

Intermediate R Workshop Notes

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Contents

Chapter 1

Introduction

This notebook is created so that the participants of the workshop can follow along with the instructors. We will constantly update this notebook during the workshop to include answers to the questions asked during the workshop. So Please ask a lot of questions!!

1.1 Workshop Schedule

We will try to cover the following material in the course:

Day 1

Time	Topic
9:00	Introductions and R markdown basics
9:30	Conditionals and Loops
10:45	Functions
13:00	Apply family
14:00	Advanced plotting ggplot2

Day 2

Time	Topic

9:00 | ggplot continued 10:45 | Rmarkdown themes, adding html and custom css
styling 14:00 | A short project to bring it all together!

Chapter 2

Rmarkdown

“If I went back to college again, I’d concentrate on two areas: learning to write and to speak before an audience. Nothing in life is more important than the ability to communicate effectively.” – Gerald R. Ford

Learning Objectives

Learn how to generate reproducible reports that display your code and results.

2.1 Set up new R Markdown file

When you perform wet lab experiments, what information do you put in your lab notebook? You probably include the protocol you used to run the experiment, information about the samples and reagents used in the protocol, and at the end you’ll likely include your results (for instance, a picture of a gel). This essentially creates a report of your experiment.

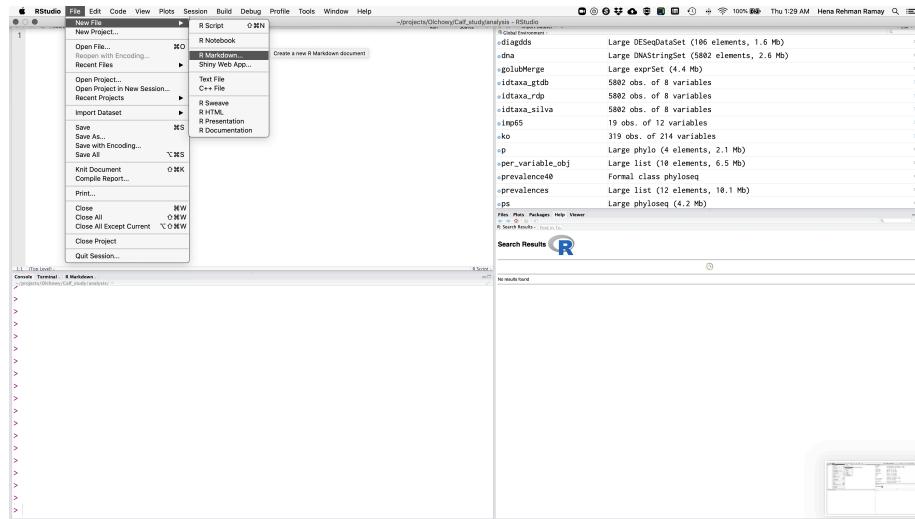
You can do the same with your dry lab analyses using a tool called R Markdown. Why would we want to do this?

- Your method, results, and interpretation are stored in one place
- If you update your methodology, you can easily update your results with the click of a button, rather than copying and pasting.
- *DONOT* cut and paste your code and results into Word or Power Point as Word often introduces hidden characters and it is not good practice to save your code in Word instead of an R script.

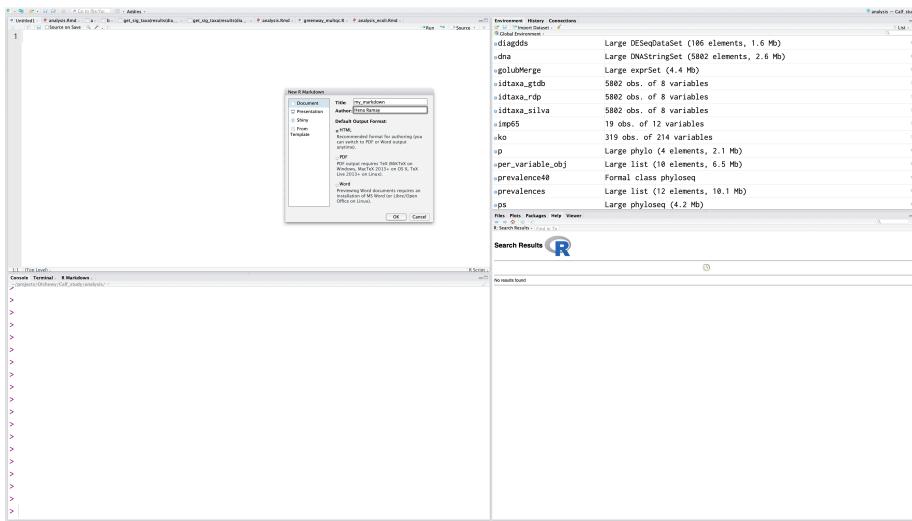
R Markdown is a fairly simple language you can use to generate reports that incorporate bits of R code along with the output they produce. There are two steps to generating reports with R Markdown and RStudio:

1. Write your code in R Markdown.
2. Assemble your report as either HTML or a PDF using the package rmarkdown.

Next, let's run through the demo R Markdown file to see some of the options. Go up to **File -> New File -> R Markdown**.



A screen will pop up asking us what kind of document we wish to create. Let's name our demo report "Trial Report" and fill in your name. Ensure that "Document" is highlighted to the left and that "HTML" is chosen. Click "Ok".



Now we have the example R Markdown file open. The first thing you'll notice at the top is a header which includes your name, the title of the document, the date, and a field called output. This header tells the package rmarkdown some information it might need about your document, including what format you want the final report rendered in.

The next thing you'll notice is white space with some text describing an R Markdown document. White space in this document represents text of the report you would like to display. You can put anything here describing your analysis, results, etc. and it will be recognized as text and not R code. This white space is interpreted as Markdown language, so you can use any of the tricks we learned in the last lesson to make lists, bold certain words, or create headers in your document.

In this trial script, you'll see how some of these markdown elements are used. For example, the word **knit** is in bolded (using asterisks), and there are code chunks near the bottom that say `echo = FALSE`.

```

1 ---
2 title: "my_markdown"
3 author: "Hena Ramay"
4 date: "2029-05-21"
5 output: html_document
6 ---
7
8 ```{r setup, include=FALSE}
9 knitr::opts_chunk$set(echo = TRUE)
10 ...
11
12 ## R Markdown
13
14 This is an R Markdown document. Markdown is a simple formatting syntax for authoring HTML, PDF, and MS Word documents. For more details on using R Markdown see http://rmarkdown.rstudio.com.
15
16 When you click the Knit button a document will be generated that includes both content as well as the output of any embedded R code chunks within the document. You can embed an R code chunk like this:
17
18 ```{r cars}
19 summary(cars)
20 ...
21
22 ## Including Plots
23
24 You can also embed plots, for example:
25
26 ```{r pressure, echo=FALSE}
27 plot(pressure)
28 ...
29
30 Note that the `echo = FALSE` parameter was added to the code chunk to prevent printing of the R code that generated the plot.
31

```

2.1.1 R Markdown components

Notice that the file contains three types of content:

1. An (optional) YAML header surrounded by —s
2. R code chunks surrounded by “`’s
3. text mixed with simple text formatting

In addition to the white space, you’ll gray blocks that have “` at the top and bottom. These are called chunks. If the start of a chunk has {r} at the end of the ticks, the code will be run and both it and its output will be displayed in the rendered HTML. In your R Markdown, the code will look like:

In your final report, the code will look like:

```
summary(cars)
```

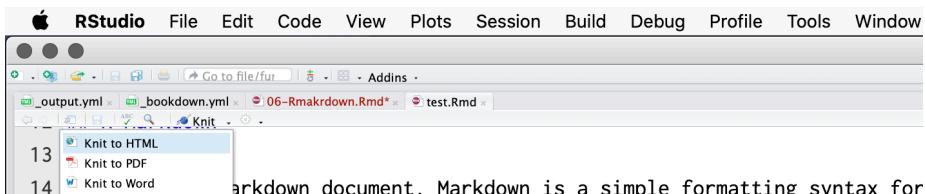
Let’s add a new chunk to end this demo document. To do so, either you can enter three backticks in a row, followed by {r}, or you can click on the green **Chunks**button and chose **Insert Chunk**. Additionally, there’s a keyboard short cut which is **ctrl+alt+i**which will also pop up a chunk in an R Markdown document.

In the chunk, let’s just examine the dimensions of the **carmdataset**:

You can actually send the code straight from the chunks over to console to be evaluated in two ways. First, you can highlight the code you want to run in the chunk and hit the Run button, which is located in the top right corner of the pane.

2.1.2 Knit R Markdown

These are the basics of writing R Markdown, but we still need to generate a report. To do this, click on the button on the top bar that says “Knit HMTL”. This will prompt you to save the file. Go ahead and save this file as `Rmarkdown_demo.Rmd` in the altmetrics directory. The ending of the file `.Rmd` indicates that this is an R Markdown file.



The screenshot shows the RStudio interface with the 'Knit' button highlighted in the toolbar. A dropdown menu is open under 'Knit' with the following options: 'Knit to HTML' (selected), 'Knit to PDF', 'Knit to Word', 'Knit with Parameters...', 'Knit Directory', and 'Clear Knitr Cache...'. The main workspace shows R code and its rendered output.

```

13 13
14 14
15 15
16 16
17 17
18 18
19 19
20 20
21 21
22 22
23 23

```

```

13
14
15
16 When you click the **Knit** button a document will be generated that inclu
17 R code chunks within the document. You can embed an R code chunk like this
18 ``{r cars}
19 summary(cars)
20 ...
21
22 ## Including Plots
23

```

When you click on this link, you see in the console that RStudio is running and rendering your R Markdown file. What is actually happening is RStudio is running the function `render`, which is part of the `rmarkdown` package. There are two things the command `render` does. First, it converts the R Markdown file to a Markdown file using the command `knit` from the `knitr` package (hence why rendering is called knitting). The second step is then the Markdown file is converted to the final file format (HTML, PDF, or Word).

The final result is that an HMTL file will pop up where you'll see the report. You can see the header has been rendered, there are code and results chunks displayed, and even plots are shown right in the report.

Also, if you now look in the altmetrics folder, you'll see an HTML file of the name `Rmarkdown_demo.html`. When `render` is run, it saves the current version of the `.Rmd` file and the generated HTML file in the directory it is stored in.

Exercise

1. Create a new project for this workshop.
2. In this project create a new markdown file called `rworkshop.Rmd`

3. Change the name of author to yours.
4. Click on the settings icon next to the knit button and go to output options. Try different themes and see how it changes your html output. Choose a theme that you like!

2.2 Knitr Chunk Options

Learning Objectives

Learn how to format chunks in R Markdown to display only the information you want to display.

You've learned the basics of how to incorporate markdown syntax with code chunks in an R Markdown file. Let's explore some additional options for making your code chunks appear the way you want them to appear in your reports. There are many ways to customize your chunks and you can explore all of the options by examining the documentation. Here, we'll introduce you to some of the most useful options that you might use frequently.

Chunk output can be customized with knitr options , arguments set in the {} of a chunk header. Above, we use five arguments:

- `include = FALSE` prevents code and results from appearing in the finished file. R Markdown still runs the code in the chunk, and the results can be used by other chunks.
- `echo = FALSE` prevents code, but not the results from appearing in the finished file. This is a useful way to embed figures.
- `message = FALSE` prevents messages that are generated by code from appearing in the finished file.
- `warning = FALSE` prevents warnings that are generated by code from appearing in the finished.
- `fig.cap = "..."` adds a caption to graphical results.

The first thing you may want to consider is naming your code chunks, which makes debugging easier, especially if you have a long script. Chunk names must be unique to each chunk.

Write the name of your chunk after the {r}, like: `{r chunk_name}`

R Markdown:

Rendered:

```
summary(cars)
```

```
##      speed         dist
##  Min.   : 4.0   Min.   :  2.00
##  1st Qu.:12.0   1st Qu.: 26.00
```

```
## Median :15.0   Median : 36.00
## Mean   :15.4   Mean   : 42.98
## 3rd Qu.:19.0   3rd Qu.: 56.00
## Max.    :25.0   Max.    :120.00
```

You can use RStudio to navigate to chunks based on their names, which can be especially useful as your script gets long. Click on the bottom left bar where it says (Top Level) and you'll see all of the chunk names in your script appear. Additionally, naming your chunks will be beneficial to identify errors in your code or slow sections when knitting your report.

Sometimes you may not want to see the code that produced a particular result in your report. You can have codeblocks in your R Markdown that are evaluated, but the code is not displayed in the final report by including `echo=FALSE` after the `{r chunk_name}`.

R Markdown:

Rendered:

```
##      speed          dist
## Min.   : 4.0   Min.   : 2.00
## 1st Qu.:12.0   1st Qu.: 26.00
## Median :15.0   Median : 36.00
## Mean   :15.4   Mean   : 42.98
## 3rd Qu.:19.0   3rd Qu.: 56.00
## Max.    :25.0   Max.    :120.00
```

Conversely, sometimes you may want to see the code, but not the output once the code is evaluated. To do so, you can include `results="hide"` after the `chunk_name`:

R Markdown:

Rendered:

```
summary(cars)
```

Sometimes, you may want to write a report where both the code and the output are suppressed. Why would you want to do that? Perhaps you're sending a report to a collaborator and you only want them to see the final figures, but not any data manipulation steps in the middle. To include a chunk that is evaluated, but no output is displayed - neither the code nor the results - put `include=FALSE` after the `chunk_name`:

R Markdown:

Rendered (I swear there's a chunk after this! It's just invisible!):

There are tons of other options you can include in your chunks: sizing your figures and whether or not to display error or warning messages. As you write

reports of your own data analysis, you can look up these options to create a report formatted in the way you want.

