along the way. The team had to make sure to not double count cases from previous days before separating out international arrival and community spread cases. But, again, these reports did not involve any complex statistics. They were, quite literally, counting cases.

So why am I discussing the New Zealand Ministry of Health’s use of R, a tool designed for statistics, to generate reports where the most complex statistic is counting? I’m using this example to highlight the power of R because it shows things that R can do that go beyond complex statistics.

Specifically, the way that the New Zealand Ministry of Health used R shows the power of a code-based tool to make work more reproducible. Reproducible is really just a fancy way of saying that it was way, way easier to make those three daily reports using R than it would have been with a point-and-click tool like Excel.

Reproducibility is a fancy word that often hides its true value. I used to hear it and think it referred to scientists recreating each other’s experiments in order to validate their results. But reproducibility really just means that code you write today can be run in another context. Sometimes this means someone else running your code. But sometimes it means you running the code you wrote last week. If last week’s code works when you run it again this week, it’s reproducible.

Getting previously written code to run day after day was key to the success of the New Zealand Ministry of Health team reporting on COVID cases. Producing the three daily reports manually would have quickly become untenable. But the process become viable because they wrote R code once and reused it day after day.

This isn’t to say that the original code the team wrote never changed. Reporting requirements shifted with time and the team at the Ministry of Health had to adapt. Chris Knox told me that, “at some points, the reporting requirements changed every day.” Fortunately, they could tweak their R code and re-run it to produce reports that met the new reporting needs.

R was an important tool in enabling a small team to generate daily reports that were key to New Zealand’s successful COVID response. It allowed a team of five or six people to produce reports much more efficiently than would otherwise have been possible. In spite of this, the intensity of the work led to some burnout. As team members left and new members joined, the Ministry of Health found that, again, R was key to their success. Because the team used code for their work, a new team member could read it, get themselves up to speed, and quickly begin contributing. The public nature of a code-based workflow stands in marked contrast the all-too-common situation where an outsized amount of institutional knowledge is found in one person’s brain (let’s call him Larry). If Larry leaves, the team’s work grinds to a halt. R not only makes work more efficient, it also ensures long-term continuity. Chris Knox described how this played out at the New Zealand Ministry of Health:

Setting up Larry’s analysis in Excel is usually faster than writing it up in code, but it’s harder to onboard people into that type of environment. If you have to just sit down, run this code, look for error messages, almost anyone can do that.

R also made collaboration among the Ministry of Health team easier. Being able to review code allowed team members to improve their collective work and learn from each other. To understand the true benefit this offers, consider again our friend Larry. If Larry works in Excel, say, so much of his work is hidden. Team members can’t see the set of points-and-clicks that Larry carries out to do his analysis. His colleagues can’t improve his work, and it’s much harder for them to learn from Larry.

R often feels intimidating to newcomers, especially those new to coding. But what the story of New Zealand’s COVID response shows us it that the power of R is huge. R was the main tool in a workflow that made it possible for a small team to produce regular reports every day for months on end. These reports didn’t involve any kind of complex statistics – they were literally counts of COVID cases. But the reproducibility of their R-based workflow is where the true value is found. As Chris Knox put it, “trying to do what we did in a point-and-click environment is not possible.” But with R, a small team helped a small island stay safe from COVID.

## How I Came to Use R

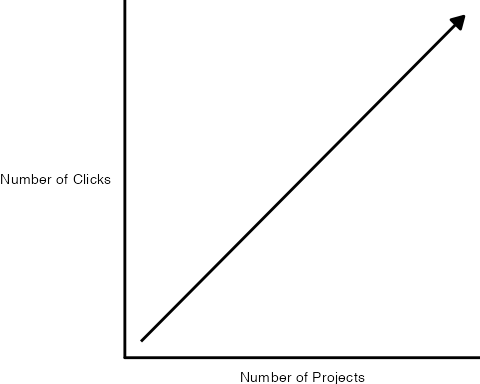
My own relationship with R goes back to 2016. At the time, I was a consultant, helping non-profits, government agencies, and educational institutions to measure the effectiveness of their work is (a field known as [program evaluation](https://www.cdc.gov/evaluation/index.htm)). A lot of my work involved conducting surveys, analyzing the resulting the data, and sharing the results with clients.

The work itself was fine, but the tools I was using to do it were getting on my nerves. Well, one tool really: Excel.

Now look, this is not a place for an anti-Excel rant. Excel is a fine tool that has empowered millions to work with data in ways they would never have been able to otherwise.

But I found Excel extremely tedious. The amount of pointing and clicking I had to do when working with the amount of data I had got old fast. Each time I would conduct a survey, I’d know that it would yield an avalanche of data and that my wrists would end up exhausted from hours of pointing and clicking.

No matter what I did, analyzing data and creating charts in Excel just involved a lot of repetitive pointing and clicking. Kind of like this:



Endless pointing and clicking was just one problem I faced using Excel. Annoying though it was, it didn’t affect the quality of my work. Or so I thought until I recalled a project I had worked on a few years earlier.

In this project, I was looking at which school districts in the state of Oregon have [outdoor education programs known as Outdoor School](https://oregonstate.app.box.com/s/83g5sjdm88xgqdxfze0ri7qo4uff5sj7). As part of this project, I had to download data on all school districts throughout Oregon, filter to only include relevant districts with fifth or sixth graders (the ages Outdoor School takes place), and then merge this with data that I collected as part of a survey I conducted.

I did the work in Excel, using a lot of (you guessed it!) pointing and clicking. The problem came when I was almost done with the project. I’ve blocked the details from my memory (as I’ve done with most things Excel-related), but what I do recall is not being 100% certain I had done my filtering and joining correctly. And, to make it worse, I had no way to check my work. Why? Because all my pointing and clicking was ephemeral, gone in the ether as soon as I had completed it.

I finished the Outdoor School project and submitted my report. The work I did was *probably* accurate, but maybe it wasn’t?

Now, you may be reading this thinking: why didn’t you write down the steps you used in Excel so you could retrace them later? Sure, I could (and should) have done that. But let’s be honest: most of us don’t.

We’re human. We’re lazy. We all make mistakes. And without a straightforward way to audit your work (and keeping a list of all of your Excel points and clicks in a separate document is not, in my view, straightforward), mistakes will happen. If you’ve used Excel to work with data, I guarantee you’ve made a mistake, just like me.

The good news is that it’s okay. There’s a solution. And that solution is R.

If I were to redo that project on Outdoor School with R, here’s what I’d do differently. Rather than watching points and clicks disappear into the ether, I’d write code that would serve as a record of everything I did. This code would:

Download data on all school districts:

# Download the data directly from the Oregon Department of Education website  
download.file(url = "https://www.oregon.gov/ode/educator-resources/assessment/Documents/TestResults2019/pagr\_schools\_ela\_tot\_raceethnicity\_1819.xlsx",  
 destfile = here::here("data/pagr\_schools\_ela\_tot\_raceethnicity\_1819.xlsx"))

# Import the downloaded data and use the `clean\_names()` function to make the variable names easy to work with  
oregon\_schools <- read\_excel(here::here("data/pagr\_schools\_ela\_tot\_raceethnicity\_1819.xlsx")) %>%   
 clean\_names()

Filter to only include districts with fifth or sixth graders:

# Start with the oregon\_schools data from above  
oregon\_schools\_fifth\_sixth\_grade <- oregon\_schools %>%   
   
 # Only keep schools with fifth or sixth graders  
 filter(grade\_level == "Grade 5" | grade\_level == "Grade 6") %>%   
   
 # Only keep the variables we need  
 select(district\_id:school) %>%   
   
 # There are multiple observations of the same school, just keep one of each  
 distinct()

Join the filtered data on school districts with my survey data:

# Use the school\_id variable to join the survey data with the oregon\_schools\_fifth\_sixth\_grade from above   
left\_join(survey\_data, oregon\_schools\_fifth\_sixth\_grade,  
 by = "school\_id")

## Code is Just a Written Record of Your Work

Code can be scary. Having to write code is one of the reasons many people never learn R. But code is just a list of things you want to do to your data. It may be written in a hard-to-parse syntax (though it gets easier over time), but it’s just a set of steps. The same steps that we should write out when we’re working in Excel, but never do. Rather than having a separate document with my steps written down, I can see my steps in my code. See that line that says filter? Guess what it’s doing? Yep, it’s filtering!

If I had done things this way when working on the Outdoor School project, I could have looked back at any point to make sure what I thought was happening to my data was in fact happening. That nagging sensation I had near the end of the project that I may have made a mistake in one of my early points or clicks? It never would have come up because I could have just reviewed my code to make sure it did what I thought it did. And if it didn’t, I could rewrite and rerun my code to get updated results.

Using R won’t mean you’ll never make mistakes again (trust me, you will). But it will mean that you can easily spot your mistakes, make changes, and fix any issues.

I started learning R to avoid tedious pointing and clicking. But what I found was that R improved my work in ways I never expected. It’s not just that my wrists are less tired. I now have more confidence that my work is accurate.

## R Can Do Much More Than Just Statistics

I used to feel ashamed about the way I use R. I use R, a tool for statistical analysis, but I don’t use it for complex statistical analysis. I don’t do machine learning. I don’t know what a random forest is. I’ve never run a regression in R. [The only statistics I do in R are descriptive statistics](https://rfortherestofus.com/2018/12/descriptive-stats-r/): counts, sums, averages, that type of thing.

For a long time, I felt like I wasn’t a “real” R user. Real R users, in my mind, used R for hardcore stats. I “only” used R for descriptive stats. I sometimes felt like I was using a souped up sports car to drive 20 miles an hour to the grocery store. What was the point in using a high-powered machine like R to do “simple” things?

Eventually, I realized that this framing misses the point. [R started out as a tool created by statisticians for other statisticians](https://rss.onlinelibrary.wiley.com/doi/10.1111/j.1740-9713.2018.01169.x). But, over a quarter century since its creation, R can do much more than statistical analysis.

My own use of R is an example of this. I think of my work with R in three buckets:

**Illuminate** through data visualization: making graphs, maps, and tables that look good and share results effectively.

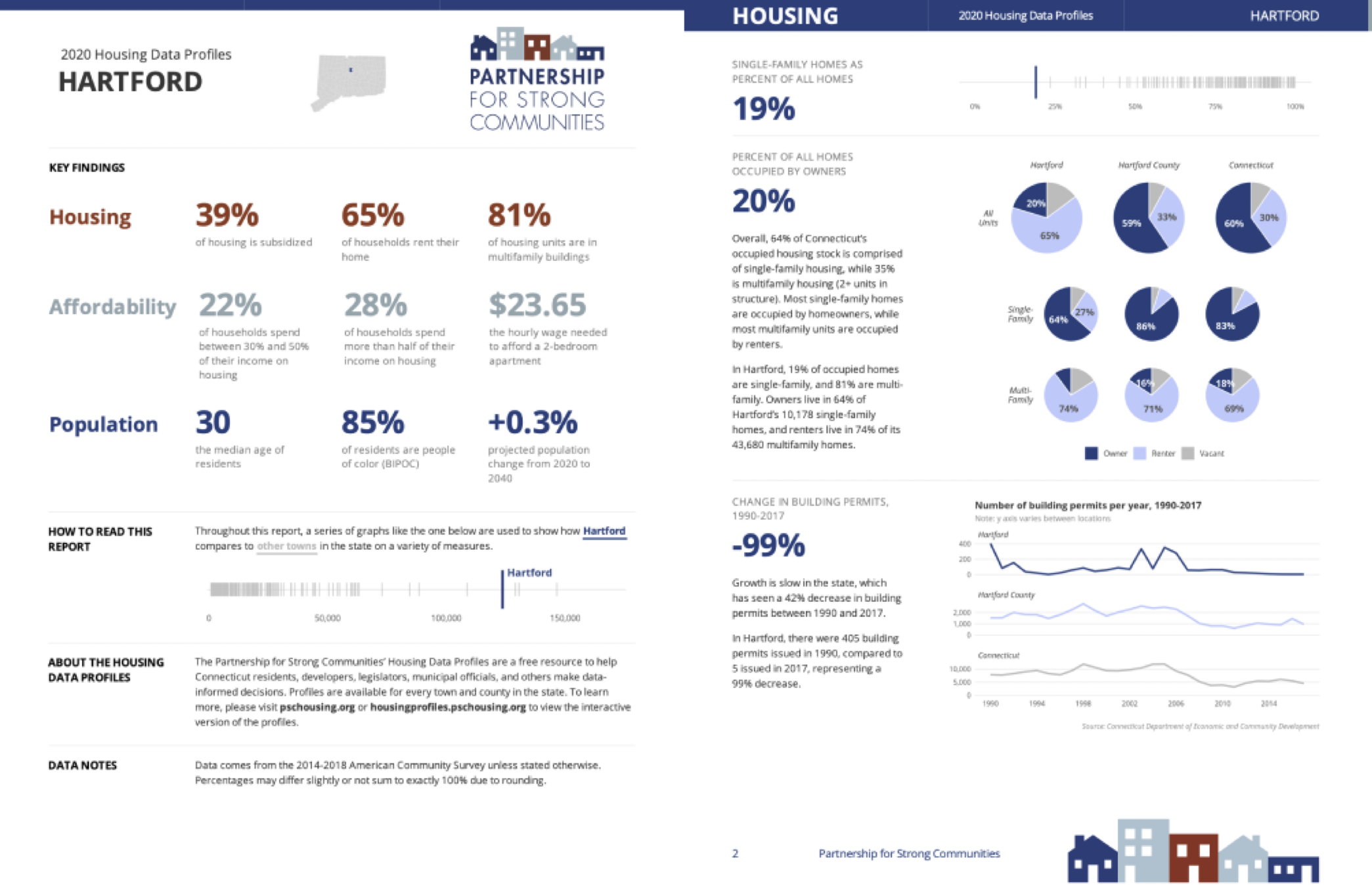


Figure 1.1: Sample pages from a report on housing in demographics in Hartford, Connecticut

**Communicate** by doing reporting with RMarkdown: moving away from the inefficient and error-prone workflow of using multiple tools to create reports by instead doing it all in the one tool that I think of as [R’s killer feature](https://rfortherestofus.com/2019/03/r-killer-feature-rmarkdown/).

A typical workflow looks like this:

1. Analyze data in SPSS
2. Copy data into Excel to make graphs
3. Copy graphs into Word and write your report

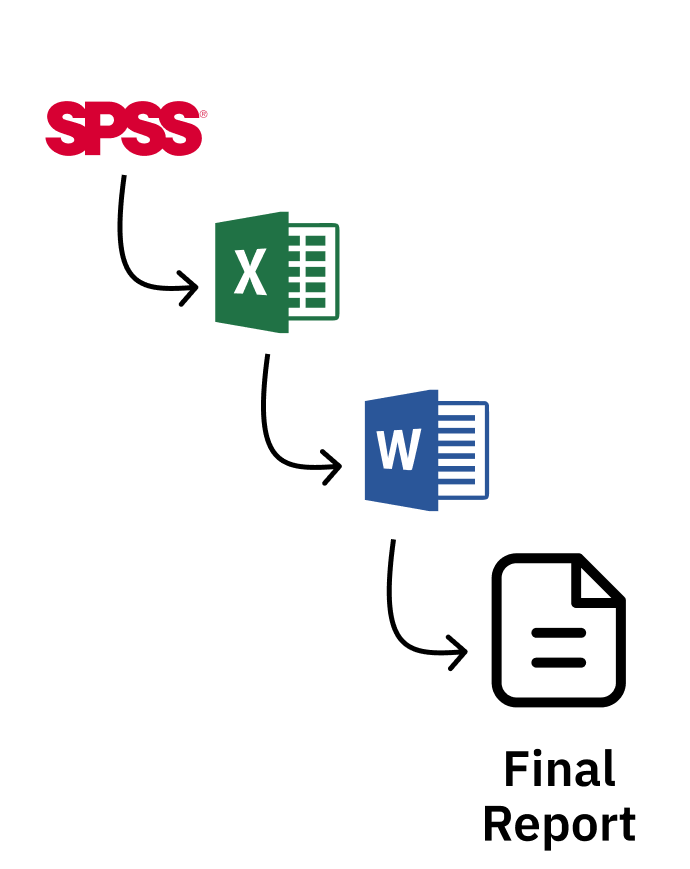


Figure 1.2: A typical non-R workflow

What happens, though, if you forget to include some data at step one? Or if you need to produce the same report with new data? You have to manually repeat the steps. It’s painful.

With R, things are different. You do your data analysis, make your graphs, and write your report all in one tool (RStudio). Once you like what you have, you export it to a format (like Word) to share.



Figure 1.3: An R-based workflow

And, best of all, if you forget to include data or need to produce your report again with new data, just re-run your code and you end up with a new Word document, ready to share.

**Automate** tedious practices: Remember my Excel-burdened wrists? Since I moved to R I’ve found so many ways to automate tedious practices, from gathering data directly from the U.S. Census Bureau to pulling survey results in from Google Sheets and more.

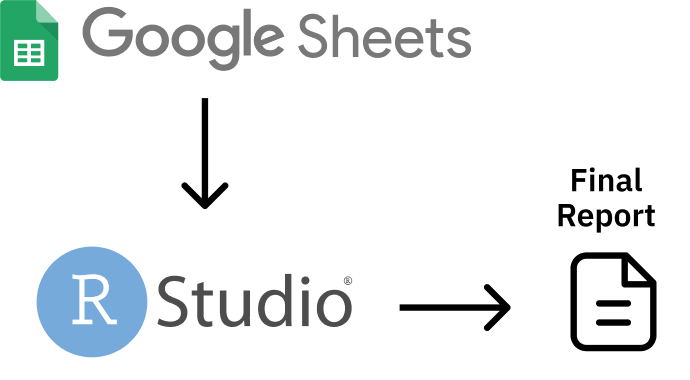


Figure 1.4: An workflow that brings data from Google Sheets directly into R

The main reason I’ve come to accept that my way of using R is as valid as anyone else’s has come through realizing that more “sophisticated” R users are doing many of the same things I am. Sure, they may also be doing statistical analyses that I am not, but everyone who uses R needs to illuminate, communicate, and automate.

Canadian statistician Sharla Gelfand has [talked about how they used R to automate an annual report on nursing registration exams in Ontario](https://twitter.com/sharlagelfand/status/1135962094938009601). Sharla told me in 2019 that, despite being a statistician, [the most statistical thing they did was calculating a median](https://rfortherestofus.com/2019/09/my-r-journey-sharla-gelfand/).

Take a look at the R community on Twitter (where users congregate under the #rstats hashtag). What gets people most excited is not the latest complex statistical analysis. [It’s tips and tricks on the foundational work that everyone who uses R needs to do](https://twitter.com/dgkeyes/status/1479473689225695234). Things like:

* [Making illuminating data visualizations](https://twitter.com/CedScherer/status/1220843943224578050) as part of the [Tidy Tuesday project](https://github.com/rfordatascience/tidytuesday).
* [Video tutorials on how to communicate through effective presentations using R](https://twitter.com/spcanelon/status/1424932510065209348).
* [Love letters to the clean\_names() function from the janitor package, which automates the process of making messy variable names easy to work with in R](https://twitter.com/WeAreRLadies/status/1228049014601342976).

No matter what else you do in R, you have to **illuminate** your findings and **communicate** your results. And, the more you use R, the more you’ll find yourself wanting to **automate** things you used to do manually (your wrists will thank you). I realize now that the things that I use R for *are* the things that everyone uses R for. R was created for statistics. But today people are just as likely to use R without statistics.

Ten years ago, if you had told me I’d be writing a book on R, I’d have laughed. As someone with an extremely non-quantitative background (I did a PhD in anthropology) who never used R in graduate school, I never thought I’d be in a position to teach people about R. But here we are. And I’m excited to be your guide on this journey through the ways you can use R without statistics.

If I only used R for the things I thought “real” R users used it for, I wouldn’t be writing this book. But, instead of slogging away in the world of complex statistical analysis, far outside of my area of expertise, I have found a place for myself in the world of R. Expanding my conception of what this tool can do has enabled me to get more out of R.

And here’s the thing: if I, a qualitatively-trained anthropologist whose most complex statistical use for R is calculating averages, can find value in R, so can you. No matter what your background or what you think about R right now, using R without statistics can transform how you work in the future.

## How This Book Works

This book shows the many ways that people use R without statistics. It’s not comprehensive (trust me, there are many ways people use R not covered here). But I hope the ideas inspire you to think about learning to use R (if you’re not yet an R user) or (if you are already on board the R train) learning to use R in ways you hadn’t previously considered.

Each chapter focuses on one novel use of R. You’ll begin by learning about a user or users who have transformed their work using R. You’ll learn about a problem they had and how R helped them to solve it.We’ll dive into their code, analyzing it line by line in order to help you understand how they used R. Each chapter will conclude with a short summary, offering lessons you can take from this novel way of using R.

I’ve tried to choose topics for each chapter that are relevant to a broad audience. Things like data visualization, report generation, and creating your own functions are things that anyone, no matter what you use R for, will find valuable.

There are some great topics that I thought to include but were just too narrow in their focus (for example, [the world of generative art made with R](https://blog.djnavarro.net/posts/2021-10-19_rtistry-posts/). If, at any point while you’re reading this book, you think, “why didn’t David include X topic?” please know that X might be a great topic, but I can only cover so much. The fact that you’re able to come up with other ideas for things that R can do is a) fantastic and b) a further display of R’s versatility. I eagerly await your follow-up book highlighting the myriad other things R can do that I am unable to cover in this book!

## A Favor to Ask

Pedants of the world (as one of you, I come in peace), I have a favor to ask.

This book is called R Without Statistics. But it’s not meant to be taken literally. Of course it’s true that if you’re making a graph you’re using statistics. So, before you start typing an angry email to me, please know that R Without Statistics is a mindset rather than a literal statement.

We’re all using R with statistics already. Let’s also learn to use R without statistics.

# 2 Principles of Data Visualization

In the spring of 2021, nearly all of the American West was in a drought. By April of that year, officials in Southern California had declared a water emergency, citing unprecedented conditions.

This wouldn’t have come as news to those living in California and other Western states. Drought conditions like those in the West in 2021 are becoming increasingly common. Yet communicating the extent of problem remains difficult. How can we show the data in a way that accurately represents it while making it compelling enough to get people to take notice? This was the challenge that data-visualization designers Cédric Scherer and Georgios Karamanis took on in the fall of 2021. Working with the magazine *Scientific American* to create a data visualization of drought conditions over the last two decades in the United States, they turned to the ggplot2 package to transform what could have been dry data (pardon the pun) into a visually arresting and impactful graph.

In this chapter, I show how Scherer and Karamanis made their data visualization. We begin by looking at why the data visualization is effective. Next, we talk about the grammar of graphics, a theory to make sense of graphs that underlies the ggplot2 package that Scherer, Karamanis, and millions of others use to make data visualization. We then return to the drought graph, recreating it step-by-step using ggplot2. In the process, we pull out some key principles of high-quality data visualization that you can use to improve your own work.

## The Drought Visualization

There was nothing unique about the data that Scherer and Karamanis used. Other news organizations had relied on the same data, from the National Drought Center, in their stories. But Scherer and Karamanis visualized it in a way that it both grabs attention and communicates the scale of the phenomenon. Figure 2.1 shows a section of the final visualization. Showing four regions over the last two decades, the increase in drought conditions, especially in California and the Southwest, is made apparent.

[F02001.pdf]

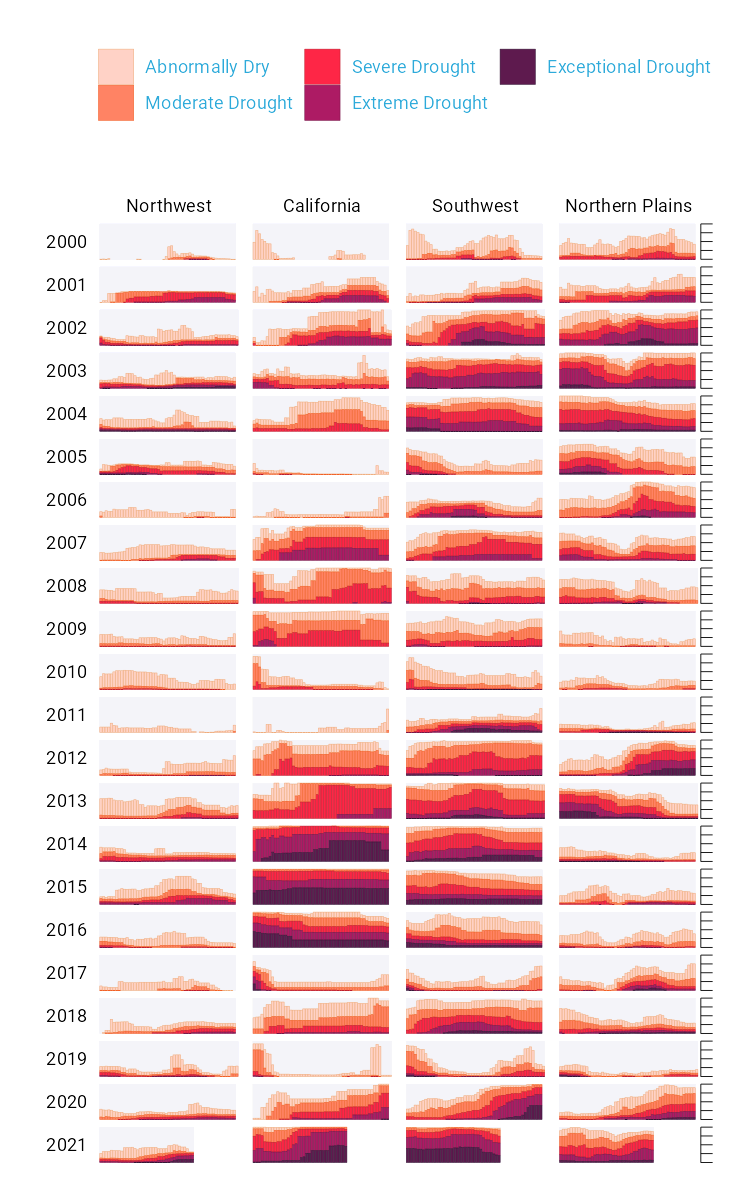


Figure 2.1: A section of the final drought visualization. If you’re incredibly eagle-eyed, you’ll see a few minor elements that differ from the version published in *Scientific American*. These are things I had to change to make the plots fit in this book (for example, altering the text size and putting legend text on two rows) or things that *Scientific American* added in post-production (such as annotations).

