

SCCDS Professional Development Book

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Teaching Data Science

SCCDS

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Preface

Part I

R Programming

R is an open-source programming language used to conduct statistical analysis.

Installing R

You can freely download and install R [here](#).

Installing on Windows

Installing on Mac

Installing RStudio

RStudio is an Integrated Development Environment ([IDE](#)) used for data science. It contains several tools needed to extend your programming and project management skills.

You can download and install the open-source (free) version of RStudio [here](#).

Installing R Packages

R Packages extends the functionality from the base functions in R. R packages contain extra functions to conduct uncommon statistical models.

As of right now, the [tidyverse](#) is a set of comprehensive packages to prepare and analyze data. To install tidyverse, use the following line in the console:

```
install.packages("tidyverse")
```

Posit Cloud

Posit Cloud is the online platform for RStudio. The free account provides users with limited computing resources that allow them to learn R and RStudio. One can access Posit Cloud [here](#).

Resources

Website	Description
R 4 Data Science Book	A highly recommended book to learn more about R for data science with a tidyverse implementation.
Advanced R	A book that provides an in depth tutorial of using more advanced R concepts such as control flow concepts and functional programming.
Efficient R	A book that provides tips to write more performative R code such as vectorization or compiling code.
R 4 Data Science Community	This is an online learning community of R users that provides events and data for individuals to learn about data science and R.
Deep R	A book that provides advance programming concepts in terms of R.
Big Book of R	A website containing a list of resources for individuals to learn R.

1 Basic R Programming

This chapter focuses on the basics of R programming. While most of your statistical analysis will be done with R functions, it is important to have an idea of what is going on. Additionally, we will cover other topics that you may or may not need to know. The topics we will cover are:

1. Basic calculations in R
2. Types of Data
3. R Objects
4. R Functions
5. R Packages

1.1 Basic Calculations

This section focuses on the basic calculation that can be done in R. This is done by using different operators in R. The table below provides some of the basic operators R can use:

Operator	Description
+	Addition
-	Subtraction
*	Multiplication
/	Divides
[^] or ^{**}	Exponent
?	Help Documentation

1.1.1 Calculator

1.1.1.1 Addition

To add numbers in R, all you need to use the `+` operator. For example $2 + 2 = 4$. When you type it in R you have:

```
2 + 2
```

```
[1] 4
```

When you ask R to perform a task, it prints out the result of the task. As we can see above, R prints out the number 4.

To add more than 2 numbers, you can simply just type it in.

```
2 + 2 + 2
```

```
[1] 6
```

This provides the number 6.

1.1.1.2 Subtraction

To subtract numbers, you need to use the `-` operator. Try $4 - 2$:

```
4 - 2
```

```
[1] 2
```

Try $4 - 6 - 4$

```
4 - 6 - 4
```

```
[1] -6
```

Notice that you get a negative number.

Now try $4 + 4 - 2 + 8$:

```
4 + 4 - 2 + 8
```

```
[1] 14
```

1.1.1.3 Multiplication

To multiply numbers, you will need to use the `*` operator. Try $4 * 4$:

```
4 * 4
```

```
[1] 16
```

1.1.1.4 Division

To divide numbers, you can use the `/` operator. Try `9 / 3`:

```
9 / 3
```

```
[1] 3
```

1.1.1.5 Exponents

To exponentiate a number to the power of another number, you can use the `^` operator. Try `2^5`:

```
2^5
```

```
[1] 32
```

If you want to find e^2 , you will use the `exp()` function. Try `exp(2)`:

```
exp(2)
```

```
[1] 7.389056
```

1.1.1.6 Roots

To take the n-th root of a value, use the `^` operator with the `/` operator to take the n-th root. For example, to take $\sqrt[5]{35}$, type `32^(1/5)`:

```
32^(1/5)
```

```
[1] 2
```

1.1.1.7 Logarithms

To take the natural logarithm of a value, you will use the `log()` function. Try `log(5)`:

```
log(5)
```

```
[1] 1.609438
```

If you want to take the logarithm of a different base, you will use the `log()` function with `base` argument. We will discuss this more in Section 1.3.

1.1.2 Comparing Numbers

Another important part of R is comparing numbers. When you compare two numbers, R will tell if the statement is `TRUE` or `FALSE`. Below are the different comparisons you can make:

Operator	Description
<code>></code>	Greater Than
<code><</code>	Less Than
<code>>=</code>	Greater than or equal
<code><=</code>	Less than or equal
<code>==</code>	Equals
<code>!=</code>	Not Equals

1.1.2.1 Less than/Greater than

To check if one number is less than or greater than another number, you will use the `>` or `<` operators. Try `5 > 4`:

```
5 > 4
```

```
[1] TRUE
```

Notice that R states it's true. It evaluates the expression and tells you if it's true or not. Try `5 < 4`:

```
5 < 4
```

```
[1] FALSE
```

Notice that R tells you it is false.

1.1.2.2 Less than or equal to/Greater than or equal to

To check if one number is less than or equal to/greater than or equal to another number, you will use the `>=` or `<=` operators. Try `5 >= 5`:

```
5 >= 5
```

[1] TRUE

Try `5 >= 4`:

```
5 >= 4
```

[1] TRUE

Try `5 <= 4`

```
5 <= 4
```

[1] FALSE

1.1.2.3 Equals and Not Equals

To check if 2 numbers are equal to each other, you can use the `==` operator. Try `3 == 3`:

```
3 == 3
```

[1] TRUE

Try `4 == 3`

```
3 == 4
```

[1] FALSE

Another way to see if 2 numbers are not equal to each other, you can use the `!=`. Try `3 != 4`:

```
3 != 4
```

```
[1] TRUE
```

Try `3 != 3`:

```
3 != 3
```

```
[1] FALSE
```

You may be asking why use `!=` instead of `==`. They both provides similar results. Well the reason is that you may need the `TRUE` output for analysis. One is only true when they are equal, while the other is true when they are not equal.

In general, the `!` operator means not or opposite. It can be used to change an `TRUE` to a `FALSE` and vice-versa.

1.1.3 Help

The last operator we will discuss is the help operator `?`. If you want to know more about anything we talked about you can type `?` in front of a function and a help page will pop-up in your browser or in RStudio's 'Help' tab. For example you can type `?Arithmetic` or `?Comparison`, to review what we talked about. For other operators we didn't talk about use `?assignOps` and `?Logic`.

1.2 Types of Data

In R, the type of data, also known as class, we are using dictates how the programming works. For the most part, users will use *numeric*, *logical*, *POSIX* and *character* data types. Other types of data you may encounter are *complex* and *raw*. To obtain more information on them, use the `?` operator.

1.2.1 Numeric

The *numeric* class is the data that are numbers. Almost every analysis that you use will be based on the numeric class. To check if you have a numeric class, you just need to use the `is.numeric()` function. For example, try `is.numeric(5)`:

```
is.numeric(5)
```

```
[1] TRUE
```

Numeric classes are essentially *double* and *integer* types of data. For example a *double* data is essentially a number with decimal value. An *integer* data are whole numbers. Try `is.numeric(5.63)`, `is.double(5.63)` and `is.integer(5.63)`:

```
is.numeric(5.63)
```

```
[1] TRUE
```

```
is.double(5.63)
```

```
[1] TRUE
```

```
is.integer(5.63)
```

```
[1] FALSE
```

Notice how the value 5.63 is a *numeric* and *double* but not *integer*. Now let's try `is.numeric(7)`, `is.double(7)` and `is.integer(7)`:

```
is.numeric(7)
```

```
[1] TRUE
```

```
is.double(7)
```

```
[1] TRUE
```

```
is.integer(7)
```

```
[1] FALSE
```

Notice how the value 7 is also considered a *numeric* and *double* but not *integer*. This is because typing a whole number will be stored as a *double*. However, if we need to store an *integer*, we will need to type the letter "L" after the number. Try `is.numeric(7L)`, `is.double(7L)`, and `is.integer(7L)`:

```
is.numeric(7L)
```

```
[1] TRUE
```

```
is.double(7L)
```

```
[1] FALSE
```

```
is.integer(7L)
```

```
[1] TRUE
```

1.2.2 Logical

A *logical* class are data where the only value is TRUE or FALSE. Sometimes the data is coded as 1 for TRUE and 0 for FALSE. The data may also be coded as T or F. To check if data belongs in the *logical* class, you will need the `is.logical()` function. Try `is.logical(3 < 4)`:

```
is.logical(3 < 4)
```

```
[1] TRUE
```

This is same comparison from Section 1.1.2. The output was TRUE. Now R is checking whether the output is of a *logical* class. Since it is, R returns TRUE. Now try `is.logical(3 > 4)`:

```
is.logical(3 > 4)
```

```
[1] TRUE
```

The output is TRUE as well even though the condition $3 > 4$ is FALSE. Since the output is a *logical* data type, it is a *logical* variable.

1.2.3 POSIX

The *POSIX* class are date-time data. Where the data value is a time component. The *POSIX* class can be very complex in how it is formatted. If you would like to learn more try `?POSIXct` or `?POSIXlt`. First, lets run `Sys.time()` to check what is today's data and time:

```
Sys.time()
```

```
[1] "2024-03-18 14:23:41 PDT"
```

Now lets check if its of POSIX class, you can use the `class()` function to figure out which class is it. Try `class(Sys.time())`:

```
class(Sys.time())
```

```
[1] "POSIXct" "POSIXt"
```

1.2.4 Character

A *character* value is where the data values follow a *string* format. Examples of *character* values are letters, words and even numbers. A *character* value is any value surrounded by quotation marks. For example, the phrase “Hello World!” is considered as one *character* value. Another example is if your data is coded with the actual words “yes” or “no”. To check if you have *character* data, use the `is.character()` function. Try `is.character("Hello World!")`:

```
is.character("Hello World!")
```

```
[1] TRUE
```

Notice that the output says TRUE. *Character* values can be created with single quotations. Try `is.character('Hello World!')`:

```
is.character('Hello World!')
```

```
[1] TRUE
```

1.2.5 Complex Numbers

Complex numbers are data values where there is a real component and an imaginary component. The imaginary component is a number multiplied by $i = \sqrt{-1}$. To create a *complex* number, use the `complex()` function. To check if a number is complex, use the `is.complex()` function. Try the following to create a complex number `complex(1, 4, 5)`:

```
complex(1, 4, 5)
```

```
[1] 4+5i
```

Now try `is.complex(complex(1, 4, 5))`:

```
is.complex(complex(1, 4, 5))
```

```
[1] TRUE
```

1.2.6 Raw

You will probably never use raw data. I have never used raw data in R. To create a raw value, use the `raw()` or `charToRaw()` functions. Try `charToRaw('Hello World!')`:

```
charToRaw('Hello World!')
```

```
[1] 48 65 6c 6c 6f 20 57 6f 72 6c 64 21
```

To check if you have raw data, use the `is.raw()` function. Try `is.raw(charToRaw('Hello World!'))`:

```
is.raw(charToRaw('Hello World!'))
```

```
[1] TRUE
```

1.2.7 Missing

The last data class in R is missing data. The table below provides a brief introduction of the different types of missing data

Value	Description	Functions
NULL	These are values indicating an object is empty. Often used for functions with values that are undefined.	<code>is.null()</code>
NA	Stands for “Not Available”, used to indicate that the value is missing in the data.	<code>is.na()</code>

Value	Description	Functions
NaN	Stands for “Not an Number”. Used to indicate a missing number.	<code>is.nan()</code>
Inf and -Inf	Indicating an extremely large value or a value divided by 0.	<code>is.infinite()</code>

1.3 R Functions

An R function is the procedure that R will execute to certain data. For example, the `log(x)` is an R function. It takes the value `x` and provides you the natural logarithm. Here `x` is known as an argument which needs to be specified to us the `log()` function. Find the `log(x = 5)`

```
log(x = 5)
```

[1] 1.609438

Another argument for the `log()` function is the `base` argument. With the previous code, we did not specify the `base` argument, so R makes the `base` argument equal to the number e . If you want to use the common log with base 10, you will need to set the `base` argument equal to 10.

Try `log(x = 5, base = 10)`

```
log(x = 5, base = 10)
```

[1] 0.69897

Now try `log(5,10)`

```
log(5,10)
```

[1] 0.69897

Notice that it provides the same value. This is because R can set arguments based on the values position in the function, regardless if the arguments are specified. For `log(5,10)`, R thinks that 5 corresponds to the first argument `x` and 10 is the second argument `base`.

To learn more about a functions, use the `?operator` on the function: `?log`.

1.4 R Objects

R objects are where most of your data will be stored. An R object can be thought of as a container of data. Each object will share some sort of characteristics that will make the unique for different types of analysis.

1.4.1 Assigning objects

To create an R object, all we need to do is assign data to a variable. The variable is the name of the R object. it can be called anything, but you can only use alphanumeric values, underscore, and periods. To assign a value to a variable, use the `<-` operator. This is known a left assignment. Kinda like an arrow pointing left. Try assigning 9 to 'x' (`x <- 9`):

```
x <- 9
```

To see if x contains 9, type x in the console:

```
x
```

```
[1] 9
```

Now x can be treated as data and we can perform data analysis on it. For example, try squaring it:

```
x^2
```

```
[1] 81
```

You can use any mathematical operation from the previous sections. Try some other operations and see what happens.

