

Statistics with R: a hands-on approach

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Chapter 1

Data review

1.1 Possibly interesting extra tidbits

In the making of this tutorial, I used several tools that you might like to access as well. Being the tedium-averse programmer I am, I use a reference manager program, in my case Zotero. You can find the full bibliography for this project, including a few entries that did not make it into the references section here because I did not cite them, at the Zotero project page.

I also want to point out awesome-public-datasets, where I foraged for the examples in this tutorial. It has several interesting datasets in the public health domain.

Finally, this tutorial is not necessarily intended to be done in order. In particular, section 2.6 should be read as needed, rather than all the beginning. Not only the section on tidying up data might be boring as a first subject on R, but it's also unlikely to make much sense without some hands-on experience using the software. However, it seemed to make sense to keep all things R together, to make it easier to find again later, when the reader encounters the unavoidable data QA issue.

1.2 Variables

When “doing science”, you will be taking measurements, usually in the hopes of understanding a phenomena often in the shape of a relationship between things you are measuring. When working with this data, the nature of the things you measure (*variables*) will influence the presentation and analysis that are appropriate.

A **qualitative variable** refers to categories, or a variable recorded with words, as opposed to a **quantitative variable**, which is measured with numbers. Examples of qualitative variables would include US state, restaurant chains and college major. Quantitative variables could be time to execute a task, waist circumference, disease rate or spending amounts.

R refers to **qualitative variables** as *factors*. **Qualitative variables** can further be divided into non ordinal and **ordinal variables**, depending on whether there is a natural order among the categories. For example, dog breed (chihuahua, husky, labrador) is a non ordinal variable, whereas level of satisfaction (dissatisfied, neutral, satisfied) is ordinal.

Quantitative variables are either **discrete variables**, where measurements are done in integers, or **continuous variables**, where they come in real numbers (you could get an infinity of decimals with a theoretical instrument of infinite precision). **Discrete variables** could be number of children, cancer deaths, or wedding age. **Continuous variables** include temperature, blood sugar level, and weight.

Furthermore, when studying variables in relationship with one another, changes in a **dependent variable** are driven or explained by an **independent variable**. Typically, this means the “x” axis of a graph will be the **independent variable**, while the “y” axis will be the **dependent variable**.

1.3 Gotchas

1.3.1 Tidy data

When working with data in R, analysis will be easier if your data is *tidy*, that is, each column in your data set contains one and only one variable. Or, more completely:

1. Each variable is in its own column
2. Each observation is in its own row
3. Each value is in its own cell

(Garrett Golemund gives an excellent introduction to the subject [4].)

For example, in a cancer dataset that we will use later, the original data is presented as in table 1.1. Here, we have four variables: cancer type, sex, number of cases, and number of deaths. While the first column is one and only one variable, the other columns mix sex with number of cases or sex with number of deaths. If you would like to analyze deaths by sex or cases per cancer type, some data manipulation will be necessary to combine the relevant columns.

Cancer Type	Cases		Deaths	
	Male	Female	Male	Female
...

Table 1.1: Cancer data set format.

If you keep your data tidy, R can usually do the combining for you, if you know how to ask nicely. As such, it is recommended that the first thing you do after successfully importing data into R is to verify it is tidy. Tools to divide or merge columns will be discussed in section 2.6.

1.3.2 Correlation is not causation, or of the importance of DoE

DoE refers to design of experiments. The common trope that “correlation is not causation” refers to the fact that because two variables vary together does not necessarily mean that one causes the other to change; for instance, they might both be responding to a common cause, when it’s not just plain old coincidence. My personal favorite exemplification of “correlation is not causation” is that the divorce rate in Maine correlates with the per capita consumption of margarine [17].

To distinguish between correlation and causation with certainty, a controlled experiment must be run. Depending on the phenomena studied, this might mean using a control group, a placebo, or directly controlling environmental conditions. For example, to determine the effect of low oxygen concentration in water on cod growth, several tanks can be set up where individual cods are randomly distributed and where oxygen levels are controlled. If you were to simply measure oxygen levels in water and cod growth at different locations and subsequently find a correlation between the two, you couldn’t tell for certain whether the difference is due to oxygen levels, or another factor like water temperature, or even the fact that cod compete with one another and that the runts, who would grow slower anyway, end up pushed into less desirable low-oxygen environments. Of course, sometimes running a controlled experiment is not feasible for practical reasons (one can’t control amount of natural sunlight, for example) or ethical reasons (having an untreated control group of people with a serious condition, when a potentially life-saving treatment might exist, is questionable).

When dealing with humans, to determine whether medication has a positive effect on an health issue, the health issue can be measured for a group who took the medication (treatment group), a group who took a placebo, and a group who took no medication at all (control group). In humans, particular effort must be placed on controlling or measuring the placebo effect, for the test subjects as well as the professionals. A recent spectacular example is the recommendation to abandon arthroscopic surgeries for knee pain because it did not show better results than physical therapy in randomized trials, despite it being the most common orthopaedic procedure in several countries [15].

Where experimental design is concerned, key factors are randomization, blocking, and replication. If terms like Completely Randomized Design, Latin Squares or Factorial Design are not familiar, I would recommend investing some time into learning the basics of experimental design before embarking in an experiment, in the interest of avoiding some common and easily remedied mistakes ([7] appears to be a well-rounded textbook).

Chapter 2

Unavoidable R before we begin

Despite the title, this chapter is not meant to be read from start to finish before you get to the other chapters. First, a long text about programming quirks can get pretty sleep-inducing. Second, the concerns addressed will probably not resonate much with you unless you’ve personally encountered this problem before, so the information retention is likely to be low.

That being said, the three first sections (2.1, 2.2, 2.3) should probably be read right now if you are not familiar with R at all. The other ones are referenced later in the text when they are relevant and can be read at that time.

2.1 Packages

R [13] should be relatively straightforward to install: download and execute, follow the wizard instructions.

Where things get a bit more complicated is when it comes to packages. While the basic R program has a lot of functions built-in, there will come a time when you will need something that is not offered out of the box. Thankfully, R has a very dynamic community with a ton of packages. For instance, a very popular package to produce figures is `ggplot2`. Let’s install it to see how packages are managed in R.

First off, to install packages in R, you will need to launch it as an administrator. If you don’t, you will get the rather unhelpful message shown in figure 2.1. To launch with administrator rights, right-click on your R launcher and find the option “Run as administrator”. How to do so from the Windows 10 start menu is shown in figure 2.2. (As a note, you should launch as administrator *only* when installing packages, as opposed to modifying your shortcut to always launch as administrator.)

Now that R is launched as administrator, you can install `ggplot2` using either the convenient Packages menu or the command line if you’re that hard-

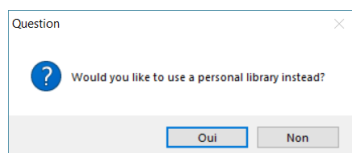


Figure 2.1: Error message displayed by R if trying to install packages without administrator rights.

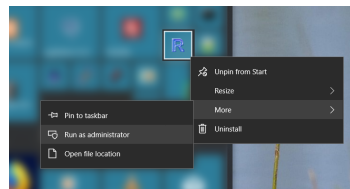


Figure 2.2: How to launch R with administrative rights.

core. Personally I use the menu; after choosing a mirror (different mirrors offer different packages; Canada NS has a wide selection and is vaguely geographically close), you can select your desired package and hit “install”, as shown in figure 2.3. Then you only need to wait until R is done doing its thing. If all the lines say “successfully unpacked”, all good; otherwise, an error has occurred and you will have to decipher the message to figure out how to remedy the situation. (If you run into any trouble, I would first recommend updating to the latest release of R.)

Note that installing a package is not enough to use it; you must also load it. Again this can be done either from the menu or with the command line, as shown in figure 2.4. This operation must be repeated *every time* you restart R.

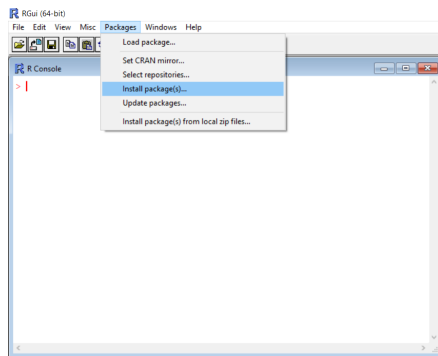
Now let’s say that `ggplot2` becomes your favoritest package in the whole world and you end up using it every day. After a week or so you will probably be very annoyed having to reload the package every time you open R. You can add packages to be loaded automatically in either of two files: `Rprofile.site` or `.Rprofile`. `Rprofile.site` is located in your R installation folder in the `etc` folder and is always executed. `.Rprofile` is located in the user home folder and is applied after the changes made by `Rprofile.site`. As the appropriate location to put `.Rprofile` seems to change from R version to version, I will showcase the `Rprofile.site` here. At the bottom of the file, add the following:

```
.First <- function(){
  library('ggplot2')
  # other libraries go here
}
```

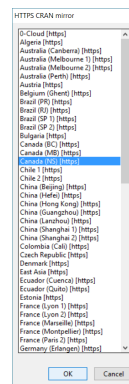
2.2 Types

While relatively accessible as far as programming languages go, R is still a programming language. As such, it has a few concerns that, while painful for the non-programmers among us, are useful tools to diagnose problems, typically when importing data that has not been properly QA’d or when a function refuses to compute because the input is in a form it refuses.

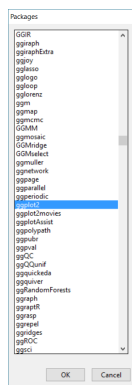
Let’s talk about *types*. Types refer to the nature of a variable in a computer



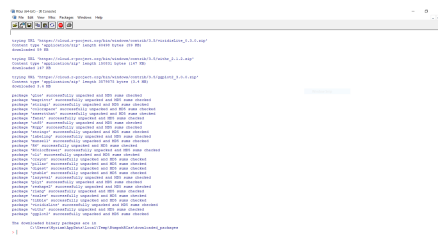
(a) Packages menu in R Gui.



(b) List of mirrors.



(c) List of packages.



(d) All successfully unpacked: successful installation.

Figure 2.3: Package installation process.

program; is it text, a number, etc.? If it's a number, can it be any number, or integers only? This is important because computing the means of grades in a class makes sense, while computing the means of the name of the students doesn't. Further, since R is a statistical program, it also includes types not typically seen in programming languages, like factors and ordinal variables. The following table gives an overview of variable types in R.

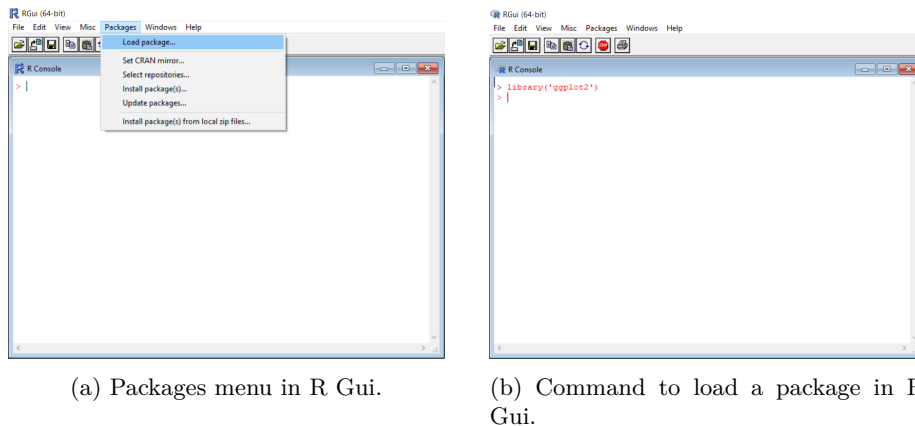


Figure 2.4: Loading packages in R.

Logical:	TRUE or FALSE
Numeric:	real, by the math definition (ex. 12.3). Double is a numeric with better precision.
Integer:	integer, by the math definition (ex. 12).
Character:	text of any length; defined by typing “text” or ‘text’
Factor:	a type that represents a qualitative variable
Ordered:	a type that represents an ordinal variable
List:	a 1D collection of “things” (may be strings, numbers, or a mix of them)
Vector:	a 1D collection of things of <i>one type</i>
Matrix:	a 2D collection of things of <i>one type</i>
Array:	a nD collection of things of <i>one type</i>
Data Frame:	a (mostly) 2D collection of things, where each column can be of a different type

For future reference, Quick R gives an excellent introduction on the subject [12]. You can convert a variable to anything reasonable (R will turn “2” into an integer, but not “abc”) using the host of `as.xyz` functions.

