

Introduction to Statistics: an integrated textbook and workbook using R

Sean Raleigh, Westminster College (Salt Lake City, UT)

2022-07-29

Contents

Introduction	5
Philosophy	5
Course structure	5
Onward and upward	5
1 Introduction to R	7
1.1 Introduction	7
1.2 What is R?	7
1.3 RStudio	8
1.4 Try something!	9
1.5 Load packages	11
1.6 Getting help	12
1.7 Understanding the data	13
1.8 Understanding the variables	16
1.9 Projects	17
1.10 Conclusion	18
2 Using R Markdown	19
2.1 Introduction	19
2.2 What is R Markdown?	20
2.3 Previewing a document	21
2.4 Literate programming	21
2.5 Reproducible research	21

2.6	Structure of an R Notebook	22
2.7	Other formatting tricks	23
2.8	R code chunks	24
2.9	Inline R commands	30
2.10	Copying and pasting	31
2.11	Conclusion	32
3	Categorical data	35
3.1	Introduction	35
3.2	Categorical data	36
3.3	Factor variables	37
3.4	Summarizing one categorical variable	38
3.5	Graphing one categorical variable	40
3.6	Summarizing two categorical variables	43
3.7	Graphing two categorical variables	46
3.8	Recoding factor variables	49
3.9	Publication-ready graphics	51
3.10	Plotting summary data	53
3.11	Conclusion	56
4	Numerical data	59
4.1	Introduction	59
4.2	A note about mathematical notation	60
4.3	Statistics	61
4.4	Graphing one numerical variable	68
4.5	Graphing two numerical variables	73
4.6	Graphing grouped numerical data	76
4.7	Publication-ready graphics	82
4.8	Conclusion	86

Introduction

Welcome to statistics!

If you want, you can also download this book as a PDF or EPUB file. Be aware that the print versions are missing some of the richer formatting of the online version. Besides, the recommended way to work through this material is to download the R notebook file (`.Rmd`) at the top of each chapter and work through it in RStudio.

Philosophy

[TODO]

Course structure

[TODO]

Onward and upward

I hope you enjoy the textbook. You can provide feedback two ways:

1. The preferred method is to file an issue on the Github page: https://github.com/VectorPosse/intro_stats/issues
2. Alternatively, send me an email: sraleigh@westminstercollege.edu

Chapter 1

Introduction to R

Functions introduced in this chapter:

```
<-, c, sum, mean, library, ?, ??, View, head, tail, str, NROW, NCOL, summary,  
$
```

1.1 Introduction

Welcome to R! This chapter will walk you through everything you need to know to get started using R.

As you go through this chapter (and all future chapters), please read slowly and carefully, and pay attention to detail. Many steps depend on the correct execution of all previous steps, so reading quickly and casually might come back to bite you later.

1.2 What is R?

R is a programming language specifically designed for doing statistics. Don't be intimidated by the word "programming" though. The goal of this course is not to make you a computer programmer. To use R to do statistics, you don't need know anything about programming at all. Every chapter throughout the whole course will give you examples of the commands you need to use. All you have to do is use those example commands as templates and make the necessary changes to adapt them to the data you're trying to analyze.

The greatest thing about R is that it is free and open source. This means that you can download it and use it for free, and also that you can inspect and modify

the source code for all R functions. This kind of transparency does not exist in commercial software. The net result is a robust, secure, widely-used language with literally tens of thousands of contributions from R users all over the world.

R has also become a standard tool for statistical analysis, from academia to industry to government. Although some commercial packages are still widely used, many practitioners are switching to R due to its cost (free!) and relative ease of use. After this course, you will be able to list some R experience on your résumé and your future employer will value this. It might even help get you a job!

1.3 RStudio

RStudio is an “Integrated Development Environment,” or IDE for short. An IDE is a tool for working with a programming language that is fancier than just a simple text editor. Most IDEs give you shortcuts, menus, debugging facilities, syntax highlighting, and other things to make your life as easy as possible.

Open RStudio so we can explore some of the areas you’ll be using in the future.

On the left side of your screen, you should see a big pane called the “Console”. There will be some startup text there, and below that, you should see a “command prompt”: the symbol “>” followed by a blinking cursor. (If the cursor is not blinking, that means that the focus is in another pane. Click anywhere in the Console and the cursor should start blinking again.)

A command prompt can be one of the more intimidating things about starting to use R. It’s just sitting there waiting for you to do something. Unlike other programs where you run commands from menus, R requires you to know what you need to type to make it work.

We’ll return to the Console in a moment.

Next, look at the upper-right corner of the screen. There are at least three tabs in this pane starting with “Environment”, “History”, and “Connections”. The “Environment” (also called the “Global Environment”) keeps track of things you define while working with R. There’s nothing to see there yet because we haven’t defined anything! The “History” tab will likewise be empty; again, we haven’t done anything yet. We won’t use the “Connections” tab in this course. (Depending on the version of RStudio you are using and its configuration, you may see additional tabs, but we won’t need them for this course.)

Now look at the lower-right corner of the screen. There are likely five tabs here: “Files”, “Plots”, “Packages”, “Help”, and “Viewer”. The “Files” tab will eventually contain the files you upload or create. “Plots” will show you the result of commands that produce graphs and charts. “Packages” will be explained later. “Help” is precisely what it sounds like; this will be a very useful place for

you to get to know. We will never use the “Viewer” tab, so don’t worry about it.

1.4 Try something!

So let’s do something in R! Go back to the Console and at the command prompt (the “>” symbol with the blinking cursor), type

```
1+1
```

and hit Enter.

Congratulations! You just ran your first command in R. It’s all downhill from here. R really is nothing more than a glorified calculator.

Okay, let’s do something slightly more sophisticated. It’s important to note that R is case-sensitive, which means that lowercase letters and uppercase letters are treated differently. Type the following, making sure you use a lowercase `c`, and hit Enter:

```
x <- c(1, 3, 4, 7, 9)
```

You have just created a “vector”. When we use the letter `c` and enclose a list of things in parentheses, we tell R to “combine” those elements. So, a vector is just a collection of data. The little arrow `<-` says to take what’s on the right and assign it to the symbol on the left. The vector `x` is now saved in memory. As long as you don’t terminate your current R session, this vector is available to you.

Check out the “Environment” pane now. You should see the vector `x` that you just created, along with some information about it. Next to `x`, it says `num`, which means your vector has numerical data. Then it says `[1:5]` which indicates that there are five elements in the vector `x`.

At the command prompt in the Console, type

```
x
```

and hit Enter. Yup, `x` is there. R knows what it is. You may be wondering about the `[1]` that appears at the beginning of the line. To see what that means, try typing this (and hit Enter—at some point here I’m going to stop reminding you to hit Enter after everything you type):

```
y <- letters
```

R is clever, so the alphabet is built in under the name `letters`.

Type

```
y
```

Now can you see what the `[1]` meant above? Assuming the letters spilled onto more than one line of the Console, you should see a number in brackets at the beginning of each line telling you the numerical position of the first entry in each new line.

Since we've done a few things, check out the "Global Environment" in the upper-right corner. You should see the two objects we've defined thus far, `x` and `y`. Now click on the "History" tab. Here you have all the commands you have run so far. This can be handy if you need to go back and re-run an earlier command, or if you want to modify an earlier command and it's easier to edit it slightly than type it all over again. To get an older command back into the Console, either double-click on it, or select it and click the "To Console" button at the top of the pane.

When we want to re-use an old command, it has usually not been that long since we last used it. In this case, there is an even more handy trick. Click in the Console so that the cursor is blinking at the blank command prompt. Now hit the up arrow on your keyboard. Do it again. Now hit the down arrow once or twice. This is a great way to access the most recently used commands from your command history.

Let's do something with `x`. Type

```
sum(x)
```

I bet you figured out what just happened.

Now try

```
mean(x)
```

What if we wanted to save the mean of those five numbers for use later? We can assign the result to another variable! Type the following and observe the effect in the Environment.

```
m <- mean(x)
```

It makes no difference what letter or combination of letters we use to name our variables. For example,

```
mean_x <- mean(x)
```

just saves the mean to a differently named variable. In general, variable names can be any combination of characters that are letters, numbers, underscore symbols (`_`), and dots (`.`). (In this course, we will prefer underscores over dots.) You cannot use spaces or any other special character in the names of variables.¹ You should avoid variable names that are the same words as predefined R functions; for example, we should not type `mean <- mean(x)`.

1.5 Load packages

Packages are collections of commands, functions, and sometimes data that people all over the world write and maintain. These packages extend the capabilities of R and add useful tools. For example, we would like to use the `palmerpenguins` package because it includes an interesting data set on penguins.

If you have installed R and RStudio on your own machine instead of accessing RStudio Workbench through a browser, you'll need to type `install.packages("palmerpenguins")` if you've never used the `palmerpenguins` package before. If you are using RStudio Workbench through a browser, you may not be able to install packages because you may not have admin privileges. If you need a package that is not installed, contact the person who administers your server.

The data set is called `penguins`. Let's see what happens when we try to access this data set without loading the package that contains it. Try typing this:

```
penguins
```

You should have received an error. That makes sense because R doesn't know anything about a data set called `penguins`.

Now—assuming you have the `palmerpenguins` package installed—type this at the command prompt:

```
library(palmerpenguins)
```

It didn't look like anything happened. However, in the background, all the stuff in the `palmerpenguins` package became available to use.

Let's test that claim. Hit the up arrow twice and get back to where you see this at the Console (or you can manually re-type it, but that's no fun!):

¹The official spec says that a valid variable name “consists of letters, numbers and the dot or underline characters and starts with a letter or the dot not followed by a number.”

```
penguins
```

Now R knows about the `penguins` data, so the last command printed some of it to the Console.

Go look at the “Packages” tab in the pane in the lower-right corner of the screen. Scroll down a little until you get to the “P”s. You should be able to find the `palmerpenguins` package. You’ll also notice a check mark by it, indicating that this package is loaded into your current R session.

You must use the `library` command in every new R session in which you want to use a package.² If you terminate your R session, R forgets about the package. If you are ever in a situation where you are trying to use a command and you know you’re typing it correctly, but you’re still getting an error, check to see if the package containing that command has been loaded with `library`. (Many R commands are “base R” commands, meaning they come with R and no special package is required to access them. The set of `letters` you used above is one such example.)

1.6 Getting help

There are four important ways to get help with R. The first is the obvious “Help” tab in the lower-right pane on your screen. Click on that tab now. In the search bar at the right, type `penguins` and hit Enter. Take a few minutes to read the help file.

Help files are only as good as their authors. Fortunately, most package developers are conscientious enough to write decent help files. But don’t be surprised if the help file doesn’t quite tell you what you want to know. And for highly technical R functions, sometimes the help files are downright inscrutable. Try looking at the help file for the `grep` function. Can you honestly say you have any idea what this command does or how you might use it? Over time, as you become more knowledgeable about how R works, these help files get less mysterious.

The second way of getting help is from the Console. Go to the Console and type

```
?letters
```

The question mark tells R you need help with the R command `letters`. This will bring up the help file in the same Help pane you were looking at before.

²If you have installed R and RStudio on your own machine instead of accessing RStudio Workbench through a browser, you’ll want to know that `install.packages` only has to be run once, the first time you want to install a package. If you’re using RStudio Workbench, you don’t even need to type that because your server admin will have already done it for you.

Sometimes, you don't know exactly what the name of the command is. For example, suppose we misremembered the name and thought it was `letter` instead of `letters`. Try typing this:

```
?letter
```

You should have received an error because there is no command called `letter`. Try this instead:

```
??letter
```

and scroll down a bit in the Help pane. Two question marks tell R not to be too picky about the spelling. This will bring up a whole bunch of possibilities in the Help pane, representing R's best guess as to what you might be searching for. (In this case, it's not easy to find. You'd have to know that the help file for `letters` appeared on a help page called `base::Constants`.)

The fourth way to get help—and often the most useful way—is to use your best friend Google. You don't want to just search for “R”. (That's the downside of using a single letter of the alphabet for the name of a programming language.) However, if you type “R _____” where you fill in the blank with the topic of interest, Google usually does a pretty good job sending you to relevant pages. Within the first few hits, in fact, you'll often see an online copy of the same help file you see in R. Frequently, the next few hits lead to StackOverflow where very knowledgeable people post very helpful responses to common questions.

Use Google to find out how to take the square root of a number in R. Test out your newly-discovered function on a few numbers to make sure it works.

1.7 Understanding the data

Let's go back to the penguins data contained in the `penguins` data set from the `palmerpenguins` package.

The first thing we do to understand a data set is to read the help file on it. (We've already done this for the `penguins` data.) Of course, this only works for data files that come with R or with a package that can be loaded into R. If you are using R to analyze your own data, presumably you don't need a help file. And if you're analyzing data from another source, you'll have to go to that source to find out about the data.

When you read the help file for `penguins`, you may have noticed that it described the “Format” as being “A tibble with 344 rows and 8 variables.” What is a “tibble”?

The word “tibble” is an R-specific term that describes data organized in a specific way. A more common term is “data frame” (or sometimes “data table”). The idea is that in a data frame, the rows and the columns have very specific interpretations.

Each row of a data frame represents a single object or observation. So in the `penguins` data, each row represents a penguin. If you have survey data, each row will usually represent a single person. But an “object” can be anything about which we collect data. State-level data might have 50 rows and each row represents an entire state.

Each column of a data frame represents a *variable*, which is a property, attribute, or measurement made about the objects in the data. For example, the help file mentions that various pieces of information are recorded about each penguin, like species, bill length, flipper length, body mass, sex, and so on. These are examples of variables. In a survey, for example, the variables will likely be the responses to individual questions.

We will use the terms tibble and data frame interchangeably in this course. They are not quite synonyms: tibbles are R-specific implementations of data frames, the latter being a more general term that applies in all statistical contexts. Nevertheless, there are no situations (at least not encountered in this course) where it makes any difference if a data set is called a tibble or a data frame.

We can also look at the data frame in “spreadsheet” form. Type

```
View(penguins)
```

(Be sure you’re using an upper-case “V” in `View`.) A new pane should open up in the upper-left corner of the screen. In that pane, the `penguins` data appears in a grid format, like a spreadsheet. The observations (individual penguins) are the rows and the variables (attributes and measurements about the penguins) are the columns. This will also let you sort each column by clicking on the arrows next to the variable name across the top.

Sometimes, we just need a little peek at the data. Try this to print just a few rows of data to the Console:

```
head(penguins)
```

We can customize this by specifying the number of rows to print. (Don’t forget about the up arrow trick!)

```
head(penguins, n = 10)
```

The `tail` command does something similar.

```
tail(penguins)
```

When we’re working with HTML documents like this one, it’s usually not necessary to use `View`, `head`, or `tail` because the HTML format will print the data frame a lot more neatly than it did in the Console. You do not need to type the following code; just look below it for the table that appears.

```
penguins
```

```
## # A tibble: 344 x 8
##   species island bill_length_mm bill_depth_mm flipper_length_mm body_mass_g
##   <fct>   <fct>         <dbl>         <dbl>         <int>         <int>
## 1 Adelie  Torgersen         39.1          18.7          181          3750
## 2 Adelie  Torgersen         39.5          17.4          186          3800
## 3 Adelie  Torgersen         40.3           18          195          3250
## 4 Adelie  Torgersen          NA           NA           NA           NA
## 5 Adelie  Torgersen         36.7          19.3          193          3450
## 6 Adelie  Torgersen         39.3          20.6          190          3650
## 7 Adelie  Torgersen         38.9          17.8          181          3625
## 8 Adelie  Torgersen         39.2          19.6          195          4675
## 9 Adelie  Torgersen         34.1          18.1          193          3475
## 10 Adelie Torgersen         42           20.2          190          4250
## # ... with 334 more rows, and 2 more variables: sex <fct>, year <int>
```

You can scroll through the rows by using the numbers at the bottom or the “Next” button. The only thing you can’t do here that you can do with `View` is sort the columns.

We want to understand the “structure” of our data. For this, we use the `str` command. Try it:

```
str(penguins)
```

This tells us several important things. First it says that we are looking at a tibble with 344 observations of 8 variables. We can isolate those pieces of information separately as well, if needed:

```
NROW(penguins)
```

```
NCOL(penguins)
```

These give you the number of rows and columns, respectively.

The `str` command also tells us about each of the variables in our data set. We'll talk about these later.

We need to be able to summarize variables in the data set. The `summary` command is one way to do it:

```
summary(penguins)
```

You may not recognize terms like “Median” or “1st Qu.” or “3rd Qu.” yet. Nevertheless, you can see why this summary could come in handy.

1.8 Understanding the variables

When we want to look at only one variable at a time, we use the dollar sign to grab it. Try this:

```
penguins$body_mass_g
```

This will list the entire `body_mass_g` column, in other words, the body masses (in grams) of all the penguins in this particular study. If we only want to see the first few, we can use `head` like before.

```
head(penguins$body_mass_g)
```

If we want the structure of the variable `body_mass_g`, we do this:

```
str(penguins$body_mass_g)
```

Notice the letters `int` at the beginning of the line. That stands for “integer” which is another word for whole number. In other words, the patients' ages all appear in this data set as whole numbers. There are other data types you'll see in the future:

- **num:** This is for general numerical data (which can be integers as well as having decimal parts).
- **chr:** This means “character”, used for character strings, which can be any sequence of letters or numbers. For example, if the researcher recorded some notes for each penguin, these notes would be recorded in a character variable.
- **factor:** This is for categorical data, which is data that groups observations together into categories. For example, `species` is categorical. These are generally recorded like character strings, but factor variables have more structure because they take on a limited number of possible values corresponding to a generally small number of categories. We'll learn a lot more about factor variables in future chapters.

There are other data types, but the ones above are by far the most common that you'll encounter on a regular basis.

If we want to summarize only the variable `body_mass_g`, we can do this:

```
summary(penguins$body_mass_g)
```

While executing the commands above, you may have noticed entries listed as `NA`. These are “missing” values. It is worth paying attention to missing values and thinking carefully about why they might be missing. For now, just make a mental note that `NA` is the code R uses for data that is missing. (This would be the same as a blank cell in a spreadsheet.)

1.9 Projects

Using files in R requires you to be organized. R uses what's called a “working directory” to find the files it needs. Therefore, you can't just put files any old place and expect R to be able to find them.

One way of ensuring that files are all located where R can find them is to organize your work into projects. Look in the far upper-right corner of the RStudio screen. You should see some text that says **Project: (None)**. This means we are not currently in a project. We're going to create a new project in preparation for the next chapter on using R Markdown.