To understand why this visualization is effective, let’s break it down into pieces. At the broadest level, the data visualization is notable for its minimalist aesthetic. There are, for example, no grid lines and few text labels, as well as little text along the axes. What Scherer and Karamanis have done is remove what statistician Edward Tufte, in his 1983 book *The Visual Display of Quantitative Information*, calls *chartjunk*. Tufte wrote (and researchers, as well as data visualization designers since, have generally agreed) that extraneous elements often hinder, rather than help, our understanding of charts.

Need proof that Scherer and Karamanis’s decluttered graph is better than the alternative? Figure 2.2 shows a version with a few small tweaks to the code to include grid lines and text labels on axes. Prepare yourself for clutter!

[F02002.pdf]

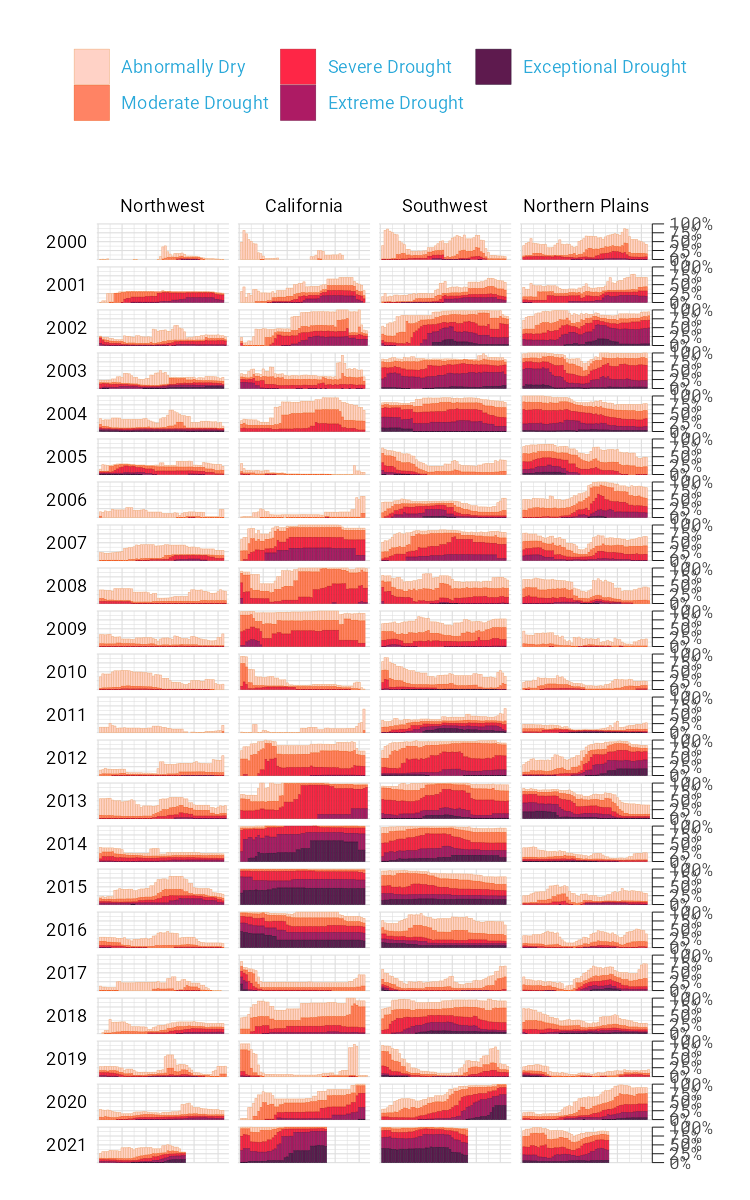


Figure 2.2: The cluttered version of the drought visualization

Again, it’s not just that this cluttered version looks worse. The clutter actively inhibits understanding. Rather than focus on overall drought patterns (the point of the graph), our brain gets stuck reading repetitive and unnecessary axis text.

One of the best ways to reduce clutter is to break a single chart into what are known as *small multiples*. When we look closely at the data visualization, we see that it is not one chart but actually a set of charts. Each rectangle represents one region in one year. If we filter to show the Southwest region in 2003 and add axis titles, we can see in Figure 2.3 that the x axis shows the week while the y axis shows the percentage of that region at different drought levels.

[F02003.pdf]

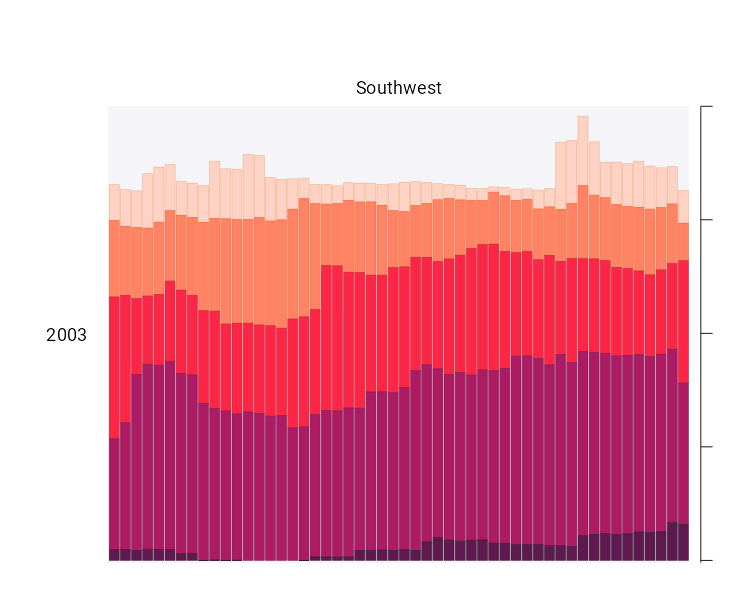


Figure 2.3: A drought visualization for the Southwest in 2003

Zooming in on a single region in a single year also makes the color choices more obvious. The lightest bars show the percentage of the region that is abnormally dry while the darkest bars show the percentage in exceptional drought conditions. These colors, as we’ll see shortly, are intentionally chosen to make differences in the drought levels visible to all readers. When I asked Scherer and Karamanis to speak with me about this data visualization, they initially told me that the code for this piece might be too simple to highlight the power of R for data visualization. No, I told them, I want to speak with you precisely because the code is not super complex. The fact that Scherer and Karamanis were able to produce this complex graph with relatively simple code shows the power of R for data visualization. And it is possible *because* of a theory called the grammar of graphics.

## The Grammar of Graphics

If you’ve used Excel to make graphs, you’re probably familiar with the menu shown in Figure 2.4. When working in Excel, your graph-making journey begins by selecting the type of graph you want to make. Want a bar chart? Click the bar chart icon. Want a line chart? Click the line chart icon.

[F02004.png]

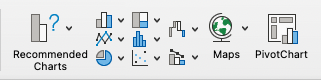


Figure 2.4: The Excel chart chooser menu

f you’ve only ever made data visualization in Excel, this first step may seem so obvious that you’ve never even considered the process of creating data visualization in any other way. But there are different models for thinking about graphs. Rather than conceptualizing graphs types as being distinct, we can recognize the things that they have in common and use these commonalities as the starting point for making them.

This approach to thinking about graphs comes from the late statistician Leland Wilkinson. For years, Wilkinson thought deeply about what data visualization is and how we can describe it. In 1999, he published a book called *The Grammar of Graphics* that sought to develop a consistent way of describing all graphs. In it, Wilkinson argued that we should think of plots not as distinct types à la Excel, but as following a grammar that we can use to describe *any* plot. Just as English grammar tells us that a noun is typically followed by a verb (which is why “he goes” works, while the opposite, “goes he,” does not), knowledge of the grammar of graphics allows us to understand why certain graph types “work.”

Thinking about data visualization through the lens of the grammar of graphics allow us to see, for example, that graphs typically have some data that is plotted on the x axis and other data that is plotted on the y axis. This is the case no matter whether the graph is a bar chart or a line chart, for example. Consider Figure 2.5, which shows two charts that use identical data on life expectancy in Afghanistan.

[F02005.pdf]

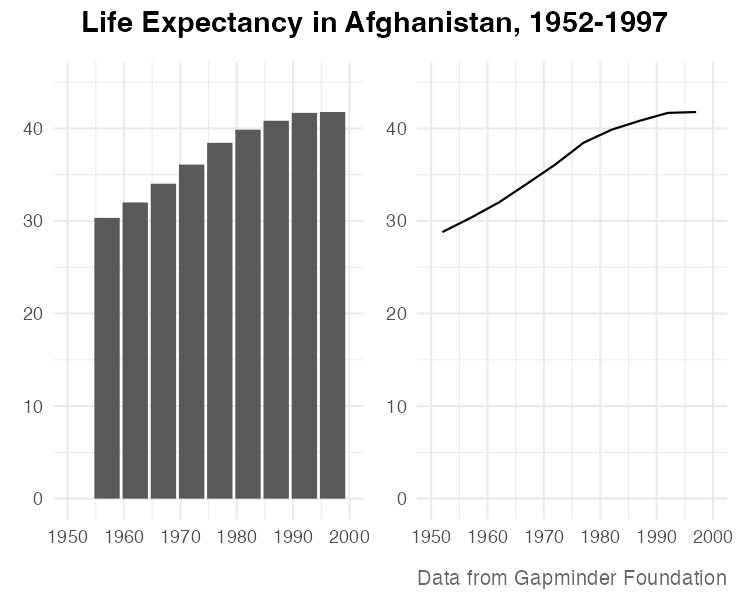


Figure 2.5: A bar chart and a line chart showing identical data on Afghanistan life expectancy

While they look different (and would, to the Excel user, be different types of graphs), Wilkinson’s grammar of graphics allows us to see their similarities. (Incidentally, Wilkinson’s feelings on graph-making tools like Excel became clear when he wrote that “most charting packages channel user requests into a rigid array of chart types.”)

When Wilkinson wrote his book, no data visualization tool could implement his grammar of graphics. This would change in 2010, when Hadley Wickham announced the ggplot2 package for R in an article titled “A Layered Grammar of Graphics.” By providing the tools to implement Wilkinson’s ideas, ggplot2 would come to revolutionize the world of data visualization.

## Working With ggplot2

The ggplot2 R package (which I, like nearly everyone in the data visualization world, will refer to simply as ggplot) relies on the idea of plots having multiple layers. Let’s walk through some of the most important layers. We’ll begin by selecting variables to map to aesthetic properties. Then we’ll choose a geometric object to use to represent our data. Next we’ll change the aesthetic properties of our chart (the color scheme, for example) using a scale\_ function. And finally we’ll use a theme\_ function to set the overall look-and-feel of our plot.

### The First Layer: Mapping Data to Aesthetic Properties

When creating a graph with ggplot, we begin by mapping data to aesthetic properties. All this really means is that we use things like the x or y axis, color, and size (the so-called aesthetic properties) to represent variables. To make this concrete, we’ll use the data on life expectancy in Afghanistan, introduced in the previous section, to generate a plot. Here’s what this data looks like:

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

If we want to make a chart with ggplot, we need to first decide which variable to put on the x axis and which to put on the y axis. Let’s say we want to show life expectancy over time. That means we would use the variable year on the x axis and the variable lifeExp on the y axis. To do so, we begin by using the ggplot() function:

ggplot(  
 data = gapminder\_10\_rows,  
 mapping = aes(  
 x = year,  
 y = lifeExp  
 )  
)

Within this function, we tell R that we’re using the data frame gapminder\_10\_rows. This is the filtered version we created from the full gapminder data frame, which includes over 1,700 rows of data. The line following this tells R to use year on the x axis and lifeExp on the y axis. When we run the code, what we get in Figure 2.6 doesn’t look like much.

[F02006.pdf]

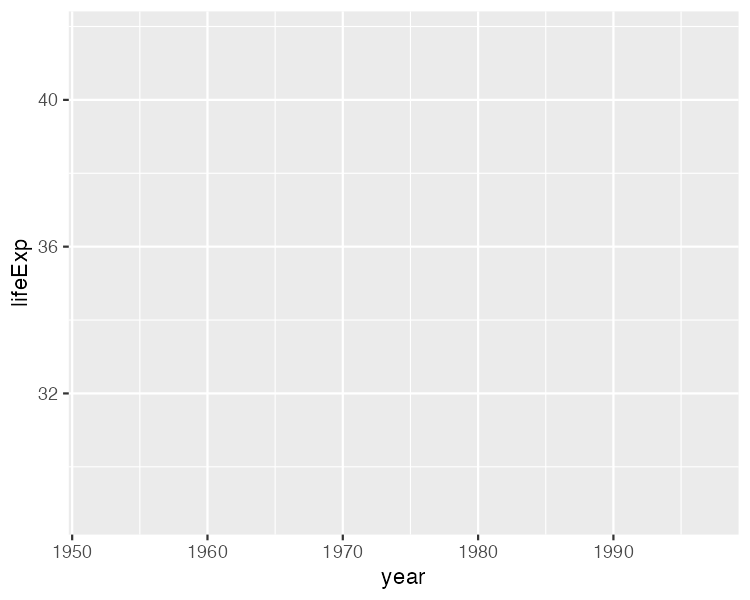


Figure 2.6: A blank chart

But, if you look closely, you can see the beginnings of a plot. Remember that x axis using year? There it is! And lifeExp on the y axis? Yup, it’s there too. I can also see that the values on the x and y axes match up to our data. In the gapminder\_10\_rows data frame, the first year is 1952 and the last year is 1997. The range of the x axis seems to have been created with this data, which goes from 1952 to 1997, in mind (spoiler: it was). And lifeExp, which goes from about 28 to about 42 will fit nicely on our y axis.

### The Second Layer: Choosing the geoms

Axes are nice, but we’re missing any type of visual representation of the data. To get this, we need to add the next layer in ggplot: geoms. Short for geometric objects, geoms are functions that provide different ways of representing data. For example, if we want to add points, we use geom\_point():

ggplot(  
 data = gapminder\_10\_rows,  
 mapping = aes(  
 x = year,  
 y = lifeExp  
 )  
) +  
 geom\_point()

Now, in Figure 2.7, we see that people in 1952 had a life expectancy of about 28 and that this value rose through every year in our data.

[F02007.pdf]

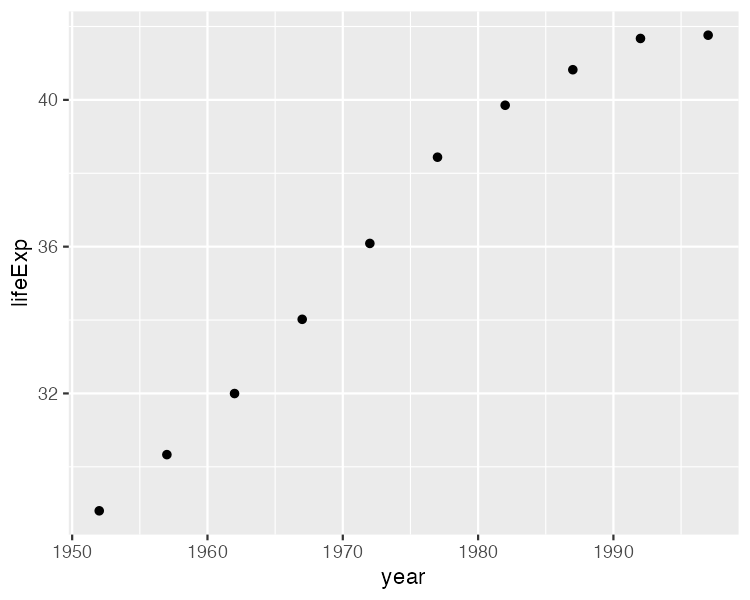


Figure 2.7: The same chart but with points added

Let’s say we change our mind and want to make a line chart instead. Well, all we have to do is replace geom\_point() with geom\_line():

ggplot(  
 data = gapminder\_10\_rows,  
 mapping = aes(  
 x = year,  
 y = lifeExp  
 )  
) +  
 geom\_line()

Figure 2.8 shows the result.

[F02008.pdf]

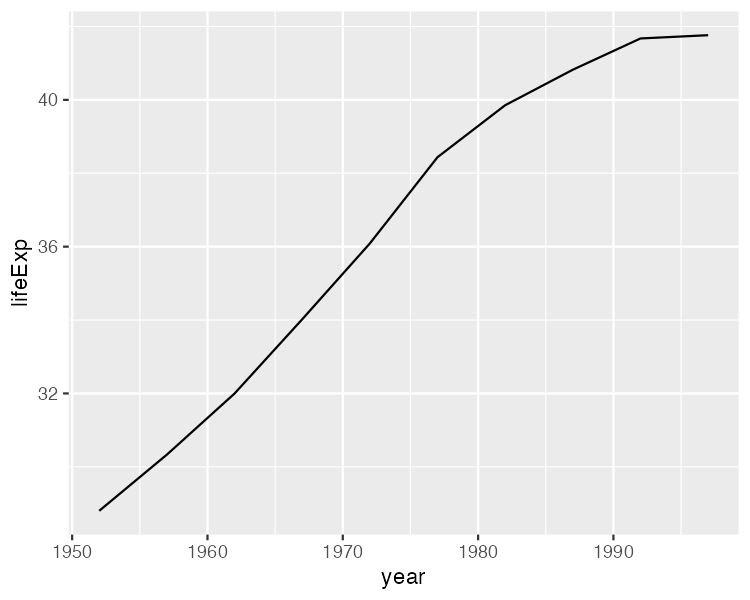


Figure 2.8: The data as a line chart

To really get fancy, what if we add both geom\_point() and geom\_line()?

ggplot(  
 data = gapminder\_10\_rows,  
 mapping = aes(  
 x = year,  
 y = lifeExp  
 )  
) +  
 geom\_point() +  
 geom\_line()

This code generates a line chart with points, as seen in Figure 2.9.

[F02009.pdf]

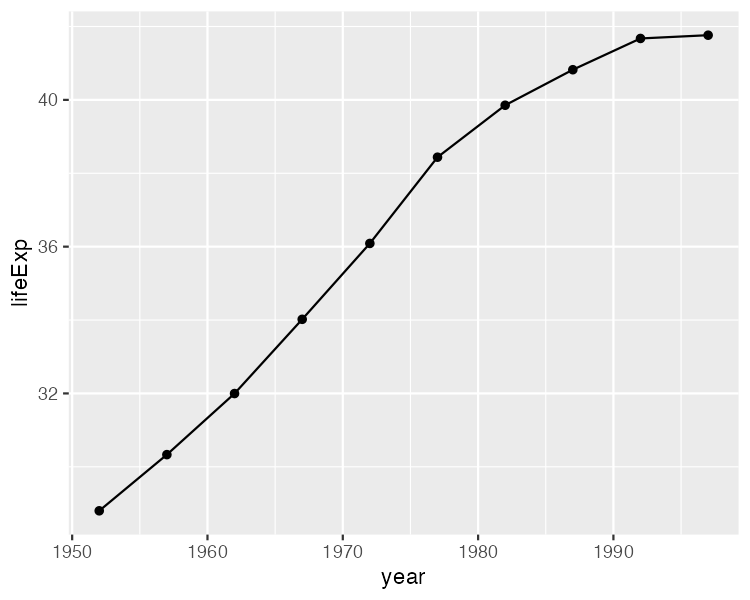


Figure 2.9: The data with points and a line

We can extend this idea further, as seen in Figure 2.10, swapping in geom\_col() to create a bar chart:

ggplot(  
 data = gapminder\_10\_rows,  
 mapping = aes(  
 x = year,  
 y = lifeExp  
 )  
) +  
 geom\_col()

Note that the y axis range has been automatically updated, going from 0 to 40 to account for the different geom.

[F02010.pdf]

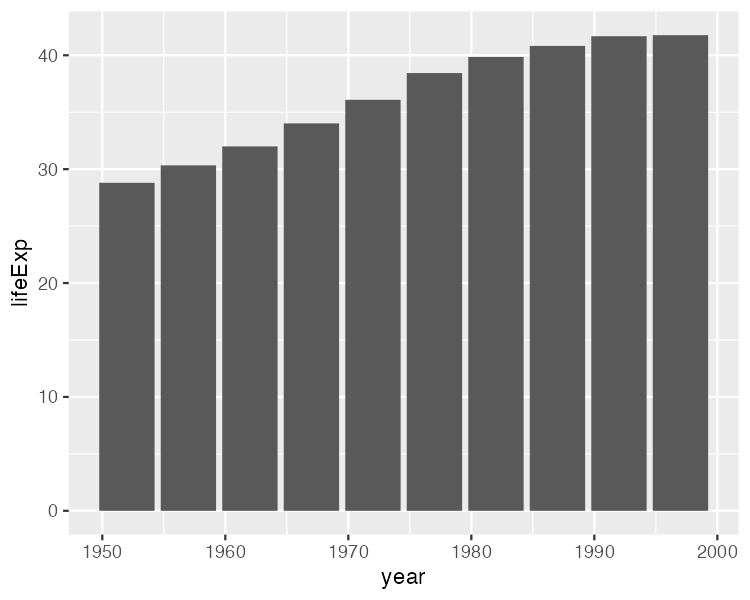


Figure 2.10: The data as a bar chart

As you can see, the difference between a line chart and a bar chart isn’t as great as the Excel chart-type picker might have us think. Both can have the same aesthetic properties (namely, putting years on the x axis and life expectancies on the y axis). They simply use different geometric objects to visually represent the data.

### The Third Layer: Altering Aesthetic Properties

Before we return to the drought data visualization, let’s look at a few additional layers that can help us can alter our bar chart. Say we want to change the color of our bars. In the grammar of graphics approach to chart-making, this means mapping some variable to the aesthetic property of fill. (Slightly confusingly, the aesthetic property of color would, for a bar chart, change only the outline of each bar). In the same way that we mapped year to the x axis and y to lifeExp, we can also map fill to a variable, such as year:

ggplot(  
 data = gapminder\_10\_rows,  
 mapping = aes(  
 x = year,  
 y = lifeExp,  
 fill = year  
 )  
) +  
 geom\_col()

The result is shown in Figure 2.11. We see now that, for earlier years, the fill is darker, while for later years, it is lighter (the legend, added to the right of our plot, shows this).

[F02011.pdf]

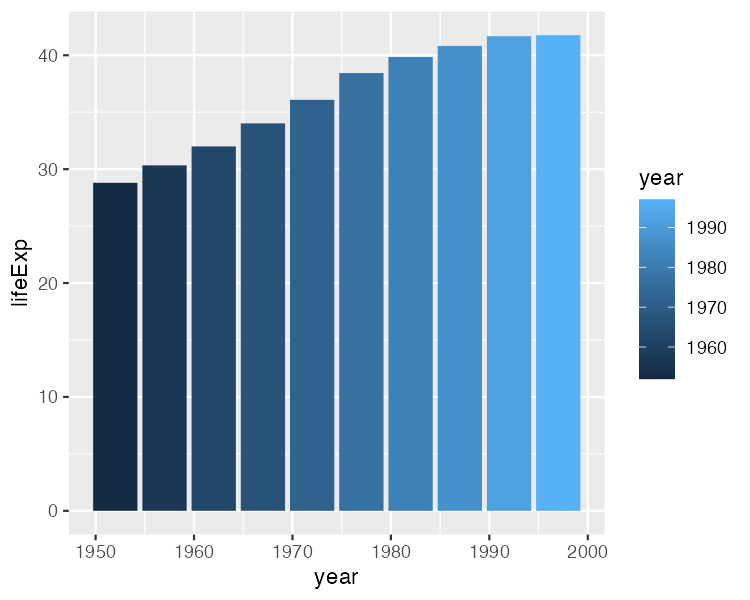


Figure 2.11: The same chart, now with added colors

What if we want to change the fill colors? For that, we use a new *scale layer*. In this case, I’ll use the scale\_fill\_viridis\_c() function. The c at the end of the function name refers to the fact that the data is continuous, meaning it can take any numeric value:

ggplot(  
 data = gapminder\_10\_rows,  
 mapping = aes(  
 x = year,  
 y = lifeExp,  
 fill = year  
 )  
) +  
 geom\_col() +  
 scale\_fill\_viridis\_c()

This function changes the default palette to one that is colorblind-friendly and prints well in grayscale. The scale\_fill\_viridis\_c() function is just one of many that start with scale\_ and can alter the fill scale.

