

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
```

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  
# ... with 14 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>  
# ... with 14 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 stack the results together in a tall rectangle.

```
## Pseudocode (i.e. will not really run)
## Also, if you do write loops, do not use them to grow dataframes in this way.

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?

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

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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.

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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

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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.

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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
```

Vectorized arithmetic again

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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

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```
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

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 = str_extract(path, "_\\d{2,3}_congress"),
         congress = 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>,
#   job_type5 <chr>, mil1 <chr>, mil2 <chr>, mil3 <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(tidycensus)

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

# A tibble: 38 × 5
  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
```

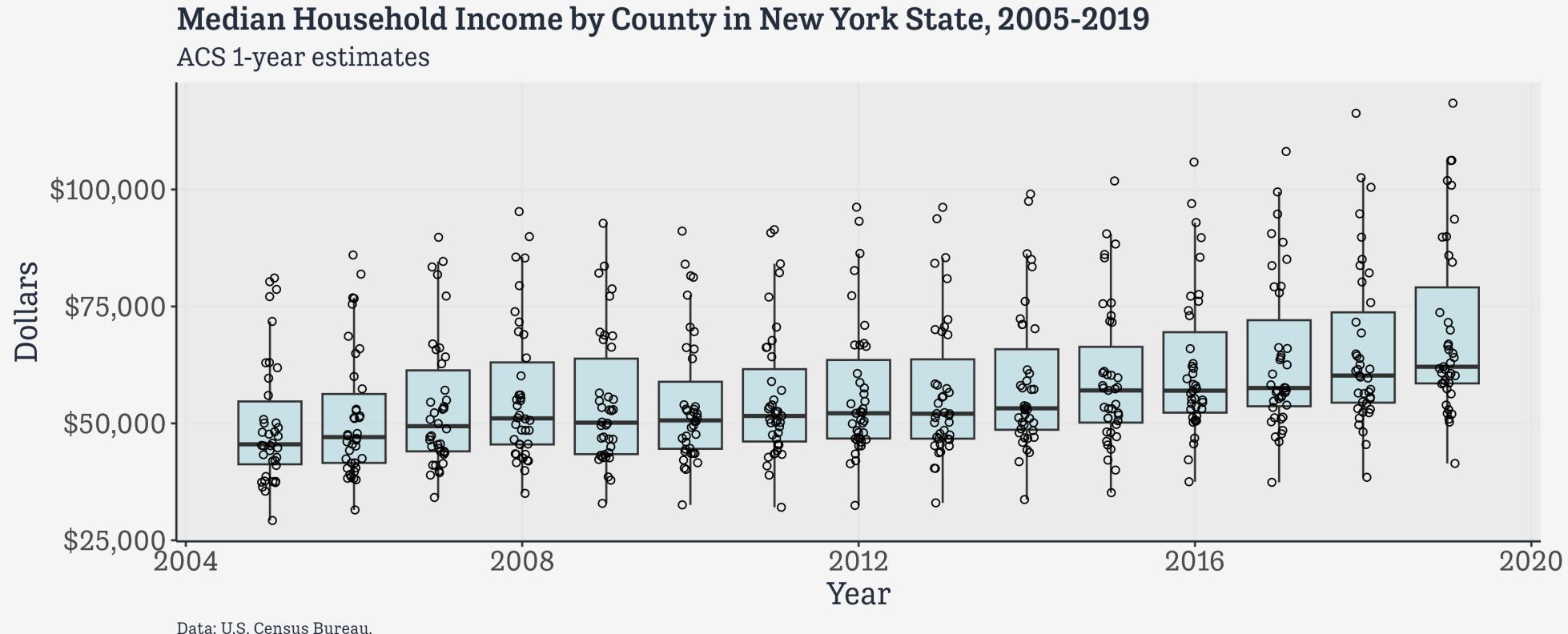
Now `year` is just the year. The `year` column will be created as a character vector, so we converted it back to an integer again at the end.

