

Coding togetherR

Alistair Bailey

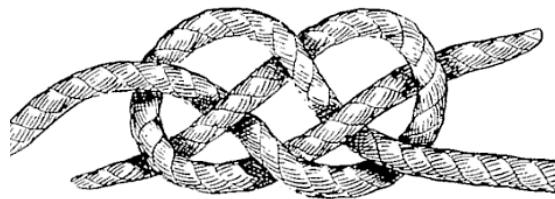
November 04 2019

Contents

Welcome	5
R and RStudio	6
Who is coding togetherR for?	6
Code of conduct	7
1 Getting started	9
1.1 Coding is for everyone	9
1.2 A little background and philosophy	9
1.3 RStudio	12
1.4 Installing and loading packages	18
1.5 Using functions	19
1.6 Getting help	19
1.7 A project orientated workflow	20
1.8 The tidyverse and tidy data	23
1.9 Atoms of R	24
1.10Assigning objects	25
1.11Lists, matrices and arrays	28
1.12Factors	30
1.13Data frames	30
1.14Plotting data	32
1.15Exporting data	34

2 Data wrangling I	37
2.1 Data organisation in spreadsheets	37
2.2 The Portal Project data	38
2.3 dplyr	41
2.4 Using dplyr to explore the effect of Kangaroo Rat exclusion on Granivore populations	51
3 Data wrangling II	57
3.1 Reshaping data with pivots	57
3.2 Missing values	61
3.3 Joining tables	71
4 Visualisation and communication	81
4.1 Visualisation	81
4.2 Reports	81
4.3 Presentations	81
5 Exploratory data analysis	83

Welcome



A Carrick bend:¹ The Carrick bend is a type of sailor's knot used for joining two lines.

Coding togetherR is a series of collaborative workshops to teach foundational R coding and data science skills at the University of Southampton in 2019. This book contains the materials covered over eight, two hour sessions.

The workshops are for anyone at the University of Southampton with data to analyse and who is struggling with their current tools. This series of eight weekly two hour workshops provides an introduction to working with data using R in a supported environment. Unlike traditional lessons, we all code together with the emphasis on participants learning by doing and by helping each other.

These materials are a mash-up of my own and many others. I've endeavoured to credit everyone appropriately, but please message me² if I've messed up and I'll correct it. The main sources used here are: R for data science (R4DS)³, the R4DS community⁴, the Carpentries⁵, Hands on Programming in R⁶, swiRlstats⁷ and Teaching Tech togetherR⁸.

¹<https://en.wikipedia.org/wiki/File:Carrick-bend-Guten-Verrill-modified.png>

²<https://ab604.uk/>

³<https://r4ds.had.co.nz/>

⁴<https://www.rfordatasci.com/>

⁵<https://carpentries.org/>

⁶<https://rstudio-education.github.io/hopr/>

⁷<https://swirlstats.com/>

⁸<http://teachtogether.tech/en/>

It was written using R (R Core Team 2019) in RStudio (RStudio Team 2018) using the bookdown package (Xie 2019).

To follow these materials you will need an up to date version of R (R Core Team 2019) and RStudio (RStudio Team 2018). This may require requesting permission to install software from Isolutions if you have a University laptop.

R and RStudio

If you are new to R, then the first thing to know is that R is a programming language and RStudio is a program for working with R called an integrated development environment (IDE). You can use R without RStudio, but not the other way around. Further details in Chapter 1.

Download R here⁹ and Download RStudio Desktop here¹⁰.

These materials were generated using R version 3.6.

Once you've installed R and RStudio, you'll also need a few R packages. Packages are collections of **functions**.

Open RStudio and put the code below into the Console window and press Enter to install the tidyverse, dslabs, janitor and here packages.

```
install.packages(c("tidyverse", "dslabs", "janitor", "here"))
```

Who is coding togetherR for?

Following the lesson design process of (Wilson 2018):

Arshad

As a PhD student in ecology Arshad doesn't have any formal coding training, but is gathering field data about bird populations. He is daunted by the prospect of learning to code. These lessons will introduce Arshad to coding by showing him how to organise and automate analysis of his data.

Jenny

⁹<https://cran.r-project.org/>

¹⁰<https://www.rstudio.com/products/rstudio/download/>

As a post doctoral researcher in gerontology Jenny has experience of research, but is unsatisfied with her current spreadsheet tools for analysing data. These lessons will show her how to write code to analyse spreadsheets.

Lin

As a principal investigator Lin has experience using MATLAB, but has not used R and would like to know more about it. These lessons will introduce Lin to R syntax and RStudio workflows.

Code of conduct

Coding togetherR is for everyone, and in order to make it a supportive and inclusive environment we subscribe to the Carpentries Code of Conduct¹¹. Please follow the link for details.

In a nutshell, expected behaviour is as follows:

- Use welcoming and inclusive language
- Be respectful of different viewpoints and experiences
- Gracefully accept constructive criticism
- Focus on what is best for the community
- Show courtesy and respect towards other community members

Participants who violate the code of conduct, will be asked to stop immediately and if necessary asked to leave the workshop and incidents reported as per University guidance on inappropriate behaviour¹².

¹¹https://docs.carpentries.org/topic_folders/policies/code-of-conduct.html

¹²<https://www.southampton.ac.uk/studentservices/need-help/student-discipline/staff-information.page>

Chapter 1

Getting started

By the end of this chapter are you will:

- understand how to install packages in RStudio.
- know how to get help when you are stuck.
- have set-up your first R project.
- understand the atoms of R and how to use them to build data frames.
- understand how to assign objects in R.
- have created a plot using the ggplot2 package.
- have written outputs from R to files.

1.1 Coding is for everyone

If, when faced with the thought of starting to learning to code you feel like the cat in Figure 1.1.

Then hopefully by the end of these materials, you'll feel a bit more like the cat in Figure 1.2.

And if you like that, there is more at R for cats³.

1.2 A little background and philosophy

“There are only two kinds of languages: the ones people complain about and the ones nobody uses”

Bjarne Stroustrup, the inventor C++

³<https://www.rforcats.net/>



Figure 1.1: Imposter syndrome¹.



Figure 1.2: R cat²

1.2.1 What is R?

R is a programming language that follows the philosophy laid down by its predecessor S. The philosophy being that users begin in an interactive environment where they don't consciously think of themselves as programming. It was created in 1993, and documented in (Ihaka and Gentleman 1996).

Reasons R has become popular include that it is both open source and cross platform, and that it has broad functionality, from the analysis of data and creating powerful graphical visualisations and web apps.

Like all languages though it has limitations, for example the syntax is initially confusing.

Users and developers of R have in recent years sought to develop an inclusive and welcoming community which can found on twitter #rstats or through RStudio Community⁴. There are many useR groups, including groups seeking to promote diversity such as R-Ladies⁵: Jumping Rivers maintains a list⁶.

1.2.2 Why learn to code at all?

In terms of the philosophy of learning to code:

1. The primary motivation for using tools such as R is to get more done, in less time and with less pain.
2. And the overall aim is to *understand and communicate* findings from our data.
3. Additionally, as per Greg Wilson's description of his motivation for teaching⁷, if we're going to help make the world a better place, a bit of coding is likely to be key tool in your kit.

As shown in Figure 1.3 of typical data analysis workflow, to achieve this aim we need to learn tools that enable us to perform the fundamental tasks of tasks of importing, tidying and often transforming the data. Transformation means for example, selecting a subset of the data to work with, or calculating the mean of a set of observations.

⁴<https://community.rstudio.com/>

⁵<https://rladies.org/about-us/>

⁶<https://jumpingrivers.github.io/meetingsR/>

⁷<http://third-bit.com/2019/01/30/why-i-teach.html>

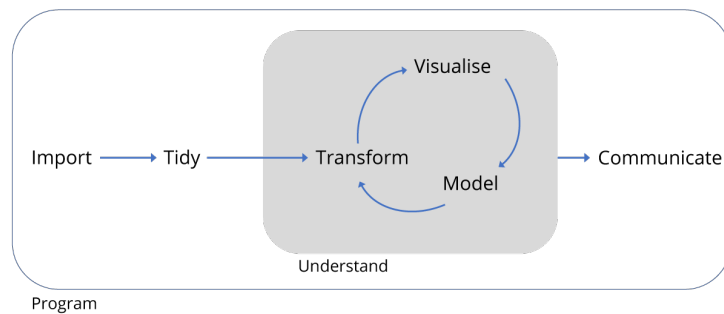


Figure 1.3: Data project workflow.

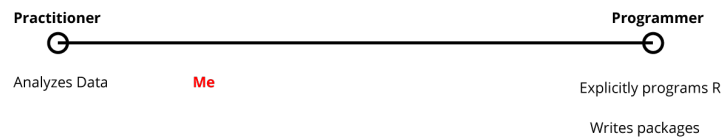


Figure 1.4: The Practitioner-Programmer spectrum

1.2.3 A little goes a long way

Returning to our cat friend in Figure 1.2, one doesn't need to be an expert programmer to find coding useful. As illustrated in Figure 1.4 there is a whole spectrum of code users from practitioners who are focused on applying some R to their specific problems, to those programmers who develop the R language itself. In reality one may move around on that spectrum as one's interests change over time.

1.3 RStudio

Let's begin by learning about RStudio⁸, the Integrated Development Environment (IDE).

R is the language and RStudio is software created to facilitate our use of R. They are installed separately. You don't need RStudio to use R, but you do need R to use RStudio.

We will use R Studio IDE to write code, navigate the files found on our computer, inspect the variables we are going to create, and visualize the plots we will

⁸<https://www.rstudio.com/>

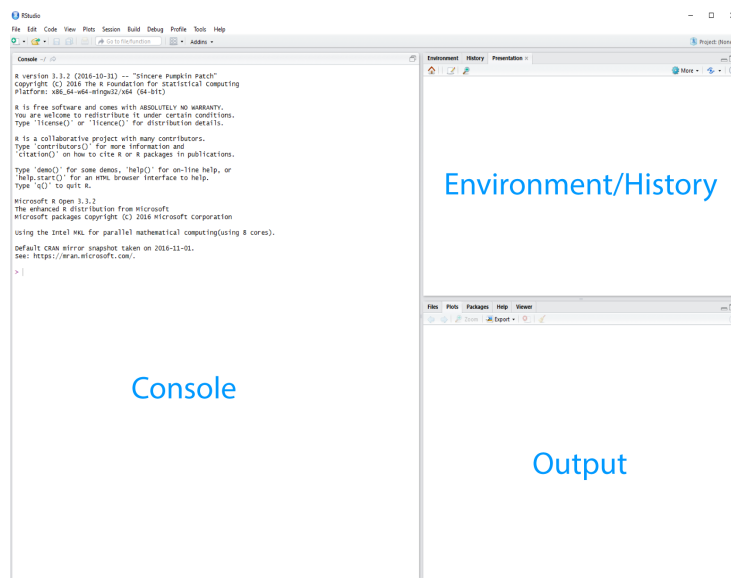


Figure 1.5: The RStudio Integrated Development Environment (IDE).

generate. R Studio can also be used for other things (e.g., version control, developing packages, writing Shiny apps) that we don't have time to cover during this workshop.

R Studio is divided into “Panels”, see Figure 1.5.

When you first open it, there are three panes, the console where you type commands, your environment/history (top-right), and your files/plots/packages/help/viewer (bottom-right).

The environment shows all the R objects you have created or are using, such as data you have imported.

The output pane can be used to view any plots you have created.

Not opened at first start up is the fourth default pane: the script editor pane, but this will open as soon as we create/edit a R script (or many other document types). *The script editor is where will be typing much of the time.*

The placement of these panes and their content can be customized (see menu, R Studio -> Tools -> Global Options -> Pane Layout). One of the advantages of using R Studio is that all the information you need to write code is available in a single window. Additionally, with many short-cuts, auto-completion, and highlighting for the major file types you use while developing in R, R Studio will make typing easier and less error-prone.

RStudio has lots of keyboard short-cuts to make coding quicker

and easier. Try to find the menu listing all the keyboard short-cuts, including the short-cut to find the menu!

Time for another philosophical diversion. . .

1.3.1 What is real?

At the start, we might consider our environment “real” - that is to say the objects we’ve created/loaded and are using are “real”. But it’s much better in the long run to consider our scripts as “real” - our scripts are where we write down the code that creates our objects that we’ll be using in our environment.

As a script is a document, it is reproducible

Or to put it another way: we can easily recreate an environment from our scripts, but not so easily create a script from an environment.

To support this notion of thinking in terms of our scripts as real, we recommend turning off the preservation of workspaces between sessions by setting the Tools > Global Options menu in R studio as shown in Figure 1.6.

1.3.2 Where am I?

The part of your computer operating system that manages files and directories (aka folders) is called the file system. This dates back to 1969 and the Unix filesystem⁹.

The idea is that we have a rooted tree, as with phylogenetic rooted trees¹⁰ in biology. From the root all other directories and files exist along paths going back to the root as shown in Figure 1.7.

On Unix based systems such as Apple or Android, the root is denoted with /. On Windows the root is a back slash \. The / or \ is used to separate directories along the path, denoting a change in the level of the tree

Note: in RStudio the path separator and root is always / regardless of the operating system.

1.3.2.1 Absolute path from the root /

In Figure 1.7 the absolute path from the root of surveys.csv is shown. In text this would be /users/alistair/Documents/coding-together-week-02/data/surveys.csv.

This is just a made-up example and the path on your machine will be different.

⁹https://en.wikipedia.org/wiki/Unix_filesystem

¹⁰https://en.wikipedia.org/wiki/Phylogenetic_tree#Rooted_tree

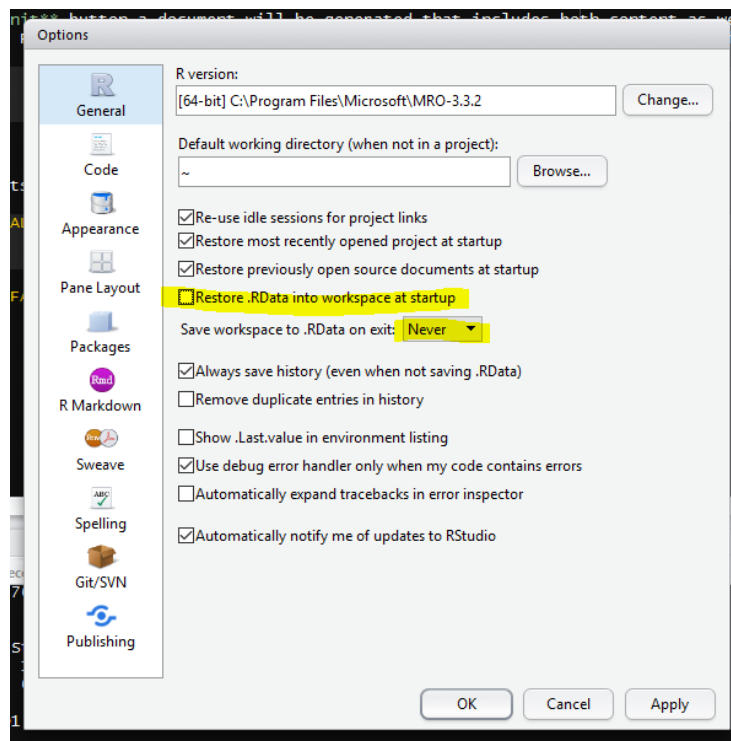


Figure 1.6: Don't save your workspace, save your script instead.