[F02012.pdf]

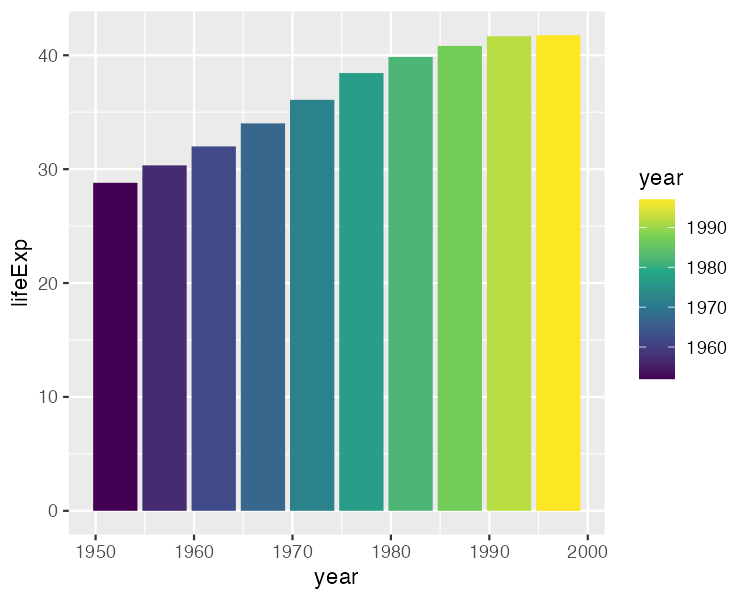


Figure 2.12: The same chart with a colorblind-friendly palette

### The Fourth Layer: Setting a Theme

A final layer we’ll look at is the theme layer. This layer allows us to change the overall look-and-feel of plots (plot backgrounds, grid lines, and so on). Just as there are a number of scale\_ functions, there are also a number of functions that start with theme\_. Here, we’ve added theme\_minimal():

ggplot(  
 data = gapminder\_10\_rows,  
 mapping = aes(  
 x = year,  
 y = lifeExp,  
 fill = year  
 )  
) +  
 geom\_col() +  
 scale\_fill\_viridis\_c() +  
 theme\_minimal()

Notice in Figure 2.13 that this theme starts to declutter our plot.

[F02013.pdf]

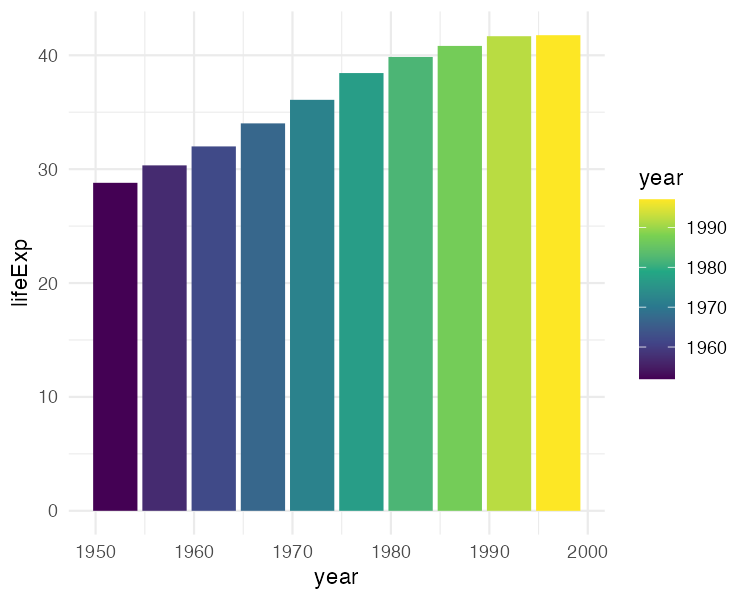


Figure 2.13: The same chart with theme\_minimal() added

We’ve now seen why Hadley Wickham described the ggplot2 package as using a layered grammar of graphics. It implements Wilkinson’s theory through the creation of multiple layers. First, we select variables to map to aesthetic properties, such as x or y axes, color, and fill. Second, we choose the geometric object (or geom) we want to use to represent our data. Third, if we want to change aesthetic properties (for example, to use a different palette), we do this with a scale\_ function. Fourth, we use a theme\_ function to set the overall look-and-feel of our plot.

We could improve the plot we’ve been working on in many ways. But rather than adding to an ugly plot, let’s instead return to the drought data visualization by Cédric Scherer and Georgios Karamanis. Going through their code will show us some familiar aspects of ggplot and reveal tips on how to make high-quality data visualization with R.

## Recreating the Drought Visualization with ggplot

The drought visualization code relies on a combination of ggplot fundamentals and some less-well-known tweaks that make it really shine. In order to understand how Scherer and Karamanis made their data visualization, we’ll start out with a simplified version of their code. We’ll build it up layer by layer, adding elements as we go.

### Plotting One Region and Year

Let’s start by looking at just one region (the Southwest) in one year (2003). First, we filter our data and save it as a new object called southwest\_2003.

southwest\_2003 <- dm\_perc\_cat\_hubs %>%  
 filter(hub == "Southwest") %>%  
 filter(year == 2003)

We can take a look at this object to see the variables we have to work with:

southwest\_2003 %>%  
 slice(1:10)  
#> # A tibble: 10 × 7  
#> date hub category perce…¹ year week max\_w…²  
#> <date> <fct> <fct> <dbl> <dbl> <dbl> <dbl>  
#> 1 2003-12-30 Southwest D0 0.0718 2003 52 52  
#> 2 2003-12-30 Southwest D1 0.0828 2003 52 52  
#> 3 2003-12-30 Southwest D2 0.269 2003 52 52  
#> 4 2003-12-30 Southwest D3 0.311 2003 52 52  
#> 5 2003-12-30 Southwest D4 0.0796 2003 52 52  
#> 6 2003-12-23 Southwest D0 0.0823 2003 51 52  
#> 7 2003-12-23 Southwest D1 0.131 2003 51 52  
#> 8 2003-12-23 Southwest D2 0.189 2003 51 52  
#> 9 2003-12-23 Southwest D3 0.382 2003 51 52  
#> 10 2003-12-23 Southwest D4 0.0828 2003 51 52  
#> # … with abbreviated variable names ¹​percentage, ²​max\_week

The date variable represents the start date of the week in which the observation took place. The hub variable is the region, and category is level of drought (a value of D0 indicates the lowest level of drought, while D5 indicates the highest level). The percentage variable is the percentage of that region that is in that drought category, ranging from 0 to 1. The year and week variables are the observation year and week number (beginning with week 1). The max\_week variable is the maximum number of weeks in a given year.

Now we can use this southwest\_2003 object for our plotting:

ggplot(  
 data = southwest\_2003,  
 aes(  
 x = week,  
 y = percentage,  
 fill = category  
 )  
) +  
 geom\_col()

In the ggplot() function, we tell R to put week on the x axis and percentage on the y axis. We also use the category variable for our fill color. We then use geom\_col() to create a bar chart in which the fill color of each bar represents the percentage of the region in a single week at each drought level. You can see the result in in 2.14.

[F02014.pdf]

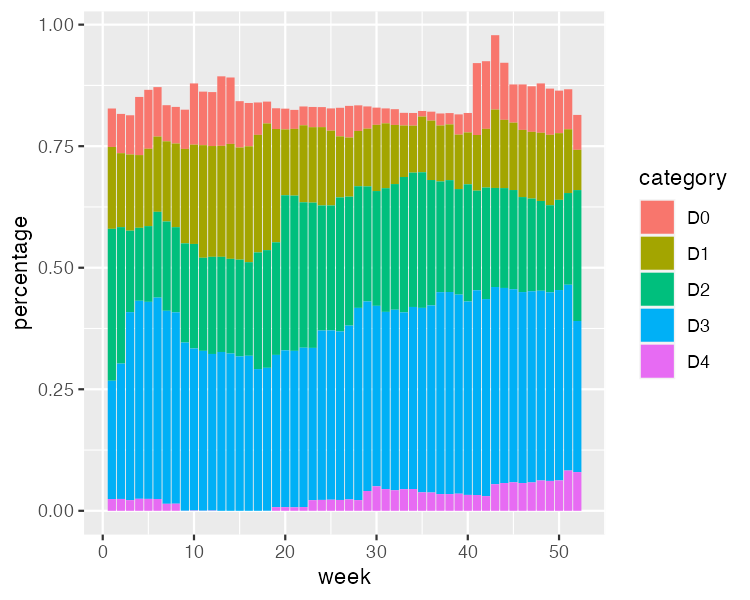


Figure 2.14: One year and region of the drought visualization

The colors don’t match the final version of the plot, but we can start to see the outlines of Scherer and Karamanis’s data visualization.

### Changing Aesthetic Properties

Scherer and Karamanis next selected different fill colors for their bars. To do so, they used the scale\_fill\_viridis\_d() function. The *d* here means that the data to which the fill scale is being applied has discrete categories, called D0, D1, D2, D3, D4, and D5:

ggplot(  
 data = southwest\_2003,  
 aes(  
 x = week,  
 y = percentage,  
 fill = category  
 )  
) +  
 geom\_col() +  
 scale\_fill\_viridis\_d(  
 option = "rocket",  
 direction = -1  
 )

They used the argument option = "rocket" to select the rocket palette (the function has several other palettes). Then they used the direction = -1 argument to reverse the order of fill colors so that darker colors mean higher drought conditions. Scherer and Karamanis also tweaked the appearance of the x and y axes:

ggplot(  
 data = southwest\_2003,  
 aes(  
 x = week,  
 y = percentage,  
 fill = category  
 )  
) +  
 geom\_col() +  
 scale\_fill\_viridis\_d(  
 option = "rocket",  
 direction = -1  
 ) +  
 scale\_x\_continuous(name = NULL,   
 guide = "none") +  
 scale\_y\_continuous(name = NULL,   
 labels = NULL,   
 position = "right")

On the x axis, they removed both the axis title (“week”) using name = NULL and the 0–50 text with guide = "none". On the y axis, they removed the title and text showing percentages using labels = NULL, which functionally does the same thing as guide = "none". They also moved the axis lines themselves to the right side using position = "right". These axis lines are only apparent as tick marks at this point but will become more visible later. Figure 2.15 shows the result of these tweaks.

[F02015.pdf]

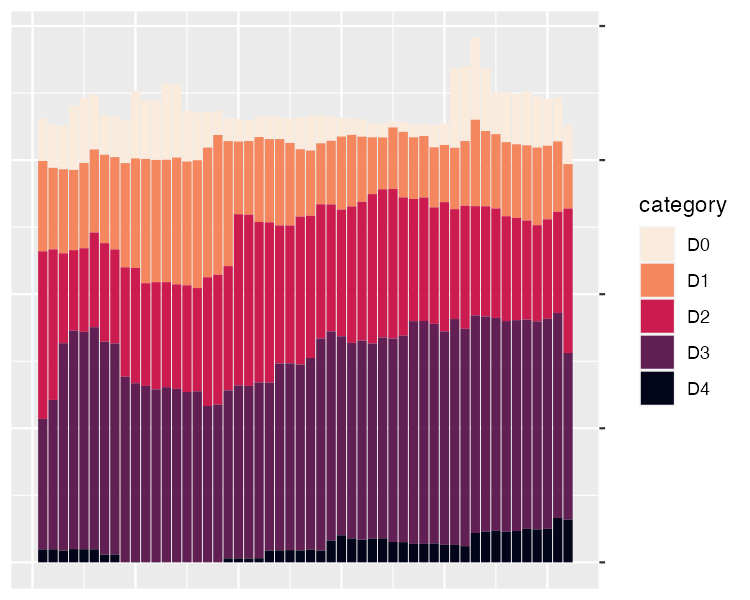


Figure 2.15: One year and region of the drought visualization with adjustments to the x and y axes

Up to this point, we’ve focused on one of the single plots that make up the larger data visualization. But the final product that Scherer and Karamanis made is actually 176 plots visualizing 22 years and eight regions. Let’s discuss the ggplot feature they used to create all of these plots.

### Faceting the Plot

One of the most useful features of ggplot is what’s known as *faceting* (or, more commonly in the data visualization world, *small multiples*). Faceting takes a single plot and makes it into multiple plots using a variable (think: a line chart showing life expectancy by country over time, but instead of multiple lines on one plot, we get multiple plots with one line per plot). With the facet\_grid() function, we can select which variable to put in rows and which to put in columns of our faceted plot.

dm\_perc\_cat\_hubs %>%  
 filter(hub %in% c("Northwest",   
 "California",   
 "Southwest",   
 "Northern Plains")) %>%  
 ggplot(aes(x = week,   
 y = percentage,  
 fill = category)) +  
 geom\_col() +  
 scale\_fill\_viridis\_d(  
 option = "rocket",  
 direction = -1  
 ) +  
 scale\_x\_continuous(name = NULL,   
 guide = "none") +  
 scale\_y\_continuous(name = NULL,   
 labels = NULL,   
 position = "right") +  
 facet\_grid(rows = vars(year),   
 cols = vars(hub),   
 switch = "y")

Scherer and Karamanis put year in rows and hub (region) in columns. The switch = "y" argument moves the year label from the right side (where it appears by default) to the left. With this code in place, we can see the final plot coming together in Figure 2.16.

[F02016.pdf]

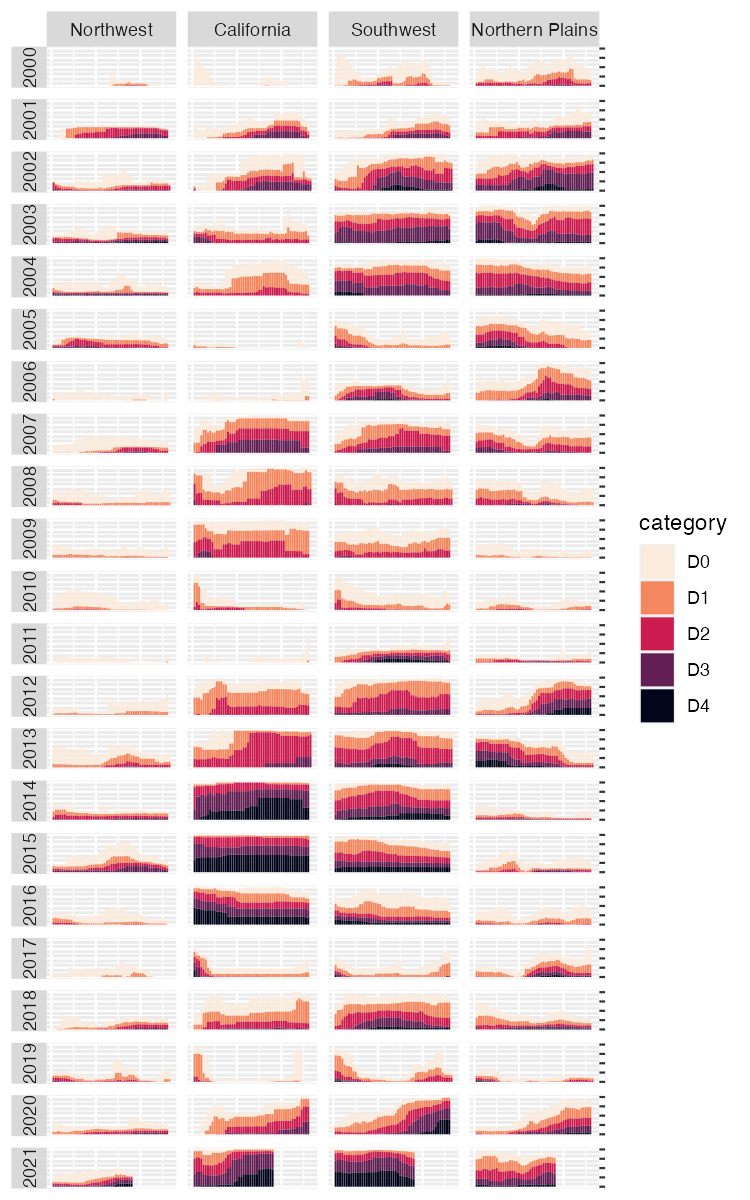


Figure 2.16: The faceted version of the drought visualization. Space considerations require me to include only four regions, but you get the idea.

Incredibly, the broad outlines of the plot took us just 10 lines to create. The rest of the code falls into the category of small polishes. That’s not to minimize how important small polishes are (very) or the time it takes to create them (lots). It does show, however, that a little bit of ggplot goes a long way.

### Applying Small Polishes

Let’s look at a few of the small polishes that Scherer and Karamanis made. The first is to apply a theme, as seen in Figure 2.17. They used theme\_light(), which removes the default gray background and changes the font to Roboto.

The theme\_light() function is what’s known as a complete theme. So-called complete themes change the overall look-and-feel of a plot. But Scherer and Karamanis didn’t stop there. They then used the theme() function to make additional tweaks to what theme\_light() gave them.

dm\_perc\_cat\_hubs %>%  
 filter(hub %in% c("Northwest",   
 "California",   
 "Southwest",   
 "Northern Plains")) %>%  
 ggplot(aes(x = week,   
 y = percentage,  
 fill = category)) +  
 geom\_col() +  
 scale\_fill\_viridis\_d(  
 option = "rocket",  
 direction = -1  
 ) +  
 scale\_x\_continuous(name = NULL,   
 guide = "none") +  
 scale\_y\_continuous(name = NULL,   
 labels = NULL,   
 position = "right") +  
 facet\_grid(rows = vars(year),   
 cols = vars(hub),   
 switch = "y") +  
 theme\_light(base\_family = "Roboto") +  
 theme(  
 axis.title = element\_text(size = 14,   
 color = "black"),  
 axis.text = element\_text(family = "Roboto Mono",   
 size = 11),  
 axis.line.x = element\_blank(),  
 axis.line.y = element\_line(color = "black",   
 size = .2),  
 axis.ticks.y = element\_line(color = "black",   
 size = .2),  
 axis.ticks.length.y = unit(2, "mm"),  
 legend.position = "top",  
 legend.title = element\_text(color = "#2DAADA",   
 face = "bold"),  
 legend.text = element\_text(color = "#2DAADA"),  
 strip.text.x = element\_text(hjust = .5,   
 face = "plain",   
 color = "black",   
 margin = margin(t = 20, b = 5)),  
 strip.text.y.left = element\_text(angle = 0,   
 vjust = .5,   
 face = "plain",   
 color = "black"),  
 strip.background = element\_rect(fill = "transparent",   
 color = "transparent"),  
 panel.grid.minor = element\_blank(),  
 panel.grid.major = element\_blank(),  
 panel.spacing.x = unit(0.3, "lines"),  
 panel.spacing.y = unit(0.25, "lines"),  
 panel.background = element\_rect(fill = "transparent",   
 color = "transparent"),  
 panel.border = element\_rect(color = "transparent",   
 size = 0),  
 plot.background = element\_rect(fill = "transparent",   
 color = "transparent",   
 size = .4),  
 plot.margin = margin(rep(18, 4))  
 )

The code in the theme() function does many different things, but let’s take a look at a few of the most important. First, it moves the legend from the right side (the default) to the top of the plot. Then, an angle = 0 argument rotates the year text in the columns so that it is no longer angled. Without this argument, the years would be much less readable.

Next, the theme() function makes the distinctive axis lines and ticks that show up on the right side of the final plot. Calling element\_blank() removes all grid lines. Finally, three lines remove the borders and make each of the individual plots have a transparent background.

Keen readers such as yourself may now be thinking, “Wait. Didn’t the individual plots have a gray background behind them?” Yes, dear reader, they did. Scherer and Karamanis made these with a separate geom, geom\_rect():

geom\_rect(  
 aes(  
 xmin = .5,  
 xmax = max\_week + .5,  
 ymin = -0.005,  
 ymax = 1  
 ),  
 fill = "#f4f4f9",  
 color = NA,  
 size = 0.4  
)

They set some additional aesthetic properties specific to this geom: xmin, xmax, ymin, and ymax, which determine the boundaries of the rectangle it produces. The result is a gray background drawn behind each small multiple, as seen in Figure 2.17.

[F02017.pdf]

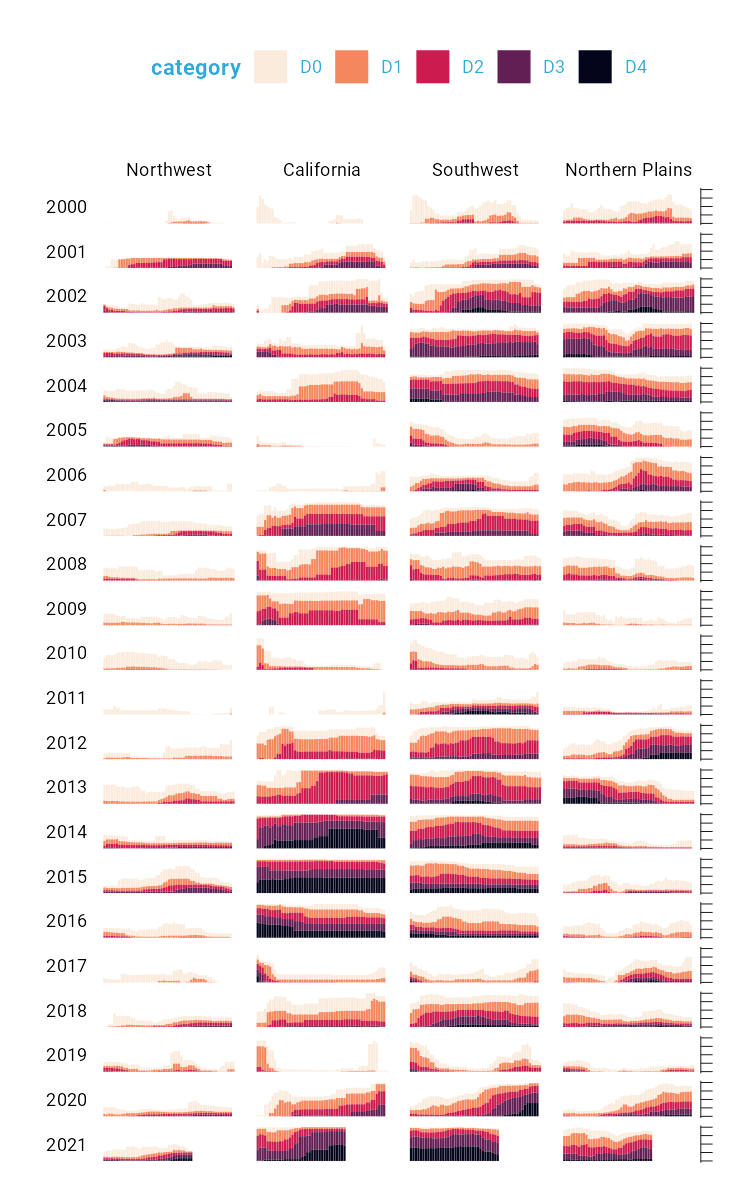


Figure 2.17: Figure 1-16 Faceted version of the drought visualization with gray backgrounds behind each small multiple

Finally, consider the tweaks made to the legend. We previously saw a simplified version of the scale\_fill\_viridis\_d() function. Here is a more complete version:

scale\_fill\_viridis\_d(  
 option = "rocket",  
 direction = -1,  
 name = "Category:",  
 labels = c(  
 "Abnormally Dry",  
 "Moderate Drought",  
 "Severe Drought",  
 "Extreme Drought",  
 "Exceptional Drought"  
 )  
)

The name argument sets the legend title, and the labels argument determines the labels that show up in the legend. Figure 2.18 shows the result of these changes.

[F02018.pdf]



Figure 2.18: Drought visualization with changes made to the legend text

Rather than D0, D1, D2, D3, and D4, we now have Abnormally Dry, Moderate Drought, Severe Drought, Extreme Drought, and Exceptional Drought.

