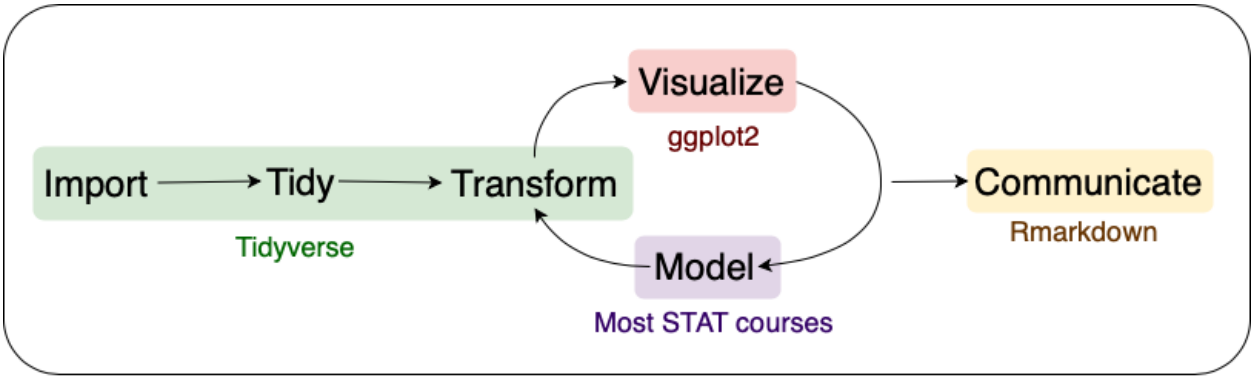
Chapter 0: Some Useful Computing Tools

We will start the class with some tools that will be useful for success in this class. Going forward, we will use these tools for any computing and data analysis tasks.



Data Analysis Pipeline

Adapted from R for Data Science, Wickham & Grolemund (2017)

In STAT400, we will cover each part of the data analysis pipeline using

1.
2.
3.

1 R

R (https://www.r-project.org) is a free, open source software environment for statistical computing and graphics that is available for every major platform.

RStudio (https://rstudio.com) is an integrated development environment (IDE) for R. It is also free, open source, and available for every major platform. It makes data analysis and projects in R go a bit smoother.

1.1 Getting Started

We can use R like an overgrown calculator.

```
# simple math
5*(10 - 4) + 44
```

```
## [1] 74
```

```
# integer division
7 %/% 2
```

```
## [1] 3
```

```
# modulo operator (Remainder)
7 %% 2
```

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

```
# powers
1.5^3
```

```
## [1] 3.375
```

We can use mathematical functions.

```
# exponentiation
exp(1)
```

```
## [1] 2.718282
```

```
# logarithms
log(100)
```

```
## [1] 4.60517
```

```
log(100, base = 10)
```

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

```
# trigonometric functions
sin(pi/2)
```

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

```
cos(pi)
```

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

```
asin(1)
```

```
## [1] 1.570796
```

We can create variables using the assignment operator `<-`,

```
# create some variables
x <- 5
class <- 400
hello <- "world"
```

and then use those variables in our functions.

```
# functions of variables
log(x)
```

```
## [1] 1.609438
```

```
class^2
```

```
## [1] 160000
```

There are some rules for variable naming.

Variable names –

1. Can't start with a number.
2. Are case-sensitive.
3. Can be the name of a predefined internal function or letter in `R` (e.g., c, q, t, C, D, F, T, I). Try not to use these.
4. Cannot be reserved words that `R` (e.g., for, in, while, if, else, repeat, break, next).

1.2 Vectors

Variables can store more than one value, called a *vector*. We can create vectors using the combine (`c()`) function.

```r
# store a vector
y <- c(1, 2, 6, 10, 17)
```

When we perform functions on our vector, the result is elementwise.

```r
# elementwise function
y/2
```

```
## [1] 0.5 1.0 3.0 5.0 8.5
```

A vector must contain all values of the same type (i.e., numeric, integer, character, etc.).