In addition to code chunks, you may want to include the results of an evaluation in line with regular text. For instance, you may want to describe the data in a paragraph, and include the number of individuals in that paragraph. To do so, you can indicate that a code box should be evaluated as R by including a lowercase r.

R Markdown:

```
The _cars_ dataset included in this analysis contains records for `r dim(cars)[1]` cars.
```

Rendered:

The _cars_ dataset included in this analysis contains records for 50 cars.

Exercise

Now that you are familiar with chunks, create a chunk in which you do $\text{sum}=1+1$. Now by searching on the web, how can you re-use this chunk later in your rmd file.

Chapter 3

Conditionals and Loops

3.1 Setup

1. Download data.

We will be using a dataset containing citation and alternative metrics for articles published in the PLOS family of journals between 2003 and 2010. The data set was compiled by Priem et al 2012 (publication).

Download the data onto your computer from this dropbox link and move it into a directory on your computer that makes sense.

2. Read in data into R.

```
counts <- read.delim("data/counts-raw.txt")
```

3.2 Conditional statements

Decision making is an important part of programming. This can be achieved in R programming using conditional statements such as `if` and `if...else`.

`if`

The syntax of an if statement is:

```

if (test_expression) {
  do_this
}

x <- 5
if (x > 0) {
  print("positive number")
}

## [1] "positive number"

```

if...else

The syntax of an if...else statement is:

```

if (test_expression) {
  do_this
} else {
  do_that
}

```

The else part is optional and is only evaluated if test_expression is FALSE. It is important that the `else` word be in the same line as the closing brace of the `if` statement.

```

x <- 1
if (x > 0){
  print("positive number")
} else {
  print("negative number")
}

## [1] "positive number"

```

Nested if...else statements

You can have more than two test expressions:

```

if (test_expression1) {
  statement1
} else if (test_expression2) {
  statement2
} else {
  statement4
}

```

```
x <- 0
if (x < 0) {
  print("negative number")
} else if (x > 0) {
  print("positive number")
} else {
  print("zero")
}
```

```
## [1] "zero"
```

EXERCISE 2.1

Write a simple if...else statement to check if 5 is an odd number and if it is print “I am odd”, otherwise print “I am even”.

3.3 Loops

Conceptually, a loop is a way to repeat a sequence of instructions under certain conditions. They allow you to automate parts of your code that are in need of repetition.

for loop

The easiest and most frequently used loop in R is a for loop. Here is a demonstration of using loops.

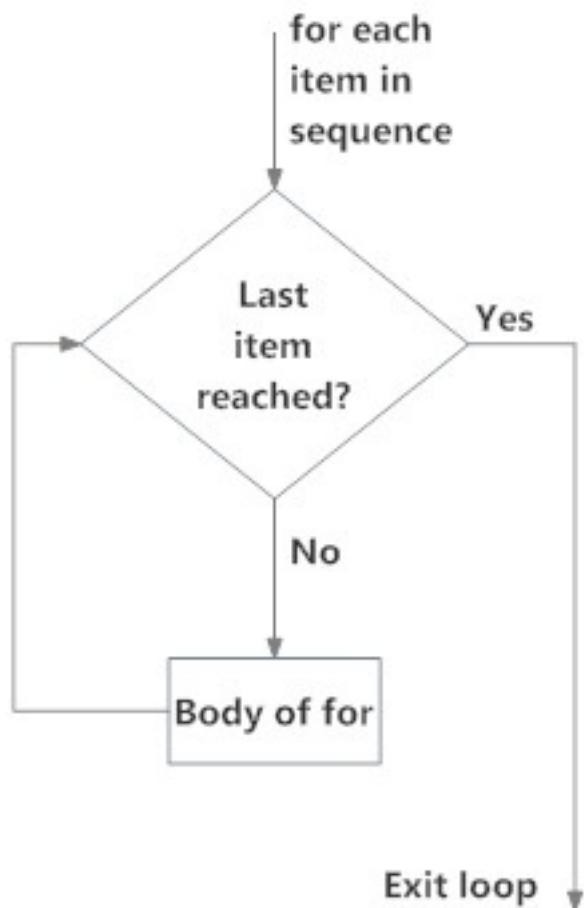


Fig: operation of for loop

```
year <- c(2015,2016,2017,2018)
for(i in 1:length(year)) {
  print(year[i])
}

## [1] 2015
## [1] 2016
## [1] 2017
## [1] 2018

for(i in 1:length(year)) {
  print(paste0("the year is ",year[i]))
}
```

```
## [1] "the year is 2015"  
## [1] "the year is 2016"  
## [1] "the year is 2017"  
## [1] "the year is 2018"
```

while loop

In contrast to a **for** loop, **while** loops are used to loop until a specific conditional statement is no longer true.

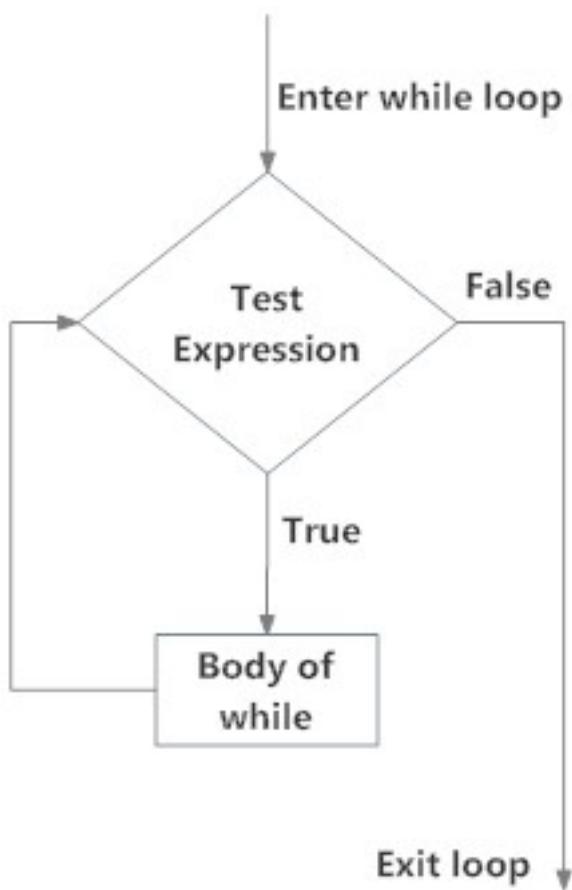


Fig: operation of while loop

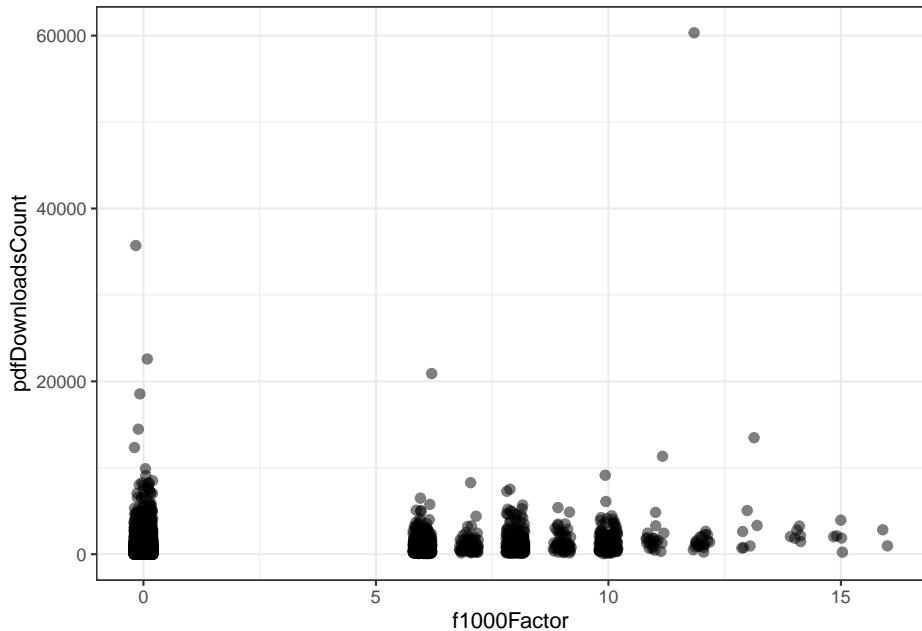
```
while (test_expression) {  
  do_this  
}
```

```
i <- 1
while (i < 6) {
  print(i)
  i <- i + 1
}

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

EXERCISE 2.2

Challenging. From the PLOS journal publication data we read into R above, here is a plot showing the impact factor according to the F1000 (Faculty of 1000) versus the number of times the PDF was downloaded.

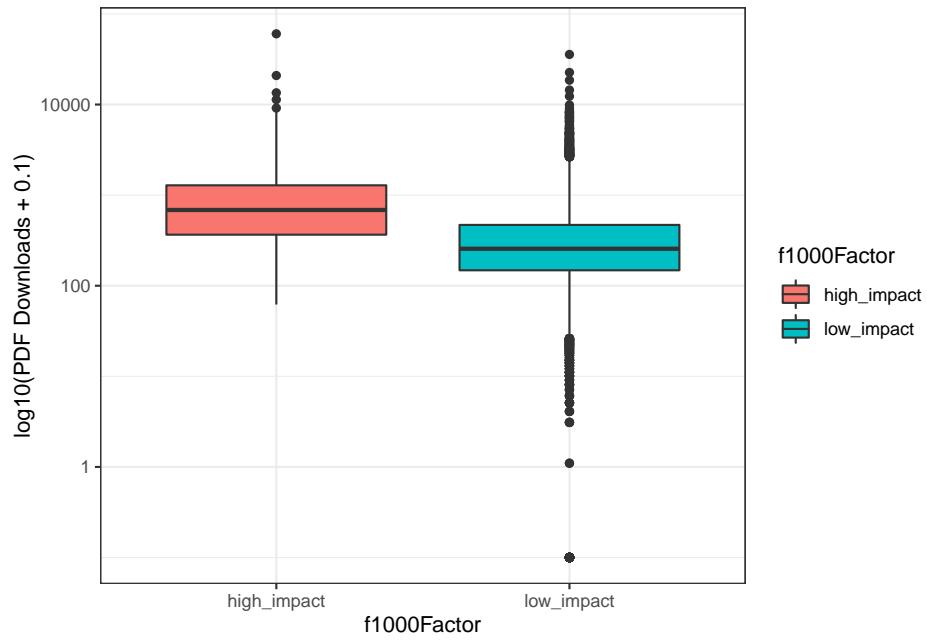


Using this dataset, write a `for` loop containing an `if...else` statement to change the `f1000Factor` column into categorical variable with two levels: high impact and low impact.

Do this by translating the following sentence into R code: for every element in the `f1000Factor` variable, if the value is greater than zero, change it to

“high_impact”, otherwise, change it to “low_impact”.

Bonus. Create a box plot (like the one below) showing the number of PDF downloads for high versus low impact articles.



Chapter 4

Functions

“Intelligence is the ability to avoid doing work, yet getting the work done.”
Linus Torvalds

Learning Objectives

- Functions have two parts: arguments and body
- Functions have their own environment
- Functions help you repeat code chunks

In the last lesson we learnt to write loops to avoid writing the same code multiple time. Now lets learn how to make our code even more efficient and re-use the same code multiple times without copy-paste!

4.1 Parts of a function

We've already been using built-in R functions: `read.csv`, `mean`, `length`, etc. These functions allow us to run the same routine with different inputs.

Let's explore `read.csv` further. All functions in R have two parts: the input arguments and the body. We can see the arguments of a function with the `args`.

```
args(read.csv)
function (file, header = TRUE, sep = ",", quote = "\"\"", dec = ".",
          fill = TRUE, comment.char = "", ...)
NULL
```

So when we pass a character vector like "data/counts-raw.", this gets assigned to the argument `file`. All the other arguments have defaults set, so we do not need to assign them a value.

After the arguments have been assigned values, then the body of the function is executed. We can view the body of a function with `body`.

```
body(read.csv)

read.table(file = file, header = header, sep = sep, quote = quote,
          dec = dec, fill = fill, comment.char = comment.char, ...)
```

`read.csv` is very short. It just calls another function, `read.table`, using the input file and the default arguments as the arguments passed to `read.table`.

When we define our own functions, we use the syntax below. We list the arguments, separated by commas, within the parentheses. The body follows, contained within curly brackets {}.

```
function_name <- function(args) {
  body
}
```

4.2 The principle of encapsulation

An important feature of functions is the principle of encapsulation: the environment inside the function is distinct from the environment outside the function. In other words, variables defined inside a function are separate from variables defined outside the function.

Here's a small example to demonstrate this idea. The function `ex_fun` takes two input arguments, `x` and `y`. It calculates `z` and returns its value.

```
ex_fun <- function(x, y) {
  z <- x - y
  return(z)
}
```

When we run `ex_fun`, the only thing returned to the global environment is the value that was assigned to `z`. The variable `z` itself was only defined in the function environment, and does not exist in the global environment.