The data frame is of particular interest, since it allows the use of a specific syntax we will use later. A data frame is closest to a “table” you would have in your spreadsheet software: it holds values for several variables, where each column is a variable, and the headers hold sensible names.

To see which type a variable has, `class` and `str` (structure) are most informative. `class` will return the type of the variable (for example, “data frame”), while `str` will make a summary of the variable and its components, if any (for example, the various columns of a data frame).

2.3 Accessing collection elements

Some of the types presented in the previous section group several values. At some point, you'll want to access one or many of the elements, but not all. Let's say you have a data frame, for example ebola deaths by country [9]:

```
> ebola
Country Deaths
1      Guinea 2543
2     Liberia 4809
3  Sierra Leone 3956
4         Mali  6
5      Nigeria  8
6 United States of America 1
```

Notice how the line with “Country” and “Deaths” is not numbered in the output? It means R is aware it's a header and not data. *Data frame columns* (not matrices) can be accessed by their name using the `$` operator, like so:

```
> ebola$Country
[1] Guinea          Liberia          Sierra
   → Leone
[4] Mali            Nigeria          United
   → States of America
6 Levels: Guinea Liberia Mali Nigeria ... United States of
   → America
```

If you want to access lines, elements or columns, you can use the `[row, column]` operator, like so:

```
> ebola[1,]
Country Deaths
1  Guinea 2543
> ebola[1,2]
[1] 2543
> ebola[,2]
Deaths
[1] 2543
[2] 4809
[3] 3956
[4] 6
[5] 8
[6] 1
```

While the `$` operator is exclusive to data frames, the `[]` is used for all collections. Vectors, lists, matrices and arrays can be accessed with the `[index]` operator for 1D structure, `[row, column]` operator for 2D structures, and `[i, j, k...]` for nD structures.

In the case you want to access several items at once, you can use a colon inside the brackets, i.e. `[begin:end]` like so:

```
> ebola[1:3,]
Country Deaths
1      Guinea  2543
2     Liberia  4809
3 Sierra Leone 3956
```

2.4 Misc

2.4.1 `c` is for concatenate

Sometimes, a function in R will use an argument that is actually a list of things; for example, the limits of the x axis are two values: the minimum and maximum values to display on the graph. Referring back to the types we just saw, R requires a **vector** of values. Since it's such a common usage, R offers a quick way to create a vector with the function `c()`.

```
> ... xlim = c(0, 100), color = c(255, 0, 0) ...
```

2.4.2 `#` is for comments

If you use `#` in R, it will consider anything to its right to be a *comment*, that is, not code, and it will be ignored. You can start a line with it or use it in the middle of a line. It can be useful to leave notes to yourself in long-ish scripts.

2.4.3 Use argument names

When you use a function, for example `barplot`, there are a certain number of unavoidable parameters, followed by several optional parameters. The optional parameters typically have a default value, so if you don't specify them, the function works as expected, using the default values. For example, let's consult the help page for `barplot` by typing `?barplot` at the R prompt.

```
...
barplot(height, ...)

## Default S3 method:
barplot(height, width = 1, space = NULL,
        names.arg = NULL, legend.text = NULL, beside = FALSE,
        horiz = FALSE, density = NULL, angle = 45,
        col = NULL, border = par("fg"),
        main = NULL, sub = NULL, xlab = NULL, ylab = NULL,
        xlim = NULL, ylim = NULL, xpd = TRUE, log = "",
        axes = TRUE, axisnames = TRUE,
        cex.axis = par("cex.axis"), cex.names = par("cex.axis"),
```

```

inside = TRUE, plot = TRUE, axis.lty = 0, offset = 0,
add = FALSE, args.legend = NULL, ...)
...

```

In this example, the parameter `height`, which is not followed by an “=” is a necessary parameter; you can’t compute a bar plot without giving it some values to put in the graph! All the other parameters are optional, and the help page lists their default value.

If you decide you want your bars to be beside one another rather than stacked, you will have to set the parameter `beside`, which is the fifth optional parameter. To avoid really strange and unfortunate guesswork on R’s part when it tries to figure out which parameter you set among the gazillion optional parameters, *always use the optional parameter names*, for example:

```

> heights = c(15, 5, 1, 12, 28)
> # barplot(heights, TRUE)
> # BAD!
> # Don't make R guess!
> # It's bad at it!
> barplot(heights, beside = TRUE)           # Good

```

2.4.4 Dates

As I may have mentioned, dates in programming are their very own Pandora box. R internally saves its dates as the number of days since January 1st, 1970.

In real life, you will likely encounter dates in a file in one of various text formats, for example something like “mm/dd/yyyy” (and since not all languages list their dates in the same order, you should pay close attention when dealing with international data), or as three different columns for the day, the month and the year. If you want R to do nice things for you like calculating the number of days between two dates, you need to transform these eminently unstandard formats into R’s own format. So let’s see how this is done for an arbitrary text format and for the three numeric columns cases.

Text to Date

For this, let’s use the traffic data from the city of Chicago [1]. After downloading the csv, in your spreadsheet software, assign appropriate types to the date, vehicle volume, latitude and longitude columns, then tweak header names, save as csv and load into R. You should obtain the following:

```

> traffic = read.csv("C:/.../r-tutorial/traffic.csv")
> str(traffic)
'data.frame':  1279 obs. of  9 variables:
 $ ID      : Factor w/ 1279 levels "1","1,000","1,001",...: 453...
 $ Address : Factor w/ 1203 levels "1 West","10 East",...: 212 ...
 $ Street  : Factor w/ 251 levels "100th St","101st St",...: 40 ..

```

```

$ Date      : Factor w/ 95 levels "1/24/2007","1/30/2007",...:54...
$ Volume    : int   14600 16500 18200 21600 18300 8600 10000 ...
$ Direction: Factor w/ 1223 levels "East Bound: 1000 / West
→ Bound: 3400",...: 397 442 484 20 495 257 939 936 981 909 ...
$ Latitude  : num   41.8 41.8 41.8 41.8 41.8 ...
$ Longitude: num  -87.7 -87.7 -87.6 -87.6 -87.6 ...
$ Location  : Factor w/ 1276 levels "(41.651861, -87.54501)",...

```

So your date has been read as a factor; dates are a kind of category, I suppose, but R doesn't make computations on factors. You can't subtract blue eyes from green eyes, but you definitely can subtract 2010/01/08 from 2010/02/07 to compute how many days have passed between them.

Thankfully, R offers the function `as.Date` to convert text to `Date`. It uses a series of codes that you can see in the details of the help page for `strptime`. For instance, `%m`, `%d` and `%Y` stand for decimal month, decimal day and decimal year including century, respectively. It is used in the following manner:

```

> traffic$Date = as.Date(traffic$Date, format="%m/%d/%Y")
> str(traffic)
'data.frame': 1279 obs. of 9 variables:
$ ID       : Factor w/ 1279 levels "1","1,000","1,001",...
$ Address  : Factor w/ 1203 levels "1 West","10 East",...: 212 ...
$ Street   : Factor w/ 251 levels "100th St","101st St",...
$ Date     : Date, format: "2006-03-09" "2006-02-28" ...
$ Volume   : int   14600 16500 18200 21600 18300 8600 10000 ...
$ Direction: Factor w/ 1223 levels "East Bound: 1000 / West
→ Bound: 3400",...: 397 442 484 20 495 257 939 936 981 909 ...
$ Latitude : num   41.8 41.8 41.8 41.8 41.8 ...
$ Longitude: num  -87.7 -87.7 -87.6 -87.6 -87.6 ...
$ Location  : Factor w/ 1276 levels "(41.651861, -87.54501)",...

```

Three numbers to Date

While R does not offer a specific function that takes three numbers and returns a date, it is easy enough to build a date string from three numbers, and then feed that to `as.Date`. For example, if the dates in the traffic data were in three columns, you could proceed this way:

```

> str(traffic2)
'data.frame': 1279 obs. of 12 variables:
#...
$ Month     : int   3 2 2 2 2 3 3 3 3 3 ...
$ Day       : int   9 28 28 28 28 9 7 7 7 7 ...
$ Year      : int  2006 2006 2006 2006 2006 2006 2006 2006 2006 ...
#...
> dateStrings = paste(traffic2$Year, traffic2$Month,
→ traffic2$Day, sep="/")

```

```

> dateStrings[1:10]
[1] "2006/3/9" "2006/2/28" "2006/2/28" "2006/2/28"
[5] "2006/2/28" "2006/3/9" "2006/3/7" "2006/3/7"
[9] "2006/3/7" "2006/3/7"
> traffic2$Date = as.Date(dateStrings, format="%Y/%m/%d")
> str(traffic2)
'data.frame': 1279 obs. of 12 variables:
#...
$ Date : Date, format: "2006-03-09" ...
$ Month : int 3 2 2 2 2 3 3 3 3 3 ...
$ Day : int 9 28 28 28 28 9 7 7 7 7 ...
$ Year : int 2006 2006 2006 2006 2006 2006 2006 2006 2006
↪ 2006 ...
#...

```

Date to text

Converting a date to text is straightforward enough and allows you to specify the format you want. By default, R prints dates following the ISO convention of YYYY-MM-DD [2]. If you really want your heretic US format, you could use `format` (which, by the way, also allows you to format numbers by defining leading zeros or number of decimals).

```

> today = Sys.Date()
> format(today, format="%m/%d/%y")
[1] "09/27/18"

```

Date computations

You can make calculations on dates. The following examples should tell you the gist of it.

```

> lastyear = Sys.Date()-365
> lastyear
[1] "2017-09-27"
> today-lastyear
Time difference of 365 days
> nextmonth=today+30
> nextmonth
[1] "2018-10-27"

```

2.5 Saving, a.k.a scripts

As long as you're doing simple things fitting on two or three lines, you probably won't feel the need to "save your file". However, as you start doing more elaborate data treatment or need to document a process used, you will want to save your progress.

One way to save is to use R's built-in **workspace**. A **workspace** is a **.RData** file that contains all the variables (used here in the computer science sense: a value that you attached a name to) you have defined since you started R. For example, if you typed the following:

```
> 1+2
[1] 3
> a = "I am text"
> x = 5+3
> y = x-8
> x
[1] 8
```

In this case, **a**, **x** and **y** would be saved in your workspace. Next time you started R, you could load the **workspace** and R would know that **x** is worth 8.

Another useful feature of R is the history, that is, the 250 (by default) last commands you typed in the window. You can access them by pressing the up arrow, which can be pretty handy when you want to tweak a command to fix a typo. You can save it in a **.Rhistory** file that you can also load the next time you start R.

Finally, if there is a small routine that you need to save, you can save it in a simple text file that you can load and execute. In the **File** menu, choose **New script** and type some text in the window, for instance:

```
x = c(1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
y = 2*x
x
y
plot(x, y)
```

As you type the commands and press enter, nothing happens, as opposed to using the main window. To run these commands, you need to select what you want to run (for example, everything: select with **ctrl+a**), then press **F5**. If you do, you should see the outputs appearing in the main window. Once you're reassured that your basic algorithm is running, you might want to tweak the plot function to add axes and labels before re-running the script. Once you're done, you can save this simple text file and have an easily viewable record of what you did.

2.6 Data: import, export, tidy

2.6.1 Import

Delimited data: **read.csv** is your friend

A typical workflow to get data from wherever into R would be as follows:

1. Copy-paste the data into your favorite spreadsheet software (Microsoft Excel, LibreOffice Calc, Google Sheets, etc.).

2. If necessary, transpose your data so that variables are in columns (rather than rows).
3. Tweak column names so they have no spaces and no special characters (é, \$, etc).
4. Assign a reasonable format (text, number, thousand separators, etc.) to all columns.
5. With your operating systems using an English locale, save as csv.
6. Use `read.csv` in R with the *full path* using *forward slashes*, and the appropriate options.

As a case study, let's import the data for infant mortality [6]. Data is already in columns and country names contain no special characters. So let's just change the first column header to "Country". Next, let's set the columns B and up (excluding the header for practical reasons seen later) to format "number". You might note that the decimal separator used in this file is a comma rather than a dot. However, setting the number format should be enough for your Spreadsheet software to convert them properly. Where to set number format will vary depending on your spreadsheet program; how to apply number formatting in LibreOffice is shown in figure 2.5. In LibreOffice in particular, make sure your number format locale is English. Save the modified file in csv format.