Open the drop-down menu here and select **New Project**. When the dialog box opens, select **New Directory**, then **New Project**.

You'll need to give your project a name. In general, this should be a descriptive name—one that could still remind you in several years what the project was about. The only thing to remember is that project names and file names should not have any spaces in them. In fact, you should avoid other kinds of special characters as well, like commas, number signs, etc. Stick to letters and numerals and you should be just fine. If you want a multi-word project name or file name, I recommend using underscores. R will allow you to name projects with spaces and modern operating systems are set up to handle file names with spaces, but there are certain things that either don't work at all or require awkward workarounds when file names have spaces. In this case, let's type `intro_stats` for the “Directory name”. Leave everything else alone and click **Create Project**.

You will see the screen refresh and R will restart.

You will see a new file called `intro_stats.Rproj` in the Files pane, but **you should never touch that file**. It's just for RStudio to keep track of your project details.

If everything works the way it should, creating a new project will create a new folder, put you in that folder, and automatically make it your working directory.

Any additional files you need for your project should be placed in this directory. In all future chapters, the first thing you will do is download the chapter file from the book website and place it here in your project folder. If you have installed R and RStudio on your own machine, you'll need to navigate your system to find the downloaded file and move or copy it to your project working directory. (This is done most easily using File Explorer in Windows and the Finder in MacOS.) If you are using RStudio Workbench through a web browser, you'll need to upload it to your project folder using the "Upload" button in the Files tab.

1.10 Conclusion

It is often said that there is a steep learning curve when learning R. This is true to some extent. R is harder to use at first than other types of software. Nevertheless, in this course, we will work hard to ease you over that first hurdle and get you moving relatively quickly. Don't get frustrated and don't give up! Learning R is worth the effort you put in. Eventually, you'll grow to appreciate the power and flexibility of R for accomplishing a huge variety of statistical tasks.

Onward and upward!

Chapter 2

Using R Markdown

2.0

Functions introduced in this chapter

No R functions are introduced here, but R Markdown syntax is explained.

2.1 Introduction

This chapter will teach you how to use R Markdown to create quality documents that incorporate text and R code seamlessly.

First, though, let's make sure you are set up in your project in RStudio.

2.1.1 Are you in your project?

If you followed the directions at the end of the last chapter, you should have created a project called `intro_stats`. Let's make sure you're in that project.

Look at the upper right corner of the RStudio screen. Does it say `intro_stats`? If so, congratulations! You are in your project and you can safely skip the next paragraph and go to the next section “Download assignment file”.

If you're not in the `intro_stats` project, click on whatever it does say in the upper right corner (probably `Project: (None)`). You can click “Open Project” but it's likely that the `intro_stats` project appears in the drop-down menu in your list of recently accessed projects. So click on the project `intro_stats`.

2.1.2 Download the R notebook file

You need to download this chapter as an R Notebook (`.Rmd`) file. Please click the following link to do so:

https://vectorposse.github.io/intro_stats/chapter_downloads/02-using_r_markdown.Rmd

The file is now likely sitting in a Downloads folder on your machine (or wherever you have set up for web files to download). If you have installed R and RStudio on your own machine, you will need to move the file from your Downloads folder into the `intro_stats` project directory you created at the end of the last chapter. (Again, if you haven't created the `intro_stats` project, please go back to Chapter 1 and follow the directions for doing that.) Moving files around is most easily done using File Explorer in Windows or the Finder in MacOS. If you are logged into RStudio Workbench instead, go to the Files tab and click the "Upload" button. From there, leave the first box alone ("Target directory"). Click the "Choose File" button and navigate to the folder on your machine containing the file `02_using-r-markdown.Rmd`. Select that file and click "OK" to upload the file. Then you will be able to open the file in RStudio simply by clicking on it.

If you are reading this text online in the browser, be aware that there are several instructions below that won't make any sense because you're not looking at the plain text file with all the code in it. Much of the material in this book can be read and enjoyed online, but the real learning comes from downloading the chapter files (starting with Chapter 2—this one) and working through them in RStudio.

2.2 What is R Markdown?

The first question should really be, "What is Markdown?"

Markdown is a way of using plain text with simple characters to indicate formatting choices in a document. For example, in a Markdown file, one can make headers by using number signs (or hashtags as the kids are calling them these days¹). The notebook file itself is just a plain text file. To see the formatting, the file has to be converted to HTML, which is the format used for web pages. (This process is described below.)

R Markdown is a special version of Markdown that also allows you to include R code alongside the text. Here's an example of a "code chunk":

```
1 + 1
```

```
## [1] 2
```

¹Also called "pound signs" or "octothorpes". This is also an example of formatting a footnote!

Click the little dark green, right-facing arrow in the upper-right corner of the code chunk. (The icon I’m referring to is next to a faint gear icon and a lighter green icon with a downward-facing arrow.) When you “run” the code chunk like this, R produces output it. We’ll say more about code chunks later in this document.

This document—with text and code chunks together—is called an R Notebook file.

2.3 Previewing a document

There is a button in the toolbar right above the text that says “Preview”. Go ahead and push it. See what happens.

Once the pretty output is generated, take a few moments to look back and forth between it and the original R Notebook text file (the plain text in RStudio). You can see some tricks that we won’t need much (embedding web links, making lists, etc.) and some tricks that we will use in every chapter (like R code chunks).

At first, you’ll want to work back and forth between the R Notebook file and the HTML file to get used to how the formatting in the plain text file get translated to output in the HTML file. After a while, you will look at the HTML file less often and work mostly in the R Notebook file, only previewing when you are finished and ready to produce your final draft.

2.4 Literate programming

R Markdown is one way to implement a “literate programming” paradigm. The concept of literate programming was famously described by Donald Knuth, an eminent computer scientist. The idea is that computer programs should not appear in a sterile file that’s full of hard-to-read, abstruse lines of computer code. Instead, functional computer code should appear interspersed with writing that explains the code.

2.5 Reproducible research

One huge benefit of organizing your work into R Notebooks is that it makes your work *reproducible*. This means that anyone with access to your data and your R Notebook file should be able to re-create the exact same analysis you did.

This is a far cry from what generally happens in research. For example, if I do all my work in Microsoft Excel, I make a series of choices in how I format and

analyze my data and all those choices take the form of menu commands that I point and click with my mouse. There is no record of the exact sequence of clicks that took me from point A to B all the way to Z. All I have to show for my work is the “clean” spreadsheet and anything I’ve written down or communicated about my results. If there were any errors along the way, they would be very hard to track down.²

Reproducibility should be a minimum prerequisite for all statistical analysis. Sadly, that is not the case in most of the research world. We are training you to be better.

2.6 Structure of an R Notebook

Let’s start from the top. Look at the very beginning of the plain R Notebook file. (If you’re in RStudio, you are looking at the R Notebook file. If you are looking at the pretty HTML file, you’ll need to go back to RStudio.) The section at the very top of the file that starts and ends with three hyphens is called the YAML header. (Google it if you really care why.) The title of the document appears already, but you’ll need to substitute your name and today’s date in the obvious places. **Scroll up and do that now.**

You’ve made changes to the document, so you’ll need to push the “Preview” button again. Once that’s done, look at the resulting HTML document. The YAML header has been converted into a nicely formatted document header with the new information you’ve provided.

Next, there is some weird looking code with instructions not to touch it. I recommend heeding that advice. This code will allow you to answer questions and have your responses appear in pretty blue boxes. In the body of the chapter, such answer boxes will be marked with tags `::: {.answer}` and `:::`. Let’s try it:

Replace this text here with something else. Then preview the document and see how it appears in the HTML file.

Be careful not to delete the two lines starting with the three colons (:::) that surround your text! If you mess this up, the rest of the document’s formatting will get screwed up.

To be clear, the colorful answer boxes are not part of the standard R Markdown tool set. That’s why we had to define them manually near the top of the file. Note that the weird code itself does not show up in the HTML file. It works in the background to define the blue boxes that show up in the HTML file.

We also have section headers throughout, which in the R Notebook file look like:

²If you think these errors are trivial, Google “Reinhart and Rogoff Excel error” to read about the catastrophic consequences of seemingly trivial Excel mistakes.

Section header

The hashtags are Markdown code for formatting headers. Additional hashtags will create subsections:

Not quite as big

We could actually use a single number sign, but `#` makes a header as big as the title, which is too big. Therefore, we will prefer `##` for section headers and `###` for subsections.

You do need to make sure that there is a blank line before and after each section header. To see why, look at the HTML document at this spot: `##` Is this a new section? Do you see the problem?

Put a blank line before and after the line above that says “Is this a new section?” Preview one more time and make sure that the line now shows up as a proper section header.

2.7 Other formatting tricks

You can make text *italic* or **bold** by using asterisks. (Don’t forget to look at the HTML to see the result.)

You can make bullet-point lists. These can be made with hyphens, but you’ll need to start after a blank line, then put the hyphens at the beginning of each new line, followed by a space, as follows:

- First item
- Second item

If you want sub-items, indent at least two spaces and use a minus sign followed by a space.

- Item
 - Sub-item
 - Sub-item
- Item
- Item

Or you can make ordered lists. Just use numbers and R Markdown will do all the work for you. Sub-items work the same way as above. (Again, make sure you’re starting after a blank line and that there is a space after the periods and hyphens.)

1. First Item

- Sub-item
- Sub-item

2. Second Item
3. Third Item

We can make horizontal rules. There are lots of ways of doing this, but I prefer a bunch of asterisks in a row.

There are many more formatting tricks available. For a good resource on all R Markdown stuff, click on this link for a “cheat sheet”. And note in the previous sentence the syntax for including hyperlinks in your document.³

2.8 R code chunks

The most powerful feature of R Markdown is the ability to do data analysis right inside the document. This is accomplished by including R code chunks. An R code chunk doesn’t just show you the R code in your output file; it also runs that code and generates output that appears right below the code chunk.

An R code chunk starts with three “backticks” followed by the letter `r` enclosed in braces, and it ends with three more backticks. (The backtick is usually in the upper-left corner of your keyboard, next to the number 1 and sharing a key with the tilde ~.)

In RStudio, click the little dark green, right-facing arrow in the upper-right corner of the code chunk below, just as you did earlier.

```
# Here's some sample R code
test <- c(1, 2, 3, 4)
sum(test)
```

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

After pushing the dark green arrow, you should notice that the output of the R code appeared like magic. If you preview the HTML output, you should see the same output appear. If you hover your mouse over the dark green arrow,

³You can also access cheat sheets through the main Help menu in RStudio.

you should see the words “Run Current Chunk”. We’ll call this the Run button for short.

We need to address something here that always confuses people new to R and R Markdown. A number sign (aka “hashtag”) in an R Notebook gives us headers for sections and subsections. In R, however, a number sign indicates a “comment” line. In the R code above, the line `# Here's some sample R code` is not executed as R code. But you can clearly see that the two lines following were executed as R code. So be careful! Number signs inside and outside R code chunks behave very differently.

Typically, the first code chunk that appears in our document will load any packages we need. We will be using a package called `tidyverse` (which is really a collection of lots of different packages) throughout the course. We load it now. Click on the Run button (the dark green, right-facing arrow) in the code chunk below.

```
library(tidyverse)

## -- Attaching packages ----- tidyverse 1.3.1 --

## v ggplot2 3.3.6      v purrr   0.3.4
## v tibble  3.1.7      v dplyr  1.0.9
## v tidyr   1.2.0      v stringr 1.4.0
## v readr   2.1.2      v forcats 0.5.1

## -- Conflicts ----- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

The output here consists of a bunch of information generated when trying to load the package. These are not errors, even though one section is labeled “Conflicts”. Usually, errors appear with the word “Error”, so it’s typically clear when something just didn’t work. Also note that once you’ve loaded a package, you don’t need to load it again until you restart your R session. For example, if you go back and try to run the code chunk above one more time, the output will disappear. That’s because `tidyverse` is already loaded, so the second “run” doesn’t actually generate output anymore.

Okay, let’s do something interesting now. We’ll revisit the `penguins` data set we introduced in the previous chapter. Remember, though, that this data set also lives in a package that needs to be loaded. Run the code chunk below to load the `palmerpenguins` package:

```
library(palmerpenguins)
```

Let's see what happens when we try to run multiple commands in one code chunk:

```
head(penguins)
```

```
## # A tibble: 6 x 8
##   species island bill_length_mm bill_depth_mm flipper_length_~ body_mass_g sex
##   <fct>   <fct>         <dbl>         <dbl>         <int>     <int> <fct>
## 1 Adelie  Torge~           39.1           18.7           181       3750 male
## 2 Adelie  Torge~           39.5           17.4           186       3800 fema~
## 3 Adelie  Torge~           40.3            18           195       3250 fema~
## 4 Adelie  Torge~           NA            NA            NA         NA <NA>
## 5 Adelie  Torge~           36.7           19.3           193       3450 fema~
## 6 Adelie  Torge~           39.3           20.6           190       3650 male
## # ... with 1 more variable: year <int>
```

```
tail(penguins)
```

```
## # A tibble: 6 x 8
##   species island bill_length_mm bill_depth_mm flipper_length_~ body_mass_g sex
##   <fct>   <fct>         <dbl>         <dbl>         <int>     <int> <fct>
## 1 Chinst~ Dream          45.7            17           195       3650 fema~
## 2 Chinst~ Dream          55.8            19.8           207       4000 male
## 3 Chinst~ Dream          43.5            18.1           202       3400 fema~
## 4 Chinst~ Dream          49.6            18.2           193       3775 male
## 5 Chinst~ Dream          50.8            19           210       4100 male
## 6 Chinst~ Dream          50.2            18.7           198       3775 fema~
## # ... with 1 more variable: year <int>
```

```
str(penguins)
```

```
## tibble [344 x 8] (S3: tbl_df/tbl/data.frame)
##  $ species      : Factor w/ 3 levels "Adelie","Chinstrap",...: 1 1 1 1 1 1 1 1 1 1
##  $ island       : Factor w/ 3 levels "Biscoe","Dream",...: 3 3 3 3 3 3 3 3 3 3
##  $ bill_length_mm : num [1:344] 39.1 39.5 40.3 NA 36.7 39.3 38.9 39.2 34.1 42 ...
##  $ bill_depth_mm  : num [1:344] 18.7 17.4 18 NA 19.3 20.6 17.8 19.6 18.1 20.2 ...
##  $ flipper_length_mm: int [1:344] 181 186 195 NA 193 190 181 195 193 190 ...
##  $ body_mass_g    : int [1:344] 3750 3800 3250 NA 3450 3650 3625 4675 3475 4250 .
##  $ sex           : Factor w/ 2 levels "female","male": 2 1 1 NA 1 2 1 2 NA NA ..
##  $ year           : int [1:344] 2007 2007 2007 2007 2007 2007 2007 2007 2007 2007
```

If you're looking at this in RStudio, it's a bit of a mess. RStudio did its best to give you what you asked for, but there are three separate commands here. The first two (`head` and `tail`) print some of the data, so the first two boxes of output are tables showing you the head and the tail of the data. The next one (`str`) normally just prints some information to the Console. So RStudio gave you an R Console box with the output of this command.

If you look at the HTML file, you can see the situation isn't as bad. Each command and its corresponding output appear nicely separated there.

Nevertheless, it will be good practice and a good habit to get into to put multiple output-generating commands in their own R code chunks. Run the following code chunks and compare the output to the mess you saw above:

```
head(penguins)
```

```
## # A tibble: 6 x 8
##   species island bill_length_mm bill_depth_mm flipper_length_~ body_mass_g sex
##   <fct>   <fct>         <dbl>         <dbl>         <int>         <int> <fct>
## 1 Adelie  Torge~           39.1           18.7           181           3750 male
## 2 Adelie  Torge~           39.5           17.4           186           3800 fema~
## 3 Adelie  Torge~           40.3            18           195           3250 fema~
## 4 Adelie  Torge~            NA            NA            NA            NA <NA>
## 5 Adelie  Torge~           36.7           19.3           193           3450 fema~
## 6 Adelie  Torge~           39.3           20.6           190           3650 male
## # ... with 1 more variable: year <int>
```

```
tail(penguins)
```

```
## # A tibble: 6 x 8
##   species island bill_length_mm bill_depth_mm flipper_length_~ body_mass_g sex
##   <fct>   <fct>         <dbl>         <dbl>         <int>         <int> <fct>
## 1 Chinst~ Dream          45.7            17           195           3650 fema~
## 2 Chinst~ Dream          55.8            19.8           207           4000 male
## 3 Chinst~ Dream          43.5            18.1           202           3400 fema~
## 4 Chinst~ Dream          49.6            18.2           193           3775 male
## 5 Chinst~ Dream          50.8            19           210           4100 male
## 6 Chinst~ Dream          50.2            18.7           198           3775 fema~
## # ... with 1 more variable: year <int>
```

```
str(penguins)
```

```
## tibble [344 x 8] (S3: tbl_df/tbl/data.frame)
## $ species      : Factor w/ 3 levels "Adelie","Chinstrap",...: 1 1 1 1 1 1 1 1 1 1 ...
```

```
## $ island          : Factor w/ 3 levels "Biscoe","Dream",...: 3 3 3 3 3 3 3 3 3 3
## $ bill_length_mm  : num [1:344] 39.1 39.5 40.3 NA 36.7 39.3 38.9 39.2 34.1 42 ...
## $ bill_depth_mm   : num [1:344] 18.7 17.4 18 NA 19.3 20.6 17.8 19.6 18.1 20.2 ...
## $ flipper_length_mm: int [1:344] 181 186 195 NA 193 190 181 195 193 190 ...
## $ body_mass_g      : int [1:344] 3750 3800 3250 NA 3450 3650 3625 4675 3475 4250 .
## $ sex              : Factor w/ 2 levels "female","male": 2 1 1 NA 1 2 1 2 NA NA ..
## $ year             : int [1:344] 2007 2007 2007 2007 2007 2007 2007 2007 2007 2007
```

This won't look any different in the HTML file, but it sure looks a lot cleaner in RStudio.

What about the two lines of the first code chunk we ran above?

```
test <- c(1, 2, 3, 4)
sum(test)
```

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

Should these two lines be separated into two code chunks? If you run it, you'll see only one piece of output. That's because the line `test <- c(1, 2, 3, 4)` works invisibly in the background. The vector `test` gets assigned, but no output is produced. Try it and see (push the Run button):

```
test <- c(1, 2, 3, 4)
```

So while there's no harm in separating these lines and putting them in their own chunks, it's not strictly necessary. You really only need to separate lines when they produce output. (And even then, if you forget, RStudio will kindly give you multiple boxes of output.)

Suppose we define a new variable called `test2` in a code chunk. FOR PURPOSES OF THIS EXERCISE, DO NOT HIT THE RUN BUTTON YET! But do go look at the HTML file.

