

Iterating on Data

Data Wrangling, Session 7

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Code Horizons

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Iterating on data with purrr and map

Load the packages, as always

```
library(here)      # manage file paths  
library(socviz)    # data and some useful functions  
library(tidyverse) # your friend and mine
```

Moar Data

More than one data file

Inside the `data/` folder of the course packet is a folder named `congress/`

```
# A little trick from the fs package:  
fs::dir_tree(here("data", "congress"))  
  
/Users/kjhealy/Documents/courses/data_wrangling/data/congress  
└── 01_79_congress.csv  
└── 02_80_congress.csv  
└── 03_81_congress.csv  
└── 04_82_congress.csv  
└── 05_83_congress.csv  
└── 06_84_congress.csv  
└── 07_85_congress.csv  
└── 08_86_congress.csv  
└── 09_87_congress.csv  
└── 10_88_congress.csv  
└── 11_89_congress.csv  
└── 12_90_congress.csv  
└── 13_91_congress.csv  
└── 14_92_congress.csv  
└── 15_93_congress.csv  
└── 16_94_congress.csv  
└── 17_95_congress.csv  
└── 18_96_congress.csv  
└── 19_97_congress.csv  
└── 20_98_congress.csv  
└── 21_99_congress.csv  
└── 22_100_congress.csv  
└── 23_101_congress.csv  
└── 24_102_congress.csv  
└── 25_103_congress.csv  
└── 26_104_congress.csv
```

More than one data file

Let's look at one.

```
read_csv(here("data", "congress", "17_95_congress.csv")) >
  janitor::clean_names() >
  head()

# A tibble: 6 × 25
  last     first    middle suffix nickname born   death sex   position party state
  <chr>   <chr>   <chr>  <chr>  <chr>   <chr> <chr> <chr> <chr> <chr>
1 Abdnor James   <NA>   <NA>   <NA>   02/1... 11/0... M   U.S. Re... Repu... SD
2 Abourezk James George <NA>   <NA>   <NA>   02/2... <NA> M   U.S. Se... Demo... SD
3 Adams    Brockm... <NA>   <NA>   Brock   01/1... 09/1... M   U.S. Re... Demo... WA
4 Addabbo  Joseph Patri... <NA>   <NA>   <NA>   03/1... 04/1... M   U.S. Re... Demo... NY
5 Aiken    George David <NA>   <NA>   <NA>   08/2... 11/1... M   U.S. Se... Repu... VT
6 Akaka    Daniel Kahik... <NA>   <NA>   <NA>   09/1... 04/0... M   U.S. Re... Demo... HI
# i 14 more variables: district <chr>, start <chr>, end <chr>, religion <chr>,
# race <chr>, educational_attainment <chr>, job_type1 <chr>, job_type2 <chr>,
# job_type3 <chr>, job_type4 <chr>, job_type5 <lgl>, mil1 <chr>, mil2 <chr>,
# mil3 <chr>
```

We often find ourselves in this situation. We know each file has the same structure, and we would like to use them all at once.

Loops?

How to read them all in?

One traditional way, which we could do in R, is to write an explicit *loop* that iterated over a vector of filenames, read each file, and then joined the results together in a tall rectangle.

```
# Pseudocode

filenames ← c("01_79_congress.csv", "02_80_congress.csv", "03_81_congress.csv",
            "04_82_congress.csv" [etc etc])

collected_files ← NULL

for(i in 1:length(filenames)) {
    new_file ← read_file(filenames[i])
    collected_files ← append_to(collected_files, new_file)
}
```

Loops?

You may have noticed we have not written any loops, however.

While loops are still lurking there underneath the surface, what we will do instead is to take advantage of the combination of vectors and functions and *map* one to the other in order to generate results.

Speaking loosely, think of **map()** as a way of **iterating** without writing loops. You start with a vector of things. You feed it one thing at a time to some function. The function does whatever it does. You get back output that is the same length as your input, and of a specific type.

Mapping is just a kind of iteration

The `purrr` package provides a big family of mapping functions. One reason there are a lot of them is that `purrr`, like the rest of the tidyverse, is picky about data types.

So in addition to the basic `map()`, which always returns a *list*, we also have `map_chr()`, `map_int()`, `map_dbl()`, `map_lgl()` and others. They always return the data type indicated by their suffix, or die trying.

Vectorized arithmetic again

The simplest cases are not that different from the vectorized arithmetic we're already familiar with.

```
a ← c(1:10)  
b ← 1  
# You know what R will do here  
a + b
```



```
[1]  2  3  4  5  6  7  8  9 10 11
```

R's vectorized rules add **b** to every element of **a**. In a sense, the **+** operation can be thought of as a function that takes each element of **a** and does something with it. In this case “add **b**”.

Vectorized arithmetic again

We can make this explicit by writing a function:

```
add_b <- function(x) {  
  b <- 1  
  x + b # for any x  
}
```

Vectorized arithmetic again

We can make this explicit by writing a function:

```
add_b <- function(x) {  
  b <- 1  
  x + b # for any x  
}
```

Now:

```
add_b(x = a)  
[1]  2  3  4  5  6  7  8  9 10 11
```

Vectorized arithmetic again

Again, R's vectorized approach means it automatically adds **b** to every element of the **x** we give it.

```
add_b(x = 10)
```

```
[1] 11
```

```
add_b(x = c(1, 99, 1000))
```

```
[1] 2 100 1001
```

Iterating in a pipeline

Some operations can't directly be vectorized in this way, which is why we need to manually iterate, or will want to write loops.

```
library(gapminder)
gapminder %>
  summarize(country_n = n_distinct(country),
           continent_n = n_distinct(continent),
           year_n = n_distinct(year),
           lifeExp_n = n_distinct(lifeExp),
           population_n = n_distinct(population))

# A tibble: 1 × 5
  country_n continent_n year_n lifeExp_n population_n
  <int>      <int>   <int>     <int>        <int>
1       142          5      12      1626        4060
```

That's tedious to write! Computers are supposed to allow us to avoid that sort of thing.

Iterating in a pipeline

So how would we iterate this? What we want is to apply the `n_distinct()` function to each column of `gapminder`, but in a way that still allows us to use pipelines and so on.

```
library(gapminder)
gapminder %>
  summarize(n_distinct(country),
            n_distinct(continent),
            n_distinct(year),
            n_distinct(lifeExp),
            n_distinct(population))

# A tibble: 1 × 5
  `n_distinct(country)` `n_distinct(continent)` `n_distinct(year)` 
    <int>                  <int>                  <int>    
1 142                      5                      12
# i 2 more variables: `n_distinct(lifeExp)` <int>,
#   `n_distinct(population)` <int>
```

Using `n_distinct()` in this context is an idea I got from Rebecca Barter's discussion of `purrr`.

Iterating in a pipeline

You'd use **across()**, like this:

```
gapminder >
  summarize(across(everything(), n_distinct))

# A tibble: 1 × 6
  country continent year lifeExp   pop gdpPercap
  <int>     <int> <int>    <int> <int>      <int>
1     142         5    12     1626  1704       1704
```

Iterating in a pipeline

But you could also do this ...

```
map(gapminder, n_distinct)
```

```
$country  
[1] 142
```

```
$continent  
[1] 5
```

```
$year  
[1] 12
```

```
$lifeExp  
[1] 1626
```

```
$pop  
[1] 1704
```

```
$gdpPerCap  
[1] 1704
```

Read it as “Feed each column of **gapminder** to the **n_distinct()** function.

(This is pretty much what **across()** is doing more nicely.)

Iterating in a pipeline

Or, in pipeline form:

```
gapminder %>  
  map(n_distinct)
```

```
$country  
[1] 142
```

```
$continent  
[1] 5
```

```
$year  
[1] 12
```

```
$lifeExp  
[1] 1626
```

```
$pop  
[1] 1704
```

```
$gdpPerCap  
[1] 1704
```

You can see we are getting a *list* back.

Iterating in a pipeline

Or, in pipeline form:

```
result ← gapminder ▷  
  map(n_distinct)
```

```
class(result)
```

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

```
result$continent
```

```
[1] 5
```

```
result[[2]]
```

```
[1] 5
```

Iterating in a pipeline

But we know `n_distinct()` should always return an integer. So we use `map_int()` instead of the generic `map()`.

```
gapminder ▶  
map_int(n_distinct)  
  
country continent      year   lifeExp      pop   gdpPercap  
142           5       12    1626     1704     1704
```

The thing about the `map()` family is that they can deal with all kinds of input types and output types.