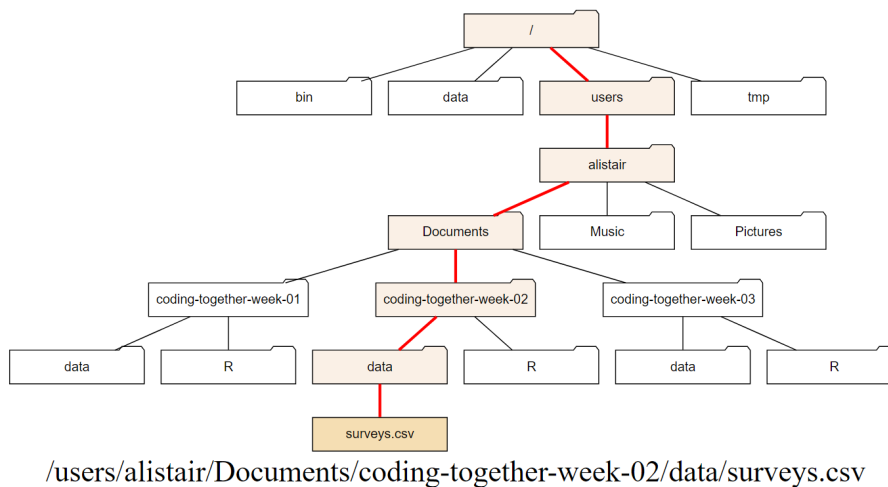


Figure 1.7: The red line shows the absolute path from the root / to surveys.csv.

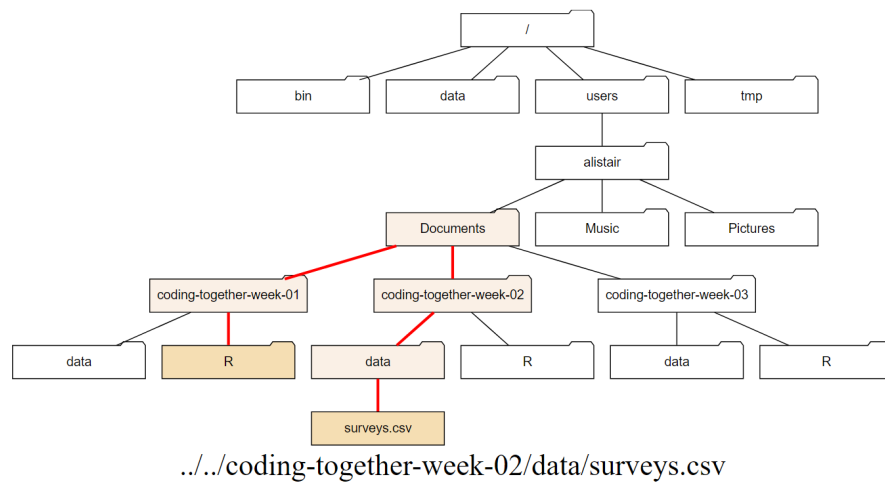


Figure 1.8: The red line represents the relative path from R to surveys.csv

1.3.2.2 Relative path from where you are ../

However, we can also consider relative paths, that is relative to where we are working at present.

In Figure 1.8 I imagine that I am working in the R directory in coding-together-week-01 folder. To access the surveys.csv file I have to go up two levels to Documents and then back down three levels. I could use the absolute path, but if I know where surveys.csv is then I can use the short-hand of ../ to go up one level, and then again to go up another, and then back down.

In text from the R directory this is: ../../coding-together-week-02/data/surveys.csv

I don't recommend this, it was just to illustrate what a relative path looks like.

1.3.2.3 Home directory path ~

The home directory is the part of the file system dedicated to the user - that's us! - and our data. Usually when we get a new computer we'll have a home directory with our user name. On Windows machines this will contain My Documents etc. and on an Apple machine it will be Documents etc. On a shared machine each user will get a home directory associated with their user name.

Because we are usually working in our home directory and it's tiresome to keep typing out paths from the root and it takes up room on the screen, the tilde ~ denotes the path from the root to our home directory.

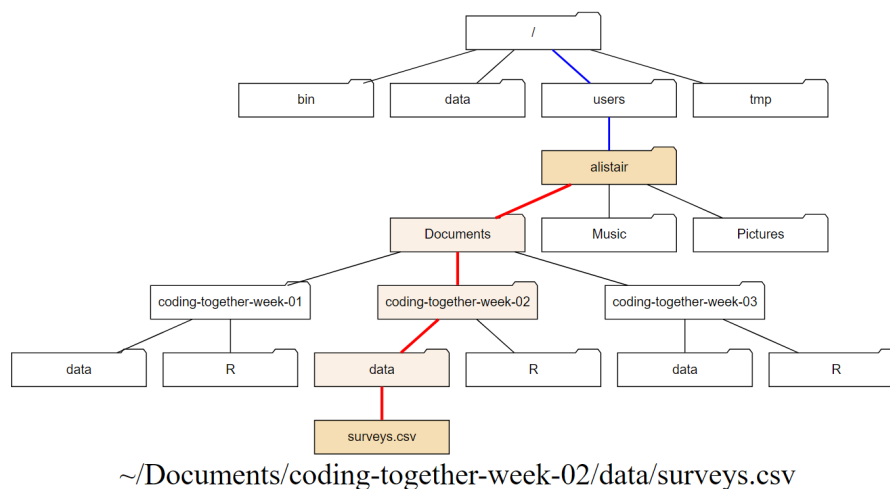


Figure 1.9: The home directory path to the `surveys.csv` with the `~` part in blue and the remaining path in red.

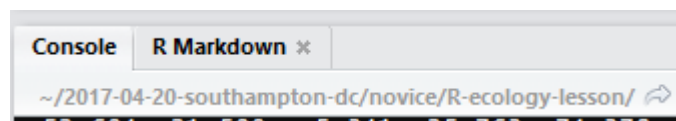


Figure 1.10: Your working directory

We can use the `~` to precede the rest of the path to shortcut an absolute path to the root.

Figure 1.9 indicates a home directory path to the `surveys.csv` with the `~` part in blue and the remaining path in red.

In text this would be: `~/Documents/coding-together-week-02/data/surveys.csv`

1.3.2.4 Working directory

R studio tells you where you are in terms of directory address as shown in Figure 1.10. Here this is a home directory path.

It is good practice to keep a set of related data, analyses, and text self-contained in a single folder, called **your working directory**. All of the scripts within this folder can then use *relative paths* to files that indicate where inside the project a file is located (as opposed to absolute paths, which point to where a file is on a specific computer). An example directory structure is illustrated in Figure 1.11. Working this way makes it a lot easier to

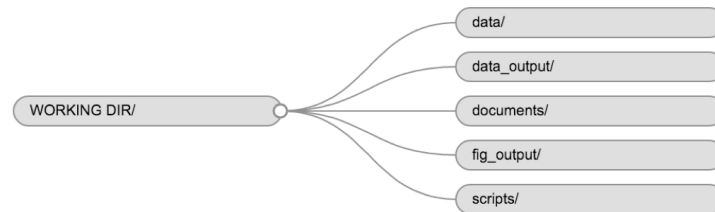


Figure 1.11: A typical directory structure

move your project around on your computer. Section 1.7 builds upon this to create a robust workflow for data analysis.

1.4 Installing and loading packages

Packages are collections of functions, and a function is a piece of code written to perform a specific task, such as installing a package.

Therefore, the function `install.packages()` is a piece of code written to perform the task of installing packages. We use it by typing `install.packages("tidyverse")` with the name of the package in quotes inside the round brackets. Here the package is `tidyverse`. Using the console panel to type this and pressing `Enter` will run the function.

We of course need to know the name of the packages we are interested in.

Once a package is installed we need to load it into our environment to use it. Loading packages is performed using the `library()` function. As with installation, we put the name of the package we want to load in between the round brackets like so `library(tidyverse)`. As before this can be done on the console, but we will usually load packages as part of script. *Note that we don't need the quotes for the library function.*

Try installing the `cowsay` package and loading it. It has one function called `say()` that you can use to create messages with animals.

1.5 Using functions

As stated in 1.4 a function is a piece of code written to perform a specific task. Functions in R have the syntax of the name of the function followed by round brackets. The round brackets are where we type the arguments that the function requires to carry out its task. For example, in 1.4 the function `install.packages()` requires the name of the package we want to install as arguments.

Many, if not most, functions can take more than one argument. The creators of the function should have given these defaults for the situation where the user provides only one or some arguments. RStudio should prompt you for the arguments as you type, but if you need to see what they are, use the help function `?` with the function name in the Console and it will open the help panel or type the function name into the help panel search box.

For example, to find out all the arguments for `install.packages()` we'd type `?install.packages` and press Enter.

Try using `say()` to say "I are programmer" in the `cowsay` package and then find out what the arguments you can provide to make it produce different types of message.

1.6 Getting help

1.6.1 Using `?` to access R function help pages

If you need help with a specific R function, let's say `barplot()`, you can type the function name without round brackets, with a question mark at the start:

```
?barplot
```

1.6.2 Using Google to find R answers

A Google or internet search "R <task>" will often either send you to the appropriate package documentation or a helpful forum question that someone else already asked, such as the RStudio Community¹¹ or Stack Overflow¹².

¹¹<https://community.rstudio.com/>

¹²<http://stackoverflow.com/questions/tagged/r>

1.6.3 Asking questions

As well as knowing where to ask¹³, the key to get help from someone is for them to grasp your problem rapidly. You should make it as easy as possible to pinpoint where the issue might be.

Try to use the correct words to describe your problem. For instance, a package is not the same thing as a library. Most people will understand what you meant, but others have really strong feelings about the difference in meaning. The key point is that it can make things confusing for people trying to help you. Be as precise as possible when describing your problem.

If possible, try to reduce what doesn't work to a simple *reproducible example* otherwise known as a *reprex*.

For more information on how to write a reproducible example see this article¹⁴ using the reprex package.

1.7 A project orientated workflow

This section is all about how to use R and RStudio to **“maximize effectiveness and reduce frustration.”**

The above quote is from Jenny Bryan's article¹⁵ about a project orientated workflow.

The main point here is that how you do things, **the workflow**, should not be mixed up with the **product of the workflow** itself.

The product being:

- the raw data.
- the code needed to produce the results from the raw data.

Ways in which you can mix workflow and product include having lines in your script that set your working directory, or using RStudio to save your environment when you are working.

But why is this a problem?

It's because **your computer isn't my computer** or **my laptop isn't my desktop** or **I'm now using a Windows machine and I wrote the code two years ago on a Mac**.

¹³<https://www.tidyverse.org/help/#where-to-ask>

¹⁴<https://www.tidyverse.org/help/#reprex>

¹⁵<https://www.tidyverse.org/articles/2017/12/workflow-vs-script/>

By hard coding the directory into a script I have ensured my code will only run on the machine in which it was written. Chances are you will want to share your code with someone, either for publication or for them to check your work, or because you are working collaboratively and therefore we need to avoid mixing workflow with product.

Likewise we can't share environments directly, but we can share the code that creates the environment.

If we organise our analysis into self-contained projects that hold everything needed to perform the analysis. These projects can be shared across machines and the analysis recreated, and thus the workflow is kept separate from the product.

What does this look like in practice?

1.7.1 RStudio Projects

Step one is to use an interactive development environment such as RStudio rather than using R on its own for your analysis.

RStudio contains a facility to keep all files associated with a particular analysis together called, as you might expect from 1.7, a Project.

Creating a Project creates a file `.Rproj` containing all the information associated with your analysis including the Project location (allowing you to quickly navigate to it), and optionally preserves custom settings and open files to make it easier to resume work after a break. This is also super helpful if you are working on multiple projects as you can switch between them at a click.

Below, we will go through the steps for creating an Project:

- Start R Studio (presentation of R Studio -below- should happen here)
- Under the File menu, click on New project, choose New directory, then Empty project
- Enter a name for this new folder (or "directory", in computer science), and choose a convenient location for it. This will be your **working directory** for the rest of the day (e.g., `~/coding-together`)
- Click on "Create project"
- Under the Files tab on the right of the screen, click on New Folder and create a folder named data within your newly created working directory. (e.g., `~/data`)
- Create a R notebook (File > New File > R notebook) and save it in your working directory (e.g. `01-coding-together-workshop-02-05-2019.Rmd`)
- Or create a new R script (File > New File > R script) and save it in your working directory (e.g. `01-coding-together-workshop-02-05-2019.R`)

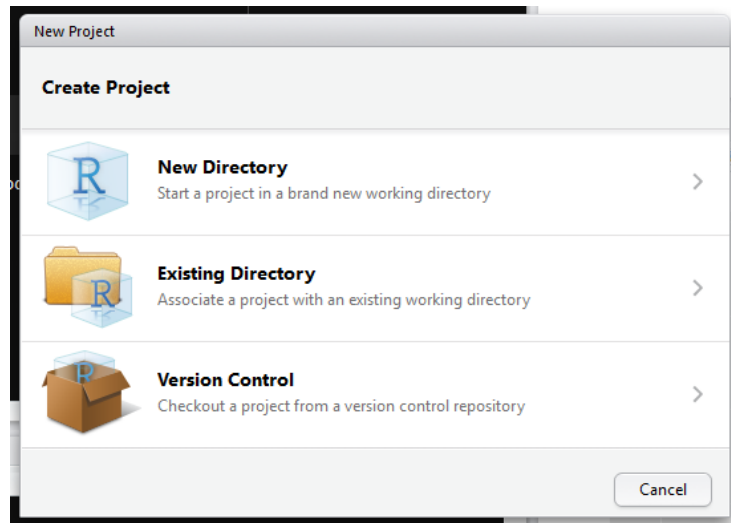


Figure 1.12: Creating a R project

1.7.2 R notebooks and R scripts

R notebooks¹⁶ combine writing text with R code in chunks. The R code chunks are indicated by three backticks and a lowercase `r` in brackets: ````{r} ````. Text can be formatted using markdown syntax¹⁷. These are great for doing analysis and report writing at the same time.

R scripts are text files containing the commands that you would enter into the R console. They are great for containing code you wish to call into another script such as code for a function, or if you are submitting a script as job to run on another computer without the need for RStudio.

1.7.3 Level up with the `here` package

This is a bit more tricky, so you might like to come back to `here` later, but Jenny Bryan loves the `here`¹⁸ package by Kirill Müller so much she wrote an ode to it¹⁹.

In a nutshell, the `here()` function sets the path implicitly to the top level of the R project you are working in. **But what does that mean, and why should I care?**

¹⁶<https://bookdown.org/yihui/rmarkdown/notebook.html>

¹⁷<https://bookdown.org/yihui/rmarkdown/markdown-syntax.html>

¹⁸<https://here.r-lib.org/index.html>

¹⁹https://github.com/jennybc/here_here

Using the `here()` function like this:

```
library(here)

here("data", "file_i_want.csv")
```

where "data" is the folder containing "file_i_want.csv", the function works out the rest of the path to the folder and file. This is useful if you open the project on different machines where the path is different. `here()` takes care of things, thus saving you some pain.

1.7.4 Naming things

Jenny Bryan²⁰ also has three principles for naming things²¹ that are well worth remembering.

When you names something, a file or an object, ideally it should be:

1. Machine readable (no white space, punctuation, upper AND lower-case...)
2. Human readable (makes sense in 6 months or 2 years time)
3. Plays well with default ordering (numerical or date order)

We'll see examples of this as we go along.

1.8 The tidyverse and tidy data

The tidyverse²² (Wickham 2017) is *"an opinionated collection of R packages designed for data science"*.

Tidyverse packages contain functions that *"share an underlying design philosophy, grammar, and data structures."* It's this philosophy that makes tidyverse functions and packages relatively easy to learn and use.

Tidy data follows three principals for tabular data as proposed in the Tidy Data paper <http://www.jstatsoft.org/v59/i10/paper> :

1. Every variable has its own column.
2. Every observation has its own row.
3. Each value has its own cell.

We'll be using the tidyverse and learning more about tidy data as we go along.

²⁰<https://ropensci.org/blog/2017/12/08/rprofile-jenny-bryan/>

²¹http://www2.stat.duke.edu/~rcs46/lectures_2015/01-markdown-git/slides/naming-slides/naming-slides.pdf

²²<https://www.tidyverse.org/>

Atomic Vectors

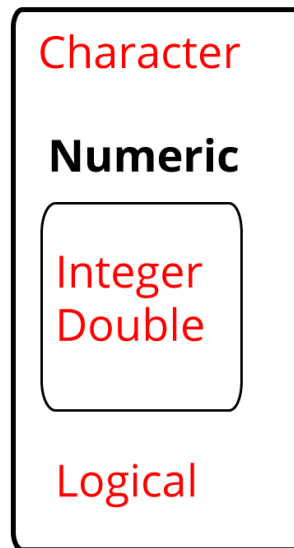


Figure 1.13: The four most used atomic vectors, the building blocks of R

1.9 Atoms of R

Having set ourselves up in RStudio, let's turn our attention to the language of R itself.

