Do you have a github account?
Give us a star! :)

Welcome!

Please download the course material:

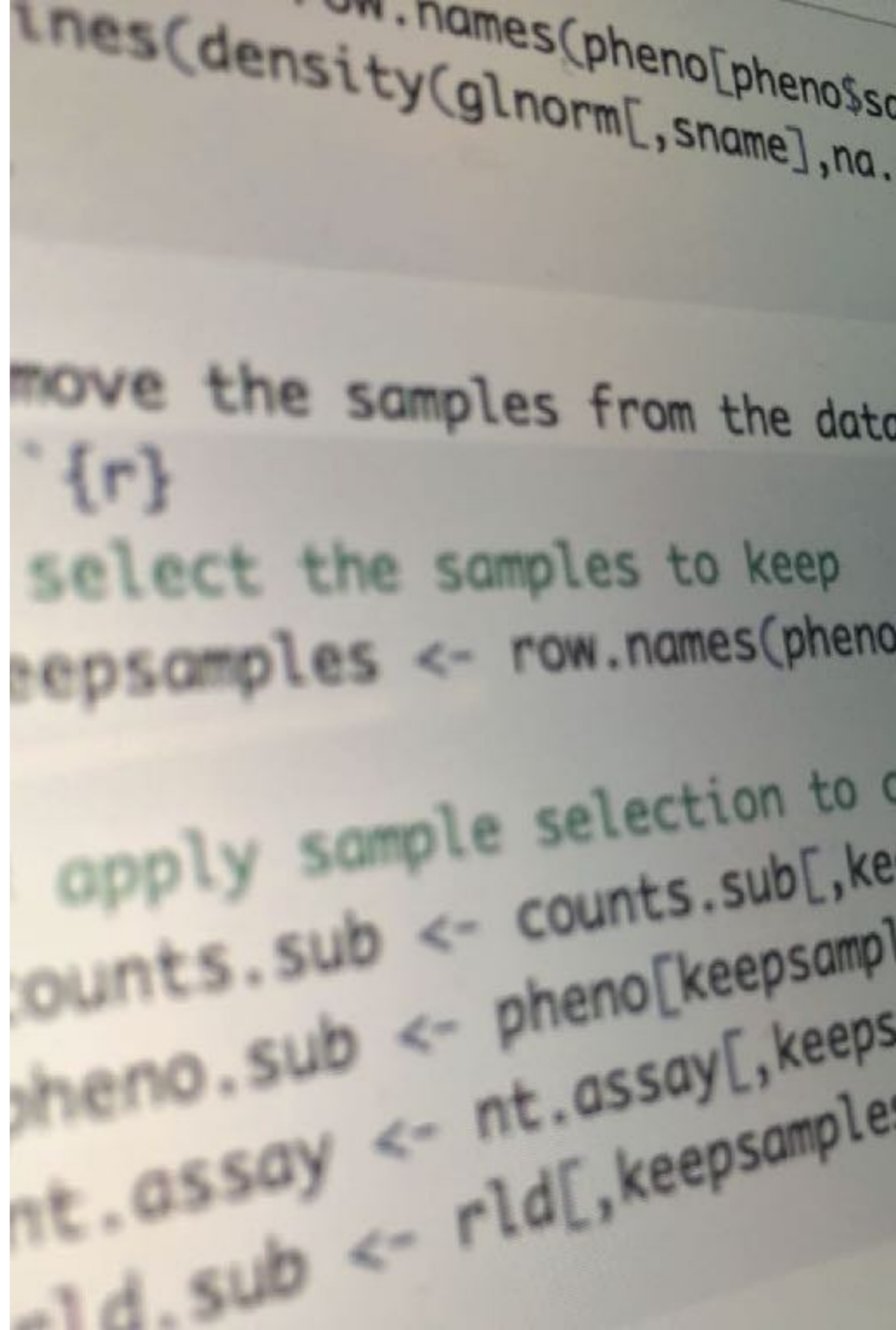
[tinyurl.com/introRData]() > Clone or download > Download ZIP

and store it in a single, accessible folder on your computer.

Introduction to R & data

Outline

- Part I: Basics of R
- Lunch (~12:15)
- Part II: Modern R with tidyverse
- Final remarks (~17:00)



Quick intro: this is us! And who are you?

Jonathan de Bruin
research data engineer @ ITS
j.debruin1@uu.nl

Barbara Vreede
subject specialist Science @ UU Library
b.m.i.vreede@uu.nl

Introduction to R & data

Part 1: Basics of R

What is R?

- Widely used programming language for data analysis
- Based on statistical programming language **S** (1976)
- Developed by **R**oss Ihaka & **R**obert Gentleman (1995)
- Very active community, with many (often subject-specific) packages

We will work in RStudio

- Integrated Development Environment for R
- Founded by JJ Allaire, available since 2010
- Bloody useful! Let’s take a look: please open RStudio!

Have you downloaded the course material?

tinyurl.com/introRData > 

> 

Please store it in a single, accessible folder on your computer.

R syntax & the RStudio console

Variable assignment

>

Variable assignment

```
> x <- 1
```

Variable assignment

```
> x <- 1

> 1 -> x

> x = 1

> 1 = x
Error in 1 = x : invalid (do_set) left-hand side to assignment
```

Variable assignment

```
> x <- 6

> hi <- "hello world"

> x * 3
[1] 18

> y <- x + 2

> log2(y)
[1] 3
```

Base R
Cheat Sheet

Maths Functions

`log(x)`	Natural log.	`sum(x)`	Sum.
`exp(x)`	Exponential.	`mean(x)`	Mean.
`max(x)`	Largest element.	`median(x)`	Median.
`min(x)`	Smallest element.	`quantile(x)`	Percentage quantiles.
`round(x, n)`	Round to n decimal places.	`rank(x)`	Rank of elements.
`signif(x, n)`	Round to n significant figures.	`var(x)`	The variance.
`cor(x, y)`	Correlation.	`sd(x)`	The standard deviation.

Variable Assignment

```
> a <- 'apple'
> a
[1] 'apple'
```

A quick note on notes

- The console is for execution, not for storage
- Everything we do is on the slides!
- BUT: you can store, if you want, by copy-pasting to a text document
- Do you want to write notes in between?

```
> # write your notes in the console like this
> # using a #hash sign.
> # pressing enter will do nothing.
> # go ahead and try!
```

Creating vectors

```
> 1:5
[1] 1   2   3   4   5
> seq(5)
[1] 1   2   3   4   5
> seq(2,4,by=0.5)
[1]  2.0  2.5  3.0  3.5  4.0
> rep(4,6)
[1] 4 4 4 4 4 4
> c(1,61,101)
[1] 1 61 101
> c(2:4,rep(8,3))
[1] 2 3 4 8 8 8
```

an integer

vs.

a float, or ‘floating point’

Vector functions

```
> p <- 1:5
> mean(p)
[1] 3
> p * 2
[1] 2 4 6 8 10
> q <- 5:1
> p * q
[1] 5 8 9 8 5
> table(p*q)
5 8 9
2 2 1
```

p * 2

p	2	
1	2	2
2	2	4
3	2	6
4	2	8
5	2	10

p * q

p	q	
1	5	5
2	4	8
3	3	9
4	2	8
5	1	5

Exercise

1. Write a line of code that produces the following vector:

(Note: there are multiple possible answers!)

```
[1]  4 4 4 10 15 20 10 7 4
```

2. Divide the vector by 3. Round up to 1 decimal.

(Hint: check the cheat sheet element ‘Maths Functions’.)

Exercise

1. Write a line of code that produces the following vector:

(Note: there are multiple possible answers!)

```
> c(rep(4,3),seq(10,20,by=5),seq(10,4,by=-3))
[1]  4  4  4 10 15 20 10  7  4
```

2. Divide the vector by 3. Round up to 1 decimal.

(Hint: check the cheat sheet element ‘Maths Functions’.)

```
> v <- c(rep(4,3),seq(10,20,by=5),seq(10,4,by=-3))
> round(v/3,1)
[1] 1.3 1.3 1.3 3.3 5.0 6.7 3.3 2.3 1.3
```

Another data type: logical

```
> T
[1] TRUE
> FALSE
[1] FALSE
> 1==1
[1] TRUE
> 3>=5
[1] FALSE
> 2!=4
[1] TRUE
```

==	is equal to
!=	is not
>=	larger than or equal to
<	smaller than

Vectors and factors

```
> fc <- c("a","b","a","c")
> fc
[1] "a" "b" "a" "c"
> fc <- factor(fc)
> fc
[1] a b a c
Levels: a b c
> fn <- 2:5
> fn
[1] 2 3 4 5
> fn <- factor(fn)
> fn
[1] 2 3 4 5
Levels: 2 3 4 5
> as.numeric(fn)
[1] 1 2 3 4
```

Note that vectors may consist of characters!

A factor is defined by its levels. Turning a factor into numeric specifies the order of the levels, but loses their content.

Exercise

1. Generate a vector that contains numeric, logical, and character elements.

2. Turn it into a factor.

3. See what happens to the content when you convert this factor into numeric, logical, and character vectors.

(Hint: check the cheat sheet element ‘Types’ for the functions.)

Exercise

1. Generate a vector that contains numeric, logical, and character elements.

```
> ft <- c(T,T,2,4,"apple","orange")
```

2. Turn it into a factor.

```
> ft <- factor(ft)
```

3. See what happens to the content when you convert this factor into numeric, logical, and character vectors.

(Hint: check the cheat sheet element 'Types' for the functions.)

```
> as.numeric(ft)
[1] 5 5 1 2 3 4
> as.logical(ft)
[1] TRUE TRUE   NA   NA   NA   NA
> as.character(ft)
[1] "TRUE"   "TRUE"   "2"      "4"      "apple"  "orange"
```

But what if there *is no data?* Introducing: NA

```
> ft <- c(T,T,2,4,"apple","orange")
> ft <- as.logical(ft)
> ft
[1] TRUE TRUE   NA   NA   NA   NA
> factor(ft)
[1] TRUE TRUE <NA> <NA> <NA> <NA>
Levels: TRUE
```

NA = **N**ot **A**vailable

Name	Age	Pet
Ann	33	Cat
Bob	25	**None**
Chloe	21	Iguana
Dan	45	**NA**

In other words:

We **know** that Bob has **no pets**.

We **do not know** if Dan has pets.

Exercise: predict the answer

```
> NA == NA
```

Predict the results. Does the (real) answer make sense to you?

Exercise: predict the answer

```
> NA == NA
[1] NA
```

Predict the results. Does the (real) answer make sense to you?

NA != NULL

```
> is.na(NA)
[1] TRUE

> is.null(NULL)
[1] TRUE
```

`NA` Information is **Not Available**

`NULL` Information **does not exist**

`"None"` Data entry specifying **"None"**

Exercise: predict the answer

```
> is.na(NA)
[1] TRUE

> is.null(NULL)
[1] TRUE
```

Predict the results. Does the (real) answer make sense to you?

```
> is.null(NA)

> is.na(NULL)
```

Exercise: try to predict the results!

```
> is.na(NA)
[1] TRUE

> is.null(NULL)
[1] TRUE
```

Predict the results. Does the (real) answer make sense to you?

```
> is.null(NA)
[1] FALSE
> is.na(NULL)
```

Exercise: try to predict the results!

```
> is.na(NA)
[1] TRUE

> is.null(NULL)
[1] TRUE
```

Predict the results. Does the (real) answer make sense to you?

```
> is.null(NA)
[1] FALSE
> is.na(NULL)
[1] logical(0)
```

Selecting vector elements by position

```
> m <- 8:4
> m
[1] 8 7 6 5 4
> m[2]
[1] 7
> m[1:3]
[1] 8 7 6
> m[-(2:4)]
[1] 8 4
```

Selecting vector elements by value

```
> m <- 8:4
> m
[1] 8 7 6 5 4
> m[m>5]
[1] 8 7 6
> m>5
[1] TRUE TRUE TRUE FALSE FALSE
> n <- 5:10
> m[m %in% n]
[1] 8 7 6 5
> m[NA]
[1] NA NA NA NA NA
```

m	m>5	result
8	TRUE	8
7	TRUE	7
6	TRUE	6
5	FALSE	
4	FALSE	

Which bracket does what?

[ ] **Indexing** vectors, lists, dataframes…

( ) Passing **arguments** to functions

{ } **Defining content** of loops, functions, etc.

```
> myvector[length(myvector)]
```

Vectors, lists, and data frames

```
> v1 <- 4:6
> v2 <- rep(3,3)

> c(v1,v2)
[1] 4 5 6 3 3 3

> list(v1,v2)
[[1]]
[1] 4 5 6

[[2]]
[1] 3 3 3

> data.frame(v1,v2)
  v1 v2
1  4  3
2  5  3
3  6  3
```

	how many dimensions?	function
vector	1	`c()`
list	any number	`list()`
data frame	2	`data.frame()`

Indexing lists

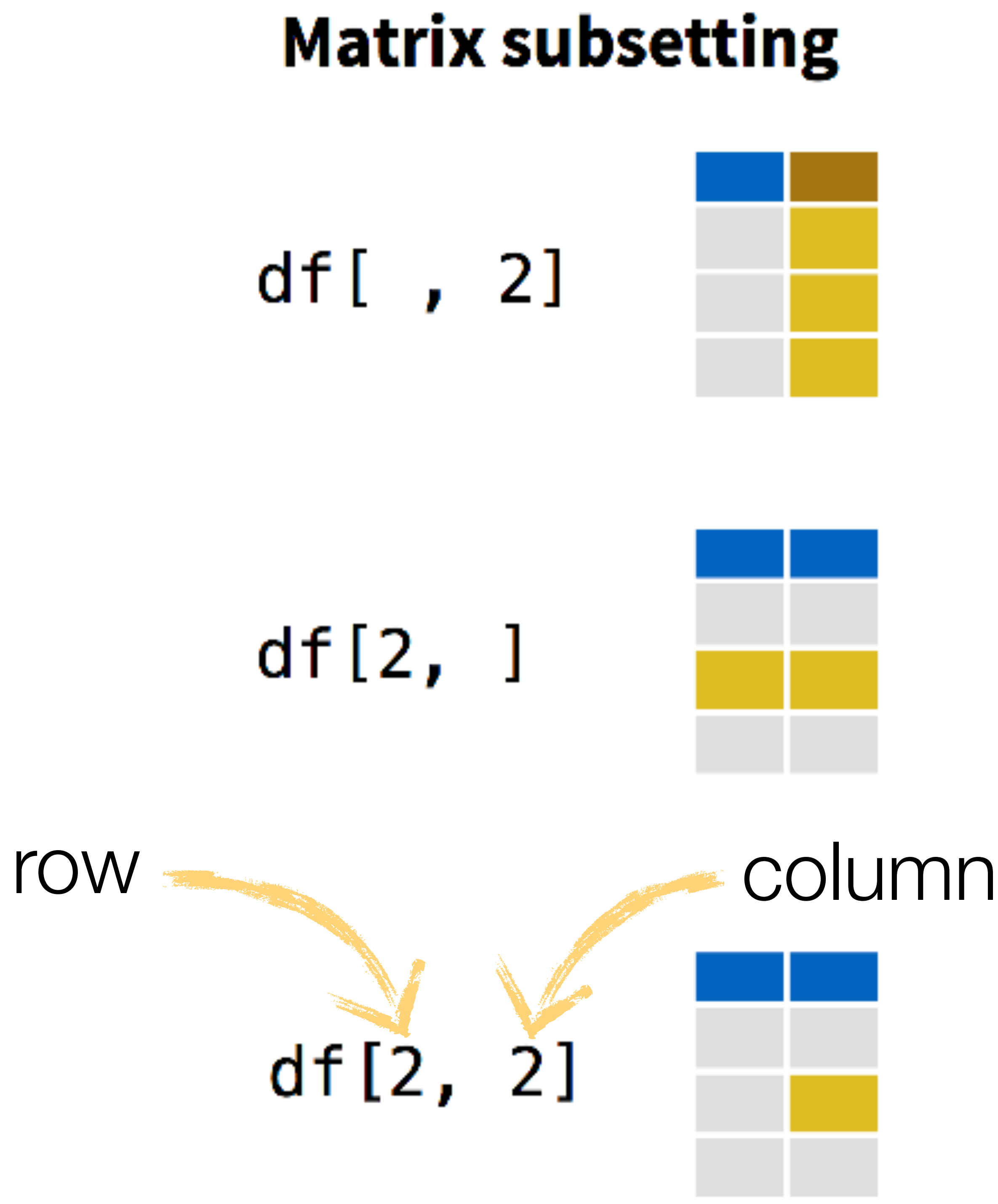
```
> v1 <- 4:6
> v2 <- rep(3,3)
> mylist <- list(v1,v2)
> mylist[1]
[[1]]
[1] 4 5 6
> mylist[[1]]
[1] 4 5 6
> mylist[[1]][2]
[1] 5
> mylist[1][2]
[[1]]
NULL
```

Indexing a data frame

```
> name <- c("Ann","Bob","Chloe","Dan")
> age <- c(33,25,21,45)
> df <- data.frame(name,age)
> df
   name  age
1   Ann   33
2   Bob   25
3 Chloe   21
4   Dan   45
```

Indexing a data frame

```
> df$age
[1] 33 25 21 45
> df[,2]
[1] 33 25 21 45
> df[2,]
  name age
2  Bob  25
> df[2,2]
[1] 25
```



Exercise

Return the names of everyone in your data frame under 30. Make good use of vectors as part of your index!

Hint: this is how you extract a column from a dataframe: `df$column_name`

Exercise

Return the names of everyone in your data frame under 30. Make good use of vectors as part of your index!

Hint: this is how you extract a column from a dataframe: `df$column_name`

```
> df[df$age<30,"name"]
```

OR

```
> df[df$age<30,1]
[1] Bob   Chloe
Levels: Ann Bob Chloe Dan
```

Question: what is the data type of your result?

Let’s breathe and recap!

What data types have you encountered so far?

`logical`
`numeric`
`integer`
`character`
`factor`

And what data collections have you encountered?