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)
```



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 durations.

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>    <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>,  
# state <chr>, district <chr>, start <date>, end <date>, religion <chr>,  
# race <chr>, educational_attainment <chr>, job_type1 <chr>, job_type2 <chr>,  
# income <chr>, and many more.
```

Table joins

x	y
1	x1
2	x2
3	x3

1	y1
2	y2
4	y4

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

Left join, `left_join()`

`left_join(x, y)`

1	x1
2	x2
3	x3

1	y1
2	y2
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()`

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

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	y1
2	x2	2	y2
3	x3	4	y4

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	y1
2	x2	2	y2
3	x3	4	y4

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**

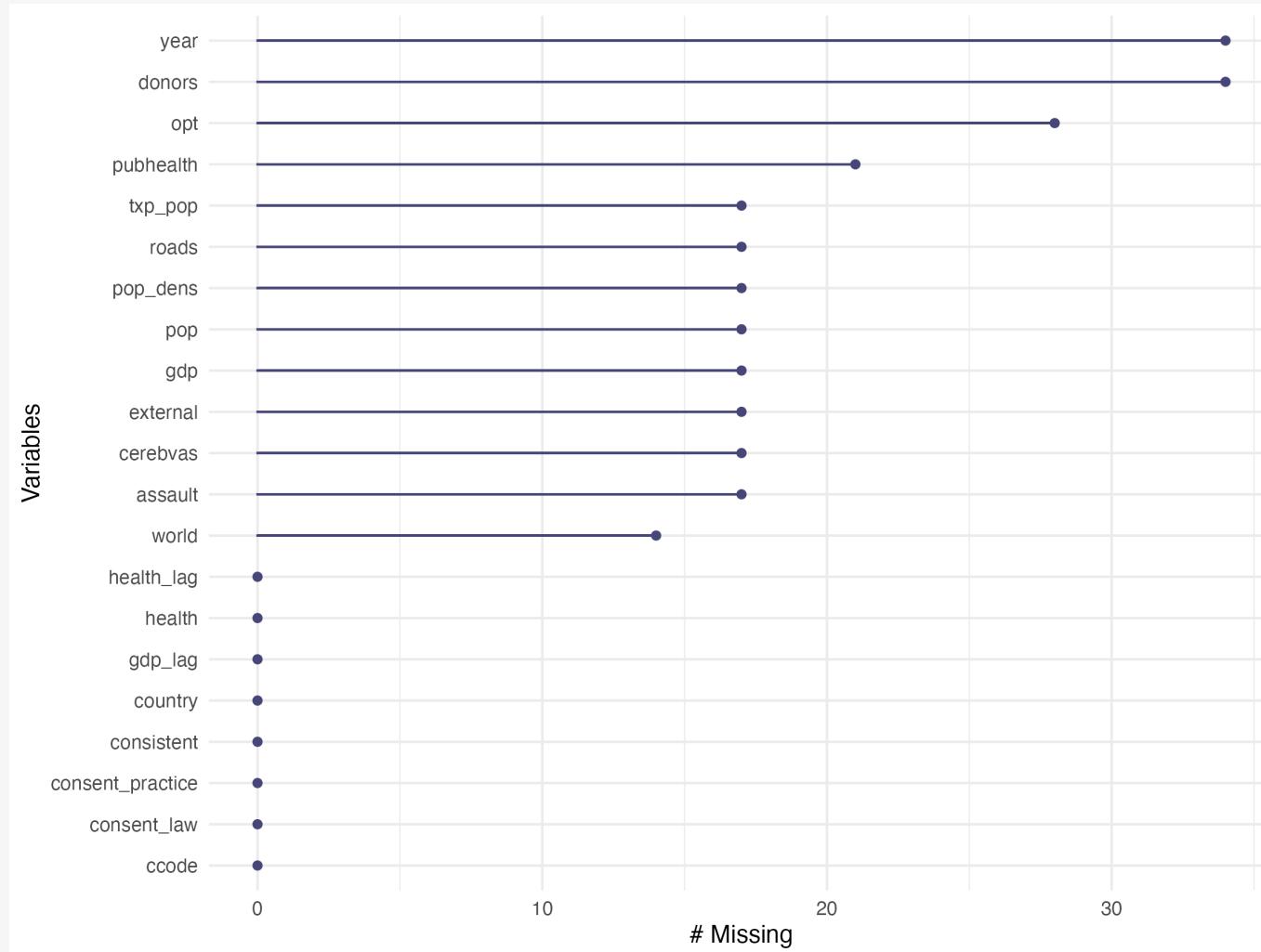
```
library(naniar)
library(visdat)

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>
```