Once in R, import the data using `read.csv`. Once that is done, however, you should always doubt that everything went well. Just to prove my point, let's examine the imported data a little more closely (see section 2.2 about data frames and section 2.3 about the `$` operator):

```
> infant = read.csv('C:/.../r-tutorial/infant.csv', header=TRUE)
> class(infant)
[1] "data.frame"
> str(infant)
'data.frame': 260 obs. of 217 variables:
 $ Country: Factor w/ 260 levels "Abkhazia","Afghanistan",...: 1
  → ...
 $ X1800 : int  NA NA NA NA NA NA NA NA NA NA NA ...
 $ X1801 : int  NA NA NA NA NA NA NA NA NA NA NA ...
 # ...
 $ X1861 : int  NA NA NA NA NA NA NA NA NA NA NA ...
 $ X1862 : Factor w/ 11 levels "", ".", "110", "131",...: 1 1 1 1 ...
 $ X1863 : Factor w/ 13 levels "", ".", "106", "113",...: 1 1 1 1 ...
 # ...
```

Wait, what? The country is of type factor, we all agree on that, but infant mortality rate for 1862 is a factor? Let's pick 1862 and see if we can't just eyeball the problem:

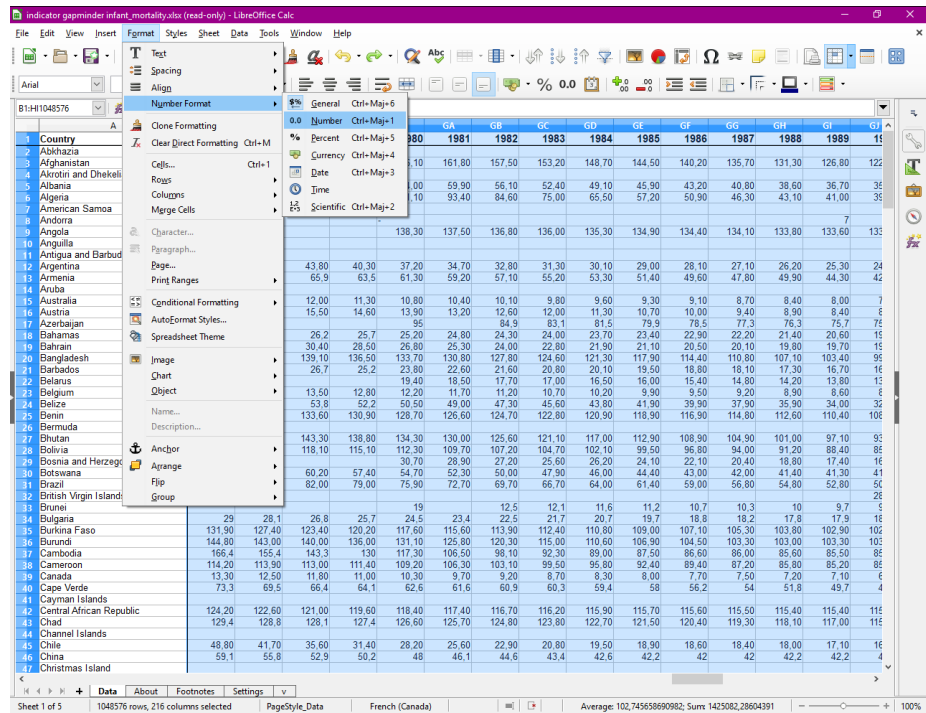


Figure 2.5: Applying number format to selected columns in LibreOffice.

```
> infant$X1862
[1]      250.00
[16]                      150.00
[31]
[46]      131.00
[61]
[76] 163.00
[91]
[106]
[121]
[136]
[151]      193.00      81.00
[166]                      110.00
[181]
[196]
[211]      175.00      139.00
[226]
[241]
[256]
```

```
Levels: . 110.00 131.00 139.00 150.00 163.00 175.00 193.00
→ 250.00 81.00
```

I don't know if you can see it, or if you think it's a speck of dust on your screen, but there's a lonely dot there somewhere between lines 226 and 241. I am going to assume it means it's a missing data point, since nothing else makes sense.

(In other languages, like French for instance, the decimal “point” is a comma, and therefore the “comma-separated” part of comma-separated value leads to some issues, not to mention the English thousand separator. This is why you set your data format in your spreadsheet: once the cell are properly formatted, your spreadsheet will export them sensibly into the csv.)

Let's try again, this time telling `read.csv` that dots are missing data:

```
> infant = read.csv("C:/.../r-tutorial/infant.csv", header=TRUE,
→ na.strings=".")
> str(infant)
'data.frame': 260 obs. of 217 variables:
$ Country: Factor w/ 260 levels "Abkhazia","Afghanistan",...: 1 2
→ 3 5 6 7 8 9 10 11 ...
$ X1800 : num NA NA NA NA NA NA NA NA NA NA ...
# ...
$ X1897 : num NA NA NA NA NA NA NA NA NA NA ...
[list output truncated]
```

This looks better, however the last line displayed is for 1897. If you're a trusting person (and you should never trust a computer), you might think everything is okay now. However, I cheated and skipped ahead and tried to use this data before and encountered another QA gem. So let's make sure to display *all* the variables with a trick we will see in detail later (section 8.1.1; for now let's just say it applies `class` to every part of `infant`).

```
> sapply(infant, class)
Country      X1800      X1801      X1802      X1803      X1804
→ X1805      X1806      X1807      X1808      X1809
"factor" "numeric" "numeric" "numeric" "numeric" "numeric"
→ "numeric" "numeric" "numeric" "numeric" "numeric"
# ...
X1953      X1954      X1955      X1956      X1957      X1958      X1959
→ X1960      X1961      X1962      X1963
"numeric" "numeric" "numeric" "numeric" "numeric" "numeric"
→ "numeric" "factor" "numeric" "numeric" "numeric"
# ...
# See that pesky 1960?
> infant$X1960
[1] 245.00 115.40 148.20 - 208.00
→ 59.87 20.30 37.30
```

```
# ...
[256] 88.00 123.20 92.60
146 Levels: - 100.60 101.60 102.00 102.10 102.20 105.00 106.70
→ 107.40 107.50 110.60 112.00 115.40 115.50 ... 94.00
```

So, apparently “-” also means missing data? Gods forbid the authors hit a snag while importing data and their software didn’t warn them something foul was afoot (like R just did to us, thank you R) and they just pasted it in the global csv without noticing. (This is why science should be in databases. Real databases. They don’t let you put a dash in a number field, they just don’t.)

Now, *finally*, we get:

```
> infant = read.csv('C:/.../r-tutorial/infant.csv', header=TRUE,
→ na.strings=c('-', '.'))
> sapply(infant, class)
Country      X1800      X1801      X1802      X1803      X1804
→ X1805      X1806      X1807      X1808      X1809
"factor" "numeric" "numeric" "numeric" "numeric" "numeric"
→ "numeric" "numeric" "numeric" "numeric" "numeric"
# ...
X2008      X2009      X2010      X2011      X2012      X2013      X2014
→ X2015
"numeric" "numeric" "numeric" "numeric" "numeric" "numeric"
→ "numeric" "numeric"
```

Fixed-width data: read.fwf

In some few cases, most often when importing data from government websites who offer them up publicly in .txt format, you will encounter fixed-width data. Delimited data uses a character (most often a comma) to signify the boundary between cells of data. Fixed-width, however, always has the same number of characters for a given field. To demonstrate, figure 2.6 shows what csv (delimited) and fixed-width data look like side by side.

<pre>Infant mortality rate,1950,1951,1952,1953,1954,1955,1956,1957,1958,1959,1960,1961,1962 Abkhazia,,,,,,,,,,,,,"245,00","240,50","236,30","232,30","228,50","224,60","220,70"," Afghanistan,,,,,,,,,,,,,"245,00","240,50","236,30","232,30","228,50","224,60","220,70"," Akrotiri and Dhekelia,,,,,,,,,,,,,"245,00","240,50","236,30","232,30","228,50","224,60","220,70"," Albania,,,,,,,,,,,,,"120,10","115,40","110,80","106,50","101,80","97,90","94,10","90,20", Algeria,,,,,,,,,,,,,"150,40","145,90","149,50","149,00","148,80","148,40","148,20","148,10", American Samoa,,,,,,,,,,,,,"150,40","145,90","149,50","149,00","148,80","148,40","148,20","148,10", Andorra,,,,,,,,,,,,,"7,7","7,5","7,6","5,6","5,6","5,2","5,5", Angola,,,,,,,,,,,,,"208,,,,,,,,,180,,,,,,,,,"138,30","137,50","136,80","136,00","135,30", Anquilla,,,,,,,,,,,,,"245,00","240,50","236,30","232,30","228,50","224,60","220,70"," Antigua and Barbuda,,,,,,,,,,,,,"245,00","240,50","236,30","232,30","228,50","224,60","220,70", Argentina,69,67,65,63,60,62,57,68,61,59,"59,87","59,73","59,59","59,39","59,25","59,11", Armenia,,,,,,,,,,,,,"70,8","68,3","65,9","63,5","61,30","59,20","57,10", Aruba,,,,,,,,,,,,,"245,00","240,50","236,30","232,30","228,50","224,60","220,70", Australia,"25,00","24,60","24,10","23,60","23,00","22,60","22,10","21,60","21,20","20,1", Austria,66,61,52,50,"46,60","45,20","43,60","41,70","39,60","37,30","35,00","3", Azerbaijan,,,,,,,,,,,,,"95","84,9","83,1","81,5","79,9","78,5","77,3", Bahamas,,,,,,,,,,,,,"51,,,,,,,,,25,"25,5","26,"26,4","26,8","27,2","27,2","26,9","26</pre>	<pre>Week Nino1+2 Nino3 Nino34 Nino4 SST SSTA SST SSTA SST SSTA SST SSTA 03JAN1990 23.4-0.4 25.1-0.3 26.6 0.0 26.6 0.3 10JAN1990 23.4-0.8 25.2-0.3 26.6 0.1 26.6 0.3 17JAN1990 24.2-0.3 25.3-0.3 26.5-0.1 26.6 0.3 24JAN1990 24.4-0.3 25.3-0.4 26.3-0.1 26.4 0.2 31JAN1990 25.1-0.2 25.5-0.2 26.7 0.1 26.4 0.2 07FEB1990 25.8 0.2 26.1-0.1 26.8 0.1 26.4 0.3 14FEB1990 26.9-0.1 26.4 0.0 26.9 0.2 26.5 0.4 21FEB1990 26.1-0.1 26.7 0.2 27.1 0.3 26.9 0.6 28FEB1990 26.1-0.2 26.7-0.1 27.2 0.3 29.0 0.6 07MAR1990 26.7 0.3 26.7-0.2 27.3 0.2 26.9 0.7 14MAR1990 26.1-0.4 26.9-0.2 27.3 0.1 26.6 0.4 21MAR1990 26.1-0.2 27.2 0.0 27.4 0.3 26.7 0.5 28MAR1990 26.7-0.4 27.8 0.2 27.8 0.3 26.8 0.5 04APR1990 26.6-0.3 27.6 0.3 27.9 0.4 26.8 0.4 11APR1990 26.1-0.6 27.6 0.2 27.9 0.2 26.8 0.3 18APR1990 26.3 0.0 27.7 0.2 28.0 0.2 26.9 0.4 25APR1990 25.1 0.0 27.7 0.4 28.2 0.4 29.2 0.6 02MAY1990 24.6-0.2 27.6 0.3 28.1 0.3 29.0 0.4 09MAY1990 24.2-0.2 27.5 0.3 28.1 0.3 29.0 0.2 16MAY1990 24.3 0.1 27.4 0.3 28.0 0.2 26.8 0.1 23MAY1990 23.7-0.2 27.4 0.2 28.0 0.3 29.0 0.2 30MAY1990 23.4-0.1 27.1 0.3 27.9 0.2 26.9 0.1</pre>
--	---

Figure 2.6: Delimited data (left) and fixed-width data (right).