```
ex_fun(3, 10)

[1] -7

z

Error in eval(expr, envir, enclos): object 'z' not found
```

4.2.1 Environments

The situation presented above is a simplified version of environments which will serve you well if you treat functions as truly encapsulated. In reality, things are more complicated. For example, if inside a function you have a variable that has not been defined in the function, it will actually search the global environment for this variable. To learn the advanced details, see the chapter Environments in Advanced R by Hadley Wickham.

4.3 The return statement

R provides the shortcut of not needing to use `return` at the end of the function. Instead, the variable on the last line of the body of the function is returned. This is useful for writing very small functions, but in these lessons we will use `return` to be more explicit about what is happening.

Exercise

1. Write your own function called `select_first`. It should take a vector as input and return the first element of the list. s
2. Now use articleType column from counts dataframe and use it as input to `select_first` function.
3. Now create a function called ‘`select_el`’ which takes two arguments, a vector and an index. It should return the value in the index of the vector. For example if I give it a vector `x=(10,22,49)` and `index=2`, it should return 22. `select_el(x,index)`
4. Now add to `select_el` funciton some code that will spit out an error if the `index > length(x)`. Hint you can use `if` statement and `stop()` function.

Chapter 5

The apply family

Learning Objectives

Learn to use apply family functions in place of loops.

Whenever you're using a for loop, you might want to revise your code and see whether you can use the lapply function instead. Learn all about this intuitive way of applying a function over a list or a vector, and its variants sapply and vapply.

5.1 apply()

apply() takes Data frame or matrix as an input and gives output in vector, list or array. apply() Function is primarily used to avoid explicit uses of loop constructs. It is the most basic of all collections can be used over a matrice.

This function takes 3 arguments:

```
apply(X, MARGIN, FUN)
```

apply() takes an array or matrix X, a Margin that takes a value 1 for rows or 2 for columns and applies a functoin FUN to it.

```
m1 <- matrix(C<-c(1:10),nrow=5, ncol=6)
m1
```

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

```
a_m1 <- apply(m1, 2, sum)
a_m1

## [1] 15 40 15 40 15 40

> m1
  [,1] [,2] [,3] [,4] [,5] [,6]
[1,] 1     6     1     6     1     6
[2,] 2     7     2     7     2     7
[3,] 3     8     3     8     3     8
[4,] 4     9     4     9     4     9
[5,] 5    10     5    10     5    10
> a_m1 <- apply(m1, 2, sum) Sum of
> a_m1 Column
[1] 15 40 15 40 15 40
>
```

Exercise

Select the columns from count.raw file from pdfDownloadsCount to hmtlDownloadsCount and using the apply function find the mean of each column.

5.2 lapply()

Before you go about solving the exercises below, have a look at the documentation of the `lapply()` function. The Usage section shows the following expression:

```
lapply(X, FUN, ...)
```

To put it generally, `lapply` takes a vector or list `X`, and applies the function `FUN` to each of its members. If `FUN` requires additional arguments, you pass them after you've specified `X` and `FUN` (...). The output of `lapply()` is a list, the same length as `X`, where each element is the result of applying `FUN` on the corresponding element of `X`.

Now that you are truly brushing up on your data science skills, let's revisit some of the most relevant figures in data science history. We've compiled a vector of famous mathematicians/statisticians and the year they were born. Up to you to extract some information!

5.2.0.1 Example

```
# The vector pioneers has already been created for you
pioneers <- c("GAUSS:1777", "BAYES:1702", "PASCAL:1623", "PEARSON:1857")

# Split names from birth year to make split_math a list
split_math <- strsplit(pioneers, split = ":")
# Convert to lowercase strings: split_low
split_low <- lapply(split_math, tolower)
# Take a look at the structure of split_low
str(split_low)

## List of 4
## $ : chr [1:2] "gauss" "1777"
## $ : chr [1:2] "bayes" "1702"
## $ : chr [1:2] "pascal" "1623"
## $ : chr [1:2] "pearson" "1857"
```

5.2.1 Use lapply with your own function

You can use `lapply()` on your own functions as well. You just need to code a new function and make sure it is available in the workspace. After that, you can use the function inside `lapply()` just as you did with base R functions. We have already created a `select_first()` function so lets apply it to a

Exercise

Use `lapply` on `split_low` list and use the `select_first()` function you created.

5.2.2 lapply and anonymous functions

Writing your own functions and then using them inside `lapply()` is quite an accomplishment! But defining functions to use them only once is kind of overkill, isn't it? That's why you can use so-called **anonymous functions** in R.

Previously, you learned that functions in R are objects in their own right. This means that they aren't automatically bound to a name. When you create a function, you can use the assignment operator to give the function a name. It's perfectly possible, however, to not give the function a name. This is called an anonymous function:

```
# Named function
select_first <- function(x) { x[1] }
```

```
# Use anonymous function inside lapply()
lapply(list(1,2,3), function(x) {x[1]})
```

5.2.2.1 Example

```
# Transform: use anonymous function inside lapply
names <- lapply(split_low, function(x) { x[1] })
```

5.2.3 Use lapply with additional arguments

In the video, the `triple()` function was transformed to the `multiply()` function to allow for a more generic approach. `lapply()` provides a way to handle functions that require more than one argument, such as the `multiply()` function:

```
multiply <- function(x, factor) {
  x * factor
}

lapply(list(1,2,3), multiply, factor = 3)
```

On the right we've included a generic version of the select functions that you've coded earlier: `select_el()`. It takes a vector as its first argument, and an index as its second argument. It returns the vector's element at the specified index.

5.2.3.1 Example

```
# Generic select function
select_el <- function(x, index) {
  x[index]
}

# Use lapply() twice on split_low: names and years
names <- lapply(split_low, select_el, index = 1)
years <- lapply(split_low, select_el, index = 2)
```

5.3 sapply()

You can use `sapply()` similar to how you used `lapply()`. `sapply` is a user-friendly version and wrapper of `lapply` by default returning a vector, matrix .The first argument of `sapply()` is the list or vector `X` over which you want

to apply a function, FUN. Potential additional arguments to this function are specified afterwards (...):

```
sapply(X, FUN, ...)
```

5.3.0.1 Example

```
# Constructing temp variable
names <- sapply(split_low, select_el, index = 1)
```

5.3.1 sapply with your own function

Like lapply(), sapply() allows you to use self-defined functions and apply them over a vector or a list:

```
sapply(X, FUN, ...)
```

Here, FUN can be one of R's built-in functions, but it can also be a function you wrote. This self-written function can be defined before hand, or can be inserted directly as an anonymous function.

5.3.2 sapply with function returning vector

In the previous exercises, you've seen how sapply() simplifies the list that lapply() would return by turning it into a vector. But what if the function you're applying over a list or a vector returns a vector of length greater than 1? If you don't remember from the video, don't waste more time in the valley of ignorance and head over to the instructions!

5.3.2.1 Example

```
temp=list(c(1,3,4,4,6),c(3,4,6,8,9))
# Create a function that returns min and max of a vector: extremes
extremes <- function(x) {
  c(min = min(x), max = max(x))
}
# Apply extremes() over temp with lapply()
lapply(temp, extremes)

## [[1]]
## min max
##   1   6
##
```

```

## [[2]]
## min max
##   3   9
# Apply extremes() over temp with sapply()
sapply(temp, extremes)

##      [,1] [,2]
## min    1    3
## max    6    9

```

5.3.3 sapply can't simplify, now what?

It seems like we've hit the jackpot with `sapply()`. On all of the examples so far, `sapply()` was able to nicely simplify the rather bulky output of `lapply()`. But, as with life, there are things you can't simplify. How does `sapply()` react?

We already created a function, `below_zero()`, that takes a vector of numerical values and returns a vector that only contains the values that are strictly below zero.

5.3.3.1 Example

```

# temp is already prepared for you in the workspace
# Definition of below_zero()
below_zero <- function(x) {
  return(x[x < 0])
}
# Apply below_zero over temp using lapply(): freezing_l
freezing_l <- lapply(temp, below_zero)
# Apply below_zero over temp using sapply(): freezing_s
freezing_s <- sapply(temp, below_zero)
# Are freezing_l and freezing_s identical?
identical(freezing_l, freezing_s)

## [1] TRUE

```

5.4 vapply()

Before you get your hands dirty with the third and last apply function that you'll learn about in this intermediate R course, let's take a look at its syntax. The function is called `vapply()`, and it has the following syntax:

```
vapply(X, FUN, FUN.VALUE, ..., USE.NAMES = TRUE)
```

Over the elements inside `X`, the function `FUN` is applied. The `FUN.VALUE` argument expects a template for the return argument of this function `FUN`. `USE.NAMES` is `TRUE` by default; in this case `vapply()` tries to generate a named array, if possible.

For the next set of exercises, you'll be working on the `temp` list again, that contains 7 numerical vectors of length 5. We also coded a function `basics()` that takes a vector, and returns a named vector of length 3, containing the minimum, mean and maximum value of the vector respectively.

5.4.0.1 Example

```
# temp is already available in the workspace
# Definition of basics()
basics <- function(x) {
  c(min = min(x), mean = mean(x), max = max(x))
}
# Apply basics() over temp using vapply()
vapply(temp, basics, numeric(3))

##      [,1] [,2]
## min    1.0   3
## mean   3.6   6
## max    6.0   9
```

5.4.0.2 Exercise

Use the `table()` function and one of the `apply` functions to see how many counts of each year and article Explain which function you used and what does the output look like?

</div>

<!--chapter:end:05-Apply_family.Rmd-->

Advanced Plotting

"The greatest value of a picture is when it forces us to notice what we never expected to see"

-John Tukey

```
## Setup
```

```
**1. Install the `tidyverse` package.**
```

```
```r
library(tidyverse)
```

## 2. Filter data.

We will be using the publication dataset that we read into R in Chapter 2 as counts.

```
research <- filter(counts, articleType == "Research Article")
```

## 5.5 Review of ggplot2 basics

ggplot2 is a plotting package that makes it simple to create complex plots from data in a data frame. Graphics are built step by step by adding new elements. Adding layers in this fashion allows for extensive flexibility and customization of plots.

A plot can be divided into different fundamental parts:

**Plot = data + aesthetics + geom**

Required building blocks:

- data
- aesthetics - describe how data are mapped to colour, size, shape, location
- geoms - geometric objects like points, lines, shapes

Optional building blocks:

- facets - describes how panel plots should be constructed
- stats - statistical transformations like binning, quantiles, smoothing
- coordinates - describes the system in which the locations of the geoms will be drawn
- scales - what scale an aesthetic map uses (ex. male = red, female = blue)

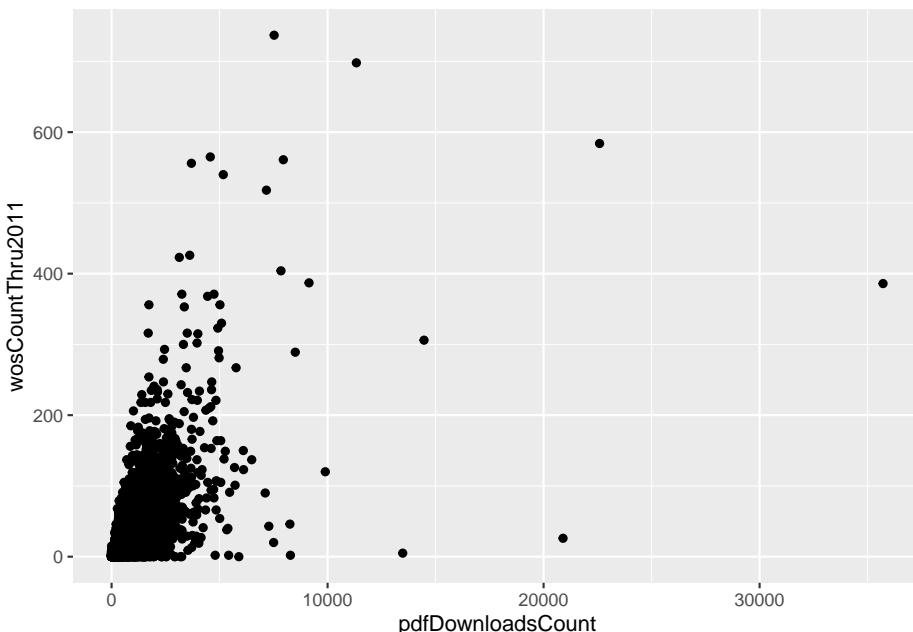
To build a ggplot, we will use the following basic template that can be used for different types of plots:

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

1. Specify which data set to use for the plot using the `data` argument.
2. Define a “mapping” (using the aesthetic (`aes`) function), by selecting the variables to be plotted and specifying how to present them in the graph, e.g. as x/y positions or characteristics such as size, shape, color, etc.
3. Add “geoms” – graphical representations of the data in the plot (points, lines, bars). `ggplot2` offers many different geoms; common ones include:
  - `geom_point()` for scatter plots, dot plots, etc.
  - `geom_boxplot()` for boxplots.
  - `geom_histogram()` for histograms.
  - `geom_barplot()` for barplots.
  - `geom_line()` for trend lines, time series, etc.