Get a vector of filenames

```
filenames ← dir(path = here("data", "congress"),
                 pattern = "*.csv",
                 full.names = TRUE)

filenames[1:15] # Just displaying the first 15, to save slide space
```

```
[1] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/01_79_congress.csv"
[2] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/02_80_congress.csv"
[3] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/03_81_congress.csv"
[4] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/04_82_congress.csv"
[5] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/05_83_congress.csv"
[6] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/06_84_congress.csv"
[7] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/07_85_congress.csv"
[8] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/08_86_congress.csv"
[9] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/09_87_congress.csv"
[10] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/10_88_congress.csv"
[11] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/11_89_congress.csv"
[12] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/12_90_congress.csv"
[13] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/13_91_congress.csv"
[14] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/14_92_congress.csv"
[15] "/Users/kjhealy/Documents/courses/data_wrangling/data/congress/15_93_congress.csv"
```

And feed it to `read_csv()`

... using `map()` and binding the resulting list into a tibble.

```
df ← filenames ▷  
  map(read_csv) ▷  
  list_rbind(names_to = "congress") ▷  
  janitor::clean_names()  
  
df  
  
# A tibble: 20,580 × 26  
  congress last   first middle suffix nickname born   death sex   position party  
  <int> <chr>  <chr> <chr>  <chr>  <chr>  <chr> <chr> <chr> <chr>  <chr>  
1      1 Abern... Thom... Gerst... <NA>   <NA>   05/1... 01/2... M    U.S. Re... Demo...  
2      1 Adams   Sher... <NA>   <NA>   <NA>   01/0... 10/2... M    U.S. Re... Repu...  
3      1 Aiken   Geor... David   <NA>   <NA>   08/2... 11/1... M    U.S. Se... Repu...  
4      1 Allen   Asa    Leona... <NA>   <NA>   01/0... 01/0... M    U.S. Re... Demo...  
5      1 Allen   Leo    Elwood  <NA>   <NA>   10/0... 01/1... M    U.S. Re... Repu...  
6      1 Almond J. Linds... Jr.   <NA>   <NA>   06/1... 04/1... M    U.S. Re... Demo...  
7      1 Ander... Herm... Carl    <NA>   <NA>   01/2... 07/2... M    U.S. Re... Repu...  
8      1 Ander... Clin... Presba <NA>   <NA>   10/2... 11/1... M    U.S. Re... Demo...  
9      1 Ander... John   Zuing... <NA>   <NA>   03/2... 02/0... M    U.S. Re... Repu...  
10     1 Andre... Augu... Herman <NA>   <NA>   10/1... 01/1... M    U.S. Re... Repu...  
# i 20,570 more rows  
# i 15 more variables: state <chr>, district <chr>, start <chr>, end <chr>,  
# religion <chr>, race <chr>, educational_attainment <chr>, job_type1 <chr>,  
# job_type2 <chr>, job_type3 <chr>, job_type4 <chr>, job_type5 <chr>,  
# mil1 <chr>, mil2 <chr>, mil3 <chr>
```

Now witness the firepower of this fully armed and operational



method of type-safe functional iteration

read_csv() can do this directly

In fact map() is not required for this particular use:

```
tmp ← read_csv(filenames, id = "path",
                 name_repair = janitor::make_clean_names)

tmp %>
  mutate(congress = stringr::str_extract(path, "_\\d{2,3}_congress"),
         congress = stringr::str_extract(congress, "\\d{2,3}")) %>
  relocate(congress)
```

```
# A tibble: 20,580 × 27
  congress path   last   first  middle suffix nickname born   death sex   position
  <chr>    <chr> <chr> <chr> <chr>  <chr>   <chr> <chr> <chr> <chr>
1 79       /User... Aber... Thom... Gerst... <NA>    <NA>    05/1... 01/2... M    U.S. Re...
2 79       /User... Adams Sher... <NA>    <NA>    <NA>    01/0... 10/2... M    U.S. Re...
3 79       /User... Aiken Geor... David   <NA>    <NA>    08/2... 11/1... M    U.S. Se...
4 79       /User... Allen Asa   Leona... <NA>    <NA>    01/0... 01/0... M    U.S. Re...
5 79       /User... Allen Leo   Elwood  <NA>    <NA>    10/0... 01/1... M    U.S. Re...
6 79       /User... Almo... J.     Linds... Jr.   <NA>    <NA>    06/1... 04/1... M    U.S. Re...
7 79       /User... Ande... Herm... Carl    <NA>    <NA>    01/2... 07/2... M    U.S. Re...
8 79       /User... Ande... Clin... Presba <NA>    <NA>    10/2... 11/1... M    U.S. Re...
9 79       /User... Ande... John   Zuing... <NA>    <NA>    03/2... 02/0... M    U.S. Re...
10 79      /User... Andr... Augu... Herman <NA>    <NA>    10/1... 01/1... M    U.S. Re...
# i 20,570 more rows
# i 16 more variables: party <chr>, state <chr>, district <chr>, start <chr>,
# end <chr>, religion <chr>, race <chr>, educational_attainment <chr>,
# job_type1 <chr>, job_type2 <chr>, job_type3 <chr>, job_type4 <chr>,
# ...
```

Example: Iterating on the US Census

Iterating on the US Census

Mapped iteration is very general, and not just for local files

```
## Register for a free Census API key
library(tidy census)

out ← get_acs(geography = "county",
               variables = "B19013_001",
               state = "NY",
               county = "New York",
               survey = "acs1",
               year = 2005)

out

# A tibble: 1 × 5
  GEOID NAME          variable   estimate    moe
  <chr> <chr>        <chr>      <dbl> <dbl>
1 36061 New York County, New York B19013_001    55973 1462
```

Iterating on the US Census

All counties in New York State for a specific year

```
out ← get_acs(geography = "county",
               variables = "B19013_001",
               state = "NY",
               survey = "acs1",
               year = 2005)

out
```

	GEOID NAME	variable	estimate	moe
	<chr> <chr>	<chr>	<dbl>	<dbl>
1	36001 Albany County, New York	B19013_001	50054	2030
2	36005 Bronx County, New York	B19013_001	29228	853
3	36007 Broome County, New York	B19013_001	36394	2340
4	36009 Cattaraugus County, New York	B19013_001	37580	2282
5	36011 Cayuga County, New York	B19013_001	42057	2406
6	36013 Chautauqua County, New York	B19013_001	35495	2077
7	36015 Chemung County, New York	B19013_001	37418	3143
8	36019 Clinton County, New York	B19013_001	44757	3500
9	36027 Dutchess County, New York	B19013_001	61889	2431
10	36029 Erie County, New York	B19013_001	41967	1231
	# i 28 more rows			

Iterating on the US Census

What if we want the results for *every* available year? First, a handy function: `set_names()`

```
x ← c(1:10)
```

```
x
```

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

```
x ← set_names(x, nm = letters[1:10])
```

```
x
```

a	b	c	d	e	f	g	h	i	j
1	2	3	4	5	6	7	8	9	10

Iterating on the US Census

By default, `set_names()` will label a vector with that vector's values:

```
c(1:10) >  
  set_names()
```

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

Iterating on the US Census

This works with `map()` just fine:

```
df ← 2005:2019 ▷  
  map(\(x) get_acs(geography = "county",  
                    variables = "B19013_001",  
                    state = "NY",  
                    survey = "acs1",  
                    year = x)) ▷  
  list_rbind(names_to = "year")  
  
df  
  
# A tibble: 580 × 6  
  year GEOID NAME                variable estimate    moe  
  <int> <chr> <chr>              <chr>     <dbl> <dbl>  
1 1 36001 Albany County, New York B19013_001 50054 2030  
2 1 36005 Bronx County, New York B19013_001 29228 853  
3 1 36007 Broome County, New York B19013_001 36394 2340  
4 1 36009 Cattaraugus County, New York B19013_001 37580 2282  
5 1 36011 Cayuga County, New York B19013_001 42057 2406  
6 1 36013 Chautauqua County, New York B19013_001 35495 2077  
7 1 36015 Chemung County, New York B19013_001 37418 3143  
8 1 36019 Clinton County, New York B19013_001 44757 3500  
9 1 36027 Dutchess County, New York B19013_001 61889 2431  
10 1 36029 Erie County, New York B19013_001 41967 1231  
# i 570 more rows
```

Iterating on the US Census

Our `id` column *tracks* the year. But we'd like it to *be* the year. So, we use `set_names()`:

```
df ← 2005:2019 ▷  
  set_names() ▷  
  map(\(x) get_acs(geography = "county",  
                    variables = "B19013_001",  
                    state = "NY",  
                    survey = "acs1",  
                    year = x)) ▷  
  list_rbind(names_to = "year") ▷  
  mutate(year = as.integer(year))
```

Iterating on the US Census

```
df
```

```
# A tibble: 580 × 6
  year    GEOID NAME          variable estimate    moe
  <int>   <chr> <chr>        <chr>     <dbl> <dbl>
1 2005 36001 Albany County, New York B19013_001 50054 2030
2 2005 36005 Bronx County, New York B19013_001 29228 853
3 2005 36007 Broome County, New York B19013_001 36394 2340
4 2005 36009 Cattaraugus County, New York B19013_001 37580 2282
5 2005 36011 Cayuga County, New York B19013_001 42057 2406
6 2005 36013 Chautauqua County, New York B19013_001 35495 2077
7 2005 36015 Chemung County, New York B19013_001 37418 3143
8 2005 36019 Clinton County, New York B19013_001 44757 3500
9 2005 36027 Dutchess County, New York B19013_001 61889 2431
10 2005 36029 Erie County, New York  B19013_001 41967 1231
# i 570 more rows
```

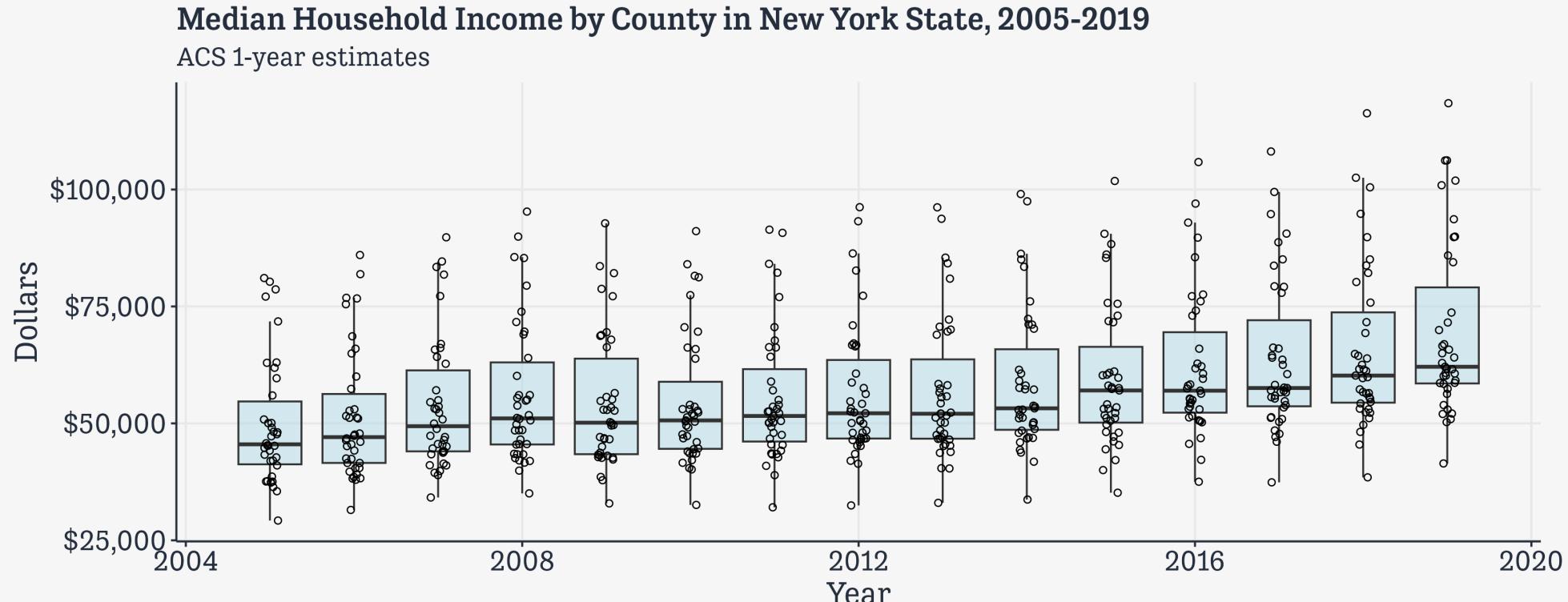
Now `year` is just the year. The `year` column will be created as a character vector, so we converted it back to an integer again at the end.