As a case study, let’s use historic water levels for a river in Canada [11]. Data looks like this:

1 Ministère du Développement durable, de l'Environnement
 et de la Lutte contre les changements climatiques
 2 Données validées jusqu'au 1994-09-30
 3 Station: 070401 Portneuf - à l'amont
 des chutes Philias
 4 Bassin versant: 3085 km2 Régime: Naturel
 5 Coordonnées: (NAD83) 48 38' 54" // -69 10' 55"
 6
 7 Date de création du fichier: 2012-06-30 02:40
 8 Particularité(s):
 9 -
 10 -
 11 -
 12 Lexique: E: La donnée est estimée.
 13 (Remarque) J: Un jaugeage a été exécuté %*à
 cette date.
 14 MC: La donnée représente un débit moyen converti.
 15 MJ: La donnée est une moyenne journalière.
 16 P: La donnée est provisoire.
 17 PL: La donnée correspond %*à la premi\ère lecture de
 niveau d'eau de la journée.
 18 R: Le débit est corrigé pour tenir compte de l'effet
 de refoulement.
 19 S: La donnée est saisie manuellement.
 20 Z: La donnée provient d'une redistribution temporelle
 des données enregistrées en raison d'une dé
 fectuosité de l'appareil de mesure.
 21
 22 Station Date Débit (m3/s)
 Remarque
 23 070401 1973/08/17 86.60 J
 24 070401 1973/08/18 79.90 MC
 25 070401 1973/08/19 73.30 MC
 26 070401 1973/08/20 68.80 MC
 27 070401 1973/08/21 65.10 MC
 28 070401 1973/08/22 63.70 MC
 29 070401 1973/08/23 63.70 MC
 30 070401 1973/08/24 62.00 MC
 31 ...
 32 070401 1994/09/25 47.55 MC
 33 070401 1994/09/26 46.74 MC
 34 070401 1994/09/27 45.95 MC
 35 070401 1994/09/28 46.26 MC
 36 070401 1994/09/29 54.98 MC
 37 070401 1994/09/30 80.23 MC

Save it as a text file on your computer as is. To read fixed-width data, you need to explicitly tell R the widths of each column. The popular Windows text editor Notepad++ shows column index, which allows to calculate them quickly: 6, 20, 15 and 12 (column starts with whitespace and ends with data). Furthermore, the “table” part of the file starts on line 23.

(Since there are accents in the file, if you were interested in the comments, you might want to take an extracurricular dive into encodings. Since this is an English document, I will not add another painful tangent, but as a quick note, if you ever encounter trouble importing European documents, try CP-1252 (Windows default) or ISO-8859-1 (Latin extended, covers French, German and Spanish, for instance).)

(Another note, there is a function to read Fortran files, which I never needed to use but might be useful to you. My condolences on dealing with Fortran.)

`read.fwf` is used this way:

```
> debit = read.fwf("C:/.../r-tutorial/debit.txt", widths=c(6, 20,
  ↳ 15, 12), header=FALSE, skip=22, strip.white=TRUE,
  ↳ col.names=c('Station', 'Date', 'Debit', 'Remarque'))
> str(debit)
'data.frame': 7715 obs. of 4 variables:
 $ Station : int 70401 70401 70401 70401 70401 70401 70401 ...
 $ Date : Factor w/ 7715 levels "1973/08/17","1973/08/18",...: 1
  ↳ 2 3 4 5 6 7 8 9 10 ...
 $ Debit : num 86.6 79.9 73.3 68.8 65.1 63.7 63.7 62 59.2 ...
 $ Remarque: Factor w/ 5 levels "E","J","MC","R",...: 2 3 3 3 3 ...
> debit[1:5,]
  Station      Date Debit Remarque
1 70401 1973/08/17 86.6      J
2 70401 1973/08/18 79.9      MC
3 70401 1973/08/19 73.3      MC
4 70401 1973/08/20 68.8      MC
5 70401 1973/08/21 65.1      MC
```

As opposed to `read.csv`, I used the argument `header=FALSE` with `read.fwf`. This is due to `read.fwf` being pickier about the header format: it wants the header to be *delimited* with a character that is not present in the rest of the file (to practice, type in `?read.fwf` in R and *attentively* read the help about the `header` argument). Since this was not the case, I manually set the column names with `col.names`. `strip.white = TRUE` automatically strips the whitespace within the columns, so your date is '1973/08/17' and not ' 1973/08/17'.

The structure of the data frame informs us that the date as been read as a factor. Since dates are their own Pandora boxes in computer science, we will not deal with them here, but you can look at section 2.4.4 if you're a masochist.

2.6.2 Export

Exporting data is useful to save it for later use or send to a spreadsheet software. Despite some internationalization issues, I would recommend using csv for the output file, since it is easy to import into spreadsheet software. In that simple case, the `write.csv` function works quite well:

```
> demo
[,1] [,2] [,3] [,4] [,5]
[1,] 82.94 115.94 89.48 101.06 91.23
[2,] 111.22 117.65 94.64 115.79 103.91
[3,] 82.10 95.96 101.11 82.44 98.84
> write.csv(demo, file='path.../demo.csv', row.names=FALSE)
```

With data frames, the column headers will make sense and, should your object have row names, you can remove the `row.names` argument.

2.6.3 Tidy

This section is quite heavy on R programmy-like stuff, so you may want to skip it until you are more familiar with R or actually need to disentangle a data set, whichever comes first.

Since their help pages are, in my opinion, easier to understand, I use the functions in the `tidyr` package, so you might want to install and load it to follow along.

n -> 1 rows: spread

When the data is placed in a table where the name of a variable is used as a value in cells, you need to make them into columns. In other words, your table has a column of *keys* followed by a column of *values*. You can do so with the `spread` function, the result of which is represented in figure 2.7.

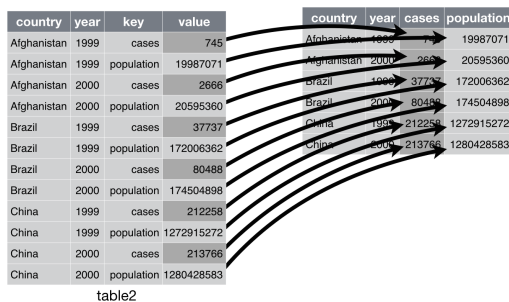


Figure 2.7: Putting variables in their own columns with `spread` (taken from [4]).

1 ->n rows: **gather**

When the data is placed in a table where the column headers are values of a variable, you need to put them into one column, as shown in figure 2.8. You can do so with the **gather** function.

country	year	cases
Afghanistan	1999	745
Afghanistan	2000	2666
Brazil	1999	37737
Brazil	2000	80488
China	1999	212258
China	2000	213766

table4

Figure 2.8: Putting a variable into only one column with **gather** (taken from [4]).

1 ->n columns: **separate**

If one of the columns contain more than one variable, for example it is a rate written as cases/population, since number of cases and population are two separate variables, you will need to split this column into several others. You can use the **separate** function for this, as shown in figure 2.9.

Country	Century	Year	Rate
Afghanistan	19	99	745/19987071
Afghanistan	20	00	2666/20595360
Brazil	19	99	37737/172006362
Brazil	20	00	80488/174504898
China	19	99	212258/1272915272
China	20	00	213766/1280428583

Country	Century	Year	Cases	Population
Afghanistan	19	99	745	19987071
Afghanistan	20	00	2666	20595360
Brazil	19	99	37737	172006362
Brazil	20	00	80488	174504898
China	19	99	212258	1272915272
China	20	00	213766	1280428583

Figure 2.9: Separate one column into two with **separate** (inspired by [4]).

n ->1 columns: **unite**

If one variable is spread across multiple columns, for example a date split in year, month and day, while the date is a single variable, you will need to combine them into a single column. This can be done with the **unite** function, as pictured in figure 2.10.

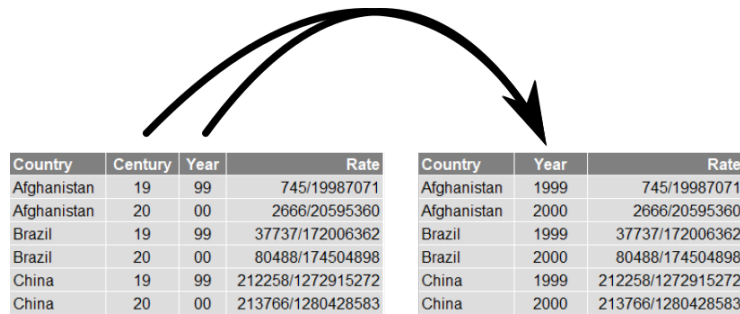


Figure 2.10: Merge two columns into one with `unite` (inspired by from [4]).

Example

The cancer data mentioned as an example in section 1.3.1 will be used as a case study for these functions. Data can most easily be copy-pasted into a Spreadsheet software from Table 1 of the peer-reviewed article version of the report online [14]. As a first step, remove sum lines and columns, remove the thousand separator and tweak header names (also, the hyphen is not a real hyphen, so retype it).

Let's identify the variables: cancer type, sex of patient, number of cases, and number of deaths. Here, we need to make sex its own column; and since there are two columns with female data, we will proceed in several steps: first, make all four columns one "variable" with `gather`. Arguments `key` and `value` are simply the name to give to the new columns that `gather` will create. The last argument is the columns to "gather", while the columns not listed will be duplicated as necessary.

```
> cancer = read.csv('C:/.../r-tutorial/cancer.csv')
> str(cancer)
'data.frame':   47 obs. of  5 variables:
 $ cancer      : Factor w/ 47 levels "Acute lymphocytic
   ↪ leukemia",...
 $ cases_male  : int  12490 7980 14250 2440 13480 16520 ...
 $ cases_female : int  4620 5600 3340 820 3810 9720 5040 ...
 $ deaths_male : int  1750 1770 2480 1280 12850 6510 810 ...
 $ deaths_female : int  760 880 750 360 3000 4290 640 23240 ...
> cancer = gather(cancer, key="tmpvar", value="n", 2:5)
> str(cancer)
'data.frame':   188 obs. of  3 variables:
 $ cancer: Factor w/ 47 levels "Acute lymphocytic leukemia",...
 $ tmpvar: chr  "cases_male" "cases_male" "cases_male" ...
 $ n      : int  12490 7980 14250 2440 13480 16520 5430 49690 ...
> cancer
      cancer      tmpvar      n
1 Tongue      cases_male 12490
```

```

2    Mouth    cases_male    7980
#...
48   Tongue   cases_female   4620
49   Mouth    cases_female   5600
#...
95   Tongue   deaths_male    1750
96   Mouth    deaths_male    1770
#...
142  Tongue   deaths_female    760
143  Mouth    deaths_female    880
#...

```

Now, we need to separate the two words in the “tmpvar” column into two columns with `separate`. Arguments should be self-explanatory.

```

> cancer = separate(cancer, col="tmpvar", into=c("category",
  → "sex"), sep="_")
> cancer
cancer category    sex      n
1    Tongue    cases   male 12490
2    Mouth     cases   male  7980
#...
48   Tongue    cases female  4620
49   Mouth     cases female  5600
#...
95   Tongue    deaths  male  1750
96   Mouth     deaths  male  1770
#...
142  Tongue    deaths female   760
143  Mouth     deaths female   880
#...

```

Finally, we need to bring “cases” and “deaths” back as their own column with `spread`. The argument `key` is the name of the column containing the variable names that you want to make into their own column. The argument `value` is the name of the column whose values you want to show under the new columns to be created. Other columns will be arranged accordingly.

```

> cancer = spread(cancer, key="category", value="n")
> str(cancer)
'data.frame':  94 obs. of  4 variables:
 $ cancer: Factor w/ 47 levels "Acute lymphocytic leukemia",...
 $ sex   : chr  "female" "male" "female" "male" ...
 $ cases : int  2670 3290 9140 10380 5620 2960 1510 1940 ...
 $ deaths: int   640  830 4490 6180 680 480 660 930 7340 9490 ...
> cancer
  cancer    sex cases deaths

```

```
#...
37 Mouth female 5600 880
38 Mouth male 7980 1770
#...
81 Tongue female 4620 760
82 Tongue male 12490 1750
#...
```

Finally, let's correctly specify that "sex" is a **qualitative variable** rather than just text.

```
> cancer$sex = as.factor(cancer$sex)
> str(cancer)
'data.frame': 94 obs. of 4 variables:
 $ cancer: Factor w/ 47 levels "Acute lymphocytic leukemia",...
 $ sex : Factor w/ 2 levels "female","male": 1 2 1 2 1 2 1 2 ...
 $ cases : int 2670 3290 9140 10380 5620 2960 1510 1940 10160 ...
 $ deaths: int 640 830 4490 6180 680 480 660 930 7340 9490 ...
```

There we go! Tidy data set!