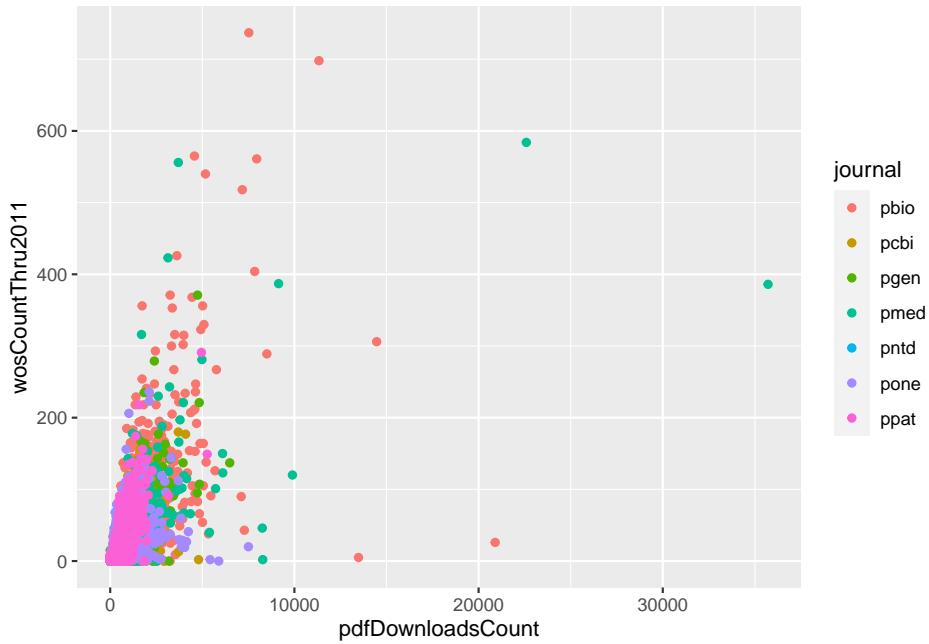
Example:

```
p <- ggplot(research, aes(x = pdfDownloadsCount, y = wosCountThru2011)) + geom_point()
p
```



Adding aesthetics:

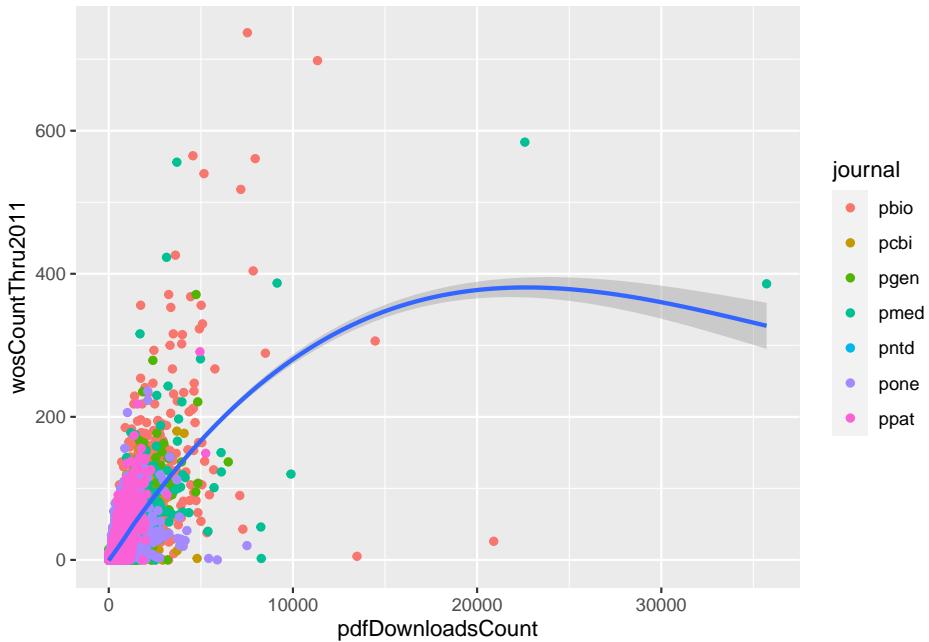
```
p <- ggplot(research, aes(x = pdfDownloadsCount,
 y = wosCountThru2011)) +
 geom_point(aes(color = journal))
p
```



## 5.6 Statistics

The function `geom_smooth()` adds a loess curve to the data along with a 95% confidence interval.

```
p <- ggplot(research, aes(x = pdfDownloadsCount,
 y = wosCountThru2011)) +
 geom_point(aes(color = journal)) +
 geom_smooth()
```



If we move the colour to the base ggplot call, we get loess curves for each level of that factor.

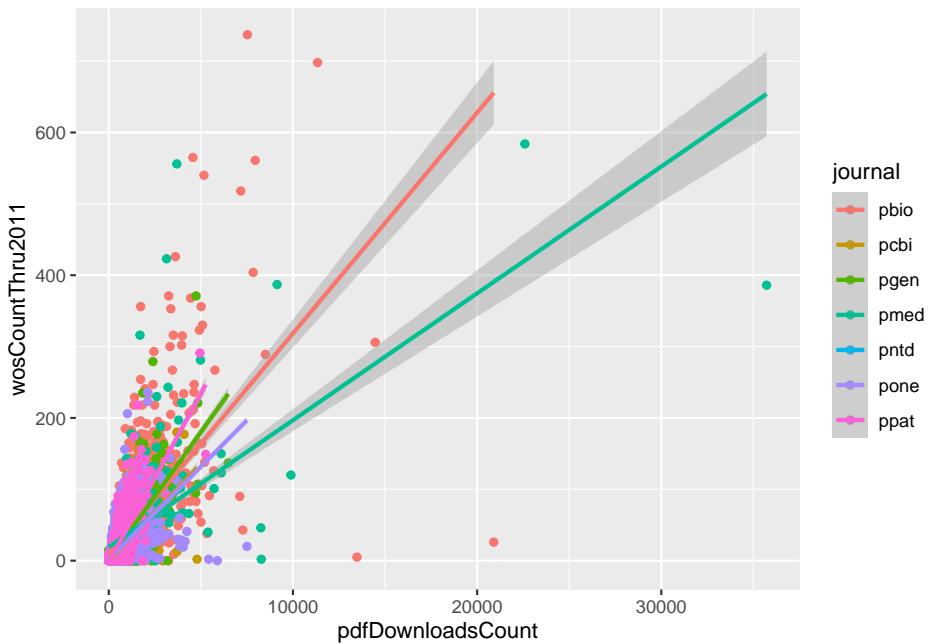
```
p <- ggplot(research, aes(x = pdfDownloadsCount,
 y = wosCountThru2011,
 color = journal)) +
 geom_point() +
 geom_smooth()
```

p



Check the help page for the function `geom_smooth()` for more information about how the curve is made. For example, to map a linear model onto the plot, you can choose `method = "lm"`.

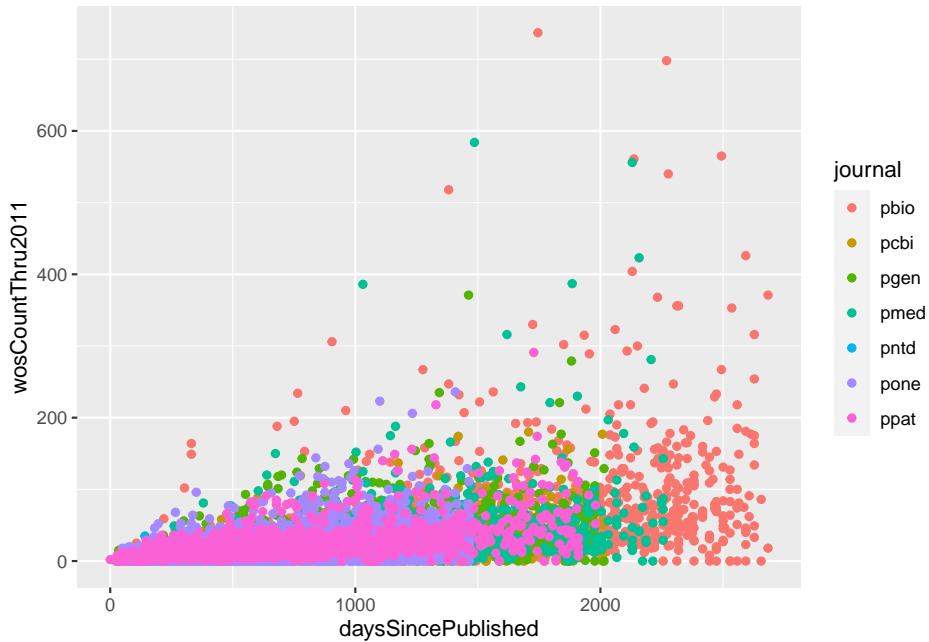
```
p <- ggplot(research, aes(x = pdfDownloadsCount,
 y = wosCountThru2011,
 color = journal)) +
 geom_point() +
 geom_smooth(method = "lm")
```



## 5.7 Scales

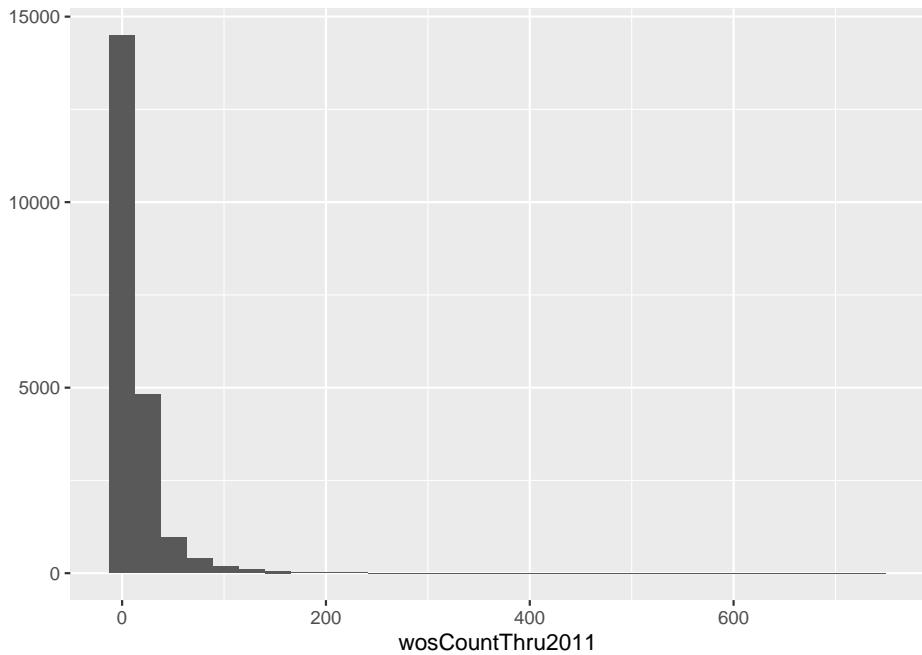
Now let's look at the relationship between days since published and citation count.

```
p <- ggplot(research, aes(x = daysSincePublished,
 y = wosCountThru2011)) +
 geom_point(aes(color= journal))
p
```



It looks like most of the citation counts are close to 0. We can quickly check the distribution of this variable using a qplot.

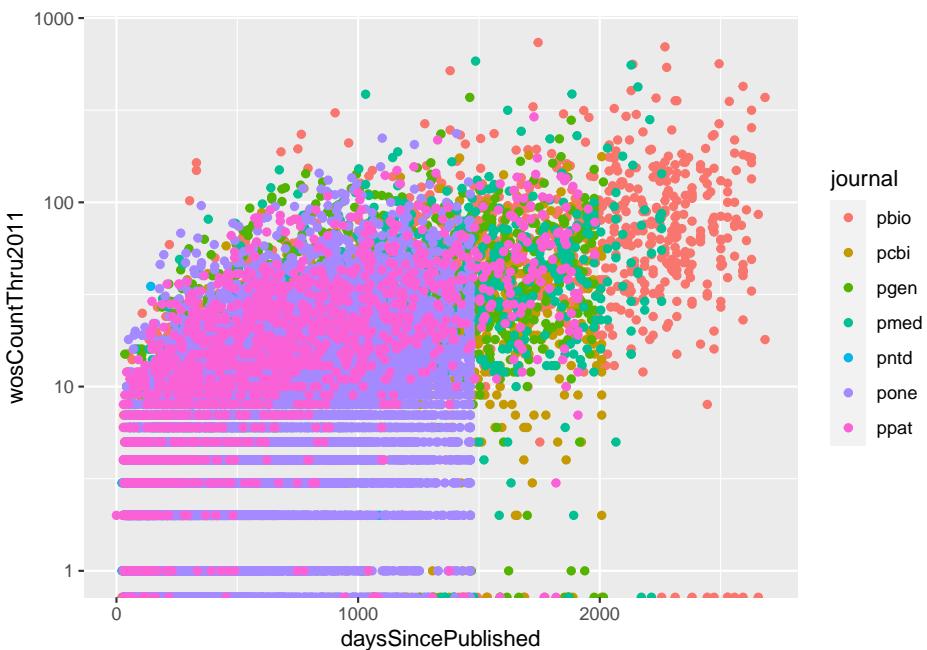
```
qplot(data = research, x = wosCountThru2011)
```



To control the plot axes, we use variants of the functions `scale_x_*` and `scale_y_*`.