Iterating on the US Census

```
p_out ← 2005:2019 ▷  
set_names() ▷  
map(\(x) get_acs(geography = "county",  
                  variables = "B19013_001",  
                  state = "NY",  
                  survey = "acs1",  
                  year = x)) ▷  
list_rbind(names_to = "year") ▷  
mutate(year = as.integer(year)) ▷  
ggplot(mapping = aes(x = year, y = estimate, group = year)) +  
geom_boxplot(fill = "lightblue", alpha = 0.5, outlier.alpha = 0) +  
geom_jitter(position = position_jitter(width = 0.1), shape = 1) +  
scale_y_continuous(labels = scales::label_dollar()) +  
labs(x = "Year", y = "Dollars",  
     title = "Median Household Income by County in New York State, 2005-2019",  
     subtitle = "ACS 1-year estimates", caption = "Data: U.S. Census Bureau.")
```

Iterating on the US Census

```
print(p_out)
```



Data: U.S. Census Bureau.

Example: cleaning up
congress

Cleaning up congress

```
df ← filenames ▷  
  map(read_csv) ▷  
  list_rbind(names_to = "congress") ▷  
  janitor::clean_names()  
  
df ▷  
  select(born, death, start, end)  
  
# A tibble: 20,580 × 4  
  born      death     start     end  
  <chr>     <chr>     <chr>     <chr>  
1 05/16/1903 01/23/1953 01/03/1945 01/03/1953  
2 01/08/1899 10/27/1986 01/03/1945 01/03/1947  
3 08/20/1892 11/19/1984 01/03/1945 01/03/1979  
4 01/05/1891 01/05/1969 01/03/1945 01/03/1953  
5 10/05/1898 01/19/1973 01/03/1945 01/02/1949  
6 06/15/1898 04/14/1986 02/04/1946 04/17/1948  
7 01/27/1897 07/26/1978 01/03/1945 01/03/1963  
8 10/23/1895 11/11/1975 01/03/1941 06/30/1945  
9 03/22/1904 02/09/1981 01/03/1945 01/03/1953  
10 10/11/1890 01/14/1958 01/03/1945 01/14/1958  
# i 20,570 more rows
```

We'll use the **lubridate** package to sort these out.

Lubridate has a wide range of functions to handle dates, times, and

Cleaning up congress

```
library(lubridate)

date_recodes ← c("born", "death", "start", "end")
df ← df ▷
  mutate(across(any_of(date_recodes), mdy),
        congress = as.integer(congress) + 78)

df

# A tibble: 20,580 × 26
  congress last     first   middle suffix nickname born       death      sex
    <dbl> <chr>   <chr>   <chr>  <chr>  <chr> <date>    <date>    <chr>
1      79 Abernethy Thomas  Gerst... <NA>   <NA>  1903-05-16 1953-01-23 M
2      79 Adams     Sherman <NA>   <NA>   <NA>  1899-01-08 1986-10-27 M
3      79 Aiken     George  David   <NA>   <NA>  1892-08-20 1984-11-19 M
4      79 Allen     Asa    Leona... <NA>   <NA>  1891-01-05 1969-01-05 M
5      79 Allen     Leo    Elwood  <NA>   <NA>  1898-10-05 1973-01-19 M
6      79 Almond    J.    Linds... Jr.  <NA>   <NA>  1898-06-15 1986-04-14 M
7      79 Andersen Herman  Carl   <NA>   <NA>  1897-01-27 1978-07-26 M
8      79 Anderson Clinton Presba <NA>   <NA>  1895-10-23 1975-11-11 M
9      79 Anderson John   Zuing... <NA>   <NA>  1904-03-22 1981-02-09 M
10     79 Andresen August Herman <NA>   <NA>  1890-10-11 1958-01-14 M
# i 20,570 more rows
# i 17 more variables: position <chr>, party <chr>, state <chr>,
#   district <chr>, start <date>, end <date>, religion <chr>, race <chr>,
#   educational_attainment <chr>, job_type1 <chr>, job_type2 <chr>,
#   job_type3 <chr>, job_type4 <chr>, job_type5 <chr>, mil1 <chr>, mil2 <chr>,
#   mil3 <chr>
```

Cleaning up congress

```
sessions ← tibble(congress = 79:116,
                    start_year = seq(1945, 2019, by = 2),
                    end_year = seq(1947, 2021, by = 2)) %>
  mutate(start_year = ymd(paste(start_year, "01", "03", sep = "-")),
        end_year = ymd(paste(end_year, "01", "03", sep = "-)))

sessions

# A tibble: 38 × 3
  congress start_year end_year
     <int>     <date>    <date>
1       79 1945-01-03 1947-01-03
2       80 1947-01-03 1949-01-03
3       81 1949-01-03 1951-01-03
4       82 1951-01-03 1953-01-03
5       83 1953-01-03 1955-01-03
6       84 1955-01-03 1957-01-03
7       85 1957-01-03 1959-01-03
8       86 1959-01-03 1961-01-03
9       87 1961-01-03 1963-01-03
10      88 1963-01-03 1965-01-03
# i 28 more rows
```

We're going to join these tables

The big table:

```
df ▷  
  select(congress, last, born)  
  
# A tibble: 20,580 × 3  
  congress last      born  
    <dbl> <chr>     <date>  
1       79 Abernethy 1903-05-16  
2       79 Adams     1899-01-08  
3       79 Aiken     1892-08-20  
4       79 Allen     1891-01-05  
5       79 Allen     1898-10-05  
6       79 Almond    1898-06-15  
7       79 Andersen  1897-01-27  
8       79 Anderson  1895-10-23  
9       79 Anderson  1904-03-22  
10      79 Andresen 1890-10-11  
# i 20,570 more rows
```

The smaller table

```
sessions  
  
# A tibble: 38 × 3  
  congress start_year end_year  
    <int> <date>     <date>  
1       79 1945-01-03 1947-01-03  
2       80 1947-01-03 1949-01-03  
3       81 1949-01-03 1951-01-03  
4       82 1951-01-03 1953-01-03  
5       83 1953-01-03 1955-01-03  
6       84 1955-01-03 1957-01-03  
7       85 1957-01-03 1959-01-03  
8       86 1959-01-03 1961-01-03  
9       87 1961-01-03 1963-01-03  
10      88 1963-01-03 1965-01-03  
# i 28 more rows
```

We're going to **join** these tables

We will use **left_join()** which is what you want most of the time when you are looking to merge a smaller table with additional information into a larger main one.

```
df ← left_join(df, sessions) ▷  
    relocate(start_year:end_year, .after = congress)
```

```
Joining with `by = join_by(congress)`
```

```
df
```

```
# A tibble: 20,580 × 28  
  congress start_year end_year   last   first middle suffix nickname born  
    <dbl>   <date>    <date>   <chr>  <chr>  <chr>  <chr>  <chr>  <date>  
1       79 1945-01-03 1947-01-03 Abern... Thom... Gerst... <NA>  <NA>  1903-05-16  
2       79 1945-01-03 1947-01-03 Adams   Sher... <NA>  <NA>  <NA>  1899-01-08  
3       79 1945-01-03 1947-01-03 Aiken   Geor... David   <NA>  <NA>  1892-08-20  
4       79 1945-01-03 1947-01-03 Allen   Asa    Leona... <NA>  <NA>  1891-01-05  
5       79 1945-01-03 1947-01-03 Allen   Leo    Elwood <NA>  <NA>  1898-10-05  
6       79 1945-01-03 1947-01-03 Almond J. Linds... Jr.   <NA>  <NA>  1898-06-15  
7       79 1945-01-03 1947-01-03 Ander... Herm... Carl    <NA>  <NA>  1897-01-27  
8       79 1945-01-03 1947-01-03 Ander... Clin... Presba <NA>  <NA>  1895-10-23  
9       79 1945-01-03 1947-01-03 Ander... John   Zuing... <NA>  <NA>  1904-03-22  
10      79 1945-01-03 1947-01-03 Andre... Augu... Herman <NA>  <NA>  1890-10-11  
# i 20,570 more rows  
# i 19 more variables: death <date>, sex <chr>, position <chr>, party <chr>,  
# i ...
```

Table joins

x		y	
1	x1	1	y1
2	x2	2	y2
3	x3	4	y4

Spiffy Join Animations courtesy [Garrick Aden-Buie](#)

Left join, `left_join()`

left_join(x, y)			
	x1		y1
1		1	
2	x2	2	y2
3	x3	4	y4

All rows from x, and all columns from x and y. Rows in x with no match in y will have NA values in the new columns.