Chapter 3

Data presentation

3.1 Frequency table (1D) or contingency table (2D)

For qualitative, discrete and continuous variables

If you feel the need to make a table with your data, use a spreadsheet software. ;) R is superior in statistics and (arguably) in figures, but spreadsheets definitely have their uses when it comes to tables.

3.2 Pie chart

For qualitative and discrete variables, max 2 values

A pie chart is a graph that can be used to visually represent proportions of a **qualitative variable** or **discrete variable**. Note that they have their critics, who recommend never using them, as our brain is bad at comparing the size of slices [10].

As an example data set, let's use ebola deaths by country [9]. An excerpt giving the source data is shown in figure 3.1. Enter the data in your favorite spreadsheet software and save it as a csv. You should get the following:

```
Country,Deaths
Guinea,2543
Liberia,4809
Sierra Leone,3956
Mali,6
Nigeria,8
United States of America,1
```

Go ahead and load your small csv into R with `read.csv`. You can then use the function `pie` to produce a pie chart. However, as shown below, a naive approach might disappoint.

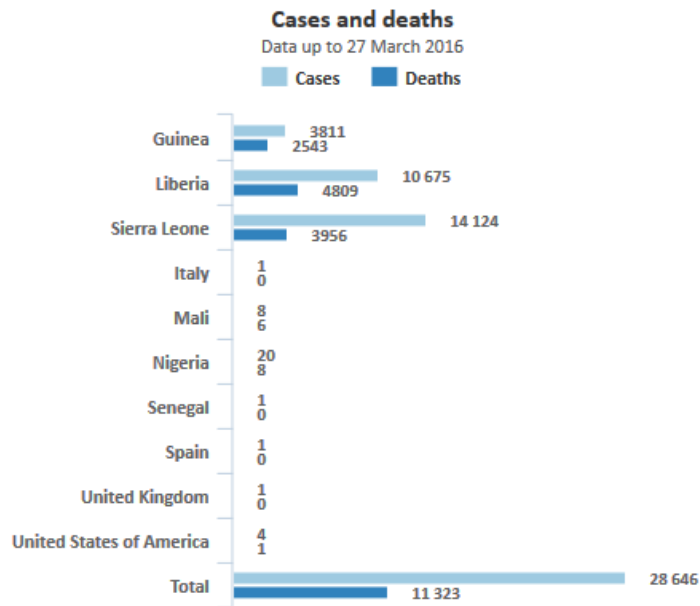


Figure 3.1: Excerpt from [9].

```
> ebola = read.csv('C:/.../r-tutorial/ebola.csv', header=TRUE)
> ebola
```

	Country	Deaths
1	Guinea	2543
2	Liberia	4809
3	Sierra Leone	3956
4	Mali	6
5	Nigeria	8
6	United States of America	1

```
> pie(ebola)
Error in pie(ebola) : 'x' values must be positive.
```

You might be scratching your head and wondering which part of 2543 or 6 is not positive, and you'd be justified to do so. Here, one must dive into computer programming concerns to understand what is going on. The “not positive” message hints at a problem with the format or the type of the input data (see section 2.2). Let's demonstrate:

```
> values = c(2543, 4809, 3956, 6, 8, 1)
> labels = c('Guinea', 'Liberia', 'Sierra Leone', 'Mali',
  → 'Nigeria', 'United States of America')
> pie(values, labels=labels)      # works! produces figure
  → below
```

```

> class(values)
[1] "numeric"
> class(labels)
[1] "character"
> class(ebola)
[1] "data.frame"
> class(ebola$Country)
[1] "factor"
> class(ebola$Deaths)
[1] "integer"
> pie(ebola$Deaths, labels=ebola$Country)      # works too now!

```

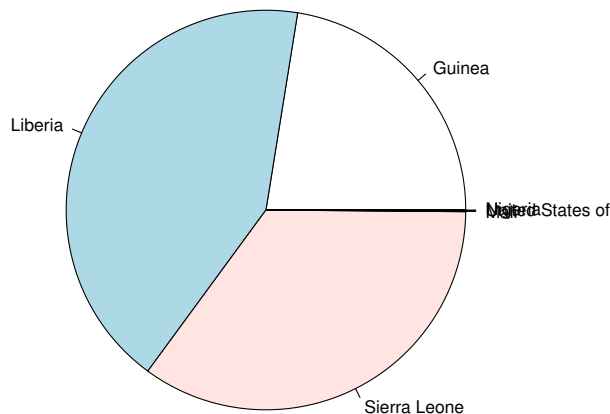


Figure 3.2: Ebola deaths in 2015-2016 by country.

Technically, `read.csv` returns a `data.frame`, while `pie` only accepts numbers. Accessing the columns of the data frame (see section 2.3) to feed `pie` the right types of arguments allows it to produce the expected figure.

Now that we have our basic pie chart, you might be thinking, “That squiggle on the right with the tiny pie slices is quite unseemly”. In addition, you might want to tweak other aspects of the graph, like adding a title or choosing colors. We will discuss common graph properties in a following section, to keep it all

in the same place. As a note, all options are always listed in the function's help page.

Let's just deal with the pie-chart specific problem of small slices here (I reiterate, you should run away, run away into the arms of a bar chart.), and add a percent annotation, as that is a common occurrence. R does not offer an option to deal with small slices out of the box (probably because it tells you in its own manual to use bar charts instead), so let's just manually tweak the labels:

```
> labels = as.character(ebola$Country)
> labels[4]='Others'
> labels[5:6]=' '
> labels
[1] "Guinea"          "Liberia"          "Sierra Leone" "Others"
↪ ""
[6] ""
> percents = ebola$Deaths/sum(ebola$Deaths)*100
> percents
[1] 22.458712355 42.471076570 34.937737349 0.052989490
↪ 0.070652654
[6] 0.008831582
> percents[4] = sum(percents[4:6])
> percents
[1] 22.458712355 42.471076570 34.937737349 0.132473726
↪ 0.070652654
[6] 0.008831582
> percents = round(percents, 2)
> percents
[1] 22.46 42.47 34.94 0.13 0.07 0.01
> labels[1:4] = paste(labels[1:4], percents[1:4], '%')
> labels
[1] "Guinea 22.46 %"      "Liberia 42.47 %"      "Sierra Leone
↪ 34.94 %"
[4] "Others 0.13 %"
> pie(ebola$Deaths, labels)
```

Hacky, but it works, and no more time should be dedicated to pie charts, so let's move on.

3.3 Bar chart

For qualitative and discrete variables

A bar chart, sometimes called a line graph, is used to represent a **qualitative variable** or a **discrete variable**, and the bars *do not touch*. As an example, data on infant mortality by country can be found at Gapminder [6]. The import process is detailed in section 2.6.1.

A barplot is relatively straightforward to produce with R, but we will see all “common” (imho) plot options here, so tie your winter hat down with wire, you’ll be sitting here a while. Let’s start by simply plotting infant mortality rate by country. To keep the plot readable, let’s choose a subset of G8 countries: Canada, France, Germany, Italy, Japan, Russia, United Kingdom and United States of America. Let’s also start by studying the mortality rate in 2000. First, we will select each of the countries by its row number, then we will stitch the G8 back together with a function called `rbind`, which binds data frames together by row, as long as all data frames have the same columns.

```
> canada = infant[38,]
> france = infant[77,]
> germany = infant[83,]
> italy = infant[109,]
> japan = infant[111,]
> russia = infant[186,]
> uk = infant[240,]
> usa = infant[241,]
> g8 = rbind(canada, france, germany, italy, japan, russia, uk,
  ↪ usa)
```

Producing a barplot now is easy:

```
> barplot(g8$X2000, names.arg=g8$Country)
```

Several things are wrong with this graph. Glaringly, a bar should not extend beyond its axis. Axes are set as plot options with `xlim` and `ylim`. Also, should you want a box around the graph, `bty` takes care of that. Usually. Bar plots are special and you need to call an extra function after your plot appears. See all graph options with `?par`, which we will use a lot more as we customize our graphs.

```
> barplot(g8$X2000, names.arg=g8$Country, ylim=c(0,20),
  ↪ bty='o')
> # why oh why won't bty work like everywhere else!
> box()
```

You probably also want all country names to show up. Easiest way to do that is to tilt the axis label text. Here we will learn about `par`, used *before* your graph function to specify general plotting settings. For this next iteration, let’s do a few things at once. First, let’s make all labels perpendicular to their axis with `par` and `las`. Let’s also demonstrate color manipulation by making each country’s bar the dominant color on their flag (I may have made some arbitrary choices) with `col`.

```
> colors = c('red', 'blue', 'black', 'green', 'white', 'snow',
  ↪ 'purple', 'purple4')
> par(las=2) # axis labels: perpendicular
```

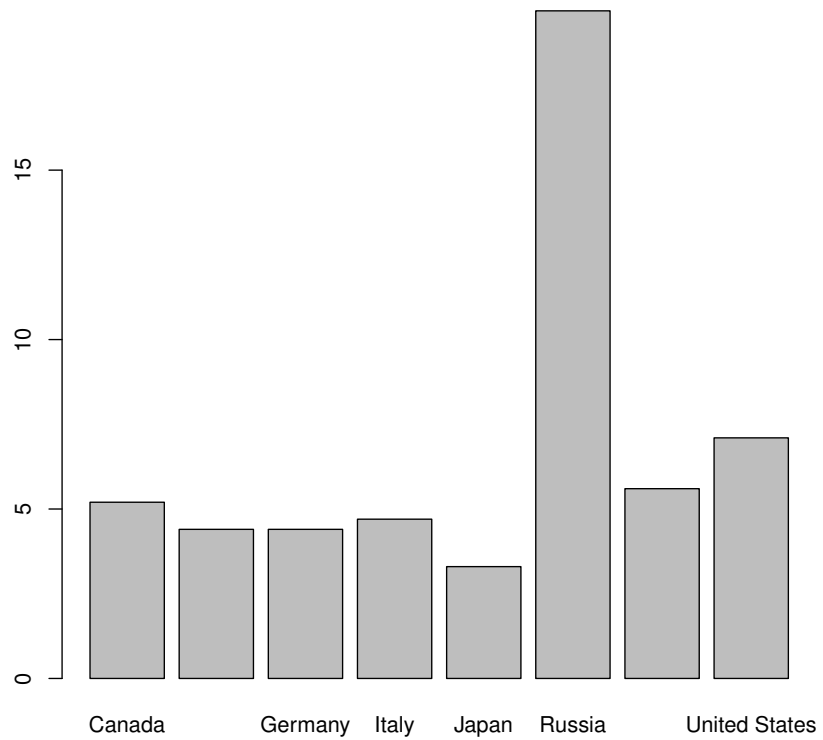


Figure 3.3: Simplest bar plot: infant mortality rate per country.

```
> barplot(g8$X2000, names.arg=g8$Country, ylim=c(0,20),  
  ↪ col=colors)  
> box()
```

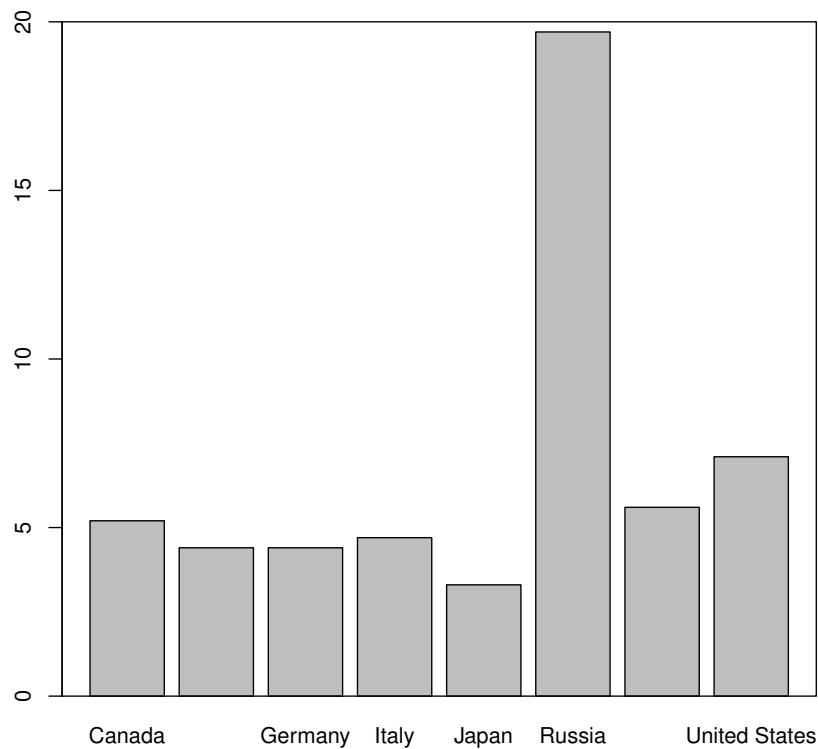


Figure 3.4: Simple bar plot: infant mortality rate per country, axis set.