Your Turn

1. Use the `rep()` function to construct the following vector: `1 1 2 2 3 3 4 4 5 5`
2. Use `rep()` to construct this vector: `1 2 3 4 5 1 2 3 4 5 1 2 3 4 5`

We can also make sequences of numbers using either `:` or `seq()`

```
# sequences
a <- 1:5
a
```

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

```
b <- seq(1, 5, by = 1)
b
```

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

and we can **extract** values by index.

```
a[3]
```

```
## [1] 3
```

Indexing is pretty powerful.

```
# indexing multiple items
a[c(1, 3, 5)]
```

```
## [1] 1 3 5
```

```
a[1:3]
```

```
## [1] 1 2 3
```

We can even tell `R` which elements we don't want.

```
a[-3]
```

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

And we can index by **logical** values. `R` has logicals built in using `TRUE` and `FALSE` (`T` and `F` also work, but can be overwritten). Logicals can result from a comparison using

- `<` : "less than"
- `>` : "greater than"
- `<=` : "less than or equal to"
- `>=` : "greater than or equal to"
- `==` : "is equal to"
- `!=` : "not equal to"

```
# indexing by vectors of logicals
a[c(TRUE, TRUE, FALSE, FALSE, FALSE)]
```

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

```
# indexing by calculated logicals
a < 3
```

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

```
a[a < 3]
```

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

Your Turn

1. Create a vector of 1300 values evenly spaced between 1 and 100.

2. How many of these values are greater than 791? (Hint: see `sum()` as a helpful functions.)

We can combine elementwise logical vectors in the following way:

- `&` : elementwise AND
- `|` : elementwise OR

```
c(TRUE, TRUE, FALSE) | c(FALSE, TRUE, FALSE)
```

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

```
c(TRUE, TRUE, FALSE) & c(FALSE, TRUE, FALSE)
```

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

There are two more useful functions for looking at the start (head) and end (tail) of a vector.

```
head(a, 2)
```

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

```
tail(a, 2)
```

```
## [1] 4 5
```

We can also modify elements in a vector.

```
a[1] <- 0
a[c(4, 5)] <- 100
a
```

```
## [1]   0   2   3 100 100
```

Your Turn

Using the vector you created of 1300 values evenly spaced between 1 and 100,

1. Modify the elements greater than 1000 to equal 9999.
2. View (not modify) the first 100 values in your vector.

As mentioned, elements of a vector must all be the same type. So, changing an element of a vector to a different type will result in all elements being converted to the *most general* type.

```
a
```

```
## [1]   0   2   3 100 100
```

```
a[1] <- ":-("
a
```

```
## [1] ":-(" "2"   "3"   "100" "100"
```

By changing a value to a string, all the other values were also changed.

There are many data types in `R`, numeric, integer, character (i.e., string), Date, and factor being the most common. We can convert between different types using the `as` series of functions.

```
as.character(b)
```

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

There are a whole variety of useful functions to operate on vectors. A couple of the more common ones are `length`, which returns the length (number of elements) of a vector, and `sum`, which adds up all the elements of a vector.

```
n <- length(b)
n
```

```
## [1] 5
```

```
sum_b <- sum(b)
sum_b
```

```
## [1] 15
```

We can then create some statistics!

```
mean_b <- sum_b/n
sd_b <- sqrt(sum((b - mean_b)^2)/(n - 1))
```

But, we don't have to.

```
mean(b)
```

```
## [1] 3
```

```
sd(b)
```

```
## [1] 1.581139
```

```
summary(b)
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##       1       2       3       3       4       5
```

```
quantile(b, c(.25, .75))
```

```
## 25% 75%
##   2   4
```

1.3 Data Frames

Data frames are the data structure you will (probably) use the most in `R`. You can think of a data frame as any sort of rectangular data. It is easy to conceptualize as a table, where wach column is a vector. Recall, each vector must have the same data type *within* the vec-

tor (column), but columns in a data frame need not be of the same type. Let's look at an example!

```
# look at top 6 rows
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
```

```
# structure of the object
str(iris)
```

```
## 'data.frame':    150 obs. of  5 variables:
##  $ Sepal.Length: num  5.1 4.9 4.7 4.6 5 5.4 4.6 5 4.4 4.9 ...
##  $ Sepal.Width : num  3.5 3 3.2 3.1 3.6 3.9 3.4 3.4 2.9 3.1 ...
##  $ Petal.Length: num  1.4 1.4 1.3 1.5 1.4 1.7 1.4 1.5 1.4 1.5 ...
##  $ Petal.Width : num  0.2 0.2 0.2 0.2 0.2 0.4 0.3 0.2 0.2 0.1 ...
##  $ Species     : Factor w/ 3 levels "setosa","versicolor",..: 1 1 1 1 1 1 1 1 1 1 ...
```

This is Anderson's Iris data set (https://en.wikipedia.org/wiki/Iris_flower_data_set), available by default in `R`.