Left join (contd), `left_join()`

<code>left_join(x, y)</code>		
1	x1	1
2	x2	2
3	x3	4
		2
		y1
		y2
		y4
		y5

If there are multiple matches between x and y, all combinations of the matches are returned.

Inner join, inner_join()

inner_join(x, y)		
1	x1	1
2	x2	2
3	x3	4

All rows from x where there are matching values in y, and all columns from x and y.

Full join, full_join()

full_join(x, y)			
1	x1	1	y1
2	x2	2	y2
3	x3	4	y4

All rows and all columns from both x and y. Where there are not matching values, returns NA for the one missing.

Semi join, semi_join()

semi_join(x, y)		
1	x1	1
2	x2	2
3	x3	4

All rows from x where there are matching values in y, keeping just columns from x.

Anti join, anti_join()

anti_join(x, y)		
1	x1	1
2	x2	2
3	x3	4

All rows from x where there are not matching values in y, keeping just columns from x.

Left join, `left_join()`

Most of the time you will be looking to make a `left_join()`

More on Missing Data

Never test for missingness with `==`

The result of almost any operation involving a missing/unknown value will be missing/unknown.

```
df ← tribble(  
  ~subject, ~age,  
  "A", 20,  
  "B", 25,  
  "C", NA,  
  "D", 34  
)  
  
df
```

```
# A tibble: 4 × 2  
  subject    age  
  <chr>     <dbl>  
1 A          20  
2 B          25  
3 C          NA  
4 D          34
```

Never test for missingness with `=`

The result of almost any operation involving a missing/unknown value will be missing/unknown.

```
# OK
df %>
  filter(age == 25)

# A tibble: 1 × 2
  subject age
  <chr>   <dbl>
1 B         25
```

Never test for missingness with `=`

The result of almost any operation involving a missing/unknown value will be missing/unknown.

```
# Nope
df %>
  filter(age == NA)

# A tibble: 0 × 2
# i 2 variables: subject <chr>, age <dbl>
```

Never test for missingness with `=`

The result of almost any operation involving a missing/unknown value will be missing/unknown.

```
# E.g.  
23 == NA
```

```
[1] NA
```

Never test for missingness with `=`

Always use `is.na()` instead

```
# Yes
df %>
  filter(is.na(age))

# A tibble: 1 × 2
  subject   age
  <chr>     <dbl>
1 C           NA
```

A quick plug for **naniar** and **visdat**

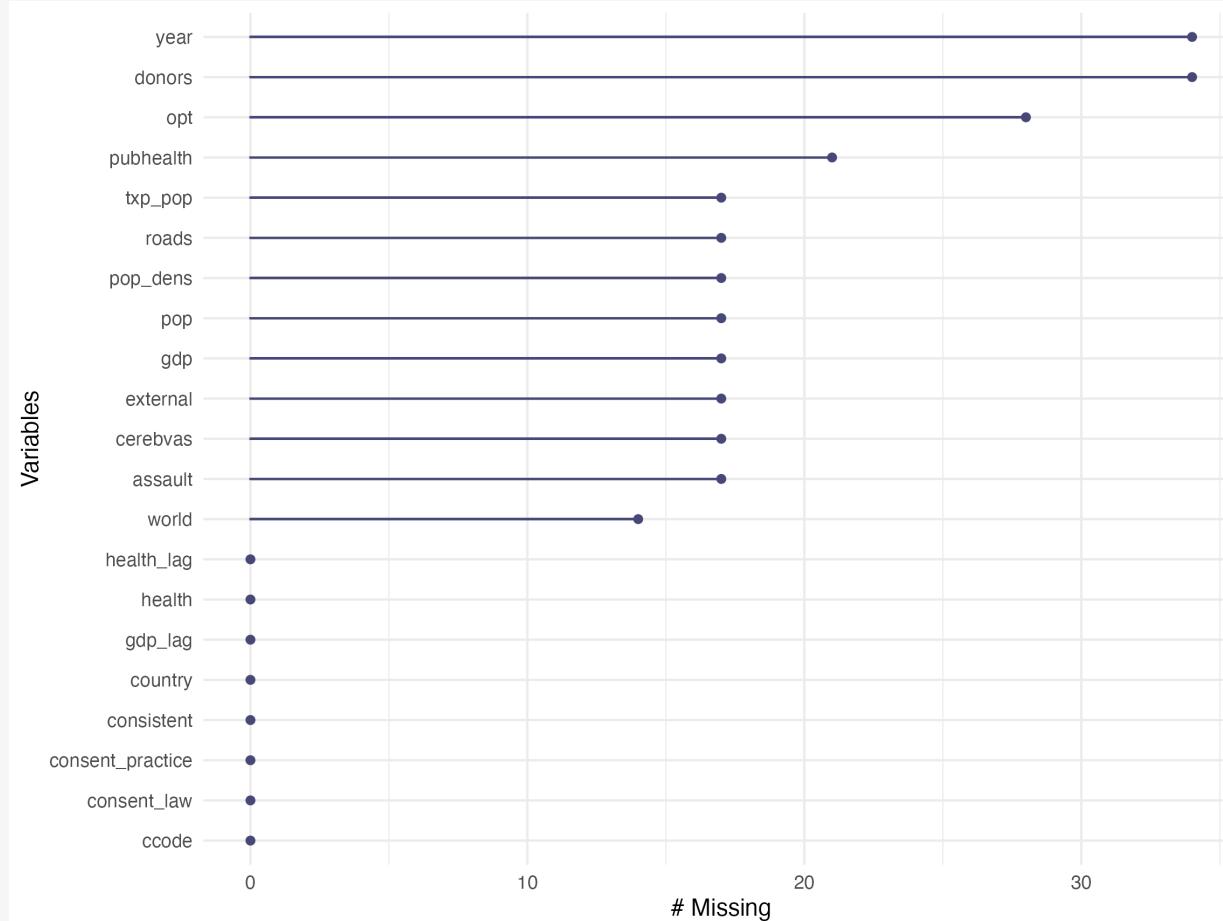
```
library(naniar)
library(visdat)

organdata

# A tibble: 238 × 21
  country   year    donors    pop  pop_dens    gdp  gdp_lag  health  health_lag
  <chr>     <date>  <dbl>  <int>    <dbl>  <int>  <dbl>    <dbl>
1 Australia NA      17065  0.220  16774  16591  1300    1224
2 Australia 1991-01-01 12.1  17284  0.223  17171  16774  1379    1300
3 Australia 1992-01-01 12.4  17495  0.226  17914  17171  1455    1379
4 Australia 1993-01-01 12.5  17667  0.228  18883  17914  1540    1455
5 Australia 1994-01-01 10.2  17855  0.231  19849  18883  1626    1540
6 Australia 1995-01-01 10.2  18072  0.233  21079  19849  1737    1626
7 Australia 1996-01-01 10.6  18311  0.237  21923  21079  1846    1737
8 Australia 1997-01-01 10.3  18518  0.239  22961  21923  1948    1846
9 Australia 1998-01-01 10.5  18711  0.242  24148  22961  2077    1948
10 Australia 1999-01-01 8.67  18926  0.244  25445  24148  2231   2077
# i 228 more rows
# i 12 more variables: pubhealth <dbl>, roads <dbl>, cerebvas <int>,
# assault <int>, external <int>, txp_pop <dbl>, world <chr>, opt <chr>,
# consent_law <chr>, consent_practice <chr>, consistent <chr>, ccode <chr>
```

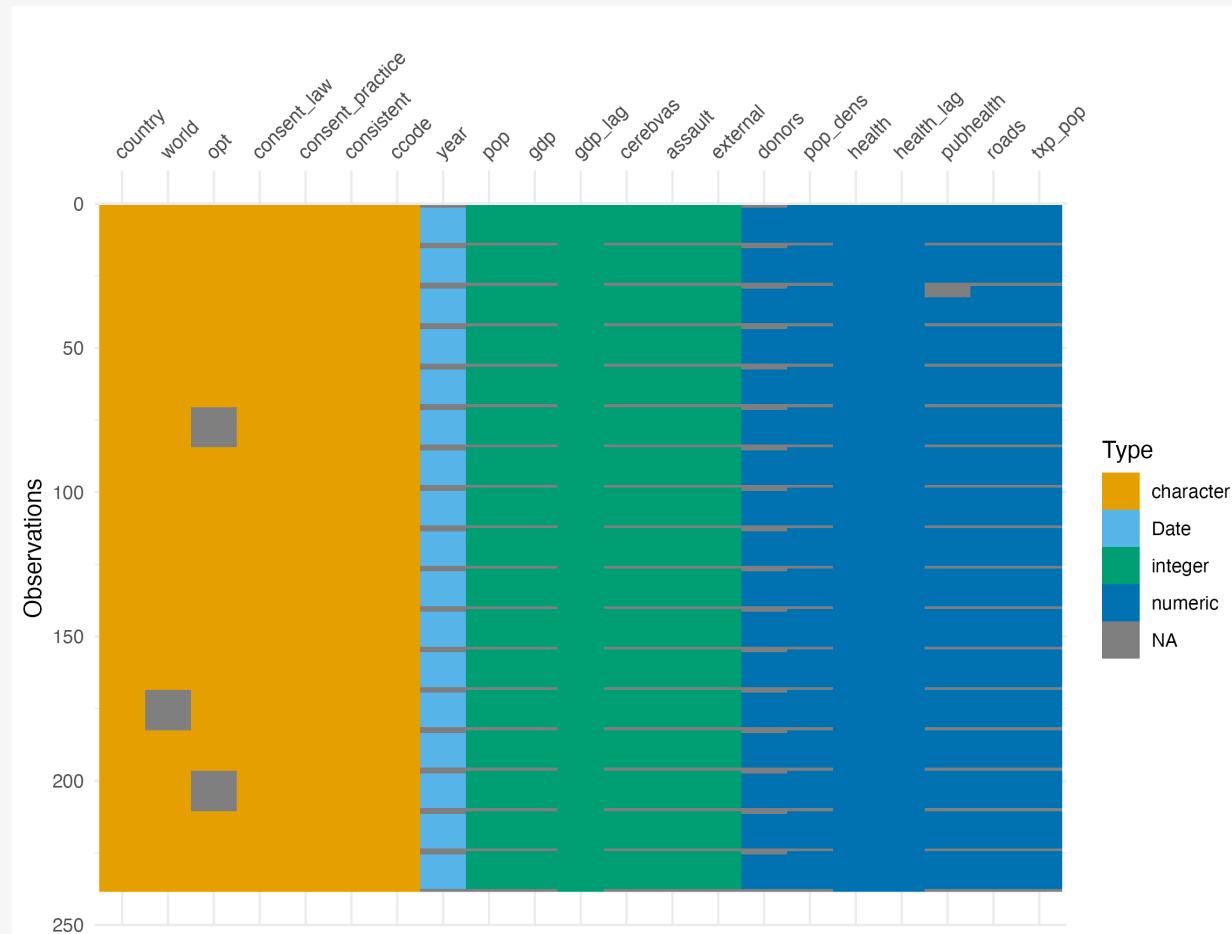
A quick plug for **naniar** and **visdat**

```
gg_miss_var(organdata)
```



