ICTR Institute for Clinical and Translational Research AT EINSTEIN AND MONTEFIORE
Building Bridges in the Bronx and Beyond

EINSTEIN Albert Einstein College of Medicine

Montefiore

R intensive

Session 1

May 14th, 2024

Welcome!

Question: How many people have experience with coding or analysis in some software package?

- EXCEL
- SPSS
- STATA
- SAS
- PYTHON
- MATLAB
- R

The goals of this workshop

- This is an introductory workshop!

- We want you to walk away today feeling comfortable:
  1. navigating the four panels of Rstudio
  2. importing data into R
  3. performing some data manipulations and cleaning using dplyr
  4. summarizing your data
  5. plotting your data

Like any language, you need to practice a lot to get fluent!

Why R?

- Cleaning, analyzing, plotting all in one place
- **Reproducibility** – you can save your code and know exactly what you did. You can also rerun code if you get new data
- It’s freely available

A few things to know first

- R has many contributed **packages** (>10,000) to **extend R** for basic and advanced analysis

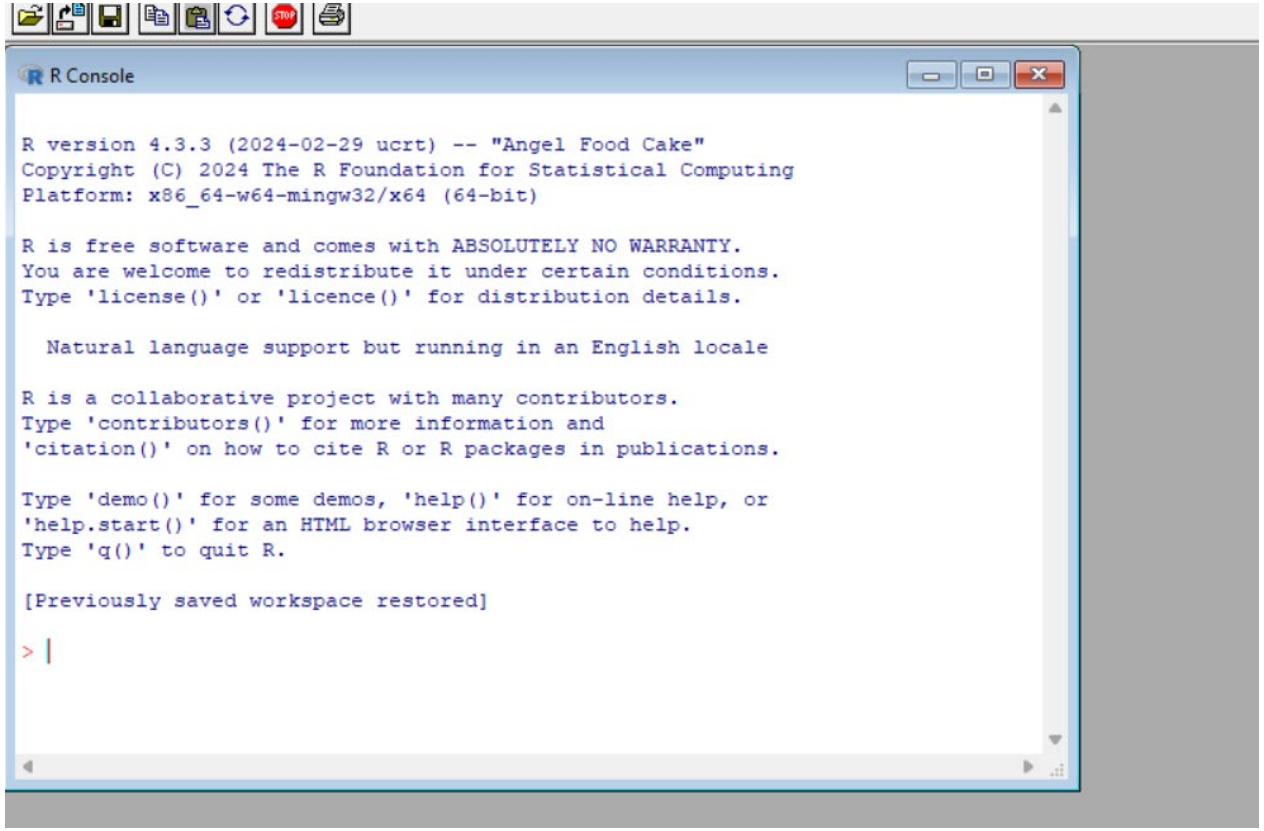
- Typically, a **package** will include code, documentation for the package, the functions inside, and data sets.

- An example of a package is the ***gam*** package. This package contains multiple functions for fitting generalized additive models. Another example is the ***shiny*** package, which make interactive, web apps with R.

- **Packages** are stored in **libraries**

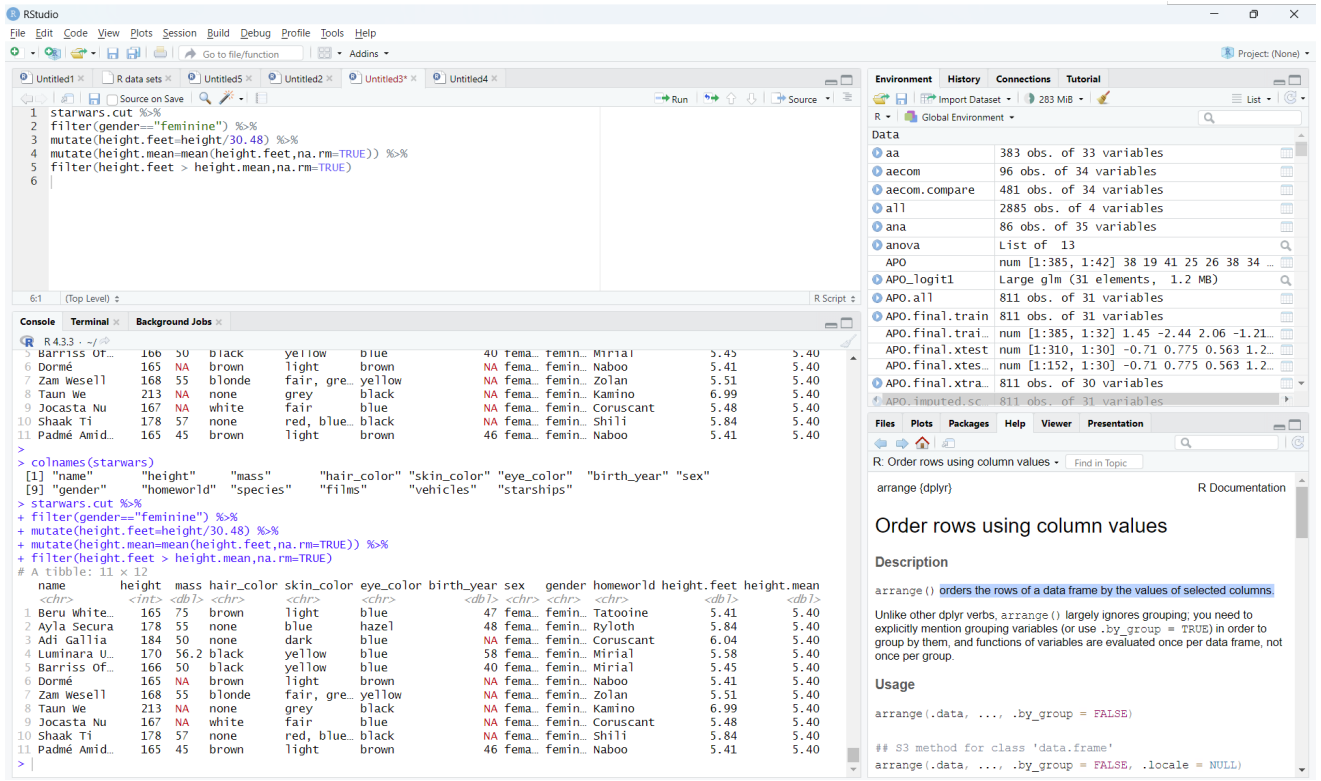
The R console

Serves as the primary interface for executing R code. The R console serves as the primary interface for executing R code.