The output R prints out can be stored in a variable using the asign operator, `<-`. Try storing x^3 in a variable called `x_cubed`:

```
x_cubed <- x^3
```

To see what is stored in `x_cubed` you can either type `x_cubed` in the console or use the `print()` function with `x_cubed` inside the parenthesis.

```
x_cubed
```

```
[1] 729
```

```
print(x_cubed)
```

```
[1] 729
```

1.4.2 Vectors

A vector is a set data values of a certain length. The R object `x` is considered as a numerical vector (because it contains a number) with the length 1. To check, try `is.numeric(x)` and `is.vector(x)`:

```
is.numeric(x)
```

```
[1] TRUE
```

```
is.vector(x)
```

```
[1] TRUE
```

Now let's create a logical vector that contains 4 elements (have it follow this sequence: T, F, T, F) and assign it to `y`. To create a vector use the `c()`¹ function and type all the values and separating them with commas. Type `y <- c(T, F, T, F)`:

```
y <- c(T, F, T, F)
```

Now, lets see how `y` looks like. Type `y`:

```
y
```

```
[1] TRUE FALSE TRUE FALSE
```

Now lets see if it's a logical vector:

¹The `c()` function allows you to put any data type and as many values as you wish. The only condition of a vector is that it must be the same data type.

```
is.logical(y)
```

```
[1] TRUE
```

```
is.vector(y)
```

```
[1] TRUE
```

Fortunately, this vector is really small to count how many elements it has, but what if the vector is really large? To find out how many elements a vector has, use the `length()` function. Try `length(y)`:

```
length(y)
```

```
[1] 4
```

1.4.3 Matrices

A matrix can be thought as a square or rectangular grid of data values. This grid can be constructed can be any size. Similar to vectors they must contain the same data type. The size of a matrix is usually denoted as $n \times k$, where n represents the number of rows and k represents the number of columns. To get a rough idea of how a matrix may look like, type `matrix(rep(1,12), nrow = 4, ncol = 3)`²:

```
matrix(rep(1, 12), nrow = 4, ncol = 3)
```

```
[,1] [,2] [,3]
[1,]    1    1    1
[2,]    1    1    1
[3,]    1    1    1
[4,]    1    1    1
```

Notice that this is a 4×3 matrix. Each element in the matrix has the value 1. Now try this `matrix(rbinom(12,1.5), nrow = 4, ncol = 3)`³:

²The function `rep()` creates a vector by repeating a value for a certain length. `rep(1,12)` creates a vector of length 12 with each element being 1. We use the `nrow` and `ncol` arguments in the function to specify the number of rows and columns, respectfully.

³The `rbinom()` function generates binomial random variables and stores them in a vector. `rbinom(12,1,5)` This creates 12 random binomial numbers with parameter $n = 1$ and $p = 0.5$.

```
matrix(rbinom(12, 1, .5), nrow = 4, ncol = 3)
```

```
[,1] [,2] [,3]
[1,] 0 1 0
[2,] 1 1 0
[3,] 0 1 1
[4,] 0 0 0
```

Your matrix may look different, but that is to be expected. Notice that some elements in a matrix are 0's and some are 1's. Each element in a matrix can hold any value.

An alternate approach to creating matrices is with the use of `rbind()` and `cbind()` functions. Using 2 vectors, and matrices, of the same length, the `rbind()` will append the vectors together by each row. Similarly, the `cbind()` function will append vectors, and matrices, of the same length by columns.

```
x <- 1:4
y <- 5:8
z <- 9:12
cbind(x, y, z)
```

```
x y z
[1,] 1 5 9
[2,] 2 6 10
[3,] 3 7 11
[4,] 4 8 12
```

```
rbind(x, y, z)
```

```
[,1] [,2] [,3] [,4]
x 1 2 3 4
y 5 6 7 8
z 9 10 11 12
```

If you want to create a matrix of a specific size without any data, you can use the `matrix()` function and only specify the `nrow` and `ncol` arguments. Here we are creating a 5×11 empty matrix:

```
matrix(nrow = 5, ncol = 11)
```

```
[,1] [,2] [,3] [,4] [,5] [,6] [,7] [,8] [,9] [,10] [,11]
[1,] NA NA
[2,] NA NA
[3,] NA NA
[4,] NA NA
[5,] NA NA
```

Lastly, if you need to find out the dimensions of a matrix, you can use `dim()` function on a matrix:

```
dim(matrix(nrow = 5, ncol = 11))
```

```
[1] 5 11
```

This will return a vector of length 2 with the first element being the number of rows and the second element being the number of columns.

1.4.4 Arrays

Matrices can be considered as a 2-dimensional block of numbers. An array is an n-dimensional block of numbers. While you may never need to use an array for data analysis. It may come in handy when programming by hand. To create an array, use the `array()` function. Below is an example of a $3 \times 3 \times 3$ with the numbers 1, 2, and 3 representing the 3rd dimension stored in an R object called `first_array`⁴.

```
(first_array <- array(c(rep(1, 9), rep(2, 9), rep(3, 9)),
                      dim=c(3,3,3)))
```

```
, , 1
```

```
[,1] [,2] [,3]
[1,] 1 1 1
[2,] 1 1 1
[3,] 1 1 1
```

⁴Notice the code is surrounded by parenthesis. This tells R to store the array and print out the results. You can surround code with parenthesis every time you create an object to also print what is stored.

```
, , 2  
[,1] [,2] [,3]  
[1,] 2 2 2  
[2,] 2 2 2  
[3,] 2 2 2
```

```
, , 3  
[,1] [,2] [,3]  
[1,] 3 3 3  
[2,] 3 3 3  
[3,] 3 3 3
```

1.4.5 Data Frames

Data frames are similar to data set that you may encounter in an excel file. However, there are a couple of differences. First, each row represents an observation, and each column represents a characteristic of the observation. Additionally, each column in a data frame will be the same data type. To get an idea of what a data frame looks like, try `head(iris)`⁵:

```
head(iris)
```

	Sepal.Length	Sepal.Width	Petal.Length	Petal.Width	Species
1	5.1	3.5	1.4	0.2	setosa
2	4.9	3.0	1.4	0.2	setosa
3	4.7	3.2	1.3	0.2	setosa
4	4.6	3.1	1.5	0.2	setosa
5	5.0	3.6	1.4	0.2	setosa
6	5.4	3.9	1.7	0.4	setosa

In the data frame, the rows indicate a specific observation and the columns are the values of a variable. In terms of the `iris` data set, we can see that row 1 is a specific flower that has a sepal length of 5.1. We can also see that flower 1 has other characteristics such as sepal width and petal length. Lastly, there are results for the other flowers.

Now try `tail(iris)`:

```
tail(iris)
```

⁵The `head()` function just tells R to only print the top few components of the data frame.

	Sepal.Length	Sepal.Width	Petal.Length	Petal.Width	Species
145	6.7	3.3	5.7	2.5	virginica
146	6.7	3.0	5.2	2.3	virginica
147	6.3	2.5	5.0	1.9	virginica
148	6.5	3.0	5.2	2.0	virginica
149	6.2	3.4	5.4	2.3	virginica
150	5.9	3.0	5.1	1.8	virginica

The `tail()` function provides the last 6 rows of the data frame.

Lastly, if you are interested in viewing a specific variable (column) from a data frame, you can use the `$` operator to specify which variable from a specific data frame. For example, if we are interested in observing the `Sepal.Length` variable from the `iris` data frame, we will type `iris$Sepal.Length`:

```
iris$Sepal.Length
```

```
[1] 5.1 4.9 4.7 4.6 5.0 5.4 4.6 5.0 4.4 4.9 5.4 4.8 4.8 4.3 5.8 5.7 5.4 5.1
[19] 5.7 5.1 5.4 5.1 4.6 5.1 4.8 5.0 5.0 5.2 5.2 4.7 4.8 5.4 5.2 5.5 4.9 5.0
[37] 5.5 4.9 4.4 5.1 5.0 4.5 4.4 5.0 5.1 4.8 5.1 4.6 5.3 5.0 7.0 6.4 6.9 5.5
[55] 6.5 5.7 6.3 4.9 6.6 5.2 5.0 5.9 6.0 6.1 5.6 6.7 5.6 5.8 6.2 5.6 5.9 6.1
[73] 6.3 6.1 6.4 6.6 6.8 6.7 6.0 5.7 5.5 5.5 5.8 6.0 5.4 6.0 6.7 6.3 5.6 5.5
[91] 5.5 6.1 5.8 5.0 5.6 5.7 5.7 6.2 5.1 5.7 6.3 5.8 7.1 6.3 6.5 7.6 4.9 7.3
[109] 6.7 7.2 6.5 6.4 6.8 5.7 5.8 6.4 6.5 7.7 7.7 6.0 6.9 5.6 7.7 6.3 6.7 7.2
[127] 6.2 6.1 6.4 7.2 7.4 7.9 6.4 6.3 6.1 7.7 6.3 6.4 6.0 6.9 6.7 6.9 5.8 6.8
[145] 6.7 6.7 6.3 6.5 6.2 5.9
```

1.4.6 Lists

To me a list is just a container that you can store practically anything. It is compiled of elements, where each element contains an R object. For example, the first element of a list may contain a data frame, the second element may contain a vector, and the third element may contain another list. It is just a way to store things.

To create a list, use the `list()` function. Create a list compiled of first element with the `mtcars` data set, second element with a vector of zeros of size 4, and a matrix 3×3 identity matrix⁶. Store the list in an object called `list_one`:

```
list_one <- list(mtcars, rep(0, 4),
                 diag(rep(1, 3)))
```

⁶An identity matrix is a matrix where the diagonal elements are 1 and the non-diagonal elements are 0

Type `list_one` to see what pops out:

```
list_one
```

```
[[1]]
```

	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
Mazda RX4	21.0	6	160.0	110	3.90	2.620	16.46	0	1	4	4
Mazda RX4 Wag	21.0	6	160.0	110	3.90	2.875	17.02	0	1	4	4
Datsun 710	22.8	4	108.0	93	3.85	2.320	18.61	1	1	4	1
Hornet 4 Drive	21.4	6	258.0	110	3.08	3.215	19.44	1	0	3	1
Hornet Sportabout	18.7	8	360.0	175	3.15	3.440	17.02	0	0	3	2
Valiant	18.1	6	225.0	105	2.76	3.460	20.22	1	0	3	1
Duster 360	14.3	8	360.0	245	3.21	3.570	15.84	0	0	3	4
Merc 240D	24.4	4	146.7	62	3.69	3.190	20.00	1	0	4	2
Merc 230	22.8	4	140.8	95	3.92	3.150	22.90	1	0	4	2
Merc 280	19.2	6	167.6	123	3.92	3.440	18.30	1	0	4	4
Merc 280C	17.8	6	167.6	123	3.92	3.440	18.90	1	0	4	4
Merc 450SE	16.4	8	275.8	180	3.07	4.070	17.40	0	0	3	3
Merc 450SL	17.3	8	275.8	180	3.07	3.730	17.60	0	0	3	3
Merc 450SLC	15.2	8	275.8	180	3.07	3.780	18.00	0	0	3	3
Cadillac Fleetwood	10.4	8	472.0	205	2.93	5.250	17.98	0	0	3	4
Lincoln Continental	10.4	8	460.0	215	3.00	5.424	17.82	0	0	3	4
Chrysler Imperial	14.7	8	440.0	230	3.23	5.345	17.42	0	0	3	4
Fiat 128	32.4	4	78.7	66	4.08	2.200	19.47	1	1	4	1
Honda Civic	30.4	4	75.7	52	4.93	1.615	18.52	1	1	4	2
Toyota Corolla	33.9	4	71.1	65	4.22	1.835	19.90	1	1	4	1
Toyota Corona	21.5	4	120.1	97	3.70	2.465	20.01	1	0	3	1
Dodge Challenger	15.5	8	318.0	150	2.76	3.520	16.87	0	0	3	2
AMC Javelin	15.2	8	304.0	150	3.15	3.435	17.30	0	0	3	2
Camaro Z28	13.3	8	350.0	245	3.73	3.840	15.41	0	0	3	4
Pontiac Firebird	19.2	8	400.0	175	3.08	3.845	17.05	0	0	3	2
Fiat X1-9	27.3	4	79.0	66	4.08	1.935	18.90	1	1	4	1
Porsche 914-2	26.0	4	120.3	91	4.43	2.140	16.70	0	1	5	2
Lotus Europa	30.4	4	95.1	113	3.77	1.513	16.90	1	1	5	2
Ford Pantera L	15.8	8	351.0	264	4.22	3.170	14.50	0	1	5	4
Ferrari Dino	19.7	6	145.0	175	3.62	2.770	15.50	0	1	5	6
Maserati Bora	15.0	8	301.0	335	3.54	3.570	14.60	0	1	5	8
Volvo 142E	21.4	4	121.0	109	4.11	2.780	18.60	1	1	4	2

```
[[2]]
```

```
[1] 0 0 0 0
```

```

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

```

Each element in the list is labeled as a number. It is more useful to have the elements named. An element is named by typing the name in quotes followed by the = symbol before your object in the `list()` function (`mtcars=mtcars`).

```

list_one <- list(mtcars = mtcars,
                  vector = rep(0, 4),
                  identity = diag(rep(1, 3)))

```

Here I am creating an object called `list_one`, where the first element is `mtcars` labeled `mtcars`, the second element is a vector of zeros labeled `vector` and the last element is the identity matrix labeled `identity`.