A quick plug for **naniar** and **visdat**

```
vis_dat(organdata)
```



A quick plug for **naniar** and **visdat**

```
miss_var_summary(organdata)

# A tibble: 21 × 3
  variable n_miss pct_miss
  <chr>     <int>    <num>
1 year         34    14.3
2 donors       34    14.3
3 opt          28    11.8
4 pubhealth    21     8.82
5 pop          17     7.14
6 pop_dens     17     7.14
7 gdp          17     7.14
8 roads         17     7.14
9 cerebvas     17     7.14
10 assault      17     7.14
# i 11 more rows
```

A quick plug for **naniar** and **visdat**

```
miss_case_summary(organdata)
```

```
# A tibble: 238 × 3
  case n_miss pct_miss
  <int>   <int>    <dbl>
1     84      12    57.1
2    182      12    57.1
3    210      12    57.1
4     14      11    52.4
5     28      11    52.4
6     42      11    52.4
7     56      11    52.4
8     70      11    52.4
9     98      11    52.4
10    112      11    52.4
# i 228 more rows
```

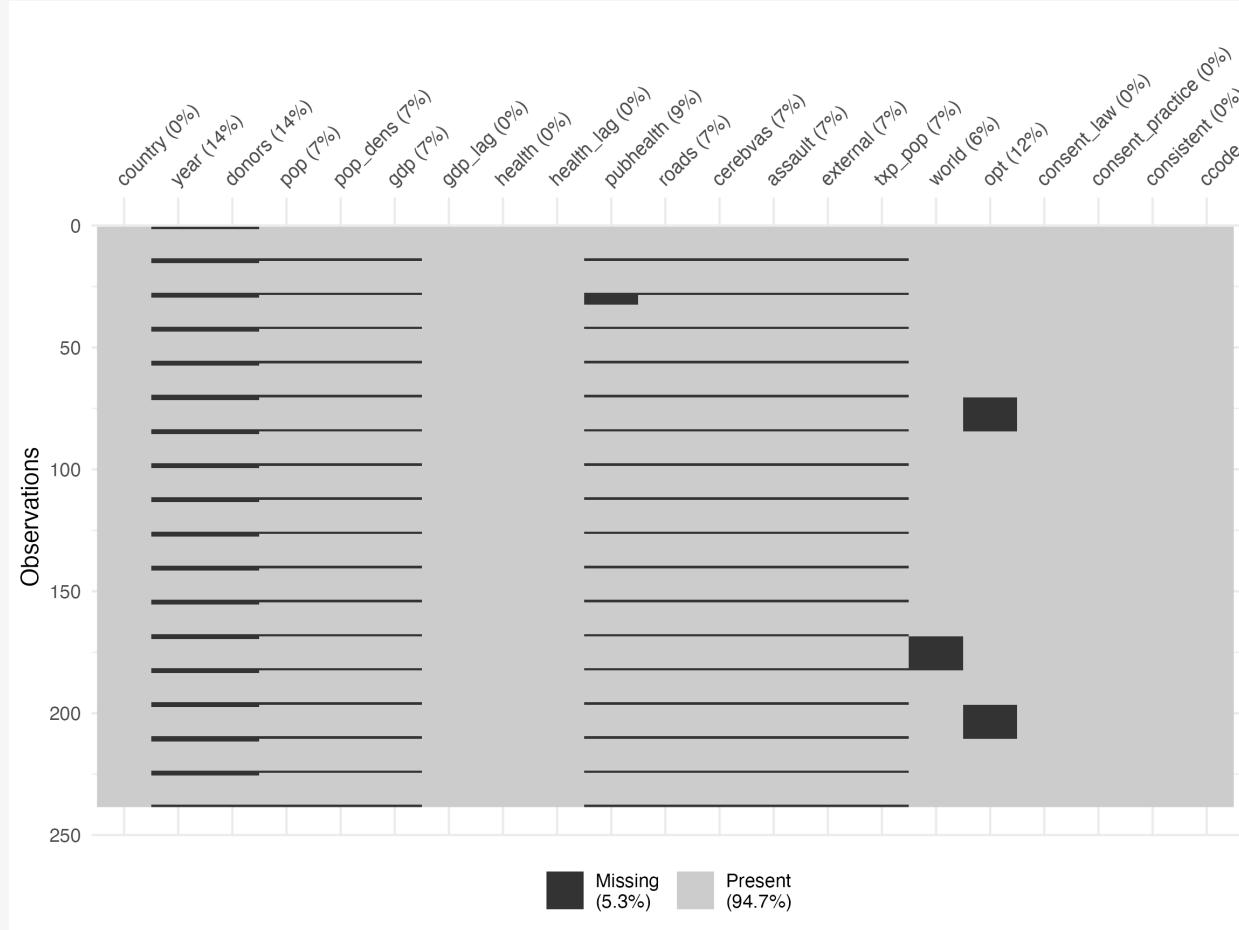
A quick plug for **naniar** and **visdat**

```
organdata >  
  select(consent_law, year, pubhealth, roads) >  
  group_by(consent_law) >  
  miss_var_summary()
```

```
# A tibble: 6 × 4  
# Groups:   consent_law [2]  
  consent_law variable n_miss pct_miss  
  <chr>       <chr>     <int>    <num>  
1 Informed    year        16     14.3  
2 Informed    pubhealth    8      7.14  
3 Informed    roads        8      7.14  
4 Presumed    year        18     14.3  
5 Presumed    pubhealth    13     10.3  
6 Presumed    roads        9      7.14
```

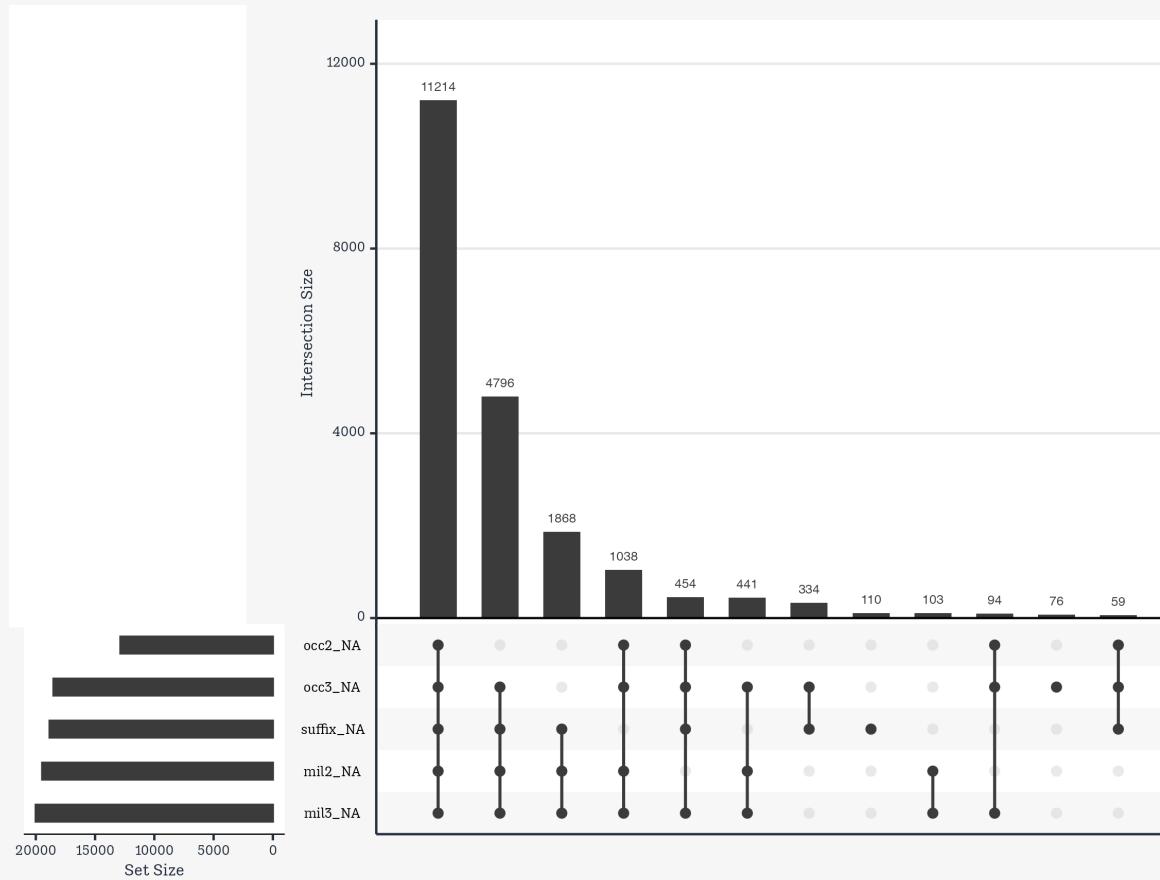
A quick plug for **naniar** and **visdat**

```
vis_miss(organdata)
```