The basic building blocks of how R stores data are called atomic vector types. It's from these atoms that more complex structures are built. Atomic vectors have one dimension, just like a single row or a single column in a spreadsheet.

The four main atoms of R are:

- Doubles: regular numbers, +ve or -ve and with or without decimal places. AKA numerics.
- Integers: whole numbers, specified with an upper-case L, e.g. `int <- 2L`
- Characters: Strings of text
- Logicals: these store `TRUE`'s and `FALSE`'s which are useful for comparisons.

Let's make a character vector and check the atomic vector type, using the `typeof()`. This also introduces a very important R function `c()`. This lower

case `c` stands for **combine**. So when we have several objects e.g. words or numbers, we can combine them into a vector the length of the number of objects, as illustrated here for a pack of cards:

```
cards <- c("ace", "king", "queen", "jack", "ten")
```

```
cards
```

```
## [1] "ace" "king" "queen" "jack" "ten"
```

```
typeof(cards)
```

```
## [1] "character"
```

Note here that we see the use of the assignment operator `<-` to assign our vector on the right as the object `cards`. We talk more about that in 1.10.

Try creating a vector of numbers from 1 to 10 using the `seq()` function. Remember to use `?seq` if you want to learn more about the function.

1.10 Assigning objects

Objects are just a way to store data inside the R environment. We assign labels to objects using the assignment operator `<-`

```
mass_kg <- 55
```

Read this as “*mass_kg is assigned to value 55*” in your head. A subtle but important point here is that the object is 55 and the value remains 55 regardless of the label we assign to it. In fact we could assign more than one label to the same object. Another way to think about this is that Bibi is a cat, and remains a cat even if I call her Princess when she refuses to go out in the rain.

Using `<-` can be annoying to type, so use RStudio’s keyboard short cut: `Alt + -` (the minus sign) to make life easier.

Many people ask why we use this assignment operator when we can use `=` instead?

Colin Fay had a Twitter thread on this subject²³, but the reason I favour most is that it provides clarity. The arrow points in the direction of the assignment

²³https://twitter.com/_colinfay/status/1006139974377443328

```
bibi <-
```



```
cat
```

Figure 1.14: Bibi remains a cat even if I call her Princess when she refuses to go out in the rain.

(it is actually possible to assign in the other direction too) and it distinguishes between creating an object in the workspace and assigning a value inside a function.

Object name style is a matter of choice, but must start with a letter and can only contain letters, numbers, `_` and `..`. We recommend using descriptive names and using `_` between words. Some special symbols cannot be used in variable names, so watch out for those.

So here we've used the name to indicate its value represents a mass in kilograms. Look in your environment pane and you'll see the `mass_kg` object containing the (data) value 55.

We can inspect an object by typing its name:

```
mass_kg
```

```
## [1] 55
```

What's wrong here?

```
mass_KG
```

```
Error: object 'mass_KG' not found
```

This error illustrates that typos matter, everything must be precise and `mass_KG` is not the same as `mass_kg`. `mass_KG` doesn't exist, hence the error.

Let's use `seq()` to create a **sequence** of numbers, and at the same time practice tab completion.

Start typing `se` in the console and you should see a list of functions appear, add `q` to shorten the list, then use the up and down arrow to highlight the function of interest `seq()` and hit Tab to select. This is tab completion.

RStudio puts the cursor between the parentheses to prompt us to enter some arguments. Here we'll use 1 as the start and 10 as the end:

```
seq(1,10)
```

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

If we left off a parentheses to close the function, then when we hit enter we'll see a `+` indicating RStudio is expecting further code. We either add the missing part or press Escape to cancel the code.

Let's call a function and make an assignment at the same time. Here we'll use the base R function `seq()` which takes three arguments: `from`, `to` and `by`.

Read the following code as *"assign my_sequence to an object that stores a sequence of numbers from 2 to 20 by intervals of 2."*

```
my_sequence <- seq(2,20,2)
```

This time nothing was returned to the console, but we now have an object called `my_sequence` in our environment.

1.10.1 Indexing and subsetting

If we want to access and subset elements of `my_sequence` we use square brackets `[]` and the index number. Indexing in R starts at 1 such that 1 is the index of the first element in the sequence, element 1 having the value of 2.

For example element five would be subset by:

```
my_sequence[5]
```

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

Here the number five is the index of the vector, not the value of the fifth element. The value of the fifth element is 10.

And returning multiple elements uses a colon `:`, like so

```
my_sequence[5:8]
```

```
## [1] 10 12 14 16
```

1.11 Lists, matrices and arrays

Lists also group data into one dimensional sets of data. The difference being that list group objects instead of individual values, such as several atomic vectors.

For example, let's make a list containing a vector of numbers and a character vector

```
list_1 <- list(1:110, "R")
```

```
list_1
```

```
## [[1]]
## [1] 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
## [18] 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
## [35] 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51
## [52] 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68
## [69] 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85
## [86] 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102
## [103] 103 104 105 106 107 108 109 110
##
## [[2]]
## [1] "R"
```

Note the double brackets to indicate the list elements, i.e. element one is the vector of numbers and element two is a vector of a single character.

We won't be working with lists a great deal in these workshops, but they are a flexible way to store data of different types in R.

Accessing list elements uses double square brackets syntax, for example `list_1[[1]]` would return the first vector in our list.

And to access the first element in the first vector would combine double and single square brackets like so: `list_1[[1]][1]`.

Don't worry if you find this confusing, everyone does when they first start with R. Hadley Wickham tweeted an image to illustrate list indexing shown in [1.15](#).

Lists alongside `NULL` which indicates the absence of a vector, complete the set of base vectors in R as illustrated in [1.16](#).



Figure 1.15: List indexing by Hadley Wickham

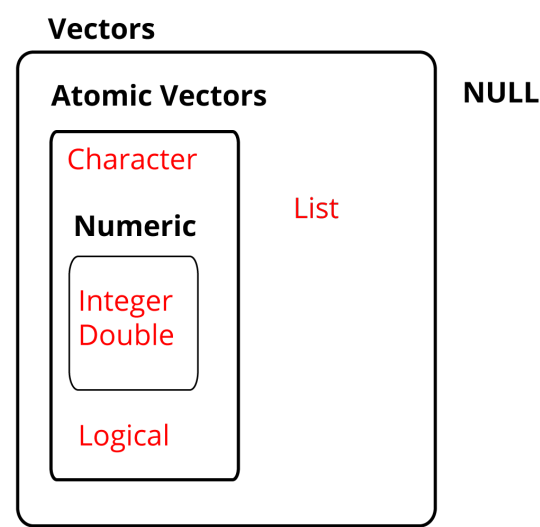


Figure 1.16: The base vectors in R.

1.11.1 Matrices and arrays

Matrices store values in a two dimensional array, whilst arrays can have n dimensions. We won't be using these either, but they are also valid R objects.

1.12 Factors

Factors are R's way of storing categorical information such as eye colour or car type. A factor is something that can only have certain values, and can be ordered (such as `low,medium,high`) or unordered such as types of fruit.

Factors are useful as they code string variables such as "red" or "blue" to integer values e.g. 1 and 2, which can be used in statistical models and when plotting, but they are confusing as they look like strings.

Factors look like strings, but behave like integers.

Historically R converts strings to factors when we load and create data, but it's often not what we want as a default. Fortunately, in the tidyverse strings are not treated as factors by default.

1.13 Data frames

For data analysis in R, we mostly be using data frames.

Data frames are two dimensional versions of lists, and this is form of storing data we are going to be using. In a data frame each atomic vector type becomes a column, and a data frame is formed by columns of vectors of the same length. Each column element must be of the same type, but the column types can vary.

Figure 1.17 shows an example data frame we'll refer to as saved as the object `df` consisting of three rows and three columns. Each column is a different atomic data type of the same length.

To create the data frame 1.17 we can use the `data.frame()` function in conjunction with the `c()` function to make the individual atomic vectors that comprise the data frame as follows. Note that I am naming the vectors as I make the data frame after the type of vector e.g. `numeric_vector = c(1,7,3)`. Also, as this is a base R function I need to tell the function not to treat the character strings as categorical data using `stringsAsFactors = FALSE`

data frame

1	"S"	TRUE
7	"A"	FALSE
3	"U"	TRUE

numeric character logical

Figure 1.17: An example data frame df.

```
df <- data.frame(numeric_vector = c(1,7,3),
                 character_vector = c("S","A","U"),
                 logical_vector = c(TRUE,FALSE,TRUE),
                 stringsAsFactors = FALSE)
```

```
df
```

```
##   numeric_vector character_vector logical_vector
## 1             1             S             TRUE
## 2             7             A            FALSE
## 3             3             U             TRUE
```

Packages in the tidyverse create a modified form of data frame called a tibble. You can read about tibbles here²⁴. One advantage of tibbles is that they don't default to treating strings as factors. We deal with transforming data frames in chapters 2 and 3.

Here's what the code to make the same data frame as before as a tibble looks like. Note how we get more information from a tibble when it is returned to the Console, it tells us what the dimensions are, and what type of vectors it contains.

```
df <- tibble(numeric_vector = c(1,7,3),
             character_vector = c("S","A","U"),
             logical_vector = c(TRUE,FALSE,TRUE))
```

```
df
```

²⁴<http://r4ds.had.co.nz/tibbles.html>

```
## # A tibble: 3 x 3
##   numeric_vector character_vector logical_vector
##           <dbl> <chr>           <lgl>
## 1             1 S             TRUE
## 2             7 A             FALSE
## 3             3 U             TRUE
```

Sub-setting data frames can also be done with square bracket syntax, but as we have both rows and columns, we need to provide index values for both row and column.

For example `df[1,2]` means **return the value of df row 1, column 2**. This corresponds with the value A.

We can also use the colon operator to choose several rows or columns, and by leaving the row or column blank we return all rows or all columns.

```
# Subset rows 1 and 2 of column 1
df[1:2,1]

# Subset all rows of column 3
df[,3]
```

Don't worry too much about this for now, we won't be doing too much of this in these lessons, but it's worth being aware of this syntax.

1.13.1 Attributes

An attribute is a piece of information you can attach to an object, such as names or dimensions. Attributes such as dimensions are added when we create an object, but others such as names can be added.

Let's look at the `mpg` data frame dimensions:

```
# mpg has 234 rows (observations) and 11 columns (variables)
dim(mpg)
```

```
## [1] 234 11
```

1.14 Plotting data

One of the most useful and important parts of any data analysis is plotting data. We'll be spending a whole lesson on it in chapter 4, but to give you an

example, we'll use the `ggplot2` package as an introduction to automating a task in code, and as a tool for understanding data.

`ggplot2` implements the *grammar of graphics*, for describing and building graphs. The idea being that we construct a plot in the following way:

1. Call the `ggplot()` function to create a graph.
2. Pass our data as the first argue to the `ggplot()` function.
3. Then pass some arguments to the aesthetics function `aes()` inside the `ggplot()` which tell `ggplot` how to plot the data e.g. which data goes on the x and y axis.
4. Then we follow the `ggplot` function with a `+` sign to indicate we are going to add more code, followed by a geometric object function, a `geom` which maps the data to type of plot we want to make e.g. a histogram or scatter plot.

Don't worry if this sounds confusing, it becomes clear with practice and all plots follow this grammar.

We'll use the `mpg` dataset that comes with the `tidyverse` to examine the question *do cars with big engines use more fuel than cars with small engines?*

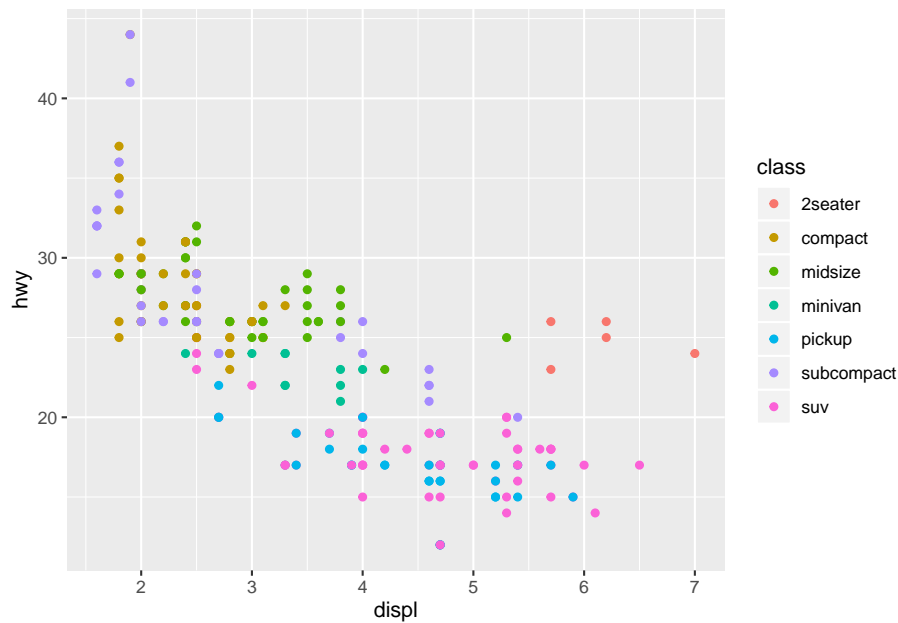
Try `?mpg` to learn more about the data.

1. Engine size in litres is in the `displ` column.
2. Fuel efficiency on the highway in miles per gallon is given in the `hwy` column.

To create a plot of engine size `displ` (x-axis) against fuel efficiency `hwy` (y-axis) we do the following:

Now try extending this code to include to add a `colour` aesthetic to the the `aes()` function, let `colour = class`, `class` being the vehicle type. This should create a plot with as before but with the points coloured according to the vehicle type to expand our understanding.

```
ggplot(data = mpg) +  
  geom_point(mapping = aes(x = displ, y = hwy, colour = class))
```



Now we can see that as we might expect, bigger cars such as SUVs tend to have bigger engines and are also less fuel efficient, but some smaller cars such as 2-seaters also have big engines and greater fuel efficiency. Hence we have a more nuanced view with this additional aesthetic.

Check out the ggplot2 documentation for all the aesthetic possibilities (and Google for examples): <http://ggplot2.tidyverse.org/reference/>

So now we have re-usable code snippet for generating plots in R:

```
ggplot(data = <DATA>) +  
  <GEOM_FUNCTION>(mapping = aes(<MAPPINGS>))
```

Concretely, in our first example <DATA> was `mpg`, the <GEOM_FUNCTION> was `geom_point()` and the arguments we supplies to map our aesthetics <MAPPINGS> were `x = displ`, `y = hwy`.

As we can use this code for any tidy data set, hopefully you are beginning to see how a small amount of code can do a lot.

1.15 Exporting data

We'll spend more time on getting data in and out of our R environment in the next chapter 3, but just to wrap this lesson up let's imagine we wanted to export our plot and data for a colleague or presentation.

1.15.1 readr

To export tibbles and data frames, we'll use the `readr` package, and the `write_excel_csv()` function. This creates a table in comma separated variable format that can be opened by spreadsheet software such as excel.

As it is a function it has round brackets and the main arguments we pass are the object containing the data we want to output and the name of the file and the location we want to write the file to.

```
write_excel_csv(df, "outputs/example-data-02-05-2019.csv")
```

Here we are writing the `df` data frame as a csv file to the `outputs` folder and a file called `example-data-02-05-2019.csv`.