```
test2 <- c("a", "b", "c")
test2
```

```
## [1] "a" "b" "c"
```

The first line defines `test2` invisibly. The second line asks R to print the value of `test2`, but in the HTML file we see no output. That's because we have not run the code chunk yet. DON'T HIT THE RUN BUTTON YET!

Okay, now go to the Console in RStudio (in the lower left corner of the screen). Try typing `test2`. You should get an "Error: object 'test2' not found."

Why does this happen? The Global Environment doesn't know about it yet. Look in the upper right corner of the screen, under the "Environment" tab. You should see `test`, but not `test2`.

Okay, NOW GO BACK AND CLICK THE RUN BUTTON IN THE LAST CHUNK ABOVE. The output appears in RStudio below the code chunk and the Global Environment has been updated.

The take home message is this:

Be sure to run all your code chunks in RStudio!

In RStudio, look in the toolbar above this document, toward the right. You should see the word "Run" with a little drop-down menu next to it. Click on that drop-down menu and select "Run All". Do you see what happened? All the code chunks ran again, and that means that anything in the Global Environment will now be updated to reflect the definitions made in the R Notebook.

It's a good idea to "Run All" when you first open a new R Notebook. This will ensure that all your code chunks have their output below them (meaning you don't have to go through and click the Run button manually for each chunk, one at a time) and the Global Environment will accurately reflect the variables you are using.

You can "Run All" from time to time, but it's easier just to "Run All" once at the beginning, and then Run individual R code chunks manually as you create them.

Now go back to the Environment tab and find the icon with the little broom on it. Click it. You will get a popup warning you that you about to "remove all objects from the environment". Click "Yes". Now the Global Environment is empty. Go back to the "Run" menu and select "Run All". All the objects you defined in the R Notebook file are back.

Clearing out your environment can be useful from time to time. Maybe you've been working on a chapter for a while and you've tried a bunch of stuff that didn't work, or you went back and changed a bunch of code. Eventually, all that junk accumulates in your Global Environment and it can mess up your R Notebook. For example, let's define a variable called `my_variable`.

```
my_variable <- 42
```

Then, let's do some calculation with `my_variable`.

```
my_variable * 2
```

```
## [1] 84
```

Perhaps later you decide you don't really need `my_variable`. Put a hashtag in front of the code `my_variable <- 42` to comment it out so that it will no longer run, but don't touch the next code chunk where you multiply it by 2. Now try running the code chunk with `my_variable * 2` again. Note that `my_variable` is still sitting in your Global Environment, so you don't get any error messages. R can still see and access `my_variable`.

Now go to the “Run” menu and select “Restart R and Run All Chunks”. This clears the Global Environment and runs all the R code starting from the top of the R Notebook. This time you will get an error message: `object 'my_variable' not found`. You've tried to calculate with a variable called `my_variable` that doesn't exist anymore. (The line in which it was defined has been commented out.)

It's best to make sure all your code chunks will run when loaded from a clean R session. The “Restart R and Run All Chunks” option is an easy way to both clear your environment and re-run all code chunks. You can do this as often as you want, but you will definitely want to do this one last time when you are done. **At the end of the chapter, when you are ready to prepare the final draft, please select “Restart R and Run All Chunks”. Make sure everything still works!**

To get rid of the error above, uncomment the line `my_variable <- 42` by removing the hashtag you added earlier.

2.9 Inline R commands

You don't need a standalone R code chunk to do computations. One neat feature is the ability to use R to calculate things right in the middle of your text.

Here's an example. Suppose we wanted to compute the mean body mass (in grams) for the penguins in the `penguins` data set. We could do this:

```
mean(penguins$body_mass_g, na.rm = TRUE)
```

```
## [1] 4201.754
```

(The `na.rm = TRUE` part is necessary because two of the penguins are missing body mass data. More on missing data in future chapters.)

But we can also do this inline by using backticks and putting the letter `r` inside the first backtick. Go to the HTML document to see how the following sentence appears:

The mean body mass for penguins in the `penguins` data set is 4201.754386 grams.

You can (and should) check to make sure your inline R code is working by checking the HTML output, but you don't necessarily need to go to the HTML file to find out. In RStudio, click so that the cursor is somewhere in the middle of the inline code chunk in the paragraph above. Now type Ctrl-Enter or Cmd-Enter (PC or Mac respectively). A little box should pop up that shows you the answer!

Notice that in addition to the inline R command that calculated the mean, I also enclosed `penguins` in backticks to make it stand out in the output. I'll continue to do that for all computer commands and R functions. But to be clear, putting a word in backticks is just a formatting trick. If you want inline R code, you also need the letter `r` followed by a space inside the backticks.

2.10 Copying and pasting

In future chapters, you will be shown how to run statistical analyses using R. Each chapter will give extensive explanations of the statistical concepts and demonstrations of the necessary R code. Afterwards, there will be one or more exercises that ask you to apply your new-found knowledge to run similar analyses on your own with different data.

The idea is that you should be able to copy and paste the R code from the previously worked examples. **But you must be thoughtful about how you do this.** The code cannot just be copied and pasted blindly. It must be modified so that it applies to the exercises with new data. This requires that you understand what the code is doing. You cannot effectively modify the code if you don't know which parts to modify.

There will also be exercises in which you are asked to provide your own explanations and interpretations of your analyses. These should **not** be copied and pasted from any previous work. These exercises are designed to help you understand the statistical concepts, so they must be in your own words, using your own understanding.

In order to be successful in these chapters, you must do the following:

1. **Read every part of the chapter carefully!**

- It will be tempting to skim over the paragraphs quickly and just jump from code chunk to code chunk. This will be highly detrimental to your ability to gain the necessary understanding—not just to complete the chapter, but to succeed in statistics overall.

2. **Copy and paste thoughtfully!**

- Not every piece of code from the early part of the chapter will necessarily apply to the later exercises. And the code that does apply will need to be modified (sometimes quite heavily) to be able to run new analyses. Your job is to understand how the code works so that you can make changes to it without breaking things. If you don't understand a piece of code, don't copy and paste it until you've read and re-read the earlier exposition that explains how the code works.

One final note about copying and pasting. Sometimes, people will try to copy and paste code from the HTML output file. This is a bad idea. The HTML document uses special characters to make the output look pretty, but these characters don't actually work as plain text in an R Notebook. The same applies to things copied and pasted from a Word document or another website. If you need to copy and paste code, be sure to find the plain text R Notebook file (the one with the .Rmd extension here in RStudio) and copy and paste from that.

2.11 Conclusion

That's it! There wasn't too much you were asked to do for this assignment that will actually show up in the HTML output. (Make sure you did do the three things that were asked of you however: one was adding your name and the date to the YAML header, one was typing something in the blue answer box, and the last was to make a section header appear properly.) As you gain confidence and as we move into more serious stats material, you will be asked to do a lot more.

2.11.1 Preparing and submitting your assignment

If you look in your project folder, you should see three files:

```
intro_stats.Rproj
02-using_r_markdown.Rmd
02-using_r_markdown.nb.html
```

The first file (with extension .Rproj) you were instructed never to touch.

The next file (with extension .Rmd) is your R Notebook file. It's the file you're looking at right now. It is really nothing more than a plain text file, although when you open it in RStudio, some magic allows you to see the output from the code chunks you run.

Finally, you have a file with extension .nb.html. That is the pretty output file generated when you hit the "Preview" button. (If you happen to see other files

in your project folder, you should ignore those and not mess with them.) This is the “final product” of your work.

There are several steps that you should follow at the end of each of every chapter.

1. From the “Run” menu, select “Restart R and Run All Chunks”.
2. Deal with any code errors that crop up. Repeat steps 1—2 until there are no more code errors.
3. Spell check your document by clicking the icon with “ABC” and a check mark.
4. Hit the “Preview” button one last time to generate the final draft of the `.nb.html` file.
5. Proofread the HTML file carefully. If there are errors, go back and fix them, then repeat steps 1–5 again.

If you have completed this chapter as part of a statistics course, follow the directions you receive from your professor to submit your assignment.

Chapter 3

Categorical data

2.0

Functions introduced in this chapter

`glimpse`, `table`, `tabyl`, `adorn_pct_formatting`, `ggplot`, `geom_bar`,
`adorn_percentages`, `mutate`, `as_factor`, `labs`, `tibble`, `geom_col`

3.1 Introduction

In this chapter, we'll learn about categorical data and how to summarize it using tables and graphs.

3.1.1 Download the R notebook file

Check the upper-right corner in RStudio to make sure you're in your `intro_stats` project. Then click on the following link to download this chapter as an R notebook file (`.Rmd`).

https://vectorposse.github.io/intro_stats/chapter_downloads/03-categorical_data.Rmd

Once the file is downloaded, move it to your project folder in RStudio and open it there.

3.1.2 Restart R and run all chunks

In RStudio, in the toolbar above this document, find the “Run” drop-down menu and select “Restart R and Run All Chunks.”

This does two important things:

1. R will restart. This will clear out the Global Environment and provide a fresh session for this new assignment. None of the clutter from previous chapters will be there to mess up your work in this chapter.
2. All the code chunks in this document will run so that you can see the output as you scroll past it. This saves you some effort in having to click the little green “Run” button in each code chunk as you come across it. (Also, if you forget to run one, that could cause errors later on, so this way, all the variables you need will be in the Global Environment for when they’re needed later.) You will still need to click the green arrow for new code chunks that you create, of course.

At the end of the assignment, you will “Restart R and Run All Chunks” once again to make sure that everything works smoothly and there are no lingering errors.

3.1.3 Load packages

We load the `tidyverse` package since it also loads the `ggplot2` package that we’ll use throughout the course to make graphs. It also loads several other packages, for example, one called `dplyr` to give us a command called `mutate`, and another called `forcats` to give us `as_factor`. (These will all be explained later.) The `janitor` package gives us the `tabyl` command for creating nice tables. Finally, We load the `palmerpenguins` package to work with the penguin data.

```
library(tidyverse)
library(janitor)

##
## Attaching package: 'janitor'

## The following objects are masked from 'package:stats':
##
##      chisq.test, fisher.test

library(palmerpenguins)
```

3.2 Categorical data

Data comes in different types depending on what is being measured. When people think of “data”, they often imagine *numerical data*, consisting of numbers. But there are other kinds of data as well.

In this chapter, we focus on *categorical data* that groups observations into categories.

For example, if we record the species of a penguin, that is not a number. It's a word that classifies that penguin into one of a finite number of types. Whenever you see words in a data set, there's a good chance that you're looking at categorical data.

Even “numbers” can sometimes represent categorical data. For example, suppose in a survey there is a Yes/No question. Instead of seeing the words “Yes” or “No”, though, you might see a data set with ones and zeros, where $1 = \text{Yes}$ and $0 = \text{No}$. The presence of numbers does not automatically make that data numerical. In fact, the data is categorical. Yes and No are categories that sort the survey respondents into two groups based on their responses to a certain question.

What about ZIP codes? They are recorded as numbers, and unlike the Yes/No example above, those numbers aren't just substitutes for words. Nevertheless, ZIP codes are categorical. They sort addresses into a finite number of groups based on geographic proximity.

Another way to think of it is this: can the numerical values of ZIP codes be treated as numbers in any meaningful way? Can you take a sum or an average of ZIP codes? Sure, technically a computer can add up or average a set of ZIP codes, but would the result be a meaningful number? Since the answer is “no” we cannot think of ZIP codes as numbers, even though they are recorded that way.

Exercise 1 Think of another type of data that would be recorded using numbers but should be thought of as categorical data.

Please write up your answer here.

3.3 Factor variables

R uses the term “factor variable” to refer to a categorical variable. Look at the structure of the `penguins` data below.

```
str(penguins)
```

```
## tibble [344 x 8] (S3: tbl_df/tbl/data.frame)
## $ species      : Factor w/ 3 levels "Adelie","Chinstrap",...: 1 1 1 1 1 1 1 1 1 1 ...
## $ island       : Factor w/ 3 levels "Biscoe","Dream",...: 3 3 3 3 3 3 3 3 3 3 ...
## $ bill_length_mm : num [1:344] 39.1 39.5 40.3 NA 36.7 39.3 38.9 39.2 34.1 42 ...
## $ bill_depth_mm : num [1:344] 18.7 17.4 18 NA 19.3 20.6 17.8 19.6 18.1 20.2 ...
```

```
## $ flipper_length_mm: int [1:344] 181 186 195 NA 193 190 181 195 193 190 ...
## $ body_mass_g      : int [1:344] 3750 3800 3250 NA 3450 3650 3625 4675 3475 4250 .
## $ sex              : Factor w/ 2 levels "female","male": 2 1 1 NA 1 2 1 2 NA NA ..
## $ year             : int [1:344] 2007 2007 2007 2007 2007 2007 2007 2007 2007 2007
```

The categorical variables `species`, `island`, and `sex` are coded correctly as factor variables.

The `tidyverse` package offers a function called `glimpse` that effectively does the same thing as `str`. We'll use `glimpse` throughout the rest of the course.

```
glimpse(penguins)
```

```
## Rows: 344
## Columns: 8
## $ species      <fct> Adelie, Adelie, Adelie, Adelie, Adelie, Adelie, Adel~
## $ island       <fct> Torgersen, Torgersen, Torgersen, Torgersen, Torgerse~
## $ bill_length_mm <dbl> 39.1, 39.5, 40.3, NA, 36.7, 39.3, 38.9, 39.2, 34.1, ~
## $ bill_depth_mm <dbl> 18.7, 17.4, 18.0, NA, 19.3, 20.6, 17.8, 19.6, 18.1, ~
## $ flipper_length_mm <int> 181, 186, 195, NA, 193, 190, 181, 195, 193, 190, 186~
## $ body_mass_g   <int> 3750, 3800, 3250, NA, 3450, 3650, 3625, 4675, 3475, ~
## $ sex          <fct> male, female, female, NA, female, male, female, male~
## $ year         <int> 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007~
```

Exercise 2 Look at the output of `str` versus `glimpse` above. Write down any advantages or disadvantages you see using one versus the other. (You may also want to check the help file for the two commands to see if they offer any clues as to why you might use one over the other.)

Please write up your answer here.

Your data set may already come with its variables coded correctly as factor variables, but often they are not. As described above, numbers are often used to represent categories, so R may think that those variables represent numerical data. Later, we'll see an example of this and learn how to handle categorical variables that are not coded as factor variables in R.

3.4 Summarizing one categorical variable

If you need to summarize a single categorical variable, a *frequency table* usually suffices. This is simply a table that counts up all the instances of each category. The word “frequency” is synonymous here with the word “count”.

We can use the `table` command:

```
table(penguins$species)

##
##      Adelie Chinstrap      Gentoo
##      152         68        124
```

Recall that the dollar sign means to grab the variable `species` from the tibble `penguins`.

You can also generate a *relative frequency table* which is a table that uses proportions or percentages instead of counts.

NOTE: For purposes of this course, we’re going to be very careful about the terms *proportion* and *percentage*. For us, a proportion will always be a number between 0 and 1 whereas a percentage will be between 0 and 100. Calculating a percentage is the same as multiplying a proportion by 100.

The `table` command stops being convenient if you want proportions instead of counts. Instead, we will use the `tabyl` command from the `janitor` package that was loaded near the top of the chapter. The syntax for this command is a little different. The tibble goes first, followed by a comma, followed by the variable you want to summarize:

```
tabyl(penguins, species)

##      species    n percent
##      Adelie 152 0.4418605
##      Chinstrap 68 0.1976744
##      Gentoo 124 0.3604651
```

Now you get both counts and proportions. Note that in the output above, it’s a little misleading to call the last column “percent”. These are actually proportions, and we would have to multiply by 100 to get percentages.

If you really want percentages, we can use an `adorn` function to get them as follows:

```
tabyl(penguins, species) %>%
  adorn_pct_formatting()

##      species    n percent
##      Adelie 152   44.2%
##      Chinstrap 68   19.8%
##      Gentoo 124   36.0%
```

The syntax above looks a little confusing with the unusual `%>%` there. You will learn more about that weird set of symbols in a later chapter. For now, you can just copy and paste this code and make any necessary changes to the tibble and/or variables names as needed.

Exercise 3(a) Use the `tabyl` command as above to create a frequency table for the sex of the penguins. (You will also get a relative frequency table for free.)

```
# Add code here to create a frequency table for sex
```

Exercise 3(b) In the table for sex that you just created, what does the last row mean?

Please write up your answer here.

Exercise 3(c) Now create a relative frequency table for sex that reports percentages and not proportions.

```
# Add code here that reports percentages instead of proportions
```

Exercise 3(d) In the previous tables, what is the difference between `percent` and `valid_percent`? Why are there two different sets of percentages being computed?

Please write up your answer here.

3.5 Graphing one categorical variable

When asked, “What type of graph should I use when graphing a single categorical variable?” the simple answer is “None.” If you do need to summarize a categorical variable, a frequency table usually suffices.

If you really, really want a graph, the standard type is a bar chart. But before we can create one, we need to start learning about the very important tool we will use throughout the course for graphing. It’s called `ggplot` and it’s part of a package called `ggplot2`.¹

We don’t have to load the `ggplot2` package explicitly because it got loaded alongside a number of other packages when we called `library(tidyverse)` early on in the chapter.

¹Why the “2”? It’s a long story. Google it if you’re interested in the history of the development of the `ggplot2` package.

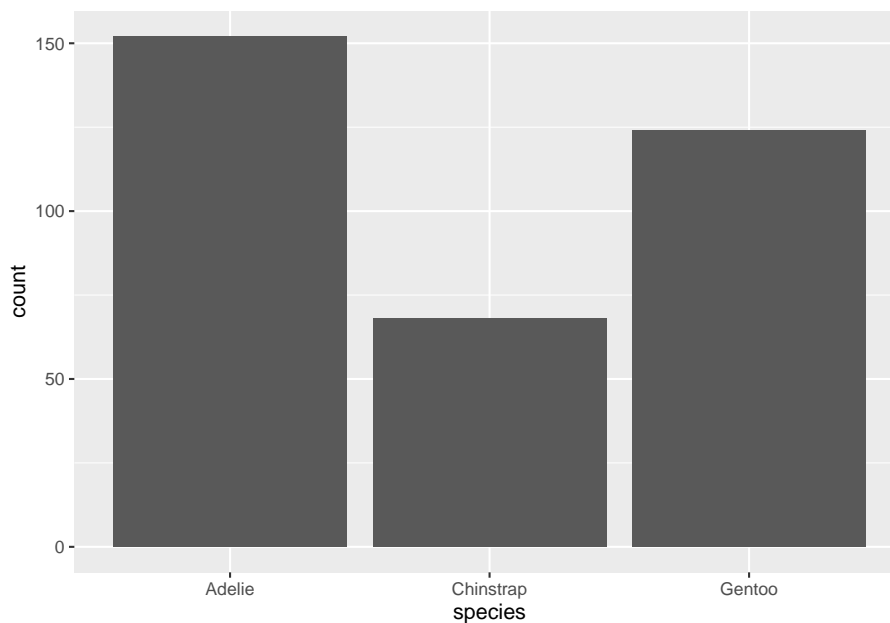
3.5.1 ggplot

The `ggplot` command is an all-purpose graphing utility. It uses a graphing philosophy derived from a book called *The Grammar of Graphics* by Leland Wilkinson. The basic idea is that each variable you want to plot should correspond to some element or “aesthetic” component of the graph. The obvious places for data to go are along the y-axis or x-axis, but other aesthetics are important too; graphs often use color, shape, or size to illustrate different aspects of data. Once these aesthetics have been defined, we will add “layers” to the graph. These are objects like dots, boxes, lines, or bars that dictate the type of graph we want to see.

In an introductory course, we won’t get too fancy with these graphs. But be aware that there’s a whole field of data visualization that studies clear and interesting ways to understand data graphically.

It will be easier to explain the `ggplot` syntax in the context of specific graph types, so let’s create a bar chart for species.