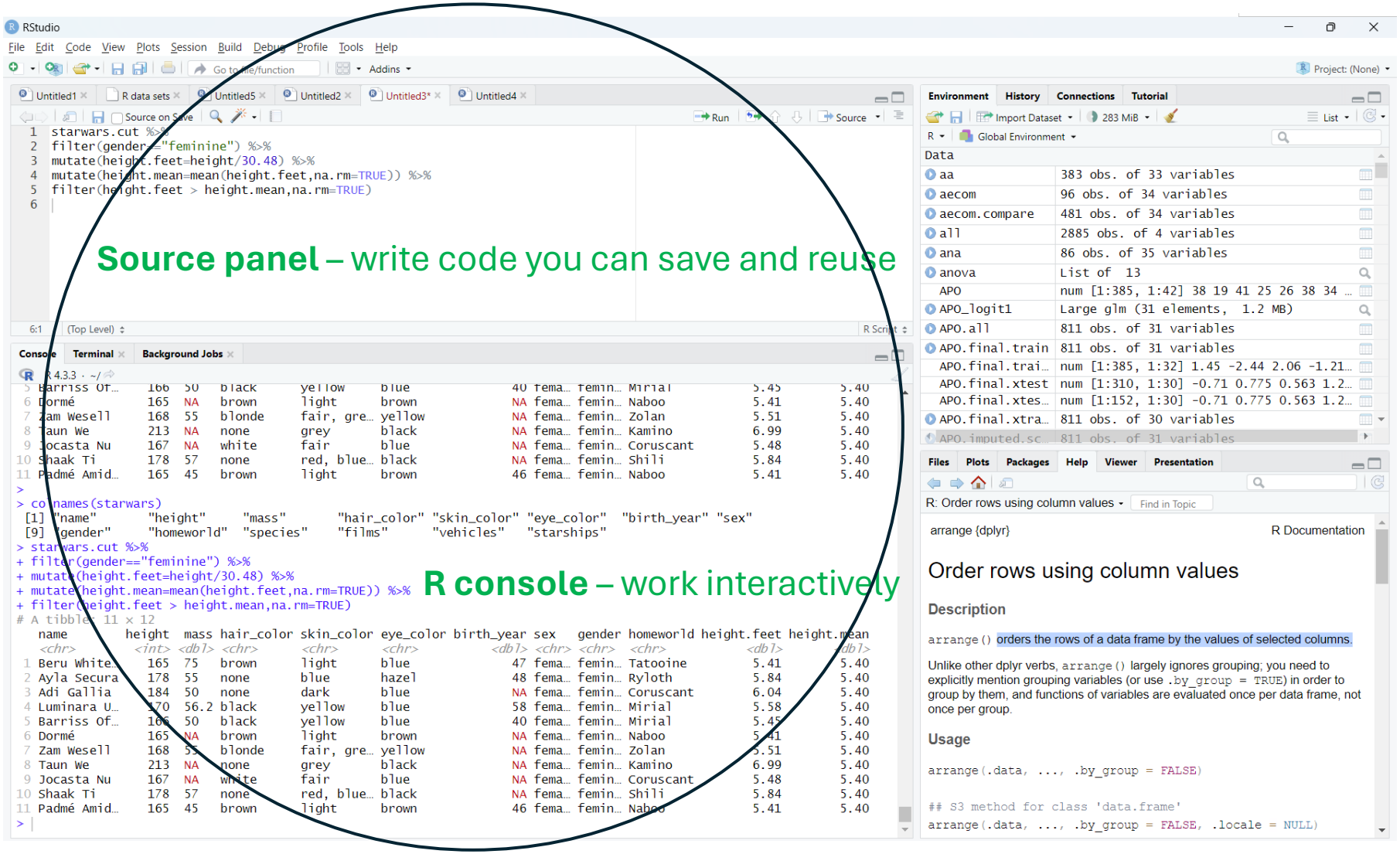


R Studio

- **R Studio** provides a user-friendly interface with various tools and features such as debugging and fill-ins.



The 4 panels of R Studio



R Studio tour – live demonstration (tour 1)

RStudio

File Edit Code View Plots Session Build Debug Profile Tools Help

Go to file/function | Addins | Project: (None)

r code for session 1 markdown.Rmd* | R session 1 tour 1.R

Source on Save | Run | Source

```
1  #This is a comment
2  ##################################
3
4  # 1.  First we are going to see how to run code in R
5  # typing up here does not do anything unless you run it!
6  ##################################
7
8  print('hello world')
9
10 print('Run the whole thing')
11
12 # 2.  Now we are going to create a couple of new variables
13
14 ## <- is the assignment operator.  You can also use an equal sign (=) but considered better form to use <-
15
16
17 x <- c(1:10)
18
19 print(x)
20
21 # we can see that x is now a variable in the global environment (see upper right panel)
22
23 y <- x*x
```

39:1 (Untitled) R Script

Console | Terminal | Render | Background Jobs

R 4.3.3 · ~/R intensive/

```
>
> ## <- is the assignment operator.  You can also use an equal sign (=) but considered .... [TRUNCATED]

> print(x)
 [1]  1  2  3  4  5  6  7  8  9 10

> # we can see that x is now a variable in the global environment (see upper right panel)
>
> y <- x*x

> # variable named y consisting of an integer vector is now also listed in the global environment
>
> # we can also work interactively in the console .... [TRUNCATED]

> #  see that the plot is now in the lower right panel
>
> plot(y)

> # we can scroll between the two plots we created
>
>
```

Environment | History | Connections | Tutorial

Import Dataset | 850 MiB | List

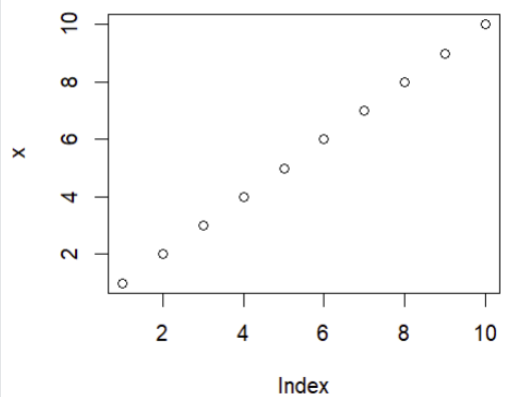
R | Global Environment

Values

x	int [1:10] 1 2 3 4 5 6 7 8 9 10
y	int [1:10] 1 4 9 16 25 36 49 64...
z	385L

Files | Plots | Packages | Help | Viewer | Presentation

Zoom | Export



Some useful shortcuts

- To clear your console –> CNTL+L
- To clear your environment -> use the broom function
- To run a selected line from the source panel -> CNTL+ENTER
- To run the whole script from the source panel -> CNTL+ALT+R
- To repeat a command in the console – use the ^ arrow

Getting data into R

- In the first tour, I created vectors x and y ***within R***, which is not the usual workflow

- Usually, you will ***import an Excel spreadsheet*** where you have collected and organized your data. We will show you how to do this.

