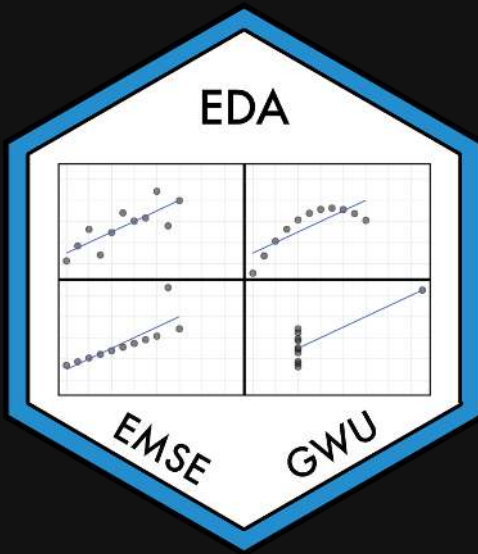




Week 2: *Tidy Data*

🏛️ EMSE 4572/6572: Exploratory Data Analysis

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📅 September 03, 2025

Week 2: *Tidy Data*

1. Tidy Data

2. Tidy Data Wrangling

BREAK

3. Tidy Data Visualization

4. Data Provenance & Curation

5. Writing a Research Question

Week 2: *Tidy Data*

1. Tidy Data

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BREAK

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5. Writing a Research Question

Federal R&D Spending by Department

```
#> # A tibble: 6 × 15
#>   year DHS   DOC   DOD   DOE   DOT   EPA   HHS Interior NASA   NIH   NSF Other USD
#>   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
#> 1  1976     0   819 35696 10882  1142   968  9226    1152 12513  8025  2372  1191  183
#> 2  1977     0   837 37967 13741  1095   966  9507    1082 12553  8214  2395  1280  179
#> 3  1978     0   871 37022 15663  1156  1175 10533    1125 12516  8802  2446  1237  196
#> 4  1979     0   952 37174 15612  1004  1102 10127    1176 13079  9243  2404  2321  205
#> 5  1980     0   945 37005 15226  1048   903 10045    1082 13837  9093  2407  2468  188
#> 6  1981     0   829 41737 14798   978   901  9644     990 13276  8580  2300  1925  196
```

Federal R&D Spending by Department

"Wide" format

```
#> # A tibble: 6 × 15
#>   year DHS   DOC   DOD   DOE   DOT   EPA   HHS   Inte
#>   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
#> 1 1976     0   819 35696 10882 1142   968   9226
#> 2 1977     0   837 37967 13741 1095   966   9507
#> 3 1978     0   871 37022 15663 1156  1175  10533
#> 4 1979     0   952 37174 15612 1004  1102  10127
#> 5 1980     0   945 37005 15226 1048   903  10045
#> 6 1981     0   829 41737 14798   978   901   9644
```

"Long" format

```
#> # A tibble: 6 × 3
#>   department year rd_budget_mil
#>   <chr>      <dbl>      <dbl>
#> 1 DOD        1976      35696
#> 2 NASA        1976      12513
#> 3 DOE         1976      10882
#> 4 HHS         1976       9226
#> 5 NIH         1976       8025
#> 6 NSF         1976       2372
```

Federal R&D Spending by Department

"Wide" format

```
#> # A tibble: 6 × 15
#>   year DHS   DOC   DOD   DOE   DOT   EPA   HHS   Inte
#>   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
#> 1 1976     0   819 35696 10882 1142   968   9226
#> 2 1977     0   837 37967 13741 1095   966   9507
#> 3 1978     0   871 37022 15663 1156  1175 10533
#> 4 1979     0   952 37174 15612 1004  1102 10127
#> 5 1980     0   945 37005 15226 1048   903 10045
#> 6 1981     0   829 41737 14798   978   901   9644
```

```
#> [1] 42 15
```

"Long" format

```
#> # A tibble: 6 × 3
#>   department year rd_budget_mil
#>   <chr>      <dbl>      <dbl>
#> 1 DOD        1976      35696
#> 2 NASA        1976      12513
#> 3 DOE         1976      10882
#> 4 HHS         1976       9226
#> 5 NIH         1976       8025
#> 6 NSF         1976       2372
```

```
#> [1] 588 3
```

