

A Short Introduction to Working With Data in R

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Prerequisites

- Access to a copy of the  software
 - ▶ Get it from www.r-project.org, or ask your system administrator.
- Tidyverse packages installed on the same system as R
 - ▶ Please run this command in R *before* the workshop:

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

- Download the [workshop files](#), including these slides, data, and scripts.
 - ▶ The workshop assumes the same file structure as in the link above.
- Knowledge of common mathematical operations: arithmetic, logarithms, etc.
- Knowledge of basic R concepts, such as *variables*, *objects*, *operators*, *functions*, *packages*, etc.
 - ▶ This is covered in the first workshop: “A Gentle Introduction to R”

Section 1

Welcome

Pop Quiz

We will review these *at the end*, so you can see how much you have learned.

- If multiple packages have functions with the same name, how can you specify which one to use?
- Does R store data in memory or temporary files?
- What is the limit to the size of objects and datasets that can be loaded into R?
- TRUE or FALSE: R has rules and conventions for naming functions
- TRUE or FALSE: if you use one package from the tidyverse, you have to use all of them.

Answer in the chat:

What is your favourite emoji? Why do you like to use it so much?

Introductions

- Name
- Job title, role

If you are comfortable sharing:

- Pronouns
- A hobby or activity you enjoy
- What are you hoping to learn most in today's workshop?

Learning Objectives

- Load tabular data into R
- Explore data to check that it was loaded correctly
- Export data from R to external files
- Data frames
- Clean data
 - ▶ re-arrange & modify rows
 - ▶ Add & change columns
 - ▶ Edit values systematically
 - ▶ Change data types
- Tidy data
 - ▶ Change the *shape* of a data frame
- Re-use code, reproducible results, automated reports
 - ▶ Scripts
 - ▶ R Markdown, R Notebooks

Disclaimer

- There is often more than one way to achieve a desired result in R
- Some are faster in certain situations
- Some require less code, or are easier to write as code
- Some are more portable (work on multiple systems)
- But there is rarely as single 'best way'.

This workshop focuses on a coherent approach, that can be learned more easily and extended as needed to tackle bigger problems.

Feel free to take what you learn here and experiment, or explore alternatives. Find what works for *you*.

Section 2

File Paths and The Working Directory

The Working Directory

- When working with external files, it helps to know the current *working directory*
 - ▶ Any paths supplied to R functions will be relative to this path.

```
getwd()
```

- You can change the working directory with this command:

```
setwd('path/to/a/directory')
```

File paths

- A *file path* is a *character string* that represents the location of a file in your system (computer and OS)
- The format of paths can depend on the operating system (OS)
 - ▶ Some use "/" to separate directories
e.g., `"/dir/subdir"`
 - ▶ Windows uses "\"
e.g., `"C:\\dir\\subdir"`
R uses this as an escape character in strings, and must be escaped itself in paths (`"\\\"`)
e.g., `"C:\\\\dir\\subdir"`

Paths in R

- R generally uses and understands "/" in paths, even on Windows.¹
 - ▶ e.g., "C:/dir/subdir"
 - ▶ on Windows, it also understands Windows-style paths:
e.g., "C:\\\\dir\\subdir"
- R also has platform-independent functions for manipulating paths, such as `file.path()`, which I will use in examples to make them as reproducible as possible.

¹For the gory details, see section 14.2 “Filepaths” in “An Introduction to R” (`help.start()`), `?file.path`, and documentation for related functions.

My paths are not like yours

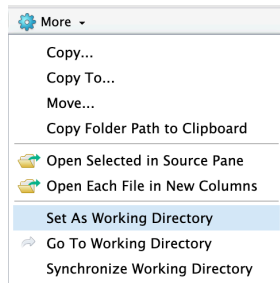
- Directory (folder) names can also vary from one computer to another — it's difficult to show a path in this document that will also work on your computer!
- Once you set a working directory *on your computer* based on the structure of the files in this project, we can use *relative paths* that should also work on your computer (assuming you downloaded the workshop files in the same structure as provided).

Set the working directory

- For this workshop, set the working directory to location where you downloaded this presentation and accompanying files.
 - ▶ the directory that *contains* the folder named 'data' that you downloaded along with the files for this workshop.
- Base R on Mac / Linux:
 - ▶ Menu item: "Misc > Change Working Directory..."
 - ▶ CMD+D on Mac; CTL+D on Linux (or Windows)
- In RStudio, you can use the *Files* pane (default bottom-right) to navigate to a directory in your system, and click on "*More > Set As Working Directory*"
 - ▶ or "*Session > Set Working Directory > To Files Pane Location*" in the RStudio menu.

- Base R on Windows:

```
setwd( choose.dir() )
```



Check your working directory

- Check to see that the working directory is in the right place, by checking to see if a known file exists (from R's perspective):

```
DF_path <- file.path("data", "data_example.csv")  
file.exists(DF_path)
```

```
# [1] TRUE
```

- If the result of the statement above is not “**TRUE**” in your session, try one of the [other approaches](#) to change your working directory, and try again.

Section 3

Loading Data into R

csv files

- 'csv' = **C**omma **S**eparated **V**alues
 - ▶ files in this format have a '.csv' file extension.
- They are:
 - ▶ plain text files
 - ▶ used to represent tabular data, with each *row* on a line, and values in each *column* separated by commas (,)
 - ▶ readable by a wide variety of analysis software (highly portable)
 - ▶ simple—no embedded metadata
- We'll try to load this file into R:
example_data.csv
 - ▶ *optional: you can try opening it in a text editor, or spreadsheet software, to see what's in the file.*

Load a csv file into R (basic)

```
?read.csv
```

```
read.csv(DF_path)
```

```
# Error in read.table(file = file, header = header, sep = sep, quot
```

```
#   more columns than column names
```

Load a csv file into R (basic)

```
?read.csv
```

```
read.csv(DF_path)
```

```
# Error in read.table(file = file, header = header, sep = sep, quote = quote, as.is = as.is,
#   more columns than column names
```

- Uh oh! Something's not right.

Check the file contents

- Let's take a peek at the first few lines and see if we can identify the problem:

```
readLines(DF_path, n = 4)
```

```
# [1] "Data from an experiment on the cold tolerance of the grass sp  
# [2] "Modified from `data(CO2)`. See `?CO2`."  
# [3] "Type,Treatment,PlantNum,95,175,250,350,500,675,1000"  
# [4] "Quebec,nonchilled,1,16,30.4,34.8,37.2,35.3,39.2,39.7"
```

Check the file contents

- Let's take a peek at the first few lines and see if we can identify the problem:

```
readLines(DF_path, n = 4)
```

```
# [1] "Data from an experiment on the cold tolerance of the grass s  
# [2] "Modified from `data(CO2)`. See `?CO2`."  
# [3] "Type,Treatment,PlantNum,95,175,250,350,500,675,1000"  
# [4] "Quebec,nonchilled,1,16,30.4,34.8,37.2,35.3,39.2,39.7"
```

- The first **2** lines don't look like comma-separated values!
- They look like extra information that is not part of the data table *structure*.

Load a csv file into R

- We can tell R to skip the lines with no data:
 - ▶ and we'll *assign* the result to a variable so we can work on it

```
DF <- read.csv(DF_path, skip = 2)
```

- Just because there were no Errors from R, doesn't mean there's nothing wrong with the data!

Section 4

Exploring Your Data

Object class: data frame

Before we explore our new data set, let's quickly review the kind of *object* we're dealing with:

```
class(DF)
```

```
# [1] "data.frame"
```

```
typeof(DF)
```

```
# [1] "list"
```

Data frames

head(): peek at the first few rows

```
head(DF)
```

```
#      Type  Treatment PlantNum  X95 X175 X250 X350
# 1 Quebec nonchilled         1 16.0 30.4 34.8 37.2
# 2 Quebec                2 13.6 27.3 37.1 41.8
# 3 Quebec                3 16.2 32.4 40.3 42.1
# 4 Québec        chilled         1 14.2 24.1 30.3 34.6
# 5 Québec                2  9.3 27.3 35.0 38.8
# 6 Québec                3 15.1 21.0 38.1 34.0
#
#           X500  X675 X1000
# 1           35.3  39.2  39.7
# 2           40.6  41.4  44.3
# 3           42.9  43.9  45.5
# 4 32.5 (umol/m^2 sec) 35,4  38.7
# 5           38.6  37,5  42.4
# 6           +38.9  39,6  41.4
```

Dimensions (rows & columns)

```
dim(DF)
```

```
# [1] 13 10
```

```
nrow(DF)
```

```
# [1] 13
```

```
ncol(DF)
```

```
# [1] 10
```

Names of elements (columns)

`names`(DF)

```
# [1] "Type"      "Treatment" "PlantNum"  "X95"  
# [5] "X175"      "X250"      "X350"      "X500"  
# [9] "X675"      "X1000"
```

`colnames`(DF)

```
# [1] "Type"      "Treatment" "PlantNum"  "X95"  
# [5] "X175"      "X250"      "X350"      "X500"  
# [9] "X675"      "X1000"
```

`rownames`(DF)

```
# [1] "1" "2" "3" "4" "5" "6" "7" "8" "9" "10" "11"  
# [12] "12" "13"
```

Look at a column

Remember: you can refer to elements within a data frame by *name*.

```
DF[, "Treatment"]
```

```
# [1] "nonchilled" "" "" "chilled"
# [5] "" "" "nonchilled" ""
# [9] "" "chilled" "" ""
# [13] ""
```

```
unique(DF$Type)
```

```
# [1] "Quebec" "Québec" "Mississippi"
```

!

Looks like there might be some missing values in the Treatment column, and inconsistencies in the Type column. We'll learn how to fix those soon, but these simple functions are already helping us understand our data.

str(): structure of an object

```
str(DF)
```

```
# 'data.frame': 13 obs. of 10 variables:
# $ Type      : chr  "Quebec" "Quebec" "Quebec" "Québec" ...
# $ Treatment: chr  "nonchilled" "" "" "chilled" ...
# $ PlantNum  : int  1 2 3 1 2 3 1 2 3 1 ...
# $ X95       : num  16 13.6 16.2 14.2 9.3 15.1 10.6 12 11.3 10.5 .
# $ X175      : num  30.4 27.3 32.4 24.1 27.3 21 19.2 22 19.4 14.9
# $ X250      : num  34.8 37.1 40.3 30.3 35 38.1 26.2 30.6 25.8 18.
# $ X350      : num  37.2 41.8 42.1 34.6 38.8 34 30 31.8 27.9 18.9
# $ X500      : chr  "35.3" "40.6" "42.9" "32.5 (umol/m^2 sec)" ...
# $ X675      : chr  "39.2" "41.4 " "43.9" "35,4" ...
# $ X1000     : num  39.7 44.3 45.5 38.7 42.4 41.4 35.5 31.5 27.8 2
```

Tip

The `str()` and `names()` functions can be used with **any** object.

summary(): statistical summaries by column

```
summary(DF)
```

```
#      Type      Treatment      PlantNum
# Length:13      Length:13      Min.    :1
# Class :character Class :character 1st Qu.:1
# Mode  :character Mode  :character Median :2
#                                           Mean  :2
#                                           3rd Qu.:3
#                                           Max.   :3
#
#      X95      X175      X250
# Min.    : 7.7   Min.    :11.4   Min.    :12.3
# 1st Qu.:10.5   1st Qu.:18.0   1st Qu.:23.9
# Median :11.3   Median :21.0   Median :30.4
# Mean   :11.9   Mean   :21.4   Mean   :28.9
# 3rd Qu.:14.2   3rd Qu.:27.3   3rd Qu.:35.5
# Max.   :16.2   Max.   :32.4   Max.   :40.3
#                                           NA's    :1
#      X350      X500      X675
# Min.    :13.0   Length:13   Length:13
```

Simple plots

```
plot(DF)
```



Spreadsheet-like View()

View(DF)

- This command opens a data frame in a spreadsheet-like view, which can be easier to navigate.
- In RStudio, you can achieve the same thing by clicking on an object name in the '*Environment*' pane (default upper-right)
 - ▶ The `View()` pane in RStudio (default upper-left; '*Source*') also allows for sorting and filtering, but these do not change the object in your session, only the view.

Encoding non-English characters

- If you are running R in Windows, you may notice that some values of the Type column look strange:
“**QuÃ©bec**” instead of “Québec”
- There is nothing wrong with the file — this indicates a *mismatch* between the *encoding* used to write the file, and what R used to read it.
- Even though ‘.csv’ files are plain text, letters (especially non-english characters) can be *encoded* in different ways to represent them in the computer.
- “UTF-8” is a character encoding standard designed to handle many non-english characters.
 - ▶ The example data file was written in “UTF-8”
 - ▶ Most OSes and many programs use “UTF-8” encoding by default.
 - ▶ But *Windows* uses “latin1” by default, and so does R (< 4.2.0) when running in Windows.
 - ▶ Starting with v4.2.0, R uses “UTF-8” as the default encoding on Windows.

Read a csv file with a different encoding

- You can specify the encoding used in the file with the ‘encoding’ argument of `read.csv()`

```
DF <- read.csv(DF_path, skip = 2, encoding = "UTF-8")
```

- If reading a file that was created on a Windows computer and encoded in “latin1”, on a different system (mac, Unix, linux, etc.) — or a recent version of R (≥ 4.2) on Windows — you can specify that, too:

```
read.csv(DF_path, skip = 2, encoding = "latin1")
```

Microsoft Excel on Windows

Excel in Windows is capable of saving files in .csv format with “UTF-8” encoding, but it adds extra contents to the file (a “BOM”) that makes it difficult to read with `read.csv()`.

See the “Extras” document from this workshop for details on how to deal with that.

Or use the `readr` package (coming up) and don't worry about it. :)

Know Your Data

- These functions are useful for exploring different aspects of a loaded data set
- But they won't tell you if these are *correct*.
- Ideally, you should always “Know Your Data”, and use these functions to verify that the data was loaded correctly.
 - ▶ Are the number of rows and columns what you expected?
 - ▶ Are the different columns of the expected type (numeric, character, etc.)?
 - ▶ Are the values in the expected range and format?
 - ▶ Is anything missing, or different than expected?

The CO2 dataset: background

The example data file is based on the 'CO2' dataset available in R (?CO2), with a few changes added to make things interesting.

From the documentation:

The CO2 uptake of six plants from Quebec and six plants from Mississippi was measured at several levels of ambient CO2 concentration. Half the plants of each type were chilled overnight before the experiment was conducted.

Exercise 1: what's wrong with this data?

The original dataset has the following properties (`str(CO2)`):

- 84 rows and 5 columns

Column Name	Description
Plant	factor with 12 levels: Qn1, Qn2, ... Mc3, Mc1
Type	factor with 2 levels: "Quebec" and "Mississippi"
Treatment	factor with 2 levels: "nonchilled" and "chilled"
conc	numeric: ambient carbon dioxide concentrations (mL/L)
uptake	numeric: carbon dioxide uptake rates ($\mu\text{mol}/\text{m}^2\cdot\text{sec}$)

Your turn

Using the functions described in this section, can you identify some possible issues and differences with the data set you loaded?

Spoiler alert: suggested answers on the next slide.

Exercise 1: what *is* wrong with this data

- The data we loaded has different dimensions!
 - ▶ Values from the `conc` column are shown as *column names*
 - ▶ `uptake` values are the values of these columns
 - ▶ This isn't necessarily *bad*: such a structure can be useful for presentation and interpretation by people, but it is not *tidy* and less convenient for analysis & visualization (more on this later).
- Some of the `uptake` values are *character*, but should be *numeric*
- One of the `Type` values is spelled inconsistently: "Quebec"/"Québec"
- Some values in the `Treatment` column are empty
 - ▶ The value is only included when it changes
- The `PlantNum` column does not contain a unique identifier, as in the original `Plant` column
 - ▶ The values are no longer *unique*, without also considering the `Type` and `Treatment` columns.

There are other differences you may have noticed: we'll look at ways to identify these automatically later.

Section 5

Re-using your code: scripts and other files

Re-using code

Before we practice cleaning our data, and saving it to use later ...

- Imagine having to repeat the multiple steps to *load*, *clean*, and *save* a dataset.
 - ▶ How will you remember which *packages* you had to load?
 - ▶ How will you remember *all* the steps, and their order?
 - ▶ What if you need to change *one* step, but repeat all preceding steps?
 - ▶ How can you share your code with others, so that they can check your work, or replicate your results?
 - ▶ How will you write out complex operations that require multiple steps, repeated operations, or only do things under certain conditions?
- The answer to all of these questions is: a ***script***

Scripts and related files will also make it easier for you to follow along with examples as they get more complicated—copy & paste into the console less often!


Scripts

An R *script* is a file that stores R code in *plain text*

- They have a .R file extension
- They are plain text files
 - ▶ so any text editor can read & write them
 - ▶ they also work well with version control systems, like [git](#), [GitHub](#), and [GitLab](#))
- All the code in a script can be run in order
 - ▶ i.e., a *program*
- They make it easy to re-use code
- Scripts provide a record of the steps in a program or analysis
 - ▶ results are more *reproducible*
 - ▶ the code is a form of documentation

Make a new script

- In your R interface (R GUI, RStudio, IDE, etc.), open a new R script

Application	Menu item	Keyboard shortcut (mac shortcut)
R GUI	File > New Document	CTL+N (CMD+N)
RStudio	File > New File > R Script	Shift+CTL+N (Shift+CMD+N)
		

- Save it with a name like “my_first_script.R”
 - ▶ You can save it in the same location as the slides for this workshop (i.e., the folder *containing* the ‘data’ folder.)

Add some code to your script

- Paste in the following code to your script file:

```
DF_path <- file.path("data", "data_example.csv")
file.exists(DF_path)

DF <- read.csv(DF_path, skip = 2, encoding = "UTF-8")

colnames(DF)
plot(DF)
```

- and save it.

Run R code in scripts

Most IDEs have a shortcut to send portions of R code (a line or *statement* spanning multiple lines) to an R session:

- R GUI: CTL+Return (mac: CMD+Return)
- RStudio: CTL+Return (mac: CMD+Return)

You can run *all* the code in a script in different ways:

- The `source()` function, with a path to the script file as an argument
 - ▶ The code will run in the current session.
 - ▶ `?source`
 - ▶ `source("my_script.R")`
- Run R in “*batch mode*”
 - ▶ “*batch mode*” is **not** interactive (no prompt)
 - ▶ It is usually invoked from a terminal or other command-line (outside an R GUI)
 - ▶ The code in the script will run in a new session
 - ▶ You can capture output in a separate file
 - ▶ `?BATCHE`

Comments

- The '#' character denotes a *comment* in R
 - ▶ *Everything on a line* after a comment character is ignored by R
 - ▶ There are no 'multi-line' comments in R

```
print("this is R code") # this is a comment
```

- You can make an entire line a comment by putting a comment character at the beginning.
 - ▶ Divide your code into *sections*
Shift+CTL+R (Shift+CMD+R) in RStudio

```
# SECTION -----
```

- ▶ Create 'comment headers' for your scripts:

```
#####  
### Title  
### Project or description  
### Author Name           R vX.X.X           YYYY-MM-DD  
#####
```

Comments in code


- You can put a comment beside a line of code (even in the middle of a multi-line statement)
 - ▶ R will ignore the rest of the line, and continue reading code on the next line

```
DF <-          # short for "data frame"
read.csv(      # read a csv file
  DF_path,     # path to file
  skip = 2     # skip lines at top of file (not data)
)
```

- Use comments to
 - ▶ organize your code (divide it into sections)
 - ▶ explain the code, where relevant
 - ▶ “comment-out” code temporarily, to stop it from running without deleting it (useful for debugging).
- Shift+CTL+C (Shift+CMD+C) comment a line in RStudio

Open a script

- All the code shown in the slides for this workshop has been collected in a script file: “R_data_scripting.R” (in the ‘source’ folder)
- Open it to follow along for the rest of the workshop.

Application	Menu item	Keyboard shortcut (mac shortcut)
R GUI	File > Open Document...	CTL+O (CMD+O)
RStudio	File > Open File...	CTL+O (CMD+O)
		

Set the Working Directory to source file location in RStudio

- Menu item: "Session > Set Working Directory > To Source File Location"
- This makes it easy to use *relative paths* in your script, relative to the location of the script file itself.

For this workshop

- All the code in this document assumes that the working directory is the *parent directory* of where this file is.
- After running the menu item above to set the working directory, run this code in your console:

```
setwd("../")    # move to the parent directory  
getwd()         # check the current working directory
```

- The code in the script should now run without errors.

Section 6

The tidyverse collection of packages

The tidyverse

```
install.packages("tidyverse")  
help(package="tidyverse")
```

- The **tidyverse** is an “opinionated” collection of packages that are designed to work together.
- All packages share an underlying design philosophy, grammar, and data structures.
 - ▶ *Unlike base R*
 - ▶ Shared naming conventions (e.g., ‘_’ instead of ‘.’ in function names)
 - ▶ Emphasis on functions that do one thing well
 - ▶ Designed to be combined together to achieve complex operations
- tidyverse is under active development.
 - ▶ New functions and features sometimes replace or supersede old ones.
 - ▶ No guarantee that functions will continue to work the same way in future versions.

Core tidyverse packages

Today, we will focus on a few of the core tidyverse packages for loading, cleaning, and manipulating data:

- `readr`, `readxl` for **loading** data
- `dplyr` for **manipulating** data (values)
- `tidyr` for **reshaping** data
- `stringr` for working with **strings**

Section 7

Load Data: The readr & readxl Packages

The readr package: reading data

readr		base R	
<code>read_csv()</code>	comma separated values	<code>read.csv()</code>	
<code>read_csv2()</code>	';' as delimiter (allows ',' for decimals)	<code>read.csv2()</code>	',' for decimals, ';' as separator
<code>read_tsv()</code>	tab separated values	<code>read.delim()</code>	delimited files (tab is default)
<code>read_delim()</code>	(generic) files with any delimiter	<code>read.table()</code>	
<code>read_fwf()</code>	fixed width files	<code>read.fwf()</code>	

readr descriptions based on [#dsbox](#)

Read a csv file using read_csv()

- In keeping with Tidyverse conventions, functions are names with words separated by “_”
 - ▶ instead of “.” or camelCase, as in many base R functions

```
library(readr)
DF_readr <- read_csv(DF_path, skip = 2)
```

```
# Rows: 13 Columns: 10
# -- Column specification -----
# Delimiter: ","
# chr (3): Type, Treatment, 500
# dbl (6): PlantNum, 95, 175, 250, 350, 1000
# num (1): 675
#
# i Use `spec()` to retrieve the full column specification for this
# i Specify the column types or set `show_col_types = FALSE` to quiet
```

Exercise 2: compare results from `read.csv()` and `read_csv()`

- Use the functions we **learned earlier** to inspect and compare the results of `read.csv()` (in base R) and `read_csv()` (from the `readr` package)
- There's a script file in the `exercises` folder to get you started.
 - ▶ “R2_exercise_2.R”

Spoiler alert:

suggested answers on the next slide.

Exercise 2: comparison of `read.csv()` and `read_csv()`

- The column names are different
 - ▶ `read.csv()` automatically applies `make.names()` to the column names to make 'syntactically valid' names to use in R.
 - ▶ convenient, but not always what we want.
 - ▶ there are other 'cleaning' functions available (e.g., `clean_names()` in the `janitor` package)
- `read_csv()` automatically replaced empty strings in the Treatment column with `NA`s.
- `read_csv()` left the '675' column as numeric, but ignored the commas, resulting in larger numbers.
- `read_csv()` produces a `tbl_df` (*tibble*) object, not a simple `data.frame`

Tibbles: `data.frames` reimagined

- A 'tibble' (`class() == "tbl_df"`) is “a modern reimaging of the `data.frame`”.
 - ▶ See the [package documentation](#) for details.
- Many tidyverse functions produce tibbles by default.
- **Tibbles are *also* `data.frames`**, and *inherit* from that class.
 - ▶ functions that work with `data.frames` should also work with tibbles.
 - ▶ but some may behave differently (by design).
 - ▶ for example, `print()`ing a tibble includes slightly more information, and only prints a few rows and columns by default, preventing large datasets from overwhelming your console.
 - ▶ when indexing a tibble, it will *not* do partial matching on column names, making it clear if a column exists or not
- For most purposes, tibbles are interchangeable with `data.frames`.
 - ▶ A tibble can be converted to a 'plain' `data.frame` with `as.data.frame()` if necessary.

Tibble examples

```
print(DF_readr, n=2)
```

```
# # A tibble: 13 x 10
#   Type      Treatment PlantNum `95` `175` `250` `350` `500`
#   <chr>    <chr>         <dbl> <dbl> <dbl> <dbl> <dbl> <chr>
# 1 Quebec nonchilled         1  16    30.4  34.8  37.2  35.3
# 2 Quebec <NA>              2 13.6   27.3  37.1  41.8  40.6
# # i 11 more rows
# # i 2 more variables: `675` <dbl>, `1000` <dbl>
```

```
is.null(DF$Treat)
```

```
# [1] FALSE
```

```
is.null(DF_readr$Treat)
```

```
# Warning: Unknown or uninitialised column: `Treat`.
```

```
# [1] TRUE
```

read_csv(): column names

- The default for `read_csv()` is to ensure all column names are *unique*, but not necessarily *syntactically valid*
- You can still refer to columns with syntactically 'invalid' names:
 - ▶ use functions that allow names as characters,
 - ▶ quote names with backticks (`)

```
DF_readr[, "95"]      # still a `data.frame` (with 1 column)
DF_readr[["95"]]      # vector
DF_readr$`95`         # quoted name
```

read_csv(): treat column names

- Change how `read_csv()` treats column names with the 'name_repair' argument

```
read_csv(  
  DF_path, skip = 2,  
  name_repair = "universal" # make names unique and syntactic  
)
```

```
read_csv(  
  DF_path, skip = 2,  
  name_repair = make.names # a function: same as read.csv()  
)
```

read_csv(): guessing column types

- By default, `read_csv()` prints a message summarizing what it did, including *guessing the data type* of each column.
 - ▶ *.csv files do not include this information as metadata*
- Control how columns are guessed with the `guess_max` argument:

```
# use the first 2 rows to guess column types (less successful,  
read_csv(DF_path, skip = 2, guess_max = 2)
```

```
# Warning: One or more parsing issues, call `problems()` on your data  
# frame for details, e.g.:  
#   dat <- vroom(...)  
#   problems(dat)
```

```
# use *all* rows to guess column types  
# - slow: has to read *every row* twice.  
read_csv(DF_path, skip = 2, guess_max = Inf)
```

read_csv(): specify column types

- If you know what the column types are (or should be), you can tell `read_csv()` what they are with the `col_types` argument.
 - ▶ for large datasets, this can be faster: read rows once
 - ▶ avoid bad guesses.

```
## Specify column types with a compact string  
read_csv(DF_path, skip = 2, col_types = "cccdhddddd")
```

```
## Or use a `column specification`  
# extract specification from tibble  
col_spec <- spec(DF_readr)  
# change a column to numeric (double)  
col_spec$cols[["500"]] <- col_double()  
read_csv(DF_path, skip = 2, col_types = col_spec)
```

```
# ?read_csv for more options
```

read_csv(): all columns as strings

- In extreme cases, you can read everything as 'character', then clean and coerce to other data types within R

```
# read all columns as character  
read_csv(DF_path, skip = 2,  
         col_types = cols(.default = col_character())  
         )
```

```
# # A tibble: 13 x 10  
#   Type      Treatment PlantNum `95`  `175` `250` `350` `500`  
#   <chr>      <chr>      <chr> <chr> <chr> <chr> <chr>  
# 1 Quebec    nonchill~ 1      16    30.4  34.8  37.2  35.3  
# 2 Quebec    <NA>      2     13.6  27.3  37.1  41.8  40.6  
# 3 Quebec    <NA>      3     16.2  32.4  40.3  42.1  42.9  
# 4 Québec   chilled    1     14.2  24.1  30.3  34.6  32.5~  
# 5 Québec   <NA>      2      9.3   27.3  35     38.8  38.6  
# 6 Québec   <NA>      3     15.1  21     38.1  34     +38.9  
# 7 Mississ~ nonchill~ 1     10.6  19.2  26.2  30     30.9  
# 8 Mississ~ <NA>      2      12     22    30.6  31.8  32.4  
# 9 Mississ~ <NA>      2      11.2  19.4  25.8  27.8  28.5
```

read_csv(): missing values

- Use the `na` argument to supply a list of values to replace with `NA`.
 - ▶ This is applied to **all** columns.

```
read_csv(DF_path, skip = 2,  
         na = c(".", "NA") # will not replace empty strings  
         )
```

```
# # A tibble: 13 x 10  
#   Type      Treatment PlantNum `95` `175` `250` `350` `500`  
#   <chr>      <chr>      <dbl> <dbl> <dbl> <dbl> <dbl> <chr>  
# 1 Quebec "nonchil~      1  16    30.4  34.8  37.2  35.3  
# 2 Quebec ""          2  13.6  27.3  37.1  41.8  40.6  
# 3 Quebec ""          3  16.2  32.4  40.3  42.1  42.9  
# 4 Québec "chilled"      1  14.2  24.1  30.3  34.6  32.5~  
# 5 Québec ""          2   9.3  27.3  35    38.8  38.6  
# 6 Québec ""          3  15.1  21    38.1  34    +38.9  
# 7 Mississ~ "nonchil~      1  10.6  19.2  26.2  30    30.9  
# 8 Mississ~ ""          2  12    22    30.6  31.8  32.4  
# 9 Mississ~ ""          3  11.3  19.4  25.8  27.9  28.5  
# 10 Mississ~ "chilled"      1  10.5  14.9  18.1  18.9  19.5
```


The readxl package

Provides functions for reading from (but not writing to) Microsoft Excel files (.xls and .xlsx)

```
library(readxl)      # load the package
## Documentation: ?read_excel  help(package="readxl")
## use an example included in the package
xl_path <- readxl_example("datasets.xlsx")
excel_sheets(xl_path) # get the names of the sheets

# [1] "iris"      "mtcars"    "chickwts"  "quakes"

## read a specified sheet from the Excel file
iris_xl <- read_excel(xl_path, "iris")
```

Example 3: read a messy Excel file

- `read_excel()` has many of the same arguments as `read_csv()` to control how data is imported.
- Use the script file in the “examples” folder as a starting point:
 - ▶ “R2_exercise_3.R”

```
XL_path <- readxl_example("deaths.xlsx")  
XL <- read_excel(XL_path, ...)
```

Example 3: read a messy Excel file

- `read_excel()` has many of the same arguments as `read_csv()` to control how data is imported.
- Use the script file in the “examples” folder as a starting point:
 - ▶ “R2_exercise_3.R”

```
XL_path <- readxl_example("deaths.xlsx")  
XL <- read_excel(XL_path, ...)
```

Tip

Use the ‘range’ argument to read data from a specific range in a sheet, ignoring contents outside this range (rows above & below, columns before & after)

Section 8

Clean Data: The dplyr Package

dplyr: a grammar of data manipulation

- dplyr provides many functions that follow a coherent framework or “*grammar*”
- They are intended to help you focus on *what* you want to do, and translate your thoughts into code.
- High-level functions have active names and called “**verbs**” — they describe what they do.
- dplyr and tidyselect provide many “**helper functions**” that work *inside* verbs and other tidyverse functions to make common tasks easier to translate into code.
 - ▶ These functions may not work on their own, outside of dplyr verbs and tidyr functions (see ?“[faq-selection-context](#)”).

dplyr verbs

Verbs can be grouped based on the component of the dataset that they work with²:

- Rows:
 - ▶ `filter()` chooses rows based on column values.
 - ▶ `slice()` chooses rows based on location.
 - ▶ `arrange()` changes the order of the rows.
- Columns:
 - ▶ `select()` changes whether or not a column is included.
 - ▶ `rename()` changes the name of columns.
 - ▶ `mutate()` changes the *values* of columns and creates new columns.
 - ▶ `relocate()` changes the order of the columns.
- Groups of rows:
 - ▶ `group_by()` defines groups of rows.
 - ▶ `summarise()` collapses a group into a single row.

²<https://dplyr.tidyverse.org/articles/dplyr.html#single-table-verbs>

Load dplyr

- When you load dplyr, you may see a message saying “objects are masked”:

```
library(dplyr)
```

```
#  
# Attaching package: 'dplyr'  
  
# The following objects are masked from 'package:stats':  
#  
#   filter, lag  
  
# The following objects are masked from 'package:base':  
#  
#   intersect, setdiff, setequal, union
```

- Some functions in dplyr have the same name as functions in other packages! (base, stats)

package::object notation

- When an “object is masked”, it means the new one (dplyr function) will take precedence over the one being “masked” when a function of that name is called.

```
?filter # more than one result!
```

- To avoid confusion, you can specify which package you mean with the “package::object” notation (*functions* are a class of *object*):

```
?filter # more than one result
?dplyr::filter
?stats::filter
```

- Because dplyr has *masked* the names from the other packages, we can simply call these functions normally (e.g., `filter()`), but if we wanted to use a masked function, we would have to use the special notation: `stats::filter()`
 - ▶ We won't be using the masked functions today, however.

Columns: `select()`

- Select (and rename) columns in a data frame, using a concise mini-language (<tidy-select>)
- Select by name: 'bare names', like regular variables; or character names

```
select(DF, Type, Treatment, PlantNum)
select(DF, "Type", "Treatment", "X95")
select(DF, Type:PlantNum)
```

- Select by position:

```
select(DF, 2:5)
```

- or both, while changing names and order along the way:

```
select(DF, c(Type, 4:6, Plant = PlantNum))
```

Columns: selection helpers

- Various **helper functions** (*selection helpers*) add ways to `select()` columns *based on criteria* (dynamically).
- Some examples (see `?select` for more):

```
select(DF, starts_with("X"))
```

```
select(DF, !starts_with("X"))
```

```
select(DF, contains("m"))
```

```
select(DF, where(is.character) & starts_with("X"))
```

```
select(DF, any_of(c("Type", "Treatment", "95")))
```

Columns: selection helpers

- Various **helper functions** (*selection helpers*) add ways to `select()` columns *based on criteria* (dynamically).
- Some examples (see `?select` for more):

```
select(DF, starts_with("X"))
select(DF, !starts_with("X"))
select(DF, contains("m"))

select(DF, where(is.character) & starts_with("X"))

select(DF, any_of(c("Type", "Treatment", "95")))
```

- `starts_with()` & `contains()` match *patterns* in names
- `where()` applies a function (`is.character()`, in this case) to each column: those where the function returns **TRUE** are kept.
- `any_of()` matches names in a character vector;
`all_of()` is similar, but names that don't exist cause an *error*.

Rows: `filter()`

- `filter()` retains rows that satisfy *all* the conditions specified
 - ▶ expressions must return a vector of *logical* values (**TRUE** or **FALSE**)

```
filter(DF, X95 < 10)
filter(CO2, conc == 95, uptake < 10)
filter(CO2, conc == 95 | uptake < 10) # | == "OR" operator

filter(DF, Treatment != "")
filter(DF, !Type %in% c("Quebec", "Mississippi"))
filter(DF, !Type %in% unique(CO2$Type))

filter(DF, X175 > mean(X175))
```

`select()` & `filter()` work well together

- For example, you can filter on a column, then remove it with `select()`

```
select( filter(DF, Treatment == "chilled"),  
        where(is.numeric)  
)
```

```
#   PlantNum  X95 X175 X250 X350 X1000  
# 1         1 14.2 24.1 30.3 34.6  38.7  
# 2         1 10.5 14.9 18.1 18.9  21.9
```

- But this is clunky! This is easier to follow:

```
DF %>% filter(Treatment == "chilled") %>%  
  select(where(is.numeric))
```

```
#   PlantNum  X95 X175 X250 X350 X1000  
# 1         1 14.2 24.1 30.3 34.6  38.7  
# 2         1 10.5 14.9 18.1 18.9  21.9
```

A 'pipe' operator

- `%>%` allows you to pass results from an expression on the left-hand side (LHS) as an argument (usually the first) to a *function call* on the right-hand side (RHS).
 - ▶ you can read a pipe operator as “then” (a `%>% b()` = “*a then b*”)

This expression ...

is equivalent to:

`x %>% f()`

`f(x)`

`x %>% f(y)`

`f(x, y)`

`x %>% f(y, z = .)`

`f(y, z = x)`

`x %>% f %>% g %>% h`

`h(g(f(x)))`

- This can make code easier to read, as expressions are written and evaluated from *left to right*, rather than from *inside to outside* nested parentheses.

magrittr's 'forward-pipe' operator



Figure 1: “La Trahison des Images” (“The Treachery of Images”) or “Ceci n'est pas une pipe” (“This is not a pipe”) by René Magritte.



- The `magrittr` package (included with `tidyverse`) provides a “forward-pipe operator”:

```
%>% # ?magrittr::`%>%`
```

- The `magrittr` package is automatically loaded when loading most `tidyverse` packages (e.g., `tidyr`, `dplyr`, `ggplot2`).
 - ▶ These packages were designed to work with this operator, and use it themselves.
 - ▶ It is often unnecessary to load `magrittr` separately, unless you are **not** using these other packages.

R now has a ‘native’ pipe operator

- A pipe operator was introduced in base R in v4.1 (May 2021)³:

```
|>      # ?pipeOp
```

- It was inspired by the “forward pipe operator” introduced by `magrittr`, but is more streamlined. See these links for details:
 - ▶ Differences between the base R and `magrittr` pipes
 - ▶ “Understanding the native R pipe `|>`”
- Because ‘`|>`’ is new, many examples online still use `magrittr`’s ‘`%>%`’.
- But ‘`|>`’ is always available *in R \geq v4.1*, without having to load additional packages.
- This document will use ‘`%>%`’ in the examples, for consistency and because many tidyverse functions were designed to work with it.

³<https://cran.r-project.org/bin/windows/base/old/4.1.0/NEWS.R-4.1.0.html>

Pipe: Exercise

Insert a pipe in R Studio with CTL+Shift+M (CMD+Shift+M)

Re-write the expressions using pipes:

```
# (1)  
sum(1:10)
```

```
# (2)  
filter(CO2, conc < 100)
```

```
# (3)  
filter(  
  select( DF,  
    where(is.character)  
  ),  
  Treatment == "")
```

```
# (4)  
gsub("X", "", names(DF))
```

Pipe: Exercise

Insert a pipe in R Studio with CTL+Shift+M (CMD+Shift+M)

Re-write the expressions using pipes:

```
# (1)  
sum(1:10)
```

```
# (2)  
filter(CO2, conc < 100)
```

```
# (3)  
filter(  
  select( DF,  
    where(is.character)  
  ),  
  Treatment == "")
```

```
# (4)  
gsub("X", "", names(DF))
```

```
# (1)  
1:10 %>% sum()
```

```
# (2)  
CO2 %>% filter(conc < 100)
```

```
# (3)  
DF %>%  
  select(  
    where(is.character)  
  ) %>%  
  filter(Treatment == "")
```

```
# (4)  
DF %>% names() %>%  
gsub("X", "", .)
```

dplyr conventions

All dplyr verbs (and other related tidyverse functions) share a few things in common:

- The first argument is a data frame (or tibble).
- Other arguments describe what to do with the data frame.
- You can refer to columns in the data frame directly without using `$`.
- The result is a new data frame.

These features work well with the pipe operator, and can help build clear and efficient workflows.

Because all the functions have these in common, it makes it easier to extend your understanding to new functions.

Find problematic values systematically

- Find columns that are character, but we expect to be numeric:

```
cols_charn <- DF %>%  
  select(starts_with("X") & where(is.character)) %>%  
  names()
```

- Loop through the identified column names (using `for`) and print values that would be `NA` if converted to numeric
 - `suppressWarnings()` suppresses the warnings we expect from `as.numeric()` in this case.

```
for (col in cols_charn) {  
  DF %>% select(1:3, all_of(col)) %>%  
    filter( get(col) %>% as.numeric() %>% is.na() %>%  
      suppressWarnings() ) %>%  
    print()  
}
```

```
#      Type Treatment PlantNum      X500  
# 1 Québec   chilled         1 32.5 (umol/m^2 sec)  
#      Type Treatment PlantNum X675  
# 1 Québec   chilled         1 35,4  
# 2 Québec                     2 37,5  
# 3 Québec                     3 39,6
```

Exercise

User-defined function

- Define your own functions with the `function` function!
 - ▶ function code goes between braces: `{}`
 - ▶ specify what value is returned with the `return()` function

```
'%==' <- function (v1, v2) {  
  same <- (v1 == v2) | (is.na(v1) & is.na(v2))  
  same[is.na(same)] <- FALSE  
  return(same)                # return the result  
}
```

test it:

```
c(1, NA, 3, 4 , NaN) %==% c(1, NA, 1, NA, NaN)
```

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

```
c(1, NA, 3, 4 , NaN) == c(1, NA, 1, NA, NaN)
```

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

- This code defines a function that compares two vectors, accounting for missing values (`NA`)

An infix operator

```
c(1, NA, 3, 4, NaN) %==% c(1, NA, 1, NA, NaN)
```

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

- This function is also a special type called an “*infix operator*”, which goes between two objects (it’s arguments) like an operator, instead of a ‘typical’ function call
 - ▶ it has exactly **2** arguments (lhs, rhs)
 - ▶ the name begins *and* ends with a percent symbol (%)

Modify Columns: `mutate()`

- `mutate()` creates new columns, or modifies existing ones, as functions of existing columns.
 - ▶ it is a dplyr workhorse, used for many tasks, since it allows you to modify values *systematically*.

Add columns:

```
DF %>% mutate(  
  Trt_n = Treatment %>% nchar(),  
  Xsum = X95 + X175  
)
```

Modify columns:

```
DF %>% mutate(X95 = X95 / mean(X95))
```


mutate() helper functions

- refer to values in the previous / next row with `lag()` and `lead`

```
DF %>% mutate(  
  Plant_lag = lag(PlantNum),  
  Plant_lead = lead(PlantNum, n=2)  
)
```

- refer to row numbers with `row_number()`

```
DF %>% mutate(  
  Plant_row = PlantNum < row_number()  
)
```

Define groups: `group_by()`

- dplyr verbs are applied to each group of rows
- Grouping columns are excluded from the operations

dplyr semantics

dplyr verbs and helper functions let you refer to column names of the data frame directly in their arguments as regular variables — without having to quote them as strings. But these names have different meanings (semantics) in different verbs.

- **“select semantics”** (<tidy-select>): in `select()` and similar functions, a column name refers to its *position* in the data frame.
 - ▶ you can refer to a column as a quoted string in `select()`, and it is interpreted as a reference to the column.
- **“mutate semantics”** (<data-masking>): in `mutate()`, a column name refers to a *vector of values*.
 - ▶ you cannot supply a column name as a string in `mutate()`, because it is treated as a vector of length 1, rather than a reference to a column of values.
- Many helper functions only work in one context or the other, so knowing the difference will tell you which helper functions to use when.

Cleaning some columns in the example data

- Normalize values of the 'Type' column:

```
DF_clean1_type <- DF %>%  
  mutate(  
    Type = if_else(Type == "Mississippi", Type, "Quebec")  
  )
```

Convert character columns to numeric

- To clean character columns, we will use functions from the `stringr` library, which provides many useful functions for working with, and manipulating strings.

```
library(stringr)
# help(package="stringr")
# vignette("stringr")
```

- Replace ',' with '.' in X675 column, and convert to numeric:

```
DF_clean2_675 <- DF_clean1_type %>%
  mutate(
    # Replace ",", " with "."
    X675 = str_replace(X675, ",", "."),
    # convert to numeric
    X675 = as.numeric(X675)
  )
```

Collapse groups: `summarise()`

summarise() multiple columns with across()

- `summarise()` uses *mutate semantics*, but `across()` applies a **function** to multiple columns, specified using *select semantics*
 - ▶ i.e., `across()` lets you use *select semantics* in a context where you would normally use *mutate semantics*
- A function can be specified by name
- For more complex operations, you may have to define a *custom function* or define an *ad hoc function* to include additional arguments
- You can also define ad hoc functions using a special “lambda” notation
 - ▶ refer to the value of the column with `‘.x’`

DF `%>%`

```
summarise( across(where(is.numeric), ~ sum(is.na(.x))))
```

Combine duplicate rows in example data

Exercise

Section 9

Reshape Data: The `tidyr` Package

Tidy data

“Happy families are all alike; every unhappy family is unhappy in its own way.”

— Leo Tolstoy

“Tidy datasets are all alike but every messy dataset is messy in its own way.”

— Hadley Wickham (doi: [10.18637/jss.v059.i10](https://doi.org/10.18637/jss.v059.i10))

- Tidy datasets provide a standardized way to link the *structure* of a dataset (its physical layout) with its *semantics* (its meaning).
- A **tidy dataset** follows three interrelated rules:
 - ▶ Each variable must have its own column.
 - ▶ Each observation must have its own row.
 - ▶ Each value must have its own cell.

The tidyr package

The tidyr package provides tools for making data *tidy*:

- “**Pivoting**” converts between *long* and *wide* forms.
 - ▶ `pivot_longer()` and `pivot_wider()`
- “**Rectangling**” turns deeply nested lists (e.g., JSON) into tidy tibbles.
 - ▶ *Not covered here: see the [vignette](#).*
- “**Nesting**” converts grouped data into nested data frames.
 - ▶ *Not covered here: see the [vignette](#).*
- **Splitting** and **combining** character columns.
 - ▶ `separate_...()` a single character column into multiple columns
 - ▶ `unite()` multiple columns into a single character column.
- Handling **missing values**
 - ▶ make implicit missing values explicit with `complete()`
 - ▶ make explicit missing values implicit with `drop_na()`
 - ▶ replace missing values with a known value using `replace_na()` or `fill()` them with the next/previous value

Section 10

Saving Data Outside R

The readr package: writing data

readr		base R
<code>write_csv()</code>	← comma separated values	<code>write.csv()</code>
<code>write_csv2()</code>	← allows ';' as delimiter and ',' for decimals (depending on locale)	<code>write.csv2()</code> ' ,' for decimals, ' ; ' as separator
<code>write_tsv()</code>	← tab separated values	
<code>write_delim()</code>	← (generic) files with an arbitrary delimiter	<code>write.table()</code>
<code>write_excel_csv()</code> , <code>write_excel_csv2()</code>	← include a UTF-8 Byte order mark, which indicates to Excel the csv is UTF-8 encoded	

Save our work

- Save a data frame to a .csv file:
 - ▶ it will be encoded with UTF-8 by default (on all platforms)

```
write_csv(DF_tidy, "data/data_clean.csv")  
write_excel_csv(DF_tidy, "data/data_excel.csv")
```

- Read it back in to check

```
save_test <- read_csv("data/data_clean.csv")  
save_test
```

Section 11

Sharing Code

Style

“L’enfer, c’est les autres” (“Hell is other people”)
— Jean-Paul Sartre (*“Huis clos”* / *“No Exit”*)

“Hell is other people’s code.” — programming aphorism

- The syntax of the R language is strict about some things, but not others, like white space and indentation.
- As mentioned at the beginning, there is often more than one way to do things in R
 - ▶ different styles of *naming things*
 - ▶ different name formats: `camelCase`, `snake_case`, etc.
- Reading someone else’s code that is written in a different style, or with inconsistent formatting, can be confusing.

Style Guides

- A “Style Guide” can be a useful tool to help you and your collaborators write code in a consistent style.
- It also simplifies writing code, by reducing the number of (style) decisions you have to make.
- A Style Guide is ***strongly recommended*** for teams collaborating on shared code.
 - ▶ Even if you are working alone, it can help you write cleaner code that’s easy for your *future-self* to read and understand, and for others to help you when you get stuck.

Some popular R style guides you can use (or adapt):

- The tidyverse style guide
 - ▶ based on an earlier version of Google’s style guide.
- Google’s R Style Guide
 - ▶ based on the current tidyverse style guide, above.

Section 12

Review

Exercise

Quiz Review

Section 13

Backmatter

Other packages to look at

- `data.table`: a high-performance version of `data.frame` with few dependencies.

Other packages in the tidyverse:

- `lubridate` and `hms`: for date & time values.
- `purrr`: functional programming (FP) tools for working with functions and vectors.
 - ▶ Replace for loops with code that is more efficient and easier to read.

References

Cheatsheets:

- [readr/readxl](#)
- [Data transformation with dplyr](#)
- [Data tidying with tidyr](#)

On the web:

- [Tidyverse documentation](#)
- [R for Data Science \(2e\)](#)
- [Data Science in a Box \(#dsbox\)](#)
- [An introduction to data cleaning with R](#)

R Documentation:

- [“R Data Import/Export”](#) (`help.start()`, under “Manuals”)