```
ggplot(penguins, aes(x = species)) +  
  geom_bar()
```



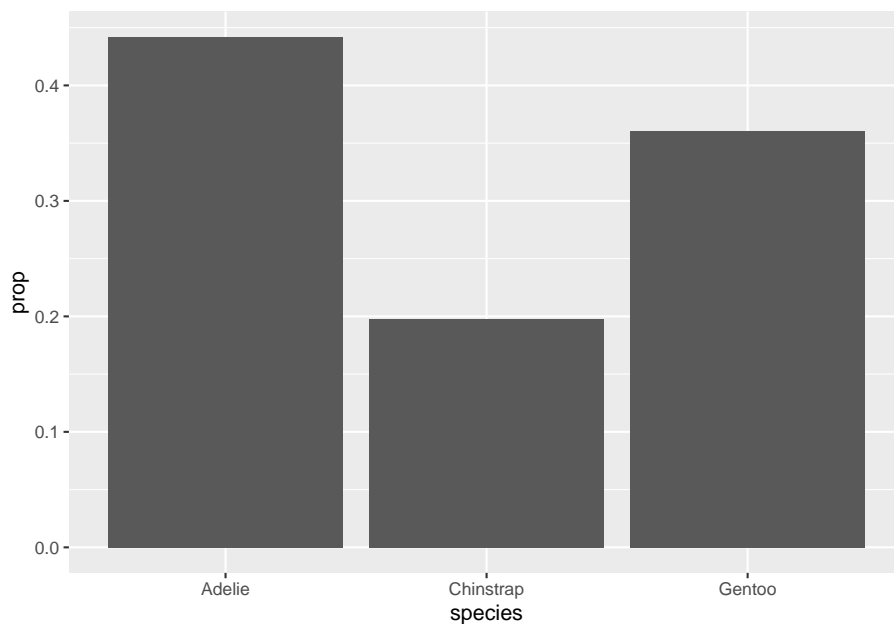
We’ll walk through this syntax step by step.

- The first argument of the `ggplot` command is the name of the tibble, in this case, `penguins`.

- Next we define the aesthetics using `aes` and parentheses. Inside the parentheses, we assign any variables we want to plot to aesthetics of the graph. For this analysis, we are only interested in the variable `species` and for a bar chart, the categorical variable typically goes on the x-axis. That's why it says `x = species` inside the `aes` argument.
- Finally, `ggplot` needs to know what kind of graph we want. Graph types are called “geoms” in the `ggplot` world, and `geom_bar()` tells `ggplot` to add a “bar chart layer”. Adding a layer is accomplished by literally typing a plus sign.

This can be modified somewhat to give proportions (relative frequencies) on the y-axis instead of counts. Unfortunately, the `ggplot` syntax is not very transparent here. My recommendation is to copy and paste the code below if you need to make a relative frequency bar chart in the future, making the necessary changes to the tibble and variable names, of course.

```
ggplot(penguins, aes(x = species, y = ..prop.., group = 1)) +  
  geom_bar()
```



These bar charts are the graphical analogues of a frequency table and a relative frequency table, respectively.

Exercise 4 In a sentence or two at most, describe the distribution of species in this data set.

Please write up your answer here.

What about pie charts? Just. Don't.

Seriously. Pie charts suck.²

3.6 Summarizing two categorical variables

A table summarizing two categorical variables is called a *contingency table* (or pivot table, or cross-tabulation, or probably several other terms as well).

For example, we might pose the following question: is the distribution of sex among penguins in our data more or less balanced across the three species?

When we work with two variables, typically we think of one variable as *response* and the other as *predictor*. The response variable is usually the variable of main interest. A predictor variable is another attribute that might predict or explain more about the response variable.

For example, our question is concerned with the sex distribution of penguins. We could create a relative frequency table of sex alone to see if male and female penguins are balanced in the data. In fact, you did that very thing above and saw that, indeed, there were roughly equal numbers of male and female penguins. But is that still true when we divide up the data into the three groups representing the separate species?

Two variables are called *associated* when there is a relationship between them. For example, if sex and species were associated, then the distribution of sex would change depending on the species. Maybe one species of penguin had more females and another had fewer females. Our prediction of the sex distribution would change based on the value of the predictor variable **species**.

On the other hand, two variables that are not associated are called *independent*. Independent variables are not related. If the sex distribution were the same across all species, then knowledge of the species would not change our predictions about the sex of a penguin. It wouldn't matter because there was no relationship between sex and species.

Most research questions that involve two or more variables are fundamentally questions of whether a response variable is associated with one or more predictor variables, or whether they are independent.

Let's check the contingency table. The `tabyl` command will place the first variable listed across the rows and the second one listed down the columns. It

²<https://medium.com/the-mission/to-pie-charts-3b1f57bcb34a>

doesn't make any difference which variable is where, but to have a consistent rule on which we can rely, **let's always list the response variable first**.

```
tabyl(penguins, sex, species)
```

```
##      sex Adelie Chinstrap Gentoo
## female    73      34      58
##  male     73      34      61
##   <NA>     6       0       5
```

Each column is a group, and our question is whether the distribution of sexes in each column is similar.

Exercise 5 Counts can be misleading. For example, there are 73 female Adelie penguins, but only 34 female Chinstrap penguins. Does that mean that Adelie penguins are more likely to be female than Chinstrap penguins? Why or why not?

Please write up your answer here.

A more fair way to compare across columns is to create relative frequencies. We can do this with a slightly different `adorn` command. The following code says that we want to compute column proportions (yes, I know the command is called `adorn_percentages`, but these are proportions):

```
tabyl(penguins, sex, species) %>%
  adorn_percentages("col")
```

```
##      sex      Adelie Chinstrap      Gentoo
## female 0.48026316      0.5 0.46774194
##  male  0.48026316      0.5 0.49193548
##   <NA> 0.03947368      0.0 0.04032258
```

If we actually want percentages, we need one more line of code. This command—`adorn_pct_formatting`—is the same as we used before with frequency tables.

```
tabyl(penguins, sex, species) %>%
  adorn_percentages("col") %>%
  adorn_pct_formatting()
```

```
##      sex Adelie Chinstrap Gentoo
## female 48.0%    50.0%  46.8%
##   male 48.0%    50.0%  49.2%
##   <NA>  3.9%     0.0%   4.0%
```

Now we can see that each column adds up to 100%. In other words, each species is now on equal footing, and only the distribution of sexes within each group matters.

Exercise 6(a) What percentage of Adelie penguins are male? What percentage of Chinstrap penguins are male? What percentage of Gentoo penguins are male?

Please write up your answer here.

Exercise 6(b) Does sex appear to be associated with species for the penguins in this data set? Or are these variables independent?

Please write up your answer here.

The islands of Antarctica on which the penguins were observed and measured are recorded in the variable called `island`. Is the distribution of the three species of penguin the same (or similar) on the three islands?

Exercise 7(a) Choosing which variables play the roles of response and predictor can be tricky. For the question above, with `species` and `island`, which is response and which is predictor?

One way to think about this is to ask the following two questions and see which one is closer to the question asked:

- Given information about the species, are you interested in which island the penguin lives on? If so, `species` is a predictor and `island` is response. (You are using `species` to predict `island`.)
- Given information about the island, are you interested in the species of the penguin? If so, `island` is a predictor and `species` is response. (You are using `island` to predict `species`.)

Please write up your answer here.

Exercise 7(b) Create a contingency table with percentages. List `species` first, followed by `island`. (Hey, that's hint in case you need to go back and change your answer to part (a).)

```
# Add code here to create a contingency table with percentages.
```

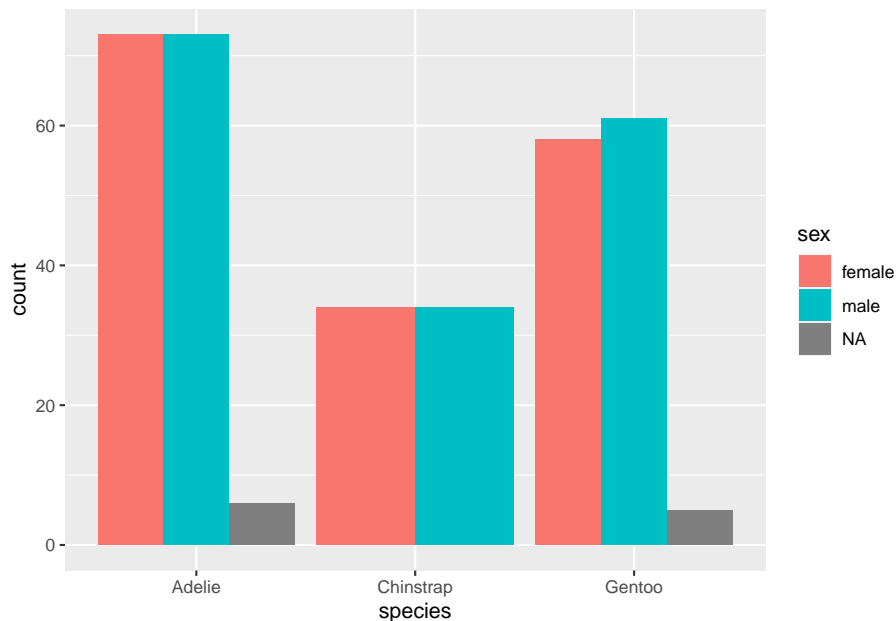
Exercise 7(c) Finally, comment on the association or independence of the two variables.

Please write up your answer here.

3.7 Graphing two categorical variables

A somewhat effective way to display two categorical variables is with a side-by-side bar chart. Here is the `ggplot` code for the relationship between `sex` and `species`.

```
ggplot(penguins, aes(fill = sex, x = species)) +  
  geom_bar(position = "dodge")
```

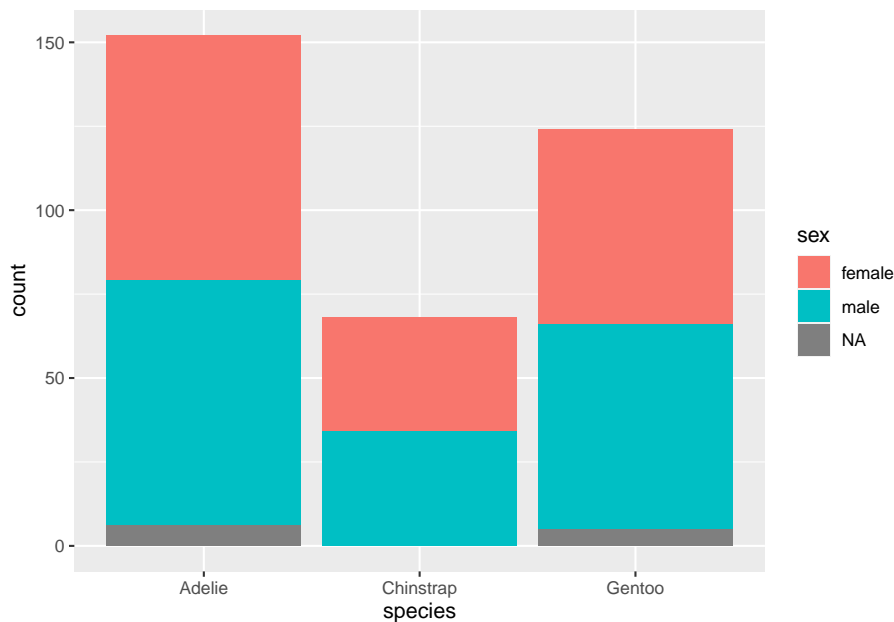


This is somewhat different from the first `ggplot` example you saw above, so let's take a moment to go through it.

- The first argument is the data frame `penguins`; no mystery there.
- The second aesthetic `x = species` also makes a lot of sense. As `species` is our predictor variable—we’re using species to group the penguins, and then within each species, we’re interested in the sex distribution—`species` goes on the x-axis.
- However, `sex` does not go on the y-axis! (This is a very common mistake for novices.) The y-axis of a bar chart is always a count or a proportion/percentage, so no variable should ever go on the y-axis of a bar chart. In that case, how does `sex` enter the picture? Through the use of color! The aesthetic `fill = sex` says to use the `sex` variable to shade or “fill” the bars with different colors. You’ll also notice that `ggplot` makes a legend automatically with the colors so you can see which color corresponds to which value (in this case, “female”, “male”, or “NA” for the missing data).

Another unusual feature is the argument `position = "dodge"` in the `geom_bar` layer. Let’s see what happens if we remove it.

```
ggplot(penguins, aes(fill = sex, x = species)) +  
  geom_bar()
```



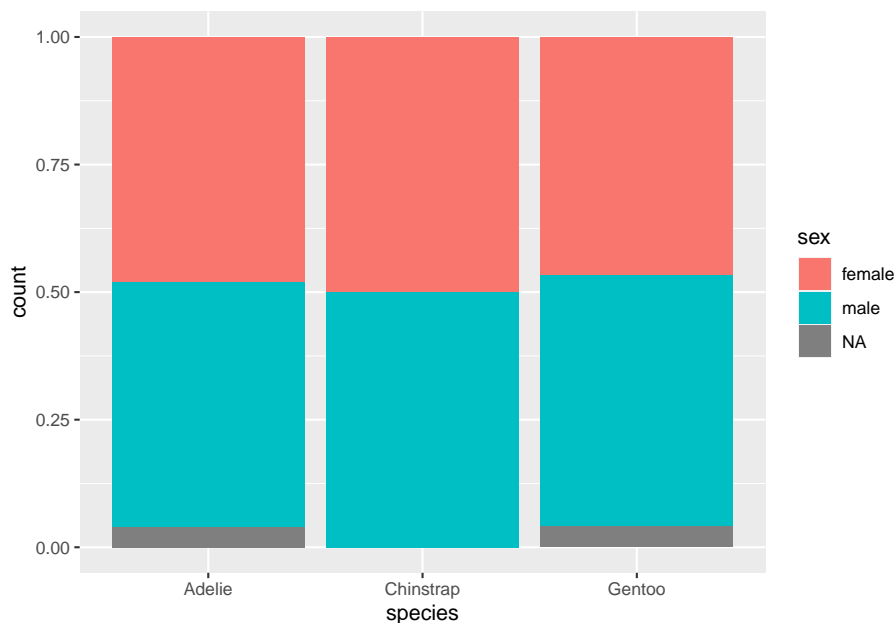
We get a stacked bar chart! This is another popular way of displaying two categorical variables, but we don’t tend to prefer it. Notice how difficult it is to compare the number of females across species; since there is no common baseline for the red segments of each bar, it is harder to determine which ones are bigger

or smaller. (In this case, it's fairly clear, but there are plenty of data sets for which the counts might be a lot closer.)

So let's agree to use side-by-side bar charts. There is still one aspect of the side-by-side bar chart that is misleading, though. For example, the red bar for Adelie penguins is bigger than the red bar for Gentoo penguins. Does this mean Adelie penguins are more likely to be female?

This is the same issue we identified in an exercise above. To fix this problem, a better option here would be to use relative frequencies (i.e., proportions/percentages within each group) instead of counts on the y-axis. This is analogous to using proportions/percentages in a contingency table. Unfortunately, it is rather difficult to do this with `ggplot`. A compromise is available: by using `position = fill`, you can create a stacked bar chart that scales every group to 100%. Making comparisons across groups can still be hard, as explained above for any kind of stacked bar chart, but it works okay if there are only two categories in the response variable (as is almost the case with `sex` here, although the missing data distorts things a little at the bottom).

```
ggplot(penguins, aes(fill = sex, x = species)) +  
  geom_bar(position = "fill")
```



This graph does correctly show that the sexes are pretty much equally balanced across all three species.

Exercise 8(a) Using `species` and `island`, create a side-by-side bar chart. Be careful, though, to change the sample code above to make sure `species` is now the response variable (using the `fill` aesthetic) and that `island` is the explanatory variable (using `x`). (Hey, that’s another hint to go back and look at the previous exercise and make sure you got part (a) right!)

```
# Add code here to make a side-by-side bar chart.
```

Exercise 8(b) Comment on the association or independence of the two variables.

Please write up your answer here.

3.8 Recoding factor variables

As mentioned earlier, there are situations where a categorical variable is not recorded in R as a factor variable. Let’s look at the `year` variable:

```
glimpse(penguins$year)
```

```
##   int [1:344] 2007 2007 2007 2007 2007 2007 2007 2007 2007 2007 2007 ...
```

These appear as integers. Yes, years are whole numbers, but why might this variable be treated as categorical data and not numerical data?

Exercise 9(a) Use the `tabyl` command to create a frequency table for `year`.