Some facts about data frames:

- Structured by rows and columns and can be indexed
- Each column is a variable of one type
- Column names or locations can be used to index a variable
- Advice for naming variables applys to naming columns
- Can be specified by grouping vectors of equal length as columns

Data frames are indexed (similarly to vectors) with `[ ]`.

- `df[i, j]` will select the element of the data frame in the `i`th row and the `j`th column.
- `df[i, ]` will select the entire `i`th row as a data frame
- `df[ , j]` will select the entire `j`th column as a vector

We can use logicals or vectors to index as well.

```
iris[1, ]
```

```
##   Sepal.Length Sepal.Width Petal.Length Petal.Width Species
## 1          5.1         3.5          1.4         0.2  setosa
```

```
iris[, 1]
```

```
##   [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
##  [18] 5.1 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
##  [35] 4.9 5.0 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
##  [52] 6.4 6.9 5.5 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
##  [69] 6.2 5.6 5.9 6.1 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
##  [86] 6.0 6.7 6.3 5.6 5.5 5.5 6.1 5.8 5.0 5.6 5.7 5.7 6.2 5.1 5.7 6.3 5.8
## [103] 7.1 6.3 6.5 7.6 4.9 7.3 6.7 7.2 6.5 6.4 6.8 5.7 5.8 6.4 6.5 7.7 7.7
## [120] 6.0 6.9 5.6 7.7 6.3 6.7 7.2 6.2 6.1 6.4 7.2 7.4 7.9 6.4 6.3 6.1 7.7
## [137] 6.3 6.4 6.0 6.9 6.7 6.9 5.8 6.8 6.7 6.7 6.3 6.5 6.2 5.9
```

```
iris[1, 1]
```

```
## [1] 5.1
```

We can also select columns by name in two ways.

```
iris$Species
```

```
##   [1] setosa     setosa     setosa     setosa     setosa     setosa
##   [7] setosa     setosa     setosa     setosa     setosa     setosa
##  [13] setosa     setosa     setosa     setosa     setosa     setosa
##  [19] setosa     setosa     setosa     setosa     setosa     setosa
##  [25] setosa     setosa     setosa     setosa     setosa     setosa
##  [31] setosa     setosa     setosa     setosa     setosa     setosa
##  [37] setosa     setosa     setosa     setosa     setosa     setosa
##  [43] setosa     setosa     setosa     setosa     setosa     setosa
##  [49] setosa     setosa     versicolor versicolor versicolor versicolor
##  [55] versicolor versicolor versicolor versicolor versicolor versicolor
##  [61] versicolor versicolor versicolor versicolor versicolor versicolor
```

```
##  [67] versicolor versicolor versicolor versicolor versicolor versicolor
##  [73] versicolor versicolor versicolor versicolor versicolor versicolor
##  [79] versicolor versicolor versicolor versicolor versicolor versicolor
##  [85] versicolor versicolor versicolor versicolor versicolor versicolor
##  [91] versicolor versicolor versicolor versicolor versicolor versicolor
##  [97] versicolor versicolor versicolor versicolor virginica  virginica
## [103] virginica  virginica  virginica  virginica  virginica  virginica
## [109] virginica  virginica  virginica  virginica  virginica  virginica
## [115] virginica  virginica  virginica  virginica  virginica  virginica
## [121] virginica  virginica  virginica  virginica  virginica  virginica
## [127] virginica  virginica  virginica  virginica  virginica  virginica
## [133] virginica  virginica  virginica  virginica  virginica  virginica
## [139] virginica  virginica  virginica  virginica  virginica  virginica
## [145] virginica  virginica  virginica  virginica  virginica  virginica
## Levels: setosa versicolor virginica
```

```
iris[, "Species"]
```

```
##   [1] setosa     setosa     setosa     setosa     setosa     setosa
##   [7] setosa     setosa     setosa     setosa     setosa     setosa
##  [13] setosa     setosa     setosa     setosa     setosa     setosa
##  [19] setosa     setosa     setosa     setosa     setosa     setosa
##  [25] setosa     setosa     setosa     setosa     setosa     setosa
##  [31] setosa     setosa     setosa     setosa     setosa     setosa
##  [37] setosa     setosa     setosa     setosa     setosa     setosa
##  [43] setosa     setosa     setosa     setosa     setosa     setosa
##  [49] setosa     setosa     versicolor versicolor versicolor versicolor
##  [55] versicolor versicolor versicolor versicolor versicolor versicolor
##  [61] versicolor versicolor versicolor versicolor versicolor versicolor
##  [67] versicolor versicolor versicolor versicolor versicolor versicolor
##  [73] versicolor versicolor versicolor versicolor versicolor versicolor
##  [79] versicolor versicolor versicolor versicolor versicolor versicolor
##  [85] versicolor versicolor versicolor versicolor versicolor versicolor
##  [91] versicolor versicolor versicolor versicolor versicolor versicolor
##  [97] versicolor versicolor versicolor versicolor virginica  virginica
## [103] virginica  virginica  virginica  virginica  virginica  virginica
## [109] virginica  virginica  virginica  virginica  virginica  virginica
## [115] virginica  virginica  virginica  virginica  virginica  virginica
## [121] virginica  virginica  virginica  virginica  virginica  virginica
## [127] virginica  virginica  virginica  virginica  virginica  virginica
## [133] virginica  virginica  virginica  virginica  virginica  virginica
## [139] virginica  virginica  virginica  virginica  virginica  virginica
## [145] virginica  virginica  virginica  virginica  virginica  virginica
## Levels: setosa versicolor virginica
```

```
# make a copy of iris
my_iris <- iris

# add a column
my_iris$sepal_len_square <- my_iris$Sepal.Length^2
head(my_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
##   sepal_len_square
## 1            26.01
## 2            24.01
## 3            22.09
## 4            21.16
## 5            25.00
## 6            29.16
```