- Today we will primarily work with data using a standard *wide* format – unique observations in rows and variables in columns

- A *long* format is used when you have multiple observations for an individual over time or space

Wide vs long data formats

Example of wide format:

ID	x1	x2	x3	x4
1	3.3	1	2	17
2	2.1	1	3	22
3	7.0	0	1	10
4	4.1	1	1	42

Example of long format:

ID	time	x1	x2	x3	x4
1	1	3.3	1	2	17
1	2	0.5	1	1	14
2	1	2.1	1	3	22
2	2	2.8	0	5	16
3	1	7.0	0	1	10
4	1	4.1	1	1	42
4	2	4.1	0	0	57
5	1	3.8	1	1	12

Data frames/tibbles

- When you import your data set into R, you typically store your data in a **data frame** within R
  - A **dataFrame** in R is a tabular (i.e., 2-dimensional, rectangular) data structure used to store values of any data type
  - A **tibble** is a newer version of the data frame, used in tidyverse

Installing and Loading R packages (libraries)

- Over 10,000 libraries to help you analyze data
- These libraries contain **R packages**, which are collections of R functions, data and compiled code
- R libraries have to be loaded every time you open an R session

tidyverse

- **Base R** refers to all the functionality that comes built into the R programming language. It is what you get when you open up the R console for the first time.

- The ***tidyverse*** is a collection of packages that **add onto R** to allow you to manipulate your data intuitively. It emphasizes readability. It does not replace base R.

- ***data.table*** is another such collection of packages

- In this session, we focus on learning the basics of some main packages in ***tidyverse (dplyr and ggplot2)***

Installing and loading the tidyverse core

```
install.packages('tidyverse’)   #Note: you did this prior to the workshop
library('tidyverse')
library('dplyr’)          #Note: dplyr automatically gets installed with tidyverse
```

Within ***tidyverse***, there is package called ***dplyr*****.** Think of the **d** as standing for **data** and the **plyr** standing for **plyers** – the goal of this package is to manipulate data frames in useful ways.

We will be focusing on the ***dplyr*** package in R this morning. This afternoon, we will learn about another package called ***ggplot2***

Live demonstration (tour 2)

RStudio

File Edit Code View Plots Session Build Debug Profile Tools Help

Go to file/function | Addins | Project: (None)

r code for session 1 markdown.Rmd* | R session 1 tour 1.R | R session tour 2.R

Source on Save | Run | Source

```
1  # Now let's load the packages we need
2
3  library(tidyverse)
4
5  # scroll the packages in the lower right panel to see what is checked
6
7  # If we need help on a particular package that has already been loaded we can type:
8
9  ?dplyr
10
11
12 # and look on the lower right panel (HELP) for more information about the dplyr package
13
14 ################################################################################
15
16 # Create a data frame/tibble by binding x and y together
17
18 xy <- bind_cols(x,y)
19
20 class(xy)
21
22 colnames(xy)=c("x","y")
23
24 plot(xy$x,xy$y)
25
26
```

1:1 (Top Level) R Script

Console | Terminal | Render | Background Jobs

R 4.3.3 · ~/R intensive/

```
> ?dplyr
>
```

Environment | History | Connections | Tutorial

Import Dataset | 293 MiB | List

R | Global Environment

Data	
xy	10 obs. of 2 variables
Values	
x	int [1:10] 1 2 3 4 5 6 7 8 9 10
y	int [1:10] 1 4 9 16 25 36 49 64 81 100
z	385L

Files | Plots | Packages | Help | Viewer | Presentation

R: dplyr: A Grammar of Data Manipulation | Find in Topic

dplyr-package {dplyr} R Documentation

dplyr: A Grammar of Data Manipulation

Description

To learn more about dplyr, start with the vignettes: `browseVignettes(package = "dplyr")`

Author(s)

Maintainer: Hadley Wickham hadley@posit.co (ORCID)

Authors:

- Romain François (ORCID)
- Lionel Henry
- Kirill Müller (ORCID)

The main verbs of ***dplyr***

I just used a simple dplyr function called **bind_cols()** to combine vectors x and y, but this is only one of many. Below are the **main verbs** we will focus on this morning

- **Operation on columns (variables)**
  - select
  - mutate
  - rename
  - relocate
  - Pull
- **Operations on rows (observations)**
  - arrange
  - filter
  - slice_min, slice_max
- **Grouping and summarizing (observations)**
  - group_by
  - summarize
- **Joining two data frames**
  - inner_join, left_join, right_join, full_join

Data transformation with dplyr : : **CHEATSHEET**

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)**

Summarize Cases

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

summarize(.data, …**)** Compute table of summaries.
mtcars |> summarize(avg = mean(mpg))

count(.data, …, wt = NULL, sort = FALSE, name = NULL**)** Count number of rows in each group defined by the variables in … Also **tally()**, **add_count()**, **add_tally()**.
mtcars |> count(cyl)

Group Cases

Use **group_by(**.data, …, .add = FALSE, .drop = TRUE**)** to create a "grouped" copy of a table grouped by columns in ... dplyr functions will manipulate each "group" separately and combine the results.

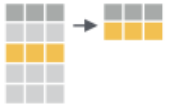
```
mtcars |>
  group_by(cyl) |>
  summarize(avg = mean(mpg))
```

Use **rowwise(**.data, …**)** to group data into individual rows. dplyr functions will compute results for each row. Also apply functions to list-columns. See tidyr cheat sheet for list-column workflow.

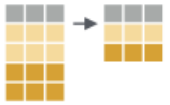
Manipulate Cases

EXTRACT CASES

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

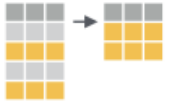


filter(.data, …, .preserve = FALSE**)** Extract rows that meet logical criteria.
mtcars |> filter(mpg > 20)

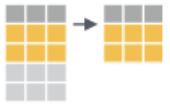


distinct(.data, …, .keep_all = FALSE**)** Remove rows with duplicate values.
mtcars |> distinct(gear)

slice(.data, …, .preserve = FALSE**)** Select rows by position.
mtcars |> slice(10:15)



slice_sample(.data, …, n, prop, weight_by = NULL, replace = FALSE**)** Randomly select rows. Use n to select a number of rows and prop to select a fraction of rows.
mtcars |> slice_sample(n = 5, replace = TRUE)



slice_min(.data, order_by, …, n, prop, with_ties = TRUE**)** and **slice_max()** Select rows with the lowest and highest values.
mtcars |> slice_min(mpg, prop = 0.25)

slice_head(.data, …, n, prop**)** and **slice_tail()** Select the first or last rows.
mtcars |> slice_head(n = 5)

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, …, .by_group = FALSE**)** Order rows by values of a column or columns (low to high), use with **desc()** to order from high to low

Manipulate Variables

EXTRACT VARIABLES

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

pull(.data, var = -1, name = NULL, …**)** Extract column values as a vector, by name or index.
mtcars |> pull(wt)

select(.data, …**)** Extract columns as a table.
mtcars |> select(mpg, wt)

relocate(.data, …, .before = NULL, .after = NULL**)** Move columns to new position.
mtcars |> relocate(mpg, cyl, .after = last_col())

Use these helpers with select() and across()
e.g. mtcars |> select(mpg:cyl)

contains(match**)**	**num_range(**prefix, range**)**	**:**, e.g., mpg:cyl
ends_with(match**)**	**all_of(**x**)/any_of(**x, …, vars**)**	**!**, e.g., !gear
starts_with(match**)**	**matches(**match**)**	**everything()**