1.15.2 ggsave

If we want to save the last plot we made in `ggplot2` we can use the `ggsave()` function²⁵

We tell `ggsave()` the filename, and it will save it as that type depending on how we name the file. For example if we use `file.pdf` it will save a PDF and if we use `file.jpeg` it will save a jpeg.

Check out `?ggsave` or the line above for more options.

To save our last plot for example:

```
ggsave("outputs/example-plot-02-05-2019.pdf")
```

1.15.3 Exercise

1. Create a new project called 'coding-assessment-01'
2. Create two folders in this project: `R` and `outputs`
3. Create a R script using best naming practices i.e. `name-date.R`
4. In the script, write some comments at the top e.g. name, date, description
5. Create a tibble comprising of a character vector, a numeric vector
6. Install and load the `dslabs` package and create a density plot with `ggplot2` using the `heights` dataset, using the `x = height` variable and `fill = sex` to create a density plot `ggplot(data = heights, aes(x = height, fill = sex)) + geom_density()`

²⁵<https://ggplot2.tidyverse.org/reference/ggsave.html>

7. Save the plot as pdf and the tibble as csv file to the output folder.

Chapter 2

Data wrangling I

By the end of this chapter you will:

- have learnt to load csv files
- have used the key verbs of the `dplyr` package for transforming data to arrange and filter observations, select variables, create new variables, and create summaries.
- have learnt how to combine functions with the pipe `%>%` from the `magrittr` package to combine tasks

The following sections are based upon the data transformation chapter¹ in R4DS and the Data Carpentry ecology lesson².

2.1 Data organisation in spreadsheets

Karl Broman and Kara Woo wrote a paper all about Data Organization in Spreadsheets³.

It's full of practical advice and context and well worth reading for helping you think about best practices for organising your data for yourself, and when working with others.

2.1.1 Flat formats and Excel files

File formats like `.csv` and `.tsv`, comma separated variables and tab separated variables respectively are plain text files. That is to say they contain only the

¹<https://r4ds.had.co.nz/transform.html>

²<https://datacarpentry.org/R-ecology-lesson/index.html>

³<https://www.tandfonline.com/doi/full/10.1080/00031305.2017.1375989>

data, as text information, and are the simplest and most convenient way to share data as most software can read and interpret them.

Excel files save files into its own proprietary format `.xls` or `.xlsx` that holds information in addition to the data itself. For reading and writing excel files in R, the tidyverse `readxl` package is very useful.

2.2 The Portal Project data

In this chapter we are going to focus on data from the Portal Project⁴, which is a long running survey of rodents and other species in the Chihuahuan Desert, as analysed in the 1994 paper by Heske et. al:

Long-Term Experimental Study of a Chihuahuan Desert Rodent Community: 13 Years of Competition, DOI: 10.2307/1939547.

A paper with details about the data and the project⁵ is also available.

Specifically they explored the effect on the populations of small seed eating rodents as a result of the exclusion of larger competitor kangaroo rats over a period from 1977 to 1991.

We'll also use some of their data to explore this question: **What is the effect of the exclusion of kangaroo rats from a plot of land on the granivore population?**

Figure 2.1 shows an image of one of the species of kangaroo rats excluded during the study.

Figure 2.2 indicates how the exclusion works, where a for number of fenced plots the kangaroo rats were either able to enter by a hole or kept out.

The plots are 50 metres by 50 metres, and a survey of the species within each plot has been ongoing once a month for many years.

The dataset is stored as a comma separated value (CSV) file. Each row holds information for a single animal, and the columns represent:

Column	Description	Type
<code>record_id</code>	Unique id for the observation	numeric
<code>month</code>	month of observation	numeric
<code>day</code>	day of observation	numeric
<code>year</code>	year of observation	numeric
<code>plot_id</code>	ID of a particular plot	numeric
<code>species_id</code>	2-letter code	character
<code>sex</code>	sex of animal ("M", "F")	character

⁴<https://portal.weecology.org/>

⁵<https://www.biorxiv.org/content/10.1101/332783v1.full>

Column	Description	Type
hindfoot_length	length of the hindfoot in mm	numeric
weight	weight of the animal in grams	numeric
genus	genus of animal	character
species	species of animal	character
taxa	e.g. Rodent, Reptile, Bird, Rabbit	character
plot_type	type of plot	character

The rodents species surveyed are:

Kangaroo Rats

species_id	Scientific name	Common name
DM	Dipodomys merriami	Merriam's kangaroo rat
DO	Dipodomys ordii	Ord's kangaroo rat
DS	Dipodomys spectabilis	Banner-tailed kangaroo rat

Granivores

species_id	Scientific name	Common name
PP	Chaetodipus penicillatus	Desert pocket mouse
PF	Perognathus flavus	Silky pocket mouse
PE	Peromyscus eremicus	Cactus mouse
PM	Peromyscus maniculatus	Deer Mouse
RM	Reithrodontomys megalotis	Western harvest mouse

2.2.1 Downloading and importing the data

First create a R project for this analysis e.g `coding-together-week-2`

The dataset is stored on-line, so we use the utility function `download.file()` to download the csv file to our data folder. (Did you create a data folder in the project directory?)

Here we pass the `url =` and `destfile =` arguments to `download.file()`.

As we have the `tidyverse` packages we can use the `readr` package it contains, which has many functions for reading files, including `read_csv()`. The advantage of `read_csv()` over base R `read.csv()` is that it defaults to reading strings as character vectors rather than factors (categorical variables) which is usually what we want.

As we read the data into our environment we need to assign a label to the



Figure 2.1: Merriam's kangaroo rat, *Dipodomys merriami*⁶

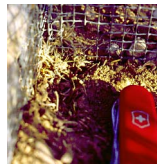


Figure 2.2: Kangaroo Rat exclusion

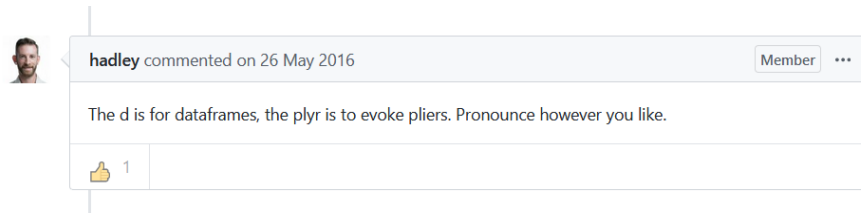


Figure 2.3: [Why is it called ‘dplyr’?](<https://github.com/tidyverse/dplyr/issues/1857>)

object we are creating. Here we assign the dataset to an object called `surveys` using the `<-` assignment operator.

```
# Download the data
download.file(url="https://ndownloader.figshare.com/files/2292169",
              destfile = "data/portal_data_joined.csv")

# Read into R as an object called surveys
surveys <- read_csv("data/portal_data_joined.csv")
```

2.3 dplyr

`dplyr`⁷ “*is a grammar of data manipulation*”. Concretely, it’s a package of functions from the tidyverse that have been created for tasks that require manipulation of data stored in data frames⁸.

We’re going to use the most common verbs in `dplyr` to examine the Portal Project surveys data.

2.3.1 Filter rows with `filter()`

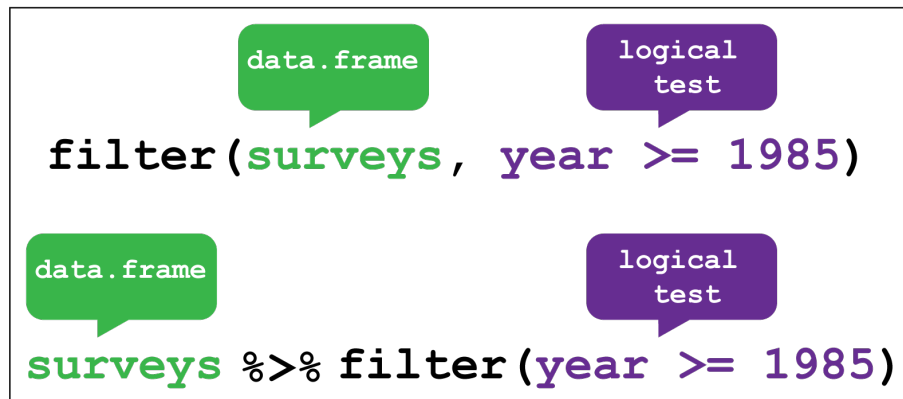
The first verb to consider is the `filter()` function which enables us to subset observations based on their value.

Consider the surveys data and sub-setting observations that only occurred from 1985 onwards. It’s fairly natural to say “*filter the survey where the year variable is equal or greater than 1985*”. And indeed this is how we use `filter()` as a verb.

Figure 2.4 shows how we give the filter function two arguments. The first is the data frame, the second is the variable and condition on which we wish to filter.

⁷<https://dplyr.tidyverse.org/>

⁸data-frames

Figure 2.4: `dplyr::filter()`

An alternative way to use `filter()` is to “pipe” the function using pipe `%>%` from the `magrittr` package which you can think of as using the word “then”. We take our data set *then* filter it. Using the pipe makes more sense when combining several operations.

Ctrl+Shift+M is a keyboard short cut to create a pipe.

For the filter itself, from R4DS:

“To use filtering effectively, you have to know how to select the observations that you want using the comparison operators. R provides the standard suite: `>`, `>=`, `<`, `<=`, `!=` (not equal), and `==` (equal). . . . For other types of combinations, you’ll need to use Boolean operators yourself: `&` is “and”, `|` is “or”, and `!` is “not”.”

See Figure 5.1⁹ in R4DS for to see how these operators work.

(Note that we aren’t assigning the output to an object here, so we can see it.)

```
# Filter observations that only occurred from 1985 onwards
filter(surveys, year >= 1985)
```

```
## # A tibble: 25,290 x 13
##   record_id month   day  year plot_id species_id sex  hindfoot_length
##   <dbl> <dbl> <dbl> <dbl> <dbl> <chr>    <chr>    <dbl>
## 1    10606     7    24  1985     2 NL      F        30
## 2    10617     7    24  1985     2 NL      M        32
## 3    10627     7    24  1985     2 NL      F        32
```

⁹<https://r4ds.had.co.nz/transform.html#fig:bool-ops>

```
## 4      10720      8      20 1985      2 NL      F      31
## 5      10923     10      13 1985      2 NL      F      31
## 6      10949     10      13 1985      2 NL      F      33
## 7      11215     12       8 1985      2 NL      F      32
## 8      11329      3       9 1986      2 NL      M      34
## 9      11496      5      11 1986      2 NL      F      31
## 10     11498      5      11 1986      2 NL      F      31
## # ... with 25,280 more rows, and 5 more variables: weight <dbl>,
## #   genus <chr>, species <chr>, taxa <chr>, plot_type <chr>
```

An example using Boolean logic, would be to use the “or” operator `|` to filter for the observations only occurring on `plot_type`’s control or long term kangaroo rat exclusion. This time we assign the output to a new data frame called `surveys_filtered`.

Note: as `plot_type` is a character vector we put the terms in quotes, and also the double equals sign `==` “for equal to”.

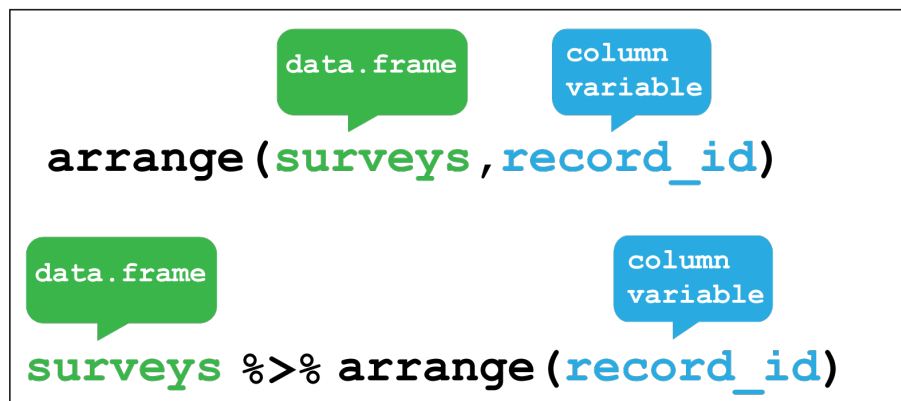
```
# Keep only the rows corresponding with the Control and Long-term Krat Exclosure
surveys_filtered <- surveys %>%
  filter(plot_type == "Control" | plot_type == "Long-term Krat Exclosure")
```

Note: `filter()` only includes rows where the condition is TRUE; it excludes both FALSE and missing NA values. We have to explicitly ask to keep NA values using `is.na()` as an additional filter.

How did I know which `plot_type`’s to filter? I used the `dplyr::distinct()` function, passing the `surveys` data frame and the `plot_type` variable to obtain a list of the unique plot types, from which I determined the Control and Long-term Krat Exclosure plots were the ones I was after. Note that you need to add the argument `.keep_all = TRUE` to `distinct()` to return all the columns in the data frame

```
distinct(surveys, plot_type)
```

```
## # A tibble: 5 x 1
##   plot_type
##   <chr>
## 1 Control
## 2 Long-term Krat Exclosure
## 3 Short-term Krat Exclosure
## 4 Rodent Exclosure
## 5 Spectab exclosure
```

Figure 2.5: `dplyr::arrange()`

2.3.2 Arrange rows with `arrange()`

The next verb is `arrange()` which also operates on the rows, and enables you to arrange the observations in a data frame according to one or more variables.

As with `filter()` we supply the variable or variables of interest as the arguments to `arrange()`.

From R4DS¹⁰:

“If you provide more than one column name, each additional column will be used to break ties in the values of preceding columns... Missing values are always sorted at the end.”

Figure 2.5 shows how to arrange the observations according to the `record_id` variable.

```
surveys %>% arrange(record_id)
```

```
## # A tibble: 34,786 x 13
##   record_id month   day  year plot_id species_id sex  hindfoot_length
##       <dbl> <dbl> <dbl> <dbl>   <dbl>   <chr>   <chr>         <dbl>
## 1         1     7    16  1977     2    NL      M             32
## 2         2     7    16  1977     3    NL      M             33
## 3         3     7    16  1977     2    DM      F             37
## 4         4     7    16  1977     7    DM      M             36
## 5         5     7    16  1977     3    DM      M             35
## 6         6     7    16  1977     1   PF      M             14
```

¹⁰<https://r4ds.had.co.nz/transform.html#arrange-rows-with-arrange>

```
## 7      7      7      16 1977      2 PE      F      NA
## 8      8      7      16 1977      1 DM      M      37
## 9      9      7      16 1977      1 DM      F      34
## 10     10     7      16 1977      6 PF      F      20
## # ... with 34,776 more rows, and 5 more variables: weight <dbl>,
## #   genus <chr>, species <chr>, taxa <chr>, plot_type <chr>
```

Or we could use `arrange()` to find the record with the shortest hindfoot. *Note:* `arrange()` defaults to ascending order.

```
surveys %>% arrange(hindfoot_length)
```

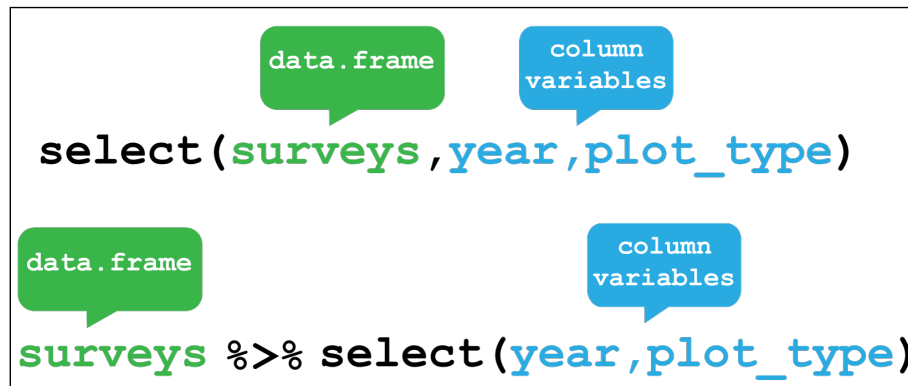
```
## # A tibble: 34,786 x 13
##   record_id month   day year plot_id species_id sex hindfoot_length
##   <dbl> <dbl> <dbl> <dbl> <dbl> <chr>      <chr>      <dbl>
## 1    31400     9    30 2000     19 PB        M          2
## 2    10067     3    16 1985     19 RM        M          6
## 3    19567     1     8 1992     19 BA        M          6
## 4    19015     9     9 1991     19 BA        F          7
## 5    21036     8    19 1993     21 PF        F          7
## 6    31457     9    31 2000     6 RM        M          8
## 7    19191    10    11 1991    13 PF        F          8
## 8     5801     4    29 1982     7 RM        <NA>       8
## 9    33647     3    14 2002     3 PF        M          9
## 10   20562    12    22 1992     5 RM        F          9
## # ... with 34,776 more rows, and 5 more variables: weight <dbl>,
## #   genus <chr>, species <chr>, taxa <chr>, plot_type <chr>
```