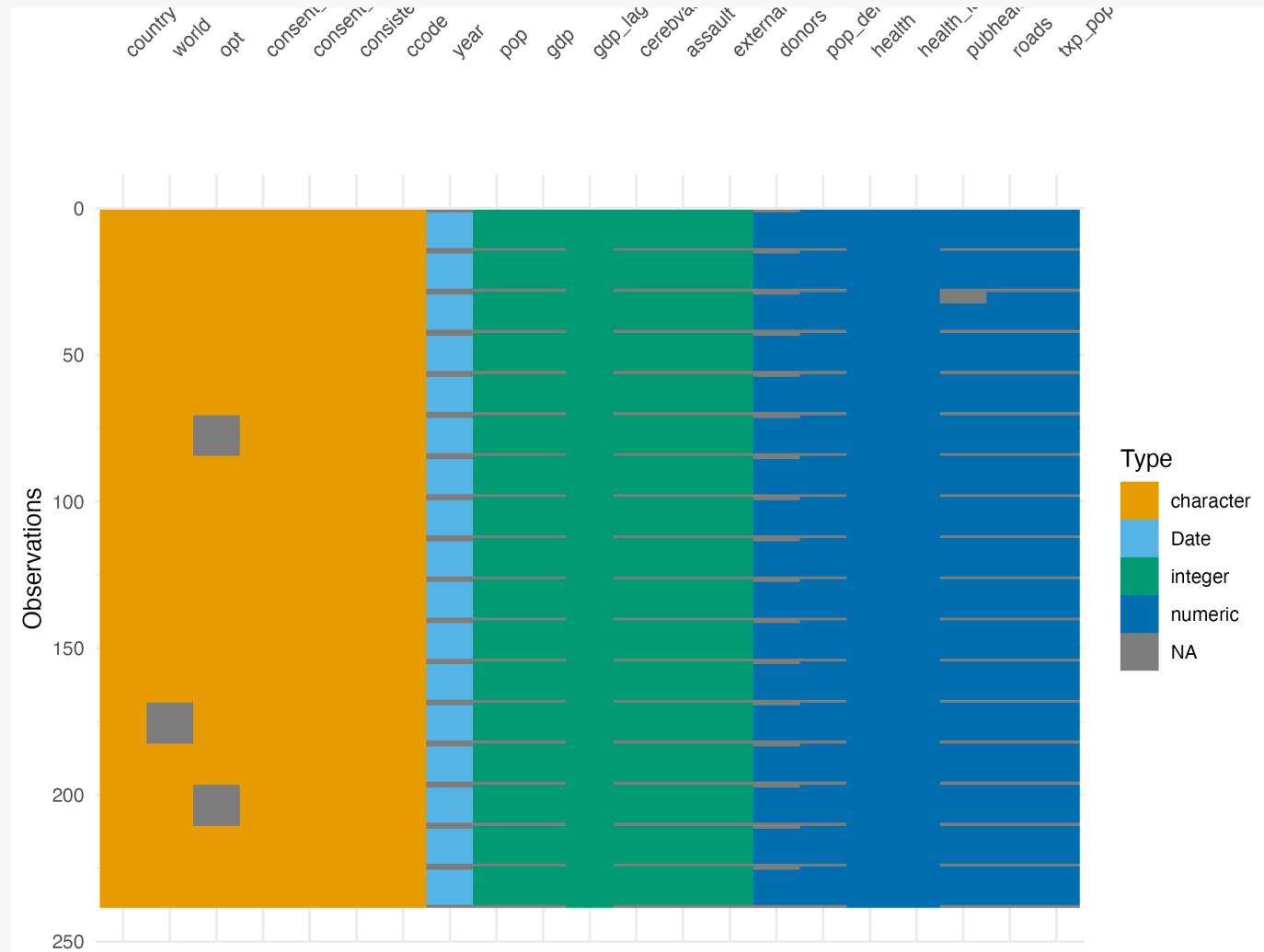
A quick plug for **naniar** and **visdat**

```
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     1      84     57.1
2     2     182     57.1
3     3     210     57.1
4     4      14     52.4
5     5      28     52.4
6     6      42     52.4
7     7      56     52.4
8     8      70     52.4
9     9      98     52.4
10    10     112     52.4
# i 228 more rows
```