`vector` (one dimension)
`data frame` (two dimensions)
`list` (++ dimensions)

Functions

What functions have you encountered so far?

```
> c()
> rep()
> round()
> as.logical()
> is.na()
> table()
...
```

And do you still know what they mean? And how to use them? **No?**

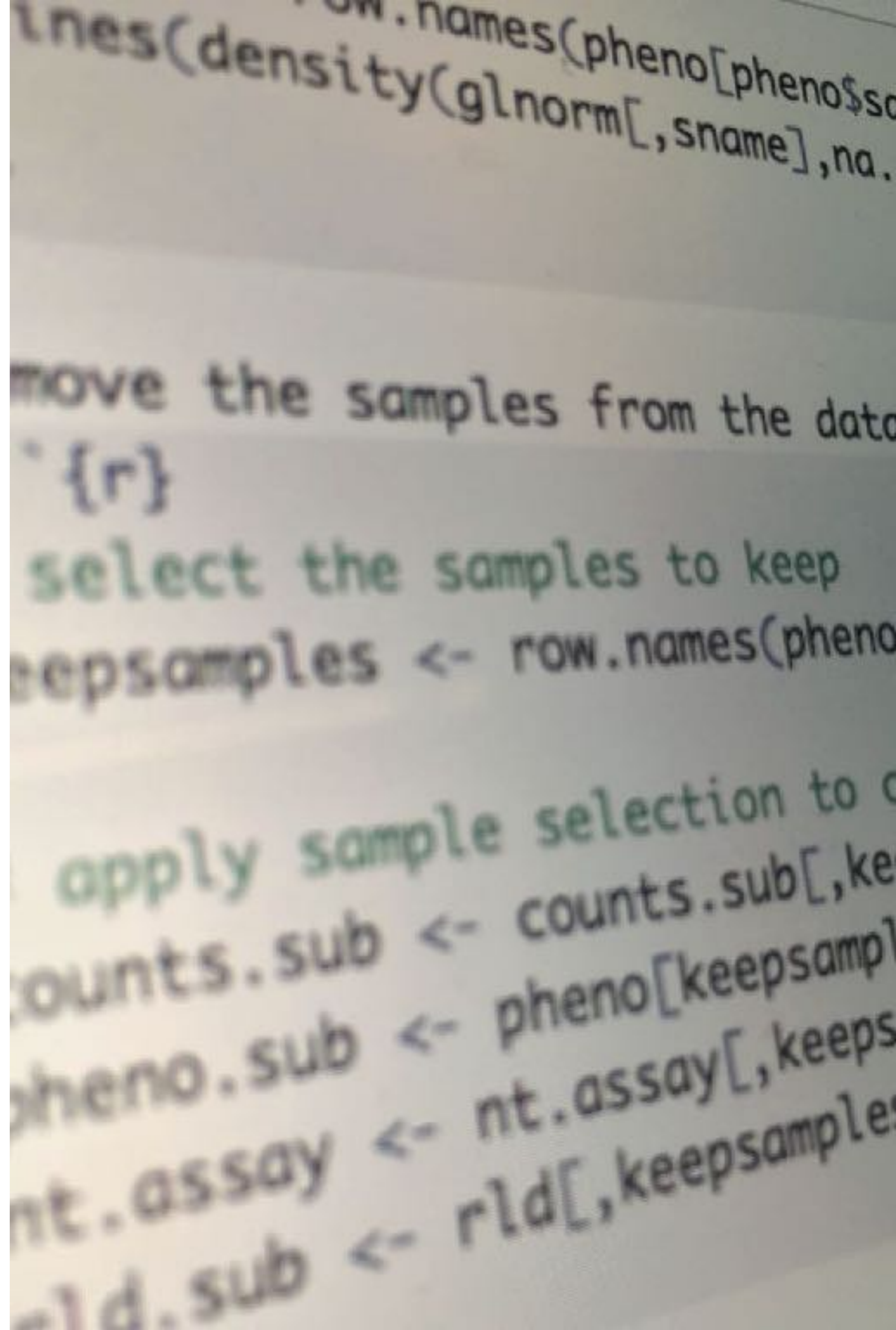
```
> ?table()
> help.search("standard deviation")
```

(or use the Help window to the right of your console)

Take a break!

Ready?

- Writing your first script
- Programming with loops and functions
- Handling and processing a dataset

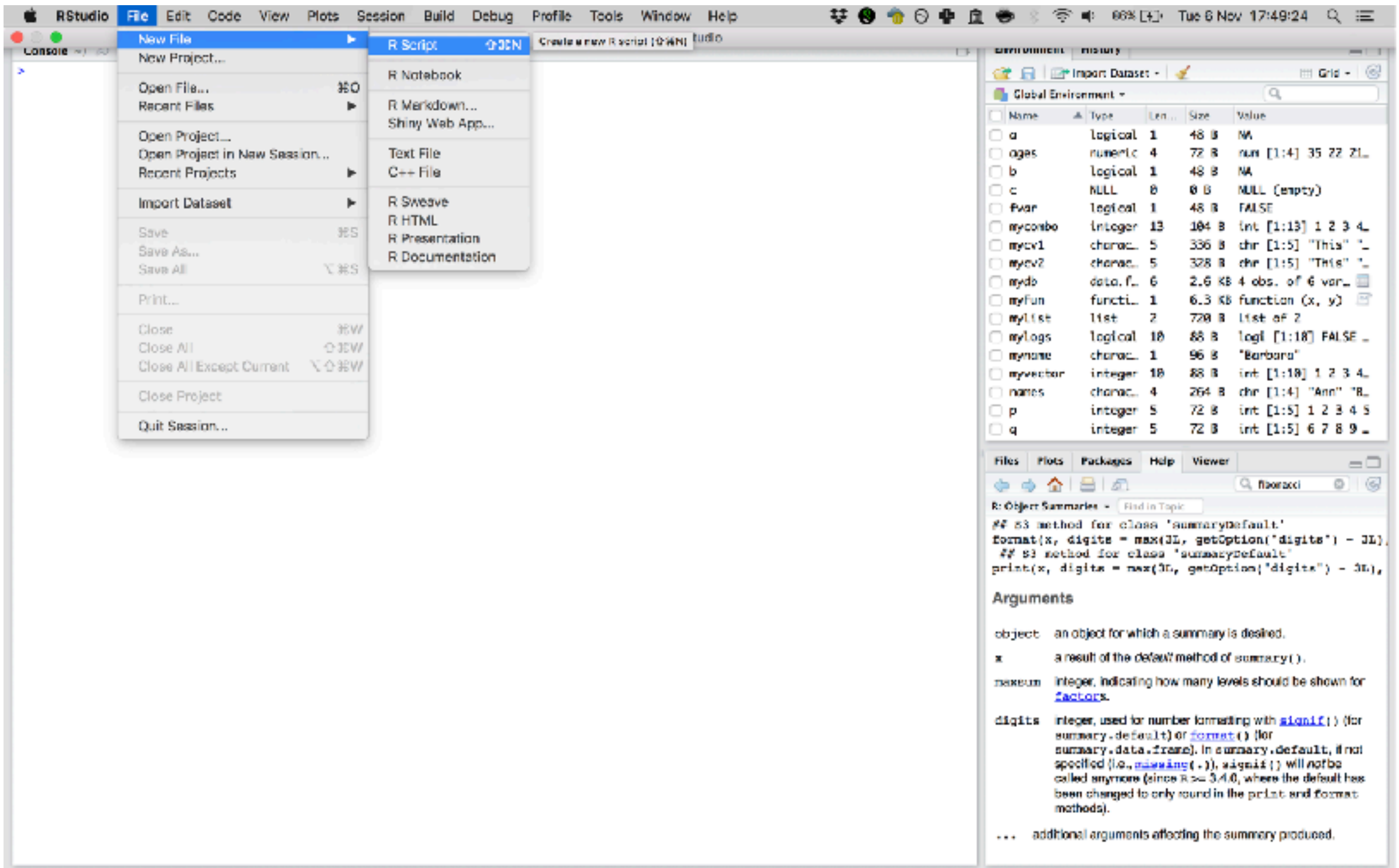


Console and Scripts

Console	Code execution	-
Script	Code	Extension: .R (example_script.R)
Rmarkdown	Code + Narrative	Extension: .Rmd (example_report.Rmd)

Ready to script?

RStudio > File > New File > R Script



Console vs script on our slides

writing in the console

```
> x <- 1
> x
[1] 1
```

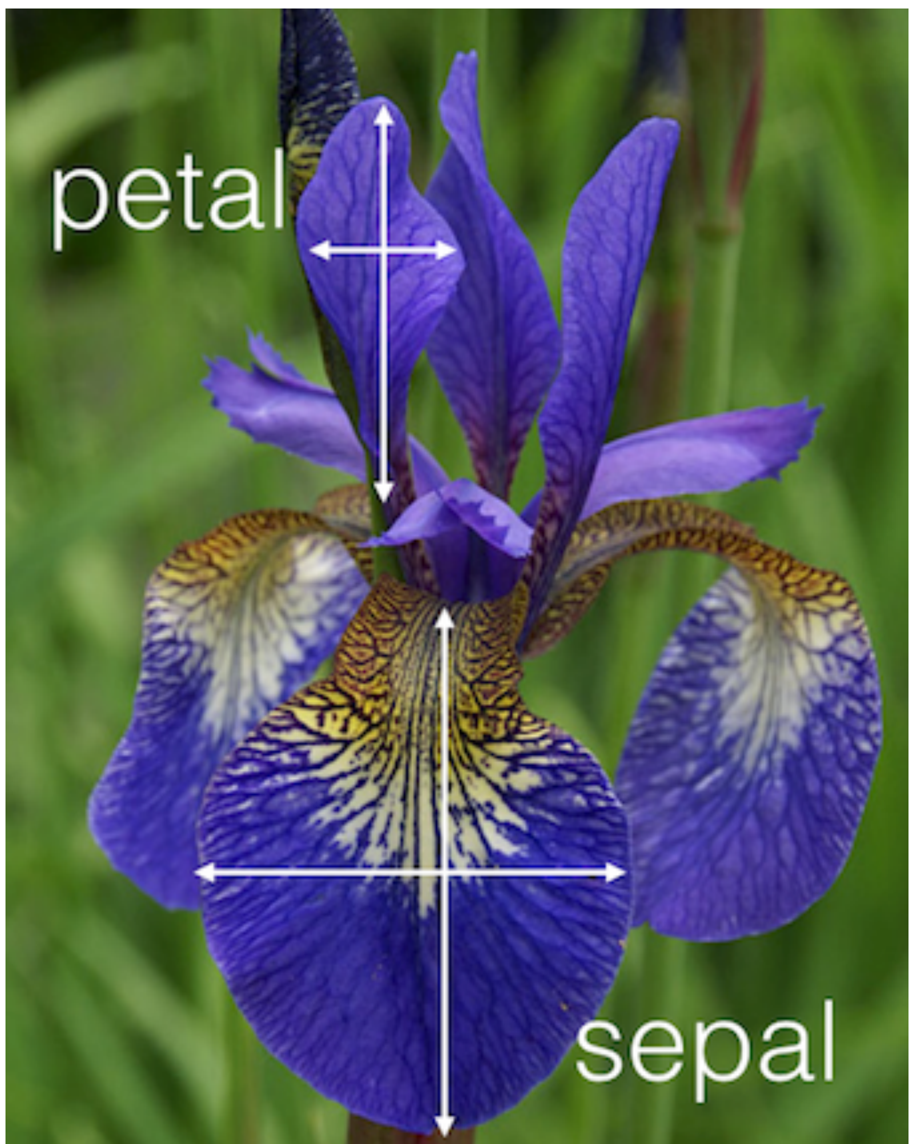
console output

 # indicates comment
computer stops reading
(but you should not!)

```
# Assigning the value 1 to x
x <- 1
```

Introducing a sample dataset

- Dataset: ‘iris’
- Standard dataset in R, measurements on 3 species of iris flowers



Introducing a sample dataset

- Dataset: ‘iris’
- Standard dataset in R, measurements on 3 species of iris flowers

```
> 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
> summary(iris)
  Sepal.Length    Sepal.Width     Petal.Length    Petal.Width          Species
 Min.   :4.300   Min.   :2.000   Min.   :1.000   Min.   :0.100   setosa    :50
 1st Qu.:5.100   1st Qu.:2.800   1st Qu.:1.600   1st Qu.:0.300   versicolor:50
 Median :5.800   Median :3.000   Median :4.350   Median :1.300   virginica :50
 Mean   :5.843   Mean   :3.057   Mean   :3.758   Mean   :1.199
 3rd Qu.:6.400   3rd Qu.:3.300   3rd Qu.:5.100   3rd Qu.:1.800
 Max.   :7.900   Max.   :4.400   Max.   :6.900   Max.   :2.500
```

Programming: for loop

```
# Iterate over 10 values
for(i in 1:10){
  print(i)
}
```

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

Calculating averages: preparation

```
# what measurements exist in the iris db?
measure <- colnames(iris)

> measure
[1] "Sepal.Length" "Sepal.Width"  "Petal.Length" "Petal.Width" "Species"

# remove "Species" from the list of names
measure <- measure[measure!="Species"]

# make a df with a single column: measurements
iris_res <- data.frame(measure)

# initiate a vector for averages
avgs <- NULL
```

Calculating averages in a for loop

```
# iterate over each measurement with a for-loop
for(m in measure){






}
```

Calculating averages in a for loop

```
# iterate over each measurement with a for-loop
for(m in measure){
  # select the appropriate column

  # calculate the average for this column

  # put the average in the averages vector

}
```

Calculating averages in a for loop

```
# iterate over each measurement with a for-loop
for(m in measure){
  # select the appropriate column
  column <- iris[,m]
  # calculate the average for this column

  # put the average in the averages vector

}
```

Calculating averages in a for loop

```
# iterate over each measurement with a for-loop
for(m in measure){
  # select the appropriate column
  column <- iris[,m]
  # calculate the average for this column
  avg <- mean(column)
  # put the average in the averages vector

}
```

Calculating averages in a for loop

```
# iterate over each measurement with a for-loop
for(m in measure){
  # select the appropriate column
  column <- iris[,m]
  # calculate the average for this column
  avg <- mean(column)
  # put the average in the averages vector
  avgs <- c(avgs,avg)
}

> avgs
[1] 5.843333 3.057333 3.758000 1.199333
```

Calculating averages in a for loop

```
# add the averages as a column to the data frame
iris_res$average <- avgs

> iris_res
           measure  average
1 Sepal.Length 5.843333
2  Sepal.Width 3.057333
3 Petal.Length 3.758000
4  Petal.Width 1.199333
```

Programming: functions

```
myFun <- function(x){
  return(x)
}
```

```
> myFun(1)
[1] 1
```

Programming: functions

```
myFun2 <- function(x){
  x <- x*20
  return(x)
}

> myFun2(1)
[1] 20
```

Programming: functions

```
myFun3 <- function(x,y){
  z <- x*y
  return(z)
}

> myFun3(2,4)
[1] 8
```

Exercise: combine functions and for loops

- Open the script **programming_exercise.R**
- You will see the for-loop (including comments) as we have just written
- You will then see the start of a function:

```
average_df <- function(df){
  measure <- colnames(df)
  measure <- measure[measure!="Species"]
  avgs <- NULL
  ### ENTER YOUR OWN CODE ###
  return(avgs)
}
```

- **Exercise**: place the for-loop in the function, and edit as necessary, so that the function now generates a list of averages.
- **TIP**: within the function, `iris` is renamed `df`!

Exercise: combine functions and for loops

```
average_df <- function(df){
  # determine measurement names and remove species
  measure <- colnames(df)
  measure <- measure[measure!="Species"]
  # initialize the vector
  avgs <- NULL
  # iterate over each measurement with a for-loop
  for(m in measure){
    # select the appropriate column
    column <- df[,m]
    # calculate the average
    avg <- mean(column)
    # put the average in the averages vector
    avgs <- c(avgs,avg)
  }
  # return the averages as a column
  return(avgs)
}
# apply the function: add the averages as a column to the data frame
iris_res$average <- average_df(iris)
```

Programming: if statement

```
if(4>5){
   print("math has changed!")
} else{
   print("all is well.")
}
```

Programming: if statement

```
if(4>5){
   print("math has changed!")
} else if(5>6){
   print("this is not good either!")
} else{
   print("all is well.")
}
```

Exercise: add an if-statement to your function

- We want to build on our **`average_df`** function so it can do more calculations!
- To do this, we add a second argument, and include an if statement.
- First, copy-paste your function, and give it a new name. Consider changing some variable names, too (and make sure to change them all!).

```
stats_df <- function(df){
  measure <- colnames(df)
  measure <- measure[measure!="Species"]
  results <- NULL
    for(m in measure){
    column <- df[,m]
    results <- mean(column)
    results <- c(results,res)
  }
  return(results)
}
```

Exercise: add an if-statement to your function

- Our function can calculate averages. We might want to add standard deviations (**`sd()`**), maximums (**`max()`**), and minimums (**`min()`**).
- Which line in the function do we need to expand on, to allow this?
- What additional information do we need?

```
stats_df <- function(df){
  measure <- colnames(df)
  measure <- measure[measure!="Species"]
  results <- NULL
    for(m in measure){
    column <- df[,m]
    results <- mean(column)
    results <- c(results,res)
  }
  return(results)
}
```

Exercise: add an if-statement to your function

```
stats_df <- function(df,fnx){
  measure <- colnames(df)
  measure <- measure[measure!="Species"]
  results <- NULL
    for(m in measure){
    column <- df[,m]
    # perform different functions based on the input
    if(fnx=="mean"){
       res <- mean(column)
    } else{
       stop("no valid input received")
    }
    results <- c(results,res)
  }
  return(res)
}
```

Exercise: add an if-statement to your function

1. Add the if-statement below to your function! (Do you understand how it works?)

```
if(fnx=="mean"){
   res <- mean(column)
} else{
   stop("no valid input received")
}
```

2. Elaborate on the statement using `else if`, adding alternative functions. Consider standard deviation (`sd()`), maximum (`max()`), and minimum (`min()`).