Colors in R

Colors in R can be specified by their names, if they are among R's list of predefined colors, which you can see by calling `colors()`.

A more visually helpful version can be found at Color Chart [3] which, incidentally, has other fascinating references about the use of color in science (good vs. bad color ramps, color blindness, etc).

Additionally, colors can be specified in other formats like `#RRGGBB`. These values can be found with graphics software or off a color generator on the internet.

Finally, if color space is a concern, additional functions exist: `rgb`, `hsv`, `hcl`, `gray` and `rainbow`.

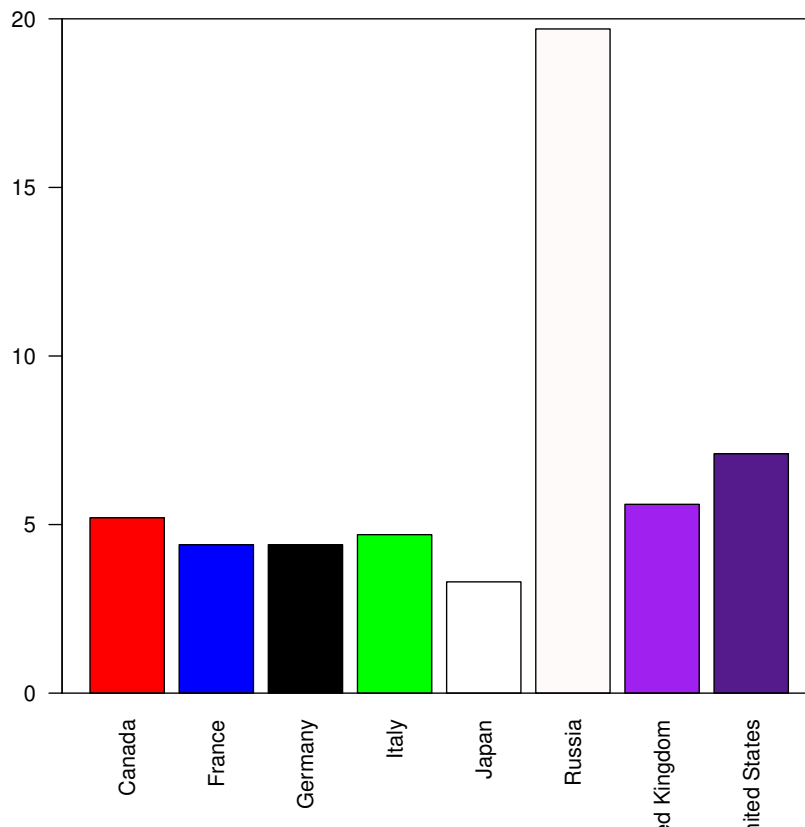


Figure 3.5: Psychedelic bar plot: infant mortality rate per country, axis set, labels perpendicular, colors.

With the country names printed at the vertical, they are running out of space at the bottom of the graph. More margin is needed there. Figures have two types of margins in R: outer and inner. The inner margin is used to draw the figure title and the axis ticks and labels and can be set in inches with `mai=c(bottom, left, top, right)` or in lines with `mar=c(bottom, left, top, right)`. The outer margin is outside the figure; it makes more sense when several plots are displayed together, as we will do a few exercises down the line. The outer margin as well can be set in inches with `omi=c(bottom, left, top, right)` or in lines with `oma=c(bottom, left, top, right)`. As for the appropriate margin necessary to display the full country name, that's a matter of trial and error. Starting with the current parameters' value of inner margin, I found that a value of 8 worked well.

```

par()$mar
[1] 5.1 4.1 4.1 2.1
> # mar = c(bottom, left, top, right)
> par(mar=c(8, 4.1, 4.1, 2.1))
> barplot(g8$X2000, names.arg=g8$Country, ylim=c(0,20),
  → col=colors)
> box()

```

Now, bar charts often use stacked bars. For example, let's use cancer rates [16]. This data includes number of cases and number of deaths by sex and cancer type. If the thing you would most like to compare is the number of cancer by type, you would stack the sexes into one bar. Let's use the tidy version of the data set produced in section 2.6.3.

```

> str(cancer)
'data.frame': 94 obs. of 4 variables:
 $ cancer: Factor w/ 47 levels "Acute lymphocytic leukemia",...
 $ sex : Factor w/ 2 levels "female","male": 1 2 1 2 1 2 1 2 ...
 $ cases : int 2670 3290 9140 10380 5620 2960 1510 1940 10160 ...
 $ deaths: int 640 830 4490 6180 680 480 660 930 7340 9490 ...

```

The help page of `barplot` tells you that the first argument can be either a vector or matrix. If `height` is a vector, for example the single column `cancer$deaths`, then the barplot shows what one would expect. If `height` is a matrix, then each *column* must be either the values to stack (`beside=FALSE`) or the values for a group of bars (`beside=TRUE`). To visualize, let's plot data for five short-named cancers in the list. And since this is a perfect occasion, let's learn about a few more figure options: the `legend` argument and how to plot several figures into one plot window.

```

> subset=rbind(cancer[11:12,], cancer[17:18,], cancer[35:36,],
  → cancer[63:64,], cancer[79:80,])
> subset = subset[, 1:3]
> subset
      cancer sex cases deaths
11 Breast female 266120 40920
12 Breast  male  2550    480
17 Colon female 47530 23240
18 Colon  male 49690 27390
35 Melanoma female 36120 3330
36 Melanoma  male 55150 5990
63 Pharynx female 3340 750
64 Pharynx  male 14250 2480
79 Thyroid female 40900 1100
80 Thyroid  male 13090 960
> fordemo = spread(subset[, 1:3], cancer, cases) # let's just use
  → cases for now

```

```

> fordemo
sex Breast Colon Melanoma Pharynx Thyroid
1 female 266120 47530 36120 3340 40900
2 male 2550 49690 55150 14250 13090
> # each column of the matrix is one cancer to stack or group
> str(fordemo)
'data.frame': 2 obs. of 6 variables:
 $ sex : Factor w/ 2 levels "female","male": 1 2
 $ Breast : int 266120 2550
 $ Colon : int 47530 49690
 $ Melanoma: int 36120 55150
 $ Pharynx : int 3340 14250
 $ Thyroid : int 40900 13090
> # but you want an actual matrix, not a data frame
> # with row and column names
> # and cells containing numbers only
> fordemo = as.matrix(fordemo[,2:6])
> fordemo
Breast Colon Melanoma Pharynx Thyroid
[1,] 266120 47530 36120 3340 40900
[2,] 2550 49690 55150 14250 13090
> rownames(fordemo) = c("female", "male")
> fordemo
Breast Colon Melanoma Pharynx Thyroid
female 266120 47530 36120 3340 40900
male 2550 49690 55150 14250 13090

```

At this point, your data is ready in the shape that `barplot` wants it: it's a matrix with each column representing a stack or group. It's also in the shape *you* want it because the row and column names are readable. Now, let's use `mfrow` to plot the results of `beside=TRUE` and `beside=FALSE` side by side, as seen in figure 3.6.

```

> par(mfrow=c(1,2)) # 1 row, 2 columns, fill by row
> # par(mfcol=c(1,2)) # 1 row, 2 columns, fill by column
> # a plot window opens, ready with 1x2 plot regions
> barplot(fordemo, beside=FALSE, legend=TRUE, main="Parameter
→ beside=FALSE")
> # first plot appears on the left
> barplot(fordemo, beside=TRUE, legend=TRUE, main="Parameter
→ beside=TRUE")
> # second plot appears on the right

```

Note that setting the `legend` argument automatically produces a human-readable result from the row names of the “fordemo” matrix.

Now, if you want to stack sexes and group cases and deaths per cancer, this is where `barplot` would fail you and you would have to resort to a package, for

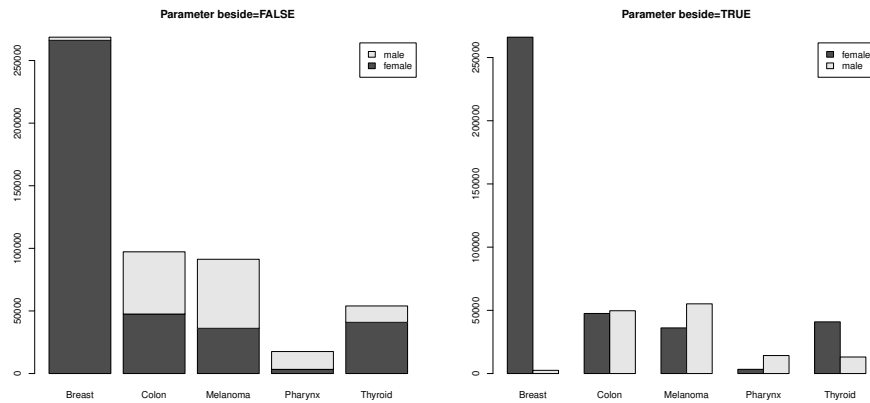


Figure 3.6: Comparing the effect of the `beside` parameter for a matrix fed to `barplot`, using `mfrow`.

example `ggplot2`. According to discussions in the R mailing lists, the basic bar plot function does not support this option because the developers felt it was too much information to fit on one figure, so keep that in mind and ask yourself whether it's a good idea. However, as shown by the pie chart section, I'm not here to judge, so here's a way to do that.

`ggplot2` is so ubiquitously used to produce peer-review quality graphics in R, while being so different from the basic graphics we have used so far that it warrants a bit of an introduction.

`ggplot2` works by sequentially adding *layers* from a *data frame*. So first, you say, "I want to make a new `ggplot`". An empty graphics window opens. Then you say, "I want to add points to this blank canvas". Then you can say, "I want to add a line in addition to the points already there", and then "I also want a main title", and so on. So you will add new function calls separated by a plus sign.

With our cancer study case, our situation is that we want to stack sexes, as well as group cases and deaths (which we will call effect) per cancer. You need each of these in their own column, and you need a data frame since that's what `ggplot` uses. Our data must be transformed this way:

```
> forgg = gather(subset, "effect", "n", 3:4)
> forgg
cancer  sex effect      n
1  Breast female cases 266120
2  Breast  male cases   2550
3  Colon  female cases  47530
4  Colon  male cases  49690
5 Melanoma female cases  36120
6 Melanoma  male cases  55150
```

7	Pharynx	female	cases	3340
8	Pharynx	male	cases	14250
9	Thyroid	female	cases	40900
10	Thyroid	male	cases	13090
11	Breast	female	deaths	40920
12	Breast	male	deaths	480
13	Colon	female	deaths	23240
14	Colon	male	deaths	27390
15	Melanoma	female	deaths	3330
16	Melanoma	male	deaths	5990
17	Pharynx	female	deaths	750
18	Pharynx	male	deaths	2480
19	Thyroid	female	deaths	1100
20	Thyroid	male	deaths	960

As for the plotting part of the work, `ggplot` loves to use scientific notation, so we'll turn that off. `ggplot` comes with several “themes”, which control a series of layout options like background color, presence of grids, etc. We'll use the classic theme since it looks most like the basic graphics package we have been using.

```
options(scipen=999)
theme_set(theme_classic())
```

`ggplot`'s first argument is the source data frame. Then, you will need to specify what it calls an *aesthetic*: what do you want to show in x and y? We want our variable “n” to be shown as y, and we want “effect” and “cancer” on x.

This leads me to talk of *facets* and *formulas*. Facets are a `ggplot2` thing, while formulas are used throughout R. So basically, we want to divide our graph into several smaller graphs, one for each type of cancer, and show them side by side. So each “subgraph” is a facet. Therefore, we will use “cancer” in the facet function, and it leaves “effect” as the x in the `ggplot`'s aesthetic.