It's quite easy to subset a data frame.

```
my_iris[my_iris$sepal_len_square < 20, ]
```

```
##    Sepal.Length Sepal.Width Petal.Length Petal.Width Species
## 9           4.4         2.9          1.4         0.2  setosa
## 14          4.3         3.0          1.1         0.1  setosa
## 39          4.4         3.0          1.3         0.2  setosa
## 43          4.4         3.2          1.3         0.2  setosa
##    sepal_len_square
## 9             19.36
## 14            18.49
## 39            19.36
## 43            19.36
```

We'll see another way to do this in Section 3 (page 27).

We can create new data frames using the `data.frame()` function,

```
df <- data.frame(NUMS = 1:5,
                 lets = letters[1:5],
                 cols = c("green", "gold", "gold", "gold", "green"))
```

and we can change column names using the `names()` function.

```
names(df)
```

```
## [1] "NUMS" "lets" "cols"
```

```
names(df)[1] <- "nums"

df
```

```
##   nums lets  cols
## 1    1    a green
## 2    2    b  gold
## 3    3    c  gold
## 4    4    d  gold
## 5    5    e green
```

Your Turn

1. Make a data frame with column 1: `1,2,3,4,5,6` and column 2: `a,b,a,b,a,b`
2. Select only rows with value “a” in column 2 using logical vector
3. `mtcars` is a built-in data set like `iris`: Extract the 4th row of the mtcars data.

There are other data structures available to you in R, namely lists and matrices. We will not cover these in the notes, but I encourage you to read more about them (https://faculty.nps.edu/sebuttre/home/R/lists.html and https://faculty.nps.edu/sebuttre/home/R/matrices.html).

1.4 Basic Programming

We will cover three basic programming ideas: functions, conditionals, and loops.

1.4.1 Functions

We have used many functions that are already built into R already. For example – `exp()`, `log()`, `sin()`, `rep()`, `seq()`, `head()`, `tail()`, etc.

But what if we want to use a function that doesn't exist?

We can write it!

Idea: We want to avoid repetitive coding because errors will creep in. Solution: Extract common core of the code, wrap it in a function, and make it reusable.