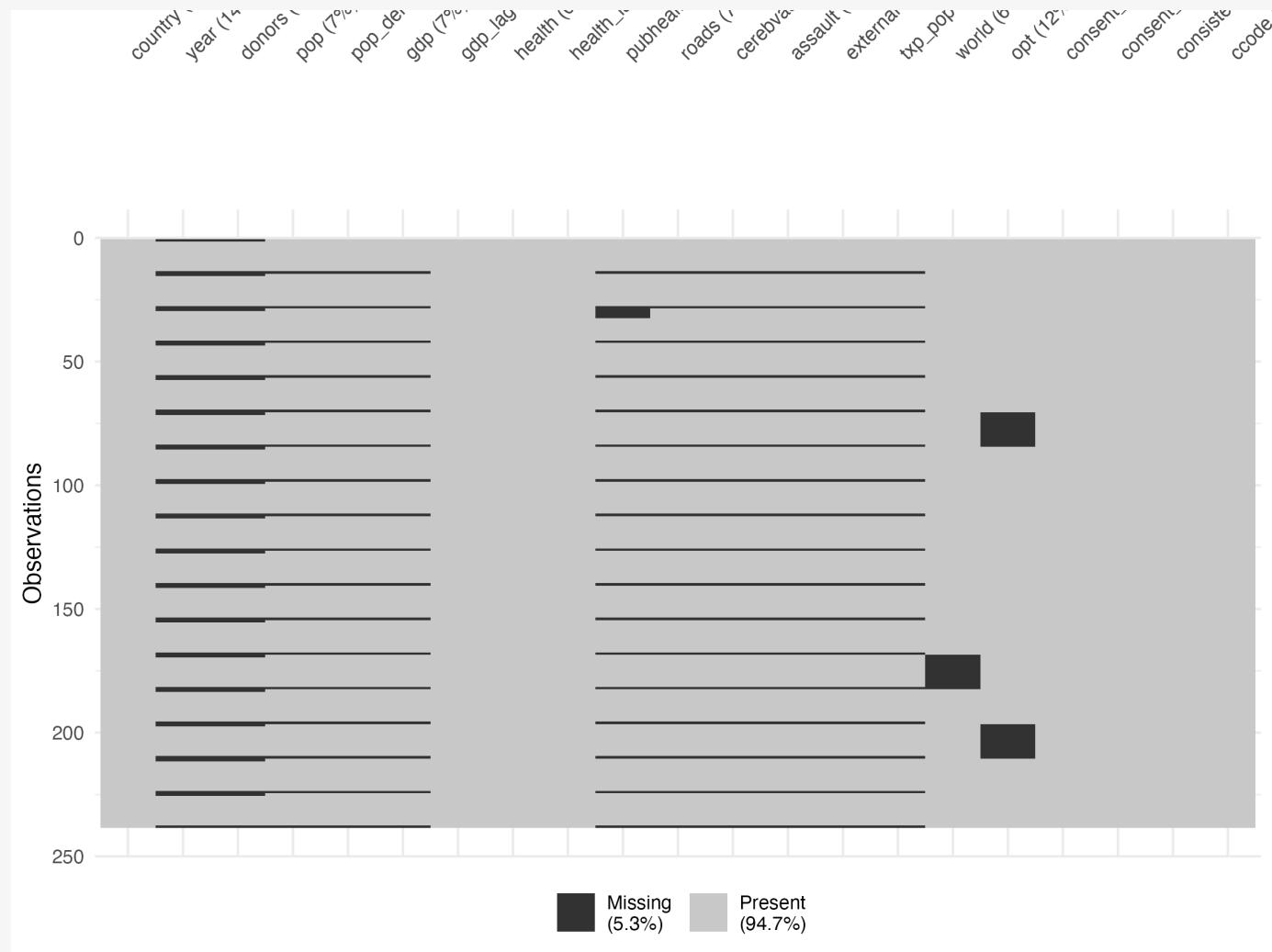
A quick plug for **naniar** and **visdat**

```
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
```