### The Complete Visualization Code

While I’ve showed you a nearly complete version of the code, I have made some small changes along the way to make it easier to understand. If you’re curious to see the full code Cédric and Georgios used to create the data viz, here it is. There are a few additional tweaks to colors and spacing, but nothing major beyond what we’ve seen so far.

ggplot(dm\_perc\_cat\_hubs, aes(week, percentage)) +  
 geom\_rect(  
 aes(  
 xmin = .5,  
 xmax = max\_week + .5,  
 ymin = -0.005,  
 ymax = 1  
 ),  
 fill = "#f4f4f9",  
 color = NA,  
 size = 0.4,  
 show.legend = FALSE  
 ) +  
 geom\_col(  
 aes(  
 fill = category,  
 fill = after\_scale(addmix(darken(fill, .05,   
 space = "HLS"),   
 "#d8005a",   
 .15)),  
 color = after\_scale(darken(fill, .2,   
 space = "HLS"))  
 ),  
 width = .9,  
 size = 0.12  
 ) +  
 facet\_grid(rows = vars(year),   
 cols = vars(hub),   
 switch = "y") +  
 coord\_cartesian(clip = "off") +  
 scale\_x\_continuous(expand = c(.02, .02),   
 guide = "none",   
 name = NULL) +  
 scale\_y\_continuous(expand = c(0, 0),   
 position = "right",   
 labels = NULL,   
 name = NULL) +  
 scale\_fill\_viridis\_d(  
 option = "rocket",  
 name = "Category:",  
 direction = -1,  
 begin = .17,  
 end = .97,  
 labels = c(  
 "Abnormally Dry",  
 "Moderate Drought",  
 "Severe Drought",  
 "Extreme Drought",  
 "Exceptional Drought"  
 )  
 ) +  
 guides(fill = guide\_legend(nrow = 2,  
 override.aes = list(size = 1))) +  
 theme\_light(base\_size = 18,   
 base\_family = "Roboto") +  
 theme(  
 axis.title = element\_text(size = 14,   
 color = "black"),  
 axis.text = element\_text(family = "Roboto Mono",   
 size = 11),  
 axis.line.x = element\_blank(),  
 axis.line.y = element\_line(color = "black",   
 size = .2),  
 axis.ticks.y = element\_line(color = "black",   
 size = .2),  
 axis.ticks.length.y = unit(2, "mm"),  
 legend.position = "top",  
 legend.title = element\_text(color = "#2DAADA",   
 size = 18,   
 face = "bold"),  
 legend.text = element\_text(color = "#2DAADA",   
 size = 16),  
 strip.text.x = element\_text(size = 16,   
 hjust = .5,   
 face = "plain",   
 color = "black",   
 margin = margin(t = 20, b = 5)),  
 strip.text.y.left = element\_text(size = 18,   
 angle = 0,   
 vjust = .5,   
 face = "plain",   
 color = "black"),  
 strip.background = element\_rect(fill = "transparent",   
 color = "transparent"),  
 panel.grid.minor = element\_blank(),  
 panel.grid.major = element\_blank(),  
 panel.spacing.x = unit(0.3, "lines"),  
 panel.spacing.y = unit(0.25, "lines"),  
 panel.background = element\_rect(fill = "transparent",   
 color = "transparent"),  
 panel.border = element\_rect(color = "transparent",   
 size = 0),  
 plot.background = element\_rect(fill = "transparent",   
 color = "transparent",   
 size = .4),  
 plot.margin = margin(rep(18, 4))  
 )

There are a few additional tweaks to colors and spacing, but most of the code reflects what you’ve seen so far.

## In Conclusion: ggplot is Your Data Viz Secret Weapon

You may start to think of ggplot as a solution to all of your data visualization problems. And yes, you have a new hammer, but no, everything is not a nail. If you look at the version of the data visualization that appeared in *Scientific American* in November 2021, you’ll see that some of its annotations aren’t visible in our recreation. That’s because they were added in post-production. While you could have found ways to create them in ggplot, it’s often not the best use of your time. Get yourself 90 percent of the way there with ggplot and then use Illustrator, Figma, or a similar tool to finish your work.

Even so, ggplot is a very powerful hammer, used to make plots that you’ve seen in *The New York Times*, FiveThirtyEight, the BBC, and other well-known news outlets. Although not the only tool that can generate high-quality data visualization, it makes the process straightforward. The graph by Scherer and Karamanis shows this in several ways:

* **It strips away extraneous elements, such as grid lines, in order to keep the focus on the data itself**. Complete themes such as theme\_light() and the theme() function allowed Scherer and Karamanis to create a decluttered visualization that communicates effectively.
* **It uses well-chosen colors**. The scale\_fill\_viridis\_d() allowed them to create a color scheme that demonstrates differences between groups, is colorblind friendly, and shows up well when printed in grayscale.
* **It uses small multiples to break data from two decades and eight regions into a set of graphs that come together to create a single plot**. With a single call to the facet\_grid() function, Scherer and Karamanis created over 100 small multiples that the tool automatically combined into a single plot.

Learning to create data visualization in ggplot involves a significant time investment. But the long-term payoff is even greater. Once you learn how ggplot works, you can look at others’ code and learn how to improve your own. By contrast, when you make a data visualization in Excel, the series of point-and-click steps disappears into the ether. To recreate a visualization you made last week, you’ll need to remember the exact steps you used, and to make someone else’s data visualization, you’ll need them to write up their process for you.

Because code-based data visualization tools allow you to keep that record of the steps you made, you don’t have to be the most talented designer to make high-quality data visualization with ggplot. You can study others’ code, adapt it to your own needs, and create your own data visualization that is beautiful and communicates effectively.

# 3 Make Your Own Theme

In 2017, BBC data journalist Nassos Stylianou was working with a backend developer on a particularly large data set. Nassos was primarily an Excel user at the time, but this data was too large for Excel. Seeing the developer work through the data with ease, a light bulb went off for Stylianou: if he and his data journalism team learned to use R, they could do this type of analysis on their own.

This realization began a journey into R. This journey, which started with needing to analyze data too large for Excel to handle, would ultimately end up in a very different place. In 2018, Stylianou, his colleague Clara Guibourg, and their team created a custom ggplot theme to create plots that match the BBC style. The code in the bbplot package is a great example of the value of developing a custom theme. But the real story of the creation of bbplot is not just about technical tools. Through learning R and creating a custom theme for others to use, Nassos, Clara and their colleagues would change the culture, remove bottlenecks, and allow the BBC to be more creative with their data viz.

To understand how big these changes were, it’s helpful to understand what things looked like at the BBC before bbplot. In the mid-2010s, journalists at the BBC who wanted to make data visualization had two choices:

1. They could use an internal tool. This tool could create data visualization, but only the predefined charts it had been designed to generate.
2. They could use Excel to create mockups and then work with a graphic designer to finalize the charts. This approach led to better results, and was way more flexible, but required extensive back-and-forth with a designer. As Stylianou described it, working with a designer “is just a very time-consuming workflow if you think of how many visualizations the BBC does.”

Neither of these choices was ideal. And this limited set of less-than-ideal choices led to a limited output of data viz.

That would all change when Stylianou, Guibourg, and their colleagues realized that R, the tool they had decided to learn for data analysis, could also do data visualization. As they began playing around with ggplot, they quickly saw its power. Guibourg said she found it “immediately addictive when I started working with ggplot to make charts.” No longer limited by the BBC’s inflexible internal tool, she found that ggplot was “completely flexible in a way that was just completely new to me.”

The biggest change, though, came from not having to work with a designer. Not because the designers were bad (they weren’t), but because ggplot allowed the BBC data journalists to explore different visualizations on their own. Working with a designer required the journalists to have a fully-formed idea that the designer could take and improve upon. Working in ggplot allowed BBC data journalists to explore different data viz ideas.

Clara Guibourg believes this freedom is what explains the addictive quality of ggplot. As she told me, “even before we got anywhere near having a production-ready chart, just trying things out, visualizing things for the first time” was completely captivating. Having learned the basics of ggplot, she saw that “you can make like the simplest chart with just a couple of lines of code.” Being able to explore different types of visualization on her own led Clara and others to produce more data viz than they had previously.

As the BBC data journalism team improved their ggplot skills, they realized that it might be possible produce for more than just exploratory data viz. They had learned to use R for data analysis and they were starting to use it for exploratory data visualization. Could they go all the way and create production-ready charts in R that could go straight onto the BBC website?

Stylianou, Guibourg, and their colleagues set about looking into what would be involved in creating production-ready charts from R. They realized that so much of this work involved small tweaks. What font should they use? Where should the legend go? Should axes have titles? Should charts have grid lines? These questions may seem small but they have a big impact. Having consistent answers to them is what enabled BBC designers to turn Excel mockups into high-quality data viz ready to go on the website. As the BBC data journalism team dug further into ggplot, they realized that they might be able to write code to make their data viz production-ready. They realized that, if making production-ready charts required asking question about fonts, legends, axes, and grid lines, ggplot had the answer. And the answer was to make a custom theme.

## Enter bbplot

In 2018, Stylianou, Guibourg, and others at the BBC developed a package called bbplot. This package has two functions: bbc\_style() and finalise\_plot(). The latter deals with things like adding the BBC logo, saving plots in the correct dimensions, and other tasks done after the plot is complete (we’ll discuss it a bit later on). For now, let’s look at the bbc\_style() function. This function applies a custom ggplot theme to any plot, making all plots look consistent and follow BBC style guidelines.

To show how this function works, let’s create a plot. We’ll do so using the palmerpenguins package, which has data on penguins living on three islands in Antarctica. To give you a sense of what this data looks like, let’s load the palmerpenguins and tidyverse packages.

library(palmerpenguins)  
library(tidyverse)

We now have data that we can work with in an object called penguins. Here’s what the first ten rows look like.

#> # A tibble: 344 × 8  
#> species island bill\_le…¹ bill\_…² flipp…³ body\_…⁴ sex   
#> <fct> <fct> <dbl> <dbl> <int> <int> <fct>  
#> 1 Adelie Torgersen 39.1 18.7 181 3750 male   
#> 2 Adelie Torgersen 39.5 17.4 186 3800 fema…  
#> 3 Adelie Torgersen 40.3 18 195 3250 fema…  
#> 4 Adelie Torgersen NA NA NA NA <NA>   
#> 5 Adelie Torgersen 36.7 19.3 193 3450 fema…  
#> 6 Adelie Torgersen 39.3 20.6 190 3650 male   
#> 7 Adelie Torgersen 38.9 17.8 181 3625 fema…  
#> 8 Adelie Torgersen 39.2 19.6 195 4675 male   
#> 9 Adelie Torgersen 34.1 18.1 193 3475 <NA>   
#> 10 Adelie Torgersen 42 20.2 190 4250 <NA>   
#> # … with 334 more rows, 1 more variable: year <int>, and  
#> # abbreviated variable names ¹​bill\_length\_mm,  
#> # ²​bill\_depth\_mm, ³​flipper\_length\_mm, ⁴​body\_mass\_g

To get our data in a more usable format, let’s count how many penguins live on each island. We do this with the count() function from the dplyr package (one of several packages that are loaded when we load the tidyverse).

This gives us some simple data that we can use for plotting below.

#> # A tibble: 3 × 2  
#> island n  
#> <fct> <int>  
#> 1 Biscoe 168  
#> 2 Dream 124  
#> 3 Torgersen 52

Because we’re going to use this data multiple times below, let’s save it as an object called penguins\_summary.

penguins\_summary <- penguins %>%  
 count(island)

Now that we’ve got some data to work with, we’re ready to create a plot. Before showing what bbplot does, let’s make a plot with ggplot defaults. Here is the code we’ll use. We’re using our penguins\_summary data frame, putting the island on the x axis, the count of the number of penguins (n) on the y axis, and making each bar a different color with the fill aesthetic property.

The resulting plot, seen in Figure 3.1, isn’t the most aesthetically pleasing chart, but we’ll be improving it soon!

[F03001.pdf]

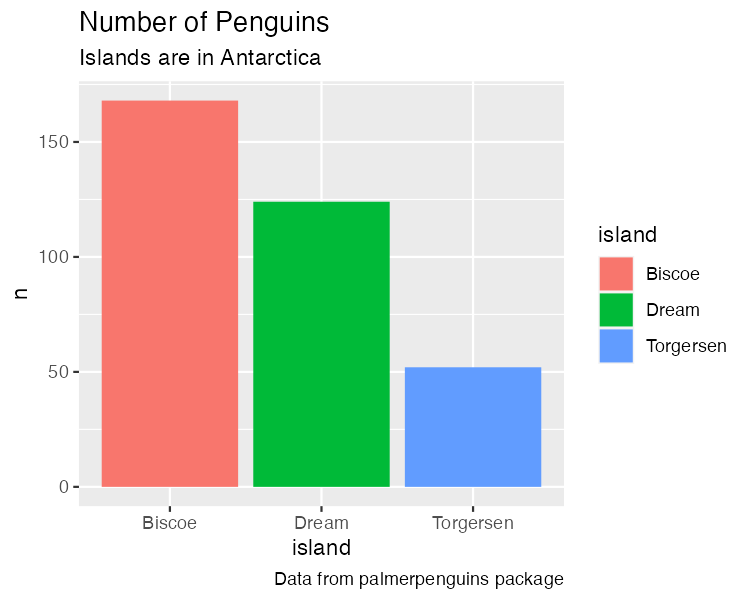


Figure 3.1: A chart with the default theme

We’re going to use this plot multiple times (with some modifications each time). To simplify things, let’s save it as an object called penguins\_plot.

penguins\_plot <- ggplot(  
 data = penguins\_summary,  
 aes(  
 x = island,  
 y = n,  
 fill = island  
 )  
) +  
 geom\_col() +  
 labs(  
 title = "Number of Penguins",  
 subtitle = "Islands are in Antarctica",  
 caption = "Data from palmerpenguins package"  
 )

### The bbc\_style() function

Now that we have a basic plot to work with, let’s make it look like a BBC chart. To do this, we load the bbplot package.

library(bbplot)

We can then apply the bbc\_style() function to our penguins\_plot.

penguins\_plot +  
 bbc\_style()

Take a look at what happens in Figure 3.2 with the application of bbc\_style() to our plot.

[F03002.pdf]



Figure 3.2: The same chart with BBC style

Way different, right? Larger font size, legend on top, no axis titles, stripped down grid lines, and a white background – these are the major changes that the bbc\_style() function makes. Let’s look at them one by one.

Here’s the code for the bbc\_style() function (taken from the bbplot GitHub repository, found at <https://github.com/bbc/bbplot>). You may be a bit confused by the way some of the code is written. This is in part because it is the code used to create a function. The first line gives the function a name (bbc\_style) and indicates that it is, in fact, a function definition. We’ll discuss functions more in Chapter 12.

You’ll see that instead of loading the package ggplot2 with the code library(ggplot2) and then using the theme() function, the code below uses ggplot2::theme(). This indicates that the theme() function comes from the ggplot2 package. Writing code in this way is something that is done when making an R package, something we’ll discuss in Chapter 13.

I’ve made some minor formatting tweaks for readability. For example, you can see the comments in ALL CAPS, which show the category of modification that the section which follows makes. Fortunately for us, the code is organized nicely and allows us to see what each section does.

bbc\_style <- function() {  
 font <- "Helvetica"  
   
 ggplot2::theme(  
   
 # TEXT FORMAT  
 # This sets the font, size, type and colour   
 # of text for the chart's title  
 plot.title = ggplot2::element\_text(  
 family = font,  
 size = 28,  
 face = "bold",  
 color = "#222222"  
 ),  
 # This sets the font, size, type and colour  
 # of text for the chart's subtitle,  
 # as well as setting a margin between the title and the subtitle  
 plot.subtitle = ggplot2::element\_text(  
 family = font,  
 size = 22,  
 margin = ggplot2::margin(9, 0, 9, 0)  
 ),  
 # This leaves the caption text element empty,   
 # because it is set elsewhere in the finalise plot function  
 plot.caption = ggplot2::element\_blank(),  
   
 # LEGEND FORMAT  
 # This sets the position and alignment of the legend,   
 # removes a title and background for it  
 # and sets the requirements for any text within the legend.  
 # The legend may often need some more manual tweaking   
 # when it comes to its exact position based on the plot coordinates.  
 legend.position = "top",  
 legend.text.align = 0,  
 legend.background = ggplot2::element\_blank(),  
 legend.title = ggplot2::element\_blank(),  
 legend.key = ggplot2::element\_blank(),  
 legend.text = ggplot2::element\_text(  
 family = font,  
 size = 18,  
 color = "#222222"  
 ),  
   
 # AXIS FORMAT  
 # This sets the text font, size and colour for the axis test,   
 # as well as setting the margins and removes lines and ticks.  
 # In some cases, axis lines and axis ticks are things we would   
 # want to have in the chart -   
 # the cookbook shows examples of how to do so.  
 axis.title = ggplot2::element\_blank(),  
 axis.text = ggplot2::element\_text(  
 family = font,  
 size = 18,  
 color = "#222222"  
 ),  
 axis.text.x = ggplot2::element\_text(margin = ggplot2::margin(5, b = 10)),  
 axis.ticks = ggplot2::element\_blank(),  
 axis.line = ggplot2::element\_blank(),  
   
 # GRID LINES  
 # This removes all minor gridlines and adds major y gridlines.  
 # In many cases you will want to change this to remove   
 # y gridlines and add x gridlines.  
 # The cookbook shows you examples for doing so.  
 panel.grid.minor = ggplot2::element\_blank(),  
 panel.grid.major.y = ggplot2::element\_line(color = "#cbcbcb"),  
 panel.grid.major.x = ggplot2::element\_blank(),  
   
 # BLANK BACKGROUND  
 # This sets the panel background as blank, removing the standard   
 # grey ggplot background colour from the plot.  
 panel.background = ggplot2::element\_blank(),  
   
 # STRIP BACKGROUND  
 # This sets the panel background for facet-wrapped plots to white,  
 # removing the standard grey ggplot background colour and sets the   
 # title size of the facet-wrap title to font size 22.  
 strip.background = ggplot2::element\_rect(fill = "white"),  
 strip.text = ggplot2::element\_text(size = 22, hjust = 0)  
 )  
}

Nearly all of the code in the bbc\_style() function exists within the theme() function from ggplot2. In the Chapter 2, we saw how Cédric Scherer and Georgios Karamanis customized their plot by applying the theme\_light() function. This a so-called complete theme, meaning you can call the function and will change the whole look-and-feel of your plot. After applying theme\_light(), Scherer and Karamanis used the theme() function make additional tweaks. The bbc\_style() theme does not use a complete theme to start. Instead, by jumping straight into the theme() function, they make tweaks to the ggplot defaults. As you can see, the bbc\_style() function does a lot of tweaking. So, let’s go through the changes it makes, section by section.

### Text Formatting

The first section of the code deals with text formatting. First, it defines a variable called “font” and assigns it the value “Helvetica.” This allows later sections of code to simply write “font” rather than repeating “Helvetica” over and over again. And, if the team ever wanted to use a different font, they could simply change “Helvetica” to, say, “Comic Sans” and change all BBC plots (I suspect higher-ups at the BBC might not be on board).

font <- "Helvetica"

Subsequent pieces of this section of the code make changes to the title, subtitle, and caption. The pattern used in code to make changes is as follows:

AREA\_OF\_CHART = ELEMENT\_TYPE(  
 PROPERTY = VALUE  
)

We begin by selecting an area of the chart (for example, plot.title). Then, we have to say what type of element it is. The options are element\_text(), element\_line(), element\_rect(), and element\_blank(). We’ll deal with the other three later on. For now, we’re working with element\_text() to handle formatting of the title, subtitle, and caption since they’re all text elements. Within the element type, we give values to properties. This can be, say, setting the font family (the property) to Helvetica (the value).

One of the main things that the bbc\_style() function does is to bump up the text size. As Nassos put it to me, on a lot of plots made with ggplot, “font and the numbers are just so small.” Increasing font size helps with legibility, especially when plots made using the bbplot package are viewed on smaller mobile devices.

The code first formats the title using Helvetica 28-point bold font in a nearly black color (that’s the hex code #222222). The subtitle is 22-point Helvetica. Some spacing is added between the title and subtitle using the margin() function, which gives the spacing, in points, for the top (9), right (0), bottom (9), and left (0) sides. Finally, the caption is removed using the element\_blank() function. This is done because the finalise\_plot() function in the bbplot package adds elements, including a caption and the BBC logo to the bottom of plots.

penguins\_plot +  
 theme(  
 plot.title = element\_text(  
 family = font,  
 size = 28,  
 face = "bold",  
 color = "#222222"  
 ),  
 plot.subtitle = element\_text(  
 family = font,  
 size = 22,  
 margin = margin(9, 0, 9, 0)  
 ),  
 plot.caption = element\_blank()  
 )

We can see these changes in Figure 3.3 below.

[F03003.pdf]

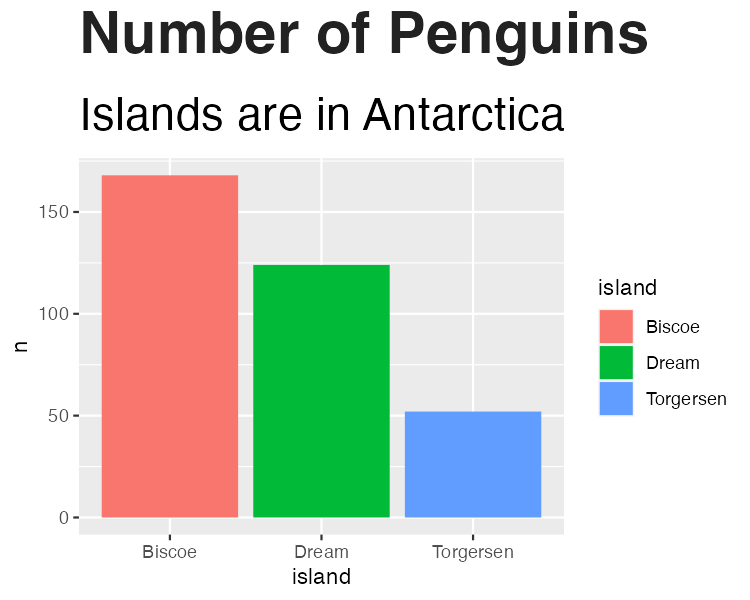


Figure 3.3: Our chart with only text formatting changed

We then save our plot as an object in order to work with it in the next section.

penguins\_plot\_text <- penguins\_plot +  
 theme(  
 plot.title = element\_text(  
 family = font,  
 size = 28,  
 face = "bold",  
 color = "#222222"  
 ),  
 plot.subtitle = element\_text(  
 family = font,  
 size = 22,  
 margin = margin(9, 0, 9, 0)  
 ),  
 plot.caption = element\_blank()  
 )

### Legend Formatting

Next, we deal with the legend. The code puts the legend on top of the plot, and left aligns the text within it. Then, it removes the legend background (this would only show up if the background color of the entire plot were different than the legend background), title, and legend key (this is a box that can show up around the boxes with the names of the islands). Finally, we make the legend text 18-point Helvetica with the same nearly black color.

penguins\_plot\_text +  
 theme(  
 legend.position = "top",  
 legend.text.align = 0,  
 legend.background = element\_blank(),  
 legend.title = element\_blank(),  
 legend.key = element\_blank(),  
 legend.text = element\_text(  
 family = font,  
 size = 18,  
 color = "#222222"  
 )  
 )

We can see the result in Figure 3.4.

[F03004.pdf]

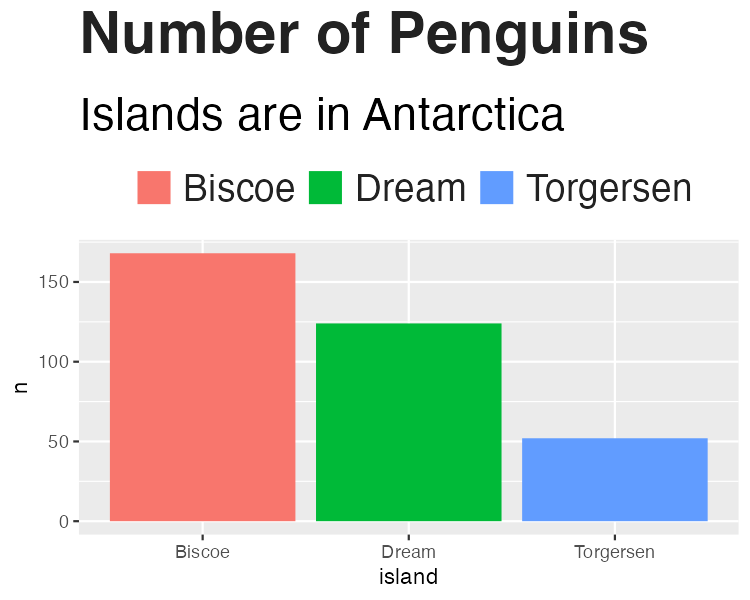


Figure 3.4: Our chart with changes to the legend

And again, we save this plot so we can continue to alter it below.

penguins\_plot\_legend <- penguins\_plot\_text +  
 theme(  
 legend.position = "top",  
 legend.text.align = 0,  
 legend.background = element\_blank(),  
 legend.title = element\_blank(),  
 legend.key = element\_blank(),  
 legend.text = element\_text(  
 family = font,  
 size = 18,  
 color = "#222222"  
 )  
 )

### Axis Formatting

Next up are the axes. The code first removes axis titles because, as Nassos told me, these tend to take up a lot of chart real estate and you can use the title and subtitle to make clear what the axes show. All text on axes becomes 18-point Helevetica nearly black. The text on the x axis (in our case, Biscoe, Dream, and Torgersen) gets a bit of spacing around it. And, finally, both axis ticks and axis lines are removed.

penguins\_plot\_legend +  
 theme(  
 axis.title = element\_blank(),  
 axis.text = element\_text(  
 family = font,  
 size = 18,  
 color = "#222222"  
 ),  
 axis.text.x = element\_text(margin = margin(5, b = 10)),  
 axis.ticks = element\_blank(),  
 axis.line = element\_blank()  
 )

We can see the changes to our axes in Figure 3.5.