The basic structure for writing a function is as follows:

- Name
- Input arguments (including names and default values)
- Body (code)
- Output values

```
# we store a function in a named value
# function is itself a function to create functions!
# we specify the inputs that we can use inside the function
# we can specify default values, but it is not necessary
name <- function(input = FALSE) {
  # body code goes here

  # return output vaues
  return(input)
}
```

Here is a more realistic first example:

```
my_mean <- function(x) {
  sum(x)/length(x)
}
```

Let's test it out.

```
my_mean(1:15)
```

```
## [1] 8
```

```
my_mean(c(1:15, NA))
```

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

Some advice for function writing:

1. Start simple, then extend.
2. Test out each step of the way.
3. Don't try too much at once.

1.4.2 Conditionals

Conditionals are functions that control the flow of analysis. Conditionals determine if a specified condition is met (or not), then direct subsequent analysis or action depending on whether the condition is met (or not).

```
if(condition) {
  # Some code that runs if condition is TRUE
} else {
  # Some code that runs if condition is TRUE
}
```

- `condition` is a length one logical value, i.e. either `TRUE` or `FALSE`
- We can use `&` and `|` to combine several conditions
- `!` negates condition

For example, if we wanted to do something with `na.rm` from our function,

```
if(na.rm) x <- na.omit(x) # na.omit is a function that removes NA values
```

might be a good option.

1.4.3 Loops

Loops (and their cousins the `apply()` function) are useful when we want to repeat the same block of code many times. Reducing the amount of typing we do can be nice, and if we have a lot of code that is essentially the same we can take advantage of looping. `R` offers several loops: for, while, repeat.

For loops will run through a specified index and perform a set of code for each value of the indexing variable.

```
for(i in index values) {
  # block of code
  # can print values also
  # code in here will most likely depend on i
}
```

```
for(i in 1:3) {
  print(i)
}
```

```
## [1] 1
## [1] 2
## [1] 3
```

```
for(species in unique(iris$Species)) {
  subset_iris <- iris[iris$Species == species,]
  avg <- mean(subset_iris$Sepal.Length)
  print(paste(species, avg))
}
```

```
## [1] "setosa 5.006"
## [1] "versicolor 5.936"
```

```
## [1] "virginica 6.588"
```

While loops will run until a specified condition is no longer true.

```
condition <- TRUE
while(condition) {
  # do stuff
  # don't forget to eventually set the condition to false
  # in the toy example below I check if the current seconds is divisible by
        5
  time <- Sys.time()
  if(as.numeric(format(time, format = "%S")) %% 5 == 0) condition <- FALSE
}
print(time)
```

```
## [1] "2019-08-24 09:06:10 MDT"
```

```
# we can also use while loops to iterate
i <- 1
while (i <= 5) {
    print(i)
    i <- i + 1
}
```

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

Your Turn

1. Alter your `my_mean()` function to take a second argument (`na.rm`) with default value `FALSE` that removes `NA` values if `TRUE`.

2. Add checks to your function to make sure the input data is either numeric or logical. If it is logical convert it to numeric.

3. The diamonds data set is included in the `ggplot2` package (not by default in `R`). It can be read into your environment with the following function.

   ```
   data("diamonds", package = "ggplot2")
   ```

   Loop over the columns of the diamonds data set and apply your mean function to all of the numeric columns (Hint: look at the `class()` function).

1.5 Packages

Commonly used `R` functions are installed with base `R`.

`R` packages containing more specialized `R` functions can be installed freely from CRAN servers using function `install.packages()`.

After packages are installed, their functions can be loaded into the current `R` session using the function `library()`.

Packages are contrbuted by `R` users just like you!

We will use some great packages in this class. Feel free to venture out and find your favorites (google R package + what you're trying to do to find more packages).

1.6 Additional resources

You can get help with `R` functions within `R` by using the `help()` function, or typing `?` before a function name.

Stackoverflow can be helpful – if you have a question, maybe somebody else has already asked it (https://stackoverflow.com/questions/tagged/r).

R Reference Card (https://cran.r-project.org/doc/contrib/Short-refcard.pdf)

Useful Cheatsheets (https://www.rstudio.com/resources/cheatsheets/)

R for Data Science (https://r4ds.had.co.nz)

Advanced R (https://adv-r.hadley.nz)