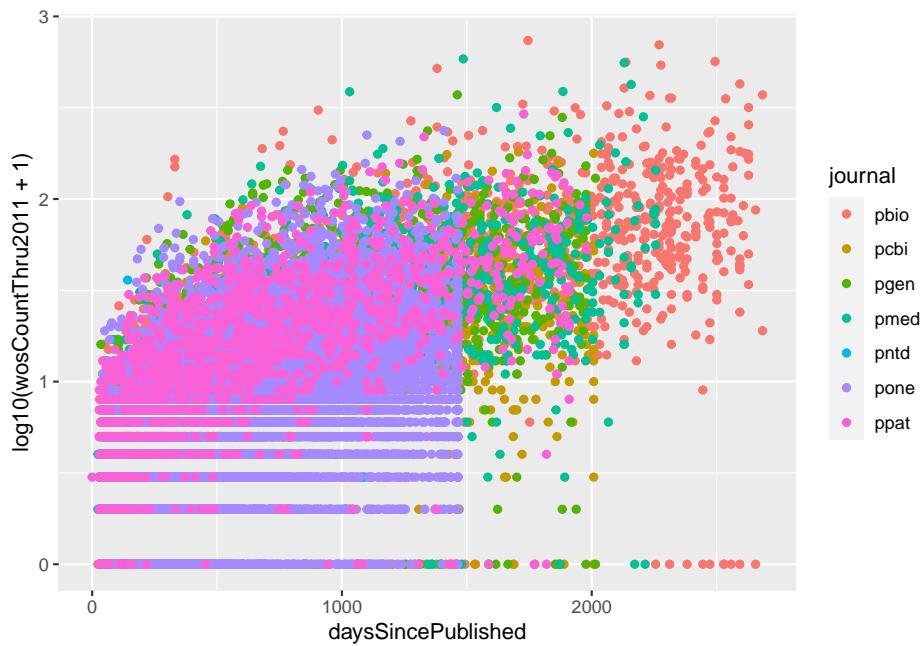
```
p <- ggplot(research, aes(x = daysSincePublished,
 y = wosCountThru2011)) +
 geom_point(aes(color= journal)) +
 scale_y_log10()
p

Warning: Transformation introduced infinite values in continuous y-axis
```



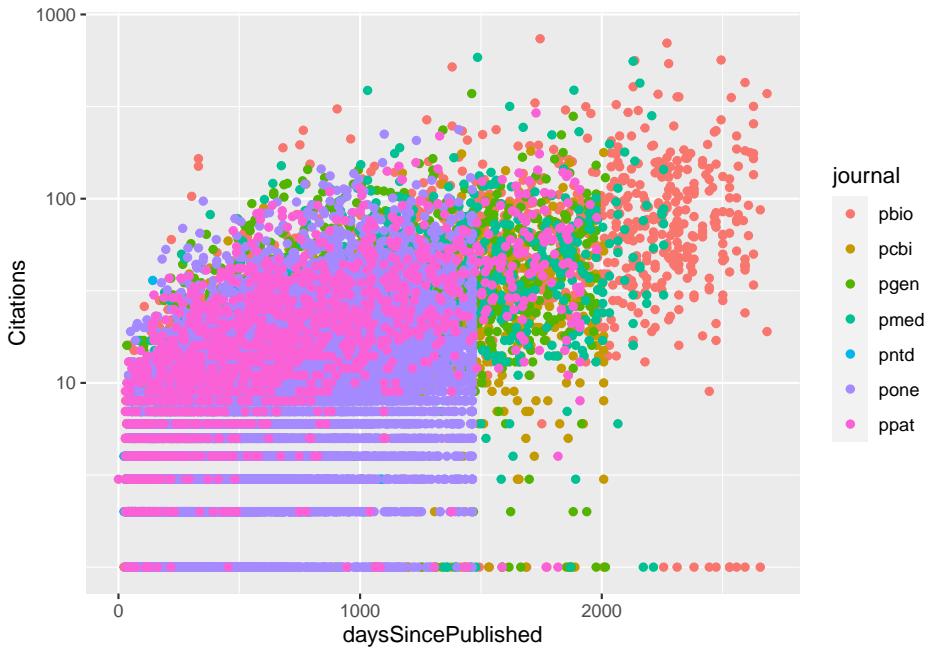
How can we fix this?

```
p <- ggplot(research, aes(x = daysSincePublished,
 y = log10(wosCountThru2011 + 1))) +
 geom_point(aes(color= journal))
p
```



Notice what this fix has done to the way the y-axis is labelled. To manually update the axis label, we can use the `scale_y_continuous()` function.

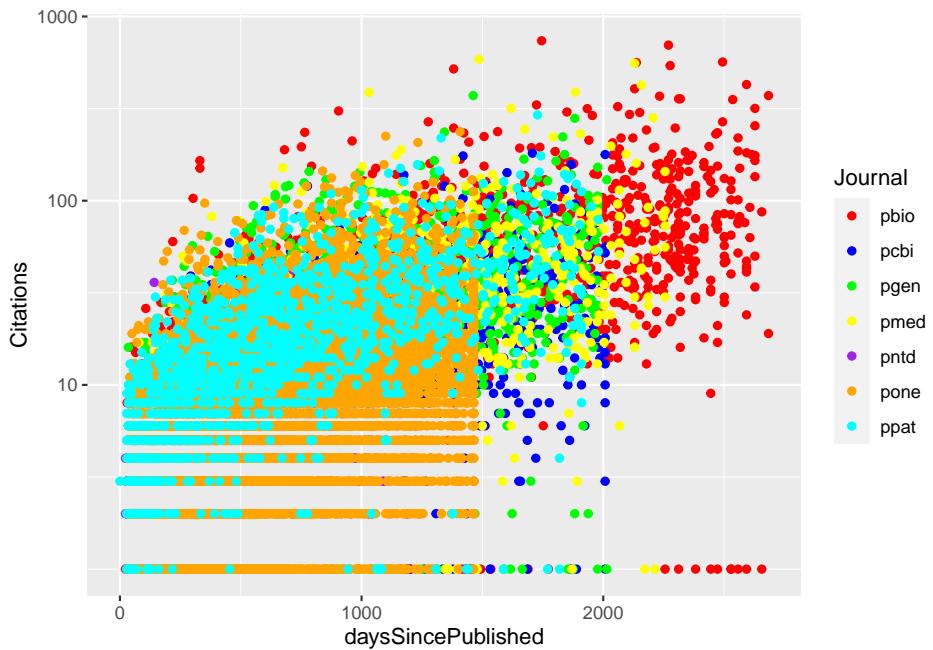
```
p <- ggplot(research, aes(x = daysSincePublished,
 y = log10(wosCountThru2011 + 1))) +
 geom_point(aes(color= journal)) +
 scale_y_continuous(breaks = c(1,2,3), labels = c(10, 100, 1000), name = "Citations")
```



The scale family of functions can also be used to change the colours.

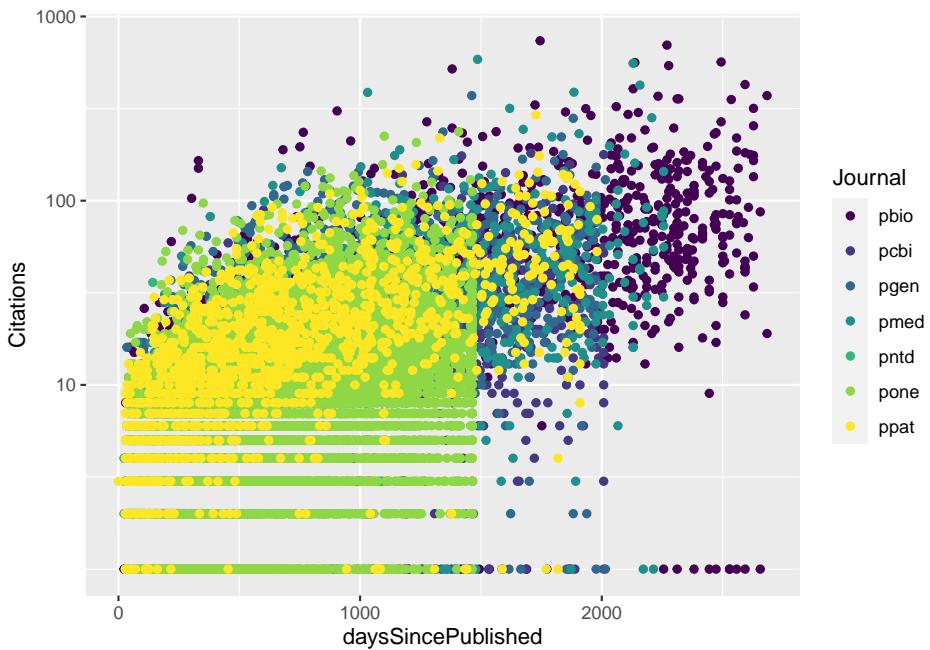
```
p <- ggplot(research, aes(x = daysSincePublished,
 y = log10(wosCountThru2011 + 1))) +
 geom_point(aes(color= journal)) +
 scale_y_continuous(breaks = c(1,2,3), labels = c(10, 100,1000), name = "Citations") +
 scale_colour_manual(values = c("red","blue", "green", "yellow", "purple", "orange","cyan"), na
```

p



```
library(viridis)

p <- ggplot(research, aes(x = daysSincePublished,
 y = log10(wosCountThru2011 + 1))) +
 geom_point(aes(color= journal)) +
 scale_y_continuous(breaks = c(1,2,3), labels = c(10, 100,1000), name = "Citations") -
 scale_colour_manual(values = viridis(7), name = "Journal")
p
```



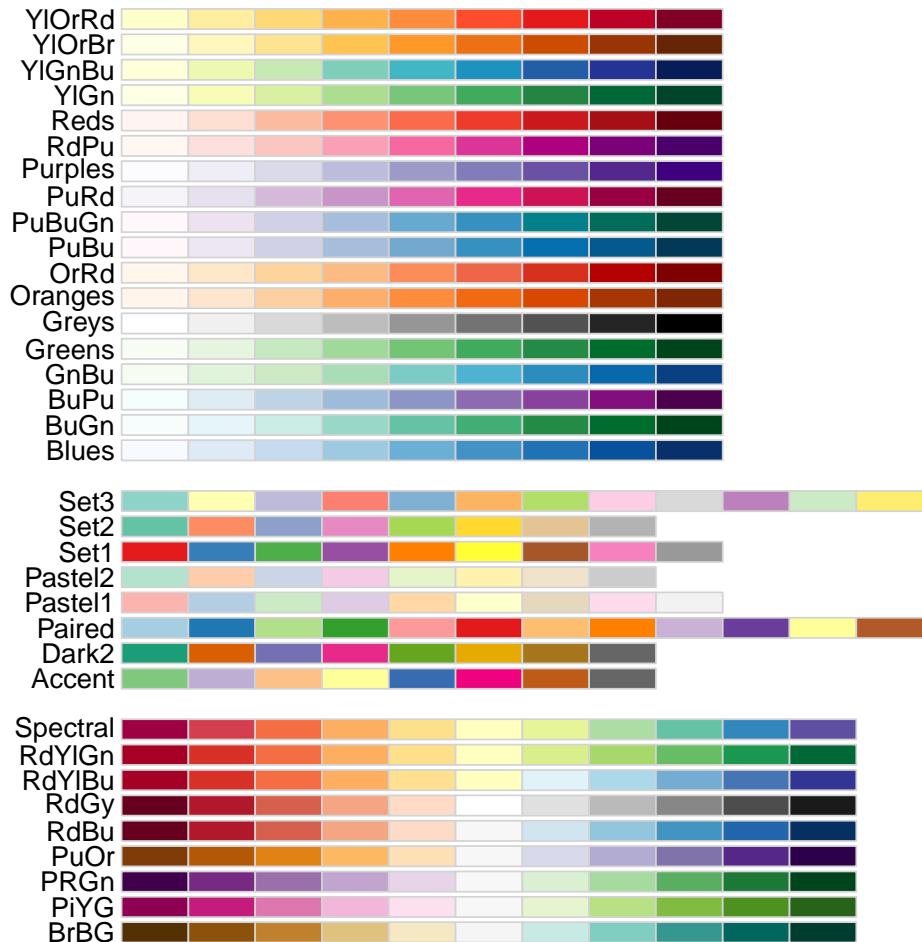
## 5.8 Colour palettes

Choosing good colours to aid visualization is not trivial and requires some (or a lot of) thought. A set of colour palettes have been developed for easy use with ggplot2 through a package called `RColorBrewer`.

There are three types of these premade palettes:

- \* Sequential
- \* Diverging
- \* Qualitative

```
library(RColorBrewer)
display.brewer.all()
```



Or, you can create your own color palettes using the `colorRamp()` or `colorRampPalette()` function.

`colorRamp()` returns a function that takes values between 0 and 1, indicating the extremes of the color palette.

`colorRampPalette()` returns a function that takes integer arguments and returns a vector of colours.

### `colorRamp()`

```
cols <- colorRamp(c("red", "blue"))
cols(0)
[,1] [,2] [,3]
```

```

[1] 255 0 0
cols(0.5)

[,1] [,2] [,3]
[1,] 127.5 0 127.5
cols(1)

[,1] [,2] [,3]
[1,] 0 0 255

colorRampPalette()

cols <- colorRampPalette(c("red", "blue"))
cols(2)

[1] "#FF0000" "#0000FF"
cols(10)

[1] "#FF0000" "#E2001C" "#C60038" "#AA0055" "#8D0071" "#71008D" "#5500AA"
[8] "#3800C6" "#1C00E2" "#0000FF"