[F03005.pdf]

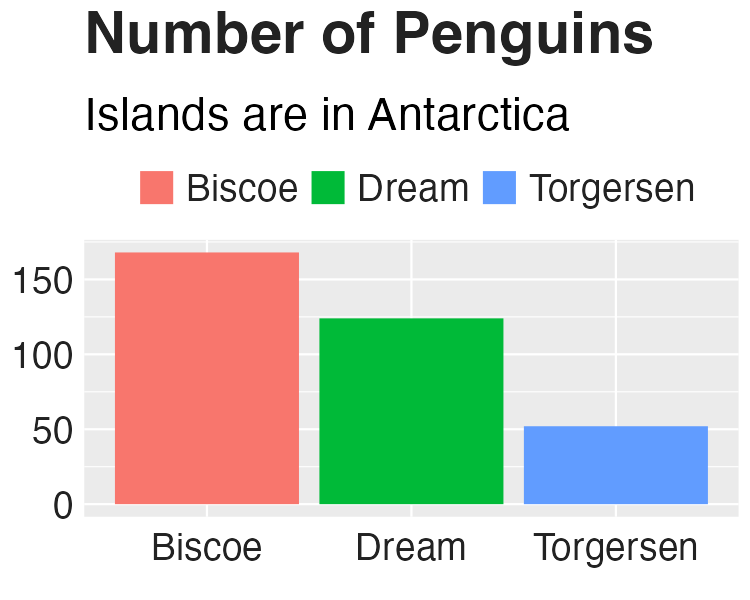


Figure 3.5: Our chart with changes to axis formatting

Let’s now save this plot as an object for future tweaks.

penguins\_plot\_axes <- penguins\_plot\_legend +  
 theme(  
 axis.title = element\_blank(),  
 axis.text = element\_text(  
 family = font,  
 size = 18,  
 color = "#222222"  
 ),  
 axis.text.x = element\_text(margin = margin(5, b = 10)),  
 axis.ticks = element\_blank(),  
 axis.line = element\_blank()  
 )

### Grid Lines Formatting

Now that we’ve tweaked overall text formatting, the legend, and the axes, let’s move onto grid lines. The approach here is fairly straightforward: remove all minor grid lines, remove major grid lines on the x axis, keeping only major grid lines on the y axis, but making them a light gray (using the #cbcbcb hex code).

penguins\_plot\_axes +  
 theme(  
 panel.grid.minor = element\_blank(),  
 panel.grid.major.y = element\_line(color = "#cbcbcb"),  
 panel.grid.major.x = element\_blank()  
 )

We can see the result of these tweaks to the grid lines in Figure 3.6.

[F03006.pdf]

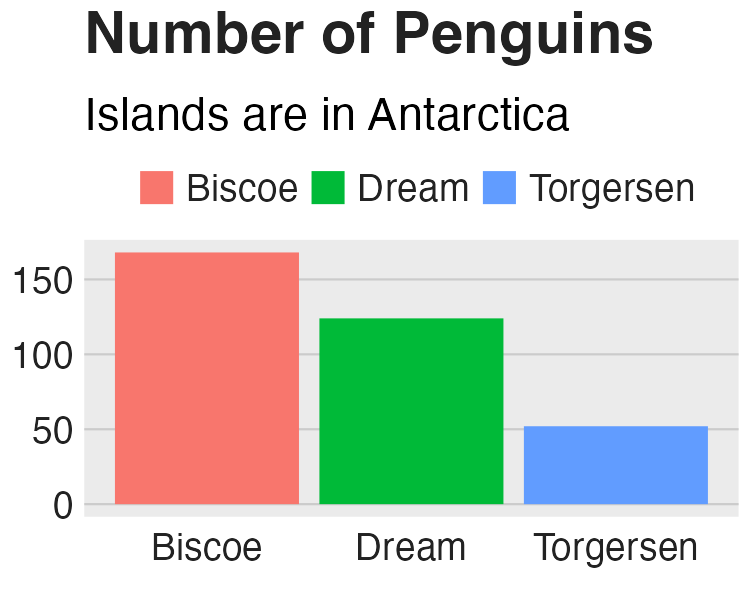


Figure 3.6: Our chart with tweaks to the grid lines

And, once again, we save our plot to an object.

### Background Formatting

Of course, in the previous iteration of our plot, it still had a gray background. The bbc\_style() function removes this with the following code.

penguins\_plot\_grid\_lines +  
 theme(  
 panel.background = element\_blank()  
 )

The plot without the gray background is seen in Figure 3.7.

[F03007.pdf]



Figure 3.7: Our chart with the gray background removed

### Small Multiples Formatting

And there we go! We’ve now recreated the plot that we made above using the bbc\_style() function. However, you may recall there is a bit more code in the bbc\_style() function. This code deals with strip.background and strip.text. Both of these occur when we make small multiples charts. Small multiples is a common technique in data visualization, where, instead of making one chart that incorporates all of the available data, we break the chart into multiple charts in order to make the final results easier for the reader to comprehend.

Let’s make an example small multiples chart to show what this looks like. I’ve used the code from the bbc\_style() function to make Figure 3.8 below.

[F03008.pdf]

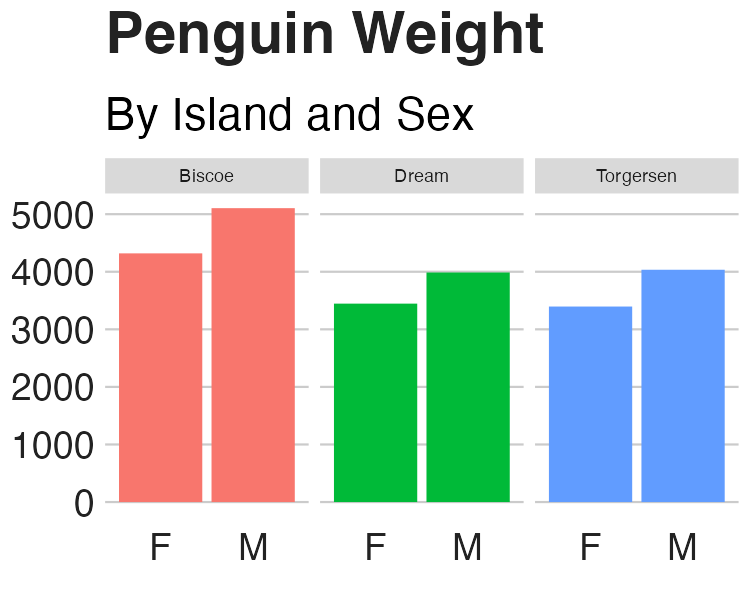


Figure 3.8: Small multiples chart with no changes to the strip text formatting

When we use the facet\_wrap() function, we are left with one chart per island. But note that, by default, the text above each chart is noticeably smaller than the rest of the chart. And the gray background behind the text stands out when we have removed the gray background from other parts of the chart.

I’ve saved the code used to make Figure 3.8 as an object (penguins\_plot\_weight). We now use this object in order to show how to change the text that shows up above each small multiples chart (in ggplot this text is called the “strip”). We remove the background (or, more accurately, make it white) and make the text larger, bold, and left aligned (using hjust = 0). (I did have to make the text size slightly smaller to fit in the book and added code to make it bold, something done in the chart on carbon impact of food chart, though not seen in the bbc\_style() code.)

penguins\_plot\_weight +  
 theme(  
 strip.background = element\_rect(fill = "white"),  
 strip.text = element\_text(size = 17, hjust = 0, face = "bold")  
 )

The result shows up in Figure 3.9.

[F03009.pdf]



Figure 3.9: Small multiples chart in the BBC style

If you take a look at any chart on the BBC site, you’ll see how similar it is to our chart. All of the tweaks in the bbc\_style() function (text formatting, legends, axes, grid lines, and backgrounds) that we used to make our example show up in charts seen by millions on the BBC website.

### What About Colors?

You might be thinking: wait, what about the colors? Doesn’t the theme change that? It’s a common point of confusion. If we read the documentation for the theme() function, though, it becomes clearer why this is the case:

Themes are a powerful way to customize the non-data components of your plots: i.e. titles, labels, fonts, background, gridlines, and legends.

Color (or, technically, in the case of the bar charts we have made in this chapter, fill) is used in plots as an aesthetic property to show something about data. In our small multiples chart, for instance, fill is mapped to the island (Biscoe is salmon, Dream is green, and Torgersen is blue). As we saw in Chapter 2, we can change fill using the various scale\_fill\_ functions. It is because fill is tied to the data rather than being about the overall look-and-feel that ggplot themes do not, on their own, change this component of plots.

## Code is the Catalyst for Culture Change

When Nassos Stylianou and Clara Guibourg started developing a custom theme for the BBC, they had one question: would they be able to create graphs in R that could go straight onto the BBC website? And, wouldn’t you know, they succeeded! The creation of the bbplot package allowed them to make plots that had a consistent look-and-feel, followed BBC standards, and, most importantly, did not need help from a designer.

Many of the principles of high-quality data visualization that we discussed in Chapter 2 can be seen in this custom theme. In particular, the removal of extraneous elements (axis titles and grid lines, for instance) helps keep the focus on the data itself. And by creating a custom theme that only requires users to add a single line to their ggplot code, it became simple to get others on board. Telling users they could just append bbc\_style() to their code and get a BBC-style plot was an eye-opener.

The development of the bbplot package would lead to significant changes at the BBC. It inspired Stylianou, Guibourg, and the other data journalists who created it to use ggplot more than before. Knowing that they had the flexibility of ggplot at their fingertips gave them license to explore. And knowing that they did not have to work with a designer to create production-ready graphics empowered them to make more and better graphics.

In addition to the bbc\_style() function, the bbplot package also provides another function called finalise\_plot() that adds a source at the bottom of the chart (recall how the bbc\_style() function removed the caption), adds the BBC logo in the footer, and gives height, width, and file name options for saving the plot. These two functions combined allowed Nassos, Clara, and others to achieve their holy grail: creating production-ready graphs that could go straight from R to the BBC website.

The impact of bbplot would also come to be seen outside of the small team of data journalists that brought it to life. Others at the BBC saw how the data journalism team was now able to produce production-ready graphs and they wanted to do the same. This led the data journalism team to set up R trainings for their colleagues and to develop a “cookbook” (found at <https://bbc.github.io/rcookbook/>) that provided examples of how to make various types of charts.

These two resources led to a large increase in R users at the BBC. As Stylianou told me, they “spurred people a lot people outside of the data journalism team to take a real interest [in R].” Having bbplot made the value of R click for many people at the BBC. He continued:

There is no, “why am I doing this?” in their mind. It’s is worth the pain [to learn R], because it is a pain at first. But seeing this graphic that a few months ago you would have had to do in this old process … if you devote a bit of time each day, here are the five lines of code that you can run and you can [make a production-ready graphic] yourself.

As so many more people at the BBC came to learn R, the quality and quantity of data visualization produced exploded. Stylianou told me, “I don’t think there’s been a day where someone at the BBC hasn’t used the package to produce a graphic.” The bbplot package came in particularly helpful during COVID. Being able to produce on-brand graphics on a quick turnaround was possible in a way it would not have been previously.

Reflecting on her experience, Guibourg attributes the successful transition to R at the BBC to its culture. As she put it, “I think that what helped me get started was that there was a really supportive environment internally at the BBC for learning.” And, indeed, this same supportive culture that led Clara to organically explore what R was capable of was reinforced after she and the data journalism team released bbplot. The custom theme they developed enabled the creation of so many BBC graphics that otherwise never would have seen the light of day. A culture open to learning led the data journalism team to insights about the power of code. And this code then facilitated a culture change around how graphics are produced at the BBC.

# 4 R is a Full-Fledged Map-Making Tool

When I first started learning R, I had no idea it could make maps. I thought of R as being designed to work with numbers, not the shapes that make up maps. So I was surprised when I first saw people making maps with R. This is possible, I wondered?

The answer is yes: you absolutely can make maps in R. And not just prosaic maps. Beautiful maps that use high-quality design principles. Maps that are good enough to be featured in top media outlets.

When many people hear “maps” they immediately think of ArcGIS. But this tool is expensive, with business licenses for ArcGIS starting at $500 per year. Excel has added support for map-making in recent years, but features are limited (making maps based on street addresses, for example, is not possible). There is QGIS, an open-source tool similar to ArcGIS. But the mental tax that comes from context switching between tools is significant. Learning to make maps in R means you can do everything, for free, in one tool.

And the best part of making maps in R is that we can use what we learned about high-quality data visualization in 2. Maps are a form of data visualization and the principles discussed in that chapter apply here as well.

Many people assume that making maps requires a ton of specialized knowledge (this is what I used to think). It doesn’t. There are a few things you need to know in order to work with geospatial data used to make maps. But once you understand the basics, you too can make high-quality maps in R. To show how anyone can make high-quality maps in R, I spoke with Abdoul Madjid. A polyglot developer originally from Benin, Madjid has been making maps with R for several years. In January 2022, he made a beautiful map that shows rates of COVID-19 in the US throughout 2021.

[TODO: ADD MAP]

Madjid is not a geospatial information system (GIS) specialist, but he has learned how to work with geospatial data in R in a way that enables him to make beautiful maps like this one. I spoke with Madjid and he explained how he obtained the data, analyzed it, and made his COVID-19 map.

In this chapter, we will begin by diving into geospatial data, giving you the minimum you need to know in order to make maps in R. We’ll then walk through Abdoul Madjid’s code, looking at the choices he made that resulted in this high-quality map. The chapter concludes with some thoughts on why R is the perfect tool for making maps.

## The Briefest of Primers on Geospatial Data

There are two main types of geospatial data: vector and raster. Vector data uses points, lines, and polygons shapes to spatially represent the world. Raster data, which often comes from digital photographs, ties each pixel in the photograph to a specific geographic location. Vector data tends to be simpler to work with, and we will be using it exclusively in this chapter (when I use the term “geospatial data” in this chapter, I’m referring to vector data).

If you are making maps today in R, consider yourself lucky. Changes in recent years have made it much simpler to work with geospatial data, and to build maps with R. Before then, there were competing standards for geospatial data, and each standard required learning a different approach. Today, though, the simple features (often abbreviated as sf) model for working with vector geospatial data has become dominant. I’m grateful for this, as simple features data is way easier to work with than were previous geospatial data models.

Geospatial data is both very similar to data you’re already used to working with in R and, in some ways, very different. To see the similarities and differences, let’s look at how simple features data works. In this section, I’ll just show you data and the maps we make with that data, providing the bare minimum you need to know in order to understand how simple features data works. The sections that follow will explain how we import, manipulate, and plot geospatial data.

Let’s begin by taking a look at some simple features geospatial data that represents the U.S. state of Wyoming.

#> Simple feature collection with 1 feature and 1 field  
#> Geometry type: POLYGON  
#> Dimension: XY  
#> Bounding box: xmin: -111.0546 ymin: 40.99477 xmax: -104.0522 ymax: 45.00582  
#> Geodetic CRS: WGS 84  
#> NAME geometry  
#> 1 Wyoming POLYGON ((-111.0449 43.3157...

You can see that we have a column for state name (NAME) and another column called geometry. Overall, this looks like the output we’re used to seeing with data in a data frame. But there are two major differences:

1. There is a bunch of metadata above the data frame
2. Our simple features data has a geometry column

### Difference #1: Metadata

Above the main output, we see a section that starts with the text “Simple feature collection with 1 feature and 1 field.” The feature here is the row and the field is the variable (NAME) that contains non-spatial data (the geometry column, which contains geospatial data, will be discussed below). This line, and the lines that follow, are metadata about the geospatial data in the wyoming object.

#### Geometry Type

The geometry type shows the type of geospatial data we’re working with. POLYGON (geometry types are typically written in all caps) means a relatively simple shape that can be represented by a single polygon. We can use ggplot to display this data. Note that geom\_sf() is a special geom designed to work with simple features (sf) data.

We can see the resulting map of Wyoming. It may not look like much, but, hey, I wasn’t the one who chose to make Wyoming a nearly perfect rectangle!

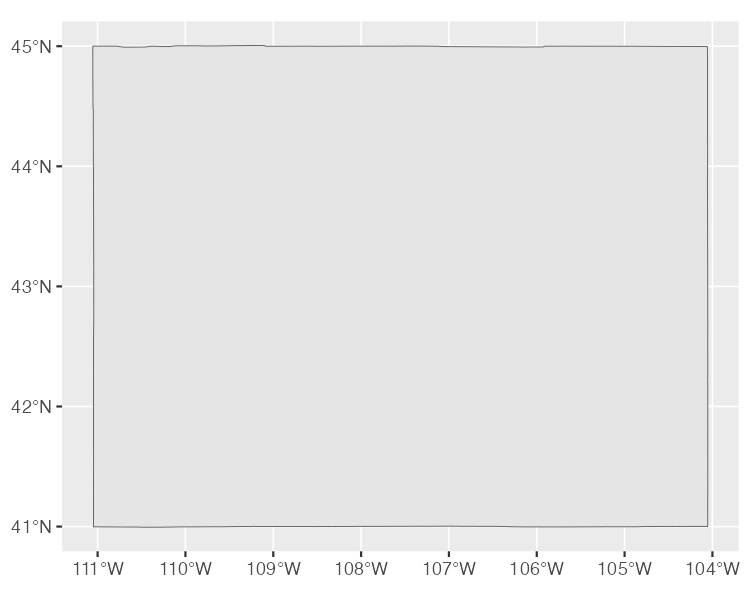


Figure 4.1: A map of Wyoming

POLYGON is one of several geometry types that sf data can be used to represent. Others include:

POINT: Used to display something like a pin on a map that shows a single location. Here’s a map showing the location of a single electric vehicle charging station in Wyoming

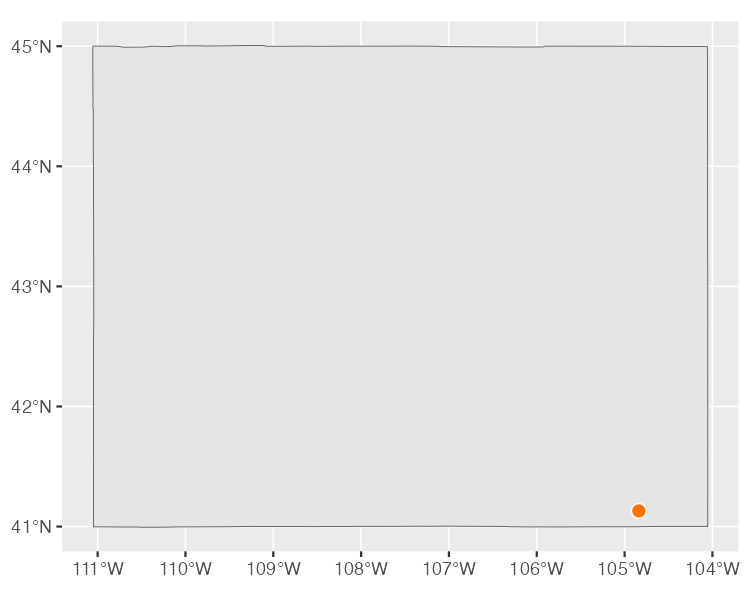
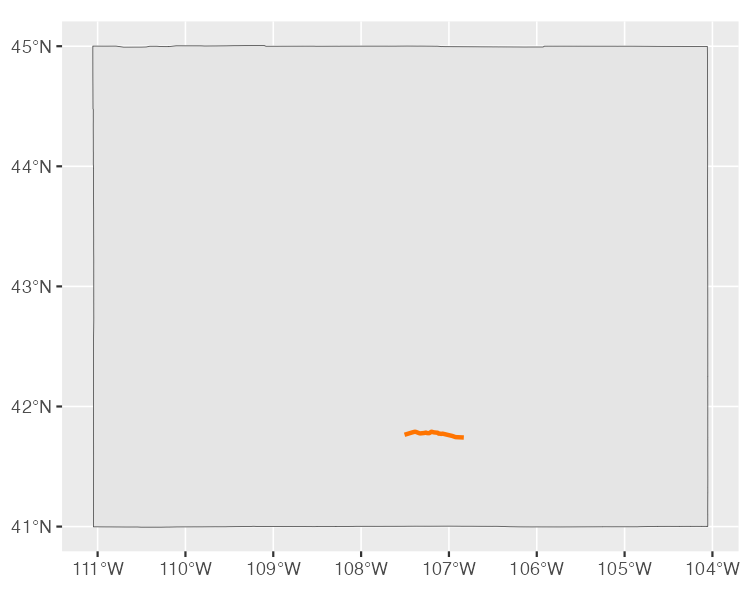
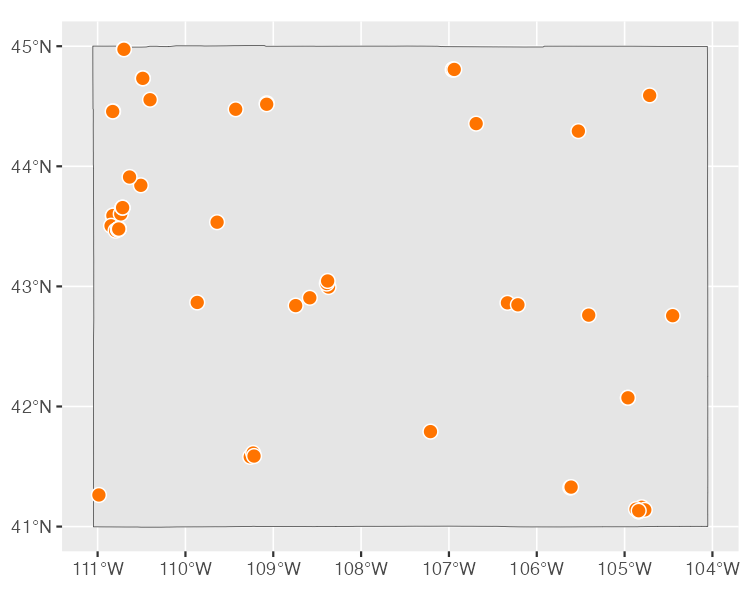


Figure 4.2: A map of a single electric vehicle charging station in Wyoming

LINESTRING: Described as a “sequence of points connected by straight, non-self intersecting line pieces,” this is often used to represent roads. Here’s an example I’ve added of a LINESTRING showing a section of U.S. Highway 30 that runs through Wyoming.



Each of these has a multi- variation (MULTIPOINT, MULTILINESTRING, and MULTIPOLYGON) to combine multiple instances of their “single” variation in one row of data. For example, the data used to make Figure (TODO: Add number) below, which shows all electric vehicle charging stations in Wyoming, is MULTIPOINT.



MULTILINESTRING data can be seen if we show not one road, but all major roads in Wyoming.

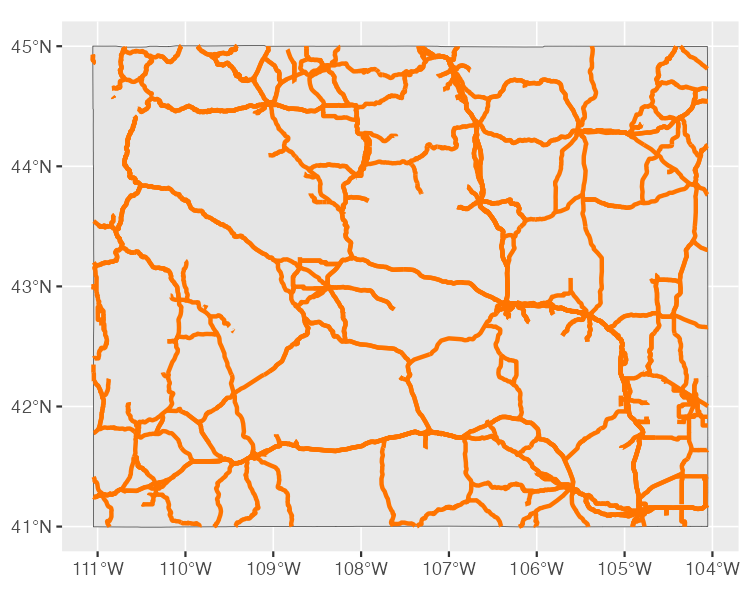


Figure 1.2: A map of all major roads in Wyoming

MULTIPOLYGON data occurs when, for example, we have a state made up of multiple polygons. To see what I mean, let’s take a look at a map of Wyoming counties. First, let’s look at simple features data used to represent the 23 counties in the state. We can see that the geometry type of this data is MULTIPOLYGON (in addition, the repeated MULTIPOLYGON text in the geometry column indicates that each row contains a shape of type MULTIPOLYGON; see section on the geometry column below).