```
# Add code here to make a frequency table for year.
```

Exercise 9(b) Why is `year` better thought of as categorical data and not numerical data (at least for this data set—we’re not claiming years should always be treated as categorical)?

Please write up your answer here.

While the `tabyl` command seemed to work just fine with the `year` data in integer format, there are other commands that will not work so well. For example, `ggplot` often fails to do the right thing when a categorical variable is coded as

a number. Therefore, we need a way to change numerically coded variables to factors.

The code below uses a command called `mutate` that takes an old variable and creates a new variable. (You'll learn more about this command in a later chapter. For now, you can just copy and paste this code if you need it again.) The name of the new variable can be anything we want; we'll just call it `year_fct`. Then the real work is being done by the `as_factor` command that converts the numeric `year` variable into a factor variable.

Observe the effect below:

```
penguins <- penguins %>%
  mutate(year_fct = as_factor(year))
glimpse(penguins)

## Rows: 344
## Columns: 9
## $ species      <fct> Adelie, Adelie, Adelie, Adelie, Adelie, Adelie, Adel~
## $ island       <fct> Torgersen, Torgersen, Torgersen, Torgersen, Torgerse~
## $ bill_length_mm <dbl> 39.1, 39.5, 40.3, NA, 36.7, 39.3, 38.9, 39.2, 34.1, ~
## $ bill_depth_mm <dbl> 18.7, 17.4, 18.0, NA, 19.3, 20.6, 17.8, 19.6, 18.1, ~
## $ flipper_length_mm <int> 181, 186, 195, NA, 193, 190, 181, 195, 193, 190, 186~
## $ body_mass_g   <int> 3750, 3800, 3250, NA, 3450, 3650, 3625, 4675, 3475, ~
## $ sex          <fct> male, female, female, NA, female, male, female, male~
## $ year         <int> 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007~
## $ year_fct      <fct> 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007, 2007~
```

Exercise 10(a) Make a contingency table of the species measured in each year using counts. Use the `species` variable first, followed by the new factor variable `year_fct`. (Think about why that order makes sense. **We will always list the response variable first so that the categories of interest will be the rows and the groups will be the columns.**)

```
# Add code here to make a contingency table for species and year with counts.
```

Exercise 10(b) Make a contingency table of the species measured in each year using column percentages (*not* proportions). (Again, be sure to use the new factor variable `year_fct`, not the old variable `year`.)

```
# Add code here to make a contingency table for species and year with percentages.
```

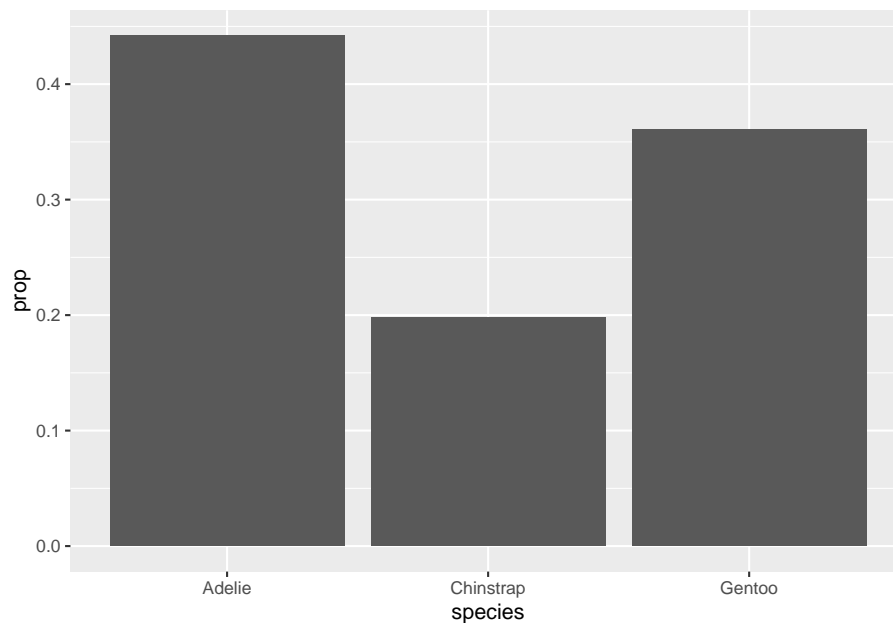
Exercise 10(c) How similar or dissimilar are the distributions of species across the three years of the study?

Please write up your answer here.

3.9 Publication-ready graphics

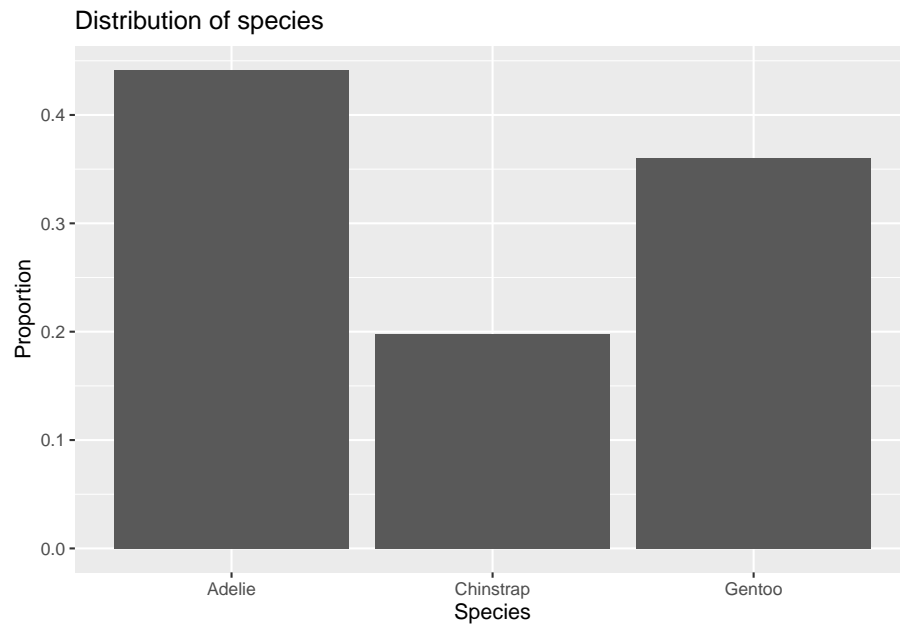
Let's go back to the first relative frequency bar chart from this chapter.

```
ggplot(penguins, aes(x = species, y = ..prop.., group = 1)) +  
  geom_bar()
```



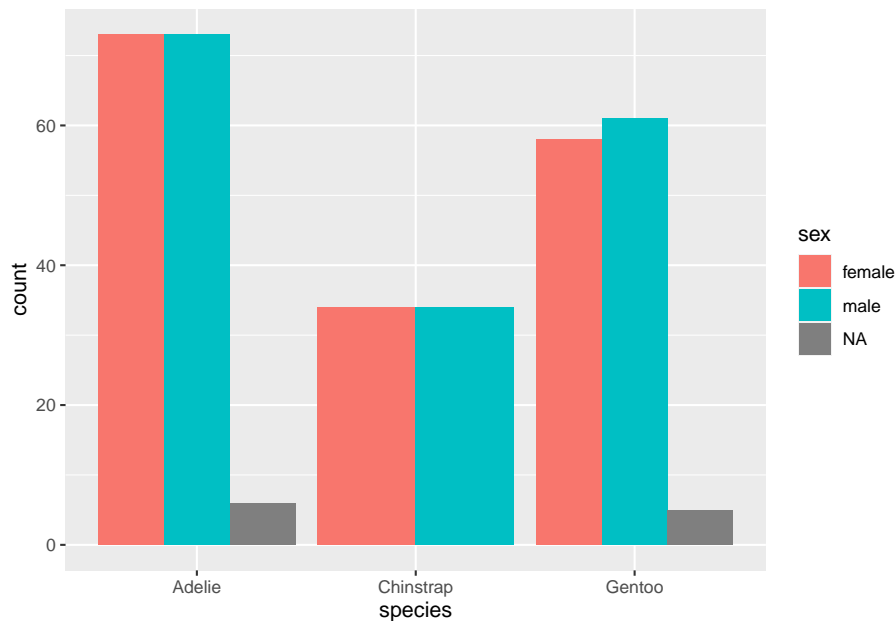
The variable name `species` is already informative, but the y-axis is labeled with “prop”. Also note that this graph could use a title. We can do all this with `labs` (for labels). Observe:

```
ggplot(penguins, aes(x = species, y = ..prop.., group = 1)) +  
  geom_bar() +  
  labs(title = "Distribution of species",  
        y = "Proportion",  
        x = "Species")
```



Exercise 11 Modify the following side-by-side bar chart by adding a title and labels for both the fill variable and the x-axis variable. (Hint: you can use `fill = sex` inside the `labs` command just like you used `title`, `y`, and `x`.)

```
# Modify the following side-by-side bar chart by adding a title and
# labels for both the x-axis and the fill variable.
ggplot(penguins, aes(fill = sex, x = species)) +
  geom_bar(position = "dodge")
```



3.10 Plotting summary data

Everything we did above was summarizing *raw data*; that is, the data consisted of all the observations for each individual penguin. Often, though, when you find data out in the wild, that data will be summarized into a table already and you may not have access to the raw data.

For example, let's suppose that you found some data online, but it looked like this:

species	count
Adelie	152
Chinstrap	68
Gentoo	124

This raises two questions:

1. How would you get this data into R?
2. How would you plot the data?

To answer the first question, we show you how to create your own tibble. Here is the syntax:

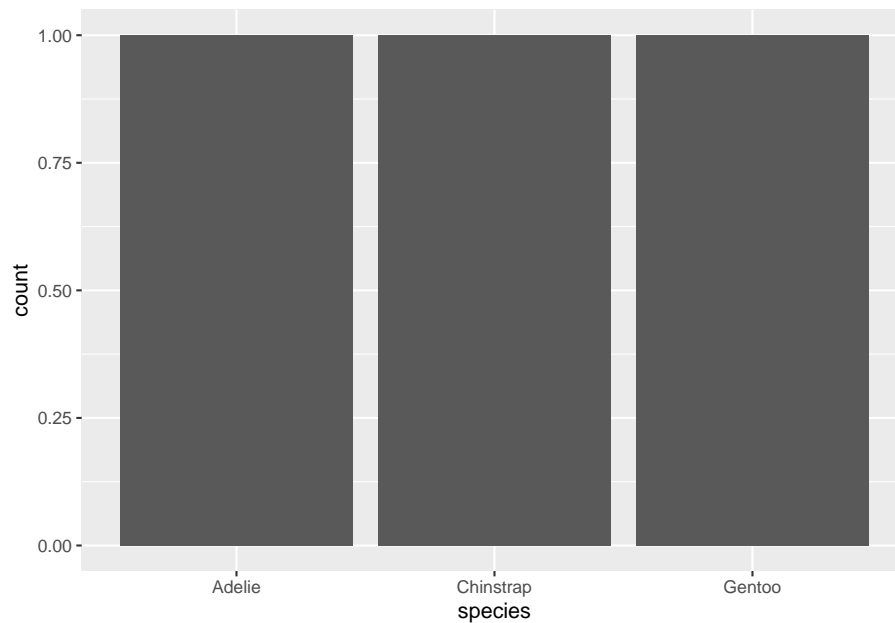
```
penguin_species_table <- tibble(  
  species = c("Adelie", "Chinstrap", "Gentoo"),  
  count = c(152, 68, 124)  
)  
penguin_species_table
```

```
## # A tibble: 3 x 2  
##   species    count  
##   <chr>     <dbl>  
## 1 Adelie     152  
## 2 Chinstrap   68  
## 3 Gentoo    124
```

Basically, the `tibble` command creates a new tibble. Then each column of data must be entered manually as a “vector” using the `c` to group all the data values together for each column. Be careful about the placement of quotation marks, commas, and parentheses.

Once we have our summary data, we want to make a bar chart. But this won’t work:

```
ggplot(penguin_species_table, aes(x = species)) +  
  geom_bar()
```

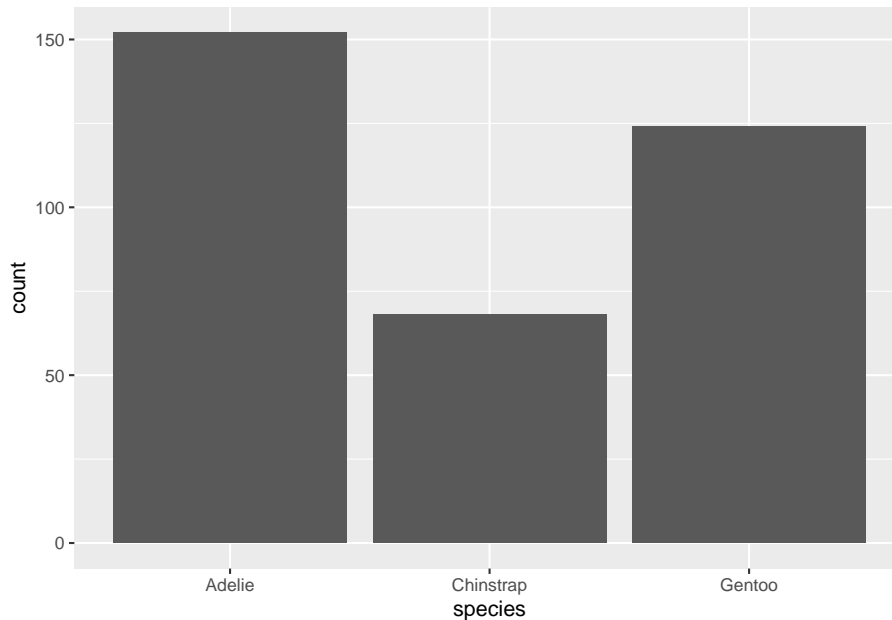


Exercise 12 Explain what went wrong with the previous command? Why does `ggplot` think that each species has count 1?

Please write up your answer here.

Instead, we need to use `geom_col`. This works a lot like `geom_bar` except that it also requires a `y` value in its aesthetics to force the command to look for the counts in some other variable in the data.

```
ggplot(penguin_species_table, aes(x = species, y = count)) +  
  geom_col()
```



Exercise 13(a) Use the `tabyl` command to create a frequency table for `island`.

```
# Add code here to create a frequency table for island
```

Exercise 13(b) Use the `tibble` command to create a new tibble manually that contains the frequency data for the `island` variable. It should have two columns, one called `island` and the other called `count`. Name it `penguin_island_table`.

```
# Add code here to create a tibble with frequency data for island
```

Exercise 13(c) Use `ggplot` with `geom_col` to create a bar chart for island.

```
# Add code here to create a bar chart for island
```

3.11 Conclusion

You can summarize a single categorical variable using a frequency table. For only one categorical variable, a graph is usually overkill, but if you really want a graph, the bar chart is the best option. Both raw counts and proportions/percentages can be useful.

We use contingency tables to summarize two categorical variables. Unless groups are of equal size, raw counts can be incredibly misleading here. You should include proportions/percentages to be able to compare the distributions across groups. If the proportions/percentages are roughly the same, the variables are more likely to be independent, whereas if the proportions/percentages are different, there may be an association between the variables. For graphing, the best choice is usually a side-by-side bar chart. A stacked bar chart will also work, especially if using relative frequencies on the y-axis, but it can be hard to compare across groups when the response variable has three or more categories.

Sometimes we come across categorical data that is recorded using numbers. Many R commands will not work properly if they expect factors and receive numbers, so we use the `mutate` command to create a new variable along with `as_factor` to convert the numbers to categories.

Sometimes we come across summary data instead of raw data. We can then manually create tibbles with that summary data and use `geom_col` instead of `geom_bar` to graph it.

3.11.1 Preparing and submitting your assignment

1. From the “Run” menu, select “Restart R and Run All Chunks”.
2. Deal with any code errors that crop up. Repeat steps 1–2 until there are no more code errors.
3. Spell check your document by clicking the icon with “ABC” and a check mark.
4. Hit the “Preview” button one last time to generate the final draft of the `.nb.html` file.
5. Proofread the HTML file carefully. If there are errors, go back and fix them, then repeat steps 1–5 again.

If you have completed this chapter as part of a statistics course, follow the directions you receive from your professor to submit your assignment.

Chapter 4

Numerical data

2.0

Functions introduced in this chapter

`mean`, `sd`, `var`, `median`, `sort`, `IQR`, `quantile`, `summary`, `min`, `max`, `geom_histogram`,
`geom_point`, `geom_boxplot`, `facet_grid`

4.1 Introduction

In this chapter, we'll learn about numerical data and how to summarize it through summary statistics and graphs.

4.1.1 Download the R notebook file

Check the upper-right corner in RStudio to make sure you're in your `intro_stats` project. Then click on the following link to download this chapter as an R notebook file (`.Rmd`).

https://vectorposse.github.io/intro_stats/chapter_downloads/04-numerical_data.Rmd

Once the file is downloaded, move it to your project folder in RStudio and open it there.

4.1.2 Restart R and run all chunks

In RStudio, select “Restart R and Run All Chunks” from the “Run” menu.

4.1.3 Load packages

We load the `tidyverse` package to get `ggplot2` and the `palmerpenguins` package to work with the penguin data.

```
library(tidyverse)
library(palmerpenguins)
```

4.2 A note about mathematical notation

From time to time, we will use mathematical notation that can't be typed directly on the keyboard. For example, let's suppose we want to typeset the quadratic formula, which involves a complicated fraction as well as a square root symbol.

When such notation appears, it will be surrounded by double dollar signs as follows:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

The R Notebook will interpret this special mathematical notation and render it on the screen as well as in the HTML document.¹ If the nicely formatted formula does not appear on your screen, place your cursor anywhere inside the math formula and hit Ctrl-Enter or Cmd-Enter (PC or Mac respectively).

Sometimes, we want such math to appear inline. We can do this with single dollar signs. For example, the distance formula is $d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$, a fact you may have learned a long time ago.

This will *not* render visually in the R Notebook, but it will show up in the HTML file. If you want to check that it worked properly without having to preview the HTML, you can either hover your cursor over the math formula and wait a second, or you can place your cursor anywhere inside the math formula and hit Ctrl-Enter or Cmd-Enter (PC or Mac respectively) to see a pop-up window previewing the mathematical content properly formatted.

You will be shown examples of any mathematical notation you need to use in any given chapter, so feel free to copy/paste/modify any math notation you need.

¹This notation is part of a mathematical document preparation system called LaTeX, pronounced “Lay-tek” (not like the rubbery substance).

4.3 Statistics

The word “statistics” has several meanings. On one hand, it’s an entire field of study, as in the subject of this course. More specifically, though, a “statistic” is any kind of numerical summary of data. While there are many ways to summarize data, they mostly fall into two main flavors: measures of *center* and measures of *spread*. Measures of center try to estimate some kind of average, middle, or common value in data. Measures of spread try to estimate something like the width, range, variability, or uncertainty of data.

There are two pairs of measurements that we will learn about in this chapter: the mean/standard deviation, and the median/IQR.

4.3.1 Mean and standard deviation

The first pair of the summary statistics we’ll discuss consists of the mean and the standard deviation.

The *mean* of a variable y —denoted \bar{y} and pronounced “y bar”—is calculated by summing all the values of the variable, and dividing by the total number of observations. In formula form, this is

$$\bar{y} = \frac{\sum y}{n}.$$

This is a measure of center since it estimates the “middle” of a set of numbers. It is calculated in R using the `mean` command.

Throughout this chapter, we will be using the `penguins` data set. (If you need a reminder, look at the help file for `penguins` using one of the methods discussed in Chapter 2.)

If we want to calculate the mean body mass of our penguins (in grams), we type the following:

```
mean(penguins$body_mass_g)
```

```
## [1] NA
```

Unfortunately, this didn’t give us an answer. As you may recall from previous chapters, this is because we are missing several values of body mass in this data. We need an extra piece of code to tell R to ignore that missing data and give us the mean of the valid data.