```

## 5.9 Faceting

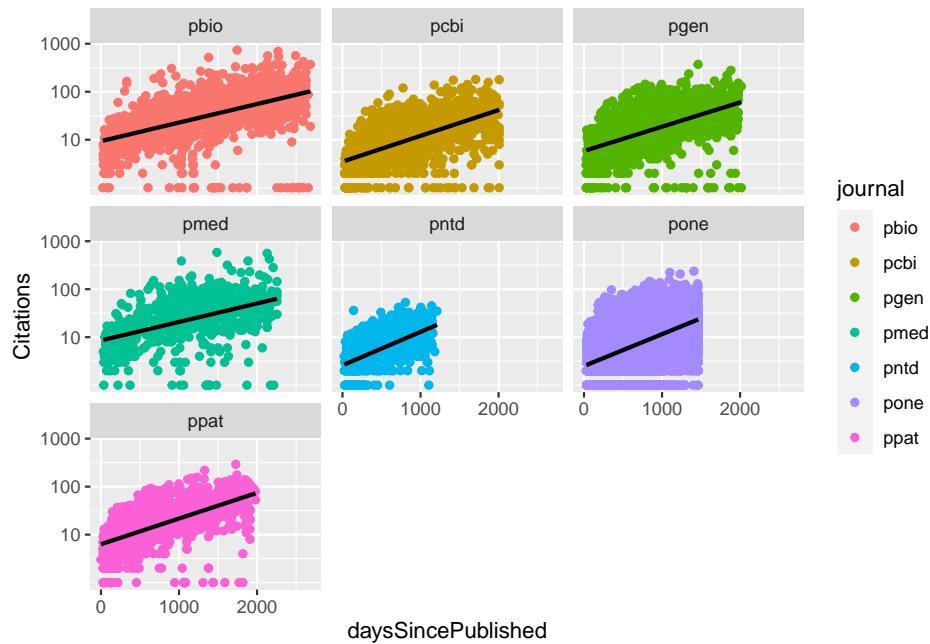
There are two functions to control how plots are divided into facets: `facet_wrap()` and `facet_grid()`.

```

facet_wrap()

p <- ggplot(research, aes(x = daysSincePublished,
 y = log10(wosCountThru2011 + 1),
 color = journal)) +
 geom_point() +
 scale_y_continuous(breaks = c(1,2,3), labels = c(10, 100,1000), name = "Citations") +
 facet_wrap(~journal) +
 geom_smooth(color = "black", method = "lm")
p

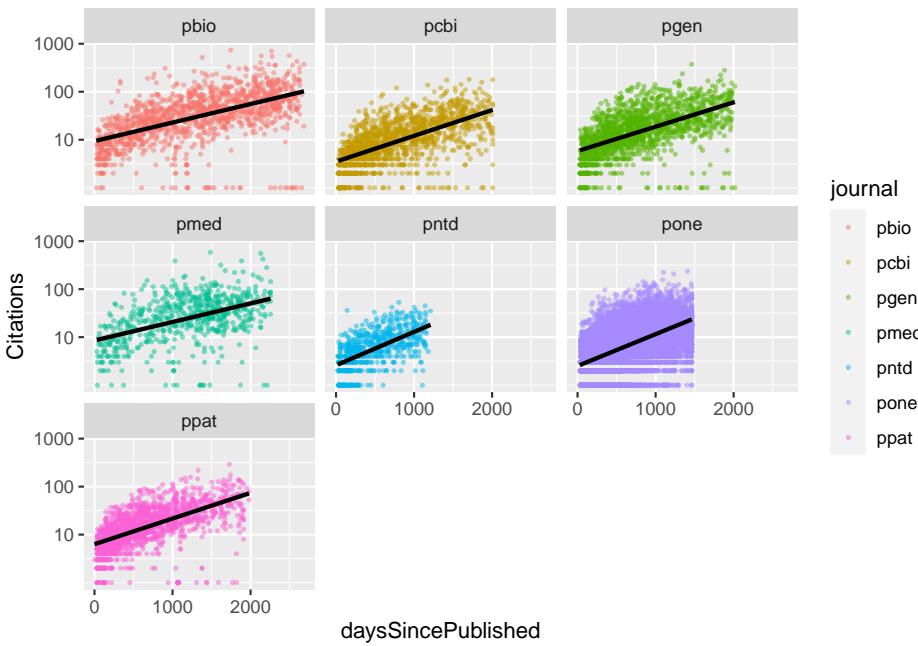
```



It is still difficult to see the spread of the data. Try making the points smaller and transparent.

```
p <- ggplot(research, aes(x = daysSincePublished,
 y = log10(wosCountThru2011 + 1),
 color = journal)) +
 geom_point(size = 0.5, alpha = 0.5) +
 scale_y_continuous(breaks = c(1,2,3), labels = c(10, 100,1000), name = "Citations") -
 facet_wrap(~journal) +
 geom_smooth(color = "black", method = "lm")
```

p



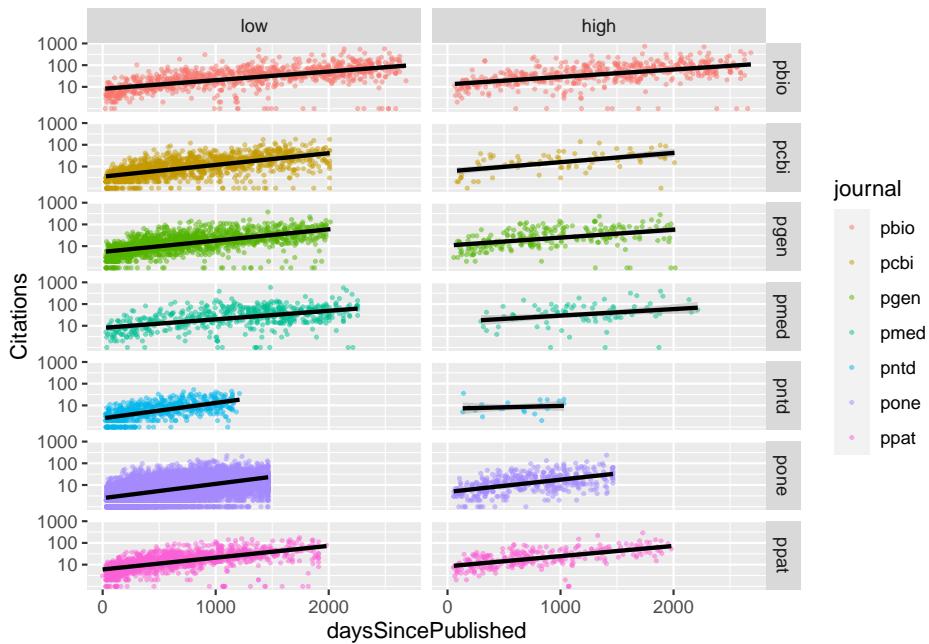
```
facet_grid()
```

What about faceting by two variables? For example, let's say we want to look at the relationship between days since published and citations for low impact versus high impact articles.

First, let's recreate a variable categorizing high and low impact based on the variable `f1000Factor`.

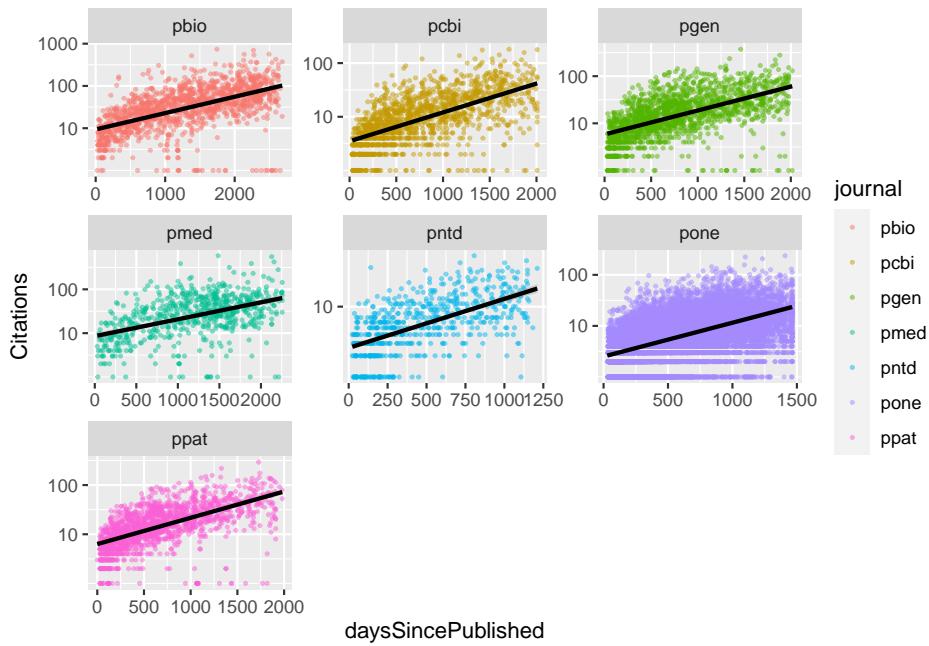
```
research <- research %>% mutate(impact = cut(f1000Factor, breaks = c(-Inf, 1, Inf), labels = c("low", "high")))

p <- ggplot(research, aes(x = daysSincePublished,
 y = log10(wosCountThru2011 + 1),
 color = journal)) +
 geom_point(size = 0.5, alpha = 0.5) +
 scale_y_continuous(breaks = c(1, 2, 3), labels = c(10, 100, 1000), name = "Citations") +
 facet_grid(journal ~ impact) +
 geom_smooth(color = "black", method = "lm")
```



By default, R will plot each panel on the same axes. You can override this using the option `scales`, setting it to `free_x` to vary the scale across rows, `scale_y` to vary it across columns, or `free` to vary across both.

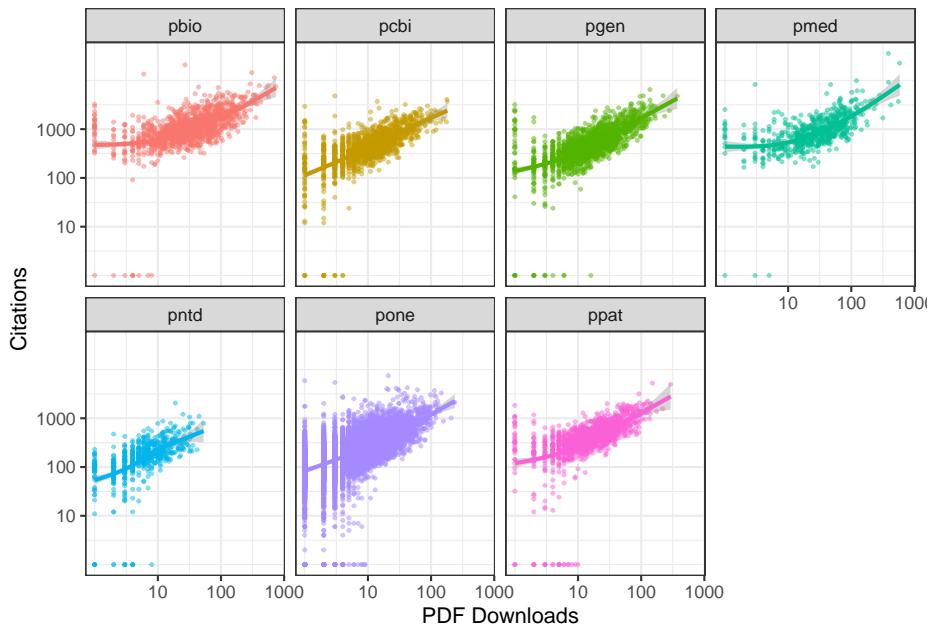
```
p <- ggplot(research, aes(x = daysSincePublished,
 y = log10(wosCountThru2011 + 1),
 color = journal)) +
 geom_point(size = 0.5, alpha = 0.5) +
 scale_y_continuous(breaks = c(1,2,3), labels = c(10, 100,1000), name = "Citations") +
 facet_wrap(~journal, scale = "free") +
 geom_smooth(color = "black", method = "lm")
```



---

**Exercise 5.6**

Use what you've learned to generate the plot below.



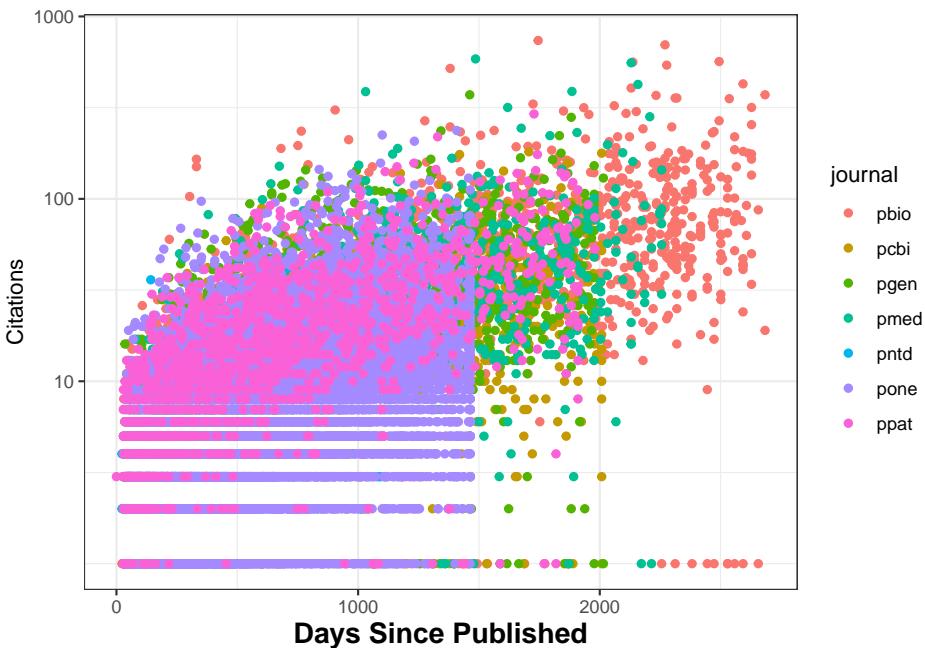
## 5.10 Themes

In addition to `theme_bw()`, which changes the plot background to white, `ggplot2` comes with several other themes which can be useful to quickly change the look of your visualization. The complete list of themes is available at <https://ggplot2.tidyverse.org/reference/ggthemee.html>. `theme_minimal()` and `theme_light()` are popular, and `theme_void()` can be useful as a starting point to create a new hand-crafted theme.

The `ggthemes` package provides a wide variety of options (including an Excel 2003 theme). The `ggplot2` extensions website provides a list of packages that extend the capabilities of `ggplot2`, including additional themes.