Now create a new list called `list_two` and store `list_one` labeled as `list_one` and `first_array` labeled as `array`.

```

(list_two <- list(list_one = list_one,
                  array = first_array))

```

```

$list_one
$list_one$mtcars
      mpg cyl disp hp drat    wt  qsec vs am gear carb
Mazda RX4        21.0   6 160.0 110 3.90 2.620 16.46  0  1    4    4
Mazda RX4 Wag    21.0   6 160.0 110 3.90 2.875 17.02  0  1    4    4
Datsun 710       22.8   4 108.0  93 3.85 2.320 18.61  1  1    4    1
Hornet 4 Drive   21.4   6 258.0 110 3.08 3.215 19.44  1  0    3    1
Hornet Sportabout 18.7   8 360.0 175 3.15 3.440 17.02  0  0    3    2
Valiant          18.1   6 225.0 105 2.76 3.460 20.22  1  0    3    1
Duster 360       14.3   8 360.0 245 3.21 3.570 15.84  0  0    3    4
Merc 240D        24.4   4 146.7  62 3.69 3.190 20.00  1  0    4    2
Merc 230          22.8   4 140.8  95 3.92 3.150 22.90  1  0    4    2
Merc 280          19.2   6 167.6 123 3.92 3.440 18.30  1  0    4    4
Merc 280C         17.8   6 167.6 123 3.92 3.440 18.90  1  0    4    4
Merc 450SE        16.4   8 275.8 180 3.07 4.070 17.40  0  0    3    3
Merc 450SL        17.3   8 275.8 180 3.07 3.730 17.60  0  0    3    3
Merc 450SLC       15.2   8 275.8 180 3.07 3.780 18.00  0  0    3    3
Cadillac Fleetwood 10.4   8 472.0 205 2.93 5.250 17.98  0  0    3    4

```

Lincoln Continental	10.4	8	460.0	215	3.00	5.424	17.82	0	0	3	4
Chrysler Imperial	14.7	8	440.0	230	3.23	5.345	17.42	0	0	3	4
Fiat 128	32.4	4	78.7	66	4.08	2.200	19.47	1	1	4	1
Honda Civic	30.4	4	75.7	52	4.93	1.615	18.52	1	1	4	2
Toyota Corolla	33.9	4	71.1	65	4.22	1.835	19.90	1	1	4	1
Toyota Corona	21.5	4	120.1	97	3.70	2.465	20.01	1	0	3	1
Dodge Challenger	15.5	8	318.0	150	2.76	3.520	16.87	0	0	3	2
AMC Javelin	15.2	8	304.0	150	3.15	3.435	17.30	0	0	3	2
Camaro Z28	13.3	8	350.0	245	3.73	3.840	15.41	0	0	3	4
Pontiac Firebird	19.2	8	400.0	175	3.08	3.845	17.05	0	0	3	2
Fiat X1-9	27.3	4	79.0	66	4.08	1.935	18.90	1	1	4	1
Porsche 914-2	26.0	4	120.3	91	4.43	2.140	16.70	0	1	5	2
Lotus Europa	30.4	4	95.1	113	3.77	1.513	16.90	1	1	5	2
Ford Pantera L	15.8	8	351.0	264	4.22	3.170	14.50	0	1	5	4
Ferrari Dino	19.7	6	145.0	175	3.62	2.770	15.50	0	1	5	6
Maserati Bora	15.0	8	301.0	335	3.54	3.570	14.60	0	1	5	8
Volvo 142E	21.4	4	121.0	109	4.11	2.780	18.60	1	1	4	2

```
$list_one$vector
[1] 0 0 0 0
```

```
$list_one$identity
[,1] [,2] [,3]
[1,] 1 0 0
[2,] 0 1 0
[3,] 0 0 1
```

```
$array
, , 1

[,1] [,2] [,3]
[1,] 1 1 1
[2,] 1 1 1
[3,] 1 1 1
```

```
, , 2
```

```
[,1] [,2] [,3]
[1,] 2 2 2
[2,] 2 2 2
[3,] 2 2 2
```

```
, , 3  
[ ,1] [ ,2] [ ,3]  
[1,] 3 3 3  
[2,] 3 3 3  
[3,] 3 3 3
```

1.5 R Packages

As I stated before, R can be extended to do more things, such as create this tutorial. This is done by installing R packages. An R package can be thought of as extra software. This allows you to do more with R. To install an R package, you will need to use `install.packages("NAME_OF_PACKAGE")`. Once you install it, you do not need to install it again. To use the R package, use `library("NAME_OF_PACKAGE")`. This allows you to load the package in R. You will need to load the package every time you start R. For more information, please watch the video: <https://vimeo.com/203516241>.

2 RStudio

RStudio is an integrated development environment ([IDE](#)) that allows users to write code in a script and execute code to the R console in one application. Furthermore, RStudio has rich set of features that make data science projects easier to execute.

While RStudio has originally been used to program in R, it has been extended to program in python with the use of the [reticulate](#) package.

2.1 Installing

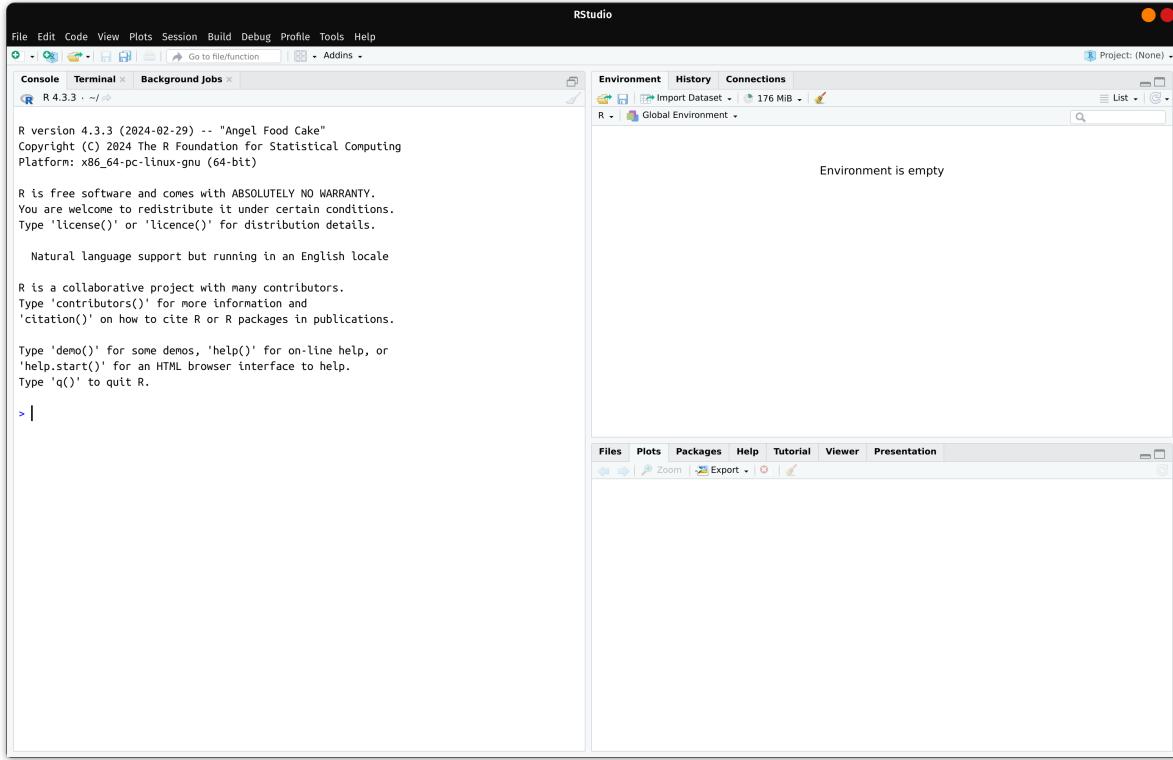
You can download and install the open-source (free) version of RStudio [here](#).

2.1.1 Installing on Windows

2.1.2 Installing on Mac

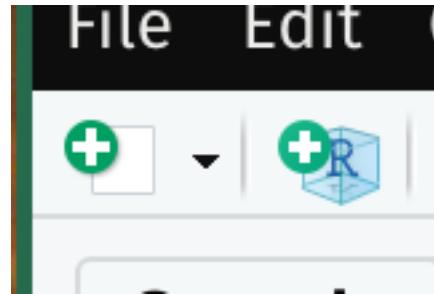
2.2 Start-up

On start-up, RStudio will look like very similar to the image below:

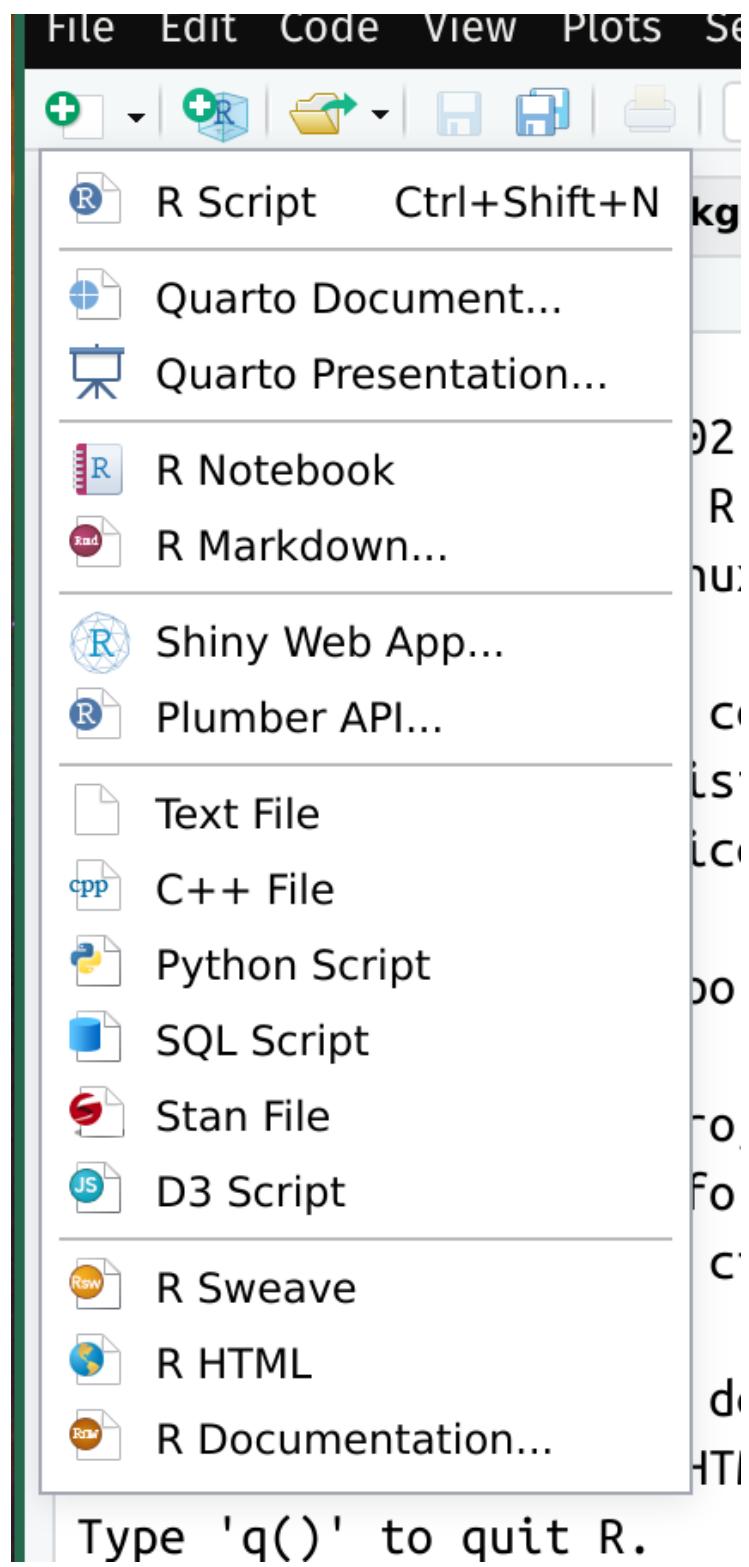


You can see that there are 3 parts in RStudio, these are known as panes.

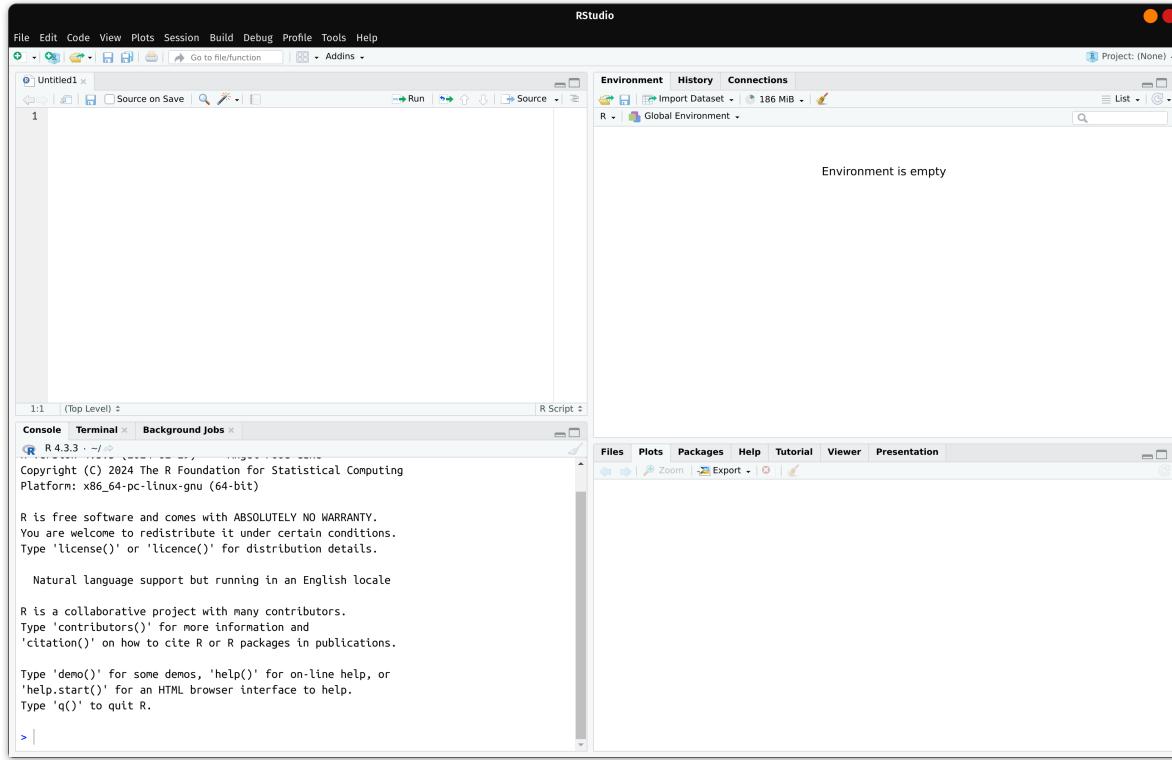
Additionally, we can add a fourth pane to RStudio for writing code in a text file. Choosing the white plus sign with a green border followed by a white document on the upper-right hand side:



This will open up a menu of text files that a user can choose to code in:



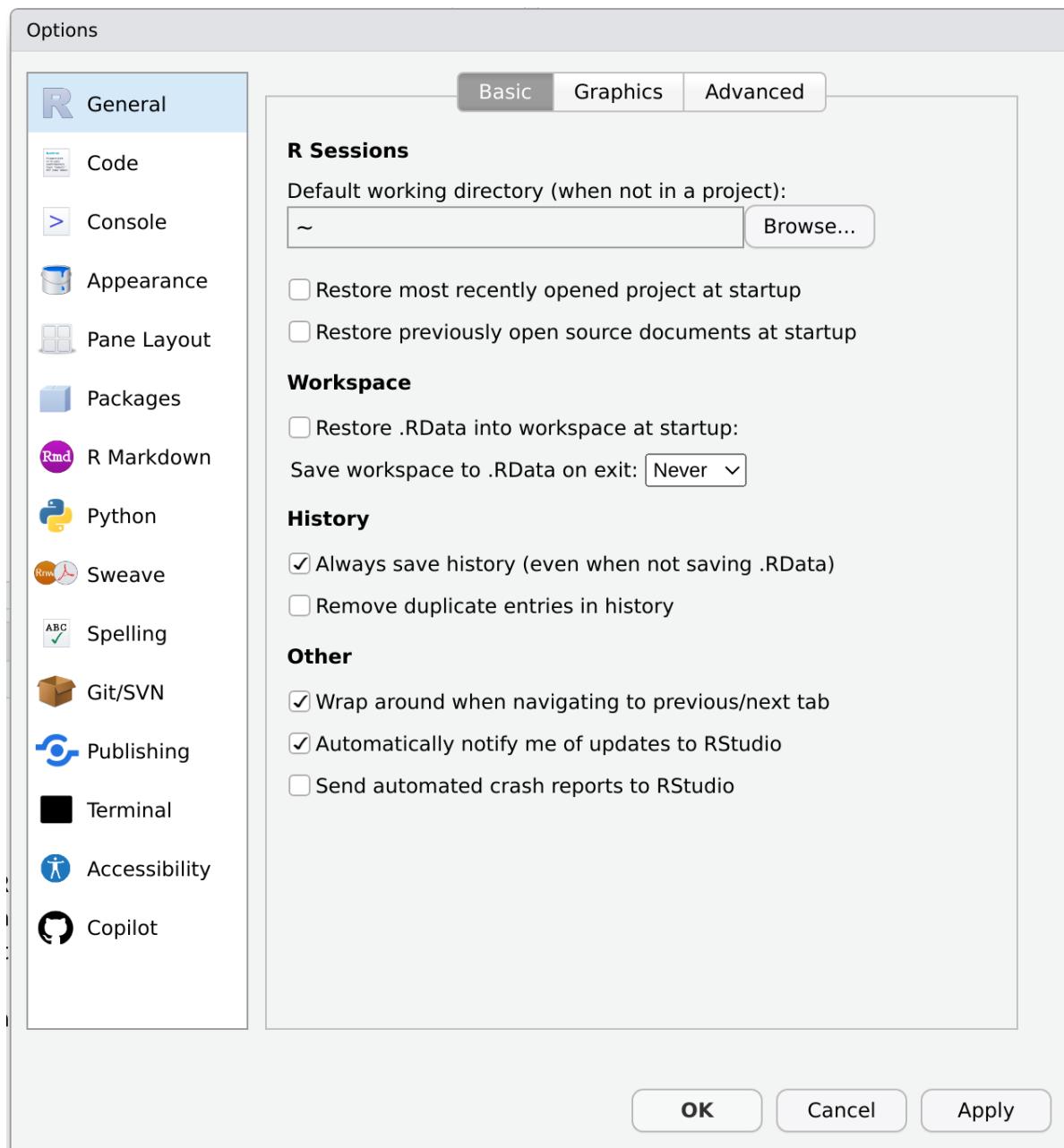
The “R Script” Button will open a standard R text file with the extension as “.R”. This is the text file that most R programmers used to save and execute code. This will make RStudio to look like this:



Notice a new pane is created on the top-left that allows you to write R code in a script. This script is also connected to the R console below which will allow you to send lines of code from the script to the console to be executed (also known as [REPL](#)).

2.3 Global Options

In this section, here are some recommended “Global Options” for users to set in RStudio. To begin, click on *Tools Global Options* from the top-menu. The following window should open:



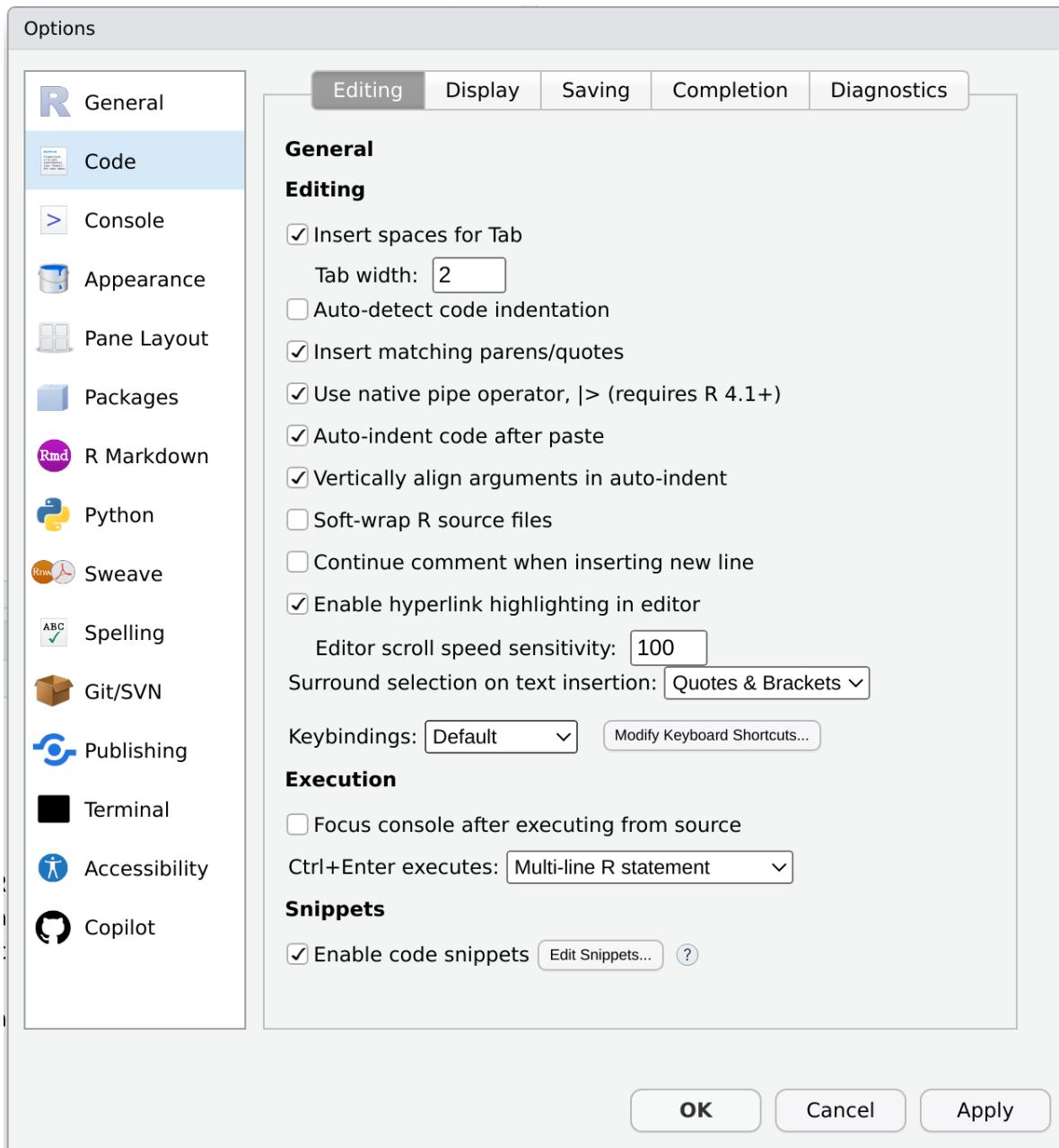
The window allows you to make several changes in RStudio that will make your experience better. Here is a list of items that are recommended for users to change:

1. *R General*

1. Make sure “Restore .RData into workspace at startup:” is unchecked (**Highly**

Recommended¹)

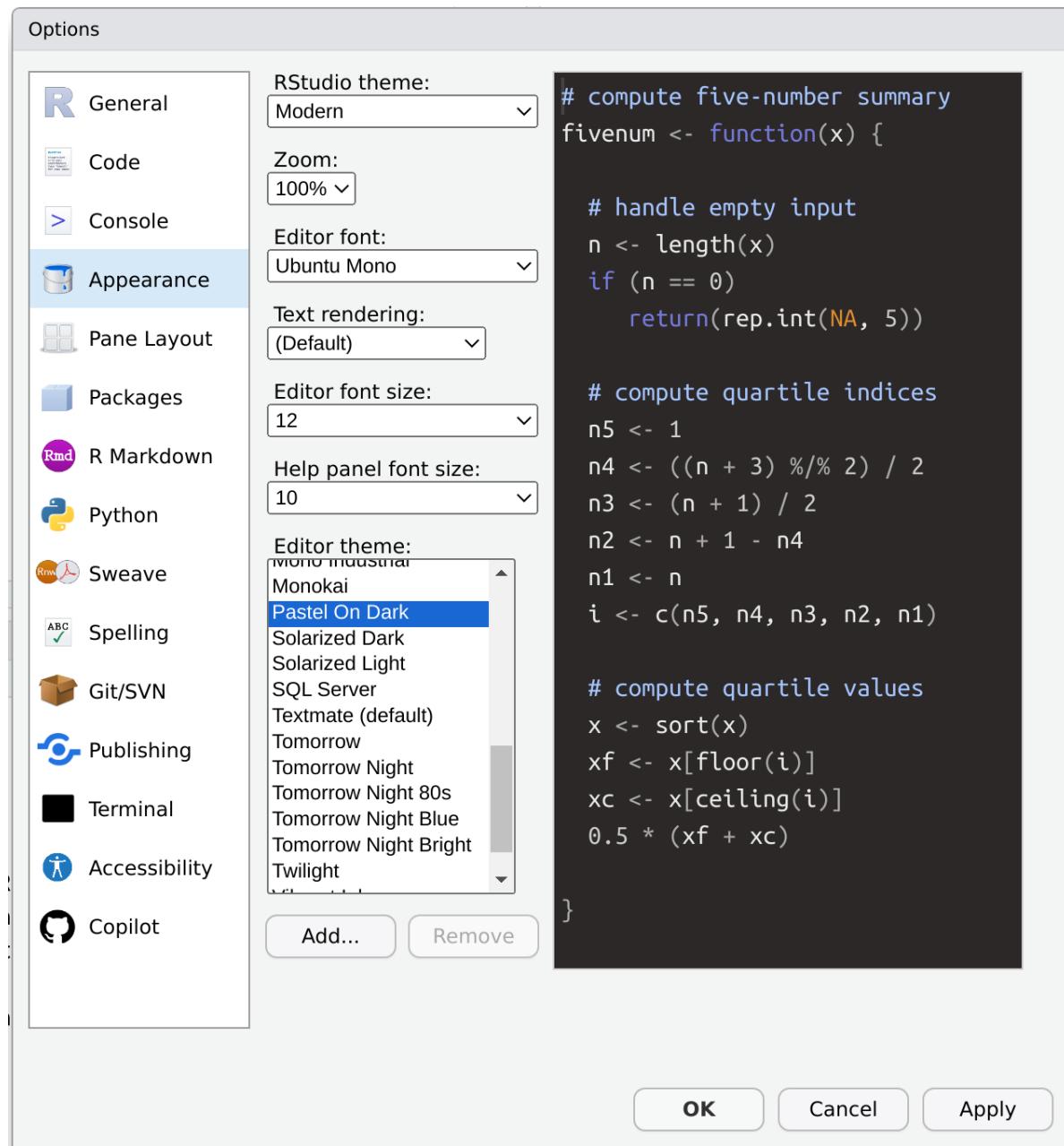
2. Set “Save workspace to .RData on exit.” to “Never” (**Highly Recommended**)



¹This will ensure that your environment is always recreated from the code you write and not from anything else. It increases reproducibility.