MANIPULATE MULTIPLE VARIABLES AT ONCE

```
df <- tibble(x_1 = c(1, 2), x_2 = c(3, 4), y = c(4, 5))
```

across(.cols, .funs, …, .names = NULL**)** Summarize or mutate multiple columns in the same way.
df |> summarize(across(everything(), mean))

c_across(.cols**)** Compute across columns in row-wise data.

```
df |>
  rowwise() |>
  mutate(x_total = sum(c_across(1:2)))
```

MAKE NEW VARIABLES

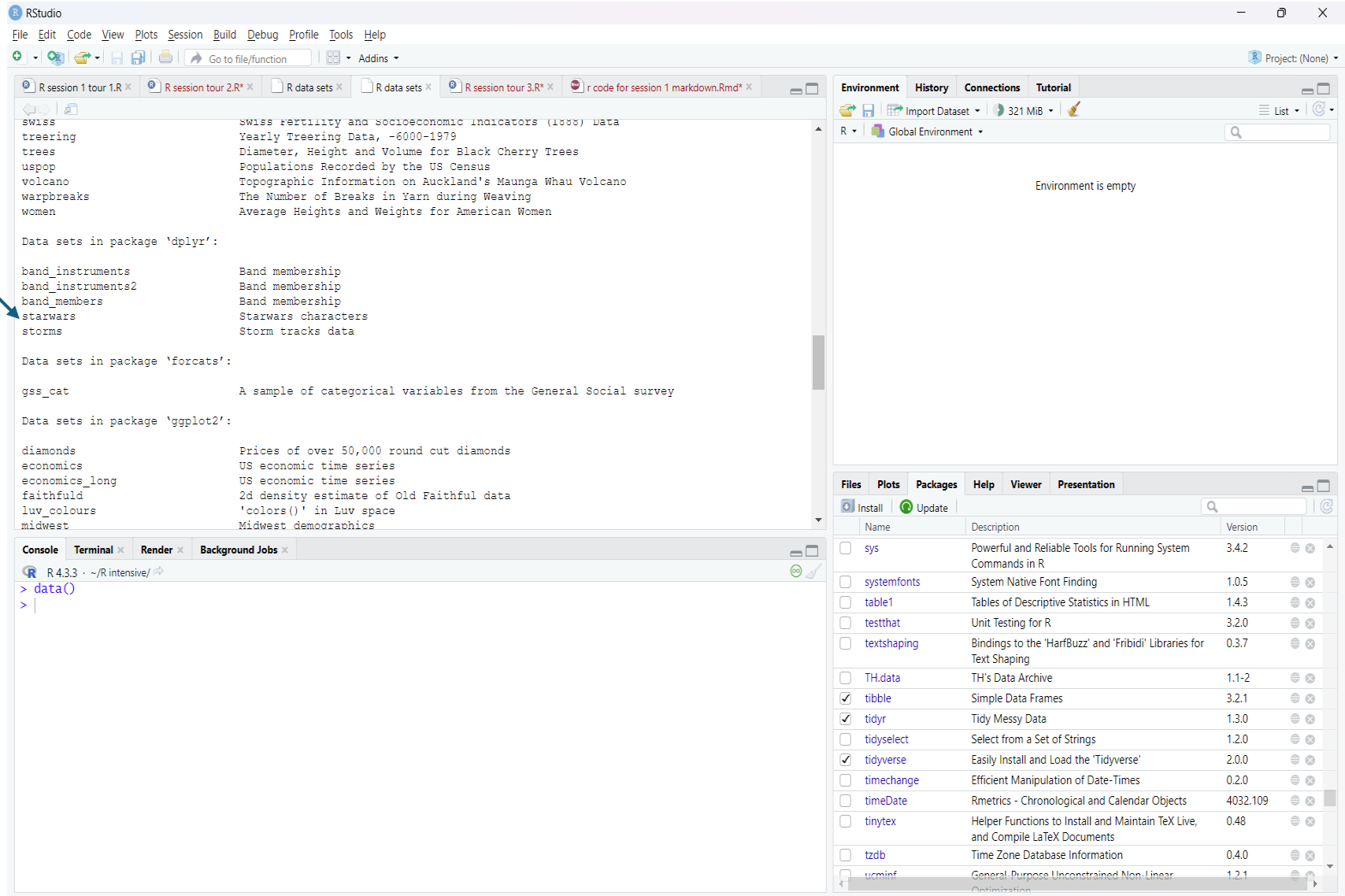
Apply **vectorized functions** to columns. Vectorized functions take vectors as input and return vectors of the same length as output (see back).

vectorized function

Example data set

We will use the **starwars data set** available in the dplyr package

This data set consists of 87 observations and 14 variables.



Example data set

> glimpse(starwars)

```
Rows: 87
Columns: 14
$ name       <chr> "Luke Skywalker", "C-3PO", "R2-D2", "Darth Vader", "Leia Organa", "Owen Lars", "Beru Whitesun lars", "R5-D4", "Biggs Da…
$ height     <int> 172, 167, 96, 202, 150, 178, 165, 97, 183, 182, 188, 180, 228, 180, 173, 175, 170, 180, 66, 170, 183, 200, 190, 177, 17…
$ mass       <dbl> 77.0, 75.0, 32.0, 136.0, 49.0, 120.0, 75.0, 32.0, 84.0, 77.0, 84.0, NA, 112.0, 80.0, 74.0, 1358.0, 77.0, 110.0, 17.0, 7…
$ hair_color <chr> "blond", NA, NA, "none", "brown", "brown, grey", "brown", NA, "black", "auburn, white", "blond", "auburn, grey", "brown…
$ skin_color <chr> "fair", "gold", "white, blue", "white", "light", "light", "light", "white, red", "light", "fair", "fair", "fair", "unkn…
$ eye_color  <chr> "blue", "yellow", "red", "yellow", "brown", "blue", "blue", "red", "brown", "blue-gray", "blue", "blue", "blue", "brown…
$ birth_year <dbl> 19.0, 112.0, 33.0, 41.9, 19.0, 52.0, 47.0, NA, 24.0, 57.0, 41.9, 64.0, 200.0, 29.0, 44.0, 600.0, 21.0, NA, 896.0, 82.0,…
$ sex        <chr> "male", "none", "none", "male", "female", "male", "female", "none", "male", "male", "male", "male", "male", "male", "ma…
$ gender     <chr> "masculine", "masculine", "masculine", "masculine", "feminine", "masculine", "feminine", "masculine", "masculine", "mas…
$ homeworld  <chr> "Tatooine", "Tatooine", "Naboo", "Tatooine", "Alderaan", "Tatooine", "Tatooine", "Tatooine", "Tatooine", "Stewjon", "Ta…
$ species    <chr> "Human", "Droid", "Droid", "Human", "Human", "Human", "Human", "Droid", "Human", "Human", "Human", "Human", "Wookiee", …
$ films      <list> <"The Empire Strikes Back", "Revenge of the Sith", "Return of the Jedi", "A New Hope", "The Force Awakens">, <"The Emp…
$ vehicles   <list> <"Snowspeeder", "Imperial Speeder Bike">, <>, <>, <>, "Imperial Speeder Bike", <>, <>, <>, <>, "Tribubble bongo", <"Ze…
$ starships  <list> <"X-wing", "Imperial shuttle">, <>, <>, "TIE Advanced x1", <>, <>, <>, <>, "X-wing", <"Jedi starfighter", "Trade Feder…
```