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#> Geometry type: MULTIPOLYGON  
#> Dimension: XY  
#> Bounding box: xmin: -111.0546 ymin: 40.99477 xmax: -104.0522 ymax: 45.00582  
#> Geodetic CRS: WGS 84  
#> First 10 features:  
#> NAME geometry  
#> 34 Lincoln MULTIPOLYGON (((-111.0472 4...  
#> 104 Fremont MULTIPOLYGON (((-109.4582 4...  
#> 121 Uinta MULTIPOLYGON (((-110.6068 4...  
#> 527 Big Horn MULTIPOLYGON (((-108.5923 4...  
#> 551 Hot Springs MULTIPOLYGON (((-109.1714 4...  
#> 601 Washakie MULTIPOLYGON (((-107.6335 4...  
#> 769 Converse MULTIPOLYGON (((-105.6985 4...  
#> 970 Sweetwater MULTIPOLYGON (((-110.0489 4...  
#> 977 Crook MULTIPOLYGON (((-105.0856 4...  
#> 1097 Carbon MULTIPOLYGON (((-106.9129 4...

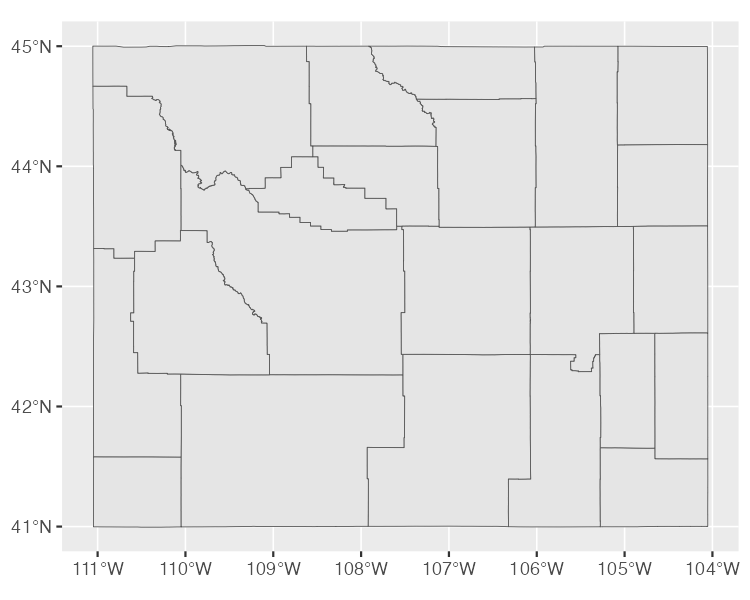


Figure 1.4: A map of Wyoming counties

#### Dimensions

The next line we see in our geospatial data frame metadata is dimension. For our Wyoming data, we had the text Dimension: XY. Dimensions refer to the type of geospatial data we’re working with. When we see XY, this means the data is two-dimensional. This is what we will see in all of the geospatial data used in this chapter. There are two other dimensions (Z and M) that you see much more rarely. Since Z and M are both less common and not relevant to the maps we’re discussing in this chapter, I’ll leave them for you to investigate further.

#### Bounding Box

The penultimate element we see in the metadata is the bounding box. For Wyoming, it looks like this:

Bounding box: xmin: -111.0569 ymin: 40.99475 xmax: -104.0522 ymax: 45.0059

A bounding box represents the smallest area in which we can fit all of our geospatial data. What we see in our metadata is the four corners of this bounding box. For Wyoming, the ymin value of 40.99475 and ymax value of 45.0059 represent the lowest and highest latitude, respectively, that the polygon that represents the state can fit into (the x values do the same for longitude). Bounding boxes are calculated automatically and are not typically something we have to worry about altering.

#### Geodetic CRS

The final piece of metadata above our data frame is the “Geodetic CRS.” This refers to the coordinate reference system (CRS) used to project our data when we plot it. The problem with representing any geospatial data is that we’re projecting data that is inherently three-dimensional (the earth, after all, is round) onto a two-dimensional map. Doing so requires us to choose a coordinate reference system that determines what type of projection to use when making our map.

Let’s look at a couple projections of our map of Wyoming Counties We’ll begin by looking at the data we’re using to make our maps. As we can see in the line Geodetic CRS: WGS 84, this uses a coordinate reference system known as WGS84.

#> Simple feature collection with 23 features and 1 field  
#> Geometry type: MULTIPOLYGON  
#> Dimension: XY  
#> Bounding box: xmin: -111.0546 ymin: 40.99477 xmax: -104.0522 ymax: 45.00582  
#> Geodetic CRS: WGS 84  
#> First 10 features:  
#> NAME geometry  
#> 34 Lincoln MULTIPOLYGON (((-111.0472 4...  
#> 104 Fremont MULTIPOLYGON (((-109.4582 4...  
#> 121 Uinta MULTIPOLYGON (((-110.6068 4...  
#> 527 Big Horn MULTIPOLYGON (((-108.5923 4...  
#> 551 Hot Springs MULTIPOLYGON (((-109.1714 4...  
#> 601 Washakie MULTIPOLYGON (((-107.6335 4...  
#> 769 Converse MULTIPOLYGON (((-105.6985 4...  
#> 970 Sweetwater MULTIPOLYGON (((-110.0489 4...  
#> 977 Crook MULTIPOLYGON (((-105.0856 4...  
#> 1097 Carbon MULTIPOLYGON (((-106.9129 4...

If we plot our map with this data, here’s what it looks like.

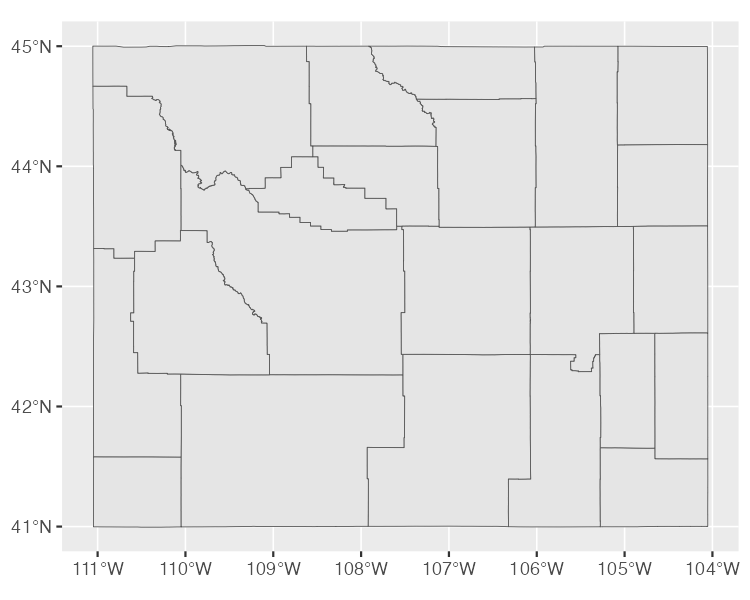


Figure 4.3: A map of Wyoming counties using the WGS84 projection

To see how different a map that uses a different projection can look, check out another map of Wyoming counties, this time using what’s known as the “Albers equal-area conic convenience projection.” Whereas Wyoming looked perfectly horizontal in our first map, in this one it appears to be tilted.

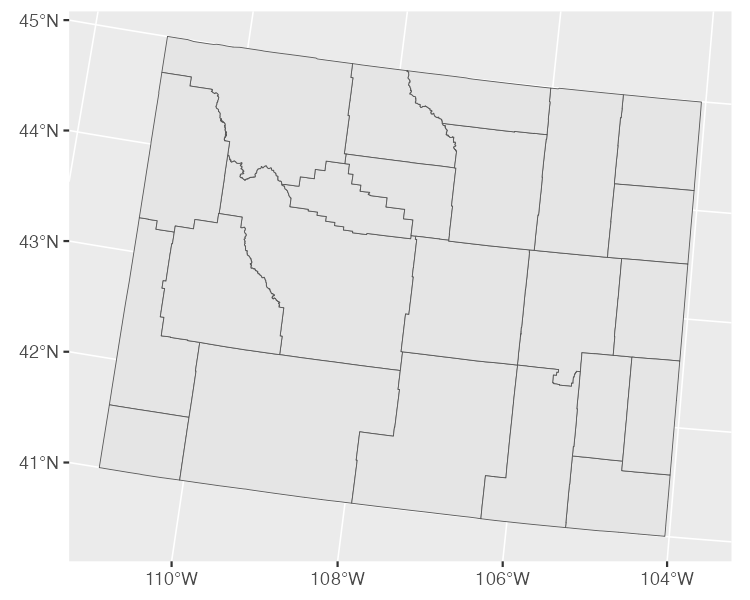


Figure 4.4: A map of Wyoming counties using the Albers equal-area conic convenience projection

If you’re curious about how to change projections when making maps of your own, fear not. I’ll show you how to do so when we look at Abdoul Madjid’s map.

### Difference #2: The geometry Column

In addition to the metadata above our data frame, there is another difference between geospatial data and traditional data frames. All simple features data has a geometry column. As you probably guessed from the name, this column holds the data needed to make our maps.

Think back to when you were a kid and you did connect-the-dots drawings. As you added lines to connect one point to the next, the subject of your drawing was eventually revealed. The geometry column is similar. It has a set of numbers, each of which corresponds to a point. If you’re using LINESTRING/MULTILINESTRING or POLYGON/MULTIPOLYGON simple features data, ggplot uses the data in the geometry column to draw each point and then add lines to connect the points (if you’re using POINT/MULTIPOINT data, it just draws the points but doesn’t connect them).

If it sounds complicated, don’t worry: you never have to worry about the details. The first time I looked in any depth at a geometry column was when I wrote this chapter. What you need to know is this: simple features data has a geometry column, and it’s what allows us to make maps.

## How to Make High-Quality Maps

Now that we’ve explained the basics of geospatial data, let’s make a map. All those concepts you just learned about geometry types, dimensions, bounding boxes, projections, and the geometry column will come into play as we return to the COVID-19 map that Abdoul Madjid made. Let’s walk through the code Madjid used to make his map. As with other chapters, I’ve made small modifications to the code, but what you’ll see below is nearly identical to the code Madjid wrote.

We’ll use a few packages to create Madjid’s COVID-19 map. The tidyverse we’ll use for data importing, manipulation, and plotting (with ggplot). The albersusa package will give us the geospatial data we need and the sf package will enable us to change its coordinate reference system to use an appropriate projection. The zoo package has functions for calculating rolling averages and the colorspace package gives us a fill scale that highlights the data well.

library(tidyverse)  
library(albersusa)  
library(sf)  
library(zoo)  
library(colorspace)

### 4.0.1 Data Import

Next, let’s import the data we need. There are three types of data we’ll import:

1. COVID rates by state over time
2. State populations
3. Geospatial data to make our map of the United States

We’ll import each of these types of data and then merge them.

First, we import COVID data. This data comes directly from the *New York Times*, which publishes daily case rates by state as a CSV on their GitHub account. I’ve dropped the fips variable (FIPS, which stands for Federal Information Processing Standards, are numeric codes used to represent states) because we can just use the state name instead.

covid\_data <- read\_csv("https://raw.githubusercontent.com/nytimes/covid-19-data/master/us-states.csv") %>%  
 select(-fips)

If we take a look at this data we can see the arrival of the first COVID cases in the United States.

#> # A tibble: 55,558 × 4  
#> date state cases deaths  
#> <date> <chr> <dbl> <dbl>  
#> 1 2020-01-21 Washington 1 0  
#> 2 2020-01-22 Washington 1 0  
#> 3 2020-01-23 Washington 1 0  
#> 4 2020-01-24 Illinois 1 0  
#> 5 2020-01-24 Washington 1 0  
#> 6 2020-01-25 California 1 0  
#> 7 2020-01-25 Illinois 1 0  
#> 8 2020-01-25 Washington 1 0  
#> 9 2020-01-26 Arizona 1 0  
#> 10 2020-01-26 California 2 0  
#> # … with 55,548 more rows

The map that Abdoul Madjid made shows not absolute rates, but per capita rates. So, to make these maps, we need to have data on population by state. Madjid downloaded this data as a CSV. The code below imports this data, keeps the State and Pop (population) variables, and saves it as an object called usa\_states.

usa\_states <- read\_csv("https://raw.githubusercontent.com/AbdoulMa/TidyTuesday/main/2022\_w1/usa\_states\_population.csv") %>%  
 select(State, Pop)

Let’s see what usa\_states looks like.

#> # A tibble: 52 × 2  
#> State Pop  
#> <chr> <dbl>  
#> 1 California 39613493  
#> 2 Texas 29730311  
#> 3 Florida 21944577  
#> 4 New York 19299981  
#> 5 Pennsylvania 12804123  
#> 6 Illinois 12569321  
#> 7 Ohio 11714618  
#> 8 Georgia 10830007  
#> 9 North Carolina 10701022  
#> 10 Michigan 9992427  
#> # … with 42 more rows

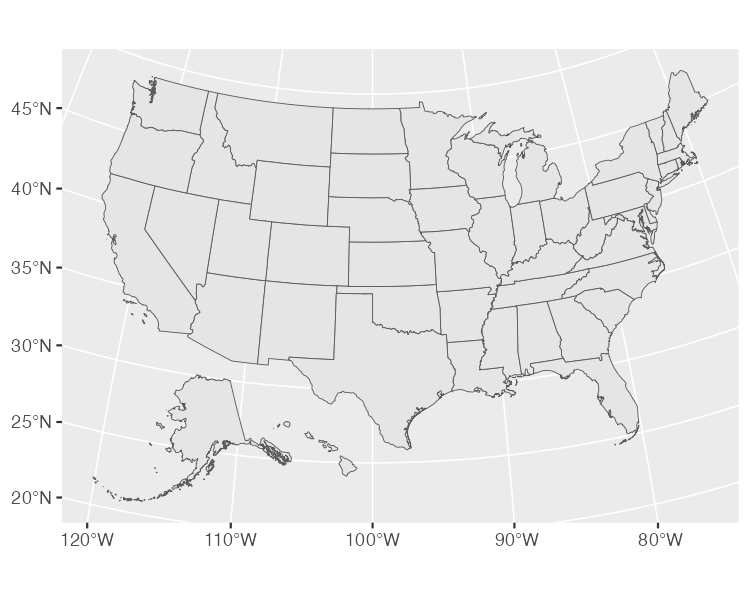
Finally, we’ll bring in our geospatial data and save it as an object called usa\_states\_geom. The usa\_sf() function from the albersausa package gives us simple features data for all U.S. states (and, conveniently, puts Alaska and Hawaii in a location and at a scale that they are easy to see. This data comes from multiple variables, but we only need the state name so Madjid only keeps the name variable. Madjid then uses the st\_transform() function from the sf package to change the coordinate reference system. The CRS that he uses comes from the us\_laea\_proj object, which comes from the alberusa package. Remember the Albers equal-area conic convenience projection we used to change the appearance of our Wyoming counties map? This is the same projection.

usa\_states\_geom <- usa\_sf() %>%  
 select(name) %>%  
 st\_transform(us\_laea\_proj)

#### 4.0.1.1 Projections examples

Let’s pause for a moment to plot our geospatial data. As we saw when making our maps of Wyoming, it only takes three lines to make a map from our simple features data.

We can see the curvature of the longitude and latitude lines and see how the land curves along with them.



If we want to see the same data projected with a different coordinate reference system, we can import the data again using the usa\_sf() function, but without setting the CRS to the Albers equal-area conic convenience projection.

usa\_states\_wgs84 <- usa\_sf()

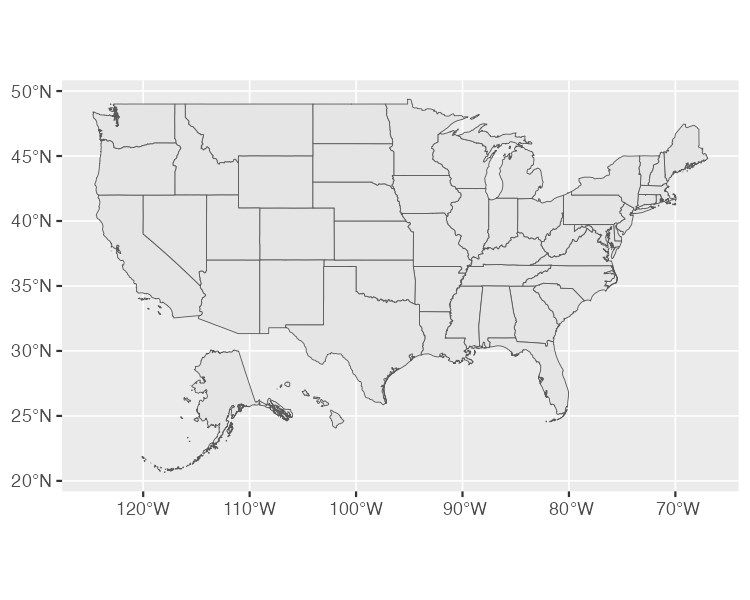
I saved this object as usa\_states\_wgs84 because, as you can see below, it uses the ubiquitous WGS84 projection.

TODO: explain that it already has a built in projection?

#> Simple feature collection with 51 features and 13 fields  
#> Geometry type: MULTIPOLYGON  
#> Dimension: XY  
#> Bounding box: xmin: -124.7332 ymin: 20.63151 xmax: -66.9499 ymax: 49.38436  
#> Geodetic CRS: WGS 84  
#> First 10 features:  
#> geo\_id fips\_state name lsad  
#> 1 0400000US04 04 Arizona   
#> 2 0400000US05 05 Arkansas   
#> 3 0400000US06 06 California   
#> 4 0400000US08 08 Colorado   
#> 5 0400000US09 09 Connecticut   
#> 6 0400000US11 11 District of Columbia   
#> 7 0400000US13 13 Georgia   
#> 8 0400000US17 17 Illinois   
#> 9 0400000US18 18 Indiana   
#> 10 0400000US22 22 Louisiana   
#> census\_area iso\_3166\_2 census pop\_estimataes\_base  
#> 1 113594.084 AZ 6392017 6392310  
#> 2 52035.477 AR 2915918 2915958  
#> 3 155779.220 CA 37253956 37254503  
#> 4 103641.888 CO 5029196 5029324  
#> 5 4842.355 CT 3574097 3574096  
#> 6 61.048 DC 601723 601767  
#> 7 57513.485 GA 9687653 9688681  
#> 8 55518.930 IL 12830632 12831587  
#> 9 35826.109 IN 6483802 6484192  
#> 10 43203.905 LA 4533372 4533479  
#> pop\_2010 pop\_2011 pop\_2012 pop\_2013 pop\_2014  
#> 1 6411999 6472867 6556236 6634997 6731484  
#> 2 2922297 2938430 2949300 2958765 2966369  
#> 3 37336011 37701901 38062780 38431393 38802500  
#> 4 5048575 5119661 5191709 5272086 5355866  
#> 5 3579345 3590537 3594362 3599341 3596677  
#> 6 605210 620427 635040 649111 658893  
#> 7 9714464 9813201 9919000 9994759 10097343  
#> 8 12840097 12858725 12873763 12890552 12880580  
#> 9 6490308 6516560 6537632 6570713 6596855  
#> 10 4545581 4575972 4604744 4629284 4649676  
#> geometry  
#> 1 MULTIPOLYGON (((-112.5386 3...  
#> 2 MULTIPOLYGON (((-94.04296 3...  
#> 3 MULTIPOLYGON (((-120.2485 3...  
#> 4 MULTIPOLYGON (((-107.3178 4...  
#> 5 MULTIPOLYGON (((-72.39743 4...  
#> 6 MULTIPOLYGON (((-77.03299 3...  
#> 7 MULTIPOLYGON (((-84.81048 3...  
#> 8 MULTIPOLYGON (((-89.36603 4...  
#> 9 MULTIPOLYGON (((-84.80412 4...  
#> 10 MULTIPOLYGON (((-88.86507 2...

We can now use the same three lines of code (switching out usa\_states\_geom for usa\_states\_wgs84) to plot our map.

If we take a look at the resulting map, we can see how different it looks. The curvature of the latitude and longitude lines is gone and the shape of the United States has changed as well, looking far more straight than our previous map.



There are many, many different projections you can use. The conclusion of this chapter talks about how to select appropriate CRS for your data.

### 4.0.2 Data Calculation

#### 4.0.2.1 Calculate cases

Next, we need to calculate the number of daily COVID cases. We have to do this because the covid\_data data frame gives us cumulative cases by state. So, to calculate the number of cases per day for each state, Madjid groups the data by state using the group\_by() function, then creates a new variable called pd\_cases, which represents the number of cases in the previous day (he uses the lag() function to create this variable). Some days do not have cases counts for the previous day so, in these cases, Madjid sets the value as 0 using the replace\_na() function. Finally, Madjid creates a new variable called daily\_cases. For this variable, he uses the case\_when() function to set up a condition: if the cases variable (cases on that day) is greater than the pd\_cases variable (cases one day prior), then daily\_cases is equal to cases minus pd\_cases; otherwise, set daily\_cases to be equal to 0. Since we grouped the data by state at the beginning, we must now remove this grouping using the ungroup() function.

covid\_cases <- covid\_data %>%  
 group\_by(state) %>%  
 mutate(  
 pd\_cases = lag(cases)  
 ) %>%  
 replace\_na(list(pd\_cases = 0)) %>%  
 mutate(  
 daily\_cases = case\_when(  
 cases > pd\_cases ~ cases - pd\_cases,  
 TRUE ~ 0  
 )  
 ) %>%  
 ungroup() %>%  
 arrange(state, date)

We can now take a look at the covid\_cases data frame we created.

#> # A tibble: 55,558 × 6  
#> date state cases deaths pd\_cases daily\_cases  
#> <date> <chr> <dbl> <dbl> <dbl> <dbl>  
#> 1 2020-03-13 Alabama 6 0 0 6  
#> 2 2020-03-14 Alabama 12 0 6 6  
#> 3 2020-03-15 Alabama 23 0 12 11  
#> 4 2020-03-16 Alabama 29 0 23 6  
#> 5 2020-03-17 Alabama 39 0 29 10  
#> 6 2020-03-18 Alabama 51 0 39 12  
#> 7 2020-03-19 Alabama 78 0 51 27  
#> 8 2020-03-20 Alabama 106 0 78 28  
#> 9 2020-03-21 Alabama 131 0 106 25  
#> 10 2020-03-22 Alabama 157 0 131 26  
#> # … with 55,548 more rows

#### 4.0.2.2 Calculate rolling means

We’re not quite done with calculating values. The data that Madjid used to make his map was not daily case counts. Instead, it was a five-day rolling average of cases per 100,000 people. Madjid creates a new data frame called covid\_cases\_rm (rm for rolling mean). The first step in its creation is to use the rollmean() function from the zoo package to create a roll\_cases variable. The k argument is the number of days (five in order to calculate the five-day rolling average) and the fill argument determines what happens in cases like the first day where we can’t calculate a five-day rolling mean because there are no days prior to this day (Madjid sets these values to be NA).

After calculating roll\_cases, Madjid started work on calculating per capita case rates. To do this, he needed population data so he joined the population data from the usa\_states data frame with the covid\_cases data. He then dropped rows with missing population data (the Pop variable). In practice, this meant getting rid of several U.S. territories (American Samoa, Guam, Northern Marianas Islands, and Virgin Islands).

Next, Madjid created a per capita case rate variable called incidence\_rate by multiplying the roll\_cases variable by 100,000 and then dividing it by the population of each state. Rather than keeping raw values (for example, the Florida on June 29, 2021 had a rate of 57.77737 cases per 100,000 people), Madjid uses the cut() function to convert the values into categories. His code in this section makes values of “>0” (greater than 0), “>5”, and so on up to a maximum value of “>50”.

The last step is to only include 2021 data because Madjid’s map only shows that year and keep only the variables (state, date, and incidence\_rate) we’ll need to create our map.

We can take a look at the covid\_cases\_rm data frame.