To find the Cactus Mouse, (`species_id == "PE"`) with the longest hindfoot we combine `filter()` with `arrange()` using the pipe:

Hint Use the `desc()` function to arrange from biggest to smallest.

```
surveys %>%
  filter(species_id == "PE") %>%
  arrange(desc(hindfoot_length))
```

```
## # A tibble: 1,299 x 13
##   record_id month   day year plot_id species_id sex hindfoot_length
##   <dbl> <dbl> <dbl> <dbl> <dbl> <chr>      <chr>      <dbl>
## 1    1202     9     3 1978     7 PE        F          30
## 2     517     1     8 1978     2 PE        M          26
## 3   32443     8    25 2001    23 PE        F          24
## 4    5080    12    30 1981    15 PE        F          23
```

Figure 2.6: `dplyr::select()`

```
## 5      5090    12    30 1981      15 PE      F      23
## 6     33700     3    14 2002       9 PE      F      23
## 7       604     2    18 1978       2 PE      M      22
## 8     12459     3     2 1987       2 PE      F      22
## 9     13992     1    24 1988       2 PE      M      22
## 10    14516     5    15 1988       2 PE      F      22
## # ... with 1,289 more rows, and 5 more variables: weight <dbl>,
## #   genus <chr>, species <chr>, taxa <chr>, plot_type <chr>
```

2.3.3 Select columns with `select()`

Often your data contains variables you don't need for the analysis you are performing, or you want to subset them to share with others. To select only the ones you need, or explore subsets of the variables, the `select()` verb enables you to keep only the columns of interest.

Figure 2.6 shows the use of `select()` to choose only the `year` and `plot_type` columns, with or without the pipe.

Selecting the variables contained in the columns can be done in various ways. For example, by the column number, the variable name or by range. Check the help function `?select` for more options.

```
# Select the year and plot type columns
surveys %>% select(year, plot_type)
```

```
## # A tibble: 34,786 x 2
##   year plot_type
##   <dbl> <chr>
```

```
## 1 1977 Control
## 2 1977 Control
## 3 1977 Control
## 4 1977 Control
## 5 1977 Control
## 6 1977 Control
## 7 1977 Control
## 8 1978 Control
## 9 1978 Control
## 10 1978 Control
## # ... with 34,776 more rows
```

We can also use negative selection by adding a minus sign – to variables we wish to discard. Here we discard `sex`, `hindfoot_length` and `weight` from the `surveys_filtered` object and keep everything else:

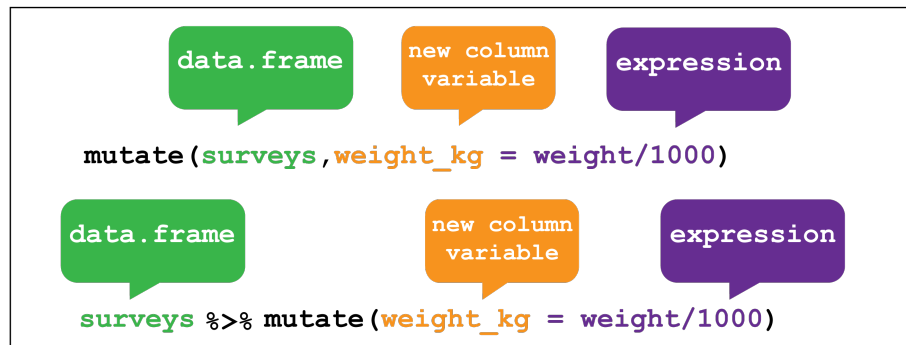
```
# Select everything except sex, hindfoot and weight
surveys_filtered %>% select(-sex, -hindfoot_length, -weight)
```

```
## # A tibble: 20,729 x 10
##   record_id month   day  year plot_id species_id genus species taxa
##   <dbl> <dbl> <dbl> <dbl> <dbl> <chr>      <chr> <chr> <chr>
## 1         1     7    16  1977     2 NL        Neot~ albigu~ Rode~
## 2        72     8    19  1977     2 NL        Neot~ albigu~ Rode~
## 3       224     9    13  1977     2 NL        Neot~ albigu~ Rode~
## 4       266    10    16  1977     2 NL        Neot~ albigu~ Rode~
## 5       349    11    12  1977     2 NL        Neot~ albigu~ Rode~
## 6       363    11    12  1977     2 NL        Neot~ albigu~ Rode~
## 7       435    12    10  1977     2 NL        Neot~ albigu~ Rode~
## 8       506     1     8  1978     2 NL        Neot~ albigu~ Rode~
## 9       588     2    18  1978     2 NL        Neot~ albigu~ Rode~
## 10      661     3    11  1978     2 NL        Neot~ albigu~ Rode~
## # ... with 20,719 more rows, and 1 more variable: plot_type <chr>
```

2.3.4 Create new variables with `mutate()`

Another common task is to create a new variable or variables, often from existing data within the data frame. For this we use the `mutate()` verb. It follows the same syntax as for `filter()`, `arrange()` and `select()` in that the first argument is the dataset, and the subsequent arguments are the new variables we wish to create.

Figure 2.7 shows how to create a new variable `weight_kg` by dividing the existing `weight` variable in grams by 1000.

Figure 2.7: `dplyr::mutate()`

A more complicated mutation, and key to our analysis exploring the question as to whether Kangaroo rats effect the size of the granivore population would be to create a variable that indicates which type of rodent an observation is recording.

To do this we can make use of another `dplyr` function called `case_when()`. This allows us to pass different values to our new `rodent_type` variable **if** they match either `species_id` values corresponding with Kangaroo rats or Granivores.

To remind us, the rodents species surveyed are:

Kangaroo Rats

species_id	Scientific name	Common name
DM	Dipodomys merriami	Merriam's kangaroo rat
DO	Dipodomys ordii	Ord's kangaroo rat
DS	Dipodomys spectabilis	Banner-tailed kangaroo rat

Granivores

species_id	Scientific name	Common name
PP	Chaetodipus penicillatus	Desert pocket mouse
PF	Perognathus flavus	Silky pocket mouse
PE	Peromyscus eremicus	Cactus mouse
PM	Peromyscus maniculatus	Deer Mouse
RM	Reithrodontomys megalotis	Western harvest mouse

The first argument to `case_when()` is the variable and value we want to match, just like `filter()`, for example `species_id == "DM"`, and then we use the tilde operator `~` followed by the value we want give our new variable **if** a we match this condition. Here we want our new variable `rodent_type` to be "Kangaroo Rat".

We do this for every case we want to match. There are other species than rodents in this data, and we have choice to either provide values for each one, ignore them which will lead to the value `NA` for those rows or we can supply a single value to the rest by giving the argument `TRUE` followed by the value. This means if there are other values in `species_id` - if this is true - then give them all the same value. Here we supply the value "Other" for the remaining species: `TRUE ~ "Other"`.


```
# Mutate surveys_filtered
surveys_mutated <- surveys_filtered %>%
  # Create rodent type variable for K-rats and Granivores. Everything else, Other.
  mutate(rodent_type = case_when(
    species_id == "DM" ~ "Kangaroo Rat",
    species_id == "DO" ~ "Kangaroo Rat",
    species_id == "DS" ~ "Kangaroo Rat",
    species_id == "PP" ~ "Granivore",
    species_id == "PF" ~ "Granivore",
    species_id == "PE" ~ "Granivore",
    species_id == "PM" ~ "Granivore",
    species_id == "RM" ~ "Granivore",
    TRUE ~ "Other"))

# Check output using distinct()
surveys_mutated %>% select(species_id, rodent_type) %>%
  distinct(species_id, .keep_all = T)
```

```
## # A tibble: 42 x 2
##   species_id rodent_type
##   <chr>      <chr>
## 1 NL        Other
## 2 DM        Kangaroo Rat
## 3 PF        Granivore
## 4 PE        Granivore
## 5 DS        Kangaroo Rat
## 6 PP        Granivore
## 7 SH        Other
## 8 OT        Other
## 9 DO        Kangaroo Rat
## 10 OX       Other
## # ... with 32 more rows
```

2.3.5 Grouped summaries with `group_by()` and `summarise()`

Finally we'll look at the verb `summarise()` and its companion `group_by()`.

`summarise()` collapses a data frame into a single row. For example as shown in Figure 2.8, we could use it to find the average weight of all the animals surveyed in the original data frame using `mean()`. (Here the `na.rm = TRUE` argument is given to remove missing values from the data, otherwise R would return NA when trying to average.)

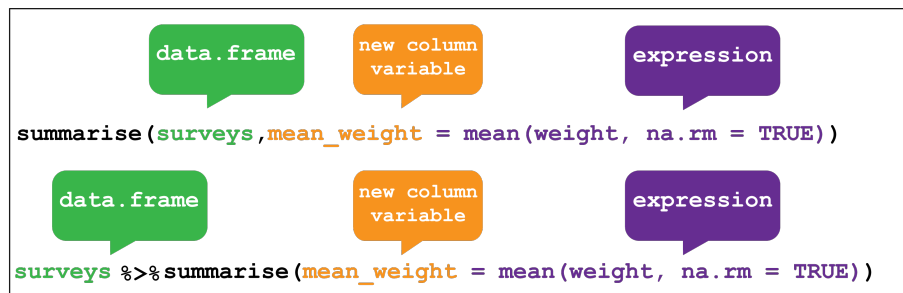


Figure 2.8: dplyr::summarise()

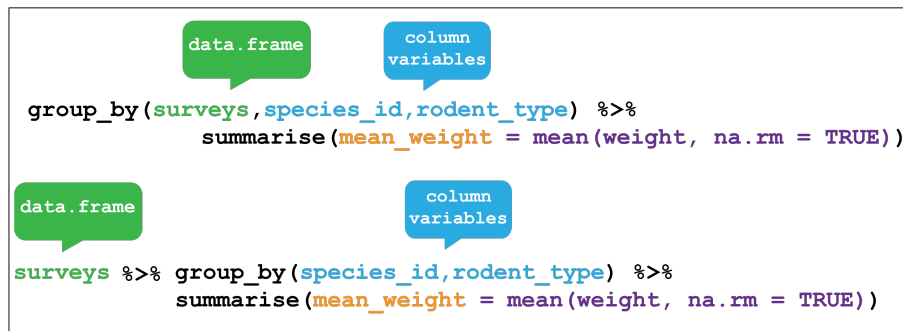


Figure 2.9: dplyr::group_by()

```

surveys %>%
  summarize(mean_weight = mean(weight, na.rm = TRUE))

```

```

## # A tibble: 1 x 1
##   mean_weight
##         <dbl>
## 1         42.7

```

However `summarise()` is most useful when paired with `group_by()` which defines the variables upon which we operate upon.

Figure 2.9 shows how by grouping the observations according to the `sex` and `species_id` variables, we can then calculate the `mean_weight` for each of these groups.

Using `group_by()` with `summarise()` now returns a table with 23 rows instead of single row. Here I use `drop_na(weight)` to only keep rows with no missing values in `weight`. This ensures that no groups with only NA values are returned as NaN which is what would happen if we used `mean(weight, na.rm = TRUE)`.

```
surveys_mutated %>%
  group_by(species_id, rodent_type) %>% drop_na(weight) %>%
  summarize(mean_weight = mean(weight))
```

```
## # A tibble: 23 x 3
## # Groups:   species_id [23]
##   species_id rodent_type mean_weight
##   <chr>      <chr>      <dbl>
## 1 BA        Other          8.76
## 2 DM        Kangaroo Rat    43.4
## 3 DO        Kangaroo Rat    48.7
## 4 DS        Kangaroo Rat   120.
## 5 NL        Other        159.
## 6 OL        Other         31.4
## 7 OT        Other         24.2
## 8 OX        Other         21.2
## 9 PB        Other         31.8
## 10 PE       Granivore     21.4
## # ... with 13 more rows
```

2.4 Using dplyr to explore the effect of Kangaroo Rat exclusion on Granivore populations

Let's use what we've learnt so far to explore the effect of Kangaroo Rats on Granivore populations for the entire time covered in the surveys dataset.

A line plot with time on the x-axis and number of rodents on the y-axis would be one way to visual this, comparing the observations between the control plots and the Kangaroo rat exclusion plots.

One way to do this is to:

1. `filter()` the observations for the control and exclusion plots.
2. Create a new `rodent_type` variable for Kangaroo Rats and Granivores.
3. Create a new variable for time from the existing `day`, `month` and `year` variables.
4. Group the data according to the `rodent_type`, plot_type our time variable, and use `summarise()` to calculate the number of observations for each group.

2.4.1 Re-cap of filter() and mutate()

Let's re-cap steps one and two:

```
# Keep only the rows corresponding with the Control and Long-term Krat Exclosure
surveys_filtered <- surveys %>%
  filter(plot_type == "Control" | plot_type == "Long-term Krat Exclosure")

# Mutate surveys_filtered
surveys_mutated <- surveys_filtered %>%
  # Create rodent type variable for K-rats and Granivores. Everything else, Other.
  mutate(rodent_type = case_when(
    species_id == "DM" ~ "Kangaroo Rat",
    species_id == "DO" ~ "Kangaroo Rat",
    species_id == "DS" ~ "Kangaroo Rat",
    species_id == "PP" ~ "Granivore",
    species_id == "PF" ~ "Granivore",
    species_id == "PE" ~ "Granivore",
    species_id == "PM" ~ "Granivore",
    species_id == "RM" ~ "Granivore",
    TRUE ~ "Other"))
```

2.4.2 Use lubridate to create new time variables

Step three introduces the tidyverse lubridate package¹¹. As the name suggests, this is a package for wrangling dates and times.

It would be clearer to plot the data on three month (quarterly) basis rather than plotting every date in the dataset, so we need to create a variable that contains the quarter in which the observation was made, for each observation.

From lubridate we will use the function make_date() in combination with mutate() first to create a single column date variable from the day, month and year variables. We then use this date variable to create another new variable containing a value for the quarter of the year in which the observation was made quarter using the quarter() function.

We'll assign this output to a new data frame called surveys_subset.

```
library(lubridate)
surveys_subset <- surveys_mutated %>%
  mutate(date = make_date(day = day, month = month, year = year),
         quarter = quarter(date, with_year = TRUE))
```

¹¹<https://lubridate.tidyverse.org/>

2.4.3 Group and summarise the data into quarterly observations

Step four is to group and summarise our quarterly observations.

We group by `rodent_type`, `plot_type` and `quarter` variables. In other words we've grouped the data according to Kangaroo Rat or Granivore, Control plot or Exclusion plot, and the quarter of the year in which the observation occurred.

Then we can calculate the number of captures for each of these groups by using `summarise()` to create a `mean_captures` variable which is equal to the number of rows for that group using the `n()` function. The value of `n` represents the total number of captures for each group per quarter. A quarter of a year is 3 months, so we divide by 3 to calculate the average captures per quarter.

Note: `n()` is a dplyr function that returns the number of observations in the current group.

```
by_quarter <- surveys_subset %>%
  group_by(rodent_type, plot_type, quarter) %>%
  summarise(mean_captures = n()/3)
```

```
by_quarter
```

```
## # A tibble: 567 x 4
## # Groups:   rodent_type, plot_type [6]
##   rodent_type plot_type quarter mean_captures
##   <chr>      <chr>      <dbl>      <dbl>
## 1 Granivore Control    1977.        5
## 2 Granivore Control    1977.       2.67
## 3 Granivore Control    1978.       3.67
## 4 Granivore Control    1978.        3
## 5 Granivore Control    1978.       4.33
## 6 Granivore Control    1978.       1.33
## 7 Granivore Control    1979.       1.67
## 8 Granivore Control    1979.        2
## 9 Granivore Control    1979.       1.67
## 10 Granivore Control    1980.       7.33
## # ... with 557 more rows
```

These steps have taken us from a table of 34,786 observations to a table of 567 observations.

2.4.4 Create a plot with ggplot

Now we can create a line and point plot, using the `by_quarter` data as our first `ggplot()` argument.

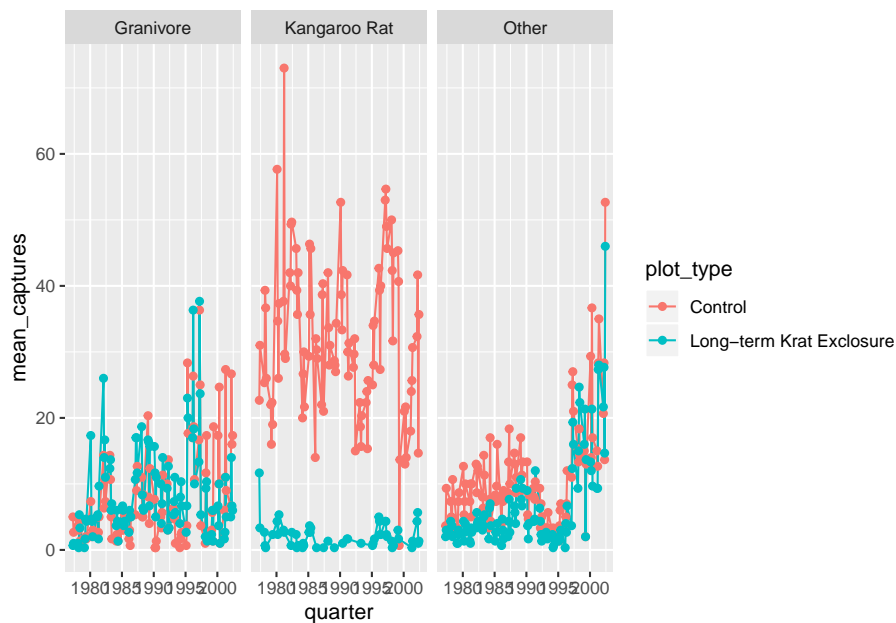
For the aesthetics we are plotting the time on the x-axis using the `quarter` variable, and the quarterly `mean_captures` on the y-axis, and we colour the data by `plot_type`.

Then we create line and point geometric mappings, and split the plot into two facets using `facet_wrap` according to `rodent_type`.

```
ggplot(by_quarter,
       aes(x=quarter, y=mean_captures, colour=plot_type)) +
  geom_line() +
  geom_point() +
  facet_wrap(~ rodent_type)
```

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

```
## Warning: Removed 5 rows containing missing values (geom_point).
```



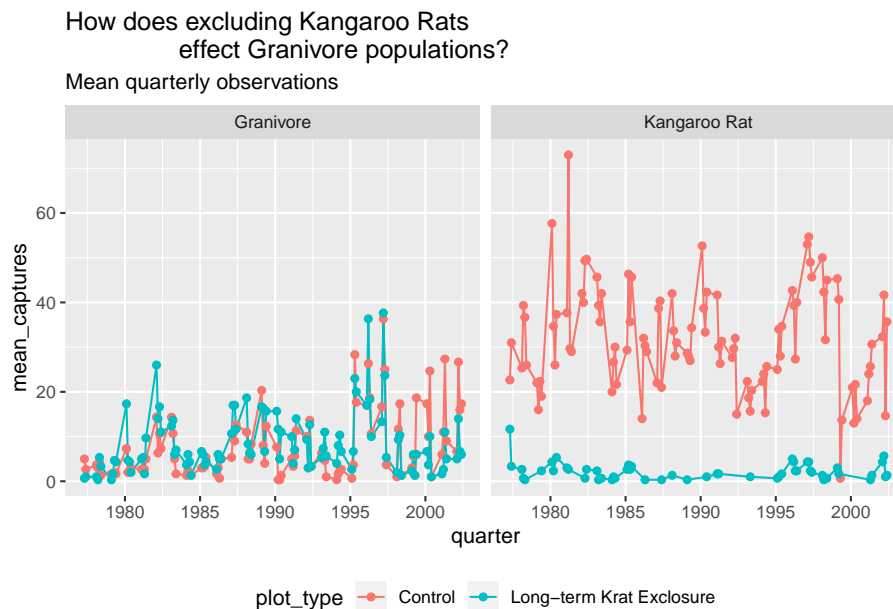
But it would be more useful to only plot the Kangaroo Rats and Granivores data, so let's filter out the other species. And move the legend to the bottom of the plot and add a title.

2.4. USING DPYLR TO EXPLORE THE EFFECT OF KANGAROO RAT EXCLUSION ON GRANIVORE POPULATIONS55

```
by_quarter %>%  
  filter(rodent_type != "Other") %>%  
  ggplot(aes(x=quarter,y=mean_captures,colour=plot_type)) +  
  geom_line() +  
  geom_point() +  
  facet_wrap(~ rodent_type) +  
  theme(legend.position = "bottom") +  
  ggtitle("How does excluding Kangaroo Rats  
    effect Granivore populations?",  
    subtitle = "Mean quarterly observations")
```

Warning: Removed 1 rows containing missing values (geom_path).

Warning: Removed 3 rows containing missing values (geom_point).



Challenge Can you do a similar analysis, but plotting the data only from 1980 to 2000 and by semester?

Chapter 3

Data wrangling II

Following on from chapter 2 this lesson deals with some common tidying problems with data using the `tidyr` package¹. By the end of this chapter the learner will:

- have learnt how to transform rows and columns to reorganise data
- have learnt some ways to deal with missing values
- have learnt how to join data contained in separate tables into a single table

3.1 Reshaping data with pivots

As you will recall tidy data² means that in a table:

1. Every variable has its own column.
2. Every observation has its own row.
3. Each value has its own cell.

Two common problems making your data untidy are that:

1. A single variable is spread across multiple columns.
2. A single observation is distributed across multiple rows.

In the first case the column names are actually the variable we are interested in, making our table **wide**.

¹<https://tidyr.tidyverse.org/>

²tidy-data

In the second case, the observation is contained in several rows instead of a single row, making our table **long**.

Hence `tidyr` has functions that **pivot** (as in turning) a table from **wide-to-long** by reducing the number of columns and increasing the number of rows. Or from **long-to-wide** by reducing the number of rows and increasing the number of columns.

Usually, the hard part is identifying in a dataset our variables and our observations, as it is not always obvious which is which.

3.1.1 `tidyr::pivot_longer`

First we'll consider the case when our variable has been recorded as column names by returning to a version of the Portal surveys data³.

A table containing the mean weight of 10 rodent species on each plot from the rodent survey data can be read directly into a `surveys_spread` object using the code below.

```
surveys_spread <- read_csv("https://raw.githubusercontent.com/ab604/ab604.github.io/main/surveys_spread.csv")
```

Feel free to explore the data, and snapshot is shown in Figure 3.1.

Imagine that we recorded the mean weight of each rodent species on a plot in the field. It makes sense to put the species as column headings, along with the plot id and then record the values in each cell.

However, really our variables of interest are the rodent species and our observational units, the rows, should contain the mean weight for a rodent species in a plot. Hence we need to reduce the number of columns and create a longer table.

To do this we `pivot_longer()` by using `names_to = "genus"` to create a new `genus` variable for the existing column heading, and `values_to = "mean_weight"` to create a variable `mean_weight` for the values. We put a minus sign before the variable `-plot_id` to tell the function not to use these values in the new variable column.

```
surveys_spread %>%
  pivot_longer(names_to = "genus", values_to = "mean_weight", -plot_id)
```

```
## # A tibble: 240 x 3
##   plot_id genus      mean_weight
##   <dbl> <chr>      <dbl>
```

³portal-project

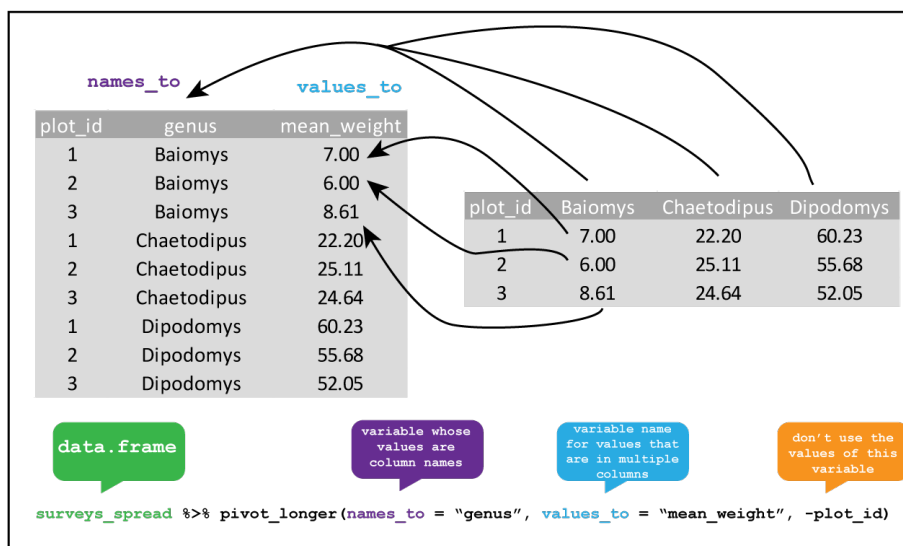


Figure 3.1: `tidyr::pivot_longer` The genus of the rodents have been used as column headings for the weights of each animal. By creating new variables `genus` which takes the column names, and another variable `mean_weight` which takes the cell values, and but not the `plot_id` column we pivot from a wide table to a long table.

```
## 1      1 Baiomys      7
## 2      1 Chaetodipus 22.2
## 3      1 Dipodomys   60.2
## 4      1 Neotoma     156.
## 5      1 Onychomys   27.7
## 6      1 Perognathus  9.62
## 7      1 Peromyscus   22.2
## 8      1 Reithrodontomys 11.4
## 9      1 Sigmodon    NA
## 10     1 Sperophilus  NA
## # ... with 230 more rows
```

3.1.2 tidyr::pivot_wider

If we wanted to go the other way, from wide to long, then we need to take values from a single column to become variables names of multiple columns, populated with values from an existing variable.

A version of the wide table in Figure 3.2 can be downloaded into our environment and assigned as `surveys_gw` as before.

```
surveys_gw <- read_csv("https://raw.githubusercontent.com/ab604/ab604.github.io/master/
```

This time we use `pivot_wider()` with the arguments `names_from` for the column we want to use to create variables, and `values_from` for the column whose values we want populate our new variable columns with.

```
surveys_gw %>%
  pivot_wider(names_from = genus, values_from = mean_weight)
```

```
## # A tibble: 24 x 11
##   plot_id Baiomys Chaetodipus Dipodomys Neotoma Onychomys Perognathus
##   <dbl>   <dbl>      <dbl>    <dbl>   <dbl>   <dbl>      <dbl>
## 1      1      7      22.2     60.2   156.    27.7      9.62
## 2      2      6      25.1     55.7   169.    26.9      6.95
## 3      3  8.61      24.6     52.0   158.    26.0      7.51
## 4      5  7.75      18.0     51.1   190.    27.0      8.66
## 5     18   9.5      26.8     61.4   149.    26.6      8.62
## 6     19  9.53      26.4     43.3   120.    23.8      8.09
## 7     20   6      25.1     65.9   155.    25.2      8.14
## 8     21  6.67      28.2     42.7   138.    24.6      9.19
## 9      4   NA      23.0     57.5   164.    28.1      7.82
## 10     6   NA      24.9     58.6   180.    25.9      7.81
## # ... with 14 more rows, and 4 more variables: Peromyscus <dbl>,
## #   Reithrodontomys <dbl>, Sigmodon <dbl>, Sperophilus <dbl>
```

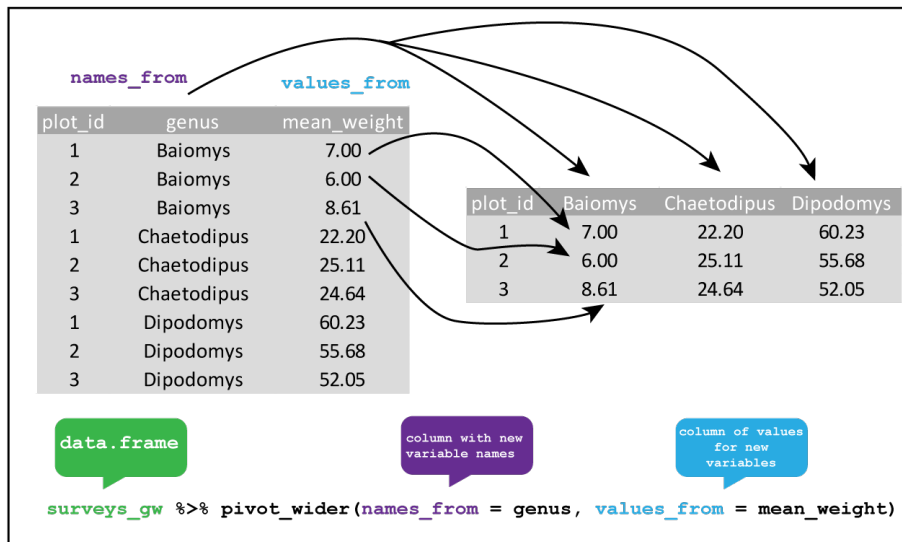


Figure 3.2: `tidyr::pivot_wider` From long table `surveys_gw` the `genus` column contains the values that become variables using `names_from` and the `mean_weight` column contains the values that fill the new columns using `values_from` in the pivot from long to wide.

3.2 Missing values

In R missing values are represented as `NA` (or `NaN` for an undefined mathematical operation such as dividing by zero).

As discussed in R4DS⁴ values can be missing in two ways:

- **Explicitly**, i.e. flagged with `NA`.
- **Implicitly**, i.e. simply not present in the data.

If we had a subset of the surveys data that looked like this table:

```
# Create a table with missing values
surveys_ms <- tibble(year = c(1991,1991,1991,1991,1992,1992,1992),
  qtr = c(1,2,3,4,1,2,4),
  mean_weight = c(3.75,2.50,NA,8.50,7.50,2.25,2.50))

surveys_ms
```

```
## # A tibble: 7 x 3
```

⁴<https://r4ds.had.co.nz/tidy-data.html#missing-values-3>

```
##   year   qtr mean_weight
##   <dbl> <dbl>      <dbl>
## 1 1991     1         3.75
## 2 1991     2         2.5
## 3 1991     3         NA
## 4 1991     4         8.5
## 5 1992     1         7.5
## 6 1992     2         2.25
## 7 1992     4         2.5
```

Then we can see that in the third quarter of 1991, no data was recorded by the explicit NA value. However the third quarter of 1992 is missing altogether, hence it is *implicitly* missing.

Another issue is that explicit missing values are often recorded in real data in various ways e.g. an empty cell or as a dash. We can't cover all cases, but the general advice is to do some manual inspection of your data in addition to using R to understand how missing values have been recorded if there are any. In an ideal world data comes with a “code book” that explains the data, but this often doesn't happen. Functions such as `read_csv()` allow you to supply a vector of values representing NA which will convert these values in your input to NAs.

Once you have identified missing values, in general there two ways to deal with them:

1. Drop incomplete observations
2. Complete the missing observations: fill or impute values.

See also `tidyr` functions for missing values⁵.