87 rows x 14 columns

Column operations

dplyr::select

- Select (and optionally rename) variables in a data frame

Example:

```
>starwars.cut <- select(starwars,c(1:6,8:10))      #dplyr

> starwars.cut <- starwars[,c(1:6,8:10)]           #base R
```

dplyr::select

Note: these are the same, though assignment operator (<-) preferred

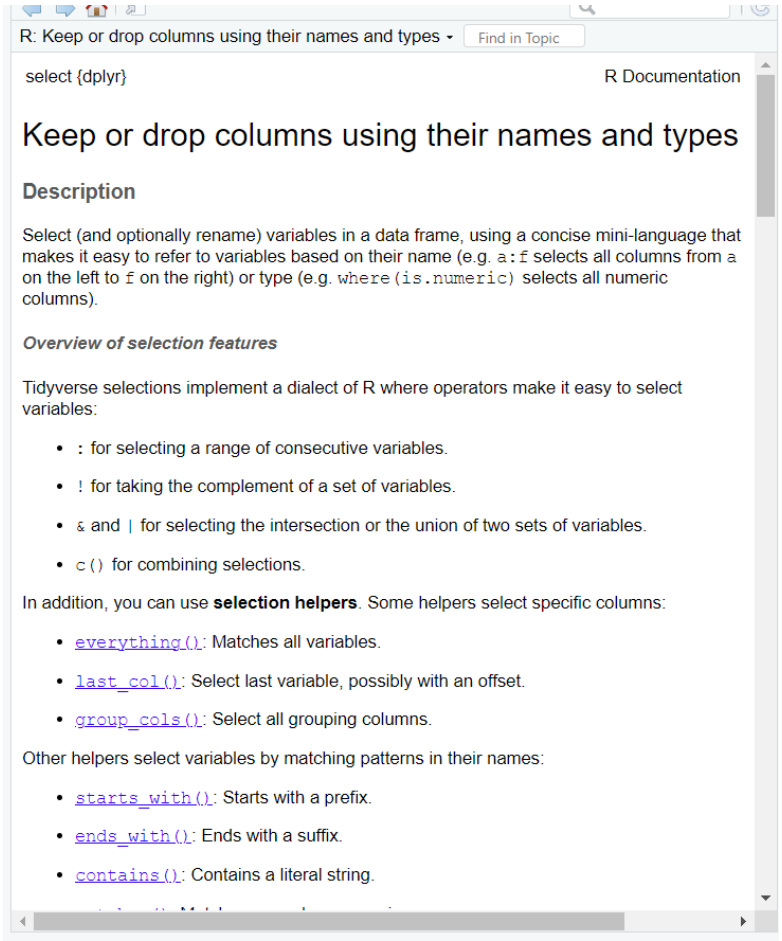
```
>starwars.cut <- select(starwars,c(1:6,8:10))
>starwars.cut = select(starwars,c(1:6,8:10))
```

Note: these are NOT the same

```
>starwars.cut <- select(starwars,c(1:6,8:10))
>starwars_cut = select(starwars,c(1:6,8:10))
```

Can’t exactly remember how the function works, key words, or options?

> ?select


R: Keep or drop columns using their names and types

Find in Topic

select {dplyr} R Documentation

Keep or drop columns using their names and types

Description

Select (and optionally rename) variables in a data frame, using a concise mini-language that makes it easy to refer to variables based on their name (e.g. `a:f` selects all columns from `a` on the left to `f` on the right) or type (e.g. `where(is.numeric)` selects all numeric columns).

Overview of selection features

Tidyverse selections implement a dialect of R where operators make it easy to select variables:

- `:` for selecting a range of consecutive variables.
- `!` for taking the complement of a set of variables.
- `&` and `|` for selecting the intersection or the union of two sets of variables.
- `c()` for combining selections.

In addition, you can use **selection helpers**. Some helpers select specific columns:

- `everything()`: Matches all variables.
- `last_col()`: Select last variable, possibly with an offset.
- `group_cols()`: Select all grouping columns.

Other helpers select variables by matching patterns in their names:

- `starts_with()`: Starts with a prefix.
- `ends_with()`: Ends with a suffix.
- `contains()`: Contains a literal string.

Practice and learn:

Create a small data set and play around with different options

Example data set

>head(starwars.cut) #base R function to print first few rows of a data frame

```
## # A tibble: 6 x 9
##   name       height  mass hair_color skin_color eye_color sex   gender homeworld
##   <chr>       <int> <dbl> <chr>      <chr>      <chr>     <chr> <chr>  <chr>
## 1 Luke Skyw~    172    77 blond      fair       blue      male  mascu~ Tatooine
## 2 C-3PO         167    75 <NA>       gold       yellow    none  mascu~ Tatooine
## 3 R2-D2          96    32 <NA>       white, bl~ red       none  mascu~ Naboo
## 4 Darth Vad~    202   136 none       white      yellow    male  mascu~ Tatooine
## 5 Leia Orga~    150    49 brown      light      brown     fema~ femin~ Alderaan
## 6 Owen Lars     178   120 brown, gr~ light      blue      male  mascu~ Tatooine
```

A tibble 6x 9 – a tibble is a tidyverse data frame.

All dplyr verbs take a tibble as input

dplyr::mutate

- Used to replace/update the values of columns

Suppose we want to compute height in feet instead of meters

>mutate(starwars.cut, height.feet = height/30.48)

	name	height	mass	hair_color	skin_color	eye_color	birth_year	sex	gender	homeworld	height.feet
	<chr>	<int>	<dbl>	<chr>	<chr>	<chr>	<dbl>	<chr>	<chr>	<chr>	<dbl>
1	Luke Skywalker	172	77	blond	fair	blue	19	male	mascu…	Tatooine	5.64
2	C-3PO	167	75	NA	gold	yellow	112	none	mascu…	Tatooine	5.48
3	R2-D2	96	32	NA	white, blue	red	33	none	mascu…	Naboo	3.15
4	Darth Vader	202	136	none	white	yellow	41.9	male	mascu…	Tatooine	6.63
5	Leia Organa	150	49	brown	light	brown	19	female	femin…	Alderaan	4.92
6	Owen Lars	178	120	brown, grey	light	blue	52	male	mascu…	Tatooine	5.84
7	Beru Whitesun lars	165	75	brown	light	blue	47	female	femin…	Tatooine	5.41
8	R5-D4	97	32	NA	white, red	red	NA	none	mascu…	Tatooine	3.18
9	Biggs Darklighter	183	84	black	light	brown	24	male	mascu…	Tatooine	6.00
10	Obi-Wan Kenobi	182	77	auburn, white	fair	blue-gray	57	male	mascu…	Stewjon	5.97

i 77 more rows

Combining verbs with pipes (%>%)

```
>mutate(starwars.cut, height.feet = height/30.48)
```

is the same as:

```
>starwars.cut %>% mutate(height.feet = height/30.48)
```

*“take the starwars.cut data set **then** add a new variable with height in feet”*

Why use pipes? It can make code easy to follow and can avoid repetitive typing of (for example) the data frame name in every function

Shortcut to type %>%: CNTL+SHIFT+M

Combining verbs with pipes (%>%)

If we instead want to create a new data frame with height.feet included:

```
> starwars.cut1 = starwars %>% mutate(height.feet = height/30.48)
```