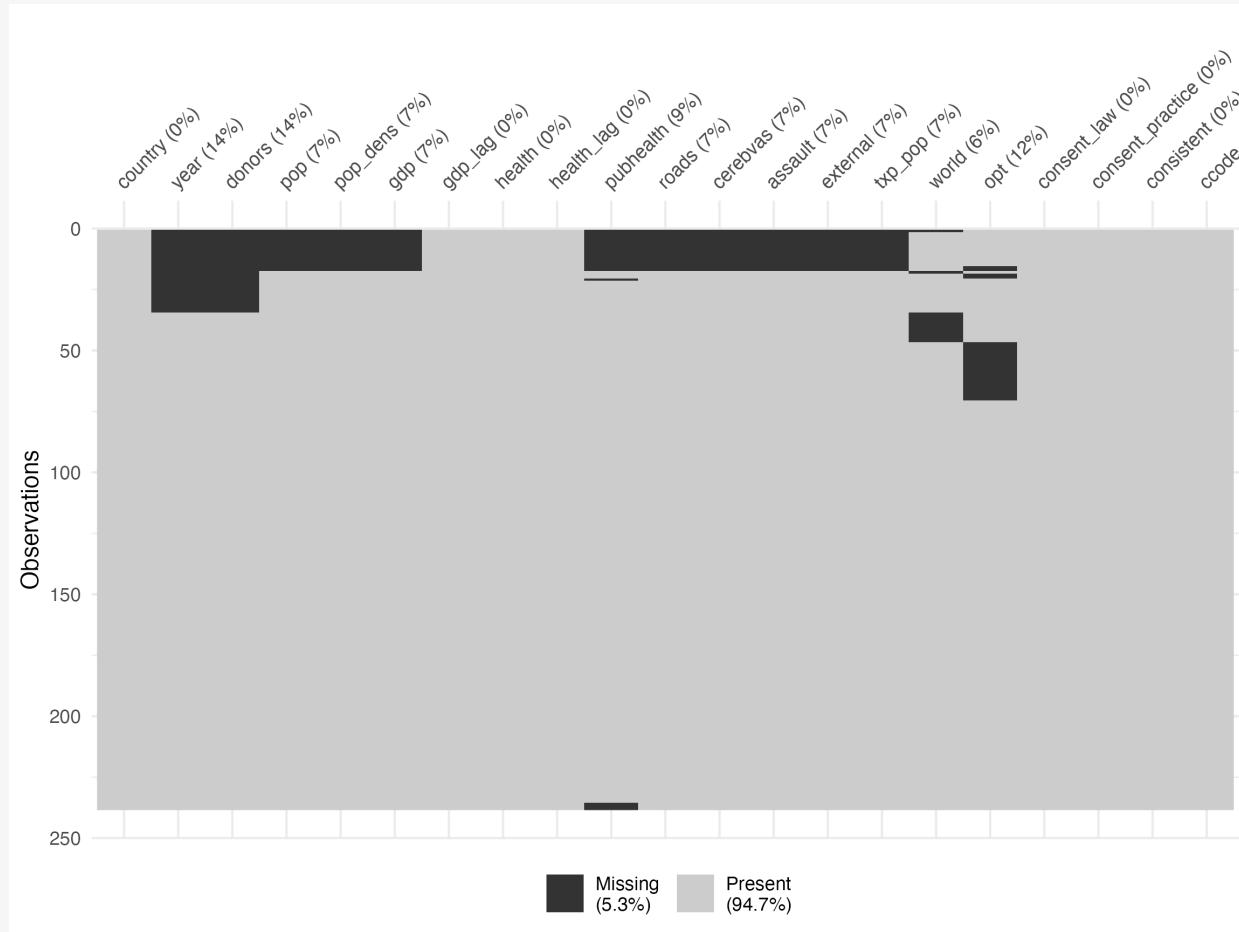
A quick plug for **naniar** and **visdat**

```
library(dwcongress)
gg_miss_upset(congress)
```



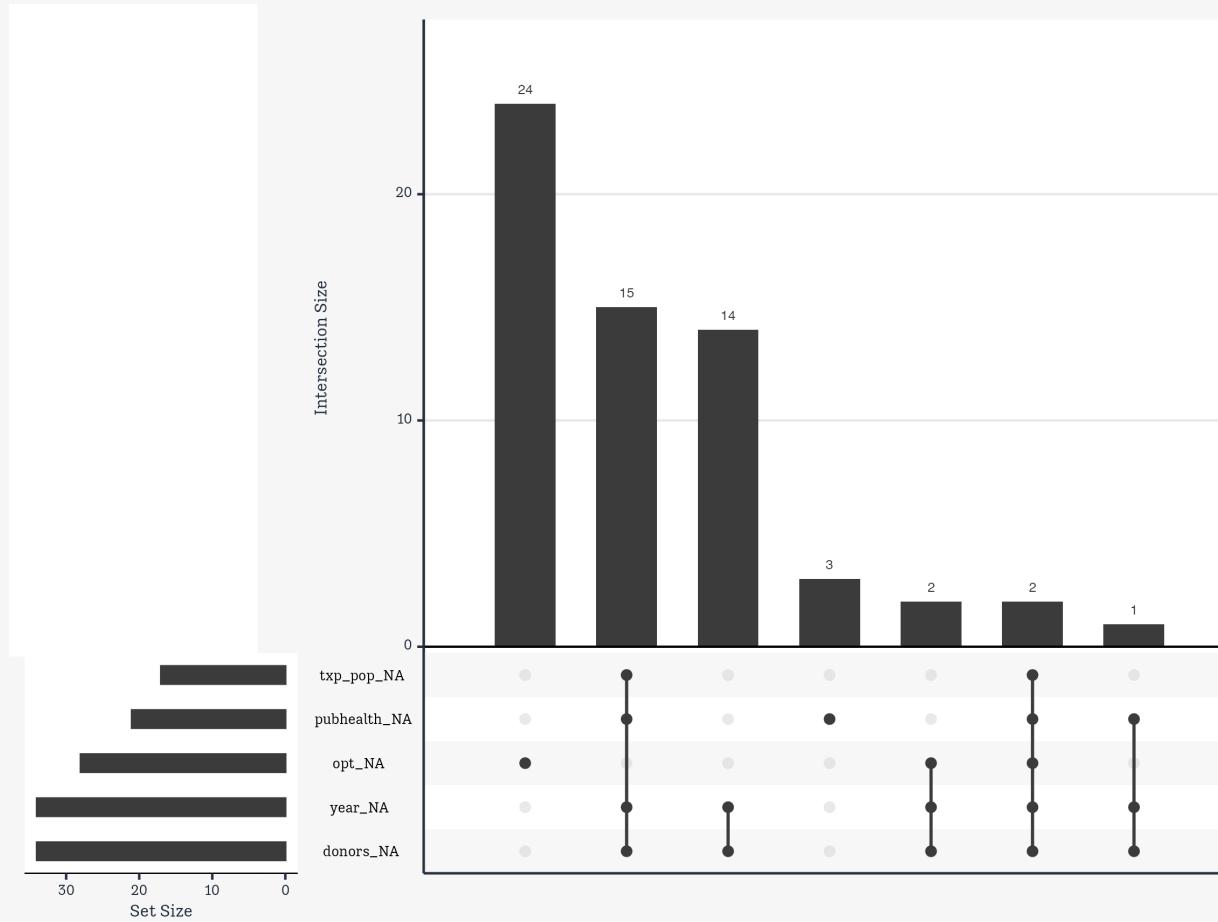
A quick plug for **naniar** and **visdat**

```
vis_miss(organdata, cluster = TRUE)
```



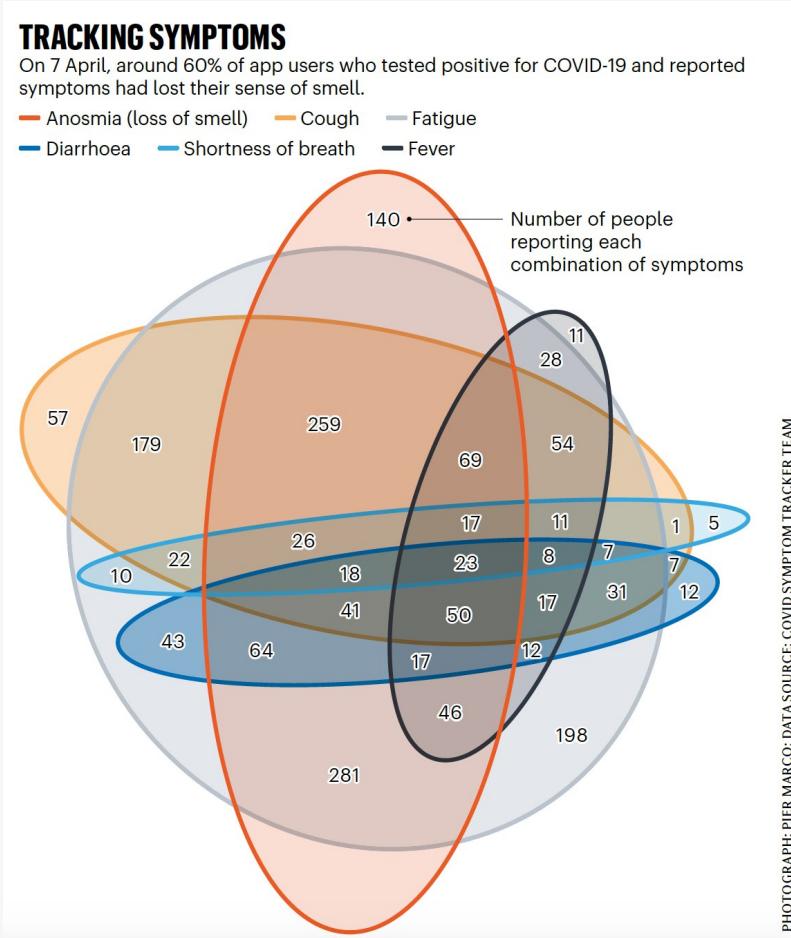
A quick plug for **naniar** and **visdat**

```
gg_miss_upset(organdata)
```