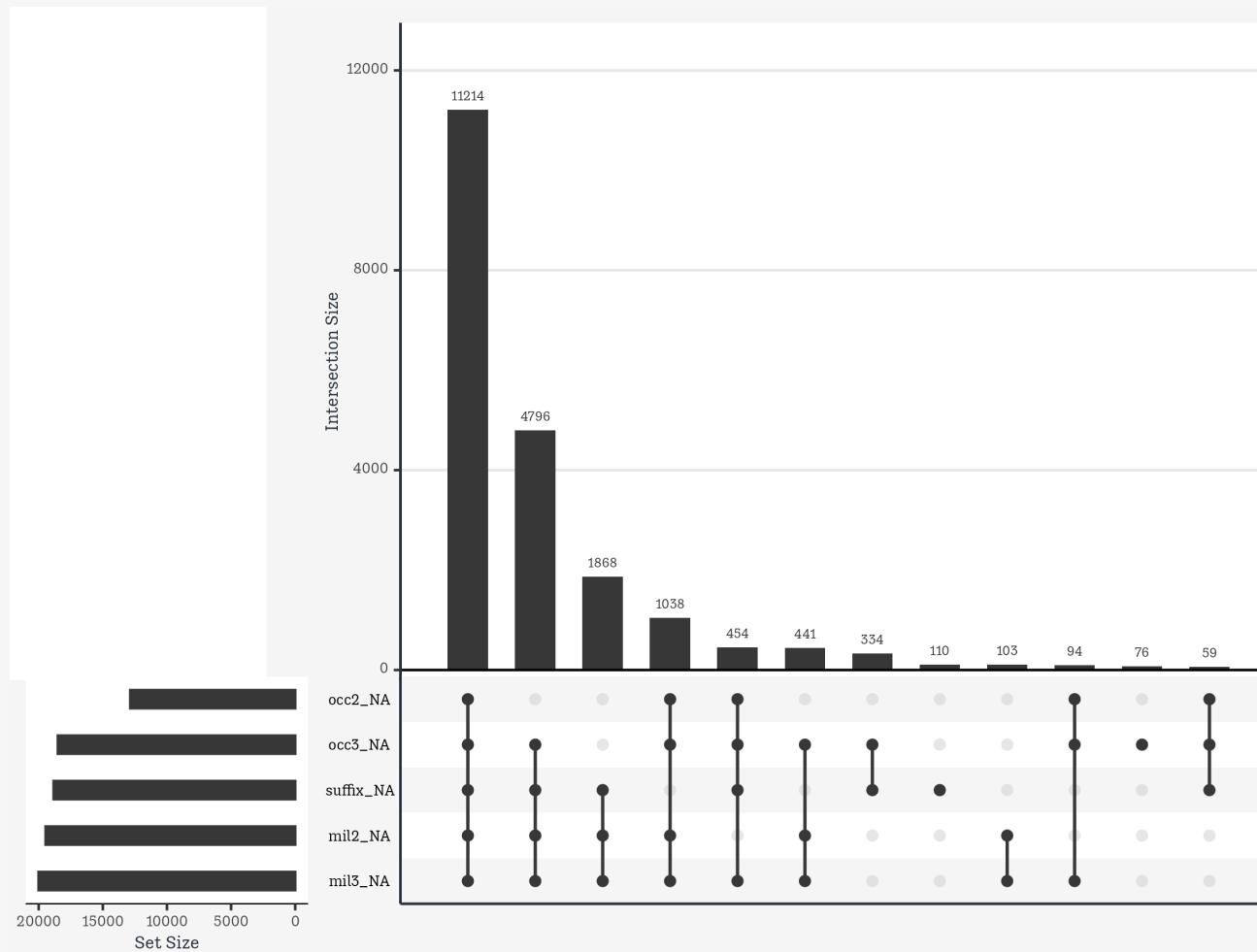
A quick plug for **naniar** and **visdat**

```
vis_miss(organdata)
```