We can now look on the top right (environment) to see this new data frame

dplyr::rename, rename_with

- Changes the name of a column

```
>rename(starwars.cut1,eye.color=eye_color)
```

```
>starwars.upper <- rename_with(starwars.cut1,toupper)
```

dplyr::relocate

- Changes column positions

> relocate(starwars.upper,MASS,.after=last_col())

```
# A tibble: 87 × 11
   NAME               HEIGHT HAIR_COLOR    SKIN_COLOR  EYE_COLOR BIRTH_YEAR SEX    GENDER    HOMEWORLD HEIGHT.FEET  MASS
   <chr>               <int> <chr>         <chr>       <chr>          <dbl> <chr>  <chr>     <chr>           <dbl> <dbl>
 1 Luke Skywalker        172 blond         fair        blue            19   male   masculine Tatooine         5.64    77
 2 C-3PO                 167 NA            gold        yellow         112   none   masculine Tatooine         5.48    75
 3 R2-D2                  96 NA            white, blue red             33   none   masculine Naboo            3.15    32
 4 Darth Vader           202 none          white       yellow          41.9 male   masculine Tatooine         6.63   136
 5 Leia Organa           150 brown         light       brown           19   female feminine  Alderaan         4.92    49
 6 Owen Lars             178 brown, grey   light       blue            52   male   masculine Tatooine         5.84   120
 7 Beru Whitesun lars    165 brown         light       blue            47   female feminine  Tatooine         5.41    75
 8 R5-D4                  97 NA            white, red  red             NA   none   masculine Tatooine         3.18    32
 9 Biggs Darklighter     183 black         light       brown           24   male   masculine Tatooine         6.00    84
10 Obi-Wan Kenobi        182 auburn, white fair        blue-gray       57   male   masculine Stewjon          5.97    77
# i 77 more rows
# i Use `print(n = ...)` to see more rows
```

dplyr::pull

Extracts a variable (column) as a vector

>pull(starwars.cut,height)

>pull(starwars.cut,2)

```
> pull(starwars.cut,height)
 [1] 172 167  96 202 150 178 165  97 183 182 188 180 228 180 173 175 170 180  66 170 183 200 190 177 175 180 150  NA  88 160 193 191 170 196
[35] 224 206 183 137 112 183 163 175 180 178  94 122 163 188 198 196 171 184 188 264 188 196 185 157 183 183 170 166 165 193 191 183 168 198
[69] 229 213 167  79  96 193 191 178 216 234 188 178 206  NA  NA  NA  NA  NA 165
> pull(starwars.cut,2)
 [1] 172 167  96 202 150 178 165  97 183 182 188 180 228 180 173 175 170 180  66 170 183 200 190 177 175 180 150  NA  88 160 193 191 170 196
[35] 224 206 183 137 112 183 163 175 180 178  94 122 163 188 198 196 171 184 188 264 188 196 185 157 183 183 170 166 165 193 191 183 168 198
[69] 229 213 167  79  96 193 191 178 216 234 188 178 206  NA  NA  NA  NA  NA 165
```

Row operations

dplyr::arrange

- arrange orders the rows of a data frame by the values of selected columns

Note: We can find more information using

??dplyr::arrange (or ??arrange) to get relevant help pages

Example using *arrange*

> starwars.cut %>% arrange(desc(height))

> arrange(starwars.cut, desc(height))

The 87x10 tibble starwars.cut is to be sorted by height

```
> starwars.cut %>% arrange(desc(height))
# A tibble: 87 × 10
   name          height  mass hair_color skin_color   eye_color     birth_year sex    gender    homeworld
   <chr>          <int> <dbl> <chr>      <chr>        <chr>              <dbl> <chr>  <chr>     <chr>
 1 Yarael Poof      264    NA none       white        yellow                NA male   masculine Quermia
 2 Tarfful          234   136 brown      brown        blue                  NA male   masculine Kashyyyk
 3 Lama Su          229    88 none       grey         black                 NA male   masculine Kamino
 4 Chewbacca        228   112 brown      unknown      blue                 200 male   masculine Kashyyyk
 5 Roos Tarpals     224    82 none       grey         orange                NA male   masculine Naboo
 6 Grievous         216   159 none       brown, white green, yellow         NA male   masculine Kalee
 7 Taun We          213    NA none       grey         black                 NA female feminine  Kamino
 8 Rugor Nass       206    NA none       green        orange                NA male   masculine Naboo
 9 Tion Medon       206    80 none       grey         black                 NA male   masculine Utapau
10 Darth Vader      202   136 none       white        yellow              41.9 male   masculine Tatooine
# i 77 more rows
# i Use `print(n = ...)` to see more rows
```

Example using *arrange*

- We can also sort by more than one variable

```
>starwars.cut %>% arrange(gender, desc(height))
```

which sorts by gender and then ascending height

```
> starwars.cut %>% group_by(gender) %>%
        arrange(desc(height),.by_group=TRUE)
```

accomplishes the same thing

dplyr::filter

- used to subset a data frame, retaining all rows that satisfy your conditions

- Useful functions:
  - == > <
  - & | ! xor()
  - is.na()
  - between()
  - near()

Examples using *filter*

```
> starwars.cut %>% filter(homeworld=="Naboo")
```

	name	height	mass	hair_color	skin_color	eye_color	birth_year	sex	gender	homeworld
	<chr>	<int>	<dbl>	<chr>	<chr>	<chr>	<dbl>	<chr>	<chr>	<chr>
1	R2-D2	96	32	NA	white, blue	red	33	none	masculine	Naboo
2	Palpatine	170	75	grey	pale	yellow	82	male	masculine	Naboo
3	Jar Jar Binks	196	66	none	orange	orange	52	male	masculine	Naboo
4	Roos Tarpals	224	82	none	grey	orange	NA	male	masculine	Naboo
5	Rugor Nass	206	NA	none	green	orange	NA	male	masculine	Naboo
6	Ric Olié	183	NA	brown	fair	blue	NA	NA	NA	Naboo
7	Quarsh Panaka	183	NA	black	dark	brown	62	NA	NA	Naboo
8	Gregar Typho	185	85	black	dark	brown	NA	male	masculine	Naboo
9	Cordé	157	NA	brown	light	brown	NA	female	feminine	Naboo
10	Dormé	165	NA	brown	light	brown	NA	female	feminine	Naboo
11	Padmé Amidala	165	45	brown	light	brown	46	female	feminine	Naboo

Examples using *filter*

```
> starwars.cut %>%
  filter(homeworld=="Naboo") %>%
  filter(hair_color != 'grey')
```

Note we can use a double ("Naboo") or single ('grey') quote interchangeably in R

	name	height	mass	hair_color	skin_color	eye_color	birth_year	sex	gender	homeworld
	<chr>	<int>	<dbl>	<chr>	<chr>	<chr>	<dbl>	<chr>	<chr>	<chr>
1	Jar Jar Binks	196	66	none	orange	orange	52	male	masculine	Naboo
2	Roos Tarpals	224	82	none	grey	orange	NA	male	masculine	Naboo
3	Rugor Nass	206	NA	none	green	orange	NA	male	masculine	Naboo
4	Ric Olié	183	NA	brown	fair	blue	NA	NA	NA	Naboo
5	Quarsh Panaka	183	NA	black	dark	brown	62	NA	NA	Naboo
6	Gregar Typho	185	85	black	dark	brown	NA	male	masculine	Naboo
7	Cordé	157	NA	brown	light	brown	NA	female	feminine	Naboo
8	Dormé	165	NA	brown	light	brown	NA	female	feminine	Naboo
9	Padmé Amidala	165	45	brown	light	brown	46	female	feminine	Naboo

More succinctly, we can type:

```
>filter(starwars.cut,homeworld =="Naboo" & hair_color != 'grey' )
```