2. Code

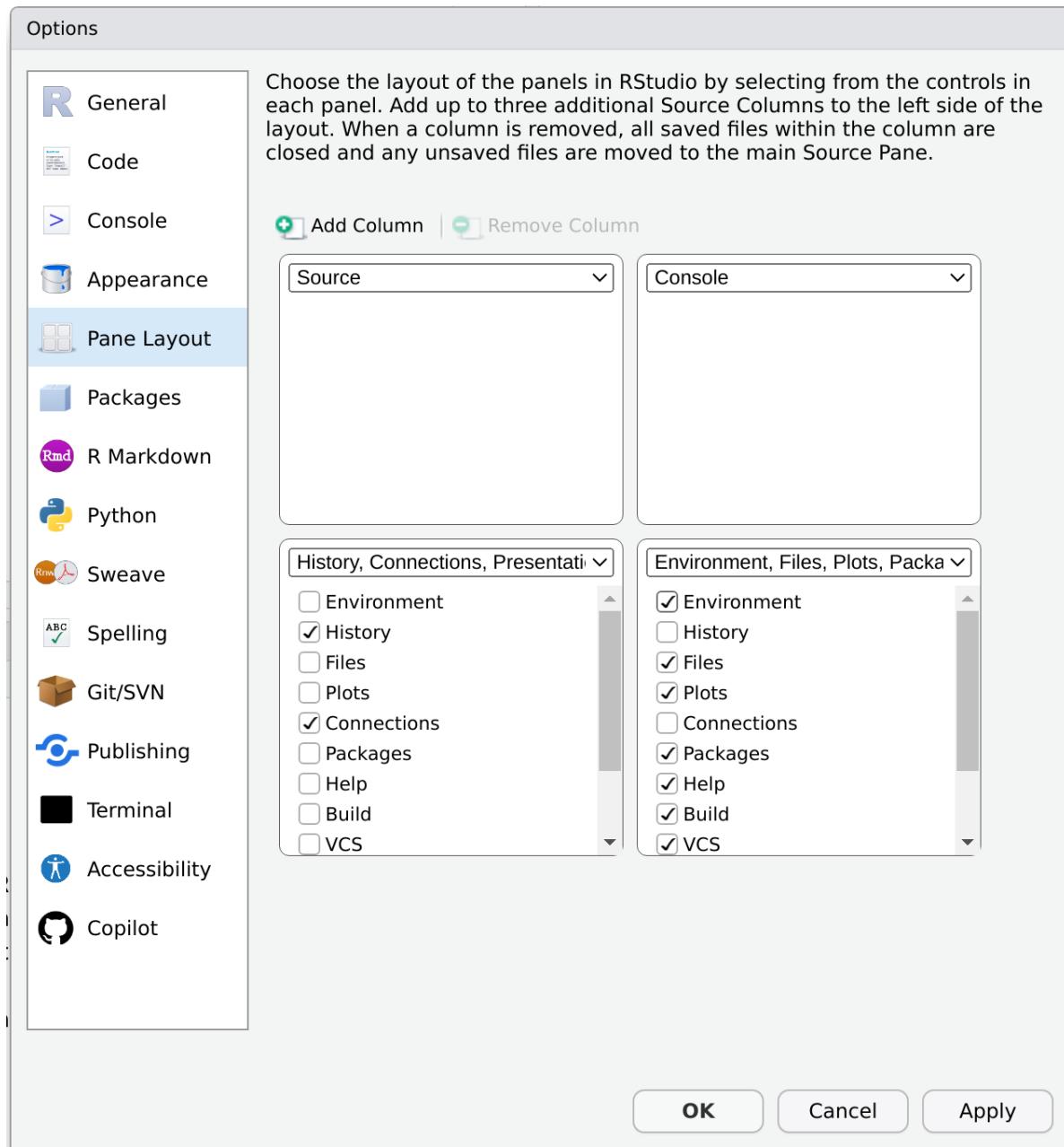
1. “Use native pipe operator `|>`” is recommended² (Optional)



²The native pipe does not require to have any packages installed. Additionally, it executes code slightly faster than `%>%`.

3. Appearance

1. In the “Editor theme:” box, choose a setting that you will prefer to work in (Optional)

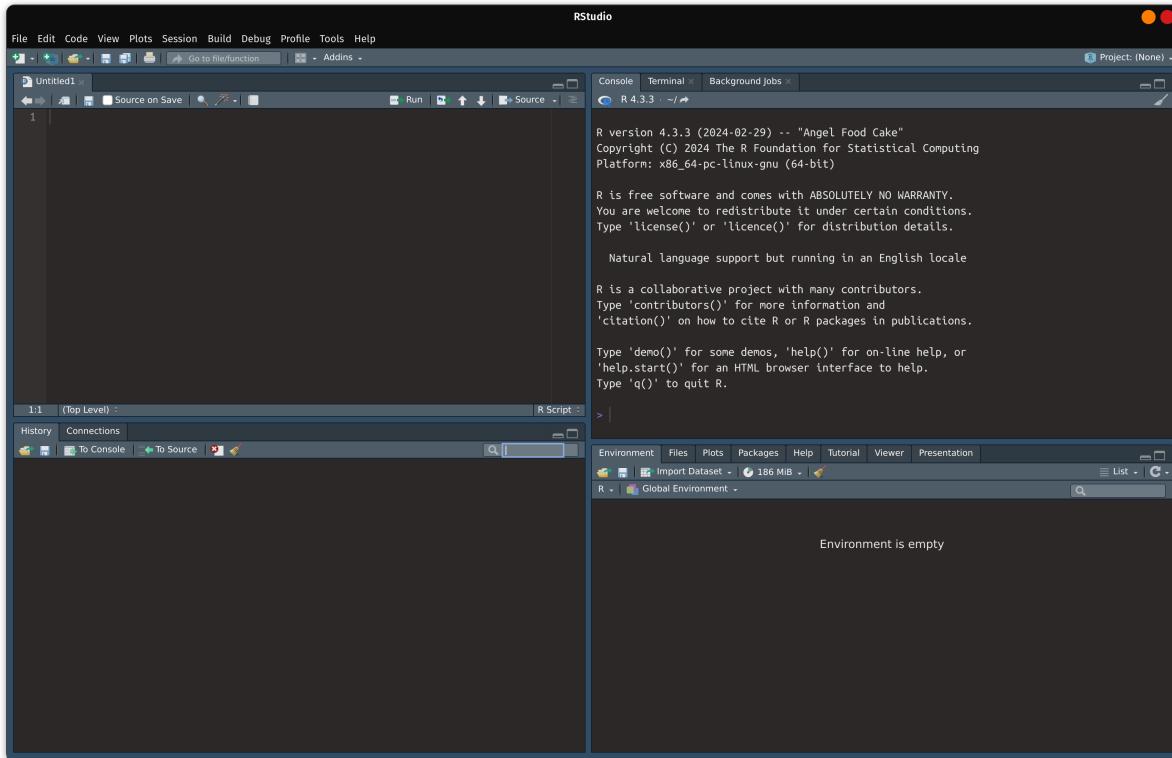


4. Pane Layout (Optional)

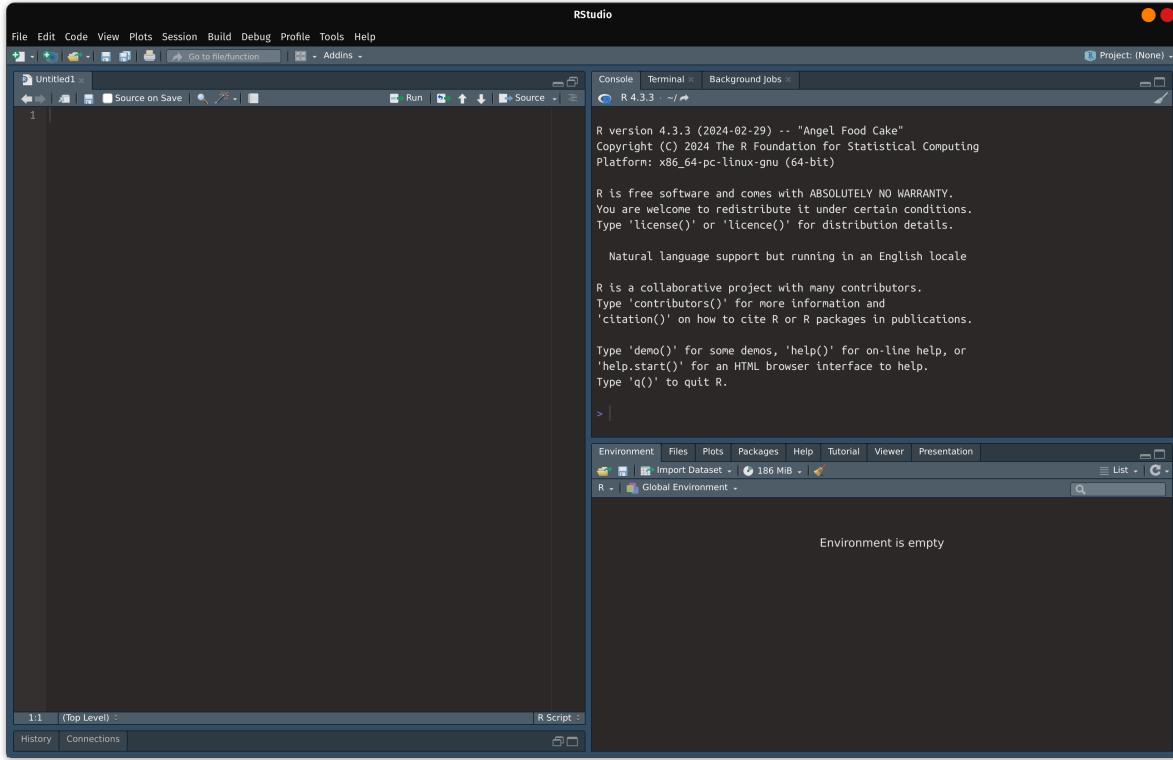
1. Change the pane layout to have the “Console” on the top-right corner
2. Add all components (checkmark) to the lower-right corner except for “History” and “Connections”

This will allow for you to expand the “Source” (script) to be expanded for the entire left hand side. It will allow you to view more code at one time.

RStudio will look more like this:

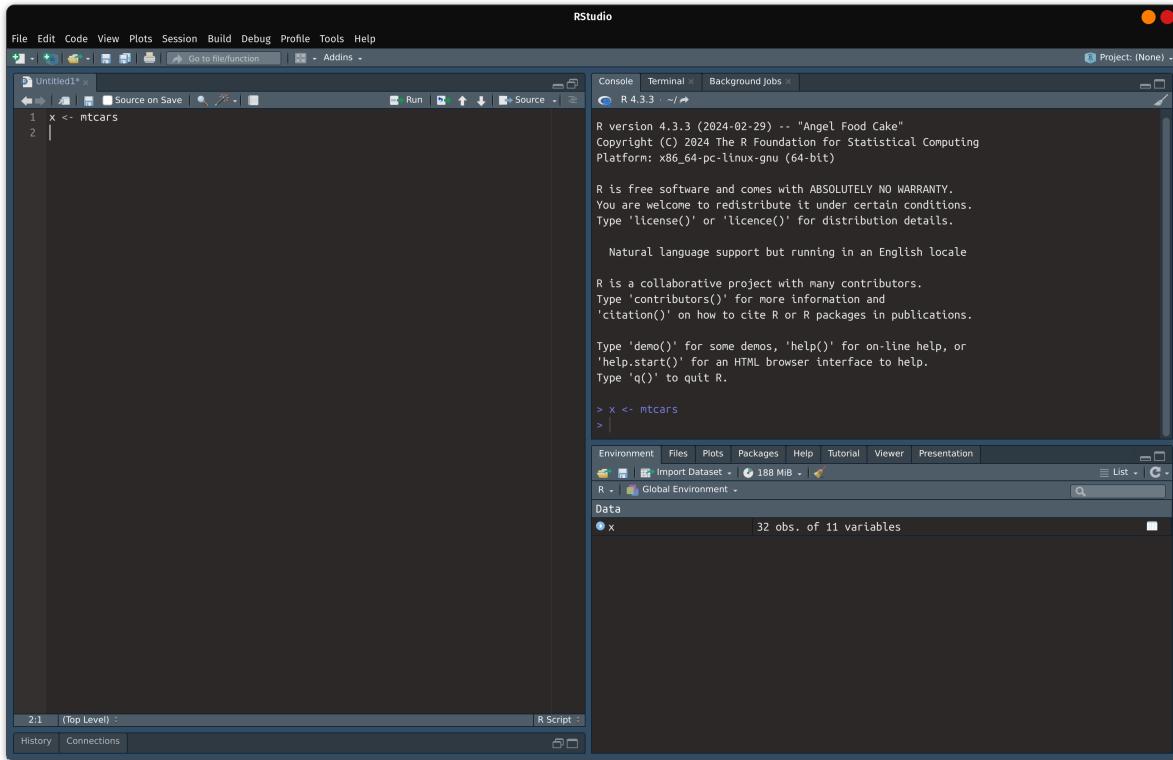


With the expanded script:



2.4 Source, Console and Plots

The source pane allows you to write an R script for analysis. Below `x <- mtcars` is written (top-left) and executed to R (top-right). Afterwards the “Environment” Tab in the lower right pane now how `x`. The “Environment” tab displays which R objects were created and available to use for further analysis.