This is also the place you can customize the text of your plot.

```
p <- ggplot(research, aes(x = daysSincePublished,
 y = log10(wosCountThru2011 + 1))) +
 geom_point(aes(color= journal)) +
 scale_y_continuous(breaks = c(1,2,3), labels = c(10, 100, 1000), name = "Citations")
 theme_bw() +
 xlab("Days Since Published") +
 theme(axis.title.x = element_text(size = 14, face = "bold"))
```



## 5.11 Multiple plots

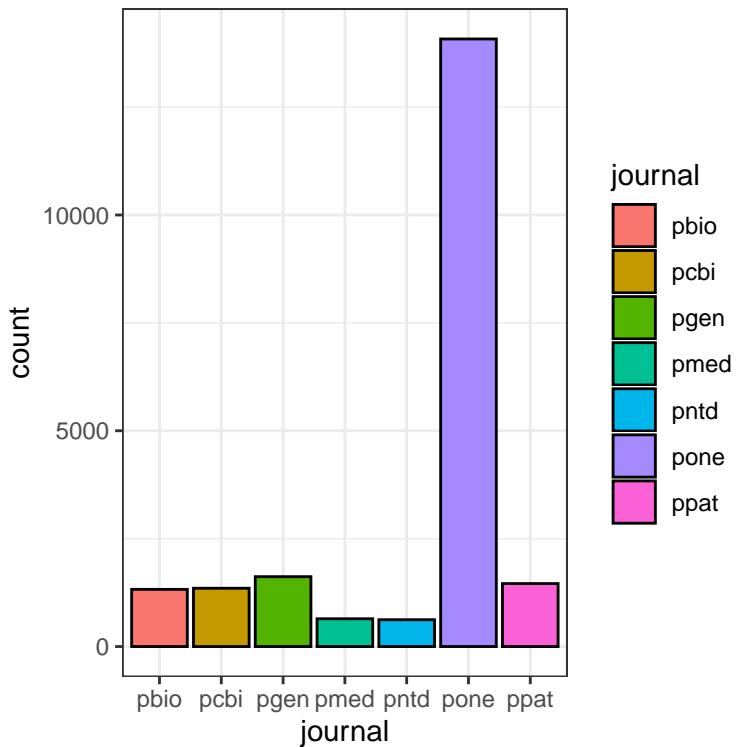
There are two useful packages for combining multiple plots: `gridExtra` and `cowplot`.

`gridExtra` has two useful functions: `grid.arrange()` and `arrangeGrob()`. However, these functions make no attempt at aligning the plot panels; instead, the plots are simply placed into the grid as they are, so the axes are not aligned. If axis alignment is required, the `plot_grid()` function of the `cowplot` package is better. We will try using both here.

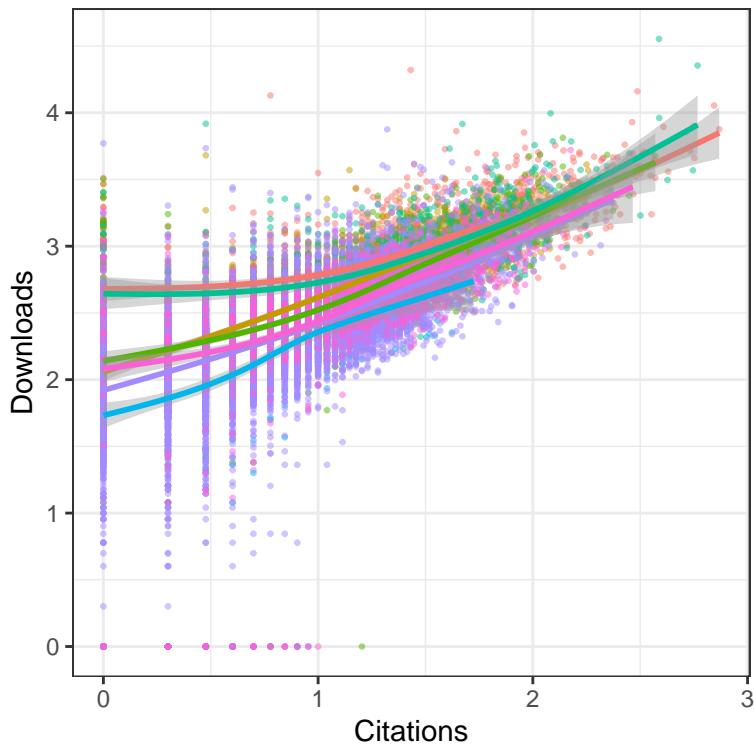
### The `gridExtra` package

Let's say we want to combine the following three plots:

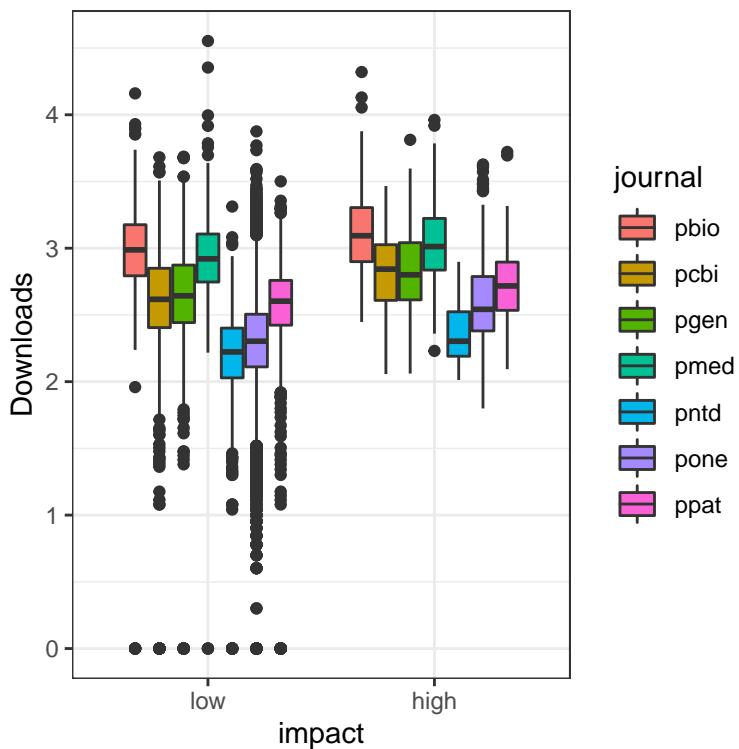
```
plot1 <- ggplot(research, aes(x = journal, fill = journal)) +
 geom_bar(color = "black") +
 theme_bw()
plot1
```



```
plot2 <- ggplot(research, aes(x = log10(wosCountThru2011 + 1),
 y = log10(pdfDownloadsCount + 1),
 color = journal)) +
 geom_point(size = 0.5, alpha = 0.5) +
 theme_bw() +
 geom_smooth() +
 xlab("Citations") +
 ylab("Downloads") +
 theme(legend.position = "none")
plot2
```

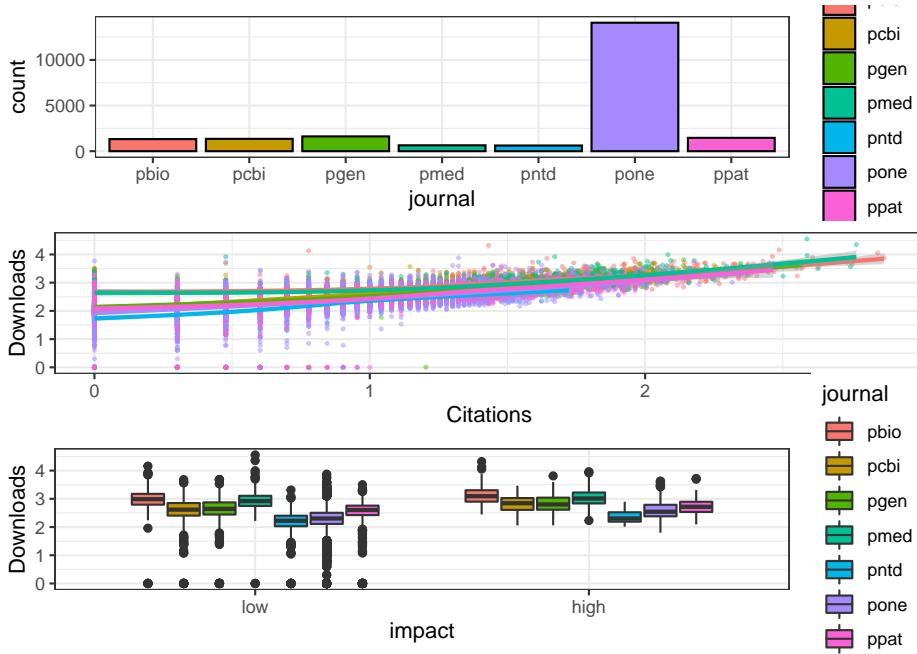


```
plot3 <- ggplot(research, aes(x = impact,
 y = log10(pdfDownloadsCount + 1),
 fill = journal)) +
 geom_boxplot() +
 theme_bw() +
 ylab("Downloads")
plot3
```



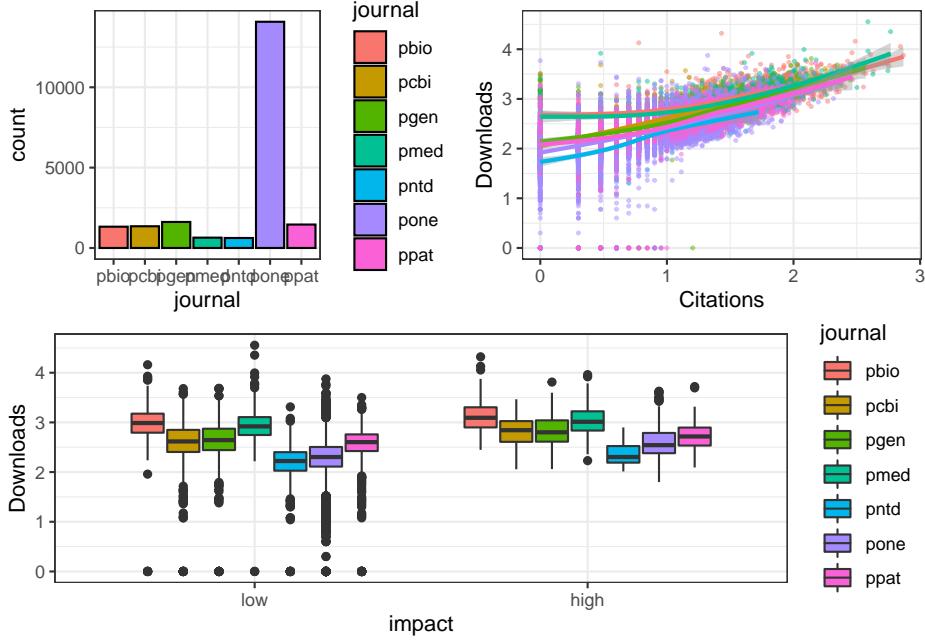
To arrange them together, use the `grid.arrange()` function.

```
library(gridExtra)
grid.arrange(plot1, plot2, plot3)
```



To modify how they are arranged, you can use the `layout_matrix` argument.

```
grid.arrange(plot1, plot2, plot3, ncol = 2, nrow = 2,
 layout_matrix = rbind(c(1,2), c(3,3)))
```

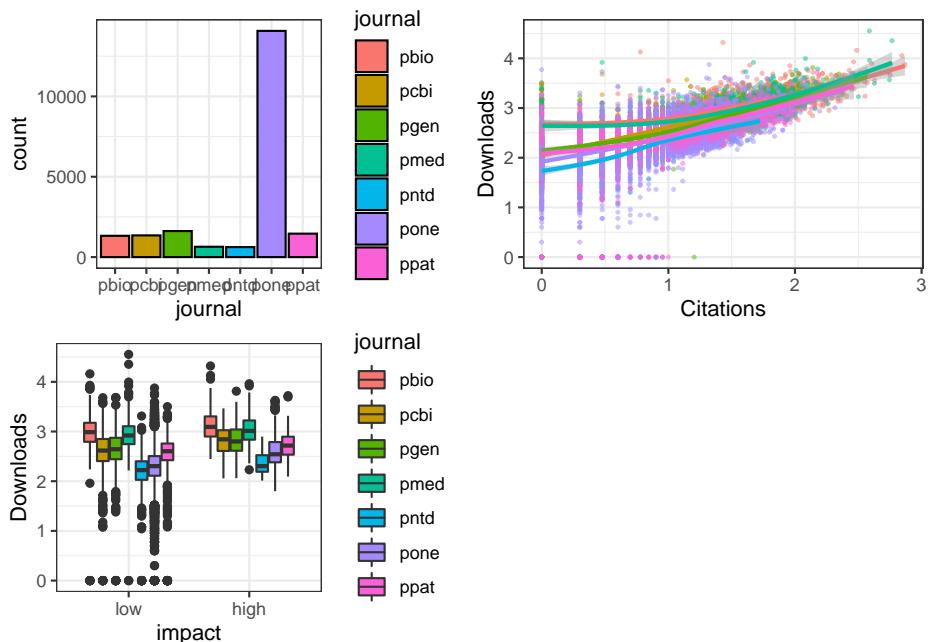


## The cowplot package

We can also arrange these plots using the `plot_grid()` function.