Examples using *filter*

> starwars.cut %>% filter(height > 200) %>% filter(mass != 'NA')

```
> starwars.cut %>% filter(height > 200 ) %>% filter(mass != 'NA')
# A tibble: 7 x 10
  name         height  mass hair_color skin_color   eye_color     birth_year sex   gender    homeworld
  <chr>         <int> <dbl> <chr>      <chr>        <chr>              <dbl> <chr> <chr>     <chr>
1 Darth Vader     202   136 none       white        yellow              41.9 male  masculine Tatooine
2 Chewbacca       228   112 brown      unknown      blue               200   male  masculine Kashyyyk
3 Roos Tarpals    224    82 none       grey         orange              NA   male  masculine Naboo
4 Lama Su         229    88 none       grey         black               NA   male  masculine Kamino
5 Grievous        216   159 none       brown, white green, yellow       NA   male  masculine Kalee
6 Tarfful         234   136 brown      brown        blue                NA   male  masculine Kashyyyk
7 Tion Medon      206    80 none       grey         black               NA   male  masculine Utapau
```

slice_min, slice_max

```
> slice_min(starwars.cut,order_by=height,by=sex,na_rm=TRUE)
# A tibble: 7 × 10
  name                height  mass hair_color skin_color       eye_color birth_year sex           gender    homeworld
  <chr>                <int> <dbl> <chr>      <chr>            <chr>           <dbl> <chr>         <chr>     <chr>
1 Yoda                    66    17 white      green            brown             896 male          masculine NA
2 R2-D2                   96    32 NA         white, blue      red                33 none          masculine Naboo
3 R4-P17                  96    NA none       silver, red      red, blue          NA none          feminine  NA
4 Leia Organa            150    49 brown      light            brown              19 female        feminine  Alderaan
5 Mon Mothma             150    NA auburn     fair             blue               48 female        feminine  Chandrila
6 Jabba Desilijic Tiure  175  1358 NA         green-tan, brown orange            600 hermaphroditic masculine Nal Hutta
7 Sly Moore              178    48 none       pale             white              NA NA            NA        Umbara
> slice_max(starwars.cut,order_by=height,by=sex,na_rm=TRUE)
# A tibble: 6 × 10
  name                height  mass hair_color skin_color       eye_color birth_year sex           gender    homeworld
  <chr>                <int> <dbl> <chr>      <chr>            <chr>           <dbl> <chr>         <chr>     <chr>
1 Yarael Poof            264    NA none       white            yellow             NA male          masculine Quermia
2 IG-88                  200   140 none       metal            red                15 none          masculine NA
3 Taun We                213    NA none       grey             black              NA female        feminine  Kamino
4 Jabba Desilijic Tiure  175  1358 NA         green-tan, brown orange            600 hermaphroditic masculine Nal Hutta
5 Ric Olié               183    NA brown      fair             blue               NA NA            NA        Naboo
6 Quarsh Panaka          183    NA black      dark             brown              62 NA            NA        Naboo
```

Grouping operations

dplyr::group_by

- Groups the data frame by a grouping variable(s). Becomes a grouped tibble where operations are performed by group until it is ungrouped

- NOT the same as sorting or ***dplyr::arrange***

```
> group_by(starwars.cut1, gender)
>ungroup(starwars.cut1)
```

group_by

```
> group_by(starwars.cut1, gender)
# A tibble: 87 × 11
# Groups:   gender [3]
   name               height  mass hair_color    skin_color  eye_color birth_year sex    gender    homeworld height.feet
   <chr>               <int> <dbl> <chr>         <chr>       <chr>          <dbl> <chr>  <chr>     <chr>           <dbl>
 1 Luke Skywalker        172    77 blond         fair        blue            19   male   masculine Tatooine         5.64
 2 C-3PO                 167    75 NA            gold        yellow         112   none   masculine Tatooine         5.48
 3 R2-D2                  96    32 NA            white, blue red             33   none   masculine Naboo            3.15
 4 Darth Vader           202   136 none          white       yellow          41.9 male   masculine Tatooine         6.63
 5 Leia Organa           150    49 brown         light       brown           19   female feminine  Alderaan         4.92
 6 Owen Lars             178   120 brown, grey   light       blue            52   male   masculine Tatooine         5.84
 7 Beru Whitesun lars    165    75 brown         light       blue            47   female feminine  Tatooine         5.41
 8 R5-D4                  97    32 NA            white, red  red             NA   none   masculine Tatooine         3.18
 9 Biggs Darklighter     183    84 black         light       brown           24   male   masculine Tatooine         6.00
10 Obi-Wan Kenobi        182    77 auburn, white fair        blue-gray       57   male   masculine Stewjon          5.97
# i 77 more rows
# i Use `print(n = ...)` to see more rows
> ungroup(starwars.cut1)
# A tibble: 87 × 11
   name               height  mass hair_color    skin_color  eye_color birth_year sex    gender    homeworld height.feet
   <chr>               <int> <dbl> <chr>         <chr>       <chr>          <dbl> <chr>  <chr>     <chr>           <dbl>
 1 Luke Skywalker        172    77 blond         fair        blue            19   male   masculine Tatooine         5.64
 2 C-3PO                 167    75 NA            gold        yellow         112   none   masculine Tatooine         5.48
 3 R2-D2                  96    32 NA            white, blue red             33   none   masculine Naboo            3.15
 4 Darth Vader           202   136 none          white       yellow          41.9 male   masculine Tatooine         6.63
 5 Leia Organa           150    49 brown         light       brown           19   female feminine  Alderaan         4.92
 6 Owen Lars             178   120 brown, grey   light       blue            52   male   masculine Tatooine         5.84
 7 Beru Whitesun lars    165    75 brown         light       blue            47   female feminine  Tatooine         5.41
 8 R5-D4                  97    32 NA            white, red  red             NA   none   masculine Tatooine         3.18
 9 Biggs Darklighter     183    84 black         light       brown           24   male   masculine Tatooine         6.00
10 Obi-Wan Kenobi        182    77 auburn, white fair        blue-gray       57   male   masculine Stewjon          5.97
# i 77 more rows
# i Use `print(n = ...)` to see more rows
```

dplyr::summarize

- Creates a new data frame.
- It returns one row for each combination of grouping variables

Example with no grouping variable:

```
>starwars.cut %>%
        mutate(height.feet=height/30.48) %>%
        summarize(mean=mean(height.feet,na.rm=TRUE),
        median=median(height.feet,na.rm=TRUE))
```

dplyr::summarize

Some basic statistics you may compute:

Objective	Function
Basic	mean()
	median()
	sum()
variation	sd()
	IQR()
range	min(), max()
	quantile()

summarize

Compute the average height in feet by gender

```
> starwars.cut %>%
      mutate(height.feet=height/30.48) %>%
      group_by(gender) %>%
      summarize(mean=mean(height.feet,na.rm=TRUE),
      count=n())
```