3.2.1 Checking for explicit missing values using R

In addition to manual inspection, one way to check for explicit missing values coded as NA in your data frame is to use the `is.na()` function which returns a logical TRUE or FALSE vector of values.

Using this to check a single variable could be done by combining it with `select()` for example using `surveys_ms`:

```
surveys_ms %>%
  select(mean_weight) %>%
  is.na()
```

⁵<https://tidyr.tidyverse.org/reference/index.html#section-missing-values>

```
##      mean_weight
## [1,]      FALSE
## [2,]      FALSE
## [3,]       TRUE
## [4,]      FALSE
## [5,]      FALSE
## [6,]      FALSE
## [7,]      FALSE
```

Or with `filter()` to return the row where there is a missing value for `mean_weight`.

```
surveys_ms %>%
  filter(is.na(mean_weight) == TRUE)
```

```
## # A tibble: 1 x 3
##   year   qtr mean_weight
##   <dbl> <dbl>     <dbl>
## 1  1991     3         NA
```

A more complicated use would be to combine `is.na()` with another function such `sum()` to provide the total number of missing values for a variable, or to combine `sum()` with `complete.cases()` to check each row for missing values.

For example, to find the number of observations (rows) in `surveys` with no missing values:

```
sum(complete.cases(surveys))
```

```
## [1] 30676
```

And for a single variable, we could extend our use of `select`:

```
surveys_ms %>%
  select(mean_weight) %>%
  is.na() %>%
  sum()
```

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

Extending this find the missing values per variable in a whole data frame requires introducing more syntax and the use of a map function from the `purrr`

package. (Base R can also do this, but we’re staying in the tidyverse where possible).

The idea here is that we want to do the same calculation *mapped* across each variable. The calculation here being count the number of missing values in each column.

We pipe `surveys` to the `map_dfr()` function where `dfr` means return a data frame. The `~` means we are applying a formula to the `surveys` input, which in this case the formula is going to be `sum(is.na(.))` where `.` is the argument for the input variable. The `map` function then does this for each variable in the `surveys` dataframe and returns the output as a data frame. I’ve piped the output to `glimpse()` for readability.

In words what this syntax is saying is **“take the surveys dataframe and for each column check if each value is NA, then sum the number of NAs in each column and return the totals for all the columns as a dataframe.”**

This is pretty complicated if you’ve never seen this before, but hopefully you can follow the idea.

This could be combined with `filter()` or `select()` prior to the `map` function if you wanted to subset the data further for example.

See R4DS map functions⁶ for more details.

```
surveys %>%
  map_dfr(~ sum(is.na(.))) %>%
  glimpse()
```

```
## Observations: 1
## Variables: 13
## $ record_id      <int> 0
## $ month          <int> 0
## $ day            <int> 0
## $ year           <int> 0
## $ plot_id        <int> 0
## $ species_id     <int> 0
## $ sex            <int> 1748
## $ hindfoot_length <int> 3348
## $ weight         <int> 2503
## $ genus          <int> 0
## $ species        <int> 0
## $ taxa           <int> 0
## $ plot_type      <int> 0
```

⁶<https://r4ds.had.co.nz/iteration.html#the-map-functions>

As we might expect the missing values are all for variables that record measurements for the rodents.

3.2.2 Dropping missing values

The simplest solution to observations with missing values is to drop those from the data set. If it makes sense to do this, then `tidyr::drop_na()` makes it easy to do this. **Note:** This will create implicit missing values.

In Section 3.2.1 we found 30,676 rows with no missing values by using `complete.cases()` on the `surveys` data of 34,786 observations.

Therefore we expect passing `surveys` to `drop_na()` will return a dataframe of 30,676 observations:

```
surveys %>%
  drop_na() %>%
  glimpse()

## Observations: 30,676
## Variables: 13
## $ record_id      <dbl> 845, 1164, 1261, 1756, 1818, 1882, 2133, 2184,...
## $ month          <dbl> 5, 8, 9, 4, 5, 7, 10, 11, 1, 5, 5, 7, 10, 11, ...
## $ day            <dbl> 6, 5, 4, 29, 30, 4, 25, 17, 16, 18, 18, 8, 1, ...
## $ year           <dbl> 1978, 1978, 1978, 1979, 1979, 1979, 1979, 1979...
## $ plot_id        <dbl> 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2...
## $ species_id     <chr> "NL", "NL", "NL", "NL", "NL", "NL", "NL", "NL"...
## $ sex            <chr> "M", "M", "M", "M", "M", "M", "F", "F", "F", "...
## $ hindfoot_length <dbl> 32, 34, 32, 33, 32, 32, 33, 30, 33, 31, 33, 30...
## $ weight         <dbl> 204, 199, 197, 166, 184, 206, 274, 186, 184, 8...
## $ genus          <chr> "Neotoma", "Neotoma", "Neotoma", "Neotoma", "N...
## $ species        <chr> "albigula", "albigula", "albigula", "albigula"...
## $ taxa           <chr> "Rodent", "Rodent", "Rodent", "Rodent", "Roden...
## $ plot_type      <chr> "Control", "Control", "Control", "Control", "C...
```

`drop_na()` can accept variables arguments, meaning only the observations with missing values in those columns will be dropped.

For example, here we drop only missing weight observations, so the rows which have missing values for `hindfoot_length` or `sex` are kept.

```
surveys %>%
  drop_na(weight) %>%
  glimpse()
```

```
## Observations: 32,283
## Variables: 13
## $ record_id      <dbl> 588, 845, 990, 1164, 1261, 1453, 1756, 1818, 1...
## $ month          <dbl> 2, 5, 6, 8, 9, 11, 4, 5, 7, 10, 11, 1, 5, 5, 7...
## $ day            <dbl> 18, 6, 9, 5, 4, 5, 29, 30, 4, 25, 17, 16, 18, ...
## $ year           <dbl> 1978, 1978, 1978, 1978, 1978, 1978, 1979, 1979...
## $ plot_id        <dbl> 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2...
## $ species_id     <chr> "NL", "NL", "NL", "NL", "NL", "NL", "NL", "NL"...
## $ sex            <chr> "M", "M", "M", "M", "M", "M", "M", "M", "M", "...
## $ hindfoot_length <dbl> NA, 32, NA, 34, 32, NA, 33, 32, 32, 33, 30, 33...
## $ weight         <dbl> 218, 204, 200, 199, 197, 218, 166, 184, 206, 2...
## $ genus          <chr> "Neotoma", "Neotoma", "Neotoma", "Neotoma", "N...
## $ species        <chr> "albigula", "albigula", "albigula", "albigula"...
## $ taxa           <chr> "Rodent", "Rodent", "Rodent", "Rodent", "Roden...
## $ plot_type      <chr> "Control", "Control", "Control", "Control", "C..."
```

3.2.3 Completing missing values

There are numerous ways to complete missing values, but what they generally have in common is the approach of guessing the missing value based on existing information, otherwise known as imputation⁷. Here we'll cover a couple of ways to do it with `dplyr` and `tidyr` functions.

First, let's deal with implicit missing values using `tidyr::complete()`.

Imagine we have the table `surveys_ms` which is missing the value for the `mean_weight` for the third quarter of 1991 and all observations for the third quarter of 1992:

```
surveys_ms
```

```
## # A tibble: 7 x 3
##   year   qtr mean_weight
##   <dbl> <dbl>       <dbl>
## 1 1991     1         3.75
## 2 1991     2         2.5
## 3 1991     3         NA
## 4 1991     4         8.5
## 5 1992     1         7.5
## 6 1992     2         2.25
## 7 1992     4         2.5
```

To add the row for the third quarter of 1992 we use `complete()` with the `year` and `qtr` variables as arguments. The function finds all the unique combinations

⁷[https://en.wikipedia.org/wiki/Imputation_\(statistics\)](https://en.wikipedia.org/wiki/Imputation_(statistics))

of year and qtr and then adds any that are missing to create a complete set of observations for 1991 and 1992 with explicit missing values.

```
surveys_ms %>%
  complete(year, qtr)
```

```
## # A tibble: 8 x 3
##   year   qtr mean_weight
##   <dbl> <dbl>     <dbl>
## 1 1991     1         3.75
## 2 1991     2         2.5
## 3 1991     3         NA
## 4 1991     4         8.5
## 5 1992     1         7.5
## 6 1992     2         2.25
## 7 1992     3         NA
## 8 1992     4         2.5
```

Next let's consider a complete table `surveys_ic` with an explicit missing value for the `species_id`.

```
surveys_ic <- tibble(species_id = c("DM", "DM", NA, "DS", "DS", "DS"),
                     mean_weight = c(3.75, 2.50, 8.50, 7.50, 5.50, 2.50))
surveys_ic
```

```
## # A tibble: 6 x 2
##   species_id mean_weight
##   <chr>         <dbl>
## 1 DM           3.75
## 2 DM           2.5
## 3 <NA>         8.5
## 4 DS           7.5
## 5 DS           5.5
## 6 DS           2.5
```

In this case we might reasonably assume that the missing value is DM as we have six observations on two species.

We can use `tidyr::fill()` to replace NA with the last non-missing value for `species_id`. This is also known as last observation carried forward.

Passing `species_id` to `fill()` completes the table:

```
surveys_ic %>%
  fill(species_id)
```

```
## # A tibble: 6 x 2
##   species_id mean_weight
##   <chr>         <dbl>
## 1 DM           3.75
## 2 DM           2.5
## 3 DM           8.5
## 4 DS           7.5
## 5 DS           NA
## 6 DS           2.5
```

Another common strategy is to impute missing values by using the mean or the median of existing values for the same variable.

We can do that using `dplyr::coalesce()`⁸ which is a function that finds the first non-missing value in a variable and then replaces it using the second argument.

For example, if we return to `surveys_ms` we used `complete()` to complete the observations, but we have two NAs in the `mean_weight` column.

Let's impute the missing values by using the median value for `mean_weight` to replace the NA values.

We can `mutate()` to overwrite the `mean_weight` variable (be careful when you do this!) using `coalesce()` with `mean_weight` as the first argument to look for missing values, and then the `median()` function is used to replace the missing values with the median `mean_weight`, remembering to remove NA.

```
surveys_ms %>%
  complete(year, qtr) %>%
  mutate(mean_weight = coalesce(mean_weight,
                                median(mean_weight, na.rm = TRUE)))
```

```
## # A tibble: 8 x 3
##   year  qtr mean_weight
##   <dbl> <dbl>         <dbl>
## 1 1991     1         3.75
## 2 1991     2         2.5
## 3 1991     3         3.12
## 4 1991     4         8.5
## 5 1992     1         7.5
```

⁸<https://dplyr.tidyverse.org/reference/coalesce.html>

```
## 6 1992      2      2.25
## 7 1992      3      3.12
## 8 1992      4      2.5
```

This gives us a complete table with . Whether it makes sense to do this is another question, and you should think carefully about your missing value strategy as it will influence your final output and conclusions.

Let's repeat part of the analysis we did to find the `mean_weight`, and now `mean_hindfoot`, for the full `surveys` dataset, but this time we'll complete the table by imputing values and compare the result to the result when we drop the observations with missing values.

For simplicity, let's just look at kangaroo rats. Here I introduce the `%in%` operator with `filter` and vector containing the `species_id` for the kangaroo rats.

This leaves 16,127 observations.

```
krats <- surveys %>%
  filter(species_id %in% c("DM","DS","DO"))

krats %>% glimpse()
```

```
## Observations: 16,127
## Variables: 13
## $ record_id      <dbl> 3, 226, 233, 245, 251, 257, 259, 268, 346, 350...
## $ month          <dbl> 7, 9, 9, 10, 10, 10, 10, 10, 11, 11, 11, 11, 1...
## $ day            <dbl> 16, 13, 13, 16, 16, 16, 16, 16, 12, 12, 12, 12...
## $ year           <dbl> 1977, 1977, 1977, 1977, 1977, 1977, 1977, 1977...
## $ plot_id        <dbl> 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2...
## $ species_id     <chr> "DM", "DM", "DM", "DM", "DM", "DM", "DM", "DM"...
## $ sex            <chr> "F", "M", "M", "M", "M", "M", "M", "M", "F", "F", "...
## $ hindfoot_length <dbl> 37, 37, 25, 37, 36, 37, 36, 36, 37, 37, 38, 36...
## $ weight         <dbl> NA, 51, 44, 39, 49, 47, 41, 55, 36, 47, 44, 40...
## $ genus          <chr> "Dipodomys", "Dipodomys", "Dipodomys", "Dipodo...
## $ species        <chr> "merriami", "merriami", "merriami", "merriami"...
## $ taxa           <chr> "Rodent", "Rodent", "Rodent", "Rodent", "Roden...
## $ plot_type      <chr> "Control", "Control", "Control", "Control", "C...
```

How many missing values are there in `krats` and for which variables?

```
# How many missing values
krats %>% map_dfr(~ sum(is.na(.))) %>% glimpse()
```

```
## Observations: 1
```

```
## Variables: 13
## $ record_id      <int> 0
## $ month          <int> 0
## $ day            <int> 0
## $ year           <int> 0
## $ plot_id        <int> 0
## $ species_id     <int> 0
## $ sex            <int> 131
## $ hindfoot_length <int> 1136
## $ weight         <int> 617
## $ genus          <int> 0
## $ species        <int> 0
## $ taxa           <int> 0
## $ plot_type      <int> 0
```

Grouping by `species_id` and `sex`, find the `mean_weight` and `mean_hindfoot` when observations with missing values are dropped:

```
krats %>% drop_na() %>% group_by(species_id,sex) %>%
  summarise(mean_weight = mean(weight),
            mean_hindfoot = mean(hindfoot_length))
```

```
## # A tibble: 6 x 4
## # Groups:   species_id [3]
##   species_id sex    mean_weight mean_hindfoot
##   <chr>      <chr>      <dbl>      <dbl>
## 1 DM        F          41.6        35.7
## 2 DM        M          44.3        36.2
## 3 DO        F          48.5        35.5
## 4 DO        M          49.1        35.7
## 5 DS        F          117.        49.6
## 6 DS        M          123.        50.4
```

Now we complete the table, first using `fill()` to impute the missing `sex` of each kangaroo rat based on the last non-missing `sex` observation. Then we group the kangaroo rats according to `species` and `sex`. Then we impute the missing `weight` and `hindfoot_length` values with `mutate()` and `coalesce()` from each groups median value. Finally we summarise again to find the `mean_weight` and `mean_hindfoot` for each group.

```
krats %>%
  fill(sex) %>%
  group_by(species_id,sex) %>%
  mutate(weight = coalesce(weight, median(weight, na.rm = TRUE))),
```

```
hindfoot_length = coalesce(hindfoot_length,
                           median(hindfoot_length, na.rm = TRUE))) %>%
summarise(mean_weight = mean(weight),
          mean_hindfoot = mean(hindfoot_length))
```

```
## # A tibble: 6 x 4
## # Groups:   species_id [3]
##   species_id sex   mean_weight mean_hindfoot
##   <chr>      <chr>      <dbl>      <dbl>
## 1 DM        F         41.6        35.7
## 2 DM        M         44.4        36.2
## 3 DO        F         48.5        35.5
## 4 DO        M         49.2        35.7
## 5 DS        F        118.        49.6
## 6 DS        M        123.        50.3
```

The results are very similar.

3.3 Joining tables

See also R4DS Relational data chapter⁹

Previously we've used data from the Portal project¹⁰ where everything we needed was already contained within a single table, but often we have *related* information spread across multiples tables that we want to analyse. In these situations we need to join pairs of tables to explore relationships of interest.

Note Joins always use two tables. To add a third relationship it would require joining the table created from the first join to another table. And so on.

We can think of three types of join, two of which correspond with `dplyr` verbs:

1. Joins that **mutate** the table. These are joins that create a new variable in one table using observations from another.
2. Joins that **filter** the table. These are joins that keep only a subset of observations from one table based on whether they match the observations in another.
3. Joins that perform **set operations**. These are joins corresponding with the mathematical operation of intersection \cap , union \cup , and difference $-$.