#> # A tibble: 18,980 × 3  
#> state date incidence\_rate  
#> <chr> <date> <fct>   
#> 1 Alabama 2021-01-01 >50   
#> 2 Alabama 2021-01-02 >50   
#> 3 Alabama 2021-01-03 >50   
#> 4 Alabama 2021-01-04 >50   
#> 5 Alabama 2021-01-05 >50   
#> 6 Alabama 2021-01-06 >50   
#> 7 Alabama 2021-01-07 >50   
#> 8 Alabama 2021-01-08 >50   
#> 9 Alabama 2021-01-09 >50   
#> 10 Alabama 2021-01-10 >50   
#> # … with 18,970 more rows

### 4.0.3 Mapping

We’ve now used two (COVID case data and state population data) of our three data sources to create the covid\_cases\_rm data frame that we’ll use to make our map. Let’s use our third data source: the geospatial data we saved as usa\_states\_geom. We start with this data frame and then merge our covid\_cases\_rm data frame into it, matching the name variable from usa\_states\_geom to the state variable in covid\_cases\_rm. Being able to merge together regular data frames with geospatial data is possible with simple features data, another mark in its favor. Next, Madjid created a new variable called fancy\_date. As the name implies, it’s a nicely formatted version of the date so that we get “Jan. 01” instead of “2021-01-01.” The format() function does the formatting while the fct\_inorder() function makes it so that the fancy\_date() variable will display in order by date (rather than, say, putting August before January because it comes first alphabetically). We save this data frame as usa\_states\_geom\_covid.

If we take a look at the usa\_states\_geom\_covid data frame, we can see the metadata and geometry columns discussed above.

#> Simple feature collection with 18615 features and 4 fields  
#> Geometry type: MULTIPOLYGON  
#> Dimension: XY  
#> Bounding box: xmin: -2100000 ymin: -2500000 xmax: 2516374 ymax: 732103.3  
#> CRS: +proj=laea +lat\_0=45 +lon\_0=-100 +x\_0=0 +y\_0=0 +a=6370997 +b=6370997 +units=m +no\_defs  
#> First 10 features:  
#> name date incidence\_rate  
#> 1 Arizona 2021-01-01 >50  
#> 2 Arizona 2021-01-02 >50  
#> 3 Arizona 2021-01-03 >50  
#> 4 Arizona 2021-01-04 >50  
#> 5 Arizona 2021-01-05 >50  
#> 6 Arizona 2021-01-06 >50  
#> 7 Arizona 2021-01-07 >50  
#> 8 Arizona 2021-01-08 >50  
#> 9 Arizona 2021-01-09 >50  
#> 10 Arizona 2021-01-10 >50  
#> geometry fancy\_date  
#> 1 MULTIPOLYGON (((-1111066 -8... Jan. 01  
#> 2 MULTIPOLYGON (((-1111066 -8... Jan. 02  
#> 3 MULTIPOLYGON (((-1111066 -8... Jan. 03  
#> 4 MULTIPOLYGON (((-1111066 -8... Jan. 04  
#> 5 MULTIPOLYGON (((-1111066 -8... Jan. 05  
#> 6 MULTIPOLYGON (((-1111066 -8... Jan. 06  
#> 7 MULTIPOLYGON (((-1111066 -8... Jan. 07  
#> 8 MULTIPOLYGON (((-1111066 -8... Jan. 08  
#> 9 MULTIPOLYGON (((-1111066 -8... Jan. 09  
#> 10 MULTIPOLYGON (((-1111066 -8... Jan. 10

It was a lot of work to end up with the surprisingly simple data frame usa\_states\_geom\_covid, but it’s all we need in order to make our map. The data may be simple, but the code that Abdoul Madjid used to make his map is quite complex. Let’s look at it in pieces.

First, a quick note: the final map is actually multiple maps, one for each day in 2021. Combining 365 days makes for a large final product. So, instead of showing every day for each step, I’m going to filter the usa\_states\_geom\_covid to just show the first three days in January. I do this using the code below and save the result as a data frame called usa\_states\_geom\_covid\_three\_days.

usa\_states\_geom\_covid\_three\_days <- usa\_states\_geom\_covid %>%  
 filter(date <= as.Date("2021-01-03"))

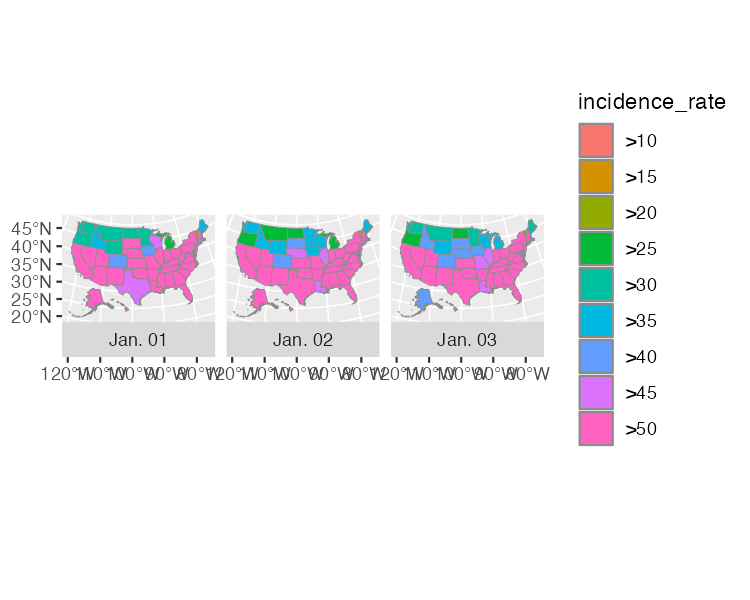
#### 4.0.3.1 Basic plot

Now that we have three days of data, let’s make some maps. Abdoul Madjid’s map-making code has three main parts:

1. Overall plotting
2. Changing colors
3. Making tweaks to the theme

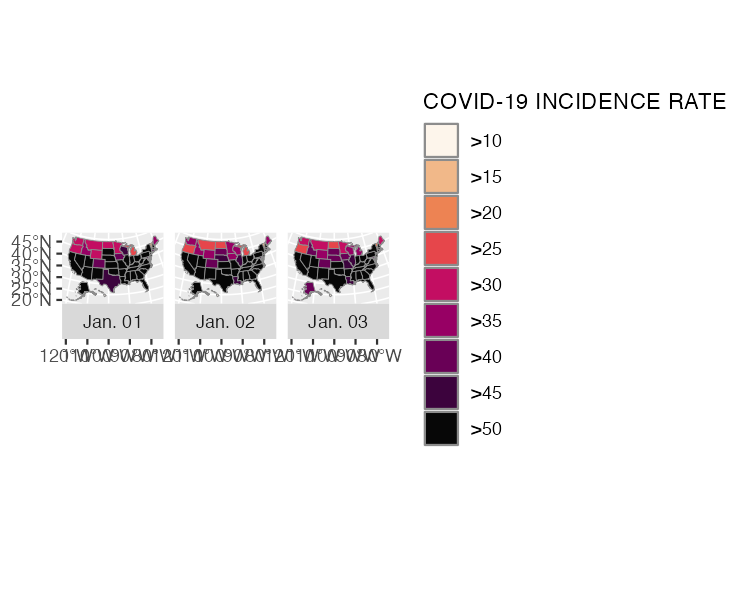
The three lines of code that we used above to make our Wyoming maps come back again, with some adornments to improve the quality of our map. Below, we can see that we’re using geom\_sf() to plot our geospatial data. Madjid modifies a couple arguments, using size = .05 to make the state borders less prominent and color = "grey55" to make the borders a medium grey color. Then, because he is making one map for each day, he uses the facet\_wrap() function. The vars(fancy\_date) code specifies that the fancy\_date variable should be used to do the facetting (in other words, make one map for each unique observation of fancy\_date) and strip.position = "bottom" moves the “Jan. 01,” “Jan. 02,” and “Jan. 03” labels to the bottom of the maps.

The resulting map can be seen in TODO add figure number below.

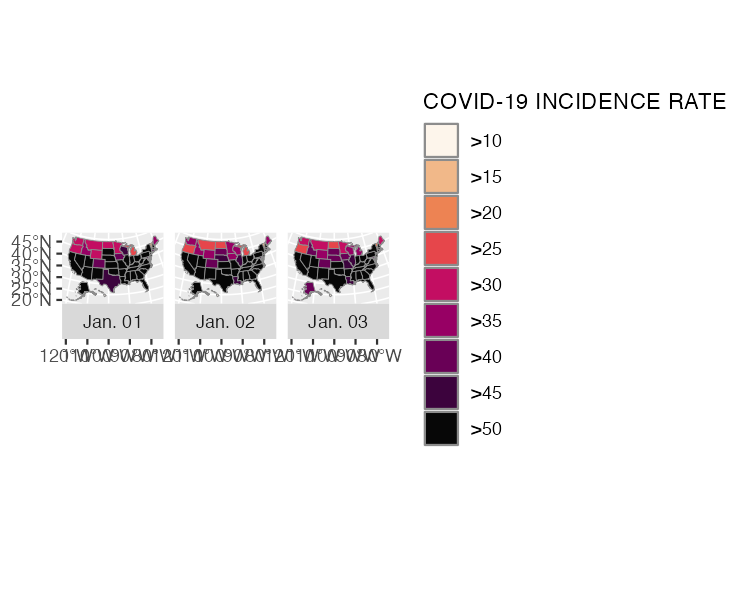


#### 4.0.3.2 Colors

Next, Madjid tweaked the colors of his maps. He used the scale\_fill\_discrete\_sequential() function from the colorspace package to set the fill scale. This function is quite similar to the scale\_fill\_viridis\_d() function that Cédric Scherer and Georgios Karamanis used to make their drought data visualization in 2. Another similarity is that both visualizations use the “rocket” palette, with the fill scale going from a tan at the low end to a black at the high end. Madjid then uses the name argument to set the title for the legend. By default, it would use the variable name (incidence\_rate), but Madjid improves it by using “COVID-19 INCIDENCE RATE” instead.



Our in-progress map can be seen below.



I’ve actually only shown a portion of the code that Abdoul Madjid used within the scale\_fill\_discrete\_sequential() function. He also used the guide argument and the guide\_legend() function to make tweaks to the legend. His code does the following:

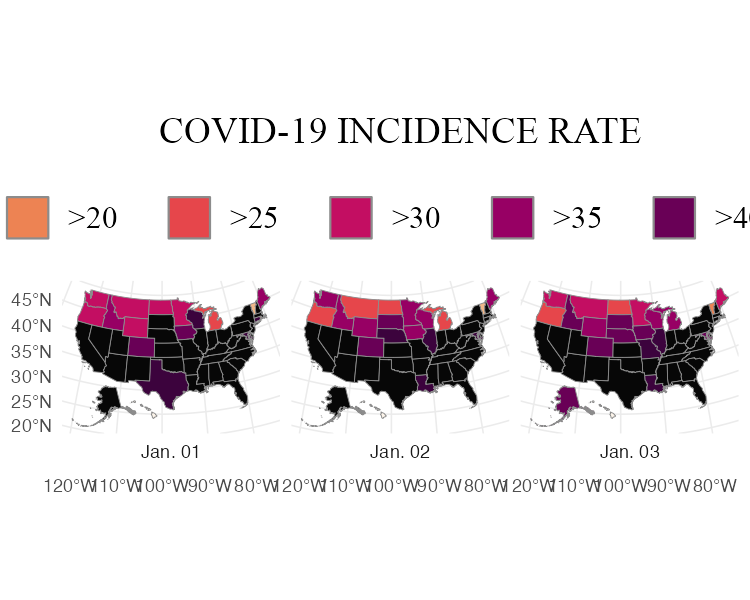
* Puts the colored squares in one row (nrow = 1) rather than the default (all in a single column)
* Sets the height and width of each colored square (.75 centimeters for each)
* Sets the font family, size, and margin of both the labels (the “>0,” “>5,” and so on) and the title (“COVID-19 INCIDENCE RATE”)
* Puts the title on top of the legend (title.position = "top") and centers it (title.hjust = .5)



#### 4.0.3.3 Theme

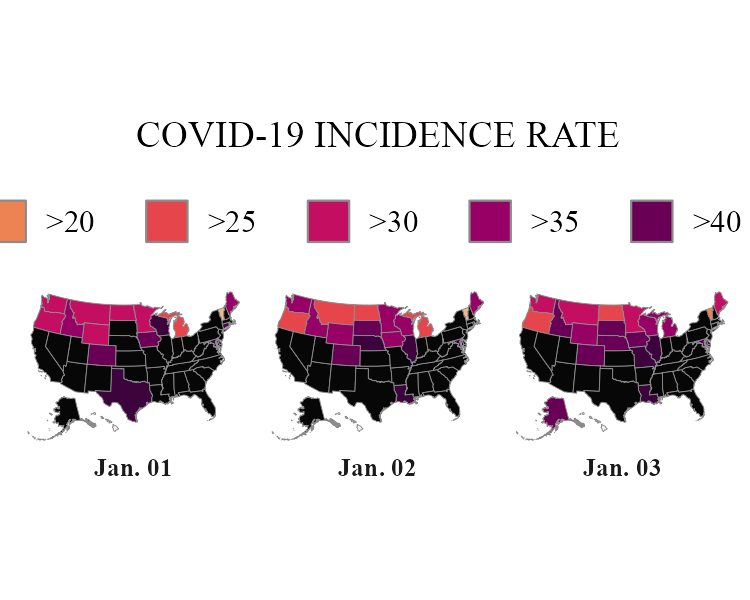
If we view our map at this point, it won’t actually look like much because the legend is currently set to the quite large in relation to the maps. In order to change this, and to make some other tweaks to improve the look-and-feel of our maps, Madjid made multiple tweaks to the maps themselves. He did this using the theme() function from the ggplot2 package. One benefit of making maps with ggplot is that all of the tweaks you use when making a regular plot can be carried over to your maps as well. Many of the tweaks within the theme() function below are similar to those seen in Chapter 2.

##### 4.0.3.3.1 Legend tweaks

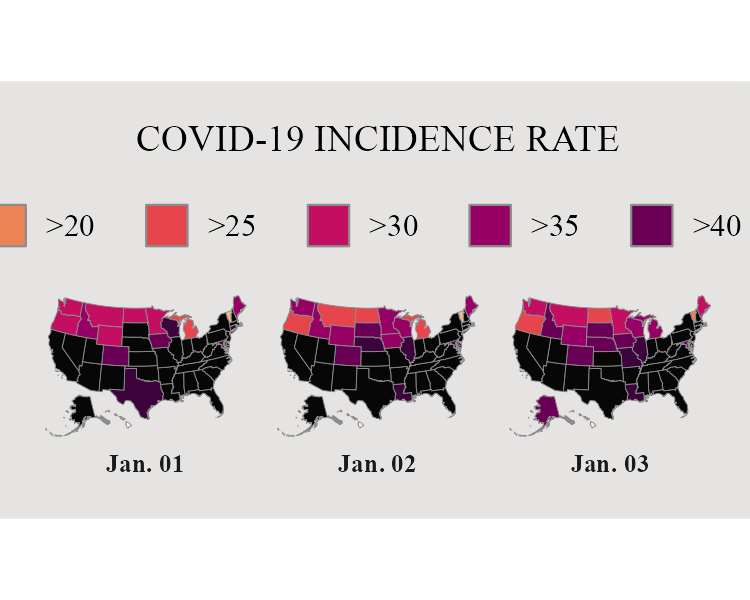


##### 4.0.3.3.2 Text

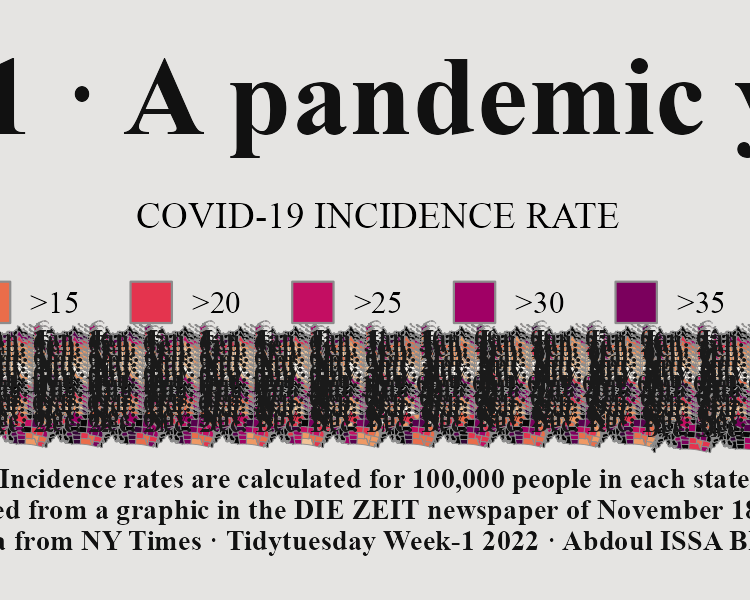
##### 4.0.3.3.3 Grid lines and axis text



##### 4.0.3.3.4 Background and margin



#### 4.0.3.4 Titles



## In Conclusion: R is a Swiss Army Knife That Can Help You Make Any Map You Want

### 4.0.4 Tutorial Stuff

#### 4.0.4.1 Where to Get Data

#### 4.0.4.2 How to Work with Data

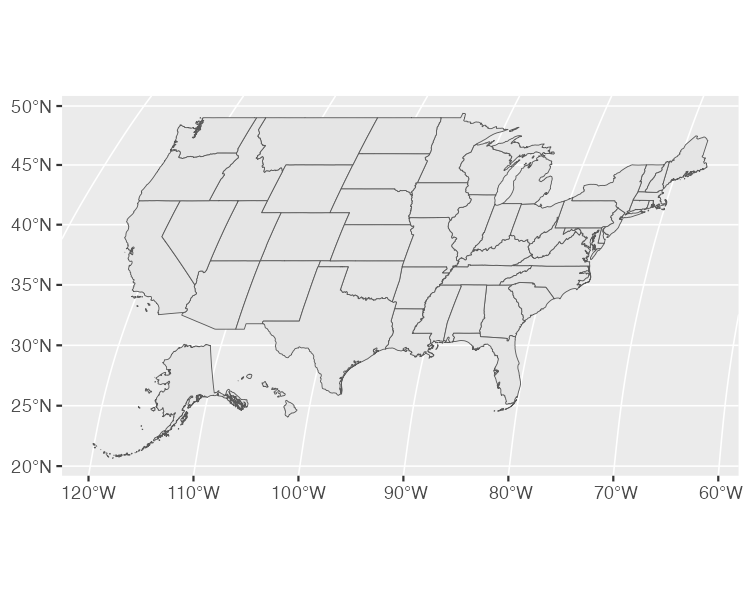
* Simple features make it possible to work with geospatial data in a way that resembles how you work with data using the tidyverse (TODO: explain tidyverse?).

#### 4.0.4.3 Projections

As Robin Lovelace, Jakub Nowosad, and Jannes Muenchow put it in their book *Geocomputation with R*, whenever we map geospatial data, “properties of the Earth’s surface are distorted in this process, such as area, direction, distance, and shape. A projected coordinate system can preserve only one or two of those properties.”

Selecting an appropriate CRS to represent our data is a combination of art and science. If you are looking for a shortcut, though, start with the ubiqitous WGS84. If you want other ideas, the crsuggest package can help. The suggest\_top\_crs() function will return a CRS that is well-suited for your data. When we run this for our Massachusetts data, we receive the suggestion 32619.

We can use this projection to re-project our Massachusetts geospatial data and make a new map.



### 4.0.5 Conceptual Stuff: Why R is Best Tool for Maps

# 5 Making High-Quality Tables

In his book *Fundamentals of Data Visualization*, Claus Wilke writes that “tables are an important tool for visualizing data.” This statement might seem might odd. Tables are often seen as the opposite of data visualization: plots are (or should be) highly-designed tools of communication; tables are where we dump numbers for the few nerds who care to read them. But Wilke sees things differently. Tables should not be data dumps devoid of design. He writes: “because of their apparent simplicity, they may not always receive the attention they need.”

Tables should be treated as data visualization because *that is exactly what they are*. As the term data visualization has become codified, it has become a synonym for graphs. But think about what the phrase data visualization really means. Don’t overthink it. It simply means to visualize data. And while bars, lines, and points in graphs are visualizations, so too are numbers in a table. When we make tables, we visualize our data.

And since we’re visualizing data, we should care about design. Need proof that good design matters when it comes to making tables? Look at tables made by reputable news organizations. Data dumps these are not. News organizations, whose job is to communicate clearly and effectively, pay a lot of attention to table design.

We saw in Chapter 2 that a few simple but significant tweaks can drastically improve the quality of our graphs. In this chapter, we’ll see that a little bit of work can go a long way toward improving our tables.

The good news for you is that R is a great tool for making high-quality tables. If you are writing reports in RMarkdown (which you can learn about in 6), you can write code that will generate a table when you export your document. Working with the same tool to generate tables alongside your text and data visualization means you don’t have to copy and paste your data, running the risk of human error.

Generating tables in Microsoft Word, the tool that many use to make tables, has other potential pitfalls. Claus Wilke found that his version of Word had 105 built-in table styles. Of those, around 80 percent violated some key principles of table design. Wilke writes:

So if you pick a Microsoft Word table layout at random, you have an 80% chance of picking one that has issues. And if you pick the default, you will end up with a poorly formatted table every time.

In R, there are a number of packages to make a wide range of tables. And within these packages, there are a number of functions designed to make sure your tables follow important design principles.

The rest of this chapter will examine what these design principles are and show how to apply them in your tables made in R. We’ll begin by with a brief trip into the world of table design. After examining the principles that Claus Wilke and other experts recommend, we’ll learn how to apply these principles. For this chapter, I spoke with Tom Mock of Posit (the company that makes RStudio), who has become something of an R table connoisseur. His 2020 blog post “10+ Guidelines for Better Tables in R” takes table design principles and shows how to implement them using the gt package. We’ll walk through examples of Tom’s code to show how small tweaks can make a big difference in improving your tables.

## Table Design Principles

Advice on data visualization has become ubiquitous in the last few years. Books, articles, blog posts, and more talk about how to make your graphs communicate effectively. Table design advice is less common, but it is out there. In addition to Claus Wilke, others including Jon Schwabish and Stephen Few have written about table design. All three of these experts come to discussing tables after having written about making effective graphs. The principles they discuss, not surprisingly, will sound similar to data visualization advice. The principles of effective communication apply no matter the form in which data is ultimately presented.

The principles below are adapted primarily from a conversation I had with Tom Mock, which focuses on his tables blog post. That blog post shows how to implement in R the ten table design principles that Jon Schwabish discusses in his article “Ten Guidelines for Better Tables.” Schwabish cites Stephen Few’s work on table design. As you can see, the world of table design is closely connected. Rather than trying to and show every single principle that Schwabish discusses and Mock implements in R, I’ve selected what I think are six of the most important.

In this chapter, I use the gt package. This is one of the most popular table-making packages and, as we’ll see below, it uses good design principles by default. The code below is a lightly adapted version of the code in Mock’s blog post.

### Principle One: Minimize Clutter

As with data visualization, one of the most important principles of table design is to minimize clutter. One of the most important ways we can do this is by removing unnecessary elements. One of the most common unnecessary elements that clutter tables is gridlines. To show you how we can make more effective tables by removing gridlines, let’s first load the packages we need. We’re relying on the tidyverse package for general data manipulation functions, gapminder for the data we’ll use, and gt to make the tables.

library(tidyverse)  
library(gapminder)  
library(gt)  
library(gtExtras)

As we saw in Chapter 2, the gapminder package provides data on country-level demographic statistics. To make a data frame we’ll use for our table, let’s use just a few countries (the first four in alphabetical order: Afghanistan, Albania, Algeria, and Angola) and a few years (1952, 1972, and 1992). The gapminder data has many years but we only need a few to demonstrate table-making principles.

I’ve created a data frame called gdp. Let’s see what it looks like.

#> # A tibble: 4 × 4  
#> Country `1952` `1972` `1992`  
#> <chr> <dbl> <dbl> <dbl>  
#> 1 Afghanistan 779. 740. 649.  
#> 2 Albania 1601. 3313. 2497.  
#> 3 Algeria 2449. 4183. 5023.  
#> 4 Angola 3521. 5473. 2628.

Now that we’ve created the data frame we can work with, it’s time to talk about reducing clutter by getting rid of gridlines. Often, you see tables that look like this:

[F05001.png]

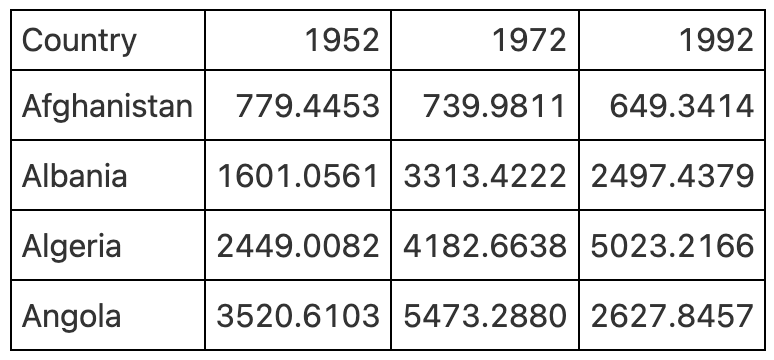


Figure 5.1: Table with gridlines everywhere

Having gridlines around every single cell in our table is unnecessary and creates visual clutter that distracts from the goal of communicating clearly. A table with minimal or even no gridlines is a much more effective communication tool.