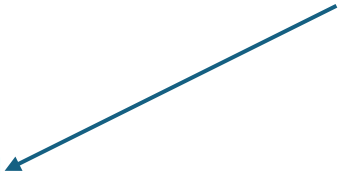
```
# A tibble: 3 × 3
  gender     mean count
  <chr>     <dbl> <int>
1 feminine   5.40    17
2 masculine  5.79    66
3 NA         5.95     4
```

mutate

Compute the deviation of each individual height (in feet) from the average for their gender

```
> starwars.cut %>%
        mutate(height.feet=height/30.48) %>%
        group_by(gender) %>%
       mutate(height.grp.mean=mean(height.feet,na.rm=TRUE)) %>%
        mutate(height.dev=height-height.grp.mean) %>%
        select(name,gender,height.feet, height.dev, height.grp.mean,)
```

mutate



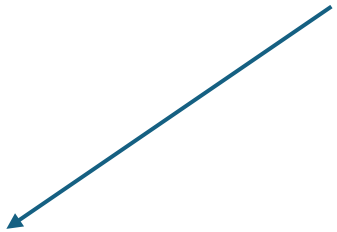
```
# A tibble: 87 × 5
# Groups:   gender [3]
   name               gender    height.feet height.dev height.grp.mean
   <chr>              <chr>           <dbl>      <dbl>            <dbl>
 1 Luke Skywalker     masculine        5.64    -0.148              5.79
 2 C-3PO              masculine        5.48    -0.312              5.79
 3 R2-D2              masculine        3.15    -2.64               5.79
 4 Darth Vader        masculine        6.63     0.836              5.79
 5 Leia Organa        feminine         4.92    -0.482              5.40
 6 Owen Lars          masculine        5.84     0.0487             5.79
 7 Beru Whitesun lars feminine         5.41     0.0103             5.40
 8 R5-D4              masculine        3.18    -2.61               5.79
 9 Biggs Darklighter  masculine        6.00     0.213              5.79
10 Obi-Wan Kenobi     masculine        5.97     0.180              5.79
# i 77 more rows
# i Use `print(n = ...)` to see more rows
```

mutate

Also compute the deviation from the overall mean:

```
> starwars.cut %>%
      mutate(height.feet=height/30.48) %>%
      group_by(gender) %>%
      mutate(height.dev=height.feet - mean(height.feet,na.rm=TRUE))%>%
      mutate(height.grp.mean=mean(height.feet,na.rm=TRUE)) %>%
      ungroup(gender) %>%
      mutate(height.overall.dev=height.feet - mean(height.feet,na.rm=TRUE)) %>%
      select(name,gender,height.feet,height.dev,height.grp.mean,height.overall.dev)
```

mutate



```
# A tibble: 87 × 6
   name               gender    height.feet height.dev height.grp.mean height.overall.dev
   <chr>              <chr>           <dbl>      <dbl>           <dbl>               <dbl>
 1 Luke Skywalker     masculine        5.64    -0.148             5.79            -0.0774
 2 C-3PO              masculine        5.48    -0.312             5.79            -0.241
 3 R2-D2              masculine        3.15    -2.64              5.79            -2.57
 4 Darth Vader        masculine        6.63     0.836             5.79             0.907
 5 Leia Organa        feminine         4.92    -0.482             5.40            -0.799
 6 Owen Lars          masculine        5.84     0.0487            5.79             0.119
 7 Beru Whitesun lars feminine         5.41     0.0103            5.40            -0.307
 8 R5-D4              masculine        3.18    -2.61              5.79            -2.54
 9 Biggs Darklighter  masculine        6.00     0.213             5.79             0.284
10 Obi-Wan Kenobi     masculine        5.97     0.180             5.79             0.251
# i 77 more rows
# i Use `print(n = ...)` to see more rows
```

Example

Output the count for each gender and eye color.

	gender	eye_color	count
	<chr>	<chr>	<int>
1	feminine	black	2
2	feminine	blue	6
3	feminine	brown	5
4	feminine	hazel	2
5	feminine	red, blue	1
6	feminine	yellow	1
7	masculine	black	8
8	masculine	blue	12
9	masculine	blue-gray	1
10	masculine	brown	15

i 13 more rows

Example

Output the count for each gender and eye color.

```
> starwars.cut %>%
      group_by(gender, eye_color) %>%
      summarize(count=n())
```

```
   gender    eye_color count
   <chr>     <chr>     <int>
 1 feminine  black         2
 2 feminine  blue          6
 3 feminine  brown         5
 4 feminine  hazel         2
 5 feminine  red, blue     1
 6 feminine  yellow        1
 7 masculine black         8
 8 masculine blue         12
 9 masculine blue-gray     1
10 masculine brown        15
# i 13 more rows
```

Example

Select all gender="feminine" individuals with height in feet greater than the overall group average height and then summarize the count in each homeworld for this subgroup

```
# A tibble: 11 x 12
   name        height  mass hair_color skin_color eye_color birth_year sex   gender homeworld height.feet height.mean
   <chr>        <int> <dbl> <chr>      <chr>      <chr>          <dbl> <chr> <chr>  <chr>           <dbl>       <dbl>
 1 Beru White…    165  75   brown      light      blue              47 fema… femin… Tatooine         5.41        5.40
 2 Ayla Secura    178  55   none       blue       hazel             48 fema… femin… Ryloth           5.84        5.40
 3 Adi Gallia     184  50   none       dark       blue              NA fema… femin… Coruscant        6.04        5.40
 4 Luminara U…    170  56.2 black      yellow     blue              58 fema… femin… Mirial           5.58        5.40
 5 Barriss Of…    166  50   black      yellow     blue              40 fema… femin… Mirial           5.45        5.40
 6 Dormé          165  NA   brown      light      brown             NA fema… femin… Naboo            5.41        5.40
 7 Zam Wesell     168  55   blonde     fair, gre… yellow            NA fema… femin… Zolan            5.51        5.40
 8 Taun We        213  NA   none       grey       black             NA fema… femin… Kamino           6.99        5.40
 9 Jocasta Nu     167  NA   white      fair       blue              NA fema… femin… Coruscant        5.48        5.40
10 Shaak Ti       178  57   none       red, blue… black             NA fema… femin… Shili            5.84        5.40
11 Padmé Amid…    165  45   brown      light      brown             46 fema… femin… Naboo            5.41        5.40
```

```
# A tibble: 8 x 2
  homeworld count
  <chr>     <int>
1 Coruscant     2
2 Kamino        1
3 Mirial        2
4 Naboo         2
5 Ryloth        1
6 Shili         1
7 Tatooine      1
8 Zolan         1
```

Example

Select all gender=“feminine” individuals with height in feet greater than the overall group average height and present a table summarizing the count of each homeworld in this subset

```
>starwars.cut %>%
        filter(gender== 'feminine') %>%
        mutate(height.feet=height/30.48) %>%
        mutate(height.mean=mean(height.feet,na.rm=TRUE)) %>%
            filter(height.feet > height.mean,na.rm=TRUE))
```

Merging data frames

dplyr::inner_join

Only keeps observations from data frame A if they have a match in in data frame B. Unmatched observations from A or B are not kept

Example:

A =

Name	Age
Joe	19
John	33
Jack	41

B=

Name	Wage/hr
Joe	15
John	21
Jack	24
Ed	35

```
> inner_join(A,B,by='Name')
  Name Age Wage
1  Joe  19   15
2 John  33   21
3 Jack  41   24
```

dplyr::left_join and dplyr::right_join

A =

Name	Age
Joe	19
John	33
Jack	41

B=

Name	Wage/hr
Joe	15
John	21
Jack	24
Ed	35

```
> left_join(A,B,by='Name')
  Name Age Wage
1  Joe  19   15
2 John  33   21
3 Jack  41   24
> right_join(A,B,by='Name')
  Name Age Wage
1  Joe  19   15
2 John  33   21
3 Jack  41   24
4   Ed  NA   35
```

Helpful online communities

R Studio

- https://forum.posit.co/

R

- https://stackoverflow.com/questions/tagged/R

Tidyverse:

- https://posit.co/resources/videos/a-gentle-introduction-to-tidy-statistics-in-r/
- https://dplyr.tidyverse.org/reference/mutate-joins.html

BERD House

https://www.einsteinmed.edu/centers/ictr/biostatistics-epidemiology-research-design-core/berd-house/