```
mean(penguins$body_mass_g, na.rm = TRUE)
```

```
## [1] 4201.754
```

(The term `na.rm` stands for “NA remove”).

We never leave such numbers without interpretation. In a full, contextually meaningful sentence, we might say, “The mean body mass of this group of penguins is approximately 4200 grams.”

Notice that we mentioned the penguins, placing this number in context, and we mentioned the units of measurement, grams. (Otherwise, what would this number mean? 4200 pounds? Okay, probably not, but you should always mention the units of measurement.) Also notice that we rounded the final value. A gram is a very small unit of measurement, so there is no need to report this value to many decimal places.

If we use inline code, we can say, “The mean body mass of this group of penguins is 4201.754386 grams.” There are ways of rounding this number as well, but it’s a bit of a hassle to do so in inline code.

The corresponding measure of spread is the *standard deviation*. Usually this is called s and is calculated using a much more complicated formula:

$$s = \sqrt{\frac{\sum (y - \bar{y})^2}{n - 1}}.$$

This is a measure of spread because the $(y - \bar{y})$ term measures the how far away each data point is from the mean.

In R, this is calculated with the `sd` command. Again, we’ll need to add `na.rm = TRUE`.

```
sd(penguins$body_mass_g, na.rm = TRUE)
```

```
## [1] 801.9545
```

“The standard deviation of this group of penguins is about 801 grams.”

Or using inline code:

“The standard deviation of this group of penguins is 801.9545357 grams.”

The mean and the standard deviation should always be reported together. One without the other is incomplete and potentially misleading.

Another related measurement is the *variance*, but this is nothing more than the standard deviation squared:

$$s^2 = \frac{\sum (y - \bar{y})^2}{n - 1}.$$

(Compare this formula to the one for the standard deviation. Nothing has changed except for the removal of the square root.) We rarely use the variance in an introductory stats class because it's not as interpretable as the standard deviation. The main reason for this is units. If the data units are grams, then both the mean and the standard deviation are also reported in grams. The variance has units of “grams squared”, but what does that even mean? If you need to calculate the variance in R, the command is `var`.

```
var(penguins$body_mass_g, na.rm = TRUE)
```

```
## [1] 643131.1
```

You can check and see that the number above really is just 801.9545357 squared. Regarding the inline code in the previous sentence, remember, in the R Notebook, you can click inside the inline code and hit Ctrl-Enter or Cmd-Enter. In the HTML document, the number will be calculated and will magically appear.

4.3.2 Median and IQR

Another choice for measuring the center and spread of a data set is the median and the IQR.

The median is just the middle value if the list of values is ordered. In R, it is calculated using the `median` command.

```
median(penguins$body_mass_g, na.rm = TRUE)
```

```
## [1] 4050
```

The median body mass of these penguins is 4050 grams.

The median value depends on whether there are an even or odd number of data points. If there are an odd number, there is a middle value in the list. Convince yourself this is true; for example, look at the numbers 1 through 7.

```
1:7
```

```
## [1] 1 2 3 4 5 6 7
```

The number 4 is in the middle of the list, with three numbers to either side.

However, if there are an even number of data points, there is no number right in the middle:

```
1:8
```

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

The “midpoint” of this list would lie between 4 and 5. If this is the case, we calculate the median by taking the mean of the two numbers straddling the middle. In the case of 1 through 8 above, the median would be 4.5.

Let’s print out the entire `body_mass_g` variable, all 342 valid values (not including the missing values, of course). If we’re clever about it, we can see them in order using the `sort` command.

```
sort(penguins$body_mass_g)
```

```
## [1] 2700 2850 2850 2900 2900 2900 2900 2925 2975 3000 3000 3050 3050 3050 3050
## [16] 3075 3100 3150 3150 3150 3150 3175 3175 3200 3200 3200 3200 3200 3250 3250
## [31] 3250 3250 3250 3275 3300 3300 3300 3300 3300 3300 3325 3325 3325 3325 3325
## [46] 3350 3350 3350 3350 3350 3400 3400 3400 3400 3400 3400 3400 3400 3425 3425
## [61] 3450 3450 3450 3450 3450 3450 3450 3450 3475 3475 3475 3500 3500 3500 3500
## [76] 3500 3500 3500 3525 3525 3550 3550 3550 3550 3550 3550 3550 3550 3575
## [91] 3600 3600 3600 3600 3600 3600 3600 3625 3650 3650 3650 3650 3650 3650 3675
## [106] 3675 3700 3700 3700 3700 3700 3700 3700 3700 3700 3700 3700 3725 3725 3725
## [121] 3750 3750 3750 3750 3750 3775 3775 3775 3775 3800 3800 3800 3800 3800 3800
## [136] 3800 3800 3800 3800 3800 3800 3825 3850 3875 3900 3900 3900 3900 3900 3900
## [151] 3900 3900 3900 3900 3950 3950 3950 3950 3950 3950 3950 3950 3950 3975
## [166] 4000 4000 4000 4000 4000 4050 4050 4050 4050 4050 4050 4075 4100 4100 4100
## [181] 4100 4100 4150 4150 4150 4150 4150 4150 4200 4200 4200 4200 4200 4250 4250
## [196] 4250 4250 4250 4275 4300 4300 4300 4300 4300 4300 4300 4300 4350 4350 4375
## [211] 4400 4400 4400 4400 4400 4400 4400 4400 4450 4450 4450 4450 4450 4475 4500
## [226] 4500 4500 4550 4550 4575 4600 4600 4600 4600 4600 4625 4625 4650 4650 4650
## [241] 4650 4650 4675 4700 4700 4700 4700 4700 4700 4725 4725 4725 4750 4750 4750
## [256] 4750 4750 4775 4800 4800 4800 4850 4850 4850 4850 4875 4875 4875 4900 4900
## [271] 4925 4925 4950 4950 4975 5000 5000 5000 5000 5000 5000 5050 5050 5050 5100
## [286] 5100 5100 5150 5150 5200 5200 5200 5200 5250 5250 5250 5300 5300 5300 5300
## [301] 5350 5350 5350 5400 5400 5400 5400 5400 5450 5500 5500 5500 5500 5500 5550
## [316] 5550 5550 5550 5550 5550 5600 5600 5650 5650 5650 5700 5700 5700 5700 5700
## [331] 5750 5800 5800 5850 5850 5850 5950 5950 6000 6000 6050 6300
```

4.3.2.0.1 Exercise 1 If there are 342 penguins in this data set with body mass data, between which two values in the list above would the median lie? In

other words, between what two positions in the list will the median be found? Verify that the median you find from this list is the same as the one we calculated with the `median` command above.

Please write up your answer here.

Calculating the *interquartile range*—or *IQR*—requires first the calculation of the first and third quartiles, denoted $Q1$ and $Q3$. If the median is the 50% mark in the sorted data, the first and third quartiles are the 25% and the 75% marks, respectively. One way to compute these by hand is to calculate the median of the lower and upper halves of the data separately. Then again, it's hard to know how to split the data set into halves if there are an odd number of observations. There are many different methods for computing percentiles in general, but you don't need to worry too much about the particular implementation in R. Once you have $Q1$ and $Q3$, the IQR is just

$$IQR = Q3 - Q1$$

In R, you can get the IQR by using—are you ready for this?—the `IQR` command.

```
IQR(penguins$body_mass_g, na.rm = TRUE)
```

```
## [1] 1200
```

The IQR for this group of penguins is 1200 grams.

The IQR is a measure of spread because the distance between $Q1$ and $Q3$ measures the span of the “middle 50%” of the data.

A general function for computing any percentile in R is the `quantile` function. For example, since $Q1$ is the 25th percentile, you can compute it as follows:

```
Q1 <- quantile(penguins$body_mass_g, 0.25, na.rm = TRUE)
Q1
```

```
## 25%
## 3550
```

The 25% label is cute, but somewhat unnecessary, and it will mess up a later command, so let's get rid of it:

```
Q1 <- unname(Q1)
Q1
```

```
## [1] 3550
```

4.3.2.0.2 Exercise 2(a) Now you compute Q3.

```
# Add code here to compute, store, and print out Q3
```

4.3.2.0.3 Exercise 2(b) Reassign Q3 using the `unname` command as we did above to strip the unnecessary label.

```
# Add code here that uses the unname command
```

4.3.2.0.4 Exercise 2(c) Finally, check that the IQR calculated above matches the value you get from subtracting Q3 minus Q1.

```
# Add code here to compute Q3 - Q1.
```

The median and the IQR should always be reported together.

Also, don't mix and match. For example, it doesn't really make sense to report the mean and the IQR. Nor should you report the median and the standard deviation. They go together in pairs: either the mean and the standard deviation together, or the median and the IQR together.

4.3.3 Robust statistics

Some statistics are more sensitive than others to features of the data. For example, outliers are data points that are far away from the bulk of the data. The mean and especially the standard deviation can change a lot when outliers are present. Also, skewness in the data frequently pulls the mean too far in the direction of the skew while simultaneously inflating the standard deviation. (We'll learn more about skewed data later in this chapter.)

On the other hand, the median and IQR are “robust”, meaning that they do not change much (or at all) in the presence of outliers and they tend to be good summaries even for skewed data.

4.3.3.0.1 Exercise 3 Explain why the median and IQR are robust. In other words, why does an outlier have little or no influence on the median and IQR? Please write up your answer here.

4.3.4 Five-number summary

A *five-number summary* is the minimum, Q1, median, Q3, and maximum of a set of numbers.

The `summary` command in R gives you the five-number summary, and throws in the mean for good measure. (Note that it does not require `na.rm = TRUE`!)

```
summary(penguins$body_mass_g)
```

```
##      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.     NA's
##      2700   3550   4050   4202   4750   6300         2
```

You can, of course, isolate the various pieces of this. You already know most of the commands below. (These individual commands all do require `na.rm = TRUE`.)

```
min(penguins$body_mass_g, na.rm = TRUE)
```

```
## [1] 2700
```

```
median(penguins$body_mass_g, na.rm = TRUE)
```

```
## [1] 4050
```

```
max(penguins$body_mass_g, na.rm = TRUE)
```

```
## [1] 6300
```

Remember the `quantile` function from earlier, where we computed Q1? We're going to use it in a new way. Instead of what we did earlier,

```
quantile(penguins$body_mass_g, 0.25, na.rm = TRUE),
```

what about this instead?

```
quantile(penguins$body_mass_g, na.rm = TRUE)
```

```
##   0%  25%  50%  75% 100%
## 2700 3550 4050 4750 6300
```

4.3.4.0.1 Exercise 4 What is the difference between the way `quantile` was used in a previous exercise versus the way it was used here? How did that change the output?

Please write up your answer here.

Also, don't forget about the trick for using R commands inline. If you need to mention a statistic in the middle of a sentence, there is no need to break the sentence and display a code chunk. Be sure you're looking at the R notebook file (not the HTML file) to note that the numbers in the next sentence are not manually entered, but are calculated on the fly:

There are 344 penguins in this data set and their median body mass is 4050 grams.

4.3.4.0.2 Exercise 5 Type a full, contextually meaningful sentence using inline R code (as above, but changing the commands) reporting the minimum and maximum body mass (in grams) in our data set.

Please write up your answer here.

4.4 Graphing one numerical variable

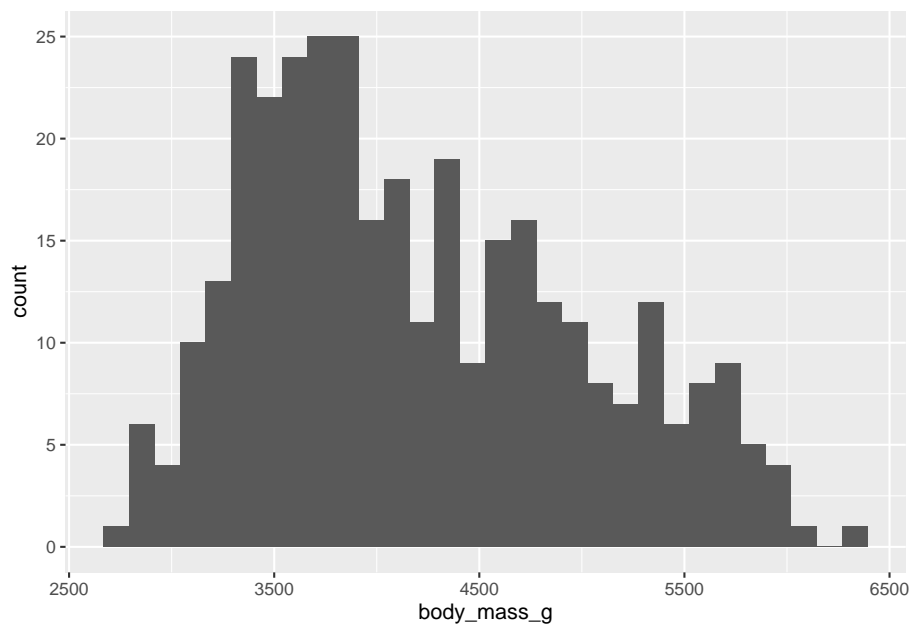
From the `penguins` data, let's consider again the body mass in grams. This is clearly a numerical variable.

The single most useful display of a single numerical variable is a histogram. Here is the `ggplot` command to do that:

```
ggplot(penguins, aes(x = body_mass_g)) +
  geom_histogram()
```

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

```
## Warning: Removed 2 rows containing non-finite values (stat_bin).
```



4.4.1 The shape of data

The way histograms work is to create “bins”, which are ranges of numbers along the x-axis. R goes through the data and counts how many observations fall into each bin. In that way, a histogram is somewhat like a bar chart. However, a bar chart uses bars to represent distinct, discrete categories, whereas a histogram uses bars that are all next to each other to represent values along a continuous numerical range. Histograms are meant to give you—at a quick glance—a sense of the “shape” of the data.

What do we mean by “shape”? Generally, we look for three things:

1. Modes

- Modes are peaks in the data. These are places where data tends to cluster, representing common values of the numerical variable. In the **penguin** data, there appears to be a big mode between about 3500 and 4000 grams. When data has one clear mode, we call the data *unimodal*. But data can also be *bimodal*, or more generally, *multimodal*. This often happens when the data contains multiple groups that are different from each other. In this case, we know there are three species of penguin in the data, so if those species are drastically different in their body mass, we might be looking at multimodal data. We’ll explore this question more later in the chapter. For now, it’s hard to say what’s going on because the above histogram has

a lot of spiky bars popping up all over. It's not completely obvious how many modes there might be.

2. Symmetry

- If there is one mode, we can also ask if the data is spread evenly to the left and right of that mode. If so, we call the data *symmetric*. No data is perfectly symmetric, but we are looking for overall balance between the areas to the left and right of the mode. When data is not symmetric, we call it *skewed*. Assuming that there is one big mode around 3500 or 4000, the body mass data above is skewed. There is clearly more data above the mode than below the mode. The right side of the histogram stretches out further to the right of the mode than to the left. Therefore, the body mass data is *right-skewed*. There is a longer “tail” to the right. If it were the opposite, it would be *left-skewed*. It is common for beginning students to confuse these two terms. Be aware that we are not concerned about where the mode is. We want to know which side has more data spread into a longer tail. That is the direction of the skewness.

3. Outliers.

- Outliers are data points that are far from the bulk of the data. The body mass data above appears to have no outliers. We are looking for a large gap between the main “mass” of data and any lingering data points far away from that mass. There is no such large gap in the histogram above.

Whenever you are asked about the “shape” of a numerical variable, be sure to comment on (1) modes, (2) symmetry, and (3) outliers.

Generally, the default binning for `ggplot` histograms is not great. This is by design. The creator of the `ggplot2` package, Hadley Wickham, said the following:

“In `ggplot2`, a very simple heuristic is used for the default number of bins: it uses 30, regardless of the data. This is perverse, and ignores all of the research on selecting good bin sizes automatically, but sends a clear message to the user that he or she needs to think about, and experiment with, the bin width. This message is reinforced with a warning that reminds the user to manually adjust the bin width.”

Indeed, if you look at the output from the graphing command above, you can see that `ggplot` informs you that you should pick a better value for the binwidth. You can also see that the bins aren't ideal. They are too narrow, which means that arbitrary differences between bins show up as “random” spikes all over the graph. These spikes can confuse the issue of how many modes appear in the data.

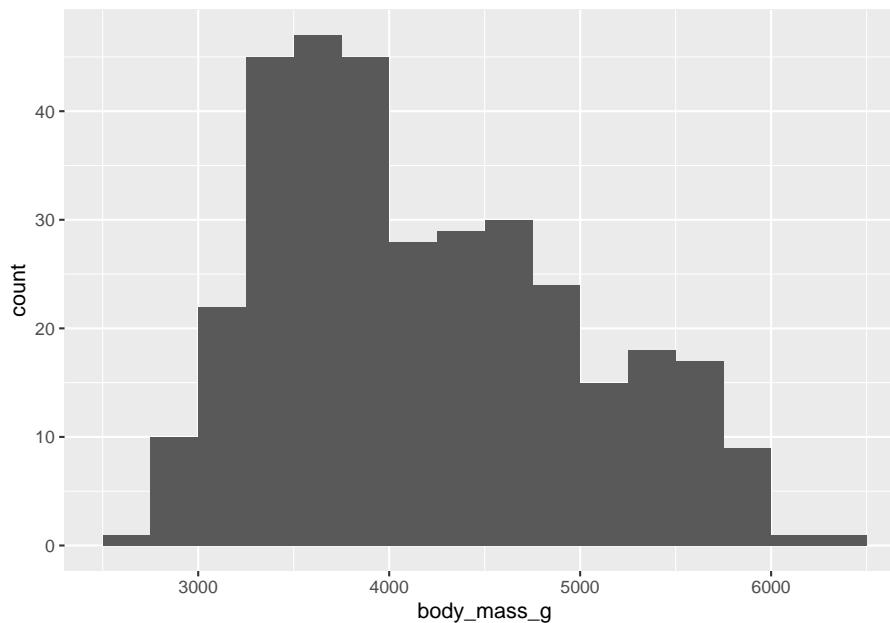
Instead, we should aim to use bins that show the overall shape of the data and smooth it out a bit. Look back at the scale of the x-axis to assess how wide each bar should be. There's no one correct answer. In this case, the bins ought to be a little wider. Since our x-axis goes from about 2500 to 6500, maybe we should try a binwidth of 250. And if 250 doesn't look good, nothing prevents us from trying a different number.

It's also easier to interpret the histogram when the bins' edges line up with numbers that are easy to see in the plot. Use **boundary** to determine where you want the bin boundaries to fall. For example, if we set the boundary to 3500, that means that one bar will start with its left edge at 3500. This is convenient because there is a tick mark labeled there on the x-axis. The boundary number is pretty arbitrary; once one boundary is set, it determines where all the other bins will line up. With a binwidth of 250, we'd get the same graph if the boundary were set to 3000 or 3250 or 5750, or even 0. Any other multiple of 250 would give the same graph.

We use **binwidth** and **boundary** inside the parentheses of the **geom_histogram** to modify these parameters.