Example: Upset Plots

Upset plots and a bit of wrangling



:scale 35%

Upset plots and a bit of wrangling

```
symptoms ← c("Anosmia", "Cough", "Fatigue",
            "Diarrhea", "Breath", "Fever")
names(symptoms) ← symptoms
symptoms
```

Anosmia	Cough	Fatigue	Diarrhea	Breath	Fever
"Anosmia"	"Cough"	"Fatigue"	"Diarrhea"	"Breath"	"Fever"

Upset plots and a bit of wrangling

```
# An Excel file!
dat ← readxl::read_xlsx(here("data", "symptoms.xlsx"))
dat > print(n = nrow(dat))
```

	combination	count
	<chr>	<dbl>
1	Anosmia	140
2	Cough	57
3	Fatigue	198
4	Diarrhea	12
5	Breath	5
6	Fever	11
7	Cough&Fatigue	179
8	Fatigue&Fever	28
9	Breath&Fatigue	10
10	Diarrhea&Fatigue	43
11	Anosmia&Fatigue	281
12	Breath&Cough	1
13	Anosmia&Diarrhea&Fatigue	64
14	Breath&Cough&Fatigue	22
15	Anosmia&Cough&Fatigue	259
16	Anosmia&Fever&Fatigue	46

Upset plots and a bit of wrangling

```
subsets ← dat ▷  
  pull(combination)  
  
## Check if each subset mentions each symptom or not  
symptom_mat ← map(subsets, \((x) str_detect(x, symptoms)) ▷  
  set_names(nm = subsets) ▷  
  map(\(x) set_names(x, nm = symptoms)) ▷  
  bind_rows(.id = "subset") ▷  
  left_join(dat, join_by(subset = combination))
```

Upset plots and a bit of wrangling

Now we have a table we can do something with.

```
symptom_mat > print(n = nrow(symptom_mat))
```

#	subset	Anosmia	Cough	Fatigue	Diarrhea	Breath	Fever	count
1	Anosmia	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	140
2	Cough	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE	57
3	Fatigue	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	198
4	Diarrhea	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	12
5	Breath	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE	5
6	Fever	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	11
7	Cough&Fatigue	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE	179
8	Fatigue&Fever	FALSE	FALSE	TRUE	FALSE	FALSE	TRUE	28
9	Breath&Fatigue	FALSE	FALSE	TRUE	FALSE	TRUE	FALSE	10
10	Diarrhea&Fatigue	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	43
11	Anosmia&Fatigue	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE	281
12	Breath&Cough	FALSE	TRUE	FALSE	FALSE	TRUE	FALSE	1
13	Anosmia&Diarrhea&Fatigue	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	64
14	Breath&Cough&Fatigue	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE	22
15	Anosmia&Cough&Fatigue	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	259
16	Anosmia&Fever&Fatigue	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE	46

Upset plots and a bit of wrangling

Uncounting tables:

```
indvs ← symptom_mat ▷  
  uncount(count)  
  
indvs  
  
# A tibble: 1,764 × 7  
  subset Anosmia Cough Fatigue Diarrhea Breath Fever  
  <chr>  <lgl>   <lgl>  <lgl>   <lgl>   <lgl>  
1 Anosmia TRUE     FALSE  FALSE    FALSE   FALSE  FALSE  
2 Anosmia TRUE     FALSE  FALSE    FALSE   FALSE  FALSE  
3 Anosmia TRUE     FALSE  FALSE    FALSE   FALSE  FALSE  
4 Anosmia TRUE     FALSE  FALSE    FALSE   FALSE  FALSE  
5 Anosmia TRUE     FALSE  FALSE    FALSE   FALSE  FALSE  
6 Anosmia TRUE     FALSE  FALSE    FALSE   FALSE  FALSE  
7 Anosmia TRUE     FALSE  FALSE    FALSE   FALSE  FALSE  
8 Anosmia TRUE     FALSE  FALSE    FALSE   FALSE  FALSE  
9 Anosmia TRUE     FALSE  FALSE    FALSE   FALSE  FALSE  
10 Anosmia TRUE    FALSE  FALSE   FALSE   FALSE  FALSE  
# i 1,754 more rows
```

Now we've reconstructed the individual-level observations.

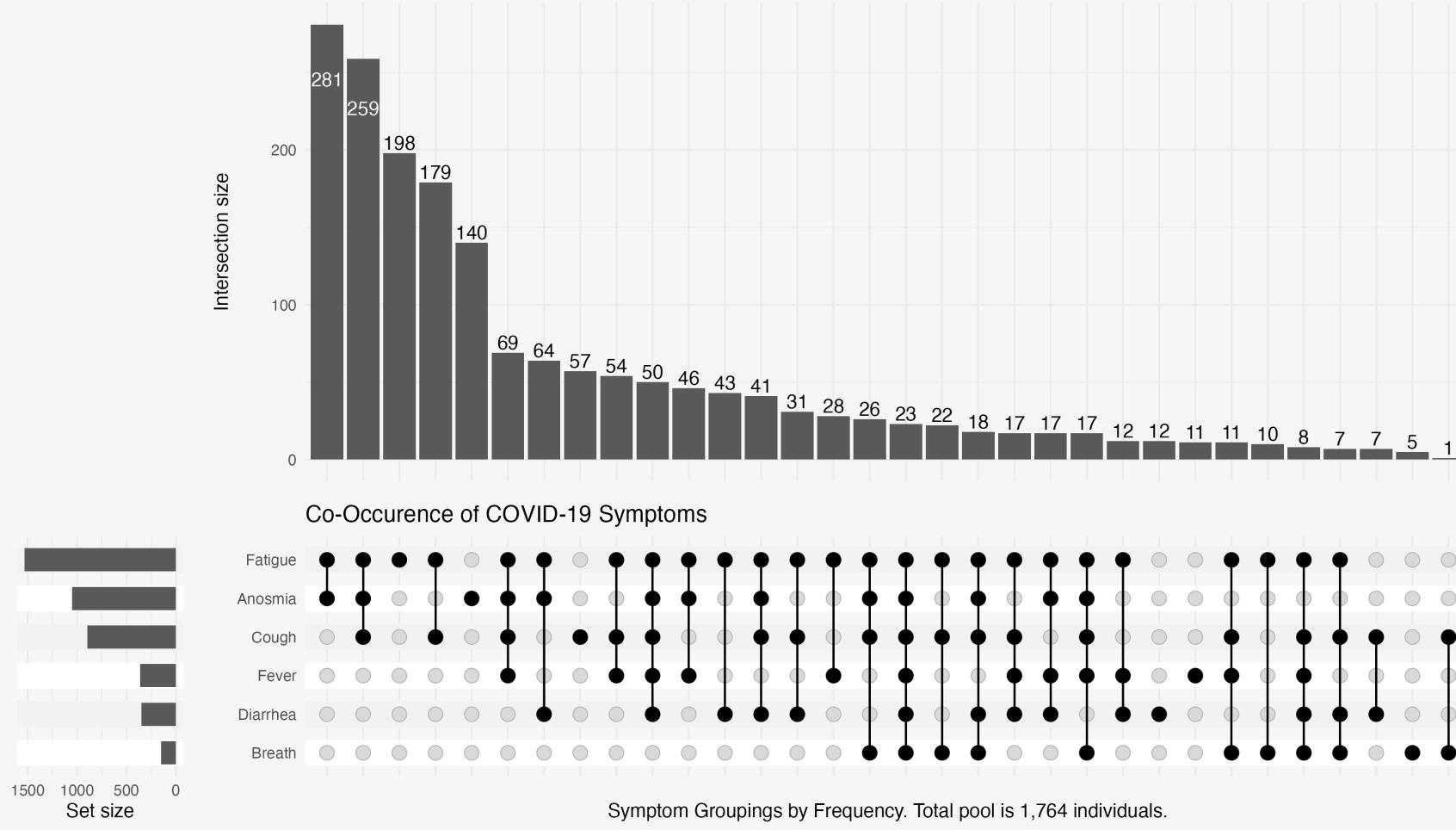
Upset plots and a bit of wrangling

```
# devtools::install_github("krassowski/complex-upset")

library(ComplexUpset)

upset(data = indvs, intersect = symptoms,
      name="Symptom Groupings by Frequency. Total pool is 1,764 individuals.",
      min_size = 0,
      width_ratio = 0.125) +
  labs(title = "Co-Occurrence of COVID-19 Symptoms",
       caption = "Data: covid.joinzoe.com/us | Graph: @kjhealy")
```

Upset plots and a bit of wrangling



Wrangling Models

This is not a **statistics** seminar!

I'll just give you an example of the sort of thing that many other modeling packages implement for all kinds of modeling techniques. Again, the principle is tidy incorporation of models and their output.