⁹<https://r4ds.had.co.nz/relational-data.html>

¹⁰portal-project

3.3.1 Keys

A key is a variable or set of variables that uniquely identifies an observation in a table. In a simple case only one variable is sufficient, but often several variables are required.

- Primary key: a key that uniquely identifies the observation in its own table e.g. `record_id` in `surveys` is unique to each set of rodent observations.
- Foreign key: a key that uniquely identifies the observation in another table. e.g. if `date` appeared in another table that recorded weather information that we wished to join `surveys` to. The `date` is not unique in `surveys` but it would be in the weather table.

Keys can be both primary and foreign, as they might be primary for one table and foreign in another or vice versa.

It's a good idea to verify a key is primary i.e. uniquely identifies an observation. See the examples in R4DS keys¹¹

If you discover your table lacks a primary key you can add one with `mutate()`.

3.3.2 Mutating joins

`inner_join()`, `left_join()`, `right_join()` and `full_join()`

The data on the

3.3.3 Species

"Portal_rodent_species.csv contains the species codes used in Portal_rodent. Any animal found in a trap is recorded. Non-rodent species are occasionally trapped and so are given species codes. Several columns are also included in the species table to restrict the species list to only rodents, only target species, or only granivores."

3.3.4 Rodent abundance data

"Portal_rodent.csv contains the rodent trapping data. Each individual of a target species is PIT tagged and data on species, location caught (plot and stake), sex, reproductive condition, weight, and hindfoot length are recorded. In almost all cases, you will want to remove negative period codes before

¹¹<https://r4ds.had.co.nz/relational-data.html#keys>

using this data. Negative period codes indicate data collected outside of the normal census protocols, and should absolutely not be used as regular trapping data."

The rodent survey data is a good example of

Does the weather influence the census? The data in this file are hourly and span three weather stations. The first only recorded Air Temperature and Precipitation, so I've created a dataset for the only the date, the air temperature and rainfall columns for the three weather stations.

```
# Rodent survey data
rodent_data <- read_csv("https://raw.githubusercontent.com/ab604/coding-together/master/exercises/por
```

Take a look:

```
rodent_data

## # A tibble: 69,980 x 6
##   date          plot species sex    hfl    wgt
##   <date>        <dbl> <chr>  <chr> <dbl> <dbl>
## 1 1977-07-16      2 <NA>    M     32    NA
## 2 1977-07-16      3 <NA>    M     33    NA
## 3 1977-07-16      2 DM      F     37    NA
## 4 1977-07-16      7 DM      M     36    NA
## 5 1977-07-16      3 DM      M     35    NA
## 6 1977-07-16      1 PF      M     14    NA
## 7 1977-07-16      2 PE      F     NA    NA
## 8 1977-07-16      1 DM      M     37    NA
## 9 1977-07-16      1 DM      F     34    NA
##10 1977-07-16      6 PF      F     20    NA
## # ... with 69,970 more rows
```

```
weather <- read_csv("https://raw.githubusercontent.com/ab604/coding-together/master/exercises/por
```

Take a look:

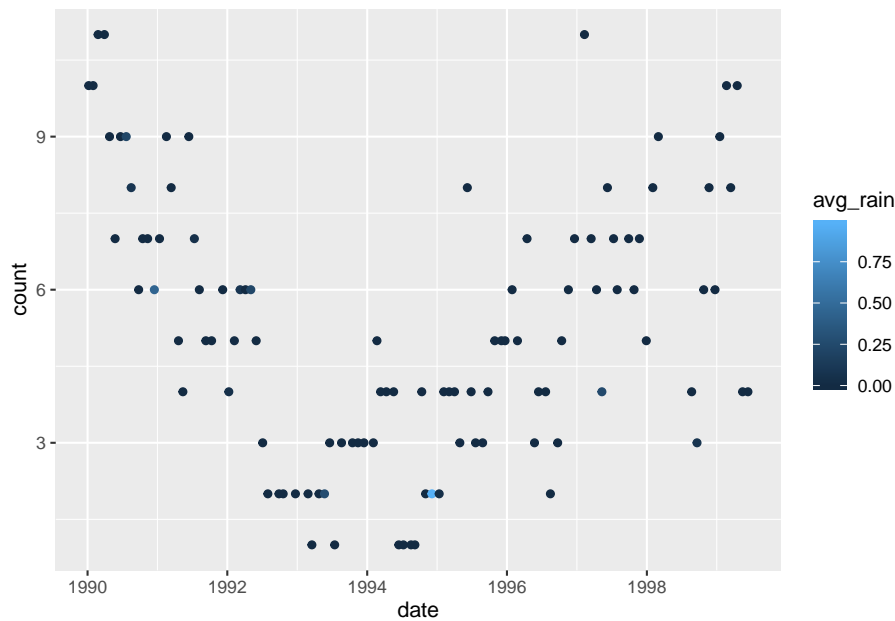
```
weather

## # A tibble: 251,879 x 3
##   date          airtemp precipitation
##   <date>        <dbl>         <dbl>
## 1 1989-06-04    27.5             0
## 2 1989-06-04    28.5             0
## 3 1989-06-04    29.6             0
```

There are multiple observations on the same date as the air temperature and rainfall are measured several times over each 24 hour period. Let's use the median for the air temperature and the mean for the precipitation to create single values for each day.

```
mean_weather %>% inner_join(rodent_data, by = "date") %>%
  glimpse()
```

```
mean_weather %>% inner_join(rodent_data, by = "date") %>%
  filter(species == "DM", plot == 4, date >= '1990-01-01' & date <= '2000-01-01')
  group_by(date, avg_temp, avg_rain) %>% summarise(count = n()) %>%
  ggplot(aes(date, count, colour = avg_rain)) +
  geom_point()
```



```
mean_weather %>% left_join(rodent_data, by = "date") %>%
  glimpse()
```

```
## Observations: 60,752
## Variables: 32
## $ date      <date> 1989-06-04, 1989-06-04, 1989-06-04, 1989-06-04, 198...
## $ mean_temp <dbl> 27.96692, 27.96692, 27.96692, 27.96692, 27.96692, 27...
## $ mean_rain <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0...
## $ recordID  <dbl> 16156, 16157, 16158, 16159, 16160, 16161, 16162, 161...
## $ month     <dbl> 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6...
## $ day       <dbl> 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4...
## $ year      <dbl> 1989, 1989, 1989, 1989, 1989, 1989, 1989, 1989, 1989...
## $ period    <dbl> 135, 135, 135, 135, 135, 135, 135, 135, 135, 135, 13...
## $ plot      <dbl> 4, 7, 3, 3, 4, 8, 14, 2, 3, 13, 9, 3, 2, 4, 8, 10, 1...
## $ note1     <dbl> NA, NA, NA, NA, NA, 13, NA, NA, 13, NA, NA, NA, NA, NA, ...
## $ stake     <dbl> 11, 11, 12, 13, 13, 13, 13, 14, 21, 21, 22, 23, 24, ...
## $ species   <chr> "DM", "RM", "SH", "RM", "SS", "DM", "DM", "SS", "SH"...
## $ sex       <chr> "M", "F", "M", "F", NA, "M", "M", NA, "F", "F", "M",...
## $ reprod    <chr> NA, "Z", NA, "Z", NA, "Z", NA, NA, "Z", "Z", NA, NA,...
## $ age       <chr> NA, NA, "J", NA, NA, NA, NA, NA, NA, NA, NA, "J", NA...
## $ testes    <chr> "S", NA, NA, NA, NA, NA, NA, "S", NA, NA, NA, "M", NA, N...
## $ vagina    <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ pregnant  <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ nipples   <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
```

```
## $ lactation <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ hfl <dbl> 37, 17, 32, 16, NA, 36, 37, NA, 33, 15, 21, 29, 36, ...
## $ wgt <dbl> 46, 9, 67, 8, NA, 34, 51, NA, 111, 11, 18, 60, 44, 2...
## $ tag <chr> "8910", "8783", "8908", "8756", "0", "8760", "7322",...
## $ note2 <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ ltag <chr> "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0...
## $ note3 <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ prevrt <chr> "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0...
## $ prevlet <chr> "0", "0", "0", "0", NA, "0", "0", NA, "0", NA, "0", ...
## $ nestdir <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ neststk <dbl> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ note4 <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ note5 <chr> NA, "R", NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA,...
```

```
mean_weather %>% right_join(rodent_data, by = "date") %>%
  glimpse()
```

```
## Observations: 69,980
## Variables: 32
## $ date <date> 1977-07-16, 1977-07-16, 1977-07-16, 1977-07-16, 197...
## $ mean_temp <dbl> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ mean_rain <dbl> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ recordID <dbl> 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 1...
## $ month <dbl> 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7, 7...
## $ day <dbl> 16, 16, 16, 16, 16, 16, 16, 16, 16, 16, 16, 16, 16, ...
## $ year <dbl> 1977, 1977, 1977, 1977, 1977, 1977, 1977, 1977, 1977...
## $ period <dbl> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1...
## $ plot <dbl> 2, 3, 2, 7, 3, 1, 2, 1, 1, 6, 5, 7, 3, 8, 6, 4, 3, 2...
## $ note1 <dbl> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ stake <dbl> 16, 23, 25, 25, 26, 27, 31, 36, 42, 46, 52, 53, 55, ...
## $ species <chr> NA, NA, "DM", "DM", "DM", "PF", "PE", "DM", "DM", "P...
## $ sex <chr> "M", "M", "F", "M", "M", "M", "F", "M", "F", "F", "F...
## $ reprod <chr> "Z", "Z", NA, "Z", "Z", NA, NA, NA, "Z", "Z", "Z", N...
## $ age <chr> NA, NA, NA, NA, NA, "J", NA, NA, NA, NA, NA, NA, NA, ...
## $ testes <chr> NA, NA, NA, NA, NA, NA, NA, "S", NA, NA, NA, "S", NA...
## $ vagina <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ pregnant <chr> NA, NA, NA, NA, NA, NA, "P", NA, NA, NA, NA, NA, NA, ...
## $ nipples <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ lactation <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ hfl <dbl> 32, 33, 37, 36, 35, 14, NA, 37, 34, 20, 53, 38, 35, ...
## $ wgt <dbl> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ tag <chr> "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0...
## $ note2 <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ ltag <chr> "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0...
## $ note3 <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
```

```
## $ prevrt      <chr> "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0..."
## $ prevlet     <chr> "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0..."
## $ nestdir     <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ neststk     <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, NA, 0, 0, 0, ...
## $ note4       <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ note5       <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
```

```
mean_weather %>% full_join(rodent_data, by = "date") %>%
  glimpse()
```

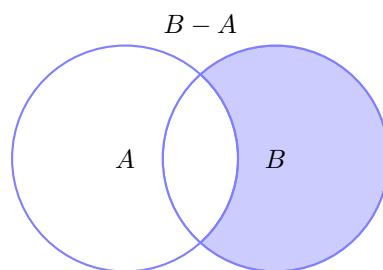
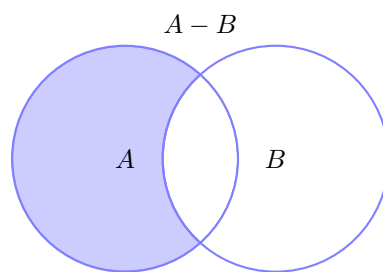
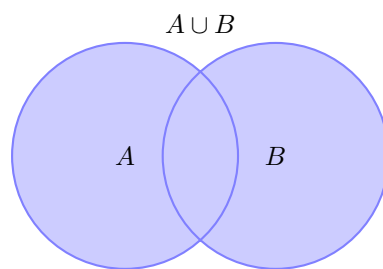
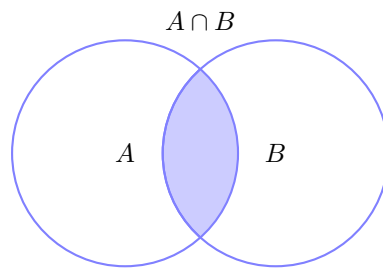
```
## Observations: 79,803
## Variables: 32
## $ date        <date> 1989-06-04, 1989-06-04, 1989-06-04, 1989-06-04, 198...
## $ mean_temp   <dbl> 27.96692, 27.96692, 27.96692, 27.96692, 27.96692, 27...
## $ mean_rain   <dbl> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0...
## $ recordID    <dbl> 16156, 16157, 16158, 16159, 16160, 16161, 16162, 161...
## $ month       <dbl> 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6...
## $ day         <dbl> 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4...
## $ year        <dbl> 1989, 1989, 1989, 1989, 1989, 1989, 1989, 1989, 1989...
## $ period      <dbl> 135, 135, 135, 135, 135, 135, 135, 135, 135, 135, 135, 13...
## $ plot        <dbl> 4, 7, 3, 3, 4, 8, 14, 2, 3, 13, 9, 3, 2, 4, 8, 10, 1...
## $ note1       <dbl> NA, NA, NA, NA, 13, NA, NA, 13, NA, NA, NA, NA, NA, NA, ...
## $ stake       <dbl> 11, 11, 12, 13, 13, 13, 13, 14, 21, 21, 22, 23, 24, ...
## $ species     <chr> "DM", "RM", "SH", "RM", "SS", "DM", "DM", "SS", "SH"...
## $ sex         <chr> "M", "F", "M", "F", NA, "M", "M", NA, "F", "F", "M",...
## $ reprod      <chr> NA, "Z", NA, "Z", NA, "Z", NA, NA, "Z", "Z", NA, NA,...
## $ age         <chr> NA, NA, "J", NA, NA, NA, NA, NA, NA, NA, NA, "J", NA...
## $ testes      <chr> "S", NA, NA, NA, NA, NA, "S", NA, NA, NA, "M", NA, N...
## $ vagina      <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ pregnant    <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ nipples     <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ lactation    <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ hfl         <dbl> 37, 17, 32, 16, NA, 36, 37, NA, 33, 15, 21, 29, 36, ...
## $ wgt         <dbl> 46, 9, 67, 8, NA, 34, 51, NA, 111, 11, 18, 60, 44, 2...
## $ tag         <chr> "8910", "8783", "8908", "8756", "0", "8760", "7322",...
## $ note2       <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ ltag        <chr> "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0...
## $ note3       <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ prevrt      <chr> "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0", "0...
## $ prevlet     <chr> "0", "0", "0", "0", NA, "0", "0", NA, "0", NA, "0", ...
## $ nestdir     <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ neststk     <dbl> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ note4       <chr> NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
## $ note5       <chr> NA, "R", NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, NA, ...
```

3.3.5 Filtering joins

`semi_join()` and `anti_join()`

3.3.6 Set operations

These are joins corresponding with the mathematical operation of intersection \cap , union \cup , and difference $-$.



->

Chapter 4

Visualisation and communication

4.1 Visualisation

4.1.1 Exploratory plots

4.1.2 Polished plots

4.2 Reports

Using R for report writing and presentations.

4.3 Presentations

Chapter 5

Exploratory data analysis

Putting everything together to perform exploratory data analysis.

Art of data science checklist

Ihaka, Ross, and Robert Gentleman. 1996. "R: A Language for Data Analysis and Graphics." *Journal of Computational and Graphical Statistics* 5 (3): 299–314.

R Core Team. 2019. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. <https://www.R-project.org/>.

RStudio Team. 2018. *RStudio: Integrated Development Environment for R*. Boston, MA: RStudio, Inc. <http://www.rstudio.com/>.

Wickham, Hadley. 2017. *Tidyverse: Easily Install and Load the 'Tidyverse'*. <https://CRAN.R-project.org/package=tidyverse>.

Wilson, Greg, ed. 2018. *Teaching Tech Together*. 2018,, <Http://Teachtogether.tech/>. Lulu.com. <http://teachtogether.tech/>.

Xie, Yihui. 2019. *Bookdown: Authoring Books and Technical Documents with R Markdown*. <https://CRAN.R-project.org/package=bookdown>.