3. Finally, call your new function to add columns to your `iris_res` dataframe!

Exercise: add an if-statement to your function

```
stats_df <- function(df,fnx){
  measure <- colnames(df)
  measure <- measure[measure!="Species"]
  results <- NULL
    for(m in measure){
    column <- df[,m]
    if(fnx=="mean"){
       res <- mean(column)
    } else if(fnx=="sd"){
       res <- sd(column)
    } else{
       stop("no valid input received")
    }
    results <- c(res,res)
  }
  return(res)
}

iris_res$standarddev <- stats_df(iris,"sd")
```

Your result: a summary data frame

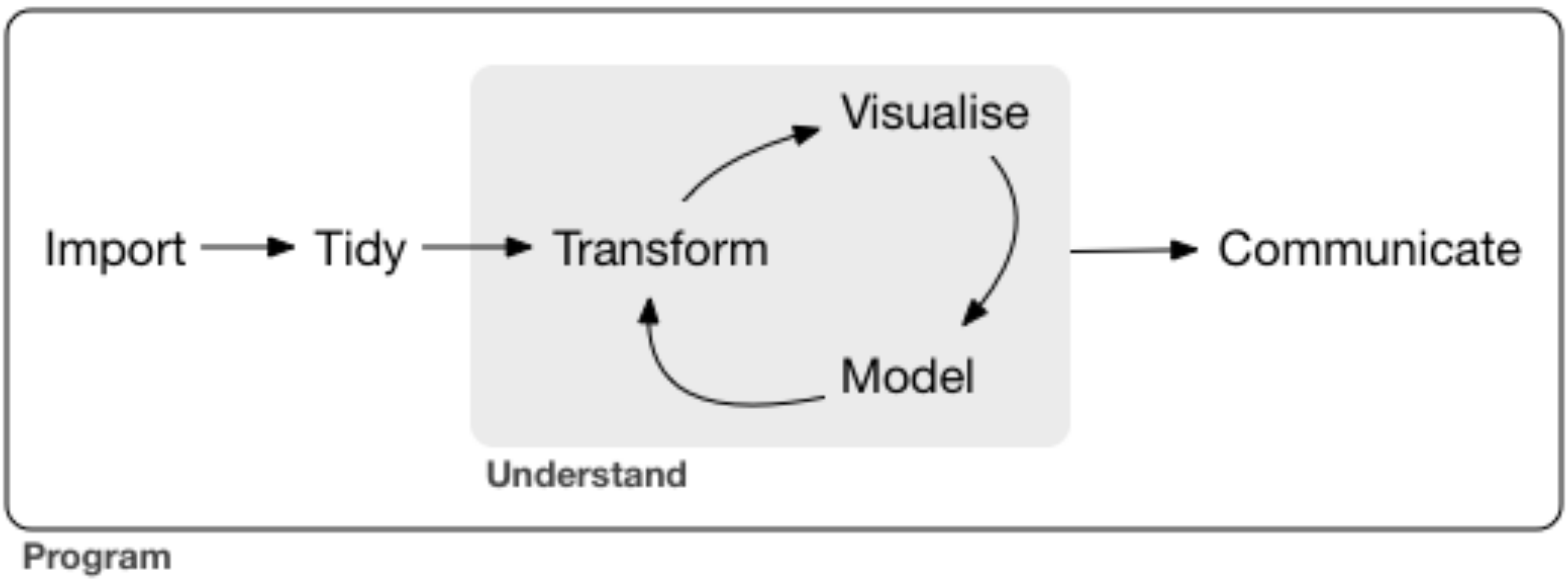
```
iris_res$standarddev <- stats_df(iris,"sd")
iris_res$largest <- stats_df(iris,"max")
iris_res$smallest <- stats_df(iris,"min")

> iris_res
       measure  average standarddev largest smallest
1 Sepal.Length 5.843333   0.8280661     7.9      4.3
2  Sepal.Width 3.057333   0.4358663     4.4      2.0
3 Petal.Length 3.758000   1.7652982     6.9      1.0
4  Petal.Width 1.199333   0.7622377     2.5      0.1

> summary(iris)
  Sepal.Length    Sepal.Width     Petal.Length    Petal.Width          Spe
 Min.   :4.300   Min.   :2.000   Min.   :1.000   Min.   :0.100   setosa
 1st Qu.:5.100   1st Qu.:2.800   1st Qu.:1.600   1st Qu.:0.300   versicolo
 Median :5.800   Median :3.000   Median :4.350   Median :1.300   virginica
 Mean   :5.843   Mean   :3.057   Mean   :3.758   Mean   :1.199
 3rd Qu.:6.400   3rd Qu.:3.300   3rd Qu.:5.100   3rd Qu.:1.800
 Max.   :7.900   Max.   :4.400   Max.   :6.900   Max.   :2.500
```

Data science workflow: scripting is crucial

- Scripting combines commands to a comprehensive set of instructions.
- A script is code that can be saved, reused, shared, published!
- In short: a crucial step towards reproducible data analysis.



a single script for a single purpose!

Starting the script: write a header

```
## Date: 7 November 2018
## Author: Barbara Vreede
## This script was written as part of the R course
## "Introduction to R & Data", at Utrecht University
```

Load packages and dependencies

```r
## Date: 7 November 2018
## Author: Barbara Vreede
## This script was written as part of the R course
## "Introduction to R & Data", at Utrecht University

# Load required packages
library(dplyr)
library(tidyr)
library(ggplot2)
```

Custom functions

```
## Date: 7 November 2018
## Author: Barbara Vreede
## This script was written as part of the R course
## "Introduction to R & Data", at Utrecht University

# Load required packages
library(dplyr)
library(tidyr)
library(ggplot2)

# Functions
myFun <- function(var){
  var <- var*2*pi
  return(var)
}
```

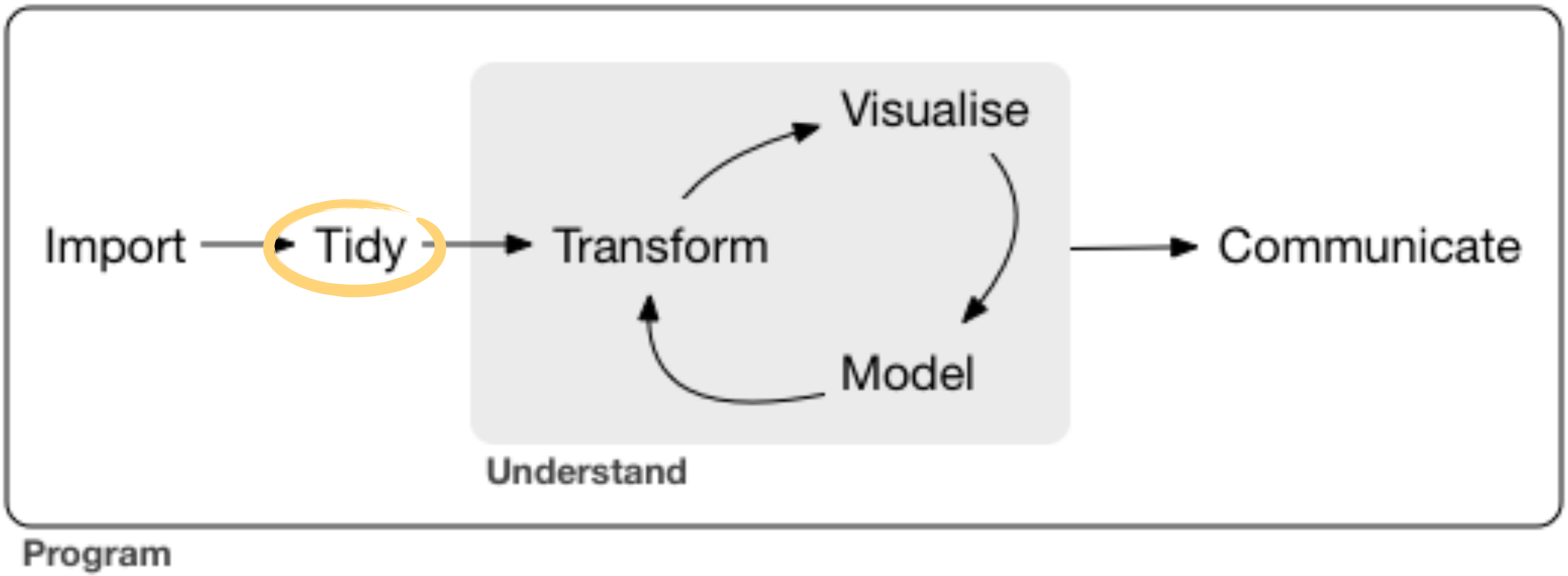
Starting your script: header, packages, functions

```r
## Date: 7 November 2018
## Author: Barbara Vreede
## This script was written as part of the R course
## "Introduction to R & Data", at Utrecht University
```

```r
# Load required packages
library(dplyr)
library(tidyr)
library(ggplot2)
```

```r
# Functions
myFun <- function(var){
  var <- var*2*pi
  return(var)
}
```

Data science workflow



Tidy data ensuresultsthat further processing can be done efficiently, and reproducibly.

Tidy data is easy to manipulate, model, and visualize.

Tidy data

- Each **variable** is a column and contains **values**
- Each **observation** is a row
- Each type of **observational unit** forms a table

values in column names

Patient	BP	Med_A	BP_after_A	Med_B	BP_after_B
122030	120_82	300	119_85	NA	NA
122021	131_91	200	132_85	85	125_90
124500	118_86	300	119_70	NA	NA
126098	99_67			100	110_71

multiple data points in a single cell

Tidy data

ID no longer unique per row
(but can still be used to collect all info on single patient)

Patient	Systolic	Asystolic	Treatment
122030	120	82	None
122030	119	85	A
122021	131	91	None
122021	132	85	A
122021	119	70	B
124500	118	86	None
124500	119	70	A
126098	99	67	None
126098	110	71	B

Time series (order) **lost**
(so make sure this is explicit)

To check before lunch: please load tidyverse

```
> library(tidyverse)
── Attaching packages ─────────────────────── tidyverse 1.2.1 ──
✔ ggplot2 3.1.0     ✔ purrr   0.3.0
✔ tibble  2.0.1     ✔ dplyr   0.7.8
✔ tidyr   0.8.2     ✔ stringr 1.4.0
✔ readr   1.3.1     ✔ forcats 0.3.0
── Conflicts ────────────────────────── tidyverse_conflicts() ──
✖ dplyr::filter() masks stats::filter()
✖ dplyr::lag()    masks stats::lag()
```

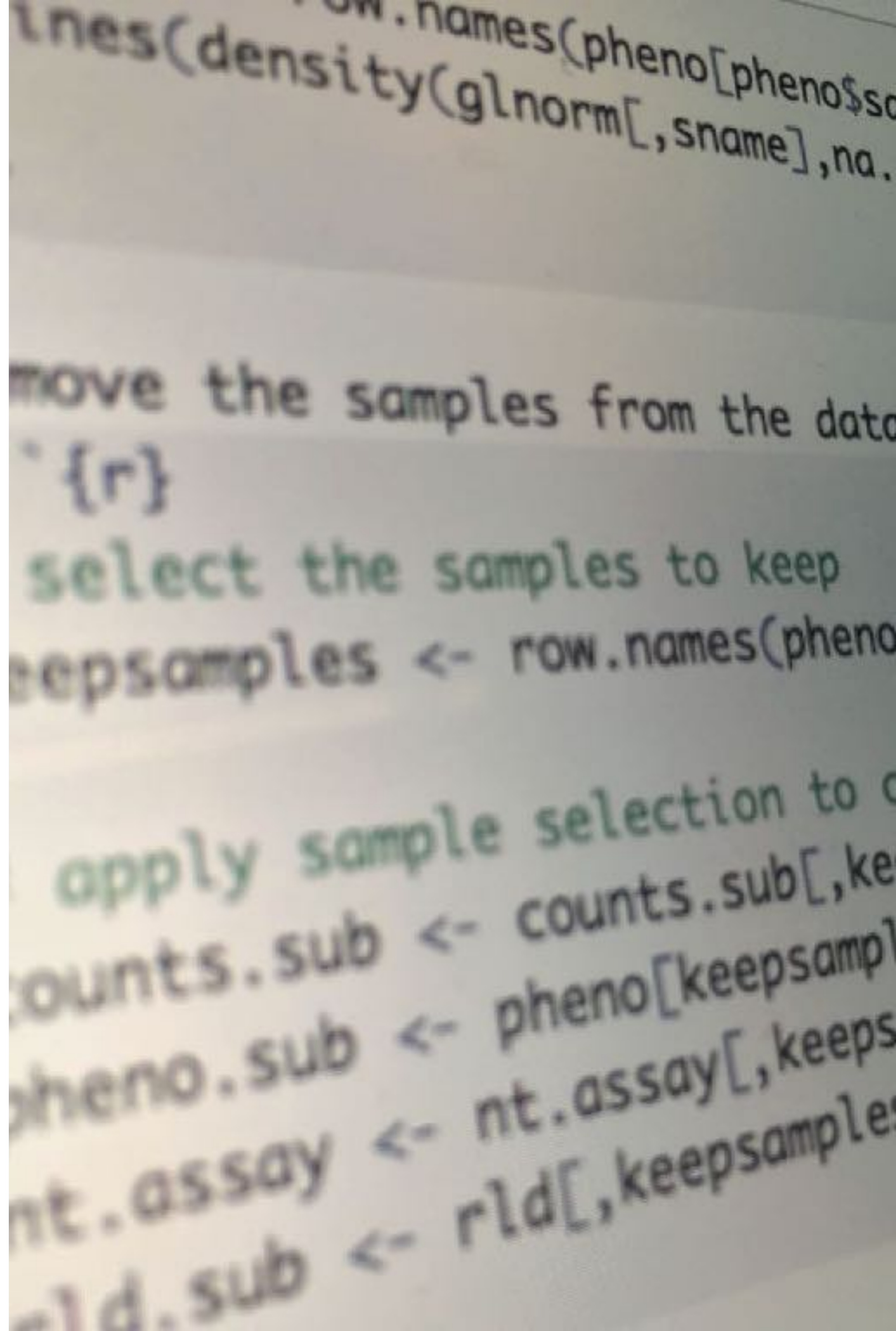
Enjoy your lunch!

Introduction to R & data

Part II: Modern R with tidyverse

Outline part II

- Introduction to **tidyverse**, **rmarkdown**, and **tibble**.
- Load and save data with **readr**
- [break]
- Data visualisation with **ggplot**
- [break]
- Data transformation with **tidyr** and **dplyr**



Tidyverse

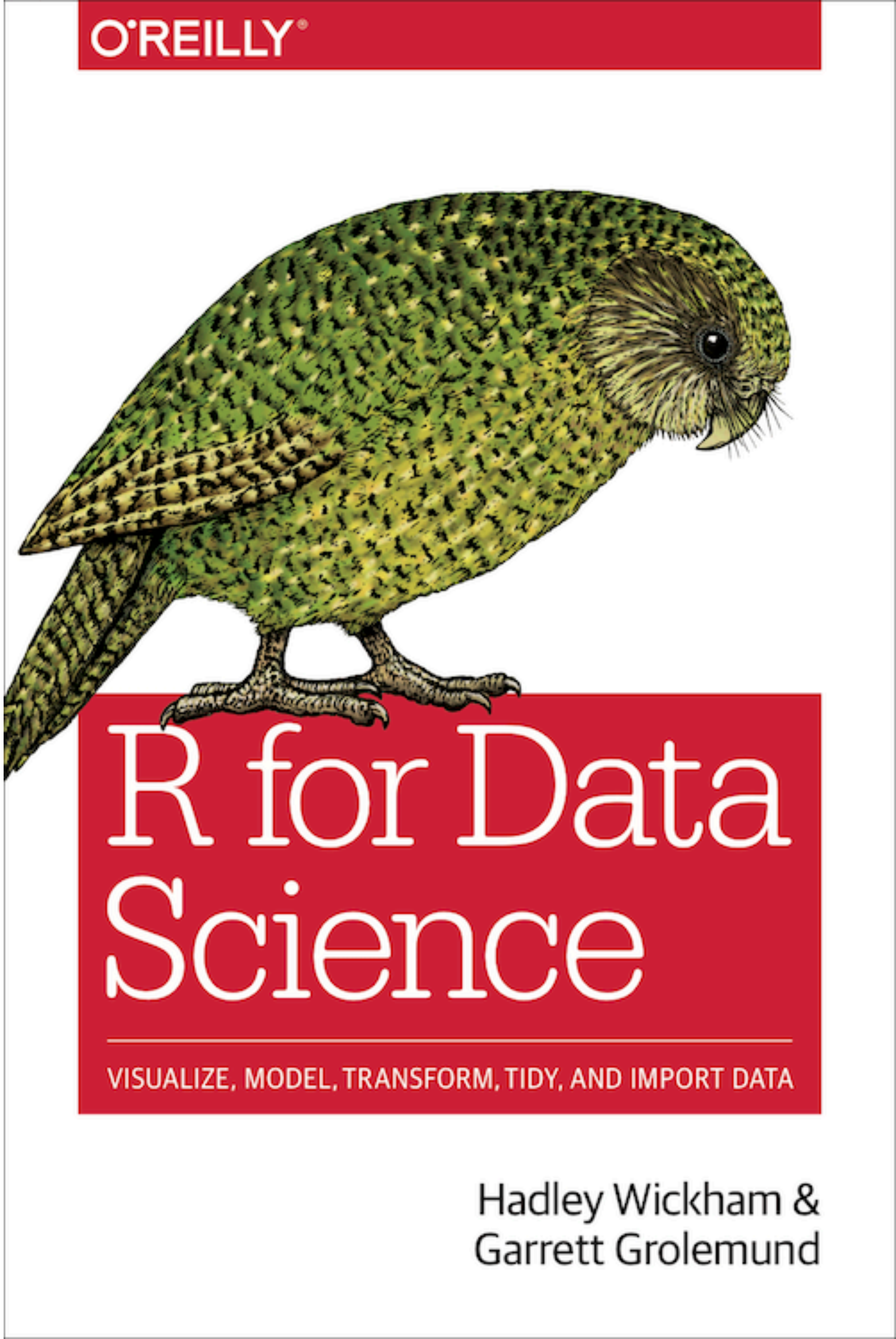
Modern R for data science

"The tidyverse is an opinionated collection of R packages designed for data science. All packages share an underlying design philosophy, grammar, and data structures."