Tidy regression output with broom

```
library(broom)
library(gapminder)

out ← lm(formula = lifeExp ~ gdpPercap + pop + continent,
         data = gapminder)
```

Tidy regression output with broom

We can't *do* anything with this, programatically.

```
summary(out)
```

Call:

```
lm(formula = lifeExp ~ gdpPercap + pop + continent, data = gapminder)
```

Residuals:

Min	1Q	Median	3Q	Max
-49.161	-4.486	0.297	5.110	25.175

Coefficients:

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	4.781e+01	3.395e-01	140.819	< 2e-16 ***
gdpPercap	4.495e-04	2.346e-05	19.158	< 2e-16 ***
pop	6.570e-09	1.975e-09	3.326	0.000901 ***
continentAmericas	1.348e+01	6.000e-01	22.458	< 2e-16 ***
continentAsia	8.193e+00	5.712e-01	14.342	< 2e-16 ***
continentEurope	1.747e+01	6.246e-01	27.973	< 2e-16 ***
continentOceania	1.808e+01	1.782e+00	10.146	< 2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Tidy regression output with broom

```
library(broom)

tidy(out)

# A tibble: 7 × 5
  term      estimate std.error statistic p.value
  <chr>     <dbl>    <dbl>     <dbl>    <dbl>
1 (Intercept) 4.78e+1  0.340     141.     0
2 gdpPerCap   4.50e-4  0.0000235   19.2   3.24e- 74
3 pop         6.57e-9  0.00000000198   3.33  9.01e- 4
4 continentAmericas 1.35e+1  0.600     22.5   5.19e- 98
5 continentAsia  8.19e+0  0.571     14.3   4.06e- 44
6 continentEurope 1.75e+1  0.625     28.0   6.34e-142
7 continentOceania 1.81e+1  1.78      10.1   1.59e- 23
```

That's a *lot* nicer. Now it's just a tibble. We know those.

Tidy regression output with broom

```
out_conf ← tidy(out, conf.int = TRUE)  
out_conf
```

	term	estimate	std.error	statistic	p.value	conf.low	conf.high
	<chr>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
1	(Intercept)	4.78e+1	3.40e-1	141.	0	4.71e+1	4.85e+1
2	gdpPerCap	4.50e-4	2.35e-5	19.2	3.24e- 74	4.03e-4	4.96e-4
3	pop	6.57e-9	1.98e-9	3.33	9.01e- 4	2.70e-9	1.04e-8
4	continentAmericas	1.35e+1	6.00e-1	22.5	5.19e- 98	1.23e+1	1.47e+1
5	continentAsia	8.19e+0	5.71e-1	14.3	4.06e- 44	7.07e+0	9.31e+0
6	continentEurope	1.75e+1	6.25e-1	28.0	6.34e-142	1.62e+1	1.87e+1
7	continentOceania	1.81e+1	1.78e+0	10.1	1.59e- 23	1.46e+1	2.16e+1

Tidy regression output with broom

```
out_conf >
  filter(term %nin% "(Intercept)") >
  mutate(nicelabs = prefix_strip(term, "continent")) >
  select(nicelabs, everything())
```

A tibble: 6 × 8

	nicelabs	term	estimate	std.error	statistic	p.value	conf.low	conf.high
	<chr>	<chr>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
1	gdpPercap	gdpPercap	4.50e-4	2.35e-5	19.2	3.24e- 74	4.03e-4	4.96e-4
2	Pop	pop	6.57e-9	1.98e-9	3.33	9.01e- 4	2.70e-9	1.04e-8
3	Americas	continent...	1.35e+1	6.00e-1	22.5	5.19e- 98	1.23e+1	1.47e+1
4	Asia	continent...	8.19e+0	5.71e-1	14.3	4.06e- 44	7.07e+0	9.31e+0
5	Europe	continent...	1.75e+1	6.25e-1	28.0	6.34e-142	1.62e+1	1.87e+1
6	Oceania	continent...	1.81e+1	1.78e+0	10.1	1.59e- 23	1.46e+1	2.16e+1

Grouped analysis and **list columns**

```
eu77 ← gapminder ▷ filter(continent = "Europe", year = 1977)
fit ← lm(lifeExp ~ log(gdpPercap), data = eu77)

summary(fit)
```

Call:
lm(formula = lifeExp ~ log(gdpPercap), data = eu77)

Residuals:

Min	1Q	Median	3Q	Max
-7.4956	-1.0306	0.0935	1.1755	3.7125

Coefficients:

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	29.489	7.161	4.118	0.000306 **
log(gdpPercap)	4.488	0.756	5.936	2.17e-06 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.114 on 28 degrees of freedom

Multiple R-squared: 0.5572, Adjusted R-squared: 0.5414

F-statistic: 35.24 on 1 and 28 DF, p-value: 2.173e-06

Grouped analysis and **list columns**

```
out_le ← gapminder ▷  
  group_by(continent, year) ▷  
  nest()  
  
out_le  
  
# A tibble: 60 × 3  
# Groups:   continent, year [60]  
  continent   year    data  
  <fct>     <int> <list>  
1 Asia         1952 <tibble [33 × 4]>  
2 Asia         1957 <tibble [33 × 4]>  
3 Asia         1962 <tibble [33 × 4]>  
4 Asia         1967 <tibble [33 × 4]>  
5 Asia         1972 <tibble [33 × 4]>  
6 Asia         1977 <tibble [33 × 4]>  
7 Asia         1982 <tibble [33 × 4]>  
8 Asia         1987 <tibble [33 × 4]>  
9 Asia         1992 <tibble [33 × 4]>  
10 Asia        1997 <tibble [33 × 4]>  
# i 50 more rows
```

Think of nesting as a kind of “super-grouping”. Look in the object inspector.

Grouped analysis and **list columns**

It's still in there.

```
out_le > filter(continent = "Europe" & year = 1977) >  
  unnest(cols = c(data))
```

```
# A tibble: 30 × 6  
# Groups: continent, year [1]  
  continent year country          lifeExp      pop gdpPercap  
  <fct>     <int> <fct>        <dbl>      <int>    <dbl>  
1 Europe      1977 Albania       68.9   2509048    3533.  
2 Europe      1977 Austria       72.2   7568430    19749.  
3 Europe      1977 Belgium       72.8   9821800    19118.  
4 Europe      1977 Bosnia and Herzegovina 69.9   4086000    3528.  
5 Europe      1977 Bulgaria      70.8   8797022    7612.  
6 Europe      1977 Croatia       70.6   4318673    11305.  
7 Europe      1977 Czech Republic 70.7   10161915   14800.  
8 Europe      1977 Denmark       74.7   5088419    20423.  
9 Europe      1977 Finland       72.5   4738902    15605.  
10 Europe     1977 France        73.8   53165019   18293.  
# i 20 more rows
```

Grouped analysis and **list columns**

Here we **map()** a custom function to every row in the **data** column.

```
fit_ols <- function(df) {  
  lm(lifeExp ~ log(gdpPercap), data = df)  
}  
  
out_le <- gapminder %>  
  group_by(continent, year) %>  
  nest() %>  
  mutate(model = map(data, fit_ols))
```

Grouped analysis and **list** columns

```
out_le
```

```
# A tibble: 60 × 4
# Groups:   continent, year [60]
  continent  year data                  model
  <fct>     <int> <list>                <list>
1 Asia        1952 <tibble [33 × 4]> <lm>
2 Asia        1957 <tibble [33 × 4]> <lm>
3 Asia        1962 <tibble [33 × 4]> <lm>
4 Asia        1967 <tibble [33 × 4]> <lm>
5 Asia        1972 <tibble [33 × 4]> <lm>
6 Asia        1977 <tibble [33 × 4]> <lm>
7 Asia        1982 <tibble [33 × 4]> <lm>
8 Asia        1987 <tibble [33 × 4]> <lm>
9 Asia        1992 <tibble [33 × 4]> <lm>
10 Asia       1997 <tibble [33 × 4]> <lm>
# i 50 more rows
```

Grouped analysis and **list columns**

We can tidy the nested models, too.

```
fit_ols <- function(df) {  
  lm(lifeExp ~ log(gdpPercap), data = df)  
}  
  
out_tidy <- gapminder %>  
  group_by(continent, year) %>  
  nest() %>  
  mutate(model = map(data, fit_ols),  
        tidied = map(model, tidy)) %>  
  unnest(cols = c(tidied)) %>  
  filter(term %nin% "(Intercept)" &  
        continent %nin% "Oceania")
```

Grouped analysis and **list columns**

```
out_tidy
```

```
# A tibble: 48 × 9
# Groups: continent, year [48]
  continent year data    model   term      estimate std.error statistic p.value
  <fct>     <int> <tibble> <lm> <chr>      <dbl>     <dbl>     <dbl>     <dbl>
1 Asia       1952 <tibble> <lm> log(gdp...  4.16      1.25      3.33  2.28e-3
2 Asia       1957 <tibble> <lm> log(gdp...  4.17      1.28      3.26  2.71e-3
3 Asia       1962 <tibble> <lm> log(gdp...  4.59      1.24      3.72  7.94e-4
4 Asia       1967 <tibble> <lm> log(gdp...  4.50      1.15      3.90  4.77e-4
5 Asia       1972 <tibble> <lm> log(gdp...  4.44      1.01      4.41  1.16e-4
6 Asia       1977 <tibble> <lm> log(gdp...  4.87      1.03      4.75  4.42e-5
7 Asia       1982 <tibble> <lm> log(gdp...  4.78      0.852     5.61  3.77e-6
8 Asia       1987 <tibble> <lm> log(gdp...  5.17      0.727     7.12  5.31e-8
9 Asia       1992 <tibble> <lm> log(gdp...  5.09      0.649     7.84  7.60e-9
10 Asia      1997 <tibble> <lm> log(gdp...  5.11      0.628     8.15  3.35e-9
# i 38 more rows
```

Grouped analysis and **list columns**

```
out_tidy %>
  ungroup() %>
  sample_n(5)

# A tibble: 5 × 9
  continent year data     model term      estimate std.error statistic p.value
  <fct>     <int> <tibble> <lm>    <chr>       <dbl>     <dbl>       <dbl>     <dbl>
1 Europe      2007 <tibble> <lm> log(gdpP...     4.23      0.525      8.06 8.98e-9
2 Africa      1972 <tibble> <lm> log(gdpP...     3.80      0.962      3.95 2.44e-4
3 Europe      1962 <tibble> <lm> log(gdpP...     5.91      0.853      6.93 1.56e-7
4 Africa      1982 <tibble> <lm> log(gdpP...     5.61      0.898      6.25 8.79e-8
5 Americas    1957 <tibble> <lm> log(gdpP...    10.3       2.40       4.31 2.61e-4
```