```
ggplot(penguins, aes(x = body_mass_g)) +  
  geom_histogram(binwidth = 250, boundary = 3500)
```

```
## Warning: Removed 2 rows containing non-finite values (stat_bin).
```

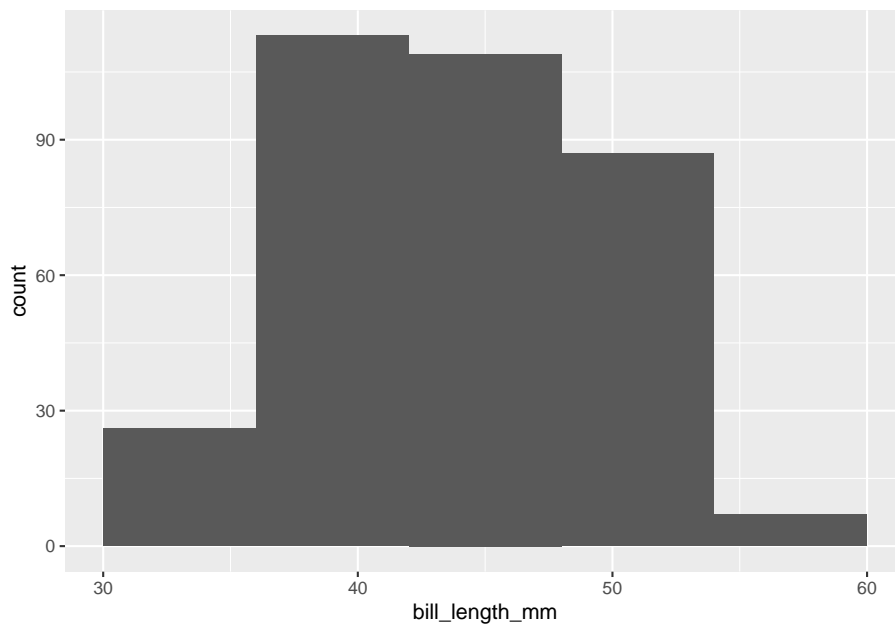


Even with the smoother look, it appears that there are multiple modes, maybe three? Do these correspond to the three species of penguin? Stay tuned.

4.4.1.0.1 Exercise 6(a) Here is a histogram of the penguin bill lengths (measured in millimeters):

```
ggplot(penguins, aes(x = bill_length_mm)) +  
  geom_histogram(binwidth = 6, boundary = 30)
```

```
## Warning: Removed 2 rows containing non-finite values (stat_bin).
```



Write a short paragraph describing the shape of the distribution of penguin bill lengths, focusing on the three key shape features (modes, symmetry, and outliers).

Please write up your answer here.

4.4.1.0.2 Exercise 6(b) The last question was a trick question!

Change the binwidth (no need to change the boundary) to something smaller to see more clearly the bimodal nature of the distribution.


```
# Add code here that changes the binwidth of the last histogram to see  
# the bimodal nature of the distribution.
```

4.4.1.0.3 Exercise 7(a) Make a histogram of the variable `flipper_length_mm`. Start with a histogram where you don't modify the binwidth or boundary.

```
# Add code here to create a histogram of flipper length
```

4.4.1.0.4 Exercise 7(b) By examining the scale on the x-axis above, repeat the command, but this time change the binwidth and the boundary until you are satisfied that the bins are neither too wide nor too narrow.

```
# Add code here to modify the histogram of flipper length,  
# adding binwidth and boundary
```

4.4.1.0.5 Exercise 7(c) Write a short paragraph describing the shape of the distribution of penguin flipper lengths, focusing on the three key shape features (modes, symmetry, and outliers).

Please write up your answer here.

4.4.2 Less useful plot types

There are several other graph types that one might see for a single numerical variable: e.g., dotplots, stem-and-leaf plots, boxplots, etc. I'm not a big fan of dotplots or stem-and-leaf plots as they are just messier versions of histograms. I do like boxplots, but they are typically less informative than histograms. Boxplots are much better for comparing groups, and we'll see them later in the chapter.

4.5 Graphing two numerical variables

The proper graph for two numerical variables is a scatterplot. We graph the response variable on the y-axis and the predictor variable on the x-axis.

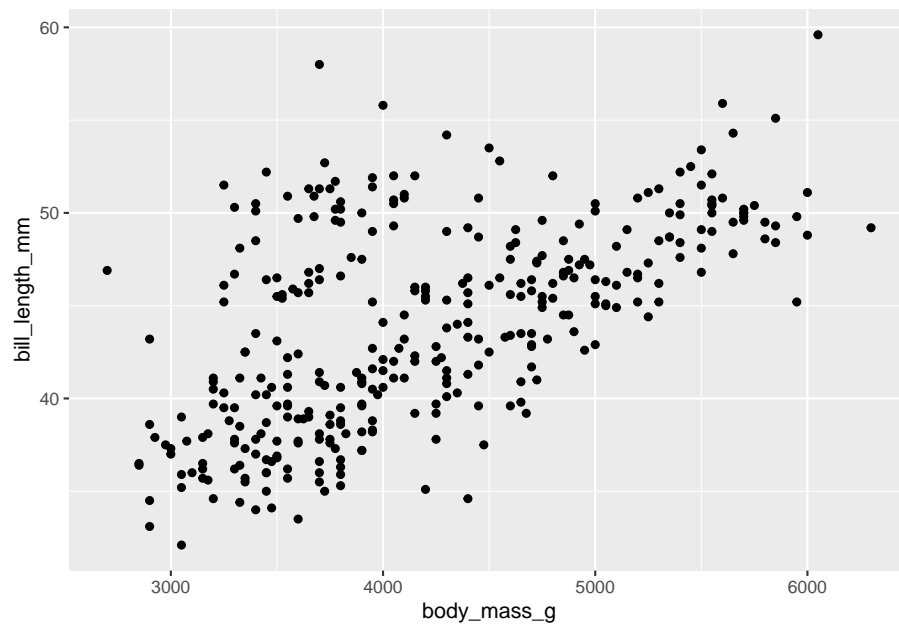
Let's consider a possible association between bill length and body mass. For this question, there is not really a strong preference for which variable serves as response and which variable serves as predictor. We'll consider bill length as the response variable and body mass as the predictor.

Since we are plotting two variables, we have two aesthetics, one on the y-axis (the response variable) and one on the x-axis (the predictor variable). Since

scatterplots use points to plot each data value, the correct layer to add is `geom_point()`.

```
ggplot(penguins, aes(y = bill_length_mm, x = body_mass_g)) +  
  geom_point()
```

```
## Warning: Removed 2 rows containing missing values (geom_point).
```



We are looking for evidence of a relationship between the two variables. This will manifest as a pattern in the data. We are interested in answering the following questions:

1. Linearity

- Is the association linear? In other words, do the data points lie roughly in a straight line pattern? The scatterplot above is a bit “cloudy” but generally moves from lower left to upper right in a straight (not curved pattern). It’s not a completely random scatter of dots.

2. Direction

- If the pattern is linear, it is a *positive* relationship or a *negative* one? Positive means that the line moves from lower left to upper right. Negative

means it moves from upper left to lower right. If you recall the direction of slopes from high school algebra class, a positive association corresponds to a line with a positive slope, and similarly for a negative association. In the data above, lower values of body mass correspond to lower bill lengths, and higher values of body mass correspond to higher bill lengths. So this is a positive association.

3. Strength

- If there is a pattern, how tight is the pattern? Do the data points stay close to a straight line, or are they pretty spread out and only generally moving in one direction. A strong relationship is one that is tightly packed around a line or curve. The relationship above is not strong. We might use terms like “weak”, “moderately weak”, or “moderate”, but definitely not strong.

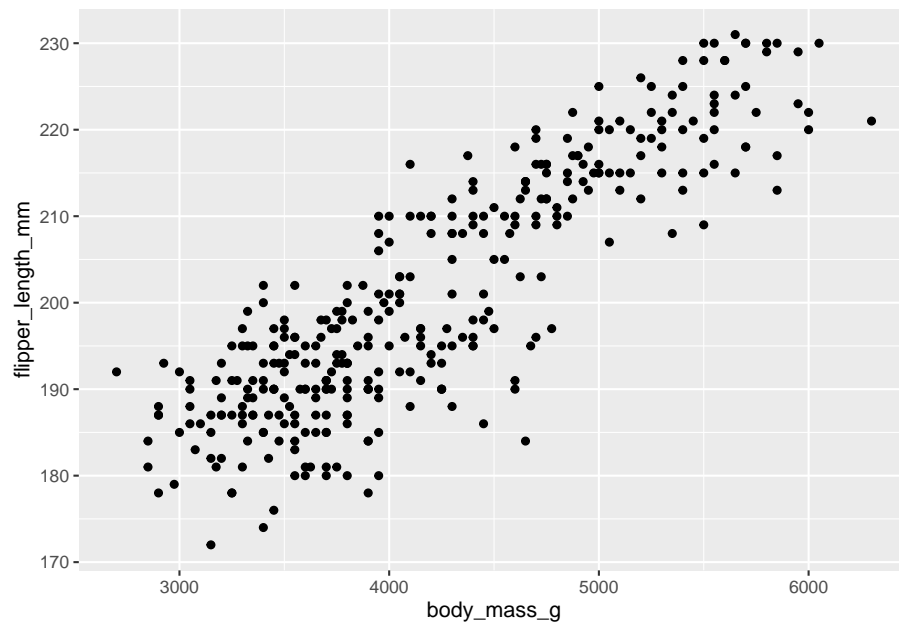
4. Outliers

- Are there outliers? These will be points that are isolated and relatively far from the bulk of the data. There are a few points above that are borderline, but none is a particularly strong outlier, especially give how spread out the rest of the data is.

4.5.0.0.1 Exercise 8 Here is a scatterplot of

```
ggplot(penguins, aes(y = flipper_length_mm, x = body_mass_g)) +  
  geom_point()
```

```
## Warning: Removed 2 rows containing missing values (geom_point).
```



Write a short paragraph describing the association of penguin flipper lengths and body mass, focusing on the four key features (linearity, direction, strength, and outliers).

Please write up your answer here.

4.6 Graphing grouped numerical data

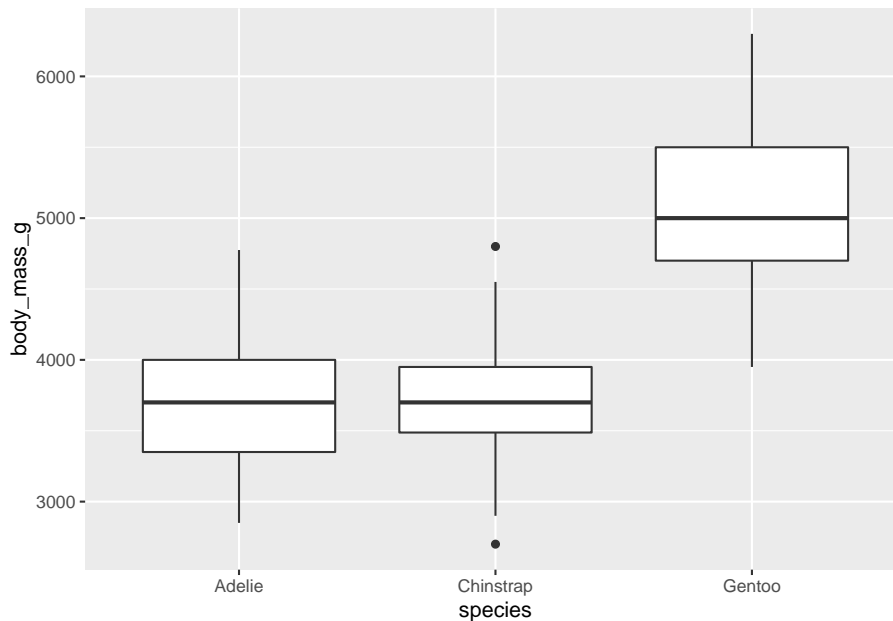
Suppose you want to analyze one numerical variable and one categorical variable. Usually, the idea here is that the categorical variable divides up the data into groups and you are interested in understanding the numerical variable for each group separately. Another way to say this is that your numerical variable is response and your categorical variable is predictor. (It is also possible for a categorical variable to be response and a numerical variable to be predictor. This is common in so-called “classification” problems. We will not cover this possibility in this course, but it is covered in more advanced courses.)

This turns out to be exactly what we need in the penguins data. Throughout the above exercises, there was a concern that the penguin measurements are fundamentally different among three different species of penguin.

Graphically, there are two good options here. The first is a side-by-side boxplot.

```
ggplot(penguins, aes(y = body_mass_g, x = species)) +  
  geom_boxplot()
```

```
## Warning: Removed 2 rows containing non-finite values (stat_boxplot).
```



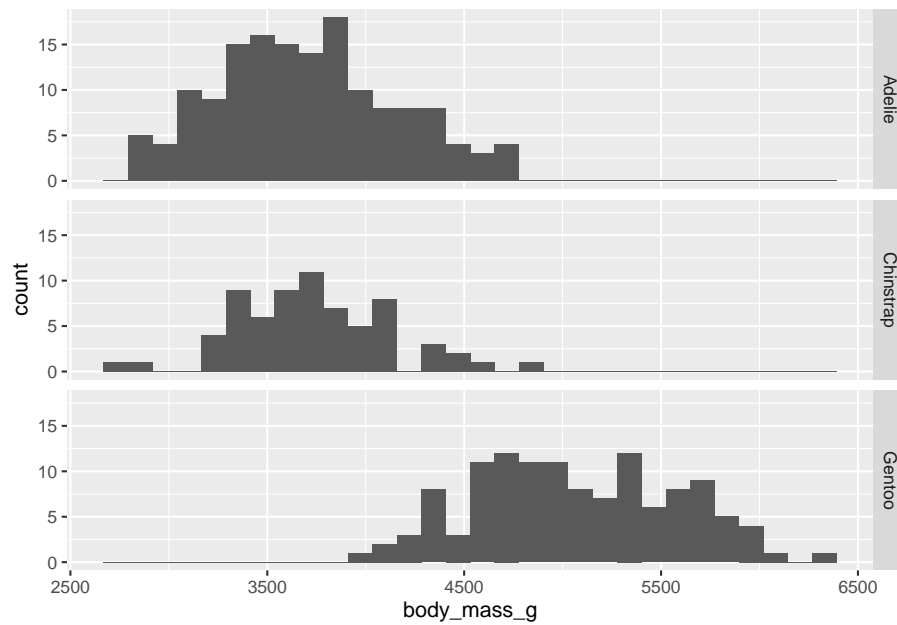
Notice the placement of the variables. The y-axis is `body_mass_g`, the numerical variable. The x-axis variable is `species`; the groups are placed along the x-axis. This is consistent with other graph types that place the response variable on the y-axis and the predictor variable on the x-axis.

The other possible graph is a stacked histogram. This uses a feature called “faceting” that creates a different plot for each group. The syntax is a little unusual.

```
ggplot(penguins, aes(x = body_mass_g)) +
  geom_histogram() +
  facet_grid(species ~ .)
```

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

```
## Warning: Removed 2 rows containing non-finite values (stat_bin).
```

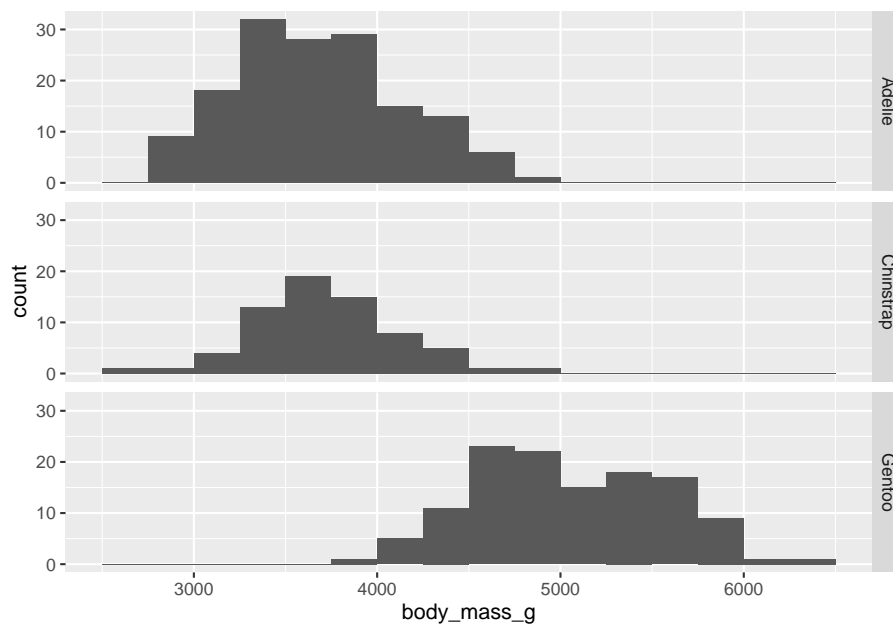


The argument `species ~ .` in the `facet_grid` function means, “Put each species on a different row.” We’ll explore this notation a little later.

As always, the default bins suck, so let’s change them.