– tidyverse.org (2018)

Learn tidyverse

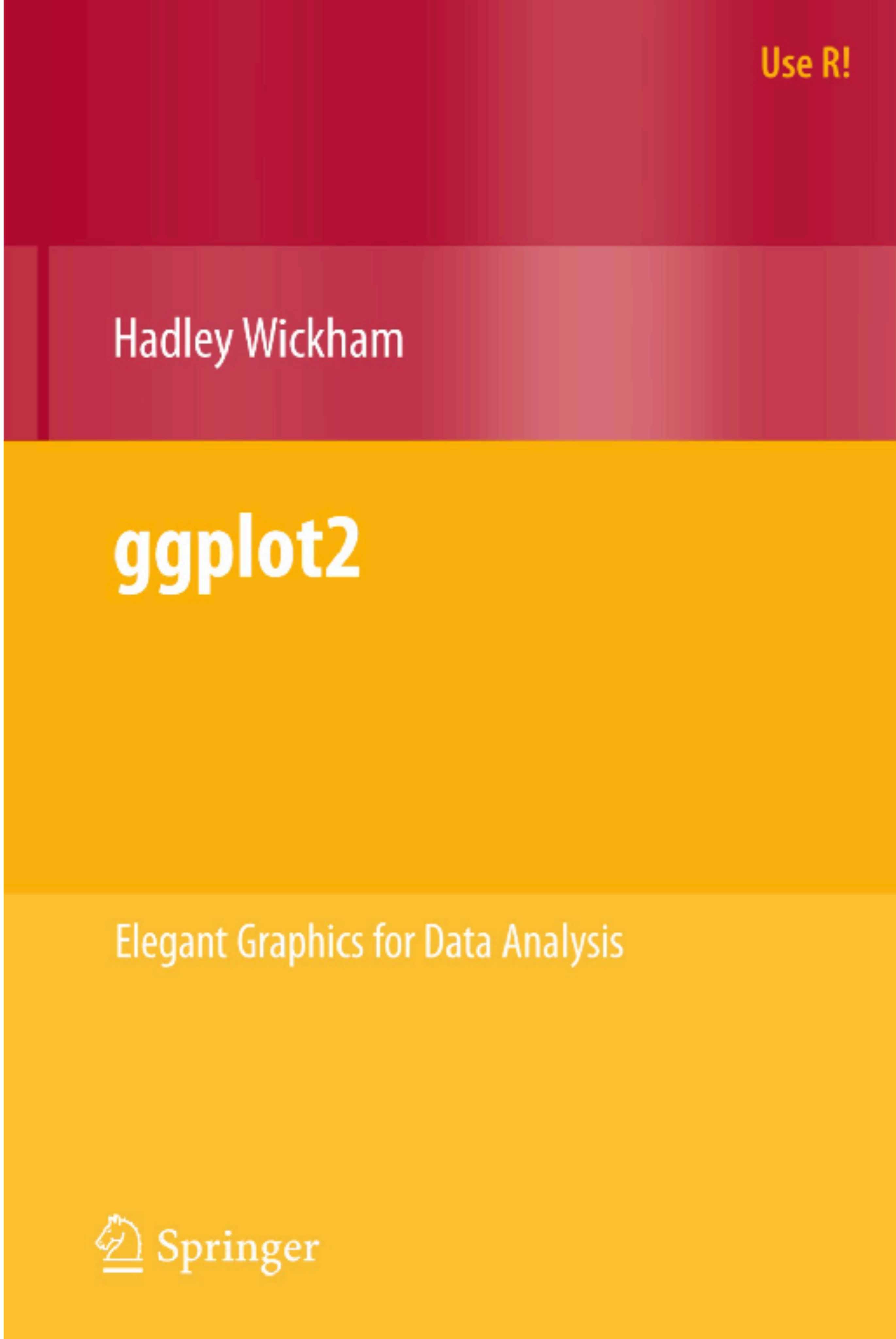
- R for Data Science (book)
  Freely available on:
  [r4ds.had.co.nz/](r4ds.had.co.nz/)



Learn tidyverse

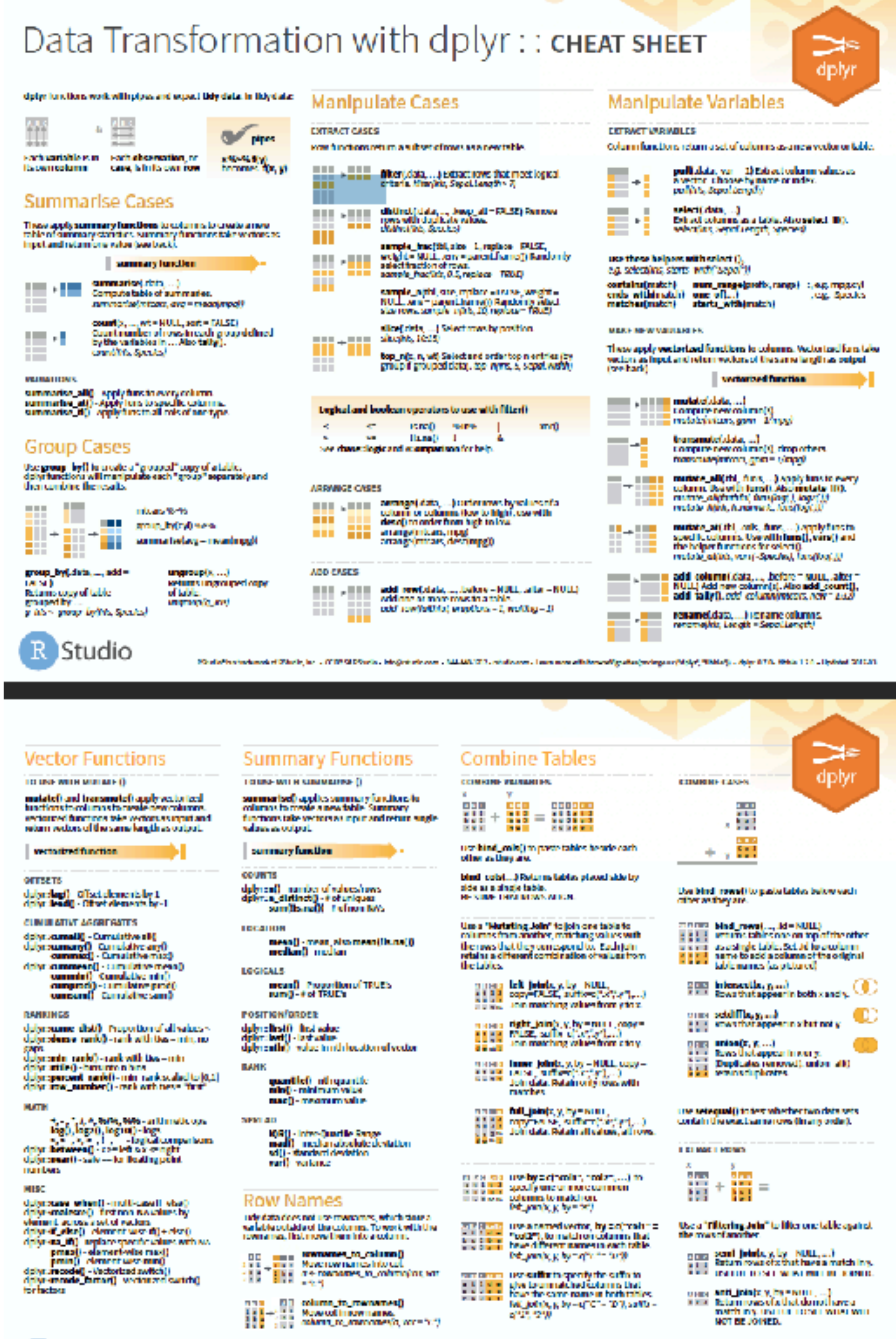
- R for Data Science (book)
  Freely available on:
  r4ds.had.co.nz/

- ggplot2 (book)



Learn tidyverse

- R for Data Science (book)
  Freely available on:
  r4ds.had.co.nz/
- ggplot2 (book)
- cheatsheets
  www.rstudio.com/resources/cheatsheets/



Your afternoon roadmap

- A short explanation on screen (~15 minutes)
- Exercises in a document on your computer (~45 minutes)
  - 2-3 basic exercises
  - optional exercises, for further practice
  - reading exercises, for some extra insight into Tidyverse
- We will work with a new data set
- The exercises are presented in Rmarkdown format. We'll explain this later!

From code to document

Turn your analyses into high quality documents with Rmarkdown

R Markdown

- **Combine code with narrative (R with markdown)**
- Turn your analyses into high quality documents, reports, presentations and dashboards.
- … or your note book.
- Rmarkdown is different from a R script
- Rmarkdown files have file extension **.Rmd** (R scripts have extension **.R**)

Console, Scripts and Rmarkdown

Console	Code execution	-
Script	Code	Extension: .R (example_script.R)
Rmarkdown	Code + Narrative	Extension: .Rmd (example_report.Rmd)

Markdown

````
# title

Some text about your project

## Section

More text about your project

```{r}
max(iris$Petal.Length)
min(iris$Petal.Length)
```
````

Rmarkdown: demo

Exercise: open the exercise Rmarkdown

1. RStudio > File > Open Project > introduction-to-R-and-data-github.Rproj

2. From the ‘files’ menu (bottom right), select modernR_exercises.Rmd

3. Update the header information with your name!

Run the first code chunk!

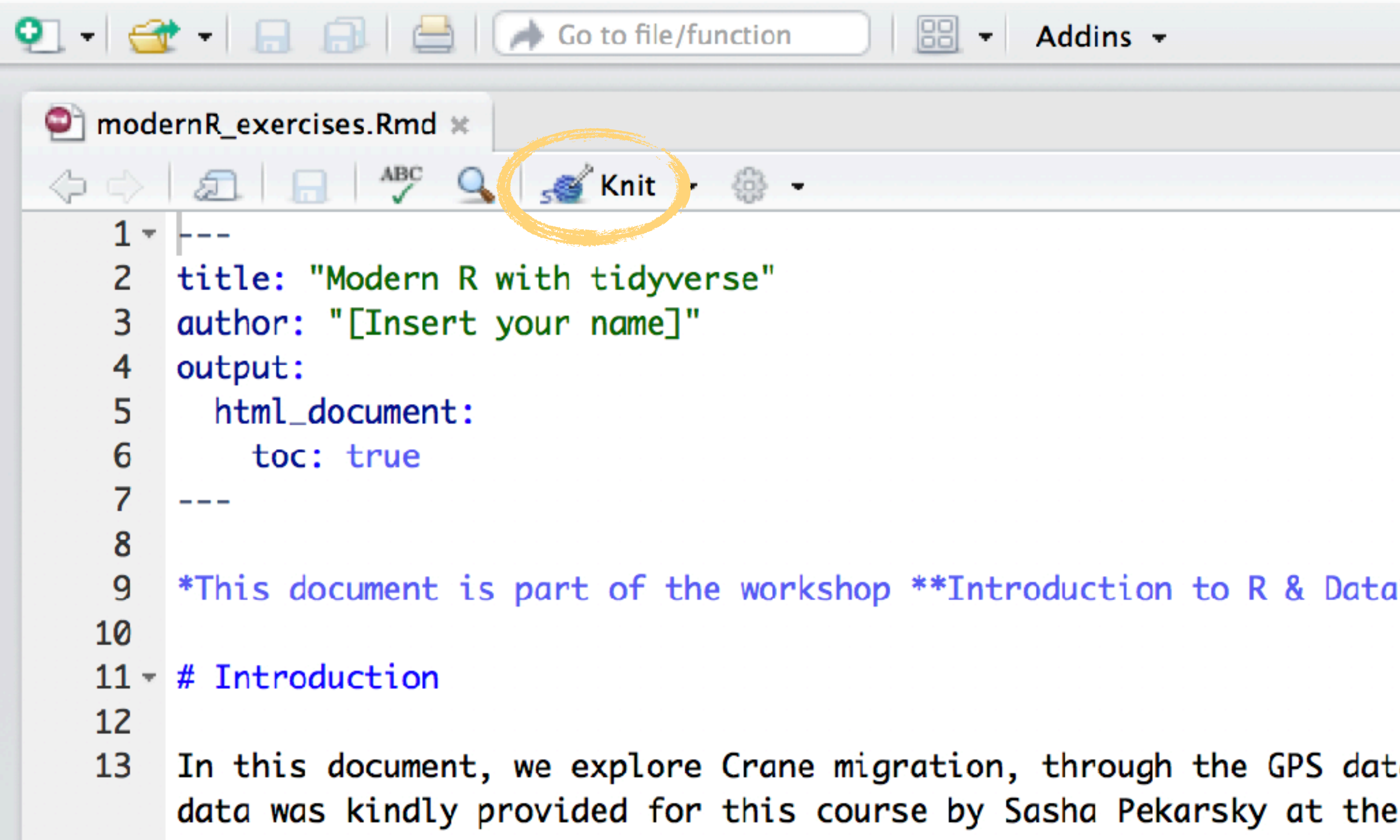
```
## Technical requirements

This project depends on the `tidyverse` package. Load tidyverse into your work
environment.

```{r}
library(tidyverse)
```
```

```
> library(tidyverse)
── Attaching packages ──────────────────────── tidyverse 1.2.1 ──
✔ ggplot2 3.1.0     ✔ purrr   0.3.0
✔ tibble  2.0.1     ✔ dplyr   0.7.8
✔ tidyr   0.8.2     ✔ stringr 1.4.0
✔ readr   1.3.1     ✔ forcats 0.3.0
── Conflicts ─────────────────────── tidyverse_conflicts() ──
✖ dplyr::filter() masks stats::filter()
✖ dplyr::lag()    masks stats::lag()
```

All done? Time to knit!



package: Tibble

Improved data frames

"Tibbles are data frames, but they tweak some older behaviours to make life a little easier."

– Hadley Wickham (creator of Tidyverse)

Tibbles

```
> tibble(a = 1:26, b = letters)
# A tibble: 26 x 2
        a b
    <int> <chr>
 1      1 a
 2      2 b
 3      3 c
 4      4 d
 5      5 e
 6      6 f
 7      7 g
 8      8 h
 9      9 i
10     10 j
# ... with 16 more rows
```

Tibbles: from data.frame to tibble

```
> as_tibble(iris)
# A tibble: 150 x 5
   Sepal.Length Sepal.Width Petal.Length Petal.Width Species
          <dbl>       <dbl>        <dbl>       <dbl> <fct>
 1         5.10        3.50         1.40       0.200 setosa
 2         4.90        3.00         1.40       0.200 setosa
 3         4.70        3.20         1.30       0.200 setosa
 4         4.60        3.10         1.50       0.200 setosa
 5         5.00        3.60         1.40       0.200 setosa
 6         5.40        3.90         1.70       0.400 setosa
 7         4.60        3.40         1.40       0.300 setosa
 8         5.00        3.40         1.50       0.200 setosa
 9         4.40        2.90         1.40       0.200 setosa
10         4.90        3.10         1.50       0.100 setosa
# ... with 140 more rows
```

Tibbles: from tibble to data.frame

```
> iris_tibble <- as_tibble(iris)
> as.data.frame(iris_tibble)
   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
7           4.6         3.4          1.4         0.3     setosa
8           5.0         3.4          1.5         0.2     setosa
9           4.4         2.9          1.4         0.2     setosa
10          4.9         3.1          1.5         0.1     setosa
11          5.4         3.7          1.5         0.2     setosa
12          4.8         3.4          1.6         0.2     setosa
13          4.8         3.0          1.4         0.1     setosa
14          4.3         3.0          1.1         0.1     setosa
```