As for formulas, they define a more “talkative” way for you to specify which relationship you want R to study for you. The most basic form is $y \sim x$, which reads “y as a function of x”. More elaborate forms include $y + z \sim x$, which is “y and z as a function of x” (note, the plus sign means “and”, not a literal addition), and $y \sim x \mid a$, which is “y as a function of x, per value of a”.

With this preliminary knowledge, we are ready to look at the code, which produces figure 3.7.

```
> ggplot(forgg, aes(effect, n)) +
  # use data frame forgg, x=effect, y=n
  geom_col(aes(fill=sex)) +
  # draw columns, fill them according to sex
  facet_wrap(~cancer, nrow=1) +
  # subdivide as a function of cancer, on 1 row
```



```
coord_cartesian(ylim = c(0, 300000)) +
  # adjust y axis limits
scale_fill_manual(values = c("female"="#FF5577",
  ↪ "male"="#0000FF"))
  #set specific colors
```

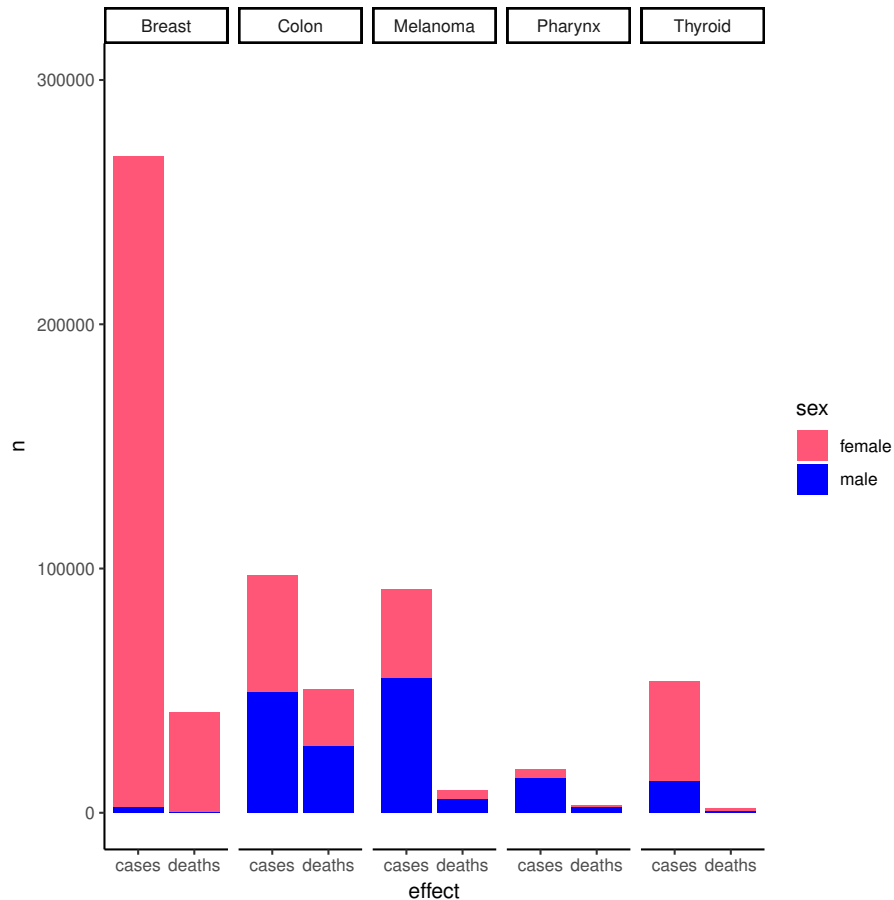


Figure 3.7: Number of cases and deaths by sex for five cancers, with the help of ggplot.

Your options of types of plots include: `geom_point` for points, `geom_col` for bars showing heights, `geom_bar` for bars showing counts.

You can control color and size of points, as well as fill of bars, by setting the appropriate options in the aesthetic, for example:

```
geom_point(aes(size=population, col=state))
geom_col(aes(fill=sex))
```

As you may have noted when we made our figure, the legend appears automatically, with the colors and sizes (if relevant) used.

You can use `facet_wrap` to make your "subgraphs" follow one after the other, or `facet_grid` to have them form a grid, for instance, see the code below, which produces figure 3.8. As for layout options regarding colors, titles, annotations, etc, they are so numerous that I can't detail them here. Digging into the help pages and asking the internet how to do things is the way to go.

```
> ggplot(forgg, aes(effect, n)) +
  geom_col(aes(fill=sex)) +
  facet_grid(cancer~sex, ) +
  scale_fill_manual(values = c("female"="#FF5577",
    ↪ "male"="#0000FF"))
```

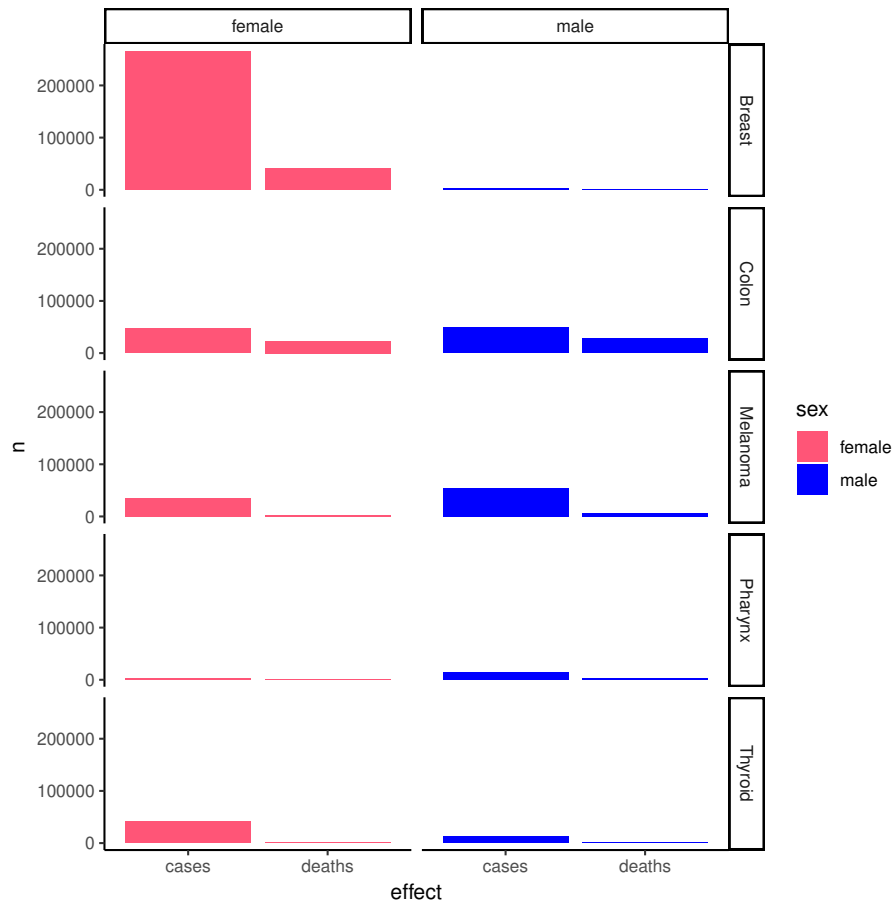


Figure 3.8: Grid presentation of number of cases and deaths per cancer per sex.

3.4 Histogram

For continuous variables

A histogram is a representation of a **continuous variable**, and *the bars touch*. It is used to visually present the shape of the distribution by compiling counts for “bins”, ranges of values. Bins are typically, but not necessarily, of equal width.

For our example, let’s use traffic data in the city of Chicago, with the import process described in section 2.4.4. A simple call to `hist`, will produce the figure 3.9.

```
> str(traffic)
'data.frame':  1279 obs. of  9 variables:
 $ ID      : Factor w/ 1279 levels "1","1,000","1,001",...
 $ Address  : Factor w/ 1203 levels "1 West","10 East",...: 212 ...
 $ Street   : Factor w/ 251 levels "100th St","101st St",...
 $ Date     : Date, format: "2006-03-09" "2006-02-28" ...
 $ Volume   : int  14600 16500 18200 21600 18300 8600 10000 ...
 $ Direction: Factor w/ 1223 levels "East Bound: 1000 ..." ...
 $ Latitude : num  41.8 41.8 41.8 41.8 41.8 ...
 $ Longitude: num  -87.7 -87.7 -87.6 -87.6 -87.6 ...
 $ Location : Factor w/ 1276 levels "(41.651861, -87.54501)",...
> hist(traffic$Volume, xlab="Car volume", ylab="Count", main="",
  ↪ ylim=c(0, 600))
> box()
```

You will note that we fed `hist` the list of car volumes, and the function automatically computed the bins and counted how many observations were in each bin before plotting the resulting histogram.

There are several ways to compute bins for histograms, but the most used is the Sturges method, used by default in R, which outputs more bins the greater the range of the data (more or less) [5].

As you may have noted, there are several outliers at the right of the graph, with such small numbers that their bar is barely visible. I don’t necessarily recommend this course of action, since you change the representativity of your figure, but you could decide to group together the small bins at the end so they are visible. Let’s say you wanted to group together the bins at the right with five or less observations. Here, let’s point out a neat feature of R. In order to produce a plot, `hist` must compute bins, counts, etc., and it actually gives you access to them if you save the output of `hist`. You can then make use those to produce your personalized histogram, producing figure 3.10.

```
> h = hist(traffic$Volume, xlab="Car volume", ylab="Count",
  ↪ main="", ylim=c(0, 600))
> h
$`breaks`
[1]      0  10000  20000  30000  40000  50000  60000  70000
```

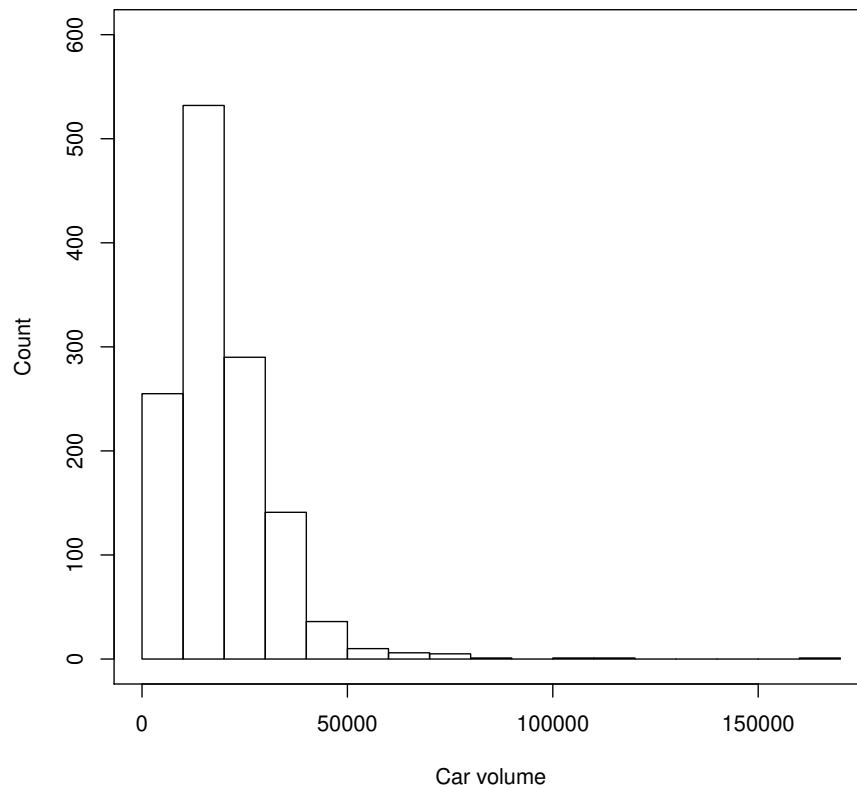


Figure 3.9: Histogram of car volumes in the city of Chicago.

```
[9] 80000 90000 100000 110000 120000 130000 140000 150000
[17] 160000 170000
```

\$counts

```
[1] 255 532 290 141 36 10 6 5 1 0 1 1 0 0
[15] 0 0 1
```

\$density

```
[1] 0.00001993745113 0.00004159499609 0.00002267396403
[4] 0.00001102423769 0.00000281469898 0.00000078186083
[7] 0.00000046911650 0.00000039093041 0.00000007818608
[10] 0.00000000000000 0.00000007818608 0.00000007818608
[13] 0.00000000000000 0.00000000000000 0.00000000000000
```

```

[16] 0.000000000000000 0.00000007818608

$mids
[1] 5000 15000 25000 35000 45000 55000 65000 75000
[9] 85000 95000 105000 115000 125000 135000 145000 155000
[17] 165000

$xname
[1] "traffic$Volume"

$equidist
[1] TRUE

attr(,"class")
[1] "histogram"
> h$breaks
[1] 0 10000 20000 30000 40000 50000 60000 70000
[9] 80000 90000 100000 110000 120000 130000 140000 150000
[17] 160000 170000
> h$counts
[1] 255 532 290 141 36 10 6 5 1 0 1 1 0 0
> mybreaks = c(h$breaks[1:7], 170000)
> mybreaks
[1] 0 10000 20000 30000 40000 50000 60000 170000
> h2 = hist(traffic$Volume, breaks=mybreaks, xlab="Car volume",
→ main="")
> h2
$`breaks`
[1] 0 10000 20000 30000 40000 50000 60000 170000

$counts
[1] 255 532 290 141 36 10 15

```

This figure has *density* as its y axis, meaning that the area (width*height) of all the bars sum to 1. This is the default behavior when using bins of different sizes. Note that your last bin, [60000, 170000[, contains 15 observations, more than the previous bin, while appearing lower in the figure; this is due to the density calculations. The *area* of the bar is representative of its data, not the *height*.