Since **x** is a data frame, clicking on **x** from the “Environment” tab will open a new tab in the Source pane containing the data set:

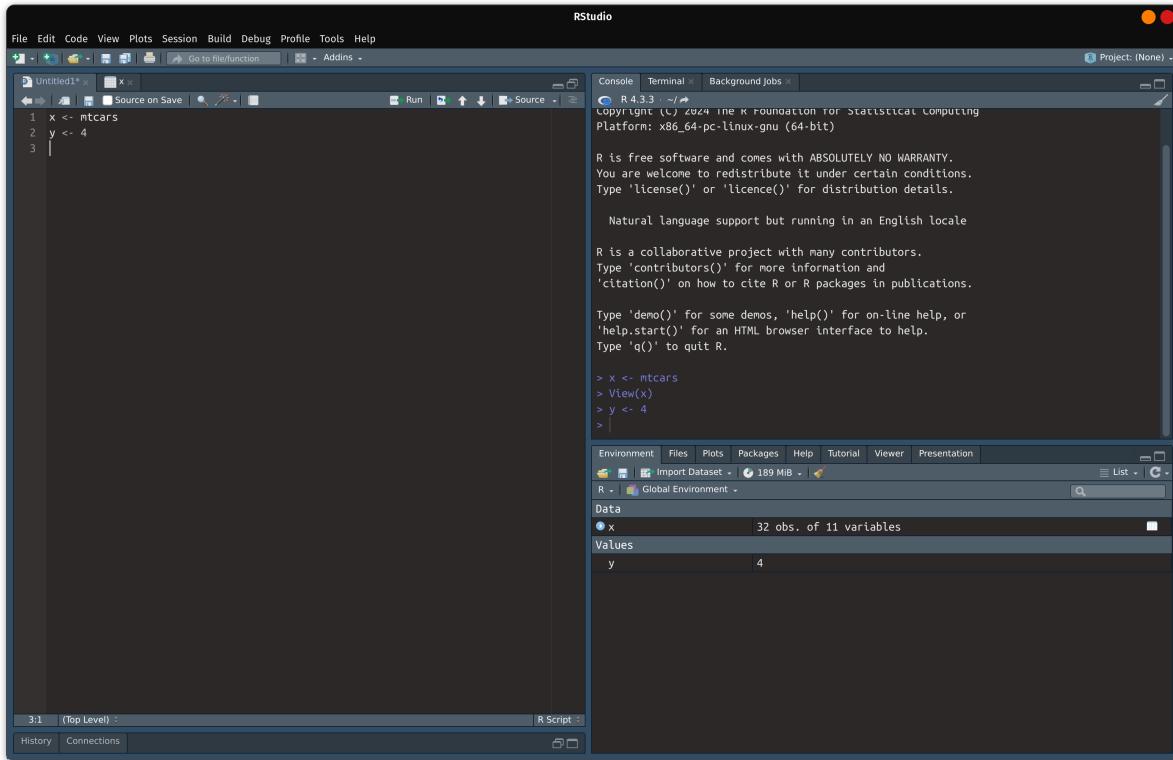
The screenshot shows the RStudio interface with the following components:

- File Edit Code View Plots Session Build Debug Profile Tools Help**: The top menu bar.
- Untitled1***: The active R script file.
- Console**: Displays the R command-line interface, including the R version information and a few commands entered by the user.
- Data**: The main workspace where the `mtcars` dataset is listed as an object with 32 observations and 11 variables.
- Environment**: A tab in the Data pane showing the new object `y` has been created.

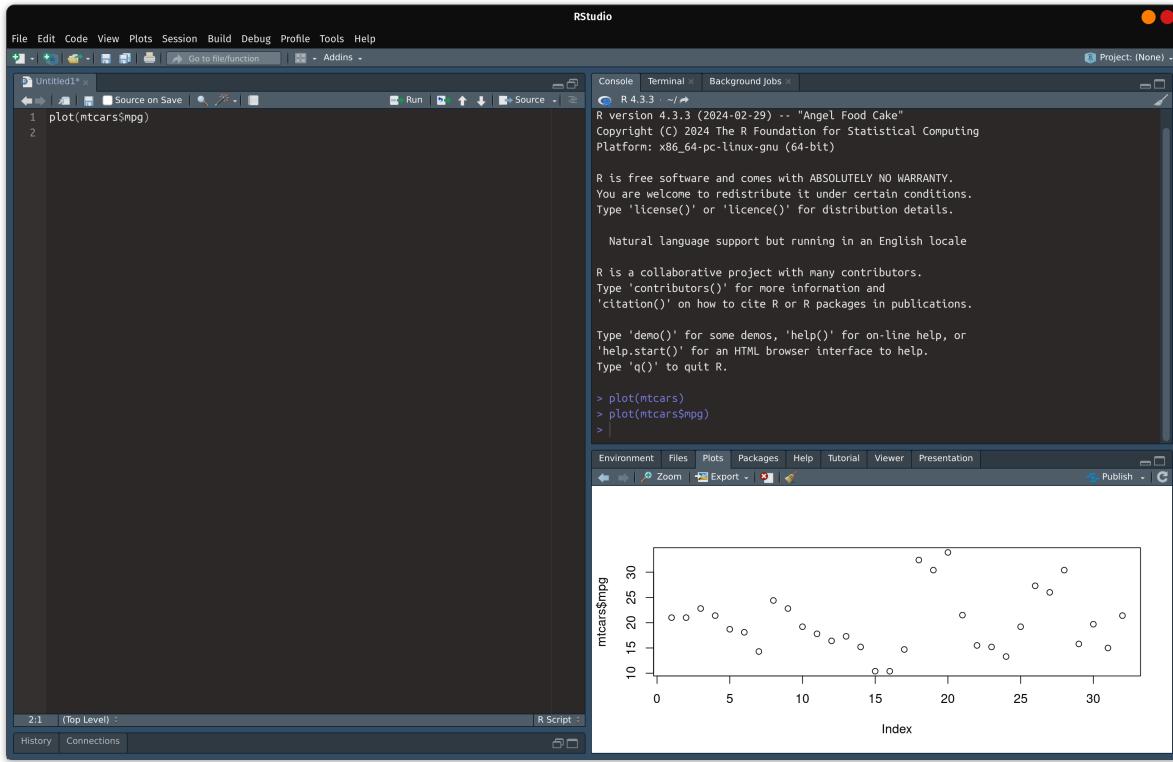
The `mtcars` dataset is displayed in a table format in the Data pane:

	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
Mazda RX4	21.0	6	160.0	110	3.90	2.620	16.46	0	1	4	4
Mazda RX4 Wag	21.0	6	160.0	110	3.90	2.875	17.02	0	1	4	4
Datsun 710	22.8	4	108.0	93	3.85	2.320	18.61	1	1	4	1
Hornet 4 Drive	21.4	6	258.0	110	3.08	3.215	19.44	1	0	3	1
Hornet Sportabout	18.7	8	360.0	175	3.15	3.440	17.02	0	0	3	2
Valiant	18.1	6	225.0	105	2.76	3.460	20.22	1	0	3	1
Duster 360	14.3	8	360.0	245	3.21	3.570	15.84	0	0	3	4
Merc 240D	24.4	4	146.7	62	3.69	3.190	20.00	1	0	4	2
Merc 230	22.8	4	140.8	95	3.92	3.150	22.90	1	0	4	2
Merc 280	19.2	6	167.6	123	3.92	3.440	18.30	1	0	4	4
Merc 280C	17.8	6	167.6	123	3.92	3.440	18.90	1	0	4	4
Merc 450SE	16.4	8	275.8	180	3.07	4.070	17.40	0	0	3	3
Merc 450SL	17.3	8	275.8	180	3.07	3.730	17.60	0	0	3	3
Merc 450SLC	15.2	8	275.8	180	3.07	3.780	18.00	0	0	3	3
Cadillac Fleetwood	10.4	8	472.0	205	9.93	5.250	17.98	0	0	3	4
Lincoln Continental	10.4	8	460.0	215	3.00	5.424	17.82	0	0	3	4
Chrysler Imperial	14.7	8	440.0	230	3.23	5.345	17.42	0	0	3	4
Fiat 128	32.4	4	78.7	66	4.08	2.200	19.47	1	1	4	1
Honda Civic	30.4	4	75.7	52	4.93	1.615	18.52	1	1	4	2
Toyota Corolla	33.9	4	71.3	65	4.22	1.835	19.90	1	1	4	1
Toyota Corona	21.5	4	120.1	97	3.70	2.485	20.01	1	0	3	1
Dodge Challenger	15.5	8	318.0	150	2.76	3.520	16.87	0	0	3	2
AMC Javelin	15.2	8	304.0	150	3.15	3.435	17.30	0	0	3	2
Camaro Z28	13.3	8	350.0	245	3.73	3.840	15.41	0	0	3	4
Pontiac Firebird	19.2	8	400.0	175	3.08	3.845	17.05	0	0	3	2
Fiat X1-9	27.3	4	79.0	66	4.08	1.935	18.90	1	1	4	1
Porsche 914-2	26.0	4	120.3	91	4.43	2.140	16.70	0	1	5	2
Lotus Europa	30.4	4	95.1	113	3.77	1.513	16.90	1	1	5	2
Ford Pantera L	15.8	8	351.0	264	4.22	3.170	14.50	0	1	5	4
Ferrari Dino	19.7	6	145.0	175	3.62	2.770	15.50	0	1	5	6
Maserati Bora	15.0	8	301.0	335	3.54	3.570	14.60	0	1	5	8
Volvo 142E	21.4	4	121.0	109	4.11	2.780	18.60	1	1	4	2

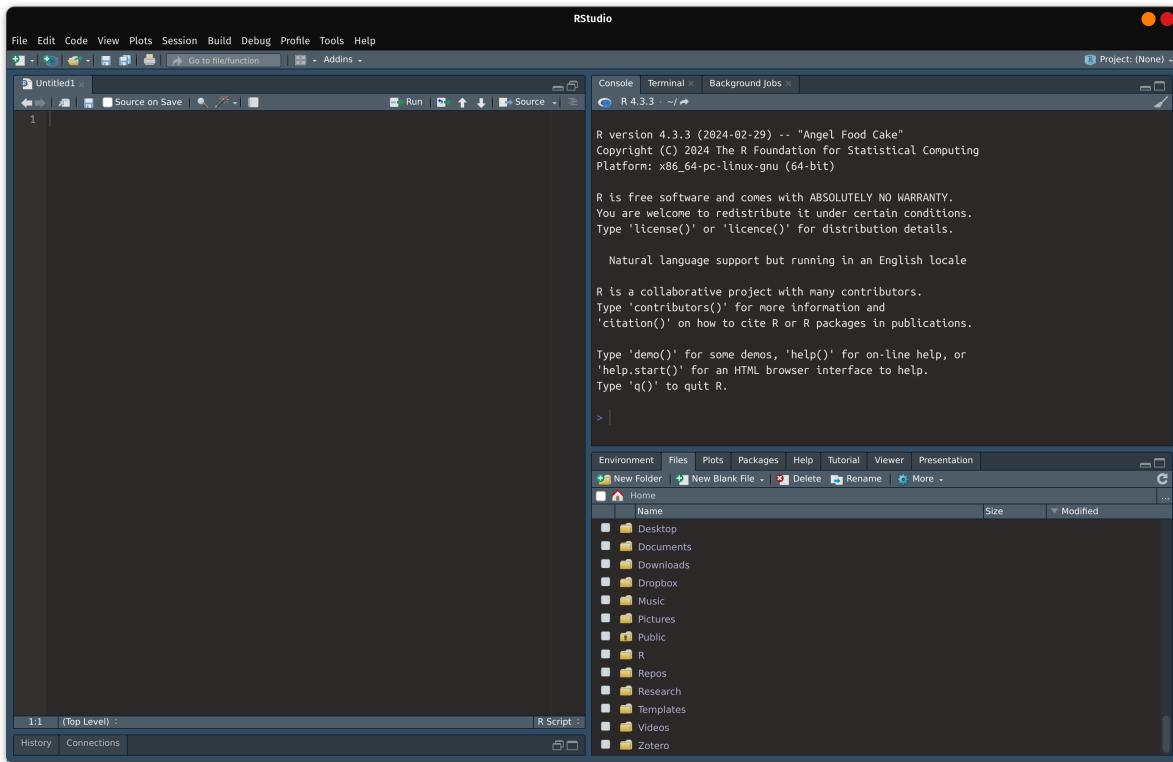
If we create an object that is a vector (`y <- 4` as pictured below), the “Environment” tab now shows a new object as a value.



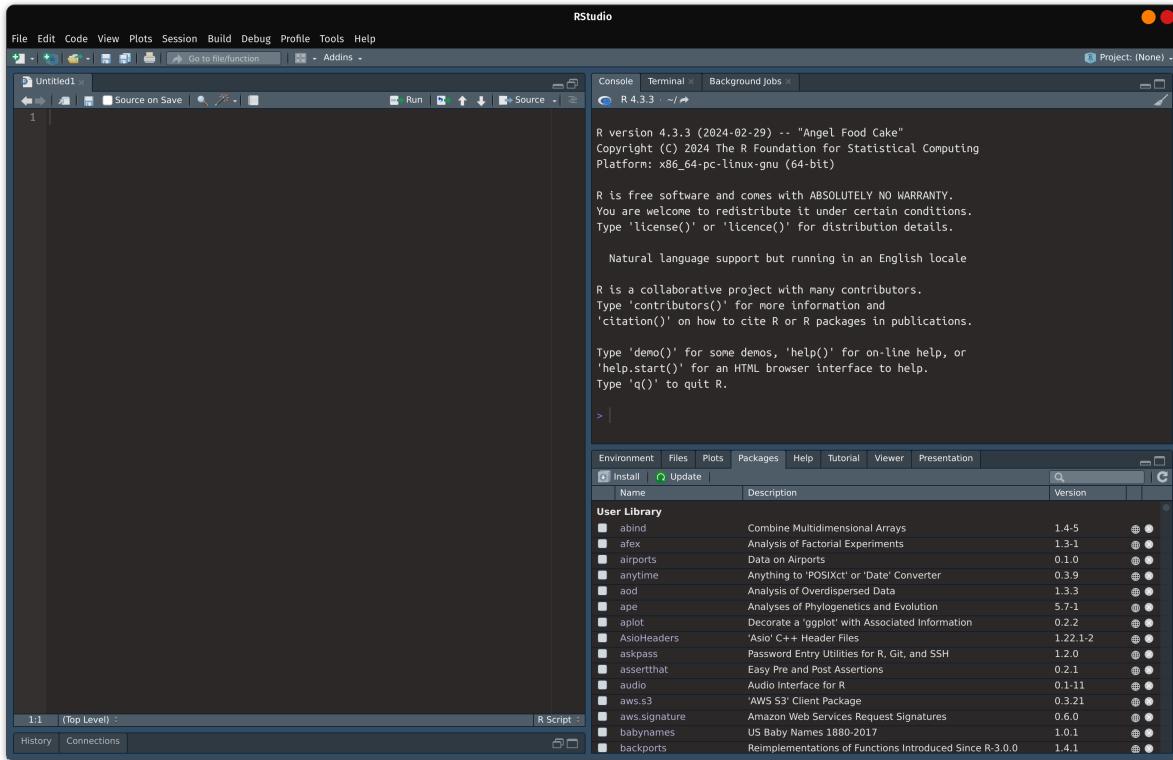
If a plot is created (`plot(mtcars$mpg)`), a plot will be displayed in the “Plots” tab in the lower-right pane.