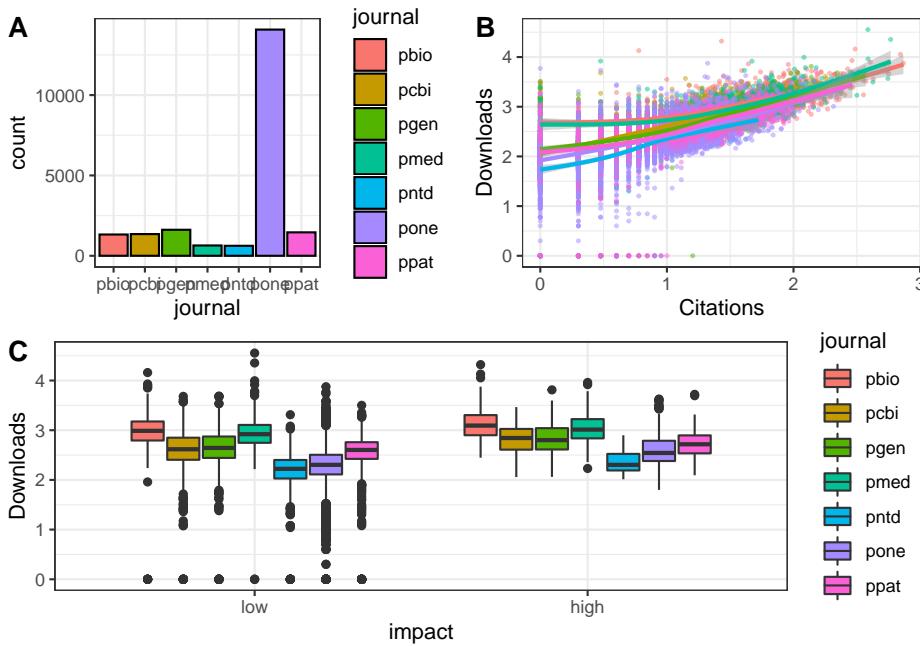
```
library(cowplot)

plot_grid(plot1, plot2, plot3)
```



```
row1 <- plot_grid(plot1, plot2, labels = c("A", "B"), nrow = 1)
row2 <- plot_grid(plot3, labels = c("C"), nrow = 1)

plot_grid(row1, row2, nrow = 2)
```



### 5.11.1 Saving plots

The easiest way to save a plot is using the `ggsave()` function.

---

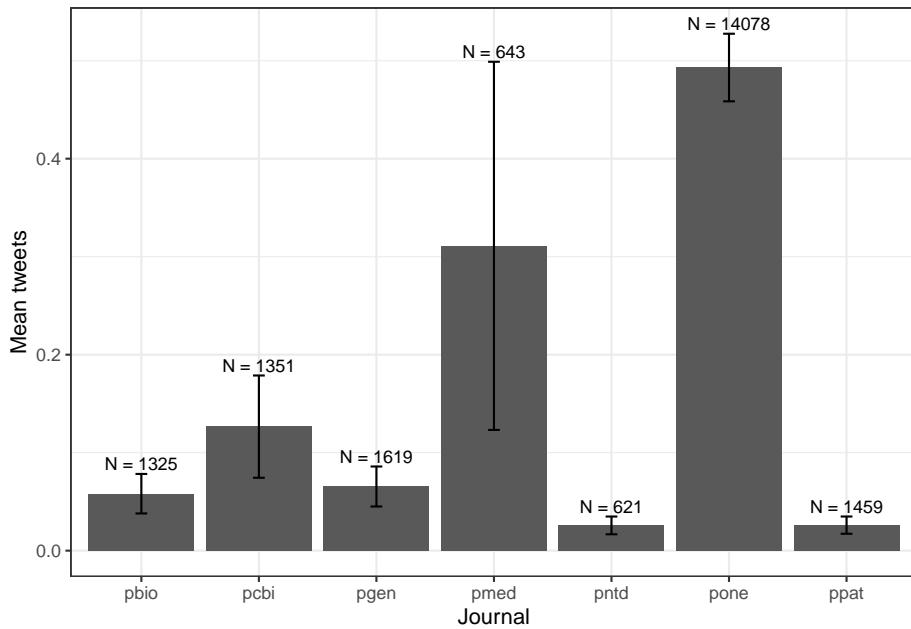
### Exercise 8.1

Using the publication dataset we've been using, complete the following tasks.

1. Generate a table containing the mean and standard error of the number of tweets per journal. It should look something like this:

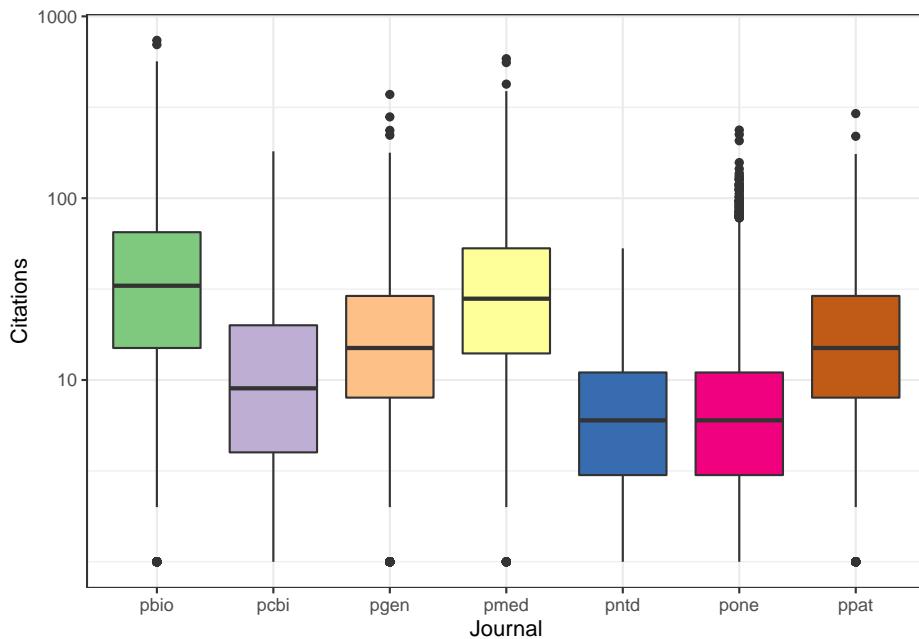
```
A tibble: 7 x 4
journal num mean sem
<fct> <int> <dbl> <dbl>
1 pbio 1325 0.0581 0.0202
2 pcbi 1351 0.127 0.0522
3 pgen 1619 0.0655 0.0204
4 pmed 643 0.311 0.188
5 pntd 621 0.0258 0.00906
6 pone 14078 0.493 0.0345
7 ppat 1459 0.0260 0.00881
```

2. Use this table to create a bar plot of mean tweets per journal, including standard error. It should look something like this:

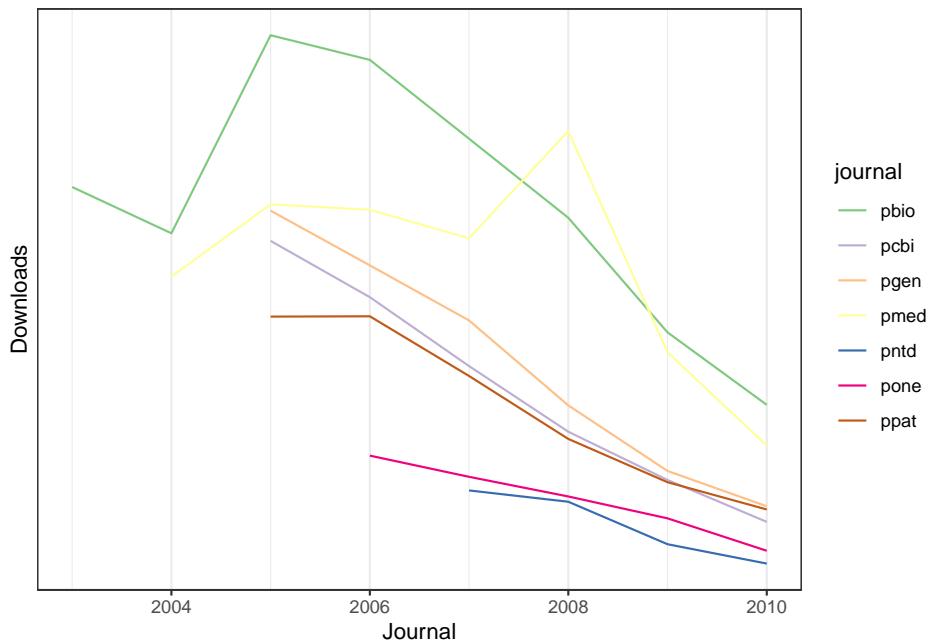


Hint: you will want to use the function `geom_errorbar()` to add the error bars.

3. Create a box plot of the number of citations per journal (ie. the variable `wosCountThur2011`). Colour the journals using the `Accent` palette from the `RColorBrewer` package. It should look something like this:



4. Generate a plot that shows the number of downloads over time, coloured by journal. It should look something like this:



## 5.12 Additional Resources

<http://www.sthda.com/english/wiki/be-awesome-in-ggplot2-a-practical-guide-to-be-highly-effective-r-software-and-data-visualization>

<http://r-statistics.co/Top50-Ggplot2-Visualizations-MasterList-R-Code.html>

- Mailing list: <http://groups.google.com/group/ggplot2>
- Wiki: <https://github.com/hadley/ggplot2/wiki>
- Website: <http://had.co.nz/ggplot2/>
- StackOverflow: <http://stackoverflow.com/questions/tagged/ggplot>

Cheatsheet

# Chapter 6

## Advanced Rmardown

So far we have used default settings to create our rmarkdown documents. Lets **prettify** our documents!!

### 6.1 YAML options for HTML documents

As we just mentioned before, Markdown was originally designed for HTML output, so it may not be surprising that the HTML format has the richest features among all output formats. We recommend that you read this full section before you learn other output formats, because other formats have several features in common with the HTML document format, and we will not repeat these features in the corresponding sections.

To create an HTML document from R Markdown, you specify the html\_document output format in the YAML metadata of your document:

```

```

```
title: first_markdown
author: ME ME
date: March 22, 2005
output: html_document

```

Lets add themes and highlight options

```
title: first_markdown
author: ME ME
date: March 22, 2005
output:
 html_document:
```

```
theme: yeti
highlight: kate
```

Now lets add a table of contents

```
title: first_markdown
author: ME ME
date: March 22, 2005
output:
 html_document:
 theme: yeti
 highlight: kate
 toc: true
 toc_float:
 collapsed: false
 toc_depth: 4
```

if you want to hide your code

```
title: first_markdown
author: ME ME
date: March 22, 2005
output:
 html_document:
 theme: yeti
 highlight: kate
 toc: true
 toc_float:
 collapsed: false
 toc_depth: 4
 code_folding: hide
```

A way to add custom css

```
title: first_markdown
author: ME ME
date: March 22, 2005
output:
 html_document:
 theme: yeti
 highlight: kate
 css: styles.css
 toc: true
 toc_float:
 collapsed: false
 toc_depth: 4
 code_folding: hide
```

## 6.2 Cool stuff in rmarkdown

### CHEATSHEET This cheat sheet has all the details on how to add figures, links, bullets, headings and tables in rmarkdown!   ### Making cools tables in rmarkdown from R code Tables generated from your R code are very useful to share modified output with other users. Simplest tables in markdown can be generated using the kable function but these table are static and to be honest boring!   ### A kable table

```
library(knitr)
kable(cars)
knitr::kable(cars)
```

speed	dist
4	2
4	10
7	4
7	22
8	16
9	10
10	18
10	26
10	34
11	17
11	28
12	14
12	20
12	24
12	28
13	26
13	34
13	34
13	46
14	26
14	36
14	60
14	80
15	20
15	26
15	54
16	32
16	40
17	32
17	40
17	50
18	42
18	56
18	76
18	84
19	36
19	46
19	68
20	32
20	48
20	52
20	56
20	64
22	66
23	54
24	70
24	92
24	93
24	120
25	85

#### A DT table

```
library(DT)
datatable(cars)

library(DT)
datatable(cars)
```

Show 10 entries Search: |

	speed	dist
1	4	2
2	4	10
3	7	4
4	7	22
5	8	16
6	9	10
7	10	18
8	10	26
9	10	34
10	11	17

Showing 1 to 10 of 50 entries Previous 1 2 3 4 5 Next

#### DT table with download options

```
library(DT)
datatable(cars,
 extensions = 'Buttons', options = list(
 dom = 'Bfrtip',
 buttons = c('copy', 'print','csv', 'excel')
)
)
library(DT)
datatable(cars,
 extensions = 'Buttons', options = list(
 dom = 'Bfrtip',
 buttons = c('copy', 'print','csv', 'excel')
)
)
```

	speed	dist
1	4	2
2	4	10
3	7	4
4	7	22
5	8	16
6	9	10
7	10	18
8	10	26
9	10	34
10	11	17

Showing 1 to 10 of 50 entries

Previous 1 2 3 4 5 Next

### 6.2.1 Making tabs in rmarkdown

You can organize content using tabs by applying the `.tabset` class attribute to headers within a document. This will cause all sub-headers of the header with the `.tabset` attribute to appear within tabs rather than as standalone sections. For example:

```
Quarterly Results {.tabset}
By Product
(tab content)
By Region
(tab content)
```

You can also specify two additional attributes to control the appearance and behavior of the tabs. The `.tabset-fade` attribute causes the tabs to fade in and out when switching between tabs. The `.tabset-pills` attribute causes the visual appearance of the tabs to be “pill” rather than traditional tabs. For example:

## Quarterly Results

By Product

By Region

(tab content)

## Quarterly Results (pill tabs)

By Product

By Region

(tab content)

## HTML and CSS basics HTML, **HyperText Markup Language**, gives content structure and meaning by defining that content as, for example, headings, paragraphs, or images. CSS, \*\*Cascading Style Sheets\*\*, is a presentation language created to style the appearance of content—using, for example, fonts or colors.

Lets look at the following examples

Simple html generated from rmarkdown

Simple html styled by css from themes

Simple html styled by custom css

#### HTML

```
<!DOCTYPE html>
<html>
<body>

<h1>My First Heading</h1>
<p>My first paragraph.</p>

</body>
</html>
```

#### Output: