Reproducible data analysis using R and RStudio

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Linda Crnic Institute for Down Syndrome

Data Science for Developing Scholars in Down Syndrome Research (DS3) 2025

INCLUDE
INvestigation of Co-occurring conditions across the Lifespan to Understand Down syndromE

Linda Crnic Institute for Down Syndrome
UNIVERSITY OF COLORADO ANSCHUTZ MEDICAL CAMPUS

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DOWN SYNDROME FOUNDATION®

Useful links for this session

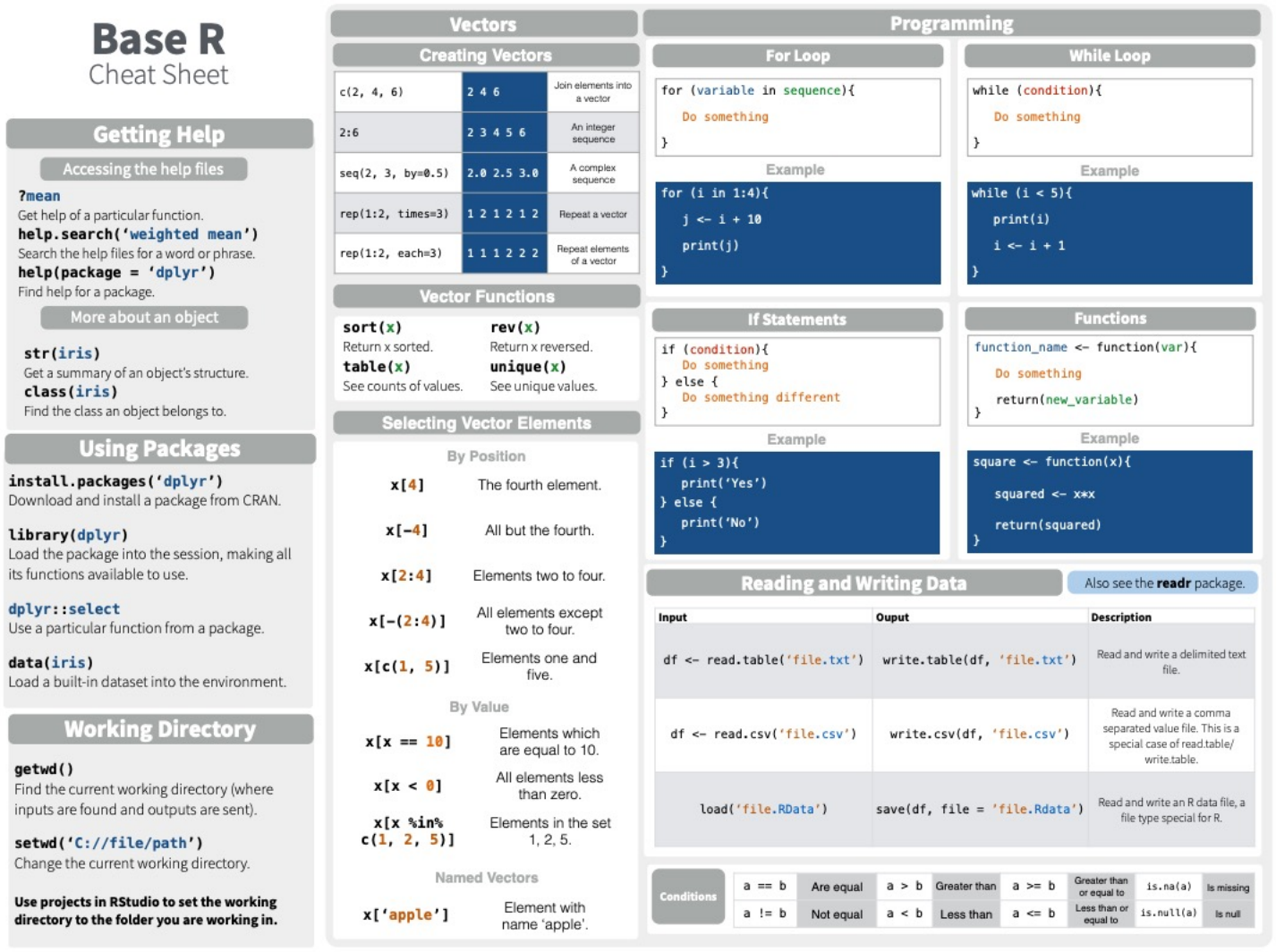
https://github.com/DS3-2025/installing_updating_R-RStudio
https://docs.posit.co/ide/user/ide/get-started/
https://rstudio.github.io/cheatsheets/base-r.pdf
https://posit.co/download/rstudio-desktop/
https://rstudio.github.io/cheatsheets/html/rstudio-ide.html

https://github.com/DS3-2025/Rproject_template
https://support.rstudio.com/hc/en-us/articles/200526207-Using-RStudio-Projects
https://r4ds.had.co.nz/workflow-projects.html

https://tidyverse.tidyverse.org/

https://ggplot2.tidyverse.org/
https://ggplot2-book.org/
https://raw.githubusercontent.com/rstudio/cheatsheets/main/data-visualization.pdf
https://www.data-to-viz.com/caveats.html
https://r-graph-gallery.com/index.html

R



Base R
Cheat Sheet

Getting Help

Accessing the help files

?mean
Get help of a particular function.

help.search('weighted mean')
Search the help files for a word or phrase.

help(package = 'dplyr')
Find help for a package.

More about an object

str(iris)
Get a summary of an object's structure.

class(iris)
Find the class an object belongs to.

Using Packages

install.packages('dplyr')
Download and install a package from CRAN.

library(dplyr)
Load the package into the session, making all its functions available to use.

dplyr::select
Use a particular function from a package.

data(iris)
Load a built-in dataset into the environment.

Working Directory

getwd()
Find the current working directory (where inputs are found and outputs are sent).

setwd('C://file/path')
Change the current working directory.

Use projects in RStudio to set the working directory to the folder you are working in.

Vectors

Creating Vectors

c(2, 4, 6)	2 4 6	Join elements into a vector
2:6	2 3 4 5 6	An integer sequence
seq(2, 3, by=0.5)	2.0 2.5 3.0	A complex sequence
rep(1:2, times=3)	1 2 1 2 1 2	Repeat a vector
rep(1:2, each=3)	1 1 1 2 2 2	Repeat elements of a vector

Vector Functions

sort(x)
Return x sorted.

rev(x)
Return x reversed.

table(x)
See counts of values.

unique(x)
See unique values.

Selecting Vector Elements

By Position

x[4]	The fourth element.
x[-4]	All but the fourth.
x[2:4]	Elements two to four.
x[-(2:4)]	All elements except two to four.
x[c(1, 5)]	Elements one and five.

By Value

x[x == 10]	Elements which are equal to 10.
x[x < 0]	All elements less than zero.
x[x %in% c(1, 2, 5)]	Elements in the set 1, 2, 5.

Named Vectors

x['apple']	Element with name 'apple'.

Programming

For Loop

```
for (variable in sequence){
   Do something
}
```

Example

```
for (i in 1:4){
   j <- i + 10
   print(j)
}
```

While Loop

```
while (condition){
   Do something
}
```

Example

```
while (i < 5){
   print(i)
   i <- i + 1
}
```

If Statements

```
if (condition){
   Do something
} else {
   Do something different
}
```

Example

```
if (i > 3){
   print('Yes')
} else {
   print('No')
}
```

Functions

```
function_name <- function(var){
   Do something
   return(new_variable)
}
```

Example

```
square <- function(x){
   squared <- x*x
   return(squared)
}
```

Reading and Writing Data

Also see the **readr** package.

Input	Ouput	Description
df <- read.table('file.txt')	write.table(df, 'file.txt')	Read and write a delimited text file.
df <- read.csv('file.csv')	write.csv(df, 'file.csv')	Read and write a comma separated value file. This is a special case of read.table/ write.table.
load('file.RData')	save(df, file = 'file.Rdata')	Read and write an R data file, a file type special for R.

Conditions

a == b	Are equal	a > b	Greater than	a >= b	Greater than or equal to	is.na(a)	Is missing
a != b	Not equal	a < b	Less than	a <= b	Less than or equal to	is.null(a)	Is null

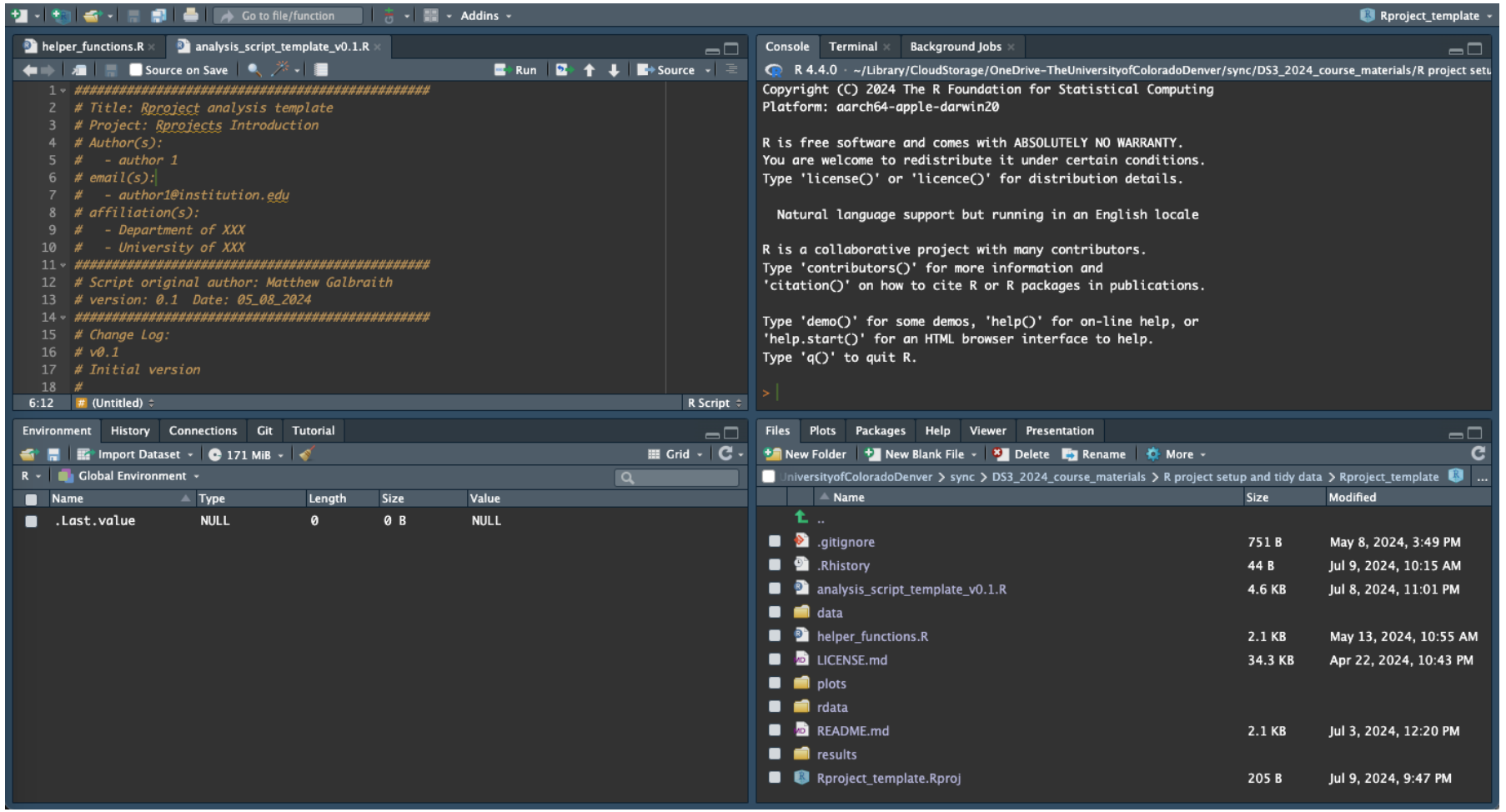
Learn more at web page or vignette • package version • Updated: 3/15

https://rstudio.github.io/cheatsheets/base-r.pdf

RStudio

Integrated Development Environment (IDE) for R

- Edit + execute R code
- Syntax highlighting, code completion, debugging
- View output, plots, help, environment



https://posit.co/download/rstudio-desktop/

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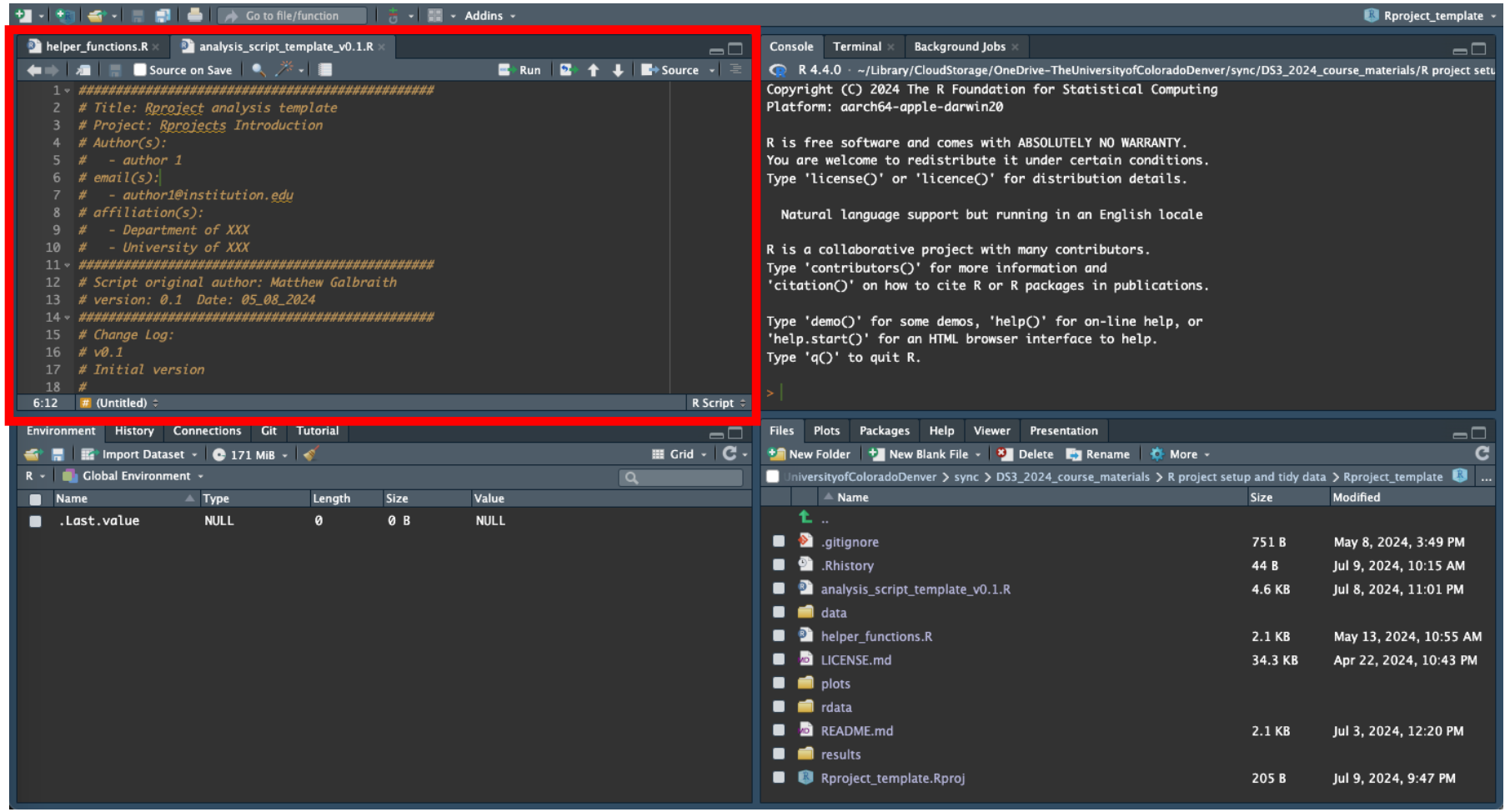
Source pane



Panes can be rearranged and customized

RStudio

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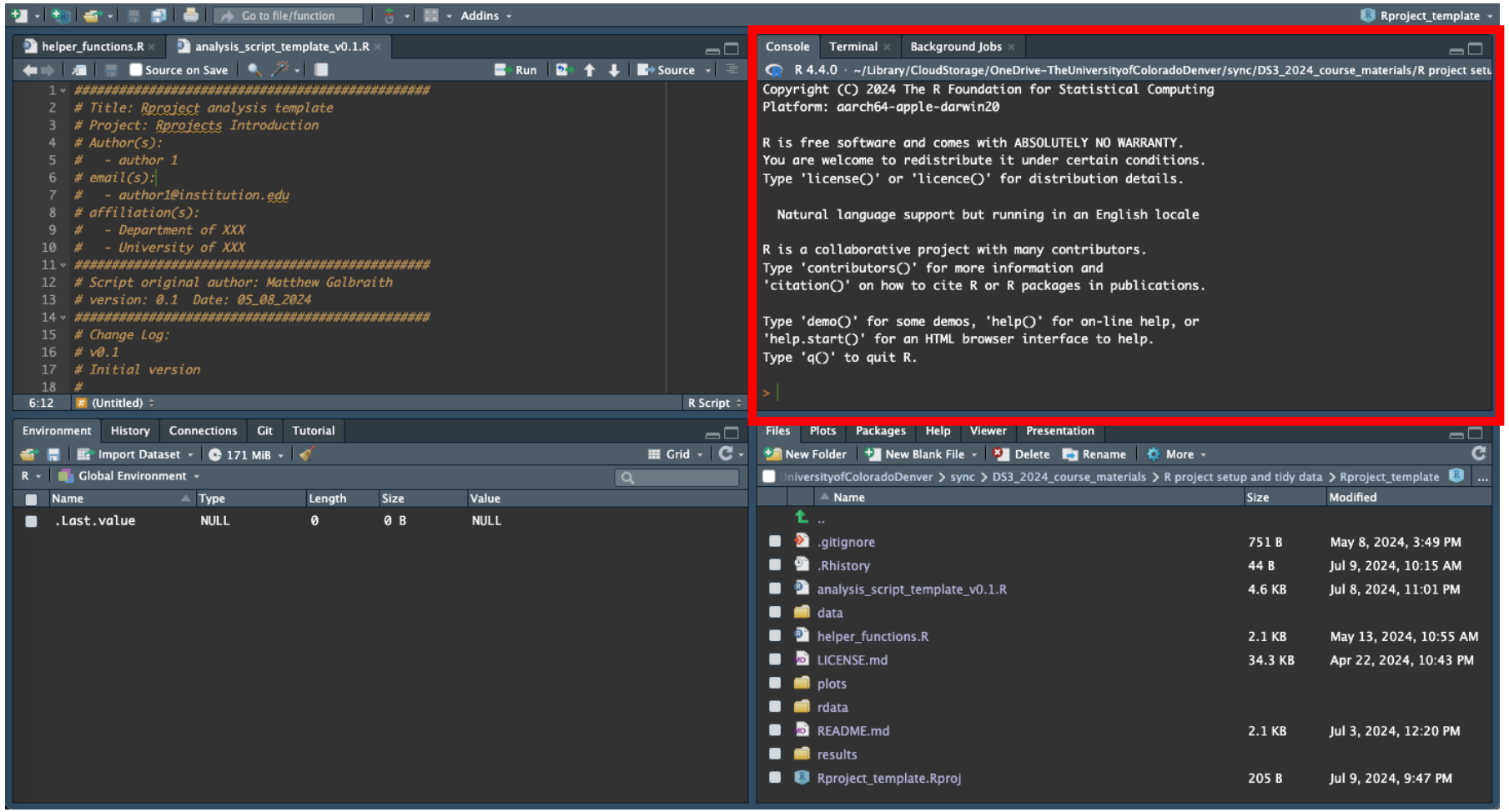

Console pane

RStudio

Integrated Development Environment (IDE) for R

- Edit + execute R code
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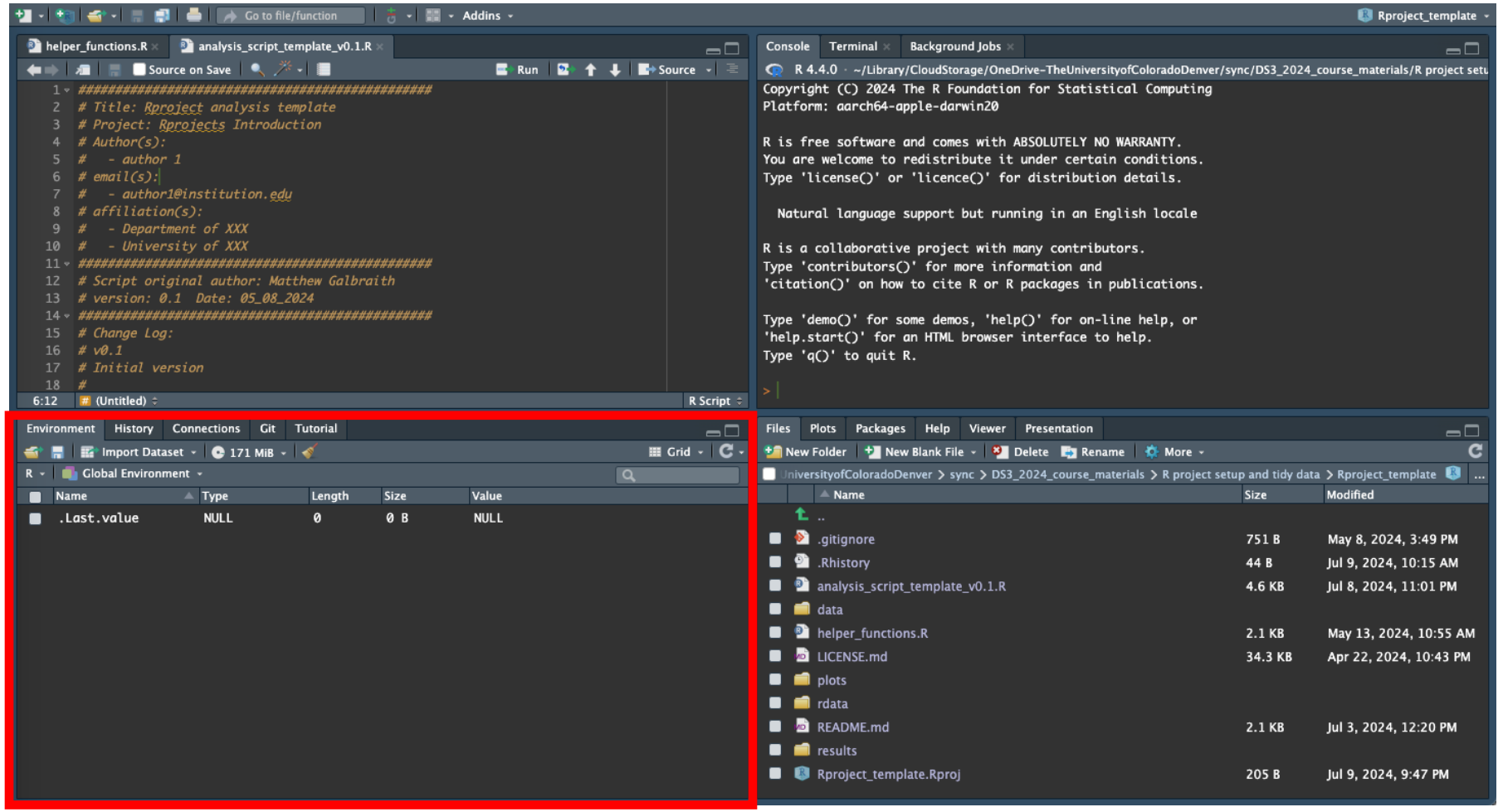
Environment etc pane



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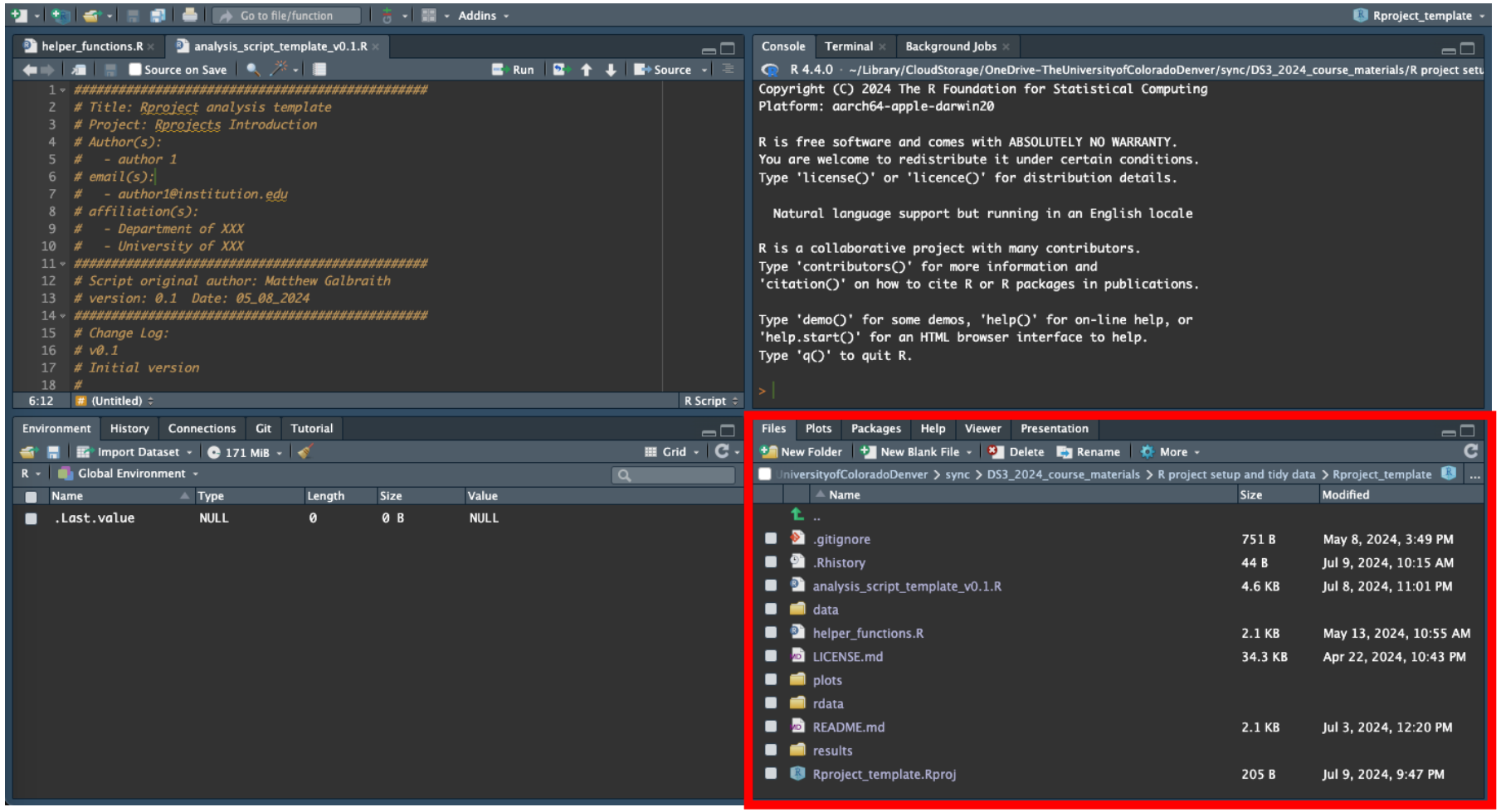


Files, Plots, Help etc pane

Rstudio – Code Sections

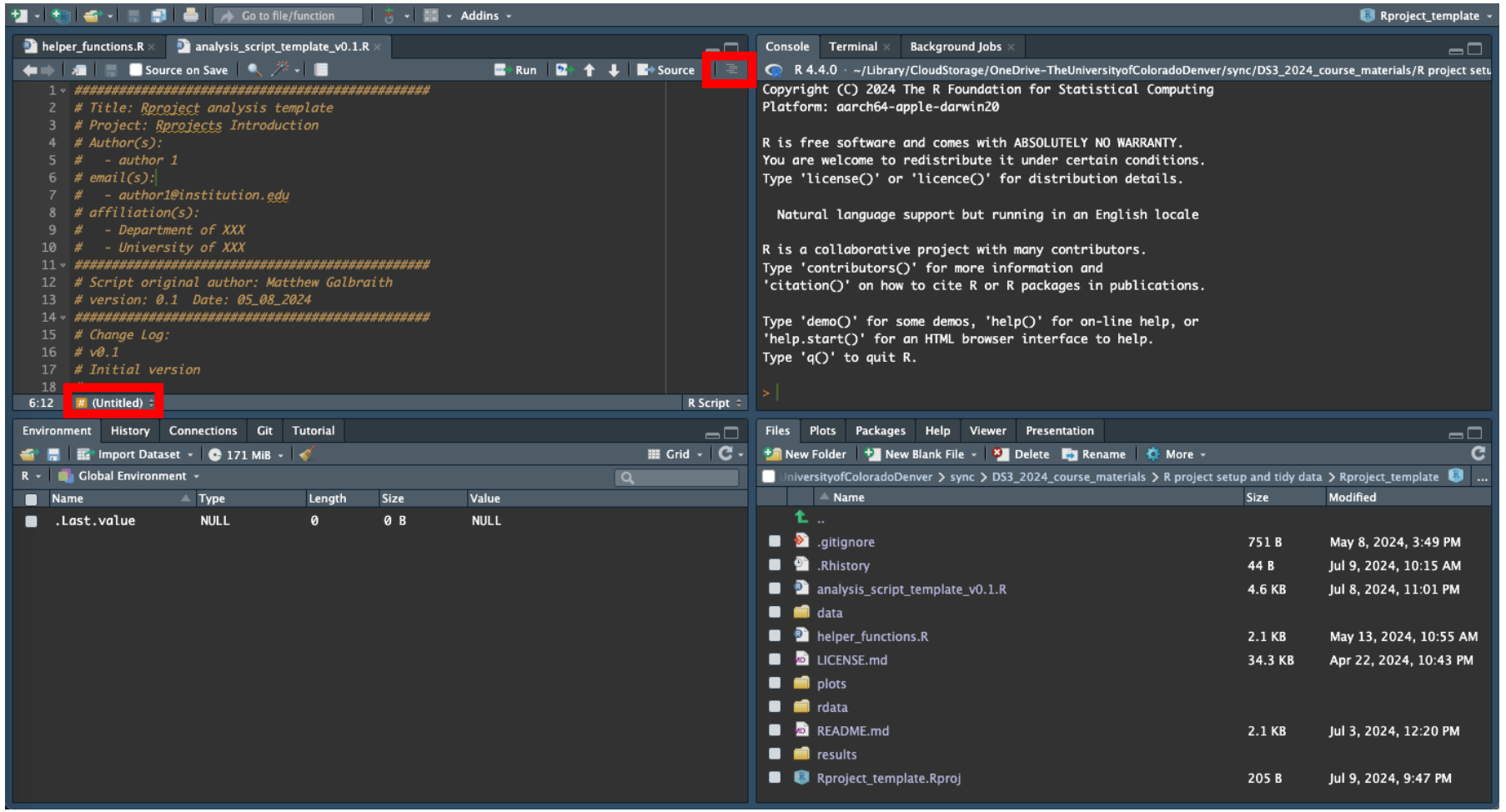
Staying organized with longer R scripts

Markdown-style comment headers, with the label followed by four or more dashes

```
# Section ----
## Subsection ----
### Sub-subsection ----
```

Show document outline

`Jump To` menu



https://support.posit.co/hc/en-us/articles/200484568-Code-Folding-and-Sections-in-the-RStudio-IDE

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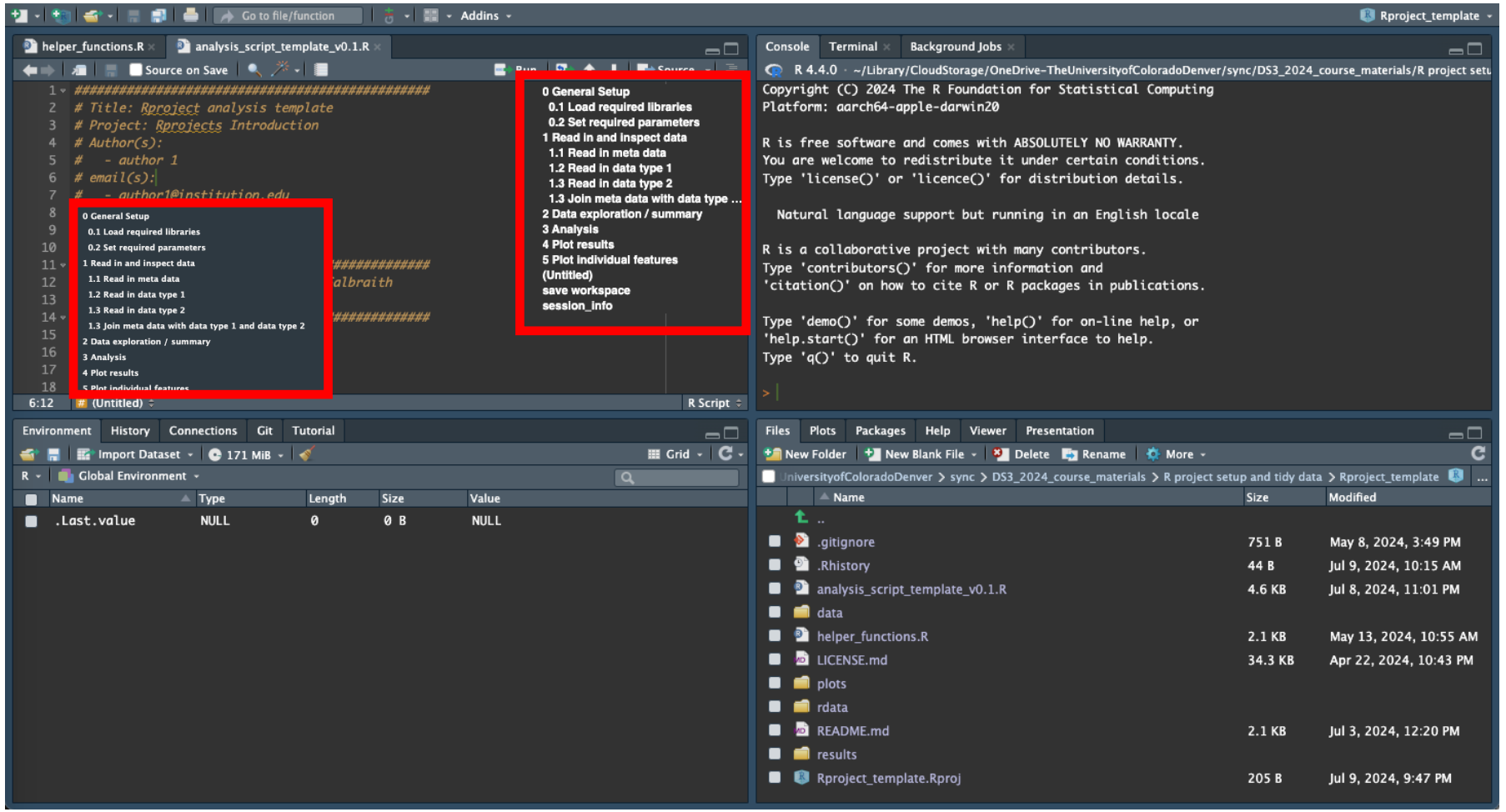

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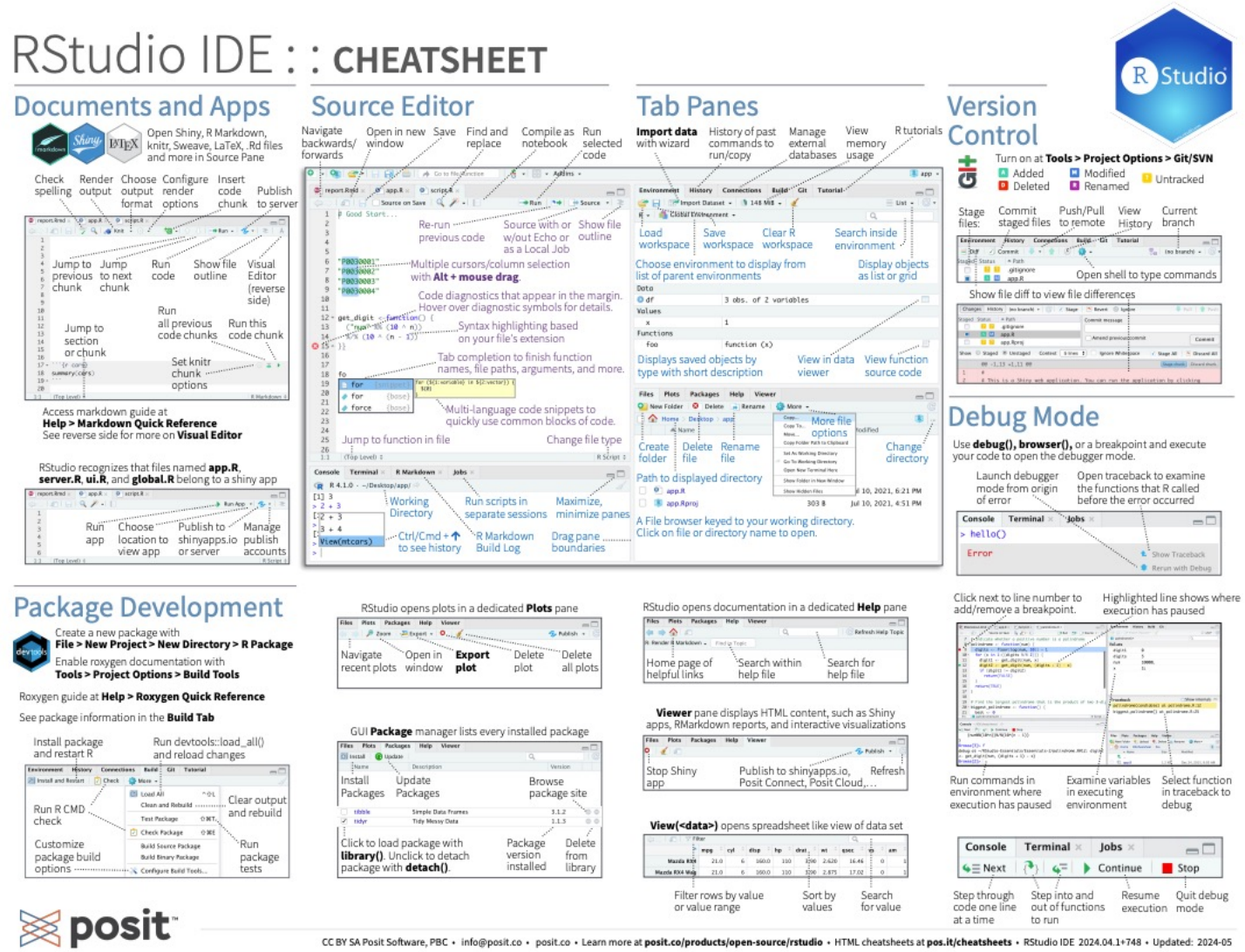
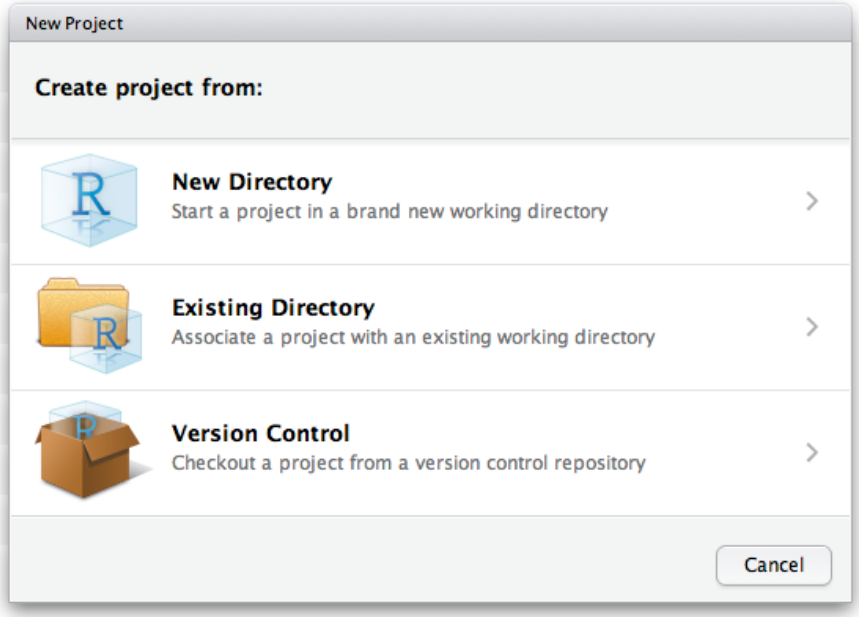
RStudio cheatsheet



https://rstudio.github.io/cheatsheets/html/rstudio-ide.html

Reproducible data analysis: RStudio Projects



- Usually open project via .Rproj file
- Automatically sets your working directory
- Self-contained set of directories, scripts, and data files (very important for multiple projects)

Organizing your Rstudio Projects

- Only **/data** and R scripts are required - everything else can be recreated (incl. earlier versions)
- Treat **/data** directory as read-only
- Analysis outputs go to **/results** or **/plots** (with version info)
- R workspace and large intermediate files stored in **/rdata**
- Additional directories added as needed, eg /Archive
- Compatible with manual or other version control

Project_directory
- **/data**
- /results
- /plots
- /rdata
- **analysis_script.R**
- **helper_functions.R**
- project.Rproj

https://support.rstudio.com/hc/en-us/articles/200526207-Using-RStudio-Projects
https://r4ds.had.co.nz/workflow-projects.html
https://github.com/DS3-2024/Rproject_template

Reproducible data analysis: Package management using renv

renv

- `install.packages("renv")`
- `renv::init()` to initialize a new project-local environment with a private R library
- `renv::install()` to install packages after initialization
- `renv::snapshot()` to save the state of your project to renv.lock
- `renv::restore()` to restore the state of your project from renv.lock

Project_directory

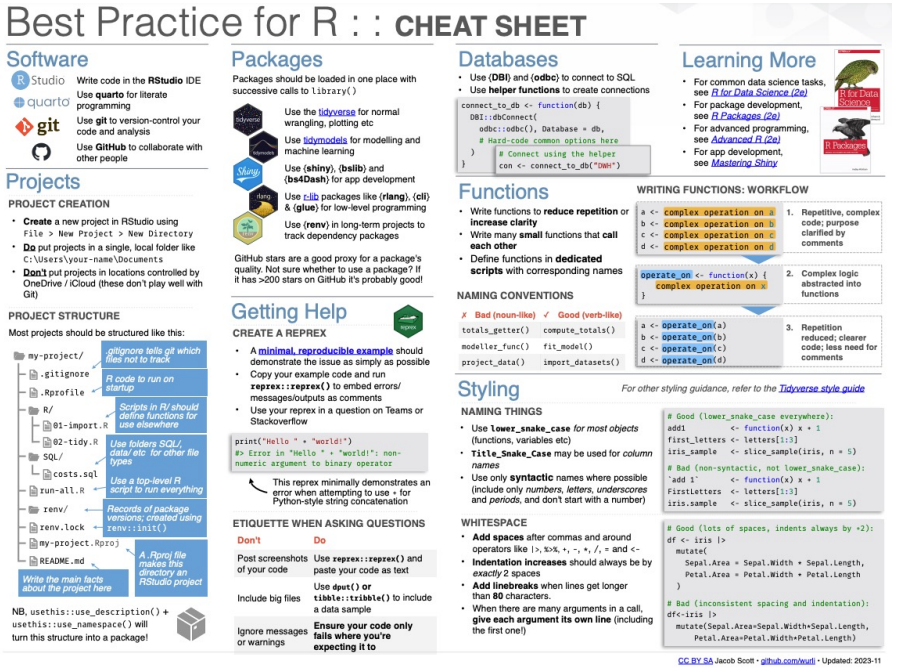
- /data
- /results
- /plots
- /rdata
- /renv
- renv.lock
- helper_functions.R
- analysis_script.R
- project.Rproj

Allows for fully self-contained R projects
(Usually) takes care of installing packages

https://rstudio.github.io/renv/articles/renv.html
https://rstudio.github.io/renv/articles/bioconductor.html

Reproducible data analysis: Best Practice

- Main analysis R script with standardized workflow (see next slides)
- Write functions to reduce repetition or increase clarity
- Define functions in dedicated script(s) (e.g. helper_functions.R) keeps main script workflow clean + makes editing easier
- Comment your code!! (but don't just write what the code is doing)
- Adopt a coding style for consistency (e.g. Tidyverse style guide)
- Track versions and log changes + filenames with versions
- Inspect the data!!!!
- Check each step!!
- Visualize your data!!!!
- Keep track of any random seeds used
- Optional: use R notebooks/R markdown/Quarto/Roxygen to allow generation of reports with code (html, pdf, etc)



https://github.com/DS3-2024/Rproject_template
https://rstudio.github.io/cheatsheets/R-best-practice.pdf

Reproducible data analysis: Standardize your workflow

Title, Project, Author(s)

```
################################################
# Title: Rproject analysis template
# Project: Rprojects Introduction
# Author(s):
#   - author 1
# email(s):
#   - author1@institution.edu
# affiliation(s):
#   - Department of XXX
#   - University of XXX
################################################
# Script original author: Matthew Galbraith
# version: 0.1  Date: 05_08_2024
################################################
# Change Log:
# v0.1
# Initial version
#
```

Keep a change log

- What was changed and why?
- When?

Reproducible data analysis: Standardize your workflow

Explain the purpose of the script + data types used

```
### Summary:
# Description of data wrangling and/or analysis being performed.
#

### Data type(s):
#   A. Meta data
#      Where/who did this data come from?
#      What is the source of the original data and where is it stored?
#   B. Data type 1
#      Where/who did this data come from?
#      What is the source of the original data and where is it stored?
#   C. Data type 2
#      Where/who did this data come from?
#      What is the source of the original data and where is it stored?
#

### Workflow:
#   1. Step 1 description
#   2. Step 2 description
#   3. Step 3 description
#   4. Step 4 description
#

## Comments:
#  Any further relevant details?
#
```

Outline the workflow steps (especially for longer scripts)

Reproducible data analysis: Standardize your workflow

Load package libraries and custom functions
Packages should be loaded in one place with successive calls to `library()`

```
# 0 General Setup -----
# Initialize and install packages with renv
# renv::init()
## 0.1 Load required libraries ----
library("tidyverse")
library("readxl") # read .xlsx files
library("openxlsx") # data export to Excel workbooks
library("skimr") # data summary and validation
library("janitor") # data cleaning etc
library("ggrepel") # labelling points in plots
library("ggforce") # sina plots etc
library("patchwork") # arranging plots
library("tidyHeatmap") # tidy interface to ComplexHeatmap
library("plotly") # generating interactive plots
library("tictoc") # timer
library("conflicted") # force all conflicts to become errors
conflict_prefer("filter", "dplyr")
conflict_prefer("select", "dplyr")
conflict_prefer("count", "dplyr")
library("here") # generate path to current project directory
#
source(here("helper_functions.R")) # load helper functions
#
```

Use comments to explain what packages are being used for
Note use of the *here* package which defines and stores project directory path
Note use of the *conflicted* package which helps manage function conflicts

Reproducible data analysis: Standardize your workflow

Define file locations and other global variables
(all input files should be in /data)

```
## 0.2 Set required parameters ----
# Input data files
meta_data_file <- here("data", "meta_data_file.txt") # comments/notes on this file?
data_type1_file <- here("data", "data_type1_file.txt") # comments/notes on this file?
data_type2__file <- here("data", "data_type1_file.txt")  # comments/notes on this file?
# Other parameters
standard_colors <- c("Group1" = "#F8766D", "Group2" = "#00BFC4")
out_file_prefix <- "analysis_script_template_v0.1_"
# End required parameters ###
```

All plots and results exports should use *out_file_prefix* (and go to /plots or /results)
Include script version number in *out_file_prefix*

Reproducible data analysis: Standardize your workflow

Read in and inspect meta data (sample and/or experiment information)

```
# 1 Read in and inspect data -----
## 1.1 Read in meta data -----
meta_data <- meta_data_file |>
  read_tsv() |>
  janitor::clean_names(case = "none")
# inspect
meta_data
meta_data |> skimr::skim()
#
```

How many samples do you expect?
How many measurements do you expect?
Which identifiers are unique?

Reproducible data analysis: Standardize your workflow

Read in and inspect your main data

```
## 1.2 Read in data type 1 ----
data_type1 <- data_type1_file |>
  read_tsv() |>
  janitor::clean_names(case = "none")
# inspect
data_type1
data_type1 |> skimr::skim()
#

## 1.3 Read in data type 2 ----
data_type2 <- data_type2_file |>
  read_tsv() |>
  janitor::clean_names(case = "none")
# inspect
data_type2
data_type2 |> skimr::skim()
#
```

How many samples do you expect?
How many measurements do you expect?
Which identifiers are unique?

Reproducible data analysis: Standardize your workflow

Join meta data with main data

```
## 1.3 Join meta data with data type 1 and data type 2 ----
combined <- meta_data |>
  inner_join(data_type1) |>
  inner_join(data_type2)
# check number of rows returned
```

Do you have all sample rows after join? CHECK

Reproducible data analysis: Standardize your workflow

Analysis specific sections:

- Data exploration
- Statistical testing
- Plot results
- Export results
- Plot individual features

```
# 2 Data exploration / summary ----
# check data distribution(s), outliers etc


# 3 Analysis ----
# statistical testing
# assemble and export results

# 4 Plot results ----
# plot results summaries


# 5 Plot individual features ----
# plot interesting/significant features
```

Reproducible data analysis: Standardize your workflow

Finally: save and/or reload workspace

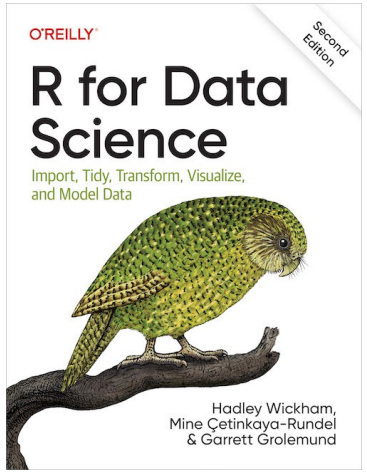
```
################################################
# save workspace -----
save.image(file = here("rdata", paste0(out_file_prefix, ".RData")), compress = TRUE, safe = TRUE) # saves entire workspace (can be slow)
# To reload previously saved workspace:
# load(here("rdata", paste0(out_file_prefix, ".RData")))
```

This can save time when resuming, but make sure to resave if something is changed or errors fixed!!

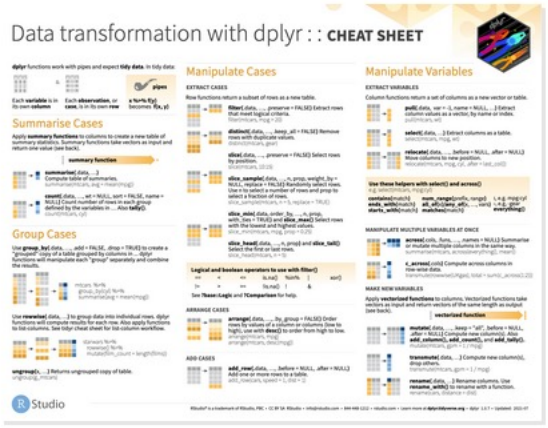
Into the Tidyverse

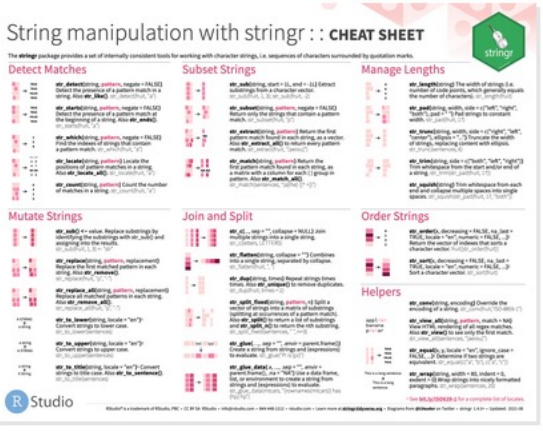
https://tidyverse.tidyverse.org/
Base R: `install.packages("tidyverse")`
renv: `renv::install("tidyverse")`

Core tidyverse packages:
ggplot2, for data visualisation.
dplyr, for data manipulation.
tidyr, for data tidying.
readr, for data import.
purrr, for functional programming.
tibble, for tibbles, a modern re-imagining of data frames.
stringr, for strings.
forcats, for factors.
lubridate, for date/times.



https://r4ds.hadley.nz/





https://posit.co/resources/cheatsheets/

Into the Tidyverse: Pipes

Pipe operator `%>%`

- Avoids nesting
- Minimizes need to create objects and functions
- Structure sequences of operations left-to-right or **top-to-bottom**
- Easy to inspect and add steps anywhere

- `x %>% f` is equivalent to `f(x)`
- `x %>% f(y)` is equivalent to `f(x, y)`
- `x %>% f %>% g %>% h` is equivalent to `h(g(f(x)))`

- Keyboard shortcut in RStudio: cmd/ctrl+shift+m

- Note: R 4.1.0 introduced a native pipe operator `|>` with some minor differences
  https://www.tidyverse.org/blog/2023/04/base-vs-magrittr-pipe/

https://r4ds.had.co.nz/pipes.html

Into the Tidyverse: syntax

Base R “dollar sign” syntax

Example - summary statistics:

one continuous variable:

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

one categorical variable:

```
table(mtcars$cyl)
```

two categorical variables:

```
table(mtcars$cyl, mtcars$am)
```

one continuous, one categorical:

```
mean(mtcars$mpg[mtcars$cyl==4])
mean(mtcars$mpg[mtcars$cyl==6])
mean(mtcars$mpg[mtcars$cyl==8])
```

Tidyverse syntax

Example - summary statistics:

one continuous variable:

```
mtcars %>% dplyr::summarize(mean(mpg))
```

one categorical variable:

```
mtcars %>%
    dplyr::group_by(cyl)%>%
    dplyr::summarize(n())
```

two categorical variables:

```
mtcars %>%
    dplyr::group_by(cyl, am) %>%
    dplyr::summarize(n())
```

one continuous, one categorical:

```
mtcars %>%
    dplyr::group_by(cyl)%>%
    dplyr::summarize(mean(mpg))
```

https://rstudio.github.io/cheatsheets/base-r.pdf
https://rstudio.github.io/cheatsheets/syntax.pdf

Into the Tidyverse

Z-score calculation with base R:

```
x <- sweep(sweep(t(dat), 1,
apply(t(dat),1,mean,na.rm=T), FUN = "-"),
1, apply(t(dat),1,sd,na.rm=T), FUN = "/")
```

- hard to decipher (learning barrier)
- have to enter target object name in several places

Z-score calc with tidyverse + scale():

```
zscores <- dat |>
      select(LabID, Analyte, Value) |>
      pivot_wider() |>
      scale()
```

- Somewhat easier to decipher, but not obvious that this calculates Z-scores, even looking at `?scale` defaults (center = TRUE, scale = TRUE)

Manual Z-score calc with tidyverse:

```
zscores <- dat |>
      select(LabID, Analyte, Value) |>
      group_by(Analyte) |>
      mutate(
       zscore = (Value - mean(Value, na.rm = TRUE)) / sd(Value, na.rm = TRUE)
      ) |>
      ungroup()
```

- Naming of new variable
- Easier to see how calculation was performed
- Easy to keep both original and transformed values for comparison

Into the Tidyverse

Z-score calculation with base R:

```
x <- sweep(sweep(t(dat), 1,
apply(t(dat),1,mean,na.rm=T), FUN = "-"),
1, apply(t(dat),1,sd,na.rm=T), FUN = "/")
```

- hard to decipher (learning barrier)
- have to enter target object name in several places

Even more verbose tidyverse version:

```
zscores <- dat |>
      select(LabID, Analyte, Value) |>
      group_by(Analyte) |>
      mutate(
       mean = mean(Value, na.rm = TRUE),
       sd = sd(Value, na.rm = TRUE),
       zscore = (Value - mean) / sd
      ) |>
      ungroup()
```

- Naming of new variable
- Easier to see how calculation was performed
- Easy to keep both original and transformed values for comparison

Into the Tidyverse: important packages

Tibbles = enhanced data frames

- Easier preview of data
- Concise summary information including data types

Importing delimited data

- Easy reading in of data from .txt, .csv, .tsv, .xlsx
- Guessing of column types
- Will not convert strings
- Imported as tibble

```
> mpg %>% as.data.frame()
   manufacturer                model displ year cyl      trans drv cty hwy fl   class
1          audi                   a4   1.8 1999   4   auto(l5)   f  18  29  p compact
2          audi                   a4   1.8 1999   4 manual(m5)   f  21  29  p compact
3          audi                   a4   2.0 2008   4 manual(m6)   f  20  31  p compact
4          audi                   a4   2.0 2008   4   auto(av)   f  21  30  p compact
5          audi                   a4   2.8 1999   6   auto(l5)   f  16  26  p compact
6          audi                   a4   2.8 1999   6 manual(m5)   f  18  26  p compact
7          audi                   a4   3.1 2008   6   auto(av)   f  18  27  p compact
```

```
83         ford        explorer 4wd   5.0 1999   8   auto(l4)   4  13  17  r     suv
84         ford     f150 pickup 4wd   4.2 1999   6   auto(l4)   4  14  17  r  pickup
85         ford     f150 pickup 4wd   4.2 1999   6 manual(m5)   4  14  17  r  pickup
86         ford     f150 pickup 4wd   4.6 1999   8 manual(m5)   4  13  16  r  pickup
87         ford     f150 pickup 4wd   4.6 1999   8   auto(l4)   4  13  16  r  pickup
88         ford     f150 pickup 4wd   4.6 2008   8   auto(l4)   4  13  17  r  pickup
89         ford     f150 pickup 4wd   5.4 1999   8   auto(l4)   4  11  15  r  pickup
90         ford     f150 pickup 4wd   5.4 2008   8   auto(l4)   4  13  17  r  pickup
 [ reached 'max' / getOption("max.print") -- omitted 144 rows ]
```

vs.

```
> mpg
# A tibble: 234 x 11
   manufacturer model      displ  year   cyl trans      drv     cty   hwy fl    class
   <chr>        <chr>      <dbl> <int> <int> <chr>      <chr> <int> <int> <chr> <chr>
 1 audi         a4           1.8  1999     4 auto(l5)   f        18    29 p     compact
 2 audi         a4           1.8  1999     4 manual(m5) f        21    29 p     compact
 3 audi         a4           2    2008     4 manual(m6) f        20    31 p     compact
 4 audi         a4           2    2008     4 auto(av)   f        21    30 p     compact
 5 audi         a4           2.8  1999     6 auto(l5)   f        16    26 p     compact
 6 audi         a4           2.8  1999     6 manual(m5) f        18    26 p     compact
 7 audi         a4           3.1  2008     6 auto(av)   f        18    27 p     compact
 8 audi         a4 quattro   1.8  1999     4 manual(m5) 4        18    26 p     compact
 9 audi         a4 quattro   1.8  1999     4 auto(l5)   4        16    25 p     compact
10 audi         a4 quattro   2    2008     4 manual(m6) 4        20    28 p     compact
# … with 224 more rows
```

Into the Tidyverse: important packages

dplyr

Data manipulation

- `mutate()` adds new variables that are functions of existing variables.
- `select()` picks variables based on their names.
- `filter()` picks rows based on their values.
- `summarize()` reduces multiple values down to a single summary.
- `arrange()` changes the ordering of the rows.
- `group_by()` perform group-wise operations.

tidyr

Reshaping data

- Conversion to/from Tidy data where each column is a variable and each row is an observation.
- `pivot_longer()` converts to Tidy/long format.
- `pivot_wider()` converts to wide format.
- `tibble::column_to_rownames(var = "id_col")` converts to data frame (required for some functions).

```
> mtcars %>% as_tibble(rownames = "Model")
# A tibble: 32 × 12
   Model              mpg   cyl  disp    hp  drat    wt  qsec    vs    am  gear  carb
   <chr>            <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
 1 Mazda RX4         21       6  160    110  3.9   2.62  16.5     0     1     4     4
 2 Mazda RX4 Wag     21       6  160    110  3.9   2.88  17.0     0     1     4     4
 3 Datsun 710        22.8     4  108     93  3.85  2.32  18.6     1     1     4     1
 4 Hornet 4 Drive    21.4     6  258    110  3.08  3.22  19.4     1     0     3     1
 5 Hornet Sportabout 18.7     8  360    175  3.15  3.44  17.0     0     0     3     2
 6 Valiant           18.1     6  225    105  2.76  3.46  20.2     1     0     3     1
 7 Duster 360        14.3     8  360    245  3.21  3.57  15.8     0     0     3     4
 8 Merc 240D         24.4     4  147.    62  3.69  3.19  20       1     0     4     2
 9 Merc 230          22.8     4  141.    95  3.92  3.15  22.9     1     0     4     2
10 Merc 280          19.2     6  168.   123  3.92  3.44  18.3     1     0     4     4
# … with 22 more rows
```

vs.

```
> mtcars %>% as_tibble(rownames = "Model") %>%
+     pivot_longer(mpg:carb, names_to = "feature", values_to = "value")
# A tibble: 352 × 3
   Model     feature value
   <chr>     <chr>   <dbl>
 1 Mazda RX4 mpg      21
 2 Mazda RX4 cyl       6
 3 Mazda RX4 disp    160
 4 Mazda RX4 hp      110
 5 Mazda RX4 drat      3.9
 6 Mazda RX4 wt        2.62
 7 Mazda RX4 qsec     16.5
 8 Mazda RX4 vs        0
 9 Mazda RX4 am        1
10 Mazda RX4 gear      4
# … with 342 more rows
```

+ add additional variables

```
> mpg
# A tibble: 234 × 11
   manufacturer model      displ  year   cyl trans      drv     cty   hwy fl    class
   <chr>        <chr>      <dbl> <int> <int> <chr>      <chr> <int> <int> <chr> <chr>
 1 audi         a4           1.8  1999     4 auto(l5)   f        18    29 p     compact
 2 audi         a4           1.8  1999     4 manual(m5) f        21    29 p     compact
 3 audi         a4           2    2008     4 manual(m6) f        20    31 p     compact
 4 audi         a4           2    2008     4 auto(av)   f        21    30 p     compact
 5 audi         a4           2.8  1999     6 auto(l5)   f        16    26 p     compact
 6 audi         a4           2.8  1999     6 manual(m5) f        18    26 p     compact
 7 audi         a4           3.1  2008     6 auto(av)   f        18    27 p     compact
 8 audi         a4 quattro   1.8  1999     4 manual(m5) 4        18    26 p     compact
 9 audi         a4 quattro   1.8  1999     4 auto(l5)   4        16    25 p     compact
10 audi         a4 quattro   2    2008     4 manual(m6) 4        20    28 p     compact
# … with 224 more rows
```

Into the Tidyverse: important packages

Character string manipulations

- `str_detect(x, pattern)` looks for match to the pattern; commonly used with `dplyr::filter()`
- `str_extract(x, pattern)` extracts the text of the match; commonly used with `dplyr::mutate()`
- `str_replace(x, pattern, replacement)` replaces the matches with new text; commonly used with `dplyr::mutate()`

Managing factors

- R uses factors to handle categorical variables
- Often important to control the ordering of factors
  eg for plotting or modelling
- `fct_relevel()` changes the order of a factor as specified by a character vector
- `fct_inorder()` changes the order of a factor as specified by current order ; commonly used with `dplyr::arrange()`

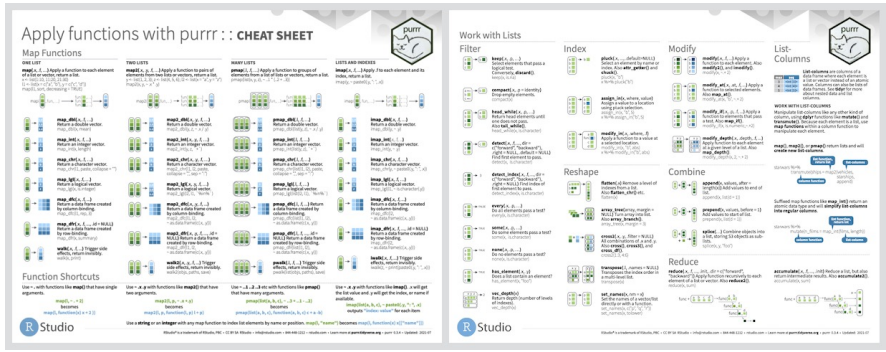
Into the Tidyverse: important packages

purrr

Functional programming tools for iterating with functions and vectors

- map() family of functions to replace for loops
- see the Iteration chapter of R for Data Science to learn more

https://github.com/rstudio/cheatsheets/blob/master/purrr.pdf



broom

Summarizes key statistical model information in tidy format

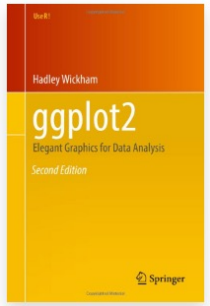
- `tidy()` summarizes information about model components.
- `glance()` reports information about the entire model.
- `augment()` adds information about observations to a dataset (eg residuals).
- Works with 100+ model objects.
- Plays well with the `nest/unnest` functions in `tidyr` and the `map` functions in `purr`

https://broom.tidymodels.org/articles/broom_and_dplyr.html

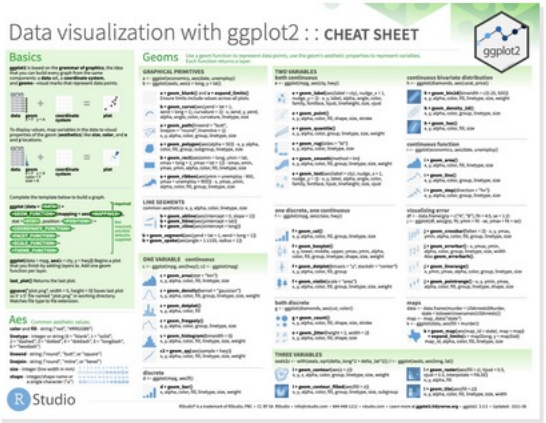
Into the Tidyverse: Visualization using ggplot2

Publication-quality data visualization

- Implements a “grammar of graphics”
- Start by defining the data to be plotted (“aesthetics”):
  `ggplot(aes(x, y, color, fill, shape, alpha, linetype))`
- Then add layers (“geoms”) to specify how data is plotted, eg:
  `+ geom_point()`
- Add additional geom layers, eg:
  `+ geom_boxplot()`
- Can split into separate plots, eg male vs. female, by “faceting”:
  `+ facet_wrap(~ Sex)`
- Finally add title and modify theme:
  ```
  + labs(title = “Plot title”, subtitle = “plot details”
  + theme(aspect.ratio = 1)
  ```



https://ggplot2-book.org/



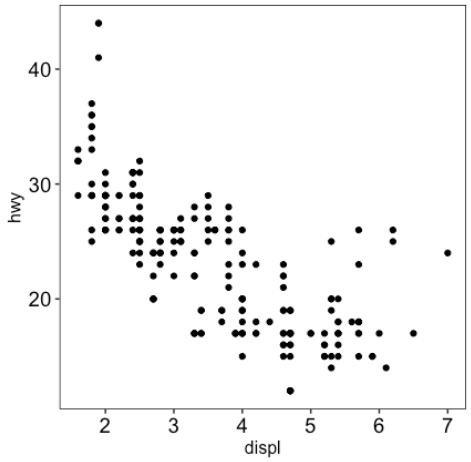
https://raw.githubusercontent.com/rstudio/cheatsheets/main/data-visualization.pdf

https://www.data-to-viz.com/caveats.html

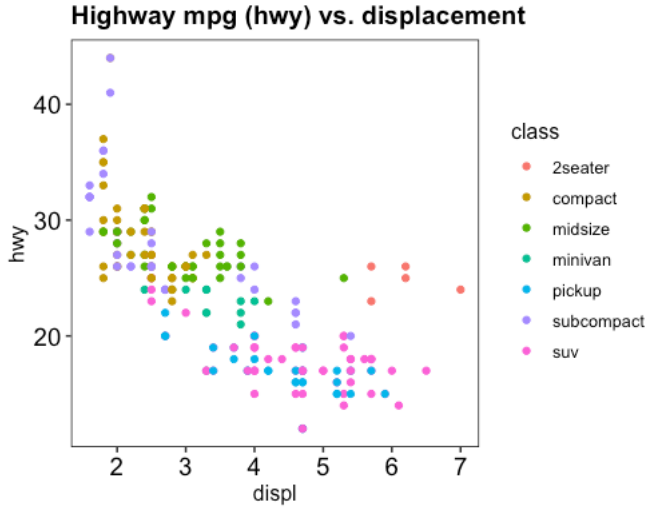
https://r-graph-gallery.com/index.html

Into the Tidyverse: Visualization using ggplot2


```
mpg %>%
    ggplot(aes(displ, hwy)) +
    geom_point()
```

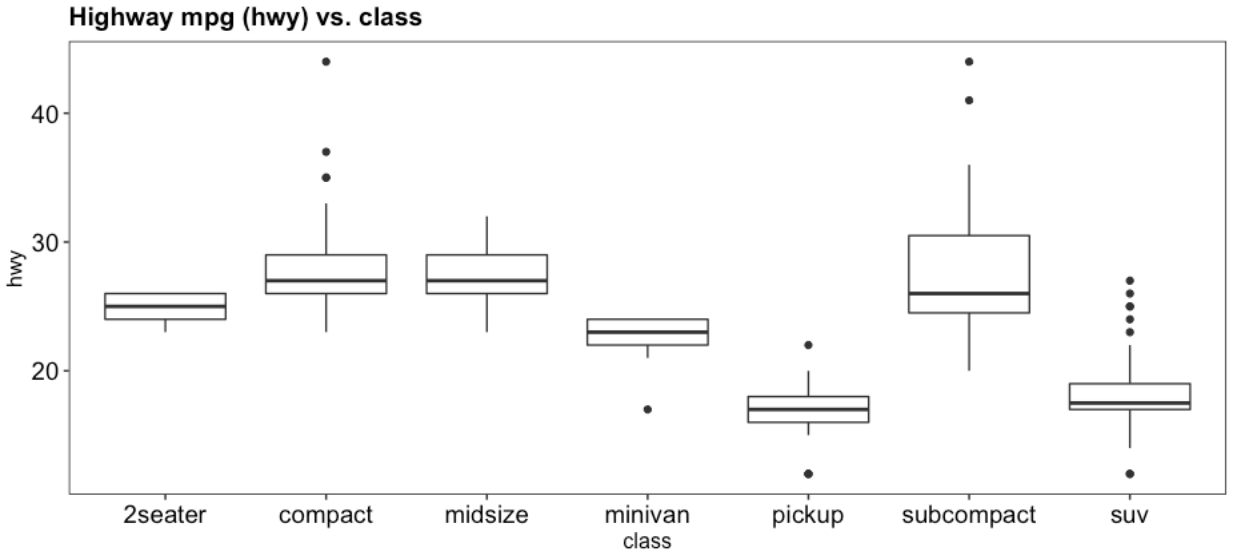



```
mpg %>%
    ggplot(aes(displ, hwy, color = class)) +
    geom_point() +
    theme(aspect.ratio = 1) +
    labs(title = "Highway mpg (hwy) vs. displacement")
```

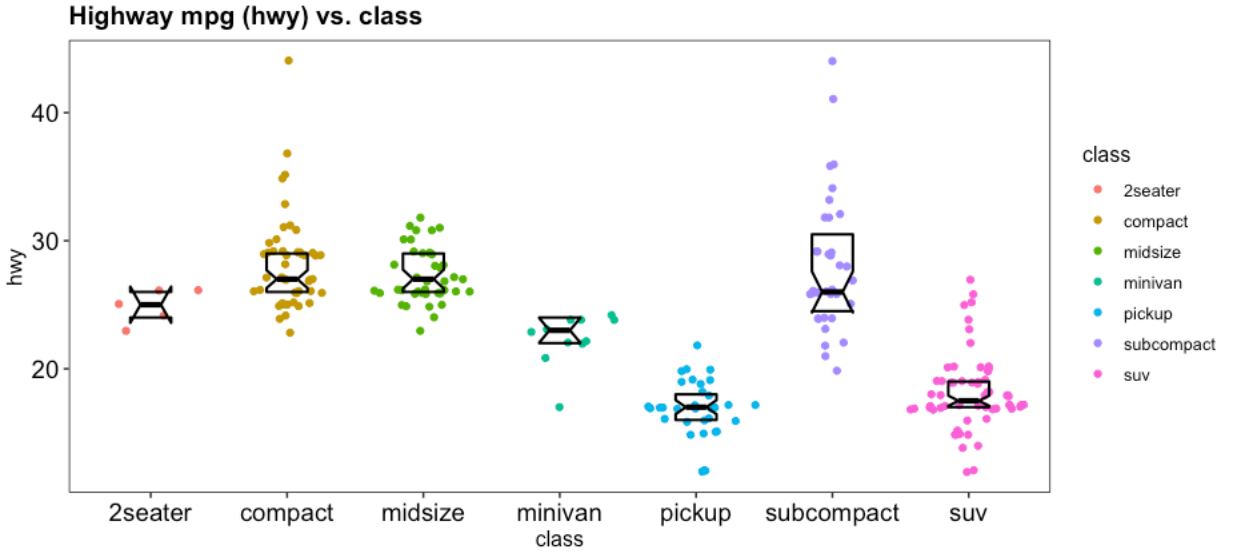


Into the Tidyverse: Visualization using ggplot2


```
mpg %>%
    ggplot(aes(class, hwy)) +
    geom_boxplot() +
    labs(title = "Highway mpg (hwy) vs. class")
```

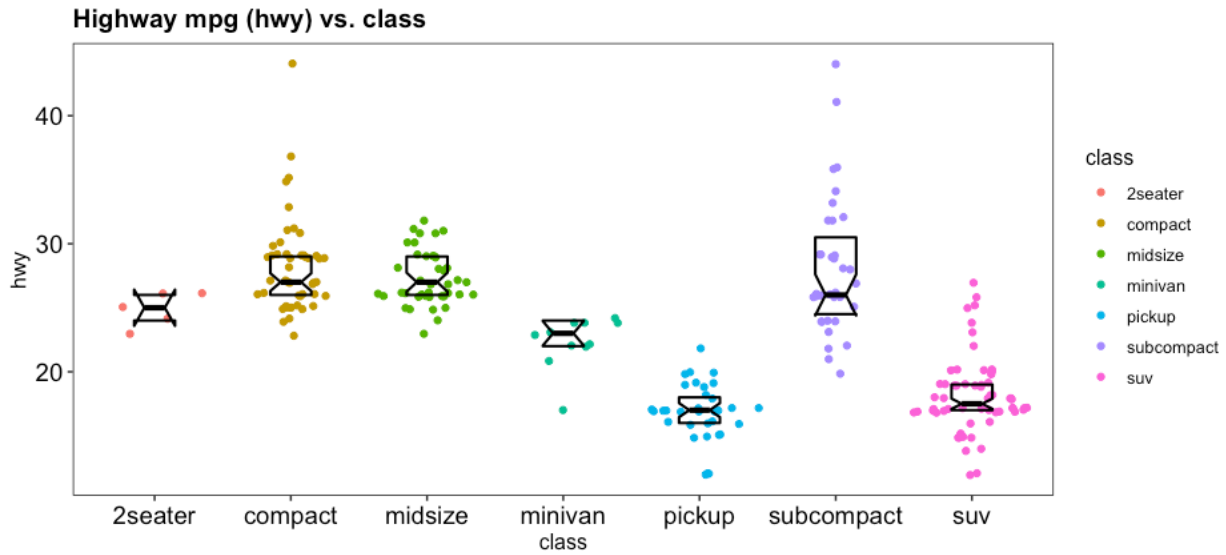


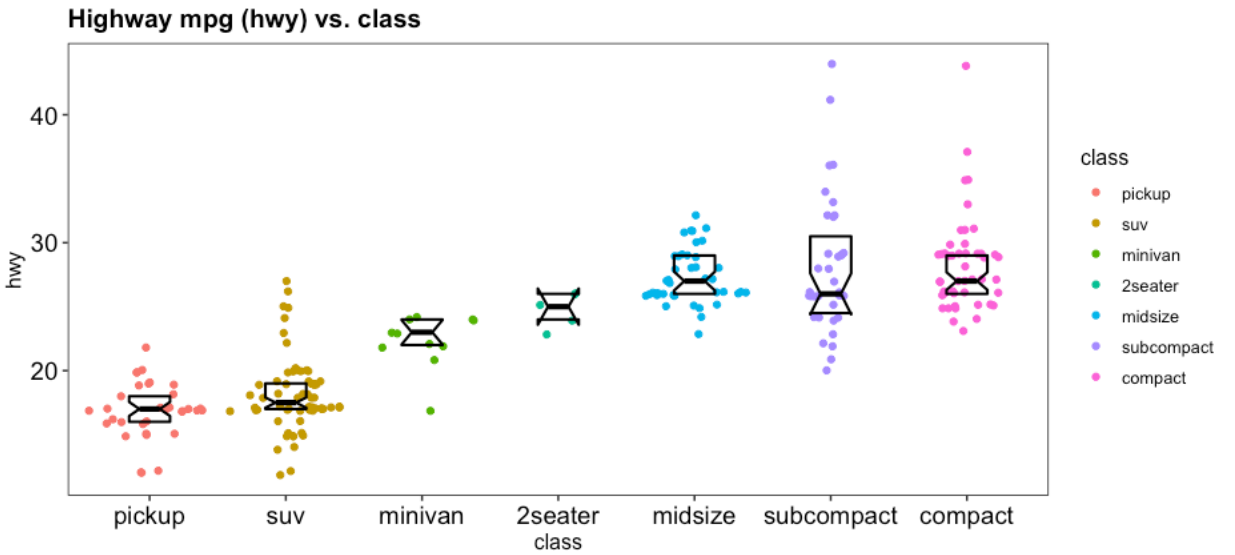

```
mpg %>%
    ggplot(aes(class, hwy, color = class)) +
    ggforce::geom_sina() +
    geom_boxplot(
       notch=TRUE, varwidth=FALSE,
       outlier.shape=NA, coef=FALSE,
       width=0.3, color="black",
       fill="transparent", size=0.75
                ) +
    labs(title = "Highway mpg (hwy) vs. class")
```



Into the Tidyverse: Visualization using ggplot2


```
mpg %>%
    group_by(class) %>%
    mutate(mean = mean(hwy)) %>%
    ungroup() %>%
    arrange(mean) %>%
    mutate(class = fct_inorder(class)) %>%
    ggplot(aes(class, hwy, color = class)) +
    ggforce::geom_sina() +
    geom_boxplot(
        notch=TRUE, varwidth=FALSE, outlier.shape=NA, coef=FALSE, width=0.3, color="black", fill="transparent", size=0.75
    ) +
    labs(title = "Highway mpg (hwy) vs. class")
```

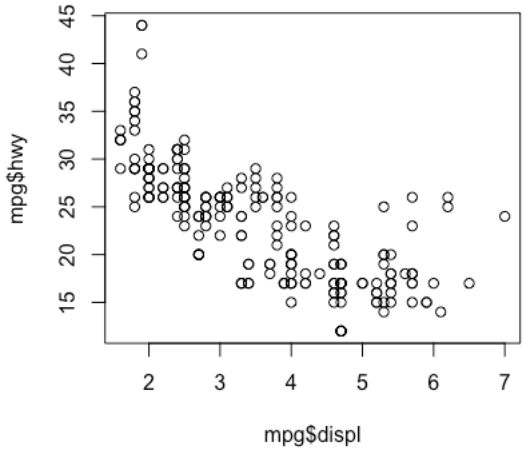




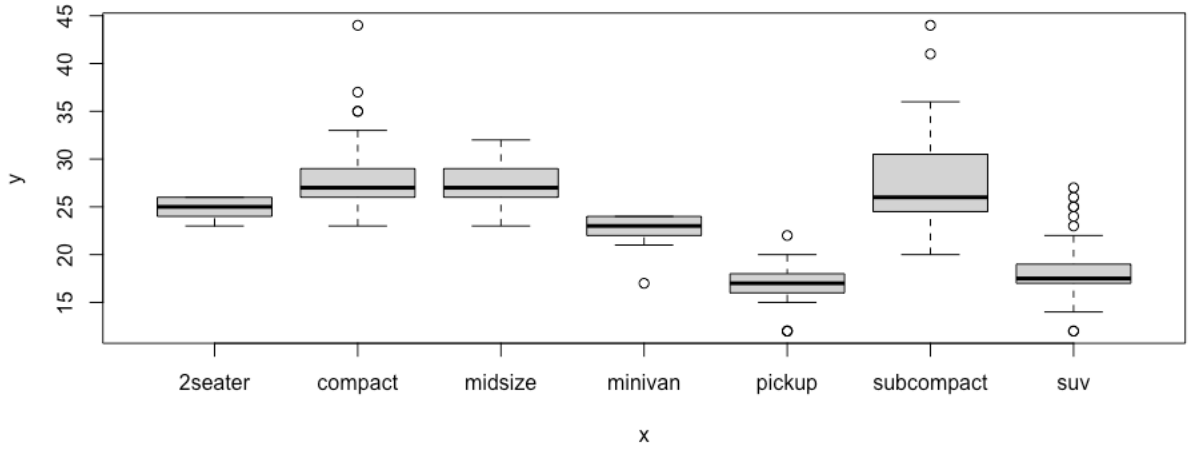
Into the Tidyverse: Visualization using ggplot2

Equivalent plots using base R

```
plot(mpg$displ, mpg$hwy)
```




```
plot(as.factor(mpg$class), mpg$hwy)
```



Other commonly used packages

ggforce
Additional plot geoms, including geom_sina()
https://ggforce.data-imaginist.com/

ggrepel
Repel overlapping text labels
https://ggrepel.slowkow.com/index.html

ggrastr
Rasterize ggplot objects or layers
https://cran.r-project.org/web/packages/ggrastr/vignettes/Raster_geoms.html

ggsignif
Test and/or add significance brackets to plots
https://cran.r-project.org/web/packages/ggsignif/vignettes/intro.html

tidyheatmap
Tidy interface to ComplexHeatmap
https://cran.r-project.org/web/packages/tidyHeatmap/vignettes/introduction.html

janitor
cleaning variable names
https://cran.r-project.org/web/packages/janitor/vignettes/janitor.html

rstatix
Tidy and pipe-friendly statistics, e.g. t-test, Wilcoxon/Mann-Whitney
https://cran.r-project.org/web/packages/rstatix/index.html

patchwork
Assemble multiple ggplot objects
https://patchwork.data-imaginist.com/index.html

Bioconductor
OPEN SOURCE SOFTWARE FOR BIOINFORMATICS

The Bioconductor Project
https://bioconductor.org/