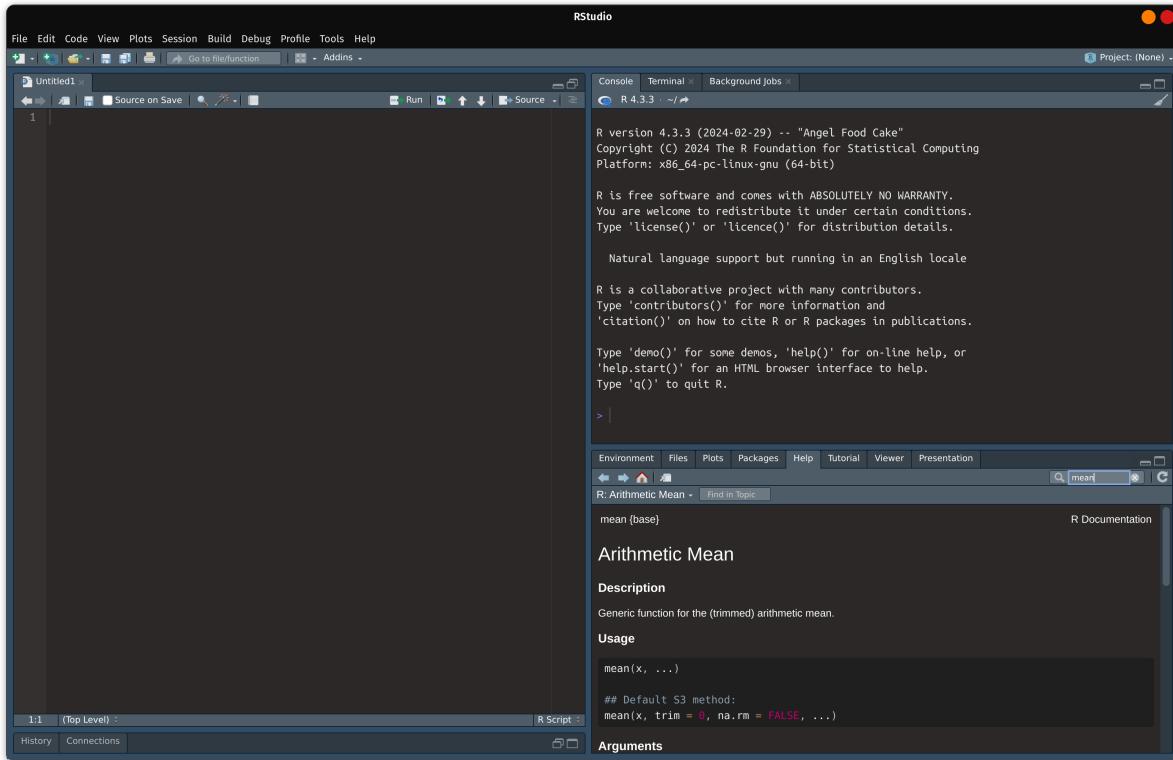
The lower right-pane also contains other useful features such as access to your computer's file directory:



Access to installed packages:



And access to help documentation:



3 Base R

4 Tidyverse

5 Teaching R

Part II

Python Programming

6 Python Basics

7 Python and Data Science

8 Teaching Python

Part III

Online Computing

9 Notebooks

10 Google Colab

11 JupyterHub

12 Integrating in Learning Management System

Part IV

Version Control

How many times when you are working finalizing a document and you save it as `final_15.docx` or something like `true_final_5.docx` or `FINAL_FINAL_3.docx` or `ONLY_LOOK_AT_THIS_ONE_FINAL_2.docx`. This is a common trait all of do to ensure that we save our updates so we can look at the differences between versions. This is where version control can help organize and track your changes between different versions of a file.

In this part of the book, we will demonstrate the basics of version control with the use of git and GitHub.

If you want a more in depth version of using git and GitHub, take a look at the following resource table:

Website	Description
Happy Git	Provide an overview of git and GitHub while using RStudio.
Pro Git	A highly recommended book for those who want to gain a deep understanding of git.
Oh S***, Git!?!?	Provides troubleshooting techniques when the inevitable mistakes occur.
Git in Simple Words	Provides git basics in simplified words.

13 GitHub

14 Git Basics

Part V

Scientific Documentation

15 Markdown Basics

Markdown files contain basic formatting capabilities. The use of the # followed by text creates a heading. Using two or more # symbols will create subheadings based on the number of #. A text is *italicized* by surrounding the text with one asterisk (**italicized**). A text is **boldfaced** by surrounding it with 2 asterisks (****boldfaced****). A text is ~~strikethrough~~ by surrounding the text with 2 tildes (~~~strikethrough~~~). A text with^{superscript} is created by surrounding a word with caret (^^{superscript}). A text with_{subscript} is created by surrounding a word with 1 tilde (~_{subscript}~).

To create an unordered list, use the - symbol at the beginning of each line. To create a sub-item, press the tab button, then the - symbol. Repeat this method for further sub-items.

Syntax	Output
<pre>- First Item - Second Item - First Sub-Item - First Sub-Sub Item - First Sub-Sub-Sub Item</pre>	<ul style="list-style-type: none">• First Item• Second Item<ul style="list-style-type: none">- First Sub-Item<ul style="list-style-type: none">* First Sub-Sub Item· First Sub-Sub-Sub Item

To create an ordered list, type the number followed by a period for each line. To create sub-lists, press the tab button twice and order them appropriately.

Syntax	Output
<ol style="list-style-type: none">1. First Item2. Second Item<ul style="list-style-type: none">a. First Sub-Item<ul style="list-style-type: none">i. First Sub-Sub-Itemii. Second Sub-Sub-Item	<ol style="list-style-type: none">1. First Item2. Second Item<ul style="list-style-type: none">a. First Sub-Item<ul style="list-style-type: none">i. First Sub-Sub Itemii. Second Sub-Sub Item

A block quote is created with the > symbol at the beginning of a line.

Markdown files allow a table to be constructed in 2 ways, manually or using a package such as the gt package. A table is manually created by using |, :, and -. The first line contains

| and the column names in between. The second line contains |:-|:-| which indicates how the table is aligned. The location of : symbol just tells RStudio about the alignment. Below is the example code of Table 15.4:

Letter	Lowercase	Code	Uppercase	Code
alpha	<code>\$\alpha\$</code>	<code>`\alpha`</code>	--	--
beta	<code>\$\beta\$</code>	<code>`\beta`</code>	--	--
gamma	<code>\$\gamma\$</code>	<code>`\gamma`</code>	<code>\$\Gamma\$</code>	<code>`\Gamma`</code>
delta	<code>\$\delta\$</code>	<code>`\delta`</code>	<code>\$\Delta\$</code>	<code>`\Delta`</code>
epsilon	<code>\$\epsilon\$</code>	<code>`\epsilon`</code>	--	--
zeta	<code>\$\zeta\$</code>	<code>`\zeta`</code>	--	--
eta	<code>\$\eta\$</code>	<code>`\eta`</code>	--	--
theta	<code>\$\theta\$</code>	<code>`\theta`</code>	<code>\$\Theta\$</code>	<code>`\Theta`</code>
iota	<code>\$\iota\$</code>	<code>`\iota`</code>	--	--
kappa	<code>\$\kappa\$</code>	<code>`\kappa`</code>	--	--
lambda	<code>\$\lambda\$</code>	<code>`\lambda`</code>	<code>\$\Lambda\$</code>	<code>`\Lambda`</code>
mu	<code>\$\mu\$</code>	<code>`\mu`</code>	--	--
nu	<code>\$\nu\$</code>	<code>`\nu`</code>	--	--
xi	<code>\$\xi\$</code>	<code>`\xi`</code>	<code>\$\Xi\$</code>	<code>`\Xi`</code>
pi	<code>\$\pi\$</code>	<code>`\pi`</code>	<code>\$\Pi\$</code>	<code>`\Pi`</code>
rho	<code>\$\rho\$</code>	<code>`\rho`</code>	--	--
sigma	<code>\$\sigma\$</code>	<code>`\sigma`</code>	<code>\$\Sigma\$</code>	<code>`\Sigma`</code>
tau	<code>\$\tau\$</code>	<code>`\tau`</code>	--	--
upsilon	<code>\$\upsilon\$</code>	<code>`\upsilon`</code>	<code>\$\Upsilon\$</code>	<code>`\Upsilon`</code>
phi	<code>\$\phi\$</code>	<code>`\phi`</code>	<code>\$\Phi\$</code>	<code>`\Phi`</code>
chi	<code>\$\chi\$</code>	<code>`\chi`</code>	--	--
psi	<code>\$\psi\$</code>	<code>`\psi`</code>	<code>\$\Psi\$</code>	<code>`\Psi`</code>
omega	<code>\$\omega\$</code>	<code>`\omega`</code>	<code>\$\Omega\$</code>	<code>`\Omega`</code>
varepsilon	<code>\$\varepsilon\$</code>	<code>`\varepsilon`</code>	--	--

15.1 Math

Quarto is capable of writing mathematical formulas using LaTeX code. A mathematical symbol can be written inline using single \$ signs. For example, `α` is viewed as α in a document. To write mathematical formulas on its own line use \$\$. For example, `$$Y=mX+b$$` is viewed as

$$Y = mX + b.$$

15.1.1 Mathematical Notation

Table 15.3: LaTeX syntax for common examples.

Notation	code
$x = y$	$\$x=y\$$
$x > y$	$\$x>y\$$
$x < y$	$\$x<y\$$
$x \geq y$	$\$x\geq y\$$
$x \leq y$	$\$x\leq y\$$
x^y	$\$x^{y}\$$
x_y	$\$x_{y}\$$
\bar{x}	$\$\bar{x}\$$
\hat{x}	$\$\\hat{x}\$$
\tilde{x}	$\$\\tilde{x}\$$
$\frac{x}{y}$	$\$\\frac{x}{y}\$$
$\frac{\partial x}{\partial y}$	$\$\\frac{\\partial x}{\\partial y}\$$
$x \in A$	$\$x\in A\$$
$x \subset A$	$\$x\subset A\$$
$x \subseteq A$	$\$x\subseteq A\$$
$x \cup A$	$\$x\cup A\$$
$x \cap A$	$\$x\cap A\$$
$\{1, 2, 3\}$	$\$\\{1, 2, 3\\}\$$
$\int_a^b f(x)dx$	$\$\\int_a^b f(x)dx\$$
$\left\{ \int_a^b f(x)dx \right\}$	$\$\\left\\{ \\int_a^b f(x)dx \\right\\}\$$
$\sum_{i=1}^n x_i$	$\$\\sum_{i=1}^n x_i\$$
$\prod_{i=1}^n x_i$	$\$\\prod_{i=1}^n x_i\$$
$\lim_{x \rightarrow 0} f(x)$	$\$\\lim_{x \\rightarrow 0} f(x)\$$
$X \sim \Gamma(\alpha, \beta)$	$\$X\\sim \\Gamma(\\alpha, \\beta)\$$

15.1.2 Greek Letters

Table 15.4: LaTeX syntax for greek letters.

Letter	Lowercase	Code	Uppercase	Code
alpha	α	$\backslash alpha$	—	—
beta	β	$\backslash beta$	—	—
gamma	γ	$\backslash gamma$	Γ	$\backslash Gamma$
delta	δ	$\backslash delta$	Δ	$\backslash Delta$
epsilon	ϵ	$\backslash epsilon$	—	—
zeta	ζ	$\backslash zeta$	—	—

Letter	Lowercase	Code	Uppercase	Code
eta	η	\eta	—	—
theta	θ	\theta	Θ	\Theta
iota	ι	\iota	—	—
kappa	κ	\kappa	—	—
lambda	λ	\lambda	Λ	\Lambda
mu	μ	\mu	—	—
nu	ν	\nu	—	—
xi	ξ	\xi	Ξ	\Xi
pi	π	\pi	Π	\Pi
rho	ρ	\rho	—	—
sigma	σ	\sigma	Σ	\Sigma
tau	τ	\tau	—	—
upsilon	υ	\upsilon	Υ	\Upsilon
phi	ϕ	\phi	Φ	\Phi
chi	χ	\chi	—	—
psi	ψ	\psi	Ψ	\Psi
omega	ω	\omega	Ω	\Omega
varepsilon	ε	\varepsilon	—	—

16 Quarto Documents with R

16.1 Introduction

Quarto is a file type used to create technical reports while including both R code, or other programming languages, and output in a document. A qmd¹ file is a fancy R Script containing extra capabilities. Additionally, qmd files allow for citations, footnotes, mathematical expressions, links, and much more. Once the document is finished, it can be rendered to a word file, pdf, html file, and much more. Quarto is the considered the next generation of [RMarkdown](#).