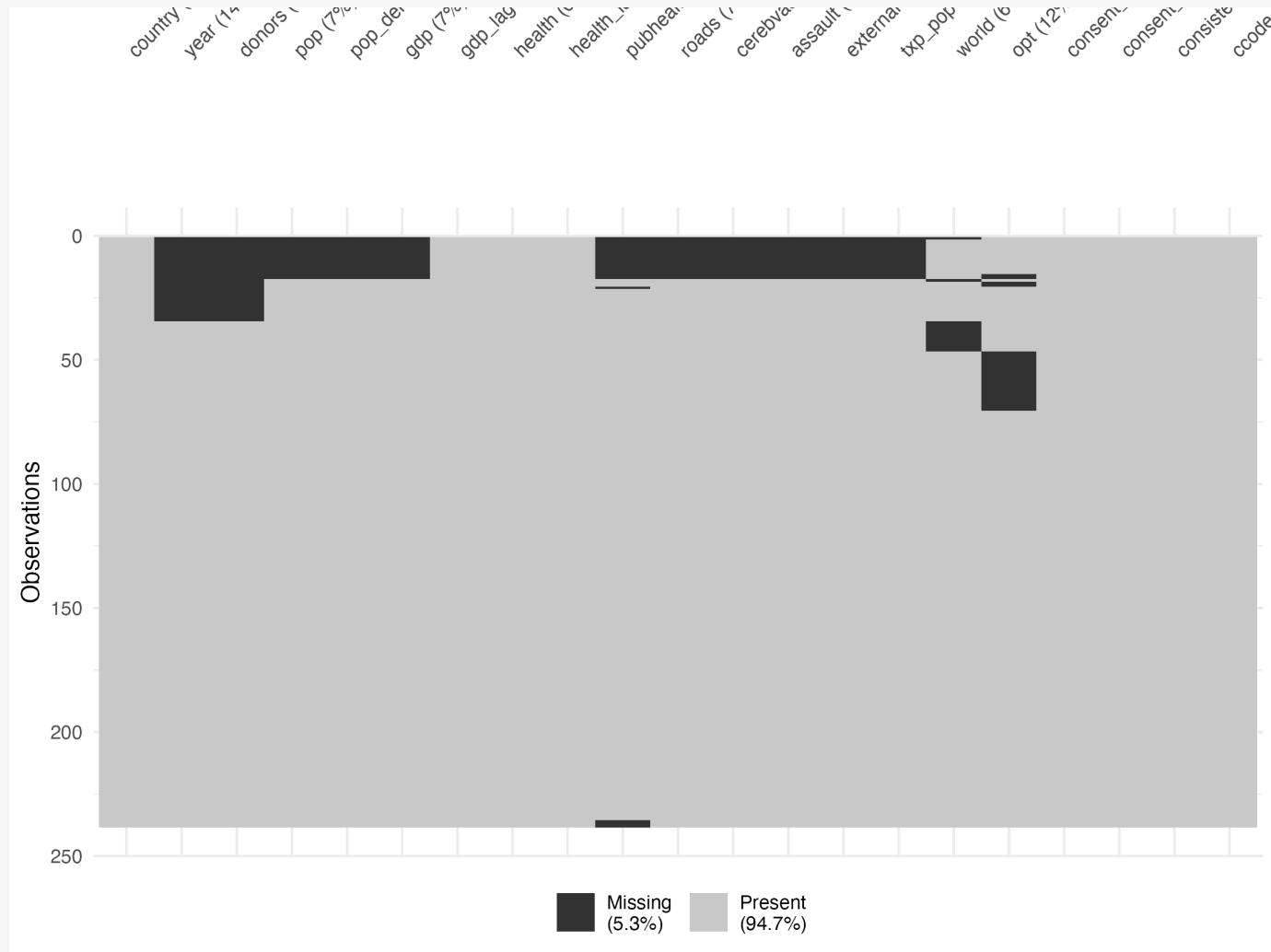
A quick plug for **naniar** and **visdat**

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



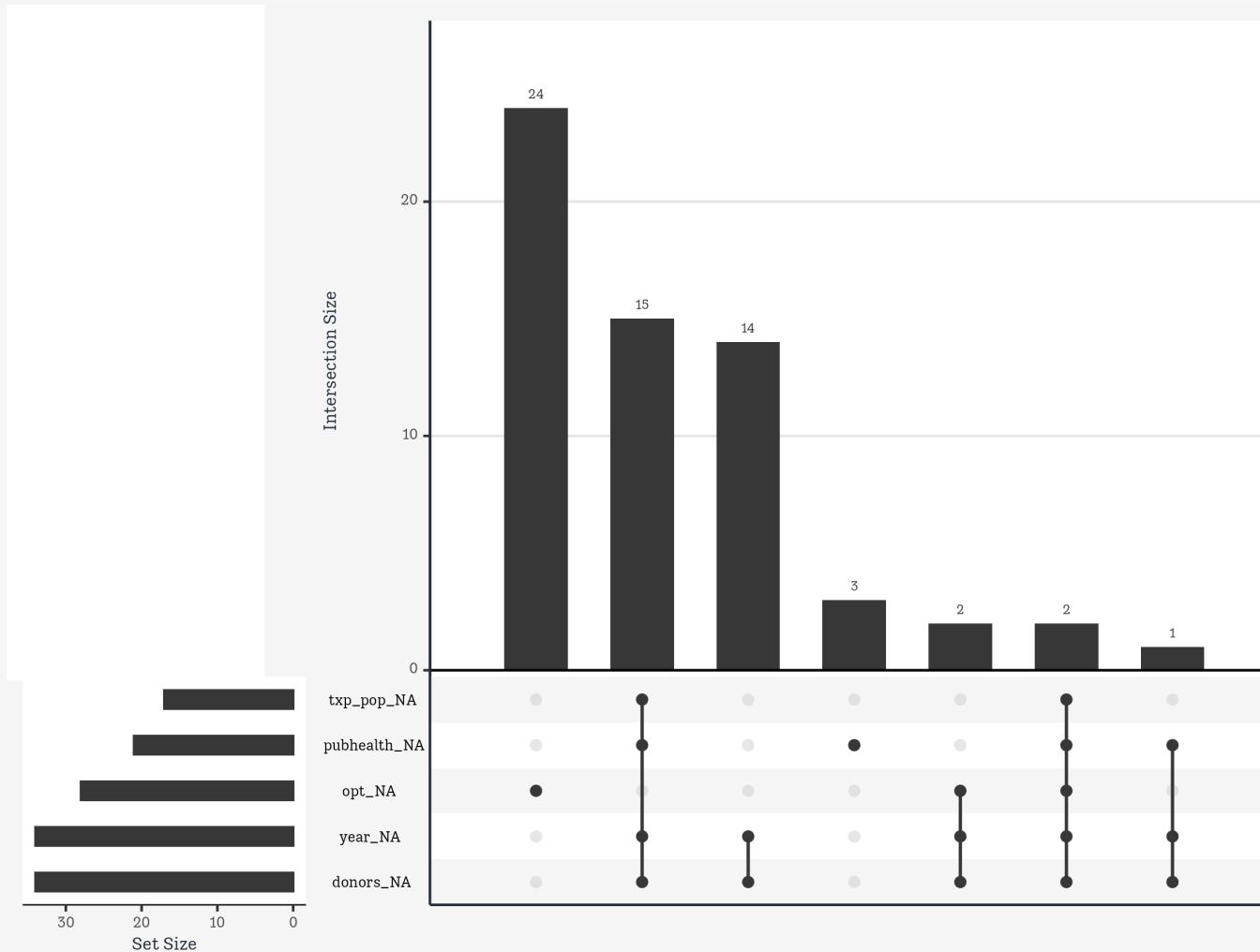
A quick plug for **naniar** and **visdat**