Load and save data

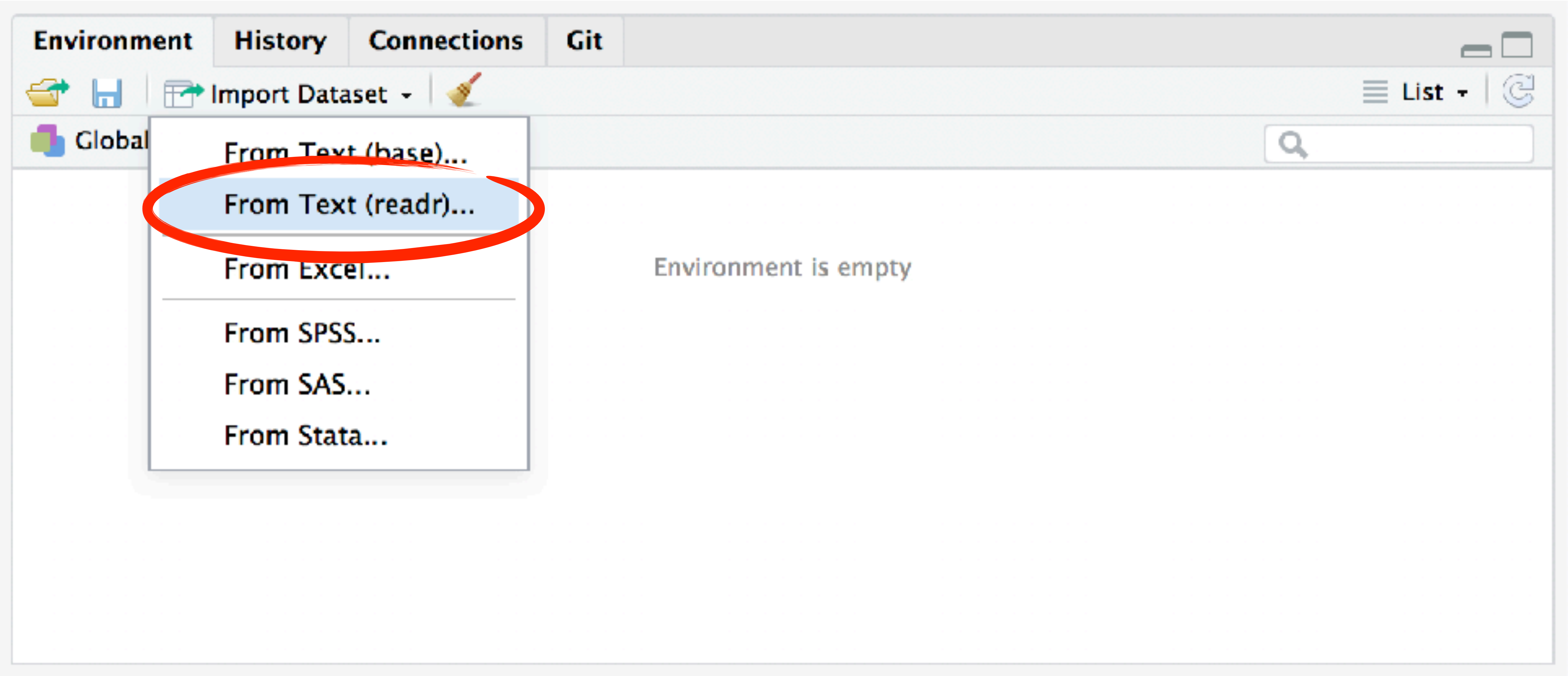
The basics of readr

Flat data files

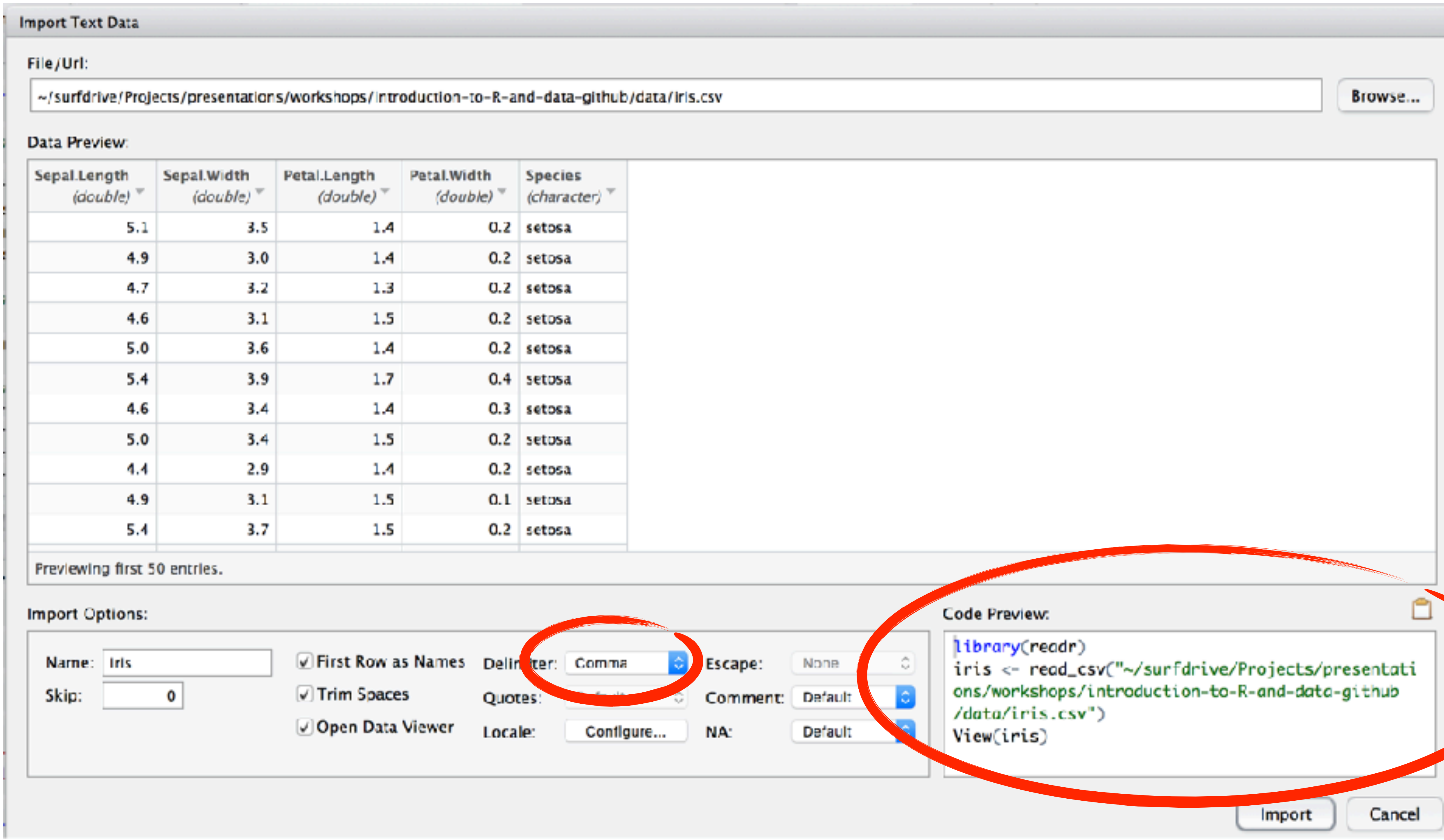
- Most common format: Comma-separated values (CSV)
- Delimiter-separated values (also stored as CSV)
- Common delimiters:
  - comma ,
  - semicolon ;
  - tab \t

```
mpg;cyl;disp;hp;drat;wt;qsec;v
21;6;160;110;3.9;2.62;16.46;0;
21;6;160;110;3.9;2.875;17.02;0
22.8;4;108;93;3.85;2.32;18.61;
21.4;6;258;110;3.08;3.215;19.4
18.7;8;360;175;3.15;3.44;17.02
18.1;6;225;105;2.76;3.46;20.22
14.3;8;360;245;3.21;3.57;15.84
24.4;4;146.7;62;3.69;3.19;20;1
22.8;4;140.8;95;3.92;3.15;22.9
19.2;6;167.6;123;3.92;3.44;18.
17.8;6;167.6;123;3.92;3.44;18.
16.4;8;275.8;180;3.07;4.07;17.
17.3;8;275.8;180;3.07;3.73;17.
15.2;8;275.8;180;3.07;3.78;18;
10.4;8;472;205;2.93;5.25;17.98
10.4;8;460;215;3;5.424;17.82;0
14.7;8;440;230;3.23;5.345;17.4
32.4;4;78.7;66;4.08;2.2;19.47;
30.4;4;75.7;52;4.93;1.615;18.5
33.9;4;71.1;65;4.22;1.835;19.9
21.5;4;120.1;97;3.7;2.465;20.0
```

Load data by using buttons



Load data by using buttons



Read flat files

```
> library(readr)
> data_iris <- read_delim("data/iris.csv", delim=',')
```

Read flat files

```
> library(readr)
> data_iris <- read_delim("data/iris.csv", delim=',')
Parsed with column specification:
cols(
  Sepal.Length = col_double(),
  Sepal.Width = col_double(),
  Petal.Length = col_double(),
  Petal.Width = col_double(),
  Species = col_character()
)
```

Read flat files

```
> library(readr)
> data_iris <- read_csv("data/iris.csv")
Parsed with column specification:
cols(
  Sepal.Length = col_double(),
  Sepal.Width = col_double(),
  Petal.Length = col_double(),
  Petal.Width = col_double(),
  Species = col_character()
)
```

Exercise dataset

- GPS data from 39 tagged individual cranes during fall migration of 2017
- Courtesy of Sasha Pekarsky at the Hebrew University of Jerusalem, Israel
- In the ‘data’ folder of your course materials.

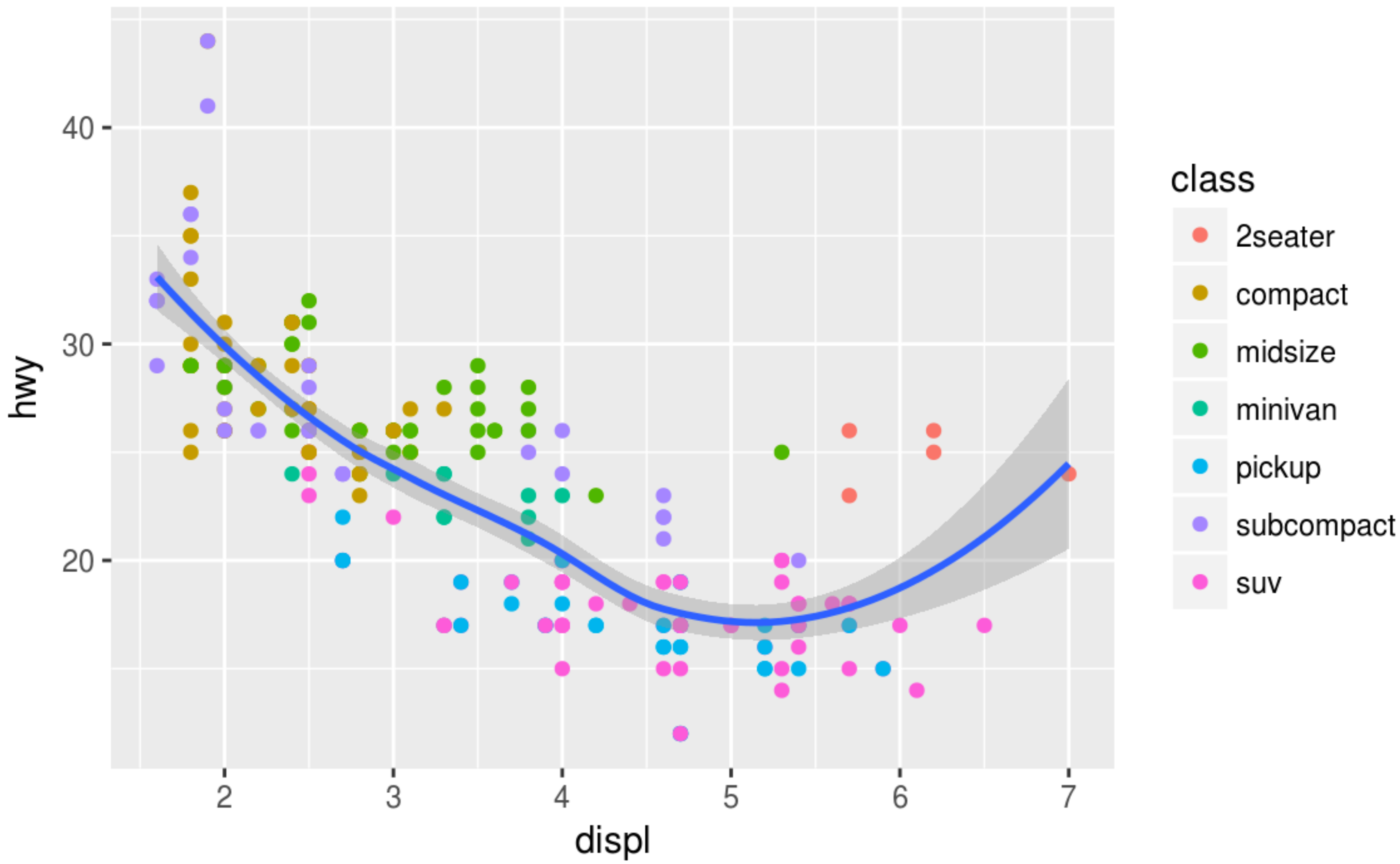
Exercises

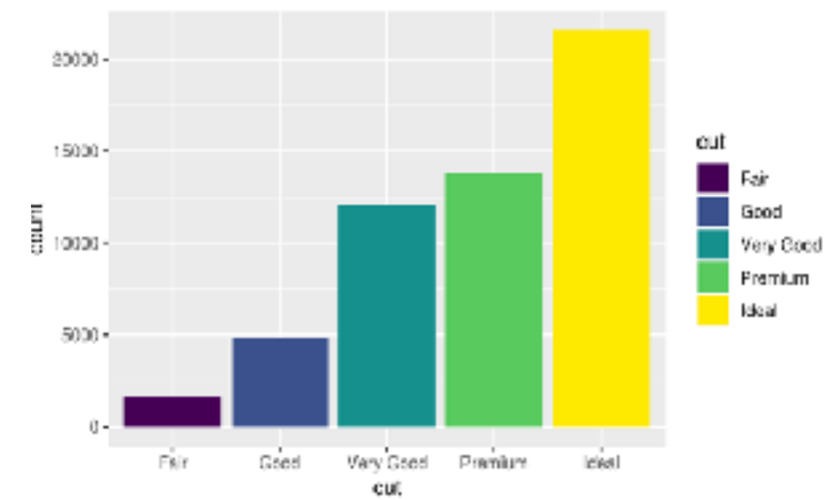
Please do basic exercises 1-I and 1-II.

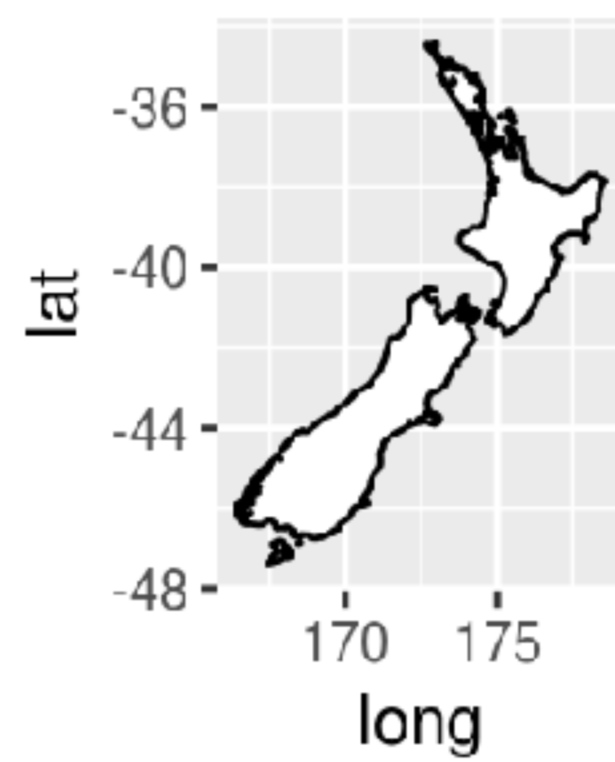
Time left? Opt for a reading exercise or optional exercise!

Data visualisation

Create eye candy with ggplot2





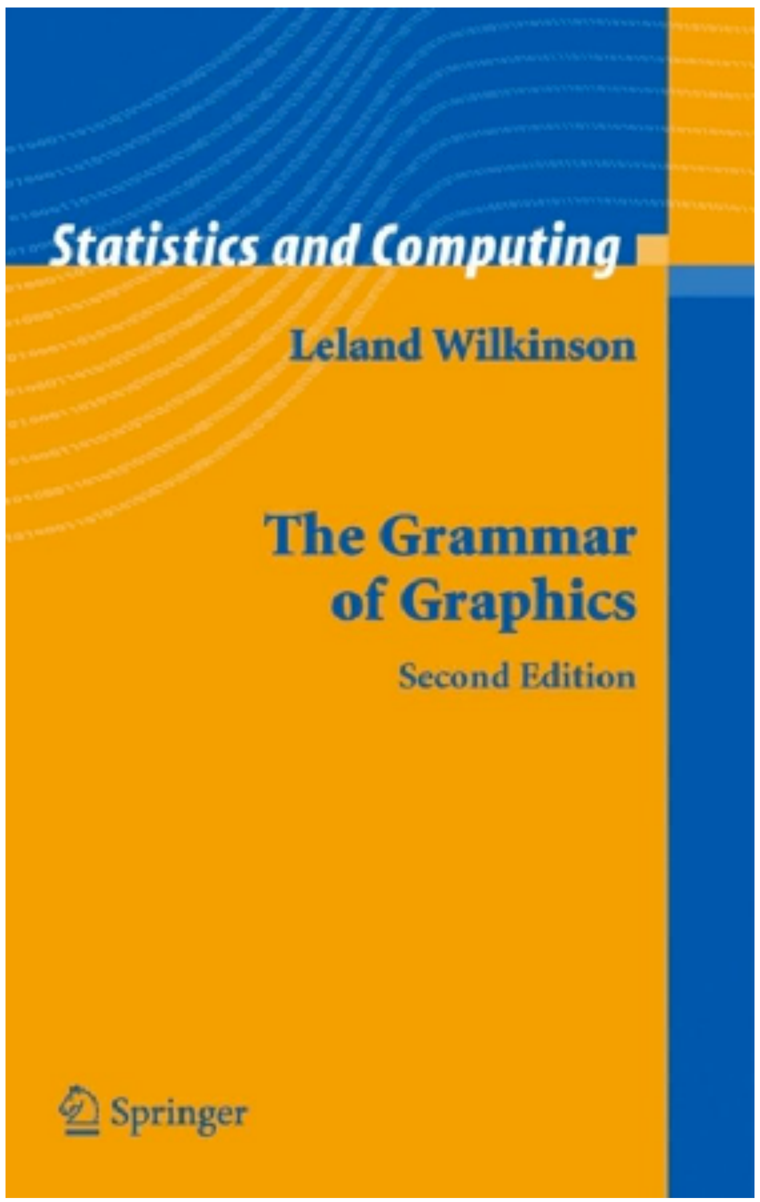


Examples of plots with R (and ggplot2)

Data visualisation with ggplot2

- **ggplot2** is an extremely popular data visualisation package for R
- Simple syntax, easy to learn, nice plots
- Developed and maintained by Hadley Wickham
- Based on the book: The Grammar of Graphics (Wilkinson, 2005)

The grammar of graphics



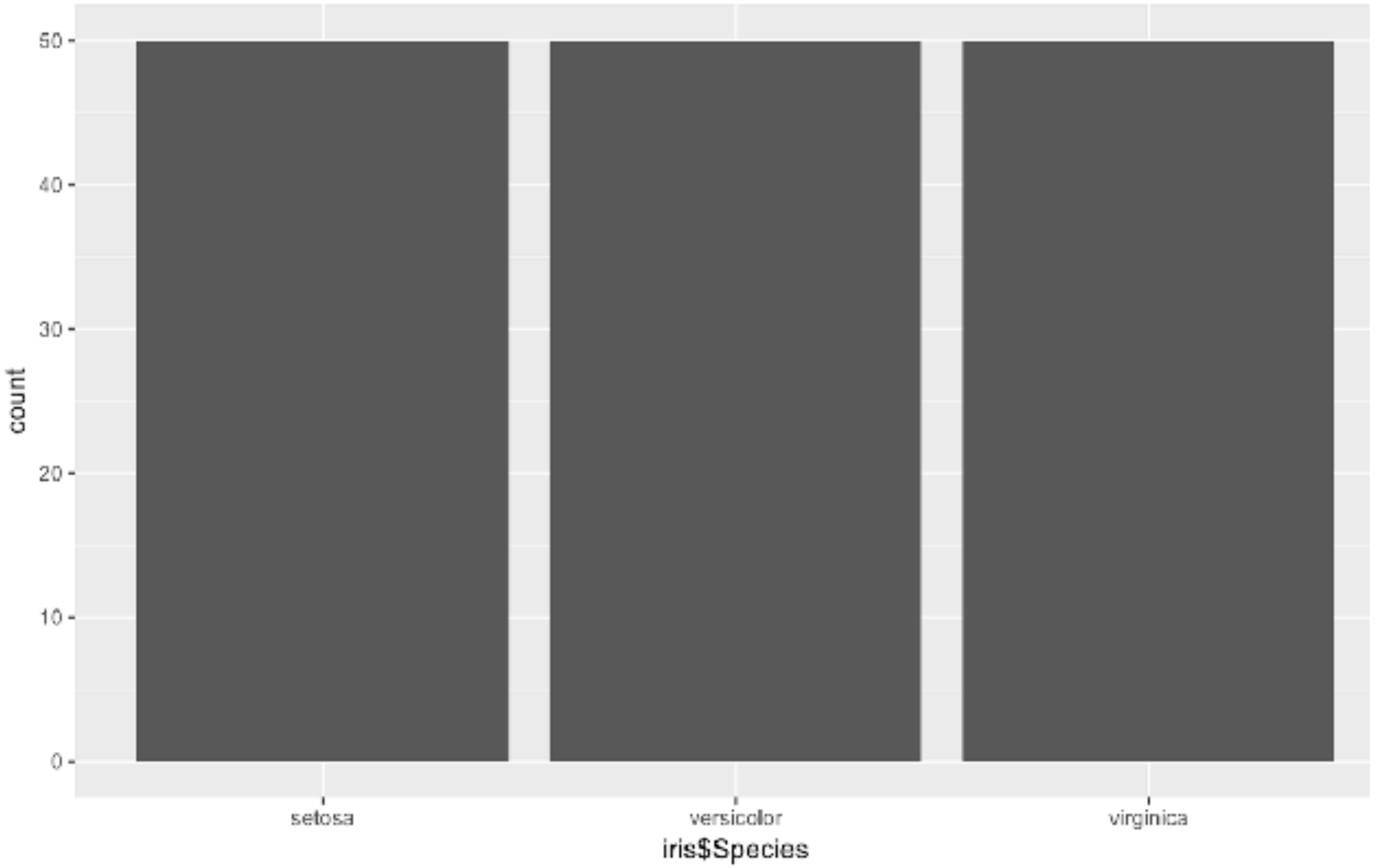
Data	The variables in a tibble or data.frame
Aesthetics	x- and y-axis, colour, size, alpha, shape
Geometries	point, line, bar, histogram

Source: https://www.youtube.com/watch?v=uiTc55clwuA

Quick plotting

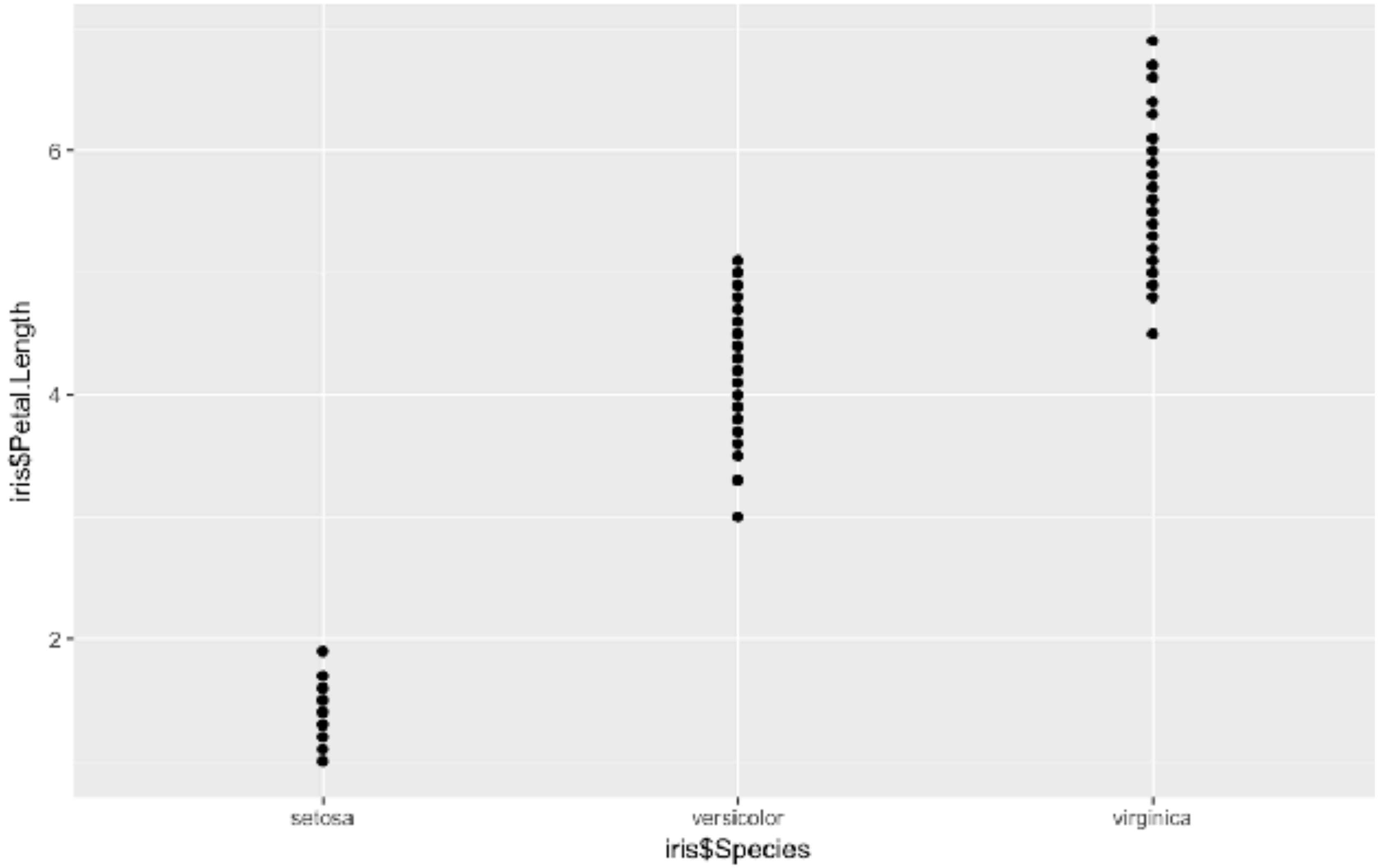
Quick plots

```
> qplot(Species, data = iris)
```



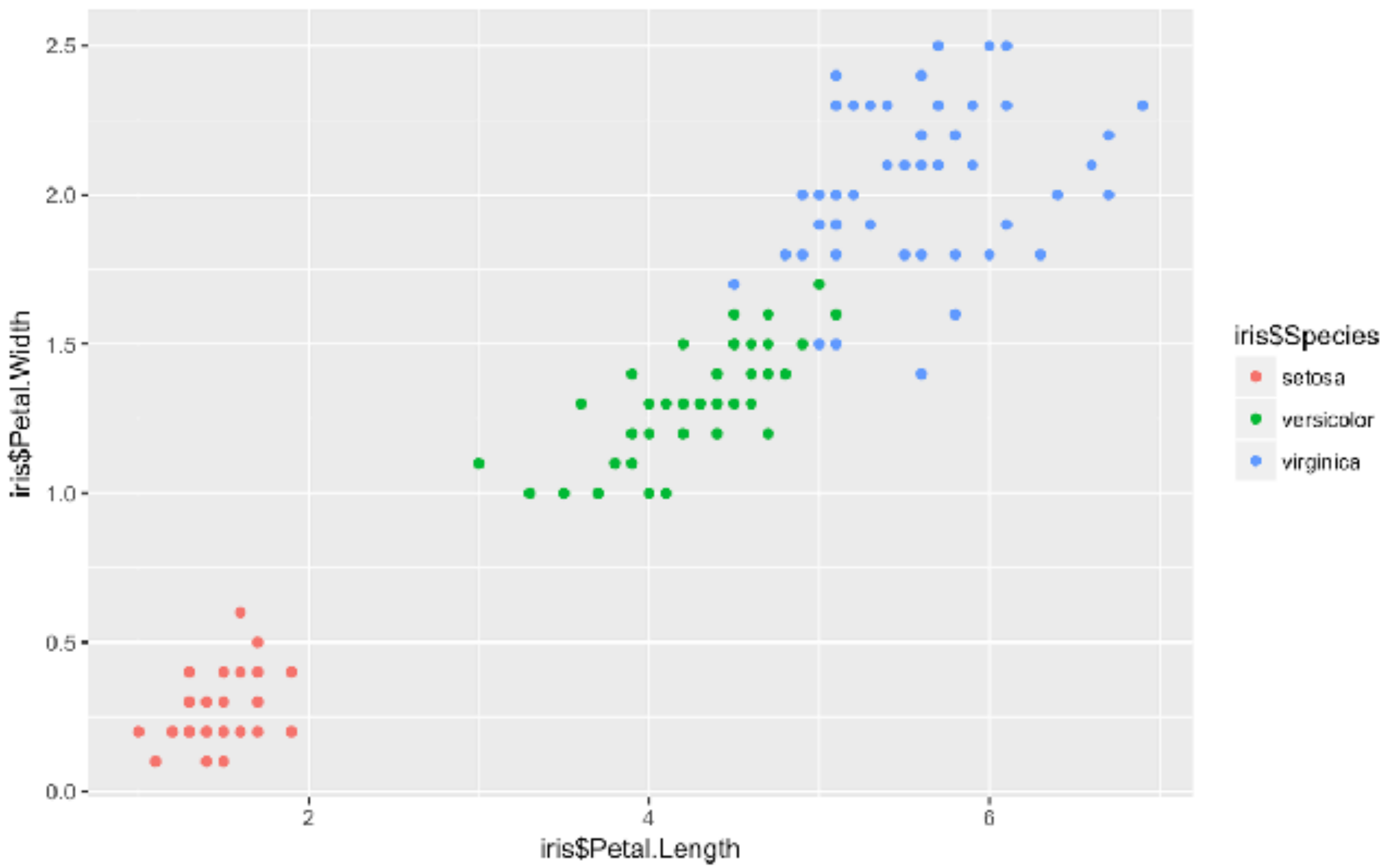
Quick plots

```
> qplot(Species, data = iris)
> qplot(Species, Petal.Length, data = iris)
```



Quick plots

```
> qplot(Species, data = iris)
> qplot(Species, Petal.Length, data = iris)
> qplot(Petal.Length, Petal.Width, data = iris, colour=Species)
```



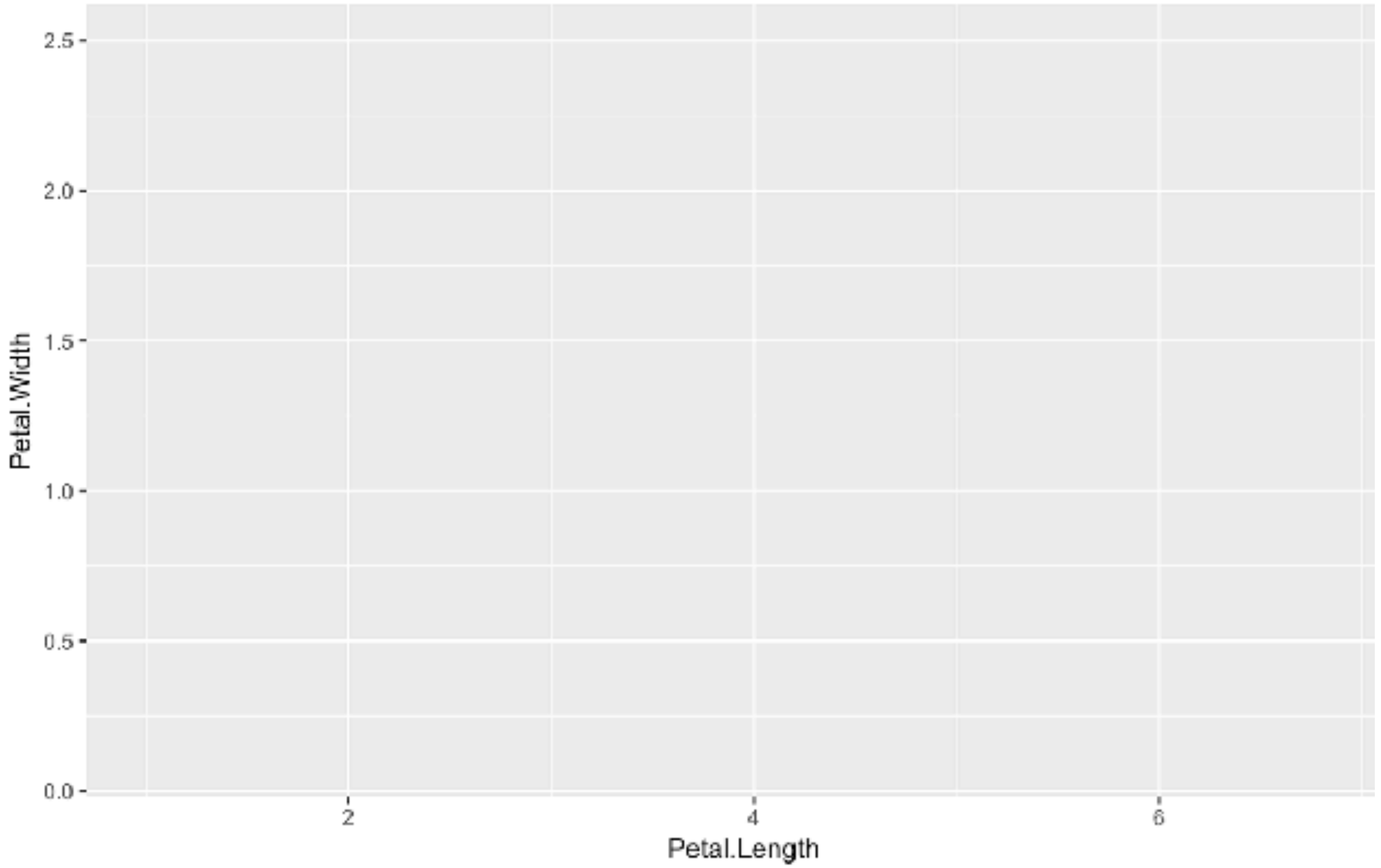
ggplot (grammar of graphics)

ggplot: Data, aesthetics, geometrics

```
> ggplot(iris)
```

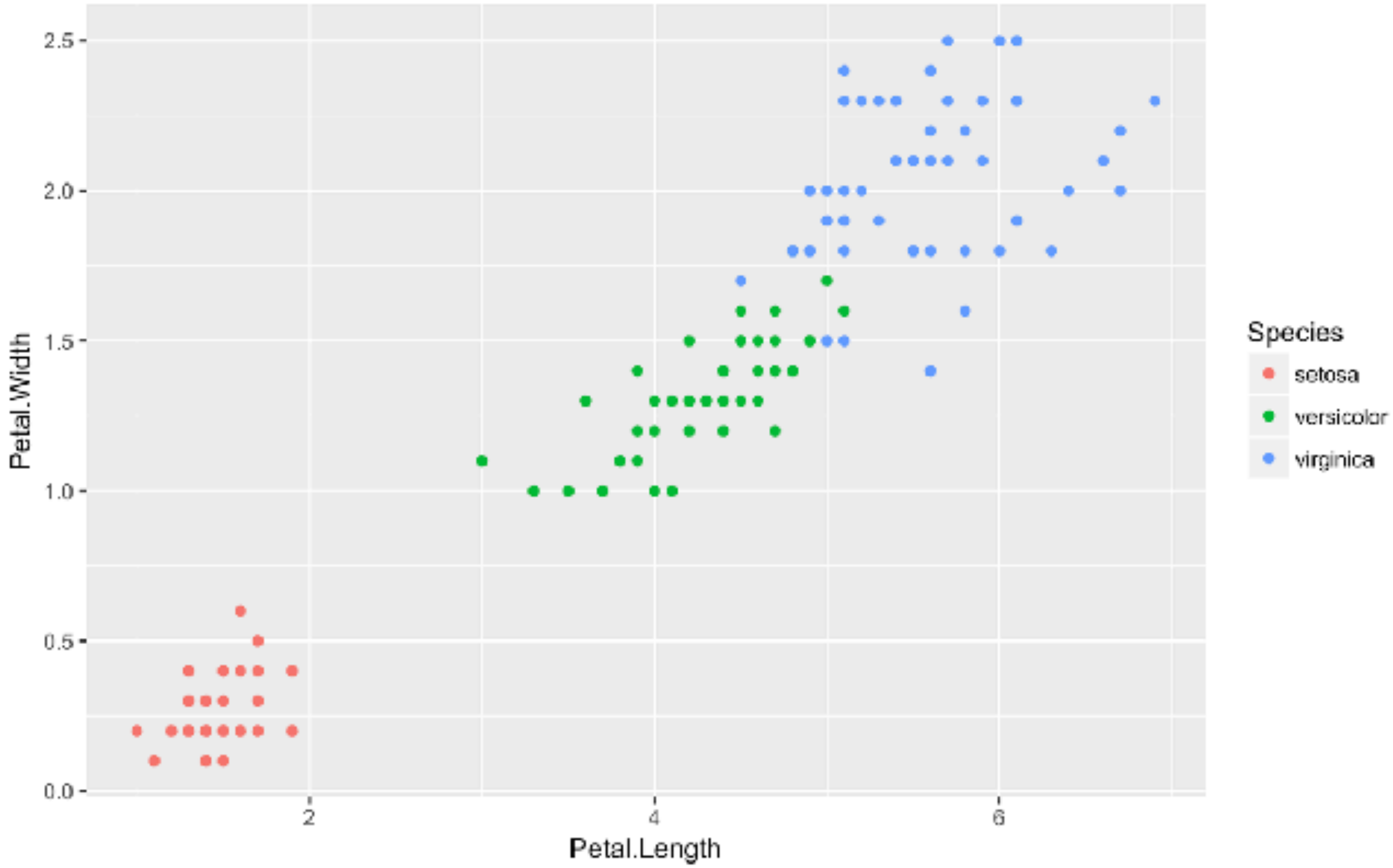
ggplot: Data, aesthetics, geometrics

```
> ggplot(iris)
> ggplot(iris, aes(x = Petal.Length, y = Petal.Width, colour=Species))
```



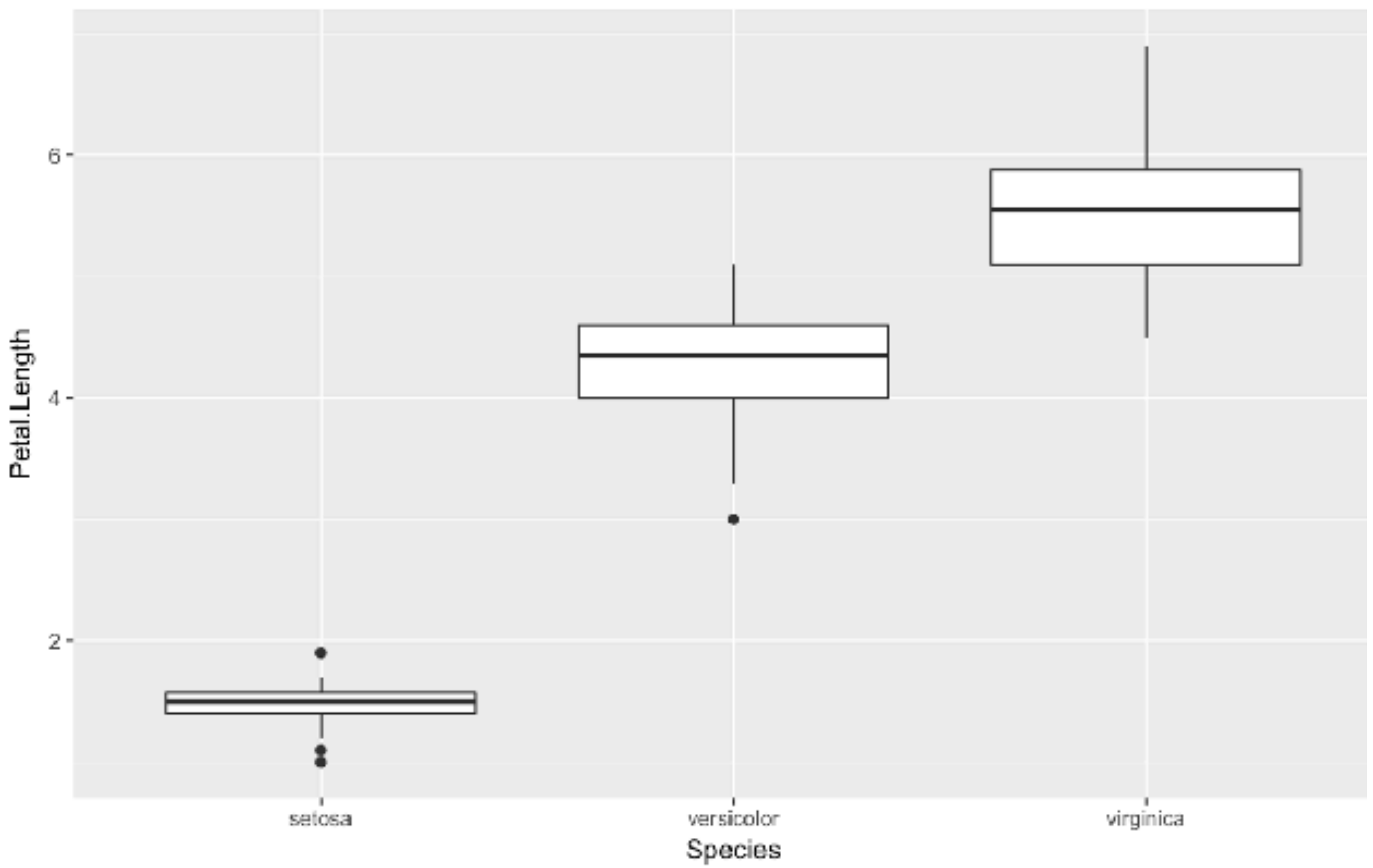
ggplot: Data, aesthetics, geometrics

```
> ggplot(iris)
> ggplot(iris, aes(x = Petal.Length, y = Petal.Width, colour=Species))
> ggplot(iris, aes(x = Petal.Length, y = Petal.Width, colour=Species)) +
    geom_point()
```



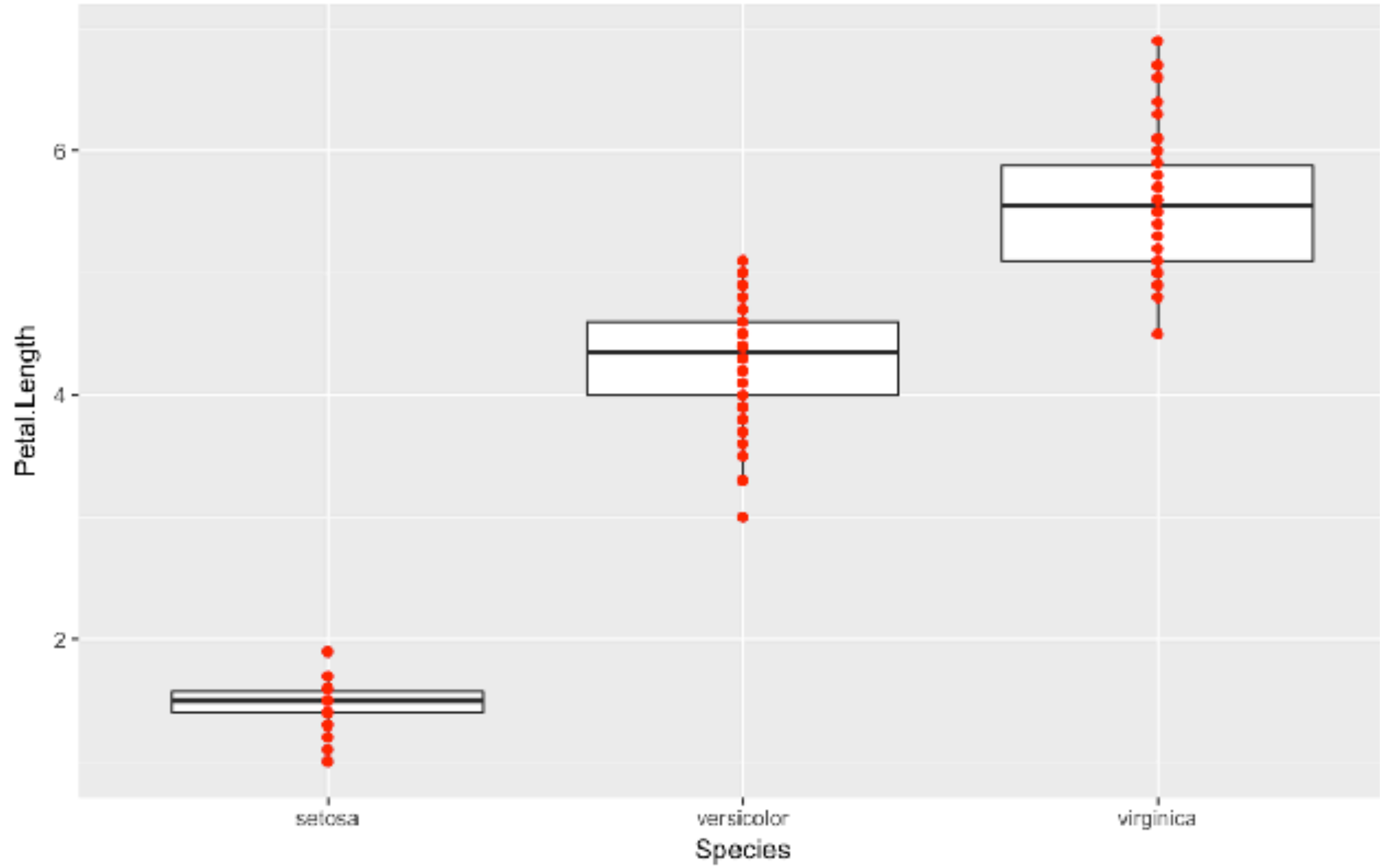
ggplot: Multiple geometric layers

```
> ggplot(iris, aes(x = Species, y = Petal.Length)) +
      geom_boxplot()
```



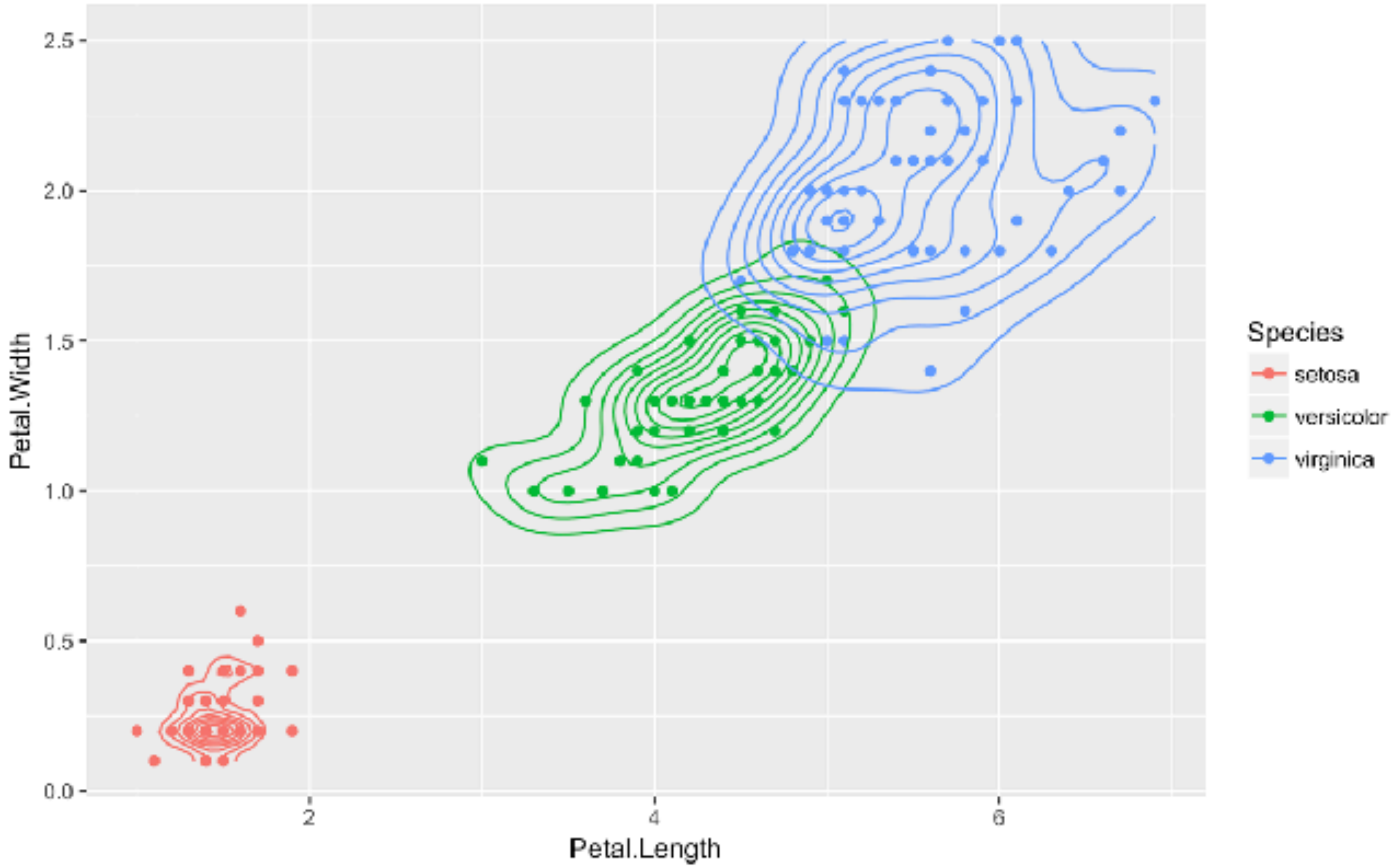
ggplot: Multiple geometric layers

```
> ggplot(iris, aes(x = Species, y = Petal.Length)) +
      geom_boxplot() +
      geom_point(colour='red')
```



ggplot: Statistical layers

```
> ggplot(iris, aes(x = Petal.Length, y = Petal.Width, colour=Species)) +
    geom_point() +
    stat_density_2d()
```



Exercises

Please do basic exercises 2-I and 2-II.

Time left? Opt for a reading exercise or optional exercise!

Data transformation

Explore the power of dplyr and tidyr

Data Transformation with dplyr : : CHEAT SHEET

dplyr

dplyr functions work with pipes and expect **tidy data**. In tidy data:

Each **variable** is in its own **column** & Each **observation**, or **case**, is in its own **row**

pipes

x %>% f(y) becomes **f(x, y)**

Summarise Cases

These apply **summary functions** to columns to create a new table of summary statistics. Summary functions take vectors as input and return one value (see back).

summary function

summarise(.data, …)
Compute table of summaries.
summarise(mtcars, avg = mean(mpg))

count(x, ..., wt = NULL, sort = FALSE)
Count number of rows in each group defined by the variables in … Also **tally**().
count(iris, Species)

VARIATIONS

summarise_all() - Apply funs to every column.
summarise_at() - Apply funs to specific columns.
summarise_if() - Apply funs to all cols of one type.

Group Cases

Use **group_by()** to create a "grouped" copy of a table. dplyr functions will manipulate each "group" separately and then combine the results.

mtcars %>%
group_by(cyl) %>%
summarise(avg = mean(mpg))

group_by(.data, ..., add = FALSE)
Returns copy of table grouped by …
g_iris <- group_by(iris, Species)

ungroup(x, …)
Returns ungrouped copy of table.
ungroup(g_iris)

Manipulate Cases

EXTRACT CASES

Row functions return a subset of rows as a new table.

filter(.data, …) Extract rows that meet logical criteria. *filter(iris, Sepal.Length > 7)*

distinct(.data, ..., .keep_all = FALSE) Remove rows with duplicate values.
distinct(iris, Species)

sample_frac(tbl, size = 1, replace = FALSE, weight = NULL, .env = parent.frame()) Randomly select fraction of rows.
sample_frac(iris, 0.5, replace = TRUE)

sample_n(tbl, size, replace = FALSE, weight = NULL, .env = parent.frame()) Randomly select size rows. *sample_n(iris, 10, replace = TRUE)*

slice(.data, …) Select rows by position.
slice(iris, 10:15)

top_n(x, n, wt) Select and order top n entries (by group if grouped data). *top_n(iris, 5, Sepal.Width)*

Logical and boolean operators to use with filter()

<	<=	is.na()	%in%	|	xor()
>	>=	!is.na()	!	&	

See **?base::logic** and **?Comparison** for help.

ARRANGE CASES

arrange(.data, …) Order rows by values of a column or columns (low to high), use with **desc**() to order from high to low.
arrange(mtcars, mpg)
arrange(mtcars, desc(mpg))

ADD CASES

add_row(.data, ..., .before = NULL, .after = NULL)
Add one or more rows to a table.
add_row(faithful, eruptions = 1, waiting = 1)

Manipulate Variables

EXTRACT VARIABLES

Column functions return a set of columns as a new vector or table.

pull(.data, var = -1) Extract column values as a vector. Choose by name or index.
pull(iris, Sepal.Length)

select(.data, …)
Extract columns as a table. Also **select_if**().
select(iris, Sepal.Length, Species)

Use these helpers with select (),
e.g. select(iris, starts_with("Sepal"))

contains(match) **num_range**(prefix, range) :, e.g. mpg:cyl
ends_with(match) **one_of**(…) -, e.g, -Species
matches(match) **starts_with**(match)

MAKE NEW VARIABLES

These apply **vectorized functions** to columns. Vectorized funs take vectors as input and return vectors of the same length as output (see back).

vectorized function

mutate(.data, …)
Compute new column(s).
mutate(mtcars, gpm = 1/mpg)

transmute(.data, …)
Compute new column(s), drop others.
transmute(mtcars, gpm = 1/mpg)

mutate_all(.tbl, .funs, …) Apply funs to every column. Use with **funs**(). Also **mutate_if**().
mutate_all(faithful, funs(log(.), log2(.)))
mutate_if(iris, is.numeric, funs(log(.)))

mutate_at(.tbl, .cols, .funs, …) Apply funs to specific columns. Use with **funs**(), **vars**() and the helper functions for select().
mutate_at(iris, vars(-Species), funs(log(.)))

add_column(.data, ..., .before = NULL, .after = NULL) Add new column(s). Also **add_count**(), **add_tally**(). *add_column(mtcars, new = 1:32)*

rename(.data, …) Rename columns.
rename(iris, Length = Sepal.Length)

RStudio

filter()

Function: filter()

```
> filter(iris, Species=="virginica")
```

Function: filter()

```
> filter(iris, Species=="virginica")
# A tibble: 50 x 5
   Sepal.Length Sepal.Width Petal.Length Petal.Width Species
          <dbl>       <dbl>        <dbl>       <dbl> <fct>
 1         6.30        3.30         6.00        2.50 virginica
 2         5.80        2.70         5.10        1.90 virginica
 3         7.10        3.00         5.90        2.10 virginica
 4         6.30        2.90         5.60        1.80 virginica
 5         6.50        3.00         5.80        2.20 virginica
 6         7.60        3.00         6.60        2.10 virginica
 7         4.90        2.50         4.50        1.70 virginica
 8         7.30        2.90         6.30        1.80 virginica
 9         6.70        2.50         5.80        1.80 virginica
10         7.20        3.60         6.10        2.50 virginica
# ... with 40 more rows
```

Function: filter()

```
> filter(iris, Species=="virginica", Sepal.Length>= 7.5)
```

Function: filter()

```
> filter(iris, Species=="virginica", Sepal.Length>= 7.5)
# A tibble: 6 x 5
  Sepal.Length Sepal.Width Petal.Length Petal.Width Species
         <dbl>       <dbl>        <dbl>       <dbl> <fct>
1         7.60        3.00         6.60        2.10 virginica
2         7.70        3.80         6.70        2.20 virginica
3         7.70        2.60         6.90        2.30 virginica
4         7.70        2.80         6.70        2.00 virginica
5         7.90        3.80         6.40        2.00 virginica
6         7.70        3.00         6.10        2.30 virginica
```

Function: filter()

```
> filter(iris, Species=="virginica", Sepal.Length>= 7.5)
# A tibble: 6 x 5
  Sepal.Length Sepal.Width Petal.Length Petal.Width Species
         <dbl>       <dbl>        <dbl>       <dbl> <fct>
1         7.60        3.00         6.60        2.10 virginica
2         7.70        3.80         6.70        2.20 virginica
3         7.70        2.60         6.90        2.30 virginica
4         7.70        2.80         6.70        2.00 virginica
5         7.90        3.80         6.40        2.00 virginica
6         7.70        3.00         6.10        2.30 virginica
```

Same as:

```
> filter(iris, Species=="virginica" & Sepal.Length>= 7.5)
```

select()

Subset Variables (Columns)

Function: select()

```
> select(iris, Sepal.Length, Sepal.Width, Species)
```

Function: select()

```
> select(iris, Sepal.Length, Sepal.Width, Species)
# A tibble: 150 x 3
   Sepal.Length Sepal.Width Species
          <dbl>       <dbl> <fct>
 1         5.10        3.50 setosa
 2         4.90        3.00 setosa
 3         4.70        3.20 setosa
 4         4.60        3.10 setosa
 5         5.00        3.60 setosa
 6         5.40        3.90 setosa
 7         4.60        3.40 setosa
 8         5.00        3.40 setosa
 9         4.40        2.90 setosa
10         4.90        3.10 setosa
# ... with 140 more rows
```

Function: select()

```
> select(iris, Sepal.Length, Sepal.Width, Species)
> select(iris, starts_with("Sepal"), Species)
```

Function: select()

```
> select(iris, Sepal.Length, Sepal.Width, Species)
> select(iris, starts_with("Sepal"), Species)
# A tibble: 150 x 3
   Sepal.Length Sepal.Width Species
          <dbl>       <dbl> <fct>
 1         5.10        3.50 setosa
 2         4.90        3.00 setosa
 3         4.70        3.20 setosa
 4         4.60        3.10 setosa
 5         5.00        3.60 setosa
 6         5.40        3.90 setosa
 7         4.60        3.40 setosa
 8         5.00        3.40 setosa
 9         4.40        2.90 setosa
10         4.90        3.10 setosa
# ... with 140 more rows
```

Function: select()

```
> select(iris, Sepal.Length, Sepal.Width, Species)
> select(iris, starts_with("Sepal"), Species)
> select(iris, -starts_with("Petal"))
```

Function: select()

```
> select(iris, Sepal.Length, Sepal.Width, Species)
> select(iris, starts_with("Sepal"), Species)
> select(iris, -starts_with("Petal"))
# A tibble: 150 x 3
   Sepal.Length Sepal.Width Species
          <dbl>       <dbl> <fct>
 1         5.10        3.50 setosa
 2         4.90        3.00 setosa
 3         4.70        3.20 setosa
 4         4.60        3.10 setosa
 5         5.00        3.60 setosa
 6         5.40        3.90 setosa
 7         4.60        3.40 setosa
 8         5.00        3.40 setosa
 9         4.40        2.90 setosa
10         4.90        3.10 setosa
# ... with 140 more rows
```

mutate()

Function: mutate()

```
> mutate(iris,
         petal_area = pi * Petal.Length/2 * Petal.Width/2)
```

Function: mutate()

```
> mutate(iris,
         petal_area = pi * Petal.Length/2 * Petal.Width/2)
# A tibble: 150 x 6
   Sepal.Length Sepal.Width Petal.Length Petal.Width Species petal_area
          <dbl>       <dbl>        <dbl>       <dbl> <fct>        <dbl>
 1          5.1         3.5          1.4         0.2 setosa       0.220
 2          4.9         3            1.4         0.2 setosa       0.220
 3          4.7         3.2          1.3         0.2 setosa       0.204
 4          4.6         3.1          1.5         0.2 setosa       0.236
 5          5           3.6          1.4         0.2 setosa       0.220
 6          5.4         3.9          1.7         0.4 setosa       0.534
 7          4.6         3.4          1.4         0.3 setosa       0.330
 8          5           3.4          1.5         0.2 setosa       0.236
 9          4.4         2.9          1.4         0.2 setosa       0.220
10          4.9         3.1          1.5         0.1 setosa       0.118
# ... with 140 more rows
```

Function: mutate()

```
> mutate(iris,
         # compute the area of a single petal
         petal_area = pi * Petal.Length/2 * Petal.Width/2,
         # abbreviate the name of the species
         Species_abbr = substring(Species, 1, 3)
)
```

Function: mutate()

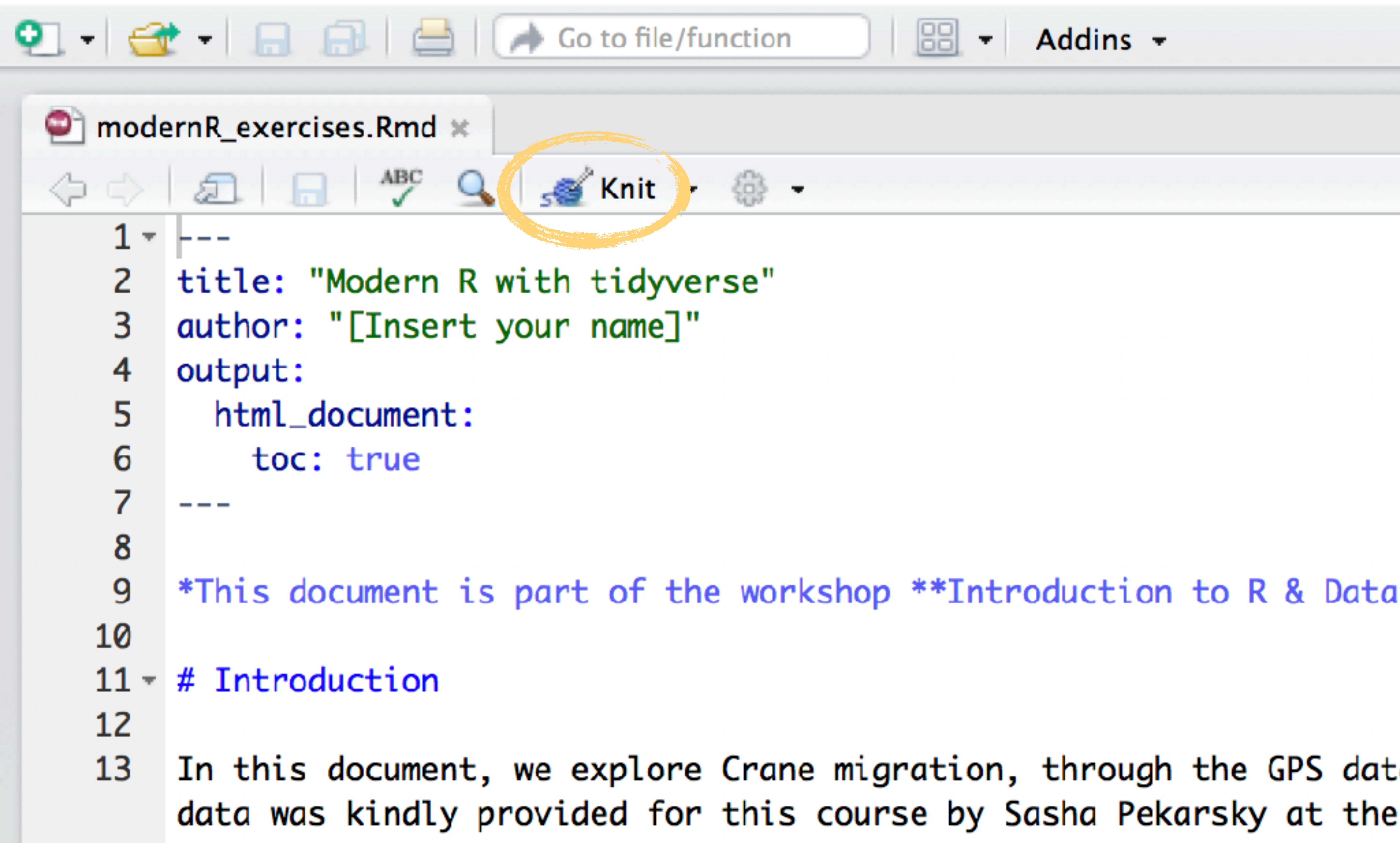
```
> mutate(iris,
         # compute the area of a single petal
         petal_area = pi * Petal.Length/2 * Petal.Width/2,
         # abbreviate the name of the species
         Species_abbr = substring(Species, 1, 3)
)
# A tibble: 150 x 7
   Sepal.Length Sepal.Width Petal.Length Petal.Width Species petal_area Species_abbr
          <dbl>       <dbl>        <dbl>       <dbl> <fct>        <dbl> <chr>
 1          5.1         3.5          1.4         0.2 setosa       0.220 set
 2          4.9         3            1.4         0.2 setosa       0.220 set
 3          4.7         3.2          1.3         0.2 setosa       0.204 set
 4          4.6         3.1          1.5         0.2 setosa       0.236 set
 5          5           3.6          1.4         0.2 setosa       0.220 set
 6          5.4         3.9          1.7         0.4 setosa       0.534 set
 7          4.6         3.4          1.4         0.3 setosa       0.330 set
 8          5           3.4          1.5         0.2 setosa       0.236 set
 9          4.4         2.9          1.4         0.2 setosa       0.220 set
10          4.9         3.1          1.5         0.1 setosa       0.118 set
# ... with 140 more rows
```

Exercises

Please do basic exercises 3-I and 3-II.

Time left? Opt for a reading exercise or optional exercise!

All done? Time to knit!



Introduction to R & data

Before you leave…

Other RDM workshops

- https://www.uu.nl/en/research/research-data-management/tools-services/training-and-workshops

- Learn to write your Data Management Plan (online course)
- Research Data Management basics
- Introduction to Python & Data (coming soon)
- Introduction to computational reproducibility (coming soon)

R Cafe

- Monthly event for R programmers
- Join the R community
- Work on your project with the ability to ask questions
- Subscribe to the newsletter or follow RDM support website
- Check https://github.com/UtrechtUniversity/R-data-cafe
- Next edition: **Monday 25/2, 15:00-17:00**

Feedback is cool.

Please send your feedback, remarks, questions to us:

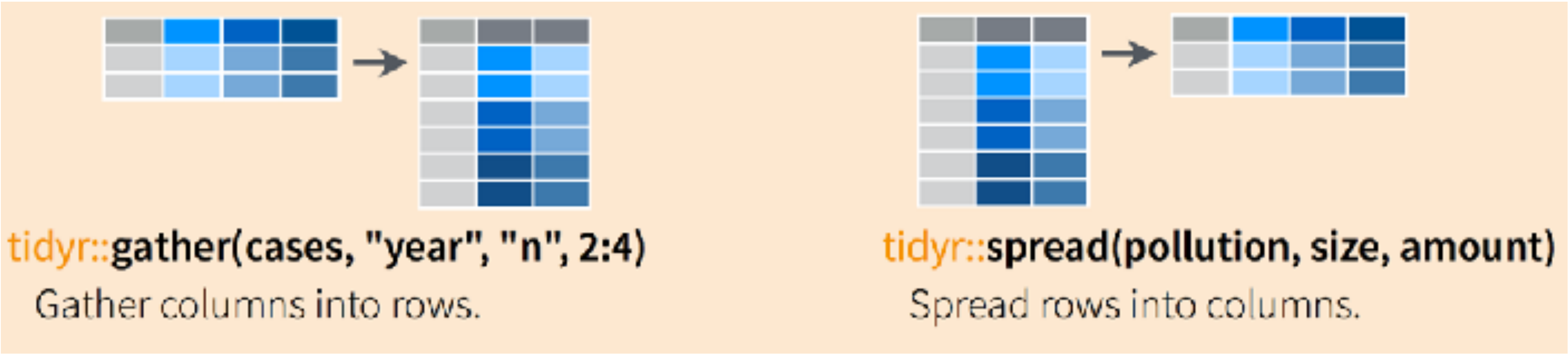
Barbara: b.m.i.vreede@uu.nl
Jonathan: j.debruin1@uu.nl

Or generate an issue on github!

tinyurl.com/introRData

```r
useR <- function(){
    print("Good luck and see you!")
}
useR()
```

gather() and spread()



Wide vs. Long

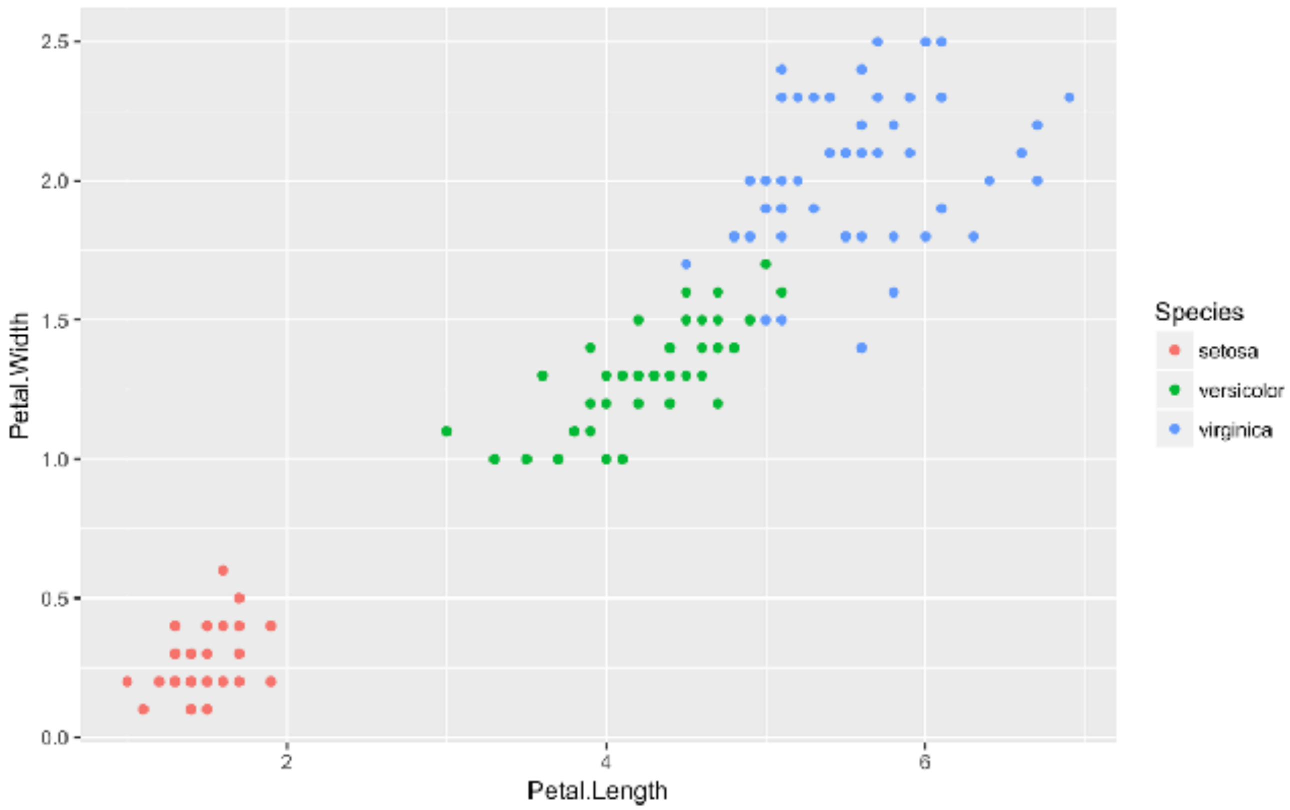
```
# A tibble: 150 x 6
   Species observation Petal.Length Petal.Width Sepal.Length Sepal.Width
   <chr>         <int>        <dbl>       <dbl>        <dbl>       <dbl>
 1 setosa            1         1.40       0.200         5.10        3.50
 2 setosa            2         1.40       0.200         4.90        3.00
 3 setosa            3         1.30       0.200         4.70        3.20
 4 setosa            4         1.50       0.200         4.60        3.10
 5 setosa            5         1.40       0.200         5.00        3.60
 6 setosa            6         1.70       0.400         5.40        3.90
 7 setosa            7         1.40       0.300         4.60        3.40
 8 setosa            8         1.50       0.200         5.00        3.40
 9 setosa            9         1.40       0.200         4.40        2.90
10 setosa           10         1.50       0.100         4.90        3.10
# ... with 140 more rows
```

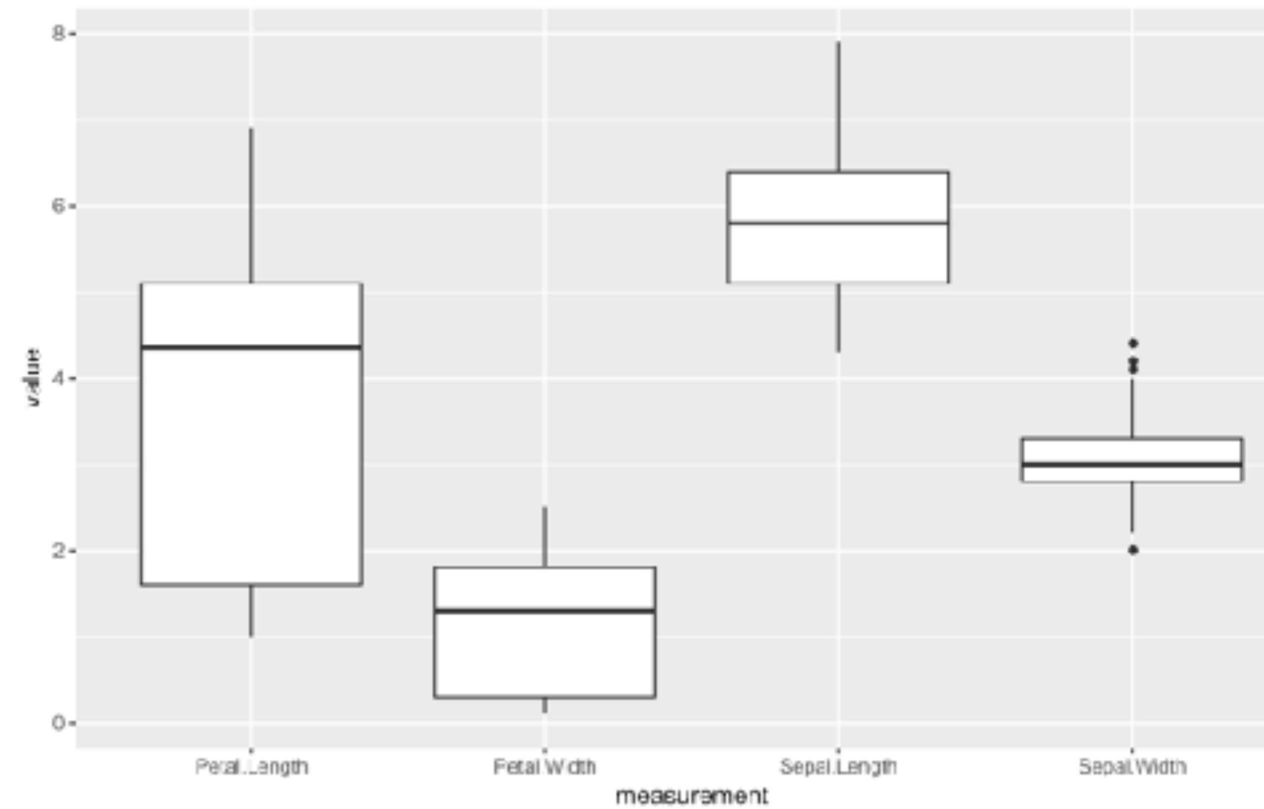
```
# A tibble: 600 x 4
   Species observation measurement  value
   <chr>         <int> <chr>        <dbl>
 1 setosa            1 Sepal.Length 5.10
 2 setosa            1 Sepal.Width  3.50
 3 setosa            1 Petal.Length 1.40
 4 setosa            1 Petal.Width  0.200
 5 setosa            2 Sepal.Length 4.90
 6 setosa            2 Sepal.Width  3.00
 7 setosa            2 Petal.Length 1.40
 8 setosa            2 Petal.Width  0.200
 9 setosa            3 Sepal.Length 4.70
10 setosa            3 Sepal.Width  3.20
# ... with 590 more rows
```

- More information per row
- Combines all measurements on a single individual
- Necessary to plot matching measurements

- More information per column
- No values as column headers (tidy)
- Single observation in single row (tidy)
- Necessary to plot large amounts of data in a single plot

Wide vs. Long





- More information per row
- Combines all measurements on a single individual
- **Necessary to plot matching measurements**

- More information per column
- No values as column headers (tidy)
- Single observation in single row (tidy)
- **Necessary to plot large amounts of data in a single plot**

Function: gather()

```
> iris_obs <- mutate(iris, observation = 1:n())
> iris_obs
```

Function: gather()

```
> iris_obs <- mutate(iris, observation = 1:n())
> iris_obs
# A tibble: 150 x 6
   Sepal.Length Sepal.Width Petal.Length Petal.Width Species observation
          <dbl>       <dbl>        <dbl>       <dbl> <chr>         <int>
 1         5.10        3.50         1.40       0.200 setosa            1
 2         4.90        3.00         1.40       0.200 setosa            2
 3         4.70        3.20         1.30       0.200 setosa            3
 4         4.60        3.10         1.50       0.200 setosa            4
 5         5.00        3.60         1.40       0.200 setosa            5
 6         5.40        3.90         1.70       0.400 setosa            6
 7         4.60        3.40         1.40       0.300 setosa            7
 8         5.00        3.40         1.50       0.200 setosa            8
 9         4.40        2.90         1.40       0.200 setosa            9
10         4.90        3.10         1.50       0.100 setosa           10
# ... with 140 more rows
```

Function: gather()

```
> iris_obs <- mutate(iris, observation = 1:n())
> iris_obs
> iris_long <- gather(iris_obs, measurement, value, Sepal.Length,
Sepal.Width, Petal.Length, Petal.Width)
> iris_long
```

column name

content/values

Function: gather()

```
> iris_obs <- mutate(iris, observation = 1:n())
> iris_obs
> iris_long <- gather(iris_obs, measurement, value, Sepal.Length,
Sepal.Width, Petal.Length, Petal.Width)
> iris_long
# A tibble: 600 x 4
   Species observation measurement  value
   <chr>         <int> <chr>        <dbl>
 1 setosa            1 Sepal.Length 5.10
 2 setosa            1 Sepal.Width  3.50
 3 setosa            1 Petal.Length 1.40
 4 setosa            1 Petal.Width  0.200
 5 setosa            2 Sepal.Length 4.90
 6 setosa            2 Sepal.Width  3.00
 7 setosa            2 Petal.Length 1.40
 8 setosa            2 Petal.Width  0.200
 9 setosa            3 Sepal.Length 4.70
```

Function: spread()

```
> iris_wide <- spread(iris_long, measurement, value)
> iris_wide
```

Function: spread()

```
> iris_wide <- spread(iris_long, measurement, value)
> iris_wide
# A tibble: 150 x 6
   Species observation Petal.Length Petal.Width Sepal.Length Sepal.Width
   <chr>         <int>        <dbl>       <dbl>        <dbl>       <dbl>
 1 setosa            1         1.40       0.200         5.10        3.50
 2 setosa            2         1.40       0.200         4.90        3.00
 3 setosa            3         1.30       0.200         4.70        3.20
 4 setosa            4         1.50       0.200         4.60        3.10
 5 setosa            5         1.40       0.200         5.00        3.60
 6 setosa            6         1.70       0.400         5.40        3.90
 7 setosa            7         1.40       0.300         4.60        3.40
 8 setosa            8         1.50       0.200         5.00        3.40
 9 setosa            9         1.40       0.200         4.40        2.90
10 setosa           10         1.50       0.100         4.90        3.10
# ... with 140 more rows
```