16.2 Anatomy of a Quarto Document

There are three main components in an qmd file: the YAML header, R code, and basic text.

The YAML header contains information on how to render the document. It is located at the beginning of the document surrounded by 3 dashes (---) above and below it. For starters, the YAML header will contain a ‘title’, ‘author’, ‘date’, and ‘output’ line.

The R code is located in a block known as chunks. A chunk tells RStudio to read the next lines as code. A chunk begins with three back ticks followed by {r} and ends with three back ticks. Everything in between the back ticks will be executed by R. In RStudio, a chunk can be inserted using the keyboard shortcut **ctrl+alt+I** or **cmd+option+I**.

An example of an R chunk is shown below:

```
```{r}
mean(mtcars$mpg)
```
```

The R chunk will be rendered as below:

```
mean(mtcars$mpg)
```

¹QMD is the file extension to use the Quarto engine. For this document Quarto and QMD are used interchangeably.

Notice the chunk includes the code in a block followed by the output from the console.

The last component of an qmd document is the text. Write anywhere in the document, and it will be rendered as is.

16.3 Chunk Options

R chunks have options that will alter how the code or the output is rendered. The chunk options can be set either globally to affect the entire qmd document or locally to affect only an individual chunk. For more information about chunk options, visit <https://yihui.org/knit/r/options/>

16.3.1 Global Chunk Options

To set global chunks options, add the two lines to YAML header:

```
---
```

```
knitr:
```

```
  opts_chunk:
```

```
---
```

Followed by the chunks and R options you want to set:

```
---
```

```
knitr:
```

```
  opts_chunk:
```

```
    eval: false
```

```
    tidy: styler
```

```
  R.options:
```

```
    digits: 2
```

```
---
```

A couple of recommended chunk options set globally are `eval: false`, and `tidy: styler`. These options make rendering the document easier.

One chunk option is `tidy: styler`. This tells Quarto to prevent code from printing in a long line, possibly off the page. For example, look at the output of this chunk:

```
## This comment is designed to show what happens when all your code is in 1 line. This is fi
```

Notice the comment being printed off the page. Using the options `tidy: styler`, the chunk is rendered as

```
## This comment is designed to show what happens when all
## your code is in 1 line. This is fine when you are
## coding, but when you are putting it in a report, it will
## run off the page.
```

The last 2 lines control how R will compute and print output. `R.Options`: tells Quarto that the options R will be changed, and each line after alters options. `digits: 2` indicates R to use 2 [significant digits](#).

16.3.2 Local Chunk Options

Local chunk options can be used to control an individual chunk will behave. To control a specific chunk, place the option below the `{r}` identifier and use the `#|` chunk option indicator. An example is provided below:

```
```{r}
#| eval: false
#| tidy: false

mean(mtcars$mpg)
```
```

The chunk option `eval` set to `false` tells Quarto to not evaluate the code within the chunk. Notice how the output was not printed the R chunk above. When we set `eval` to `true`, the output is printed:

```
```{r}
#| eval: true
mean(mtcars$mpg)
```
```

```
[1] 20.1
```

The `echo` option will control if the code within the chunk should be printed in the document. This next chunk contains `#| echo: true`:

```
mean(mtcars$mpg)
```

```
[1] 20.1
```

Now the chunk contains `#| echo: false`:

```
[1] 20.1
```

The R Code disappears.

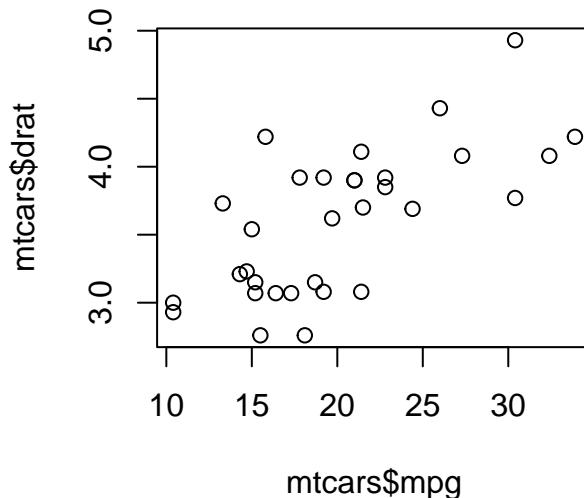
There are chunk options for figures as well. A few options are `fig-height`, `fig-width`, `fig-align`, and `fig-cap`.

This chunk contains `fig-height: 3.5; fig-width: 3.5; fig-align: left`.

```
```{r}
#| eval: true
#| fig-height: 3.5
#| fig-width: 3.5
#| fig-align: left

plot(mtcars$mpg, mtcars$drat)
```

```



The chunk options tells RStudio to create an image that is 3.5 inches in height and width, and align the image to the left.

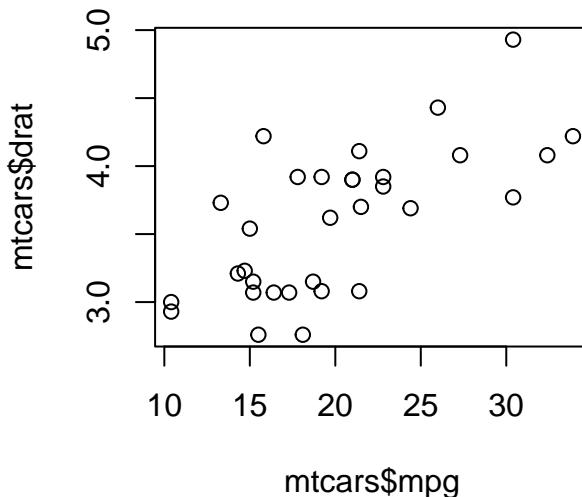
The following chunk contains `fig-height: 3.5; fig-width: 3.5; fig-align: left; fig-cap: "This is a scatter plot of MTCARS' MPG and DRAT"; label: fig-mtcars`.

```

```{r}
#| eval: true
#| fig-height: 3.5
#| fig-width: 3.5
#| fig-align: center
#| fig-cap: "This is a scatter plot of MTCARS' MPG and DRAT"
#| label: fig-mtcars

plot(mtcars$mpg, mtcars$drat)
```

```



16.4 Formatting

Qmd files allows a table to be constructed in 2 ways, manually or using a package such as the `gt` package. Below is the example code of Table 15.4:

| Letter | Lowercase | Code | Uppercase | Code |
|------------|------------------------------|--------------------------|---------------------------|-----------------------|
| alpha | <code>\$\alpha\$</code> | <code>\alpha</code> | -- | -- |
| beta | <code>\$\beta\$</code> | <code>\beta</code> | -- | -- |
| gamma | <code>\$\gamma\$</code> | <code>\gamma</code> | <code>\$\Gamma\$</code> | <code>\Gamma</code> |
| delta | <code>\$\delta\$</code> | <code>\delta</code> | <code>\$\Delta\$</code> | <code>\Delta</code> |
| epsilon | <code>\$\epsilon\$</code> | <code>\epsilon</code> | -- | -- |
| zeta | <code>\$\zeta\$</code> | <code>\zeta</code> | -- | -- |
| eta | <code>\$\eta\$</code> | <code>\eta</code> | -- | -- |
| theta | <code>\$\theta\$</code> | <code>\theta</code> | <code>\$\Theta\$</code> | <code>\Theta</code> |
| iota | <code>\$\iota\$</code> | <code>\iota</code> | -- | -- |
| kappa | <code>\$\kappa\$</code> | <code>\kappa</code> | -- | -- |
| lambda | <code>\$\lambda\$</code> | <code>\lambda</code> | <code>\$\Lambda\$</code> | <code>\Lambda</code> |
| mu | <code>\$\mu\$</code> | <code>\mu</code> | -- | -- |
| nu | <code>\$\nu\$</code> | <code>\nu</code> | -- | -- |
| xi | <code>\$\xi\$</code> | <code>\xi</code> | <code>\$\Xi\$</code> | <code>\Xi</code> |
| pi | <code>\$\pi\$</code> | <code>\pi</code> | <code>\$\Pi\$</code> | <code>\Pi</code> |
| rho | <code>\$\rho\$</code> | <code>\rho</code> | -- | -- |
| sigma | <code>\$\sigma\$</code> | <code>\sigma</code> | <code>\$\Sigma\$</code> | <code>\Sigma</code> |
| tau | <code>\$\tau\$</code> | <code>\tau</code> | -- | -- |
| upsilon | <code>\$\upsilon\$</code> | <code>\upsilon</code> | <code>\$\Upsilon\$</code> | <code>\Upsilon</code> |
| phi | <code>\$\phi\$</code> | <code>\phi</code> | <code>\$\Phi\$</code> | <code>\Phi</code> |
| chi | <code>\$\chi\$</code> | <code>\chi</code> | -- | -- |
| psi | <code>\$\psi\$</code> | <code>\psi</code> | <code>\$\Psi\$</code> | <code>\Psi</code> |
| omega | <code>\$\omega\$</code> | <code>\omega</code> | <code>\$\Omega\$</code> | <code>\Omega</code> |
| varepsilon | <code>\$\varepsilon\$</code> | <code>\varepsilon</code> | -- | -- |

: LaTeX syntax for greek letters. {#tbl-greektbl}

The last line will adds a caption to the table and `{#tbl-greektbl}` creates a label to reference the table in the text using `@tbl-greektbl`.

The `gt` function from the `gt` package creates a table from a data frame or R object. Here is an example code to create a table from the first 6 rows of the `mtcars` dataset:

```
```{r}
#| label: tbl-mtcarsdata
```

mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
21.0	6	160	110	3.90	2.62	16.5	0	1	4	4
21.0	6	160	110	3.90	2.88	17.0	0	1	4	4
22.8	4	108	93	3.85	2.32	18.6	1	1	4	1
21.4	6	258	110	3.08	3.21	19.4	1	0	3	1
18.7	8	360	175	3.15	3.44	17.0	0	0	3	2
18.1	6	225	105	2.76	3.46	20.2	1	0	3	1

Table 16.1

```
#| eval: true

mtcars |>
 head() |>
 gt::gt() |>
 gt::tab_caption("The MTCARS Dataset")
```

```

Notice that Table 16.1 is easily produced using the `gt()` function with a caption

Table Table 16.1 is referenced by using the label created in the chunk and the `@tbl-mtcarsdata`. To install `gt` run the following line in your console:

```
install.packages("gt")
```

16.5 Citations and References

Qmd documents contains capabilities to add citations and a bibliography. For example, to cite this textbook [@mendenhallSecondCourseStatistics2012], use the `@` symbol followed by a citation identifier from the `.bib` file surrounded by square brackets, [@mendenhallSecondCourseStatistics2012]. To cite your textbook again [-@mendenhallSecondCourseStatistics2012] without the authors names, use a `-` sign in front of the `@` symbol, [-@mendenhallSecondCourseStatistics2012]. To cite multiple books [@casellaStatisticalInference1990; @rohatgiIntroductionProbabilityStatistics2015; @resnickProbabilityPath2014; @lehmannTheoryPointEstimation1998; @lehmannTestingStatisticalHypotheses2005], add each citation inside the square brackets with the `@` symbol and separate them with semicolons, [@casellaStatisticalInference1990; @rohatgiIntroductionProbabilityStatistics2015; @resnickProbabilityPath2014; @lehmannTheoryPointEstimation1998; @lehmannTestingStatisticalHypotheses2005].

The references will be added automatically at the end of the document.

In order to use citations and references, the qmd file needs a `.bib` file containing all the information of the references. First, save the `.bib` file in the same folder (directory) as your `qmd` file. Then add the line `bibliography: NAME.bib` to the YAML header. Make any changes appropriately to the line, such as the name of the `.bib` file.

16.5.1 .bib File

The `.bib` file is an ordinary text file containing “bib” entries with information about each reference. Below is an example bib entry about R:

```
@Manual{,
  title = {R: A Language and Environment for Statistical Computing},
  author = {{R Core Team}},
  organization = {R Foundation for Statistical Computing},
  address = {Vienna, Austria},
  year = {2024},
  url = {https://www.R-project.org/},
}
```

Creating a `.bib` file is tedious; however, there are reference managers that can help. I recommend using [Zotero](#), an open-source reference manager designed to import and manage citations. Once a citation is in Zotero, you can export your library as a `.bib` file. Make sure to check your references in Zotero for any mistakes.

16.6 Rendering a Document

A qmd file can be rendered into either an html file, pdf document or word document. Rendering the qmd file to an html file or word document can be easily done using the knit button above. However, rendering the qmd file to a pdf document requires LaTeX to be installed. There are two methods to install LaTeX: from the LaTeX website or from R. I recommend installing the full LaTeX distribution from the <https://www.latex-project.org/get/>. This provides you with everything you may need. You can also install it from R:

```
install.packages("tinytex")
tinytex::install_tinytex()
```

You will only need to run these lines of code once and then you can render pdf documents easily.

HTML

```
---
```

```
format: html
```

```
--
```

PDF

```
---
```

```
format: pdf
```

```
--
```

Word Document

```
---
```

```
format: docx
```

```
--
```

16.7 Resources and Tips

Quarto

- [Quarto](#)
- [Markdown Basics](#)
- [Formats](#)

RMarkdown

- [RStudio](#)
- [Bookdown](#)

YAML

- [UCLA Resource](#)
- [Reproducible Research](#)
- [RMarkdown Crash Course](#)

Tips

- Render your document often so it easier to identify problems with rendering
- The Visual Mode in RStudio eases the process of creating a document and makes it more bearable.
- YAML is tricky with spacing. Make sure that spaces when indenting options. Also make sure that there are not extra spaces at the end of each line.

16.8 References

17 Quarto Presentations in R