3.5 Scatter graph

For continuous variables

This figure is used to illustrate the relationship between two **continuous variables**. As an incendiary correlation-is-not-causation example, let's use the

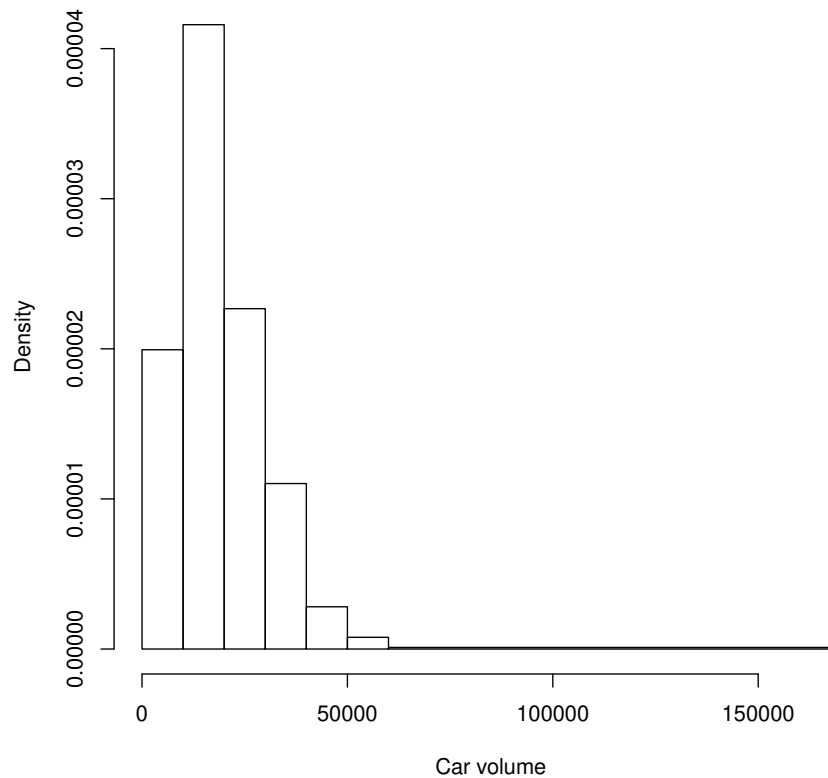


Figure 3.10: *Density* histogram of car volumes in the city of Chicago.

National Health Interview Survey data to study the relationship between diabetes and body mass index [8]. The Sample Adult file has the information we'll use. The Variable summary file will inform you that the column labels that interest you are DIBEV1 (diagnosis of diabetes), DIBTYPE (diabetes type) and BMI (body mass index). The variable layout will inform you of the meaning of the values in the file.

For diabetes diagnosis:

- 1 Yes
- 2 No
- 3 Borderline or prediabetes
- 7 Refused
- 8 Not ascertained
- 9 Don't know

```

Type of diabetes
1 Type 1
2 Type 2
3 Other
7 Refused
8 Not ascertained
9 Don't know

```

And BMI is the number you'd expect multiplied by 100.

For once, simply loading the csv into R gives the expected results. I will spare you the sanity check on import integrity, given the number of variables in the file. Let's just remove all the columns we're not interested with at the moment, divide BMI, and correctly create factors from the integer codes for the other two. Then let's take a quick look at sample data:

```

> nhis=read.csv("C:/.../r-tutorial/samadult.csv")
> nhis$BMI = nhis$BMI/100
> nhis = as.data.frame(cbind(nhis$BMI, nhis$DIBTYPE,
  ↪ nhis$DIBEV1))
> colnames(nhis)=c("BMI", "Type", "Diagnosis")
> nhis$Type = factor(nhis$Type,
+ levels=c(1, 2, 3, 7, 8, 9),
+ labels=c("Type I", "Type II", "Other", "Refused", "Not
  ↪ Ascertained", "Don't know"))
> nhis$Diagnosis = factor(nhis$Diagnosis,
+ levels=c(1, 2, 3, 7, 8, 9),
+ labels=c("Yes", "No", "Borderline or prediabetes", "Refused",
  ↪ "Not Ascertained", "Don't know"))
> str(nhis)
'data.frame': 26742 obs. of 3 variables:
 $ BMI      : num 29.3 23.1 35.4 43.1 32.3 ...
 $ Type      : Factor w/ 6 levels "Type I","Type II",...: NA NA NA
  ↪ NA NA NA NA 2 1 NA ...
 $ Diagnosis: Factor w/ 6 levels "Yes","No","Borderline or
  ↪ prediabetes",...: 2 2 2 2 2 2 2 1 1 2 ...
> nhis[1:20,]
      BMI      Type Diagnosis
1  29.30    <NA>      No
2  23.09    <NA>      No
3  35.44    <NA>      No
4  43.13    <NA>      No
5  32.27    <NA>      No
6  23.25    <NA>      No
7  24.67    <NA>      No
8  41.97 Type II      Yes
9  33.51 Type I       Yes
10 26.62    <NA>      No

```

```

11 22.61    <NA>      No
12 28.72    <NA>      No
13 28.17    <NA>      No
14 27.83    <NA>      No
15 36.58 Type II      Yes
16 21.81    <NA>      No
17 27.41    <NA>      No
18 27.80    Other     Yes
19 27.36    Other     Yes
20 20.81    <NA>      No

```

Now, to simplify our analysis and our figure, let's just concern ourselves with the diagnosis values of yes or no and diabetes types 1 or 2. To do this, I will use the `filter` function. Since R has two `filter` functions, one in the `stats` and the other in the `dplyr` package, I will manually specify which one I want. `filter` works by giving it some data, then specifying a condition, and it returns the rows where the condition is verified.

In our case, we want all the cases where the diagnosis is "No" (in that case, diabetes type is NA). We also want rows where diagnosis is "Yes", but only if their value of type is I or II. Verbally, it is:

```

Diagnosis = No
OR
(Diagnosis = Yes AND (Type = I OR Type = II))

```

Note that the parenthesis are important, even though it would not appear to make a difference with our data. Instead, to demonstrate, let's consider this table:

Name	Sex	Eyes
Sarah	Female	Green
James	Male	Blue
Nicholas	Male	Brown

Now, let's compare the following parentheses placement:

```

Female OR (Male AND blue)
=> (Sarah) OR (James) => Sarah, James
(Female OR Male) AND blue
=> (Sarah, James, Nicholas) AND (blue) => James

```

This kind of statement is called boolean algebra, and it definitely needs some getting used to. Moreover, in R, when using "=" to mean a comparison rather than the assignment of a value to a variable, you must actually type "==". | means "or" and & means "and". This leads to the following code:

```

> library(dplyr)
> nhis = filter(nhis, Diagnosis=="No" | (Diagnosis=="Yes" &
  ↪ (Type=="Type I" | Type=="Type II")))
> nhis[1:20, ]

```


	BMI	Type	Diagnosis
1	29.30	<NA>	No
2	23.09	<NA>	No
3	35.44	<NA>	No
4	43.13	<NA>	No
5	32.27	<NA>	No
6	23.25	<NA>	No
7	24.67	<NA>	No
8	41.97	Type II	Yes
9	33.51	Type I	Yes
10	26.62	<NA>	No
11	22.61	<NA>	No
12	28.72	<NA>	No
13	28.17	<NA>	No
14	27.83	<NA>	No
15	36.58	Type II	Yes
16	21.81	<NA>	No
17	27.41	<NA>	No
18	20.81	<NA>	No
19	23.72	<NA>	No
20	22.33	<NA>	No

3.6 Box and whiskers graph

Chapter 4

Data description

4.1 Center tendency measurements

4.1.1 Mean

4.1.2 Median

4.1.3 Mode

4.2 Dispersion measurements

4.2.1 Range

4.2.2 Variance

4.2.3 Standard deviation

4.2.4 Coefficient of variation

4.2.5 Quartiles and percentiles

4.3 Shape measurements

4.3.1 Skewness

4.3.2 Kurtosis

4.3.3 L-moments

Chapter 5

Probabilities

5.1 Factorial

5.2 Combinations

5.3 Permutations

5.4 Probability Mass/Density Function

Chapter 6

Statistics

- 6.1 Binomial distribution
- 6.2 Multinomial distribution
- 6.3 Poisson distribution
- 6.4 Inverse binomial distribution
- 6.5 Hypergeometric distribution
- 6.6 Normal distribution
- 6.7 Exponential distribution
- 6.8 Gamma distribution
- 6.9 χ^2 distribution
- 6.10 Fisher-Snedecor distribution
- 6.11 Student's law

Chapter 7

Inferential statistics

- 7.1 Student's test
- 7.2 Student's paired test
- 7.3 Bartlett's test
- 7.4 Single-factor ANOVA
- 7.5 χ^2 test
- 7.6 Wilcoxon-Mann-Whitney test
- 7.7 Kolmogorov-Smirnov test
- 7.8 Kruskal-Wallis test
- 7.9 Pearson's test
- 7.10 Spearman's test
- 7.11 Kendall's test
- 7.12 Simple linear regression
- 7.13 Multiple linear regression

Chapter 8

Programming

8.1 Sequence, iteration, branching

8.1.1 Iteration

8.1.2 Branching

8.2 Functions

8.3 Misc

Chapter 9

Cheat sheet

9.1 Plumbing

<code>?</code>	<code>?exact_function_name</code>
<code>??</code>	<code>??keyword</code>
<code>class</code>	<code>class(R_variable)</code>
<code>str</code>	<code>str(R_variable)</code>
<code>colnames</code>	<code>colnames(R_variable)</code>
<code>as.integer</code>	<code>as.integer(R_variable)</code>
<code>rbind</code>	<code>rbind(var, var...)</code>
<code>cbind</code>	<code>cbind(var, var...)</code>

9.2 Data import and export

<code>read.csv</code>	<code>read.csv('delimited_data.csv', header=TRUE, sep=",", dec=".")</code>
<code>read.fwf</code>	<code>read.fwf('fixed_width_data.txt', widths=c(10, 5, 4), header=FALSE, skip=2, strip.white=TRUE, ...)</code>
<code>write.csv</code>	<code>write.csv(R_variable, file='desired_file_name.csv', row.names=FALSE, append=FALSE)</code>

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Glossary

continuous variable A variable that refers to continuous data, i.e. that can take on an infinite number of values (ex. height in mm), as opposed to categorical data (ex. color of eyes). 5, 42, 44

dependent variable The "explained" variable in a relationship, the one we try to understand as a consequence of another factor. For example, when studying the effect of smoking on lung cancer, lung cancer is the dependent variable.. 5

discrete variable A variable that refers to categorical data (ex. color of eyes), as opposed to continuous data (ex. height in mm). 5, 28, 31

independent variable The "explaining" variable in a relationship, the one that drives a phenomena. For example, when trying to understand the causes of diabetes, body mass index would be an independent variable.. 5

ordinal variable A qualitative variable where the values can be ordered (ex. small, medium, large). 5, 10

qualitative variable A variable that is recorded with words rather than numbers (ex. color of eyes, state of mind). 4, 5, 10, 27, 28, 31

quantitative variable A variable that is measured with numbers (ex. number of cases, height in mm). 4, 5