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



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

```
gg_miss_upset(organdata)
```



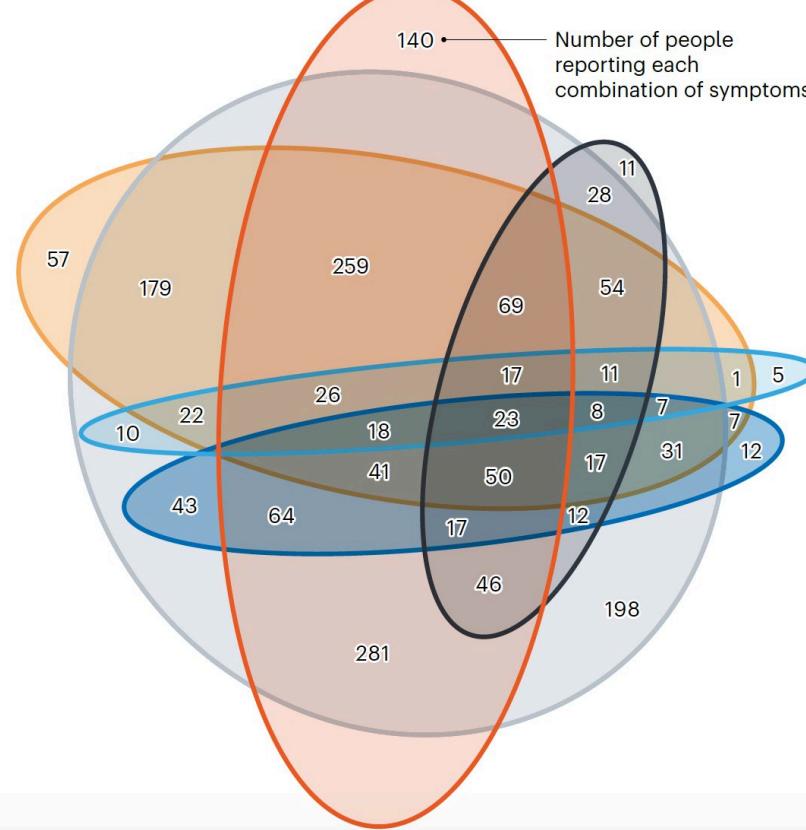
Example: Upset Plots

Upset plots and a bit of wrangling

TRACKING SYMPTOMS

On 7 April, around 60% of app users who tested positive for COVID-19 and reported symptoms had lost their sense of smell.

— Anosmia (loss of smell) — Cough
— Diarrhoea — Shortness of breath — Fever



PHOTOGRAPH: PIER MARCO; DATA SOURCE: COVID SYMPTOM TRACKER TEAM

: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))
```

```
# A tibble: 32 × 2
  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))

# A tibble: 32 × 8
#> #> #> #> #> #> #> #>
#> #> subset      Anosmia Cough Fatigue Diarrhea Breath Fever count
#> <chr>        <lgl>   <lgl>  <lgl>    <lgl>   <lgl>  <lgl> <dbl>
#> 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.