```
ggplot(penguins, aes(x = body_mass_g)) +
  geom_histogram(binwidth = 250, boundary = 3500) +
  facet_grid(species ~ .)
```

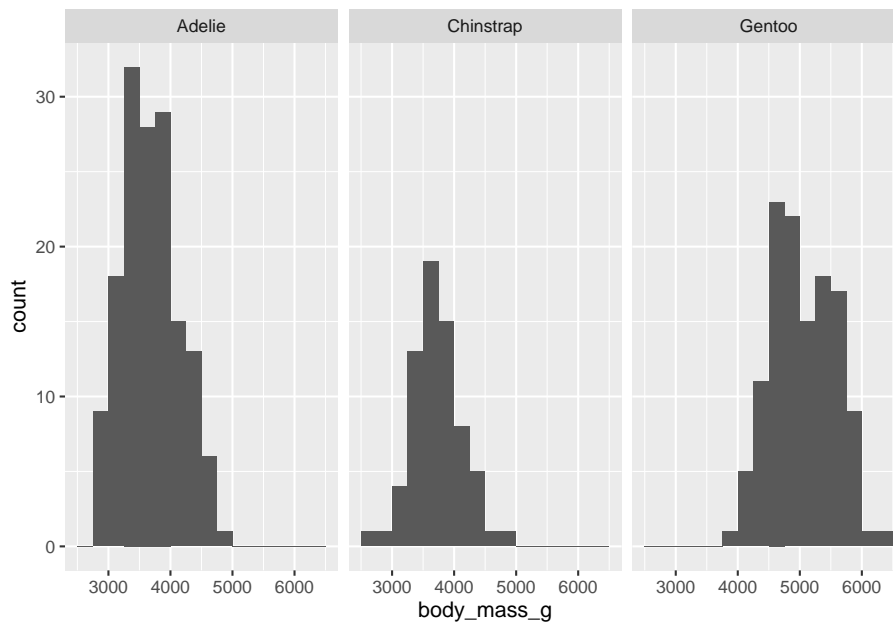
```
## Warning: Removed 2 rows containing non-finite values (stat_bin).
```



Consider the following subtle change in notation:

```
ggplot(penguins, aes(x = body_mass_g)) +  
  geom_histogram(binwidth = 250, boundary = 3500) +  
  facet_grid(. ~ species)
```

```
## Warning: Removed 2 rows containing non-finite values (stat_bin).
```



4.6.0.0.1 Exercise 9(a) Explain why that last graph (which might be called a side-by-side histogram) is less effective than the earlier stacked histogram. (Hint: what stays lined up when the histograms are stacked vertically rather than horizontally?)

Please write up your answer here.

4.6.0.0.2 Exercise 9(b) Can you figure out what's going on with the weird syntax of `species ~ .` vs `. ~ species`? Explain it in your own words.

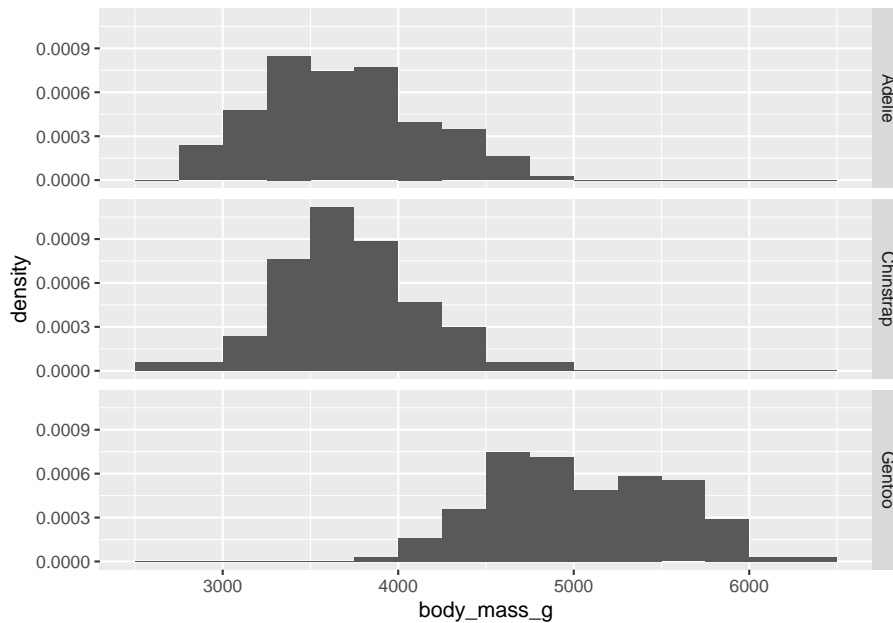
Please write up your answer here.

The other thing that kind of sucks is the fact that the y-axis is showing counts. That makes it harder to see the distribution of body mass among Chinstrap penguins, for example, as there are fewer of them in the data set. It would be nice to scale these using percentages.

```
ggplot(penguins, aes(x = body_mass_g)) +
  geom_histogram(aes(y = ..density..),
                 binwidth = 250, boundary = 3500) +
  facet_grid(species ~ .)
```



```
## Warning: Removed 2 rows containing non-finite values (stat_bin).
```



Due to some technical issues in `ggplot2`, these are not strictly proportions. (If you were to add up the heights of all the bars, they would not add up to 100%.) Nevertheless, the graph is still useful because it does scale the groups to put them on equal footing. In other words, it treats each group as if they all had the same sample size.

4.6.0.0.3 Exercise 10 Choose a numerical variable that's not body mass and a categorical variable that's not species from the `penguins` data set. Make both a side-by-side boxplot and a stacked histogram. Discuss the resulting graphs. Comment on the association (or independence) of the two variables. If there is an association, be sure to focus on the four key features (linearity, direction, strength, and outliers).

```
# Add code here to create a side-by-side boxplot.
```

```
# Add code here to create a stacked histogram.
```

Please write up your answer here.

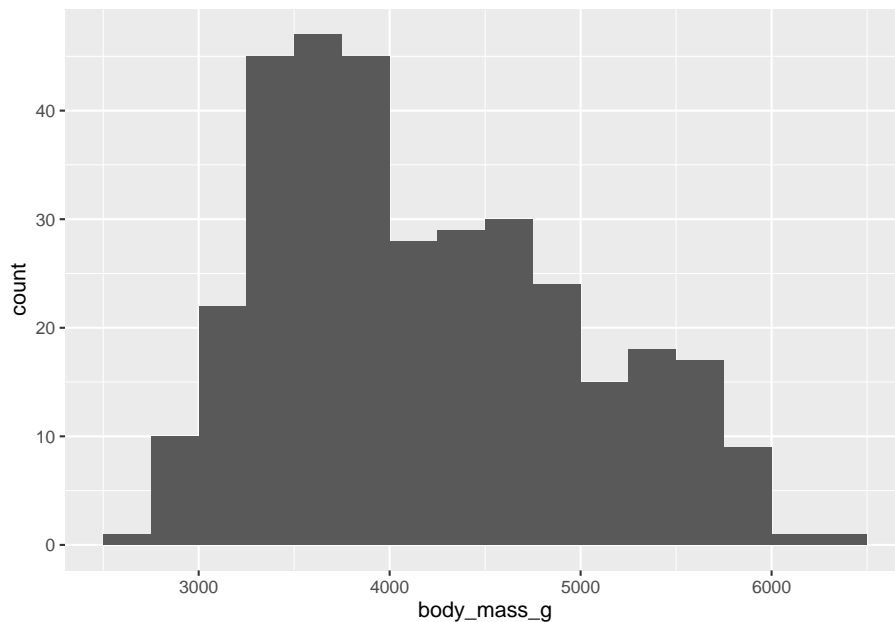
4.7 Publication-ready graphics

The great thing about `ggplot2` graphics is that they are already quite pretty. To take them from exploratory data analysis to the next level, there are a few things we can do to tidy them up.

Let's go back to the first histogram from this chapter.

```
ggplot(penguins, aes(x = body_mass_g)) +  
  geom_histogram(binwidth = 250, boundary = 3500)
```

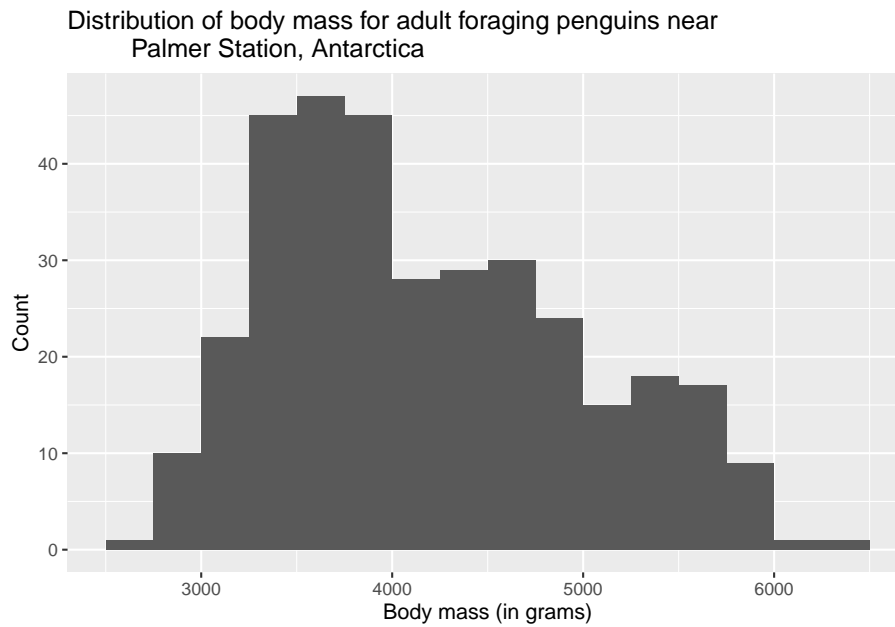
```
## Warning: Removed 2 rows containing non-finite values (stat_bin).
```



The variable names of this data set are already pretty informative, but we can do a little better with `labs` (for labels). Observe:

```
ggplot(penguins, aes(x = body_mass_g)) +  
  geom_histogram(binwidth = 250, boundary = 3500) +  
  labs(title = "Distribution of body mass for adult foraging penguins near  
         Palmer Station, Antarctica",  
        x = "Body mass (in grams)",  
        y = "Count")
```

```
## Warning: Removed 2 rows containing non-finite values (stat_bin).
```

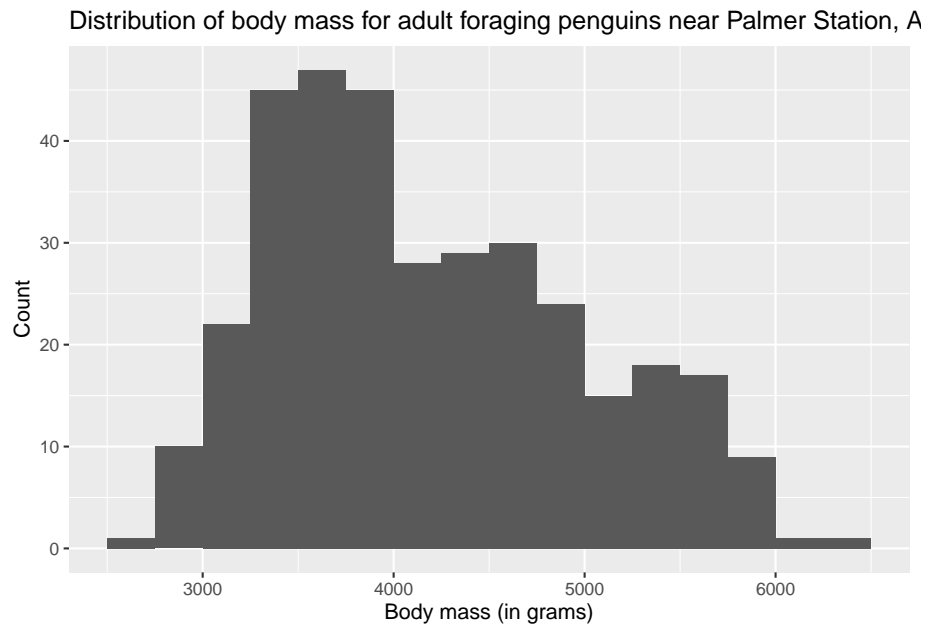


You can also see that we took the opportunity to mention the units of measurement (grams) for our variable in the x-axis label. This is good practice.

A quick note about formatting in R code chunks. Notice that I put different parts of the last `ggplot` command on their own separate lines. The command would still work if I did this:

```
ggplot(penguins, aes(x = body_mass_g)) + geom_histogram(binwidth = 250, boundary = 3500) + labs(t
```

```
## Warning: Removed 2 rows containing non-finite values (stat_bin).
```

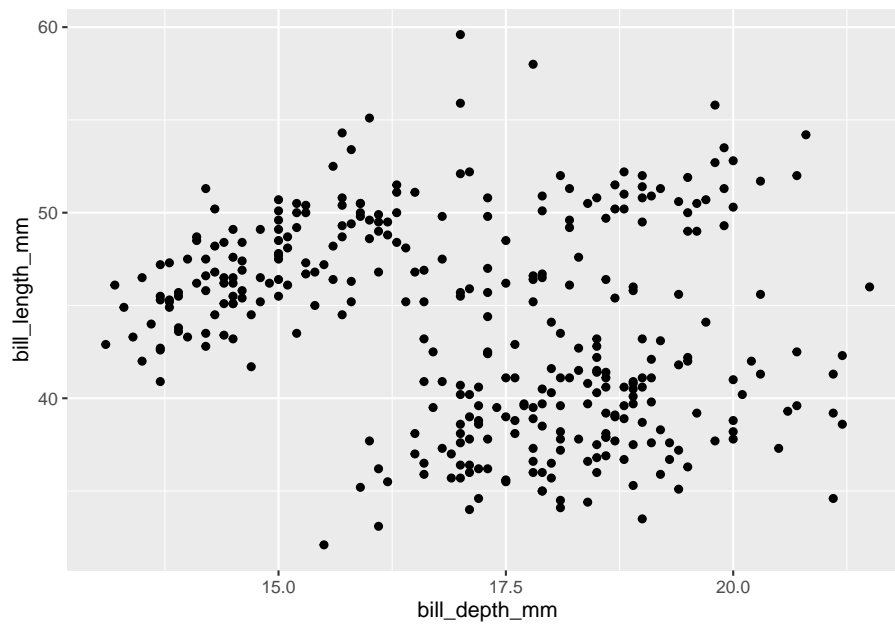


But it's much harder to read. If you find that your code is “wrapping” to the next line, find some spots like commas or plus signs to break the code. Be sure to break the line after the comma or plus sign.

4.7.0.0.1 Exercise 11 Modify the following scatterplot by adding a title and labels for both the y-axis and x-axis.

```
# Modify the following scatterplot by adding a title and
# labels for both the y-axis and x-axis.
ggplot(penguins, aes(y = bill_length_mm, x = bill_depth_mm)) +
  geom_point()
```

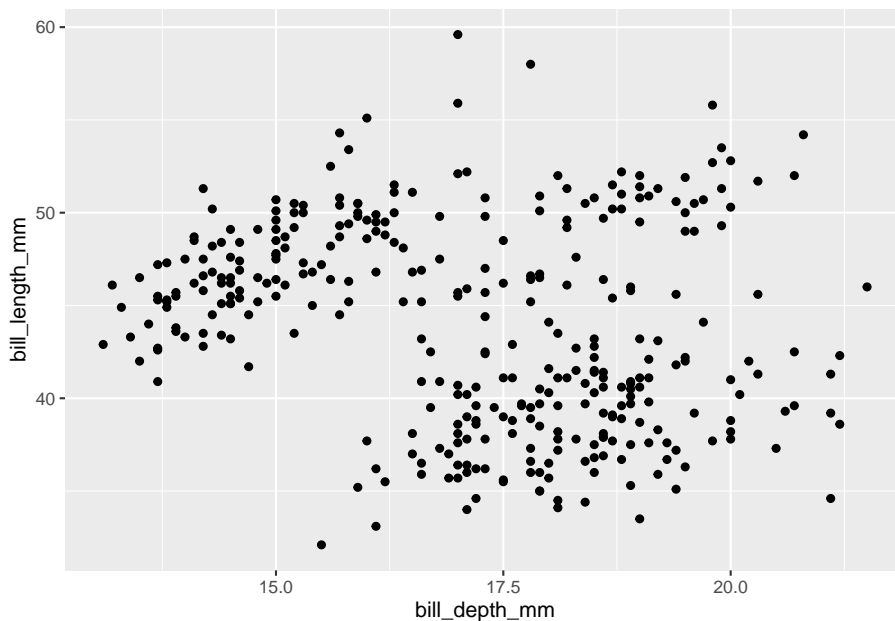
```
## Warning: Removed 2 rows containing missing values (geom_point).
```



4.7.0.0.2 Exercise 12 The previous scatterplot looked a little funny due to some odd groupings that we suspect (as usual) might be due to multiple species being measures. Add a new aesthetic (so, inside the parentheses following `aes`) to the following code to assign `color = species`. Comment on what you see.

```
# Modify the code below to add color = species
ggplot(penguins, aes(y = bill_length_mm, x = bill_depth_mm)) +
  geom_point()
```

```
## Warning: Removed 2 rows containing missing values (geom_point).
```



Please write up your answer here.

Every part of the graph can be customized, from the color scheme to the tick marks on the axes, to the major and minor grid lines that appear on the background. We won't go into all that, but you can look at the `ggplot2` documentation online and search Google for examples if you want to dig in and figure out how to do some of that stuff. However, the default options are often (but not always) the best, so be careful that your messing around doesn't inadvertently make the graph less clear or less appealing.

4.8 Conclusion

Summary statistics are simple numbers that describe and summarize data sets. Measures of center tell us where the “middle” of our numerical data lies, and measures of spread tell us how spread out our numerical data is. These measures should always be reported in pairs, for example the mean/standard deviation, or the median/IQR.

The `ggplot2` package with its `ggplot` command is a very versatile tool for creating nice graphs relatively easily. For a single numerical variable, the standard graph type is a histogram. For two numerical variables, use a scatterplot. For a numerical response with a categorical predictor, use either a side-by-side boxplot or a stacked histogram.

4.8.1 Preparing and submitting your assignment

1. From the “Run” menu, select “Restart R and Run All Chunks”.
2. Deal with any code errors that crop up. Repeat steps 1—2 until there are no more code errors.
3. Spell check your document by clicking the icon with “ABC” and a check mark.
4. Hit the “Preview” button one last time to generate the final draft of the `.nb.html` file.
5. Proofread the HTML file carefully. If there are errors, go back and fix them, then repeat steps 1–5 again.

If you have completed this chapter as part of a statistics course, follow the directions you receive from your professor to submit your assignment.