[F05002.png]

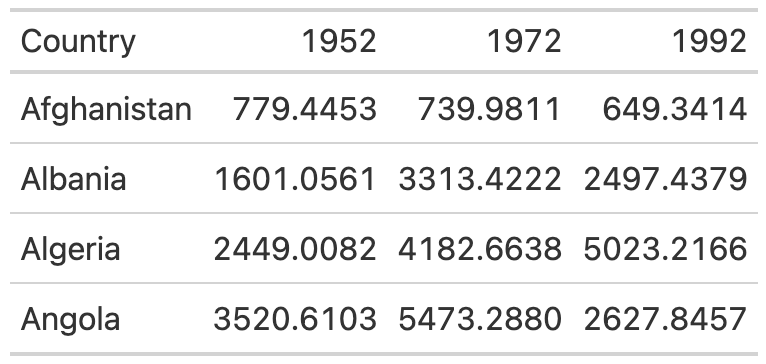


Figure 5.2: Table with only horizontal gridlines

You know how I mentioned before that gt uses good table design principles by default? This is a great example of it. The second table, with minimal gridlines, requires just two lines. We pipe our gdp data into the gt() function, which creates a table.

gdp %>%   
 gt()

To make the example with gridlines everywhere, we would have to add additional code. The code that follows gt() here adds gridlines.

gdp %>%   
 gt() %>%   
 tab\_style(  
 style = cell\_borders(  
 side = "all",  
 color = "black",  
 weight = px(1),  
 style = "solid"  
 ),  
 locations = list(  
 cells\_body(  
 everything()  
 ),  
 cells\_column\_labels(  
 everything()  
 )  
 )  
 ) %>%   
 opt\_table\_lines(extent = "none")

Since I don’t recommend doing this, I won’t walk through the code. The important thing to remember is that you get good defaults using gt(). Take advantage of them!

If we wanted to remove additional gridlines, we could use the following code. The tab\_style() function uses a two-step approach:

1. Identify the style we want to modify (in this case the borders).
2. Tell the function where to apply these styles.

Here, we tell tab\_style() that we want to modify the borders using the cell\_borders() function, making our borders transparent. Then, we say that we want this to apply to the cells\_body() location (other options include cells\_column\_labels() for the row with country, 1952, 1972, and 1992).

gdp %>%   
 gt() %>%   
 tab\_style(  
 style = cell\_borders(color = "transparent"),  
 locations = cells\_body()  
 )

Doing this gives us a table with no gridlines at all in the body.

[F05003.png]

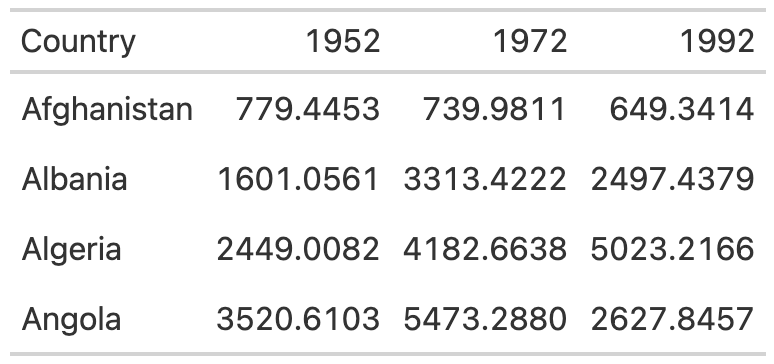


Figure 5.3: Table with gridlines only on the header row and bottom

I’ll then save this table as an object called table\_no\_gridlines so that we can add onto it below.

### Principle Two: Differentiate the Header from the Body

While reducing clutter is an important goal, going too far can have negative consequences. A table with no gridlines at all can make it hard to differentiate between the header row and the table body.

[F05004.png]

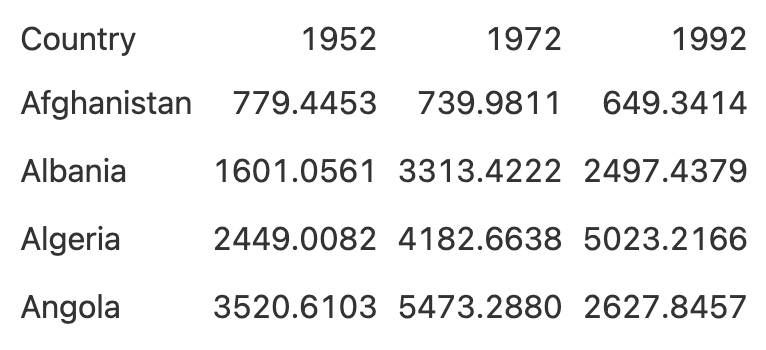


Figure 5.4: Table with all gridlines removed

We saw how to use appropriate gridlines above. We can make our header row bold to make it stand out even more. We start with the table\_no\_gridlines object (our saved table from above). Then, we apply our formatting with the tab\_style() function two-step, first saying we want to alter the text (using the cell\_text() function) by setting the weight to bold and then saying we want this to happen only to the header row (using the cells\_column\_labels() function).

table\_no\_gridlines %>%   
 tab\_style(  
 style = cell\_text(weight = "bold"),  
 locations = cells\_column\_labels()  
 )

We can see what our table with headers bolded looks like below.

[F05005.png]

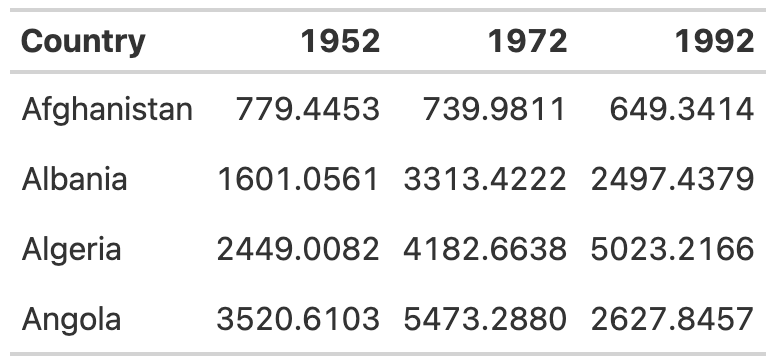


Figure 5.5: Table with header row bolded

Let’s save this table as table\_bold\_header in order to reuse it below and add additional formatting on top of what’s already there.

### Principle Three: Align Appropriately

A third principle of high-quality table design is appropriate alignment. Specifically, numbers in tables should be right-aligned. Tom Mock explains why:

Left-alignment or center-alignment of numbers impairs the ability to clearly compare numbers and decimal places. Right-alignment lets you align decimal places and numbers for easy parsing.

We can see this in action. In the table below, we’ve left aligned 1952, center aligned 1972, and right aligned 1992. You can see how much easier it is to compare the values in 1992 than in the other two columns. In both 1952 and 1972, it is much more difficult to compare the numeric values because the numbers in the same columns (the tens place, for example) are not in the same vertical position. In 1992, however, the number in the tens place in Afghanistan (4) aligns with the number in the tens place in Albania (9) and all other countries. This vertical alignment makes it easier to scan the table.

[F05006.png]

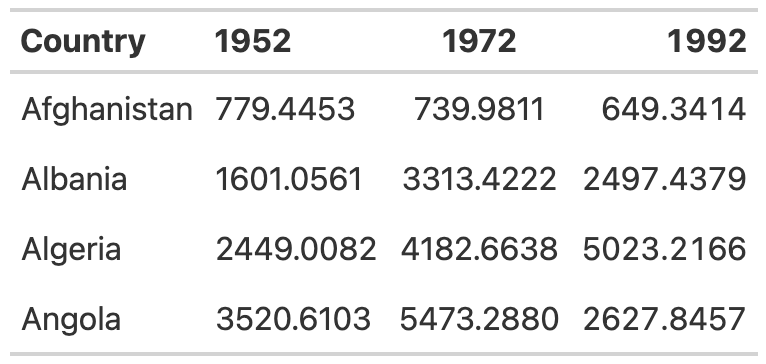


Figure 5.6: Table with year columns aligned left, center, and right

As with other tables, we’ve actually had to override the defaults to get the gt package to misalign the columns (code shown below). By default, gt will right align numeric values. So, just don’t change anything and you’ll be golden!

table\_bold\_header %>%   
 cols\_align(align = "left",  
 columns = 2) %>%   
 cols\_align(align = "center",  
 columns = 3) %>%   
 cols\_align(align = "right",  
 columns = 4)

Right alignment is best practice for numeric columns, but for text columns, we want to use left alignment. As Jon Scwabish points out, it’s much easier to read longer text cells when they are left aligned. This is even easier to see if we add a country with a long name to our table. I’ve added Bosnia and Herzegovina and saved this as a data frame called gdp\_with\_bosnia.

gdp\_with\_bosnia  
#> # A tibble: 5 × 4  
#> Country `1952` `1972` `1992`  
#> <chr> <dbl> <dbl> <dbl>  
#> 1 Afghanistan 779. 740. 649.  
#> 2 Albania 1601. 3313. 2497.  
#> 3 Algeria 2449. 4183. 5023.  
#> 4 Angola 3521. 5473. 2628.  
#> 5 Bosnia and Herzegovina 974. 2860. 2547.

Let’s then take the gdp\_with\_bosnia data frame and create a table with the country column center aligned. In this table, it is hard to scan the country names and that center-aligned column just looks a bit weird.

[F05007.png]

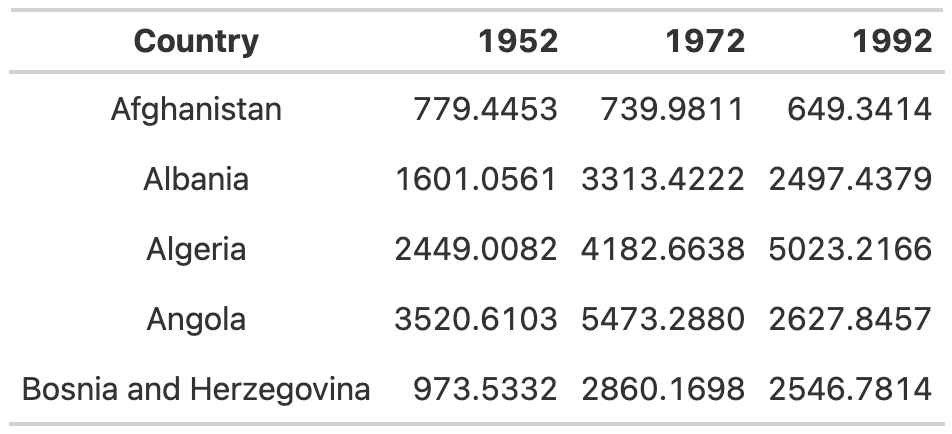


Figure 5.7: Table with country column center aligned

This is another example where we’ve had to change the gt defaults to mess things up. The gt package has good default alignment practices for other column types as well. In addition to right aligning numeric columns by default, it will also left align character columns. So, if we don’t touch anything, gt will give us the alignment we’re looking for.

[F05008.png]

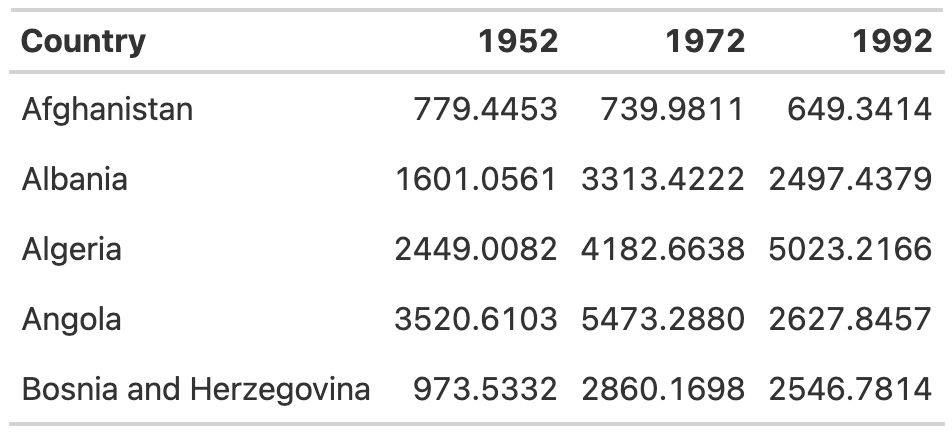


Figure 5.8: Table with country column left aligned

If you ever do want to override the default alignments, you can use the cols\_align() function. Within this function, we use the columns argument to tell gt which columns to align and the align argument to select our alignment. That table above with the country names center aligned? Here’s how I made it.

gdp\_with\_bosnia %>%   
 gt() %>%   
 tab\_style(  
 style = cell\_borders(color = "transparent"),  
 locations = cells\_body()  
 ) %>%   
 tab\_style(  
 style = cell\_text(weight = "bold"),  
 locations = cells\_column\_labels()  
 ) %>%   
 cols\_align(columns = "Country",  
 align = "center")

### Principle Four: Use the Right Level of Precision

In all of the tables we’ve made so far, we’ve used the data exactly as it came to us. In all of the numeric columns, we have data to four decimal places. This is almost certainly too many. Having more decimal places than necessary makes our table harder to read. There is always a balance between what Jon Schwabish describes as “necessary precision and a clean, spare table.” I’ve also heard it described that, if adding additional decimal places would change some action, keep them; otherwise, take them. out My general experience is that people tend to leave too many decimal places in, assuming that accuracy to a very high degree is more important than it is (and, in the process, they reduce the legibility of their tables).

Looking at our GDP table, we can use the fmt\_currency() function to format our numeric values. The gt package has a whole series of functions for formatting values in tables. All of these functions start with fmt\_. In the code below, we set fmt\_currency() to be applied to the 1952, 1972, and 1992 columns. I then use decimals argument to tell fmt\_currency() to format the values with zero decimal places (the difference between a GDP of $799.4453 and $779 is unlikely to lead to different decisions so I’m comfortable with sacrificing precision for legibility).

table\_bold\_header %>%  
 fmt\_currency(  
 columns = c(`1952`, `1972`, `1992`),  
 decimals = 0  
 )

What we end up with is values formatted as dollars, with a thousands-place comma automatically added by fmt\_currency() to make the values even easier to read.

[F05009.png]

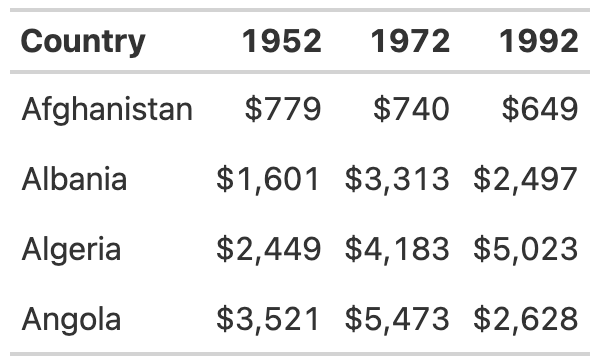


Figure 5.9: Table with numbers rounded to whole numbers and dollar sign added

Let’s now save our table for reuse below.

### Principle Five: Use Color Intentionally

Up to this point, our table has not had any color. We’re now going to add some, using color to highlight outliers. Especially for those readers who want to scan your table, highlighting outliers with color can help significantly. Let’s make the highest value in any single year a different color. To do this, we again use the tab\_style() function. Within this function, I’m using the cell\_text() function to change both the color of text to orange and make it bold. I’m then using the locations argument to say that we want to adjust cells in the body of the table. Within the cells\_body() function, we have to specify both the columns we want to apply our change to and the rows. If we just look at 1952, we see that we set the columns equal to that year. The rows are set to a more complicated formula. The text rows = 1952 == max(1952) means that the text transformation will occur in rows where the value is equal to the maximum value in that year.

table\_whole\_numbers %>%   
 tab\_style(style = cell\_text(color = "orange",  
 weight = "bold"),  
 locations = cells\_body(  
 columns = `1952`,  
 rows = `1952` == max(`1952`)  
 ))

We then repeat this same code for 1972 and 1992, with the result shown below.

[F05010.png]

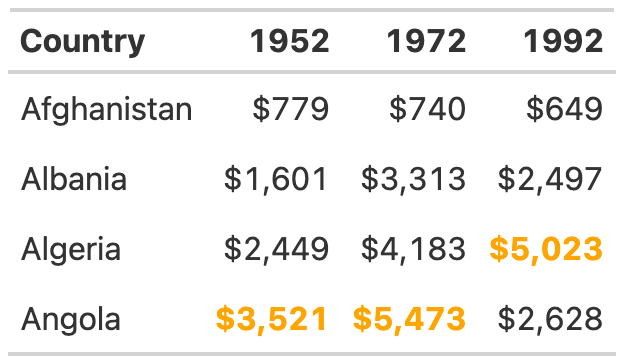


Figure 5.10: Table with color added to show the highest value in each year

As always, we save this table to avoid having to repeat all of the formatting code we’ve created up to this point.

### Principle Six: Add Data Visualization Where Appropriate

Adding color to highlight outliers is one way to help guide the reader’s attention. Another way is to incorporate graphs into tables. Tom Mock has developed an add-on package for gt called gtExtras that makes it possible to do just this. In our table that we’ve made we might want to show the trend of GDP by country. To do that, we’ll add a new column that shows this trend using a sparkline (essentially, a simple line chart). The gt\_plt\_sparkline() function that we’ll use to do this requires us to have a single column with all of the values needed to make the sparkline. We’ll create a variable called Trend using group\_by() and mutate(). This variable will be a list of the values for each country (so, for Afghanistan, it would be 779.4453145, 739.9811058, and 649.3413952). We’ll save this as an object called gdp\_with\_trend.

gdp\_with\_trend <- gdp %>%   
 group\_by(Country) %>%   
 mutate(Trend = list(c(`1952`, `1972`, `1992`))) %>%   
 ungroup()

From there, we create our table, same as before. But at the end of our code, we add the gt\_plt\_sparkline() function. Within this function, we specify which column to use to create the sparkline (Trend). We set label = FALSE to remove text labels that gt\_plt\_sparkline() adds by default. And we add palette = c("black", "transparent", "transparent", "transparent", "transparent") to make the sparkline black and all other elements of it transparent (by default, the function will make different parts of the sparkline different colors).

gdp\_with\_trend %>%   
 gt() %>%   
 tab\_style(  
 style = cell\_borders(color = "transparent"),  
 locations = cells\_body()  
 ) %>%  
 tab\_style(  
 style = cell\_text(weight = "bold"),  
 locations = cells\_column\_labels()  
 ) %>%  
 fmt\_currency(  
 columns = c(`1952`, `1972`, `1992`),  
 decimals = 0  
 ) %>%   
 tab\_style(style = cell\_text(color = "orange",  
 weight = "bold"),  
 locations = cells\_body(  
 columns = `1952`,  
 rows = `1952` == max(`1952`)  
 )) %>%   
 tab\_style(style = cell\_text(color = "orange",  
 weight = "bold"),  
 locations = cells\_body(  
 columns = `1972`,  
 rows = `1972` == max(`1972`)  
 )) %>%   
 tab\_style(style = cell\_text(color = "orange",  
 weight = "bold"),  
 locations = cells\_body(  
 columns = `1992`,  
 rows = `1992` == max(`1992`)  
 )) %>%   
 gt\_plt\_sparkline(column = Trend,  
 label = FALSE,  
 palette = c("black", "transparent", "transparent", "transparent", "transparent"))

This stripped-down sparkline now allows the reader to see the trend for each country at a glance.

[F05011.png]

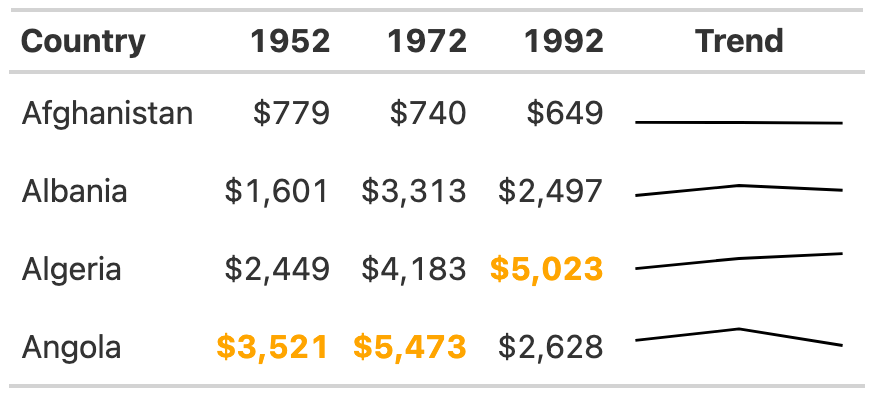


Figure 5.11: Table with sparkline added to show trend over time

## Conclusion

Many of the tweaks we made to create an effective table are quite subtle. Things like removing excess gridlines, bolding header text, right aligning numeric values, and adjusting the level of precision can often go unnoticed. But skip them and your table will be far less effective. What we ended up with is not flashy, but it does communicate clearly, which is the main goal of tables.

We used the gt package to make a high-quality table. One benefit of using this package is that we were able to use the gt\_plt\_sparkline() function from the gtExtras package to easily add a sparkline to our table. gtExtras does way more than this, though. This package has a set of “theme” functions to allow you to make your tables look like those made by FiveThirtyEight, the *New York Times*, the *Guardian*, and other news outlets. I’ve removed the formatting we created and instead used the gt\_theme\_538() function to make our tables look like they came from that organization.

gdp %>%   
 group\_by(Country) %>%   
 mutate(Trend = list(c(`1952`, `1972`, `1992`))) %>%   
 ungroup() %>%   
 gt() %>%   
 tab\_style(style = cell\_text(color = "orange",  
 weight = "bold"),  
 locations = cells\_body(  
 columns = `1952`,  
 rows = `1952` == max(`1952`)  
 )) %>%   
 tab\_style(style = cell\_text(color = "orange",  
 weight = "bold"),  
 locations = cells\_body(  
 columns = `1972`,  
 rows = `1972` == max(`1972`)  
 )) %>%   
 tab\_style(style = cell\_text(color = "orange",  
 weight = "bold"),  
 locations = cells\_body(  
 columns = `1992`,  
 rows = `1992` == max(`1992`)  
 )) %>%   
 fmt\_currency(  
 columns = c(`1952`, `1972`, `1992`),  
 decimals = 0  
 ) %>%   
 gt\_plt\_sparkline(column = Trend,  
 label = FALSE,  
 palette = c("black", "transparent", "transparent", "transparent", "transparent")) %>%   
 gt\_theme\_538()

Take a look at tables on the FiveThirtyEight website and you’ll see the similarities to this table.

[F05012.png]

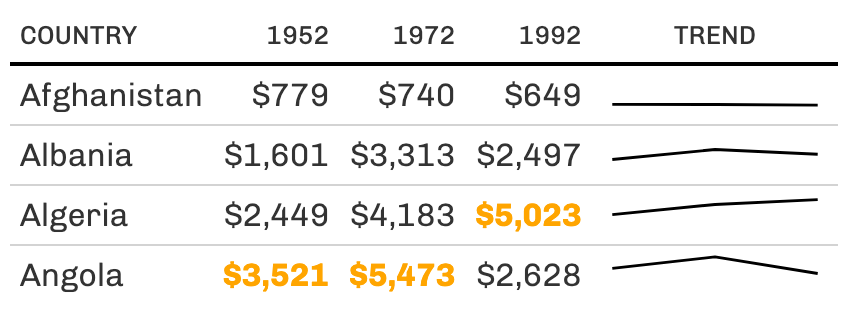


Figure 5.12: Table redone in FiveThirtyEight style

Add-on packages like gtExtras are common in the table-making landscape. If you are working with the reactable package to make interactive tables, for example, you can also use the reactablefmtr to add interactive sparklines, themes, and more. The functionality that you get from these packages is enough to never make you go back to making tables in Word!

No matter which package you use to make tables, it’s essential to treat them as worthy of as much thought as data visualization (because, let me remind you, tables *are* data visualization). Good tables are well designed; they are not data dumps. And fortunately for us, R is well-suited to making well designed tables. The gt package, as we’ve repeatedly seen, has good defaults built in. Oftentimes, you don’t need to change much to end up with high-quality tables.

And it’s not just that we have good packages to make tables. R is a great tool for making tables because it’s the tool you’re already using to create your reports (especially if you’re using RMarkdown, a tool we discuss in 6). What better than using just a few lines of code to make publication-ready tables?

# 6 Use RMarkdown to Communicate Accurately and Efficiently

# 7 Use RMarkdown to Instantly Generate Hundreds of Reports

# 8 Create Beautiful Presentations with RMarkdown

# 9 Make Websites to Share Results Online

* When to do static vs when you need Shiny

# 10 Access Up to Date Census Data with the tidycensus Package

# 11 Pull in Survey Results as Soon as They Come In

# 12 Stop Copying and Pasting Code by Creating Your Own Functions

<https://twitter.com/hadleywickham/status/1574373127349575680>

# 13 Bundle Your Functions Together in Your Own R Package

# 14 Come for the Data, Stay for the Community