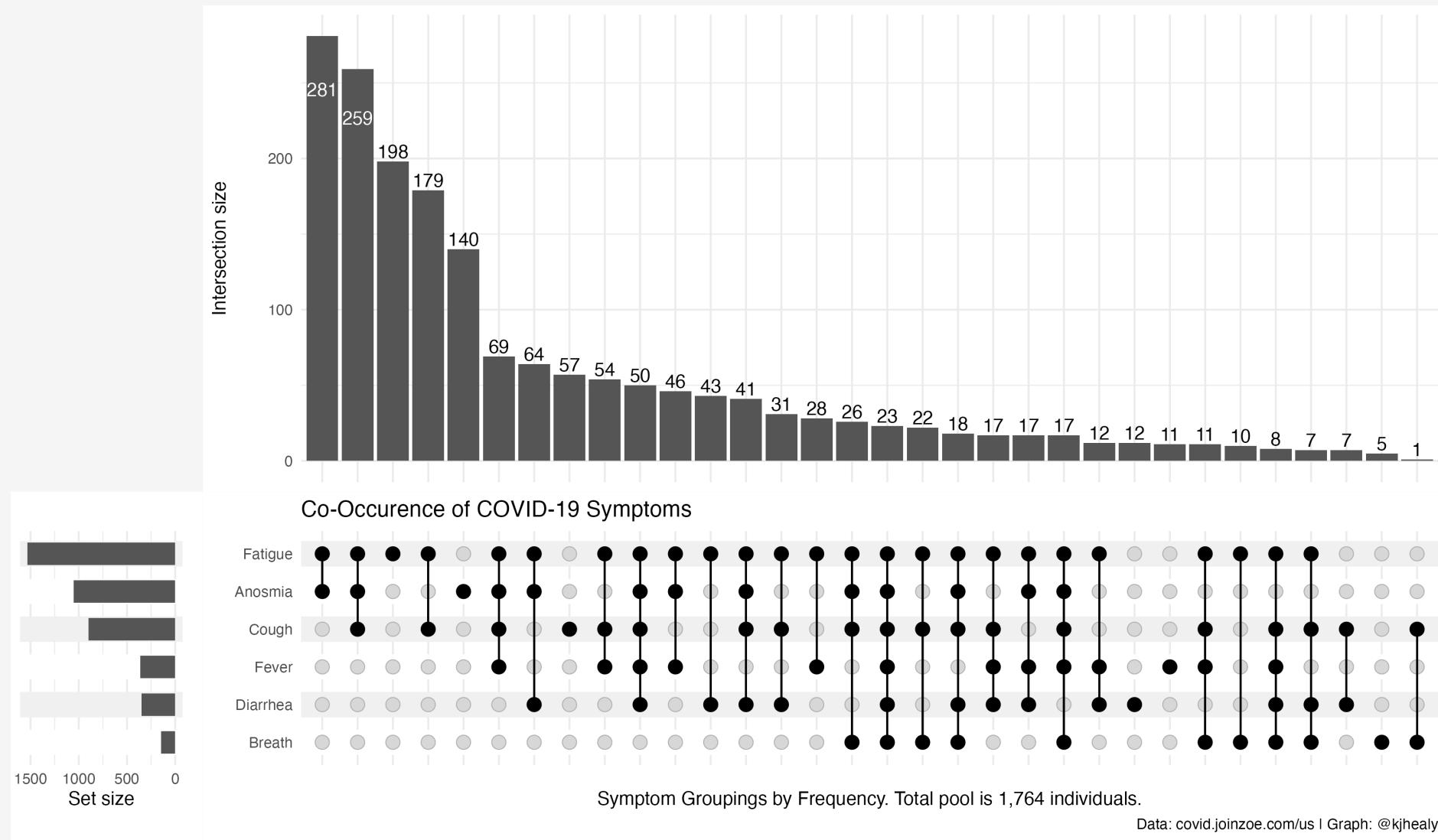
Upset plots and a bit of wrangling

```
# 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> <list> <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> <list> <list> <chr>        <dbl>     <dbl>     <dbl>     <dbl>
1 Europe      1992 <tibble> <lm> log(gdpP...     3.48      0.545      6.39 6.44e-7
2 Americas    1952 <tibble> <lm> log(gdpP...    10.4       2.72      3.84 8.27e-4
3 Africa      1952 <tibble> <lm> log(gdpP...     2.34      0.971      2.41 1.99e-2
4 Africa      1967 <tibble> <lm> log(gdpP...     3.07      0.988      3.11 3.13e-3
5 Asia        1957 <tibble> <lm> log(gdpP...     4.17      1.28      3.26 2.71e-3
```