Tidy data = "Long" format

- Each **variable** has its own **column**
- Each **observation** has its own **row**

country	year	cases	population
Afghanistan	1999	212258	19987071
Afghanistan	2000	216766	20595360
Brazil	1999	31737	172006362
Brazil	2000	80488	174504898
China	1999	212258	127291272
China	2000	216766	128042583

variables

country	year	cases	population
Afghanistan	1999	212258	19987071
Afghanistan	2000	216766	20595360
Brazil	1999	31737	172006362
Brazil	2000	80488	174504898
China	1999	212258	127291272
China	2000	216766	128042583

observations

country	year	cases	population
Afghanistan	1999	212258	19987071
Afghanistan	2000	216766	20595360
Brazil	1999	31737	172006362
Brazil	2000	80488	174504898
China	1999	212258	127291272
China	2000	216766	128042583

values

Tidy data

- Each **variable** has its own **column**
- Each **observation** has its own **row**

```
#> # A tibble: 6 × 3
#>   department year rd_budget_mil
#>   <chr>      <dbl>      <dbl>
#> 1 DOD        1976      35696
#> 2 NASA        1976      12513
#> 3 DOE         1976      10882
#> 4 HHS         1976       9226
#> 5 NIH         1976       8025
#> 6 NSF         1976       2372
```

country	year	cases	population
Afghanistan	1999	745	19987071
Afghanistan	2000	866	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898
China	1999	212258	127291272
China	2000	216766	128042583

variables

country	year	cases	population
Afghanistan	1999	745	19987071
Afghanistan	2000	866	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898
China	1999	212258	127291272
China	2000	216766	128042583

observations

country	year	cases	population
Afghanistan	1999	745	19987071
Afghanistan	2000	866	20595360
Brazil	1999	37737	172006362
Brazil	2000	80488	174504898
China	1999	212258	127291272
China	2000	216766	128042583

values

"Long" format

```
#> # A tibble: 6 × 3
#>   department year rd_budget_mil
#>   <chr>      <dbl>      <dbl>
#> 1 DOD        1976      35696
#> 2 NASA        1976      12513
#> 3 DOE         1976      10882
#> 4 HHS         1976       9226
#> 5 NIH         1976       8025
#> 6 NSF         1976       2372
```

"Wide" format

```
#> # A tibble: 6 × 15
#>   year DHS   DOC   DOD   DOE   DOT   EPA   HHS   Inte
#>   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
#> 1 1976     0   819 35696 10882 1142   968   9226
#> 2 1977     0   837 37967 13741 1095   966   9507
#> 3 1978     0   871 37022 15663 1156  1175  10533
#> 4 1979     0   952 37174 15612 1004  1102  10127
#> 5 1980     0   945 37005 15226 1048   903  10045
#> 6 1981     0   829 41737 14798   978   901   9644
```

Do the names describe the values?

Yes: "Long" format

```
#> # A tibble: 6 × 3
#>   department year rd_budget_mil
#>   <chr>      <dbl>      <dbl>
#> 1 DOD        1976      35696
#> 2 NASA        1976      12513
#> 3 DOE         1976      10882
#> 4 HHS         1976       9226
#> 5 NIH         1976       8025
#> 6 NSF         1976       2372
```

No: "Wide" format

```
#> # A tibble: 6 × 8
#>   year DHS   DOC   DOD   DOE   DOT   EPA   HHS
#>   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
#> 1  1976     0   819 35696 10882  1142   968  9226
#> 2  1977     0   837 37967 13741  1095   966  9507
#> 3  1978     0   871 37022 15663  1156  1175 10533
#> 4  1979     0   952 37174 15612  1004  1102 10127
#> 5  1980     0   945 37005 15226  1048   903 10045
#> 6  1981     0   829 41737 14798   978   901  9644
```

Quick practice 1: "long" or "wide" format?

Description: Tuberculosis cases in various countries

```
#> # A tibble: 6 × 4
#>   country      year  cases population
#>   <chr>      <dbl>  <dbl>      <dbl>
#> 1 Afghanistan 1999     745    19987071
#> 2 Afghanistan 2000    2666    20595360
#> 3 Brazil      1999   37737   172006362
#> 4 Brazil      2000   80488   174504898
#> 5 China       1999  212258  1272915272
#> 6 China       2000  213766  1280428583
```

Quick practice 2: "long" or "wide" format?

Description: Word counts in LOTR trilogy

```
#> # A tibble: 9 × 4
#>   Film                Race    Female    Male
#>   <chr>              <chr>    <dbl> <dbl>
#> 1 The Fellowship Of The Ring Elf      1229    971
#> 2 The Fellowship Of The Ring Hobbit     14   3644
#> 3 The Fellowship Of The Ring Man         0   1995
#> 4 The Return Of The King    Elf     183    510
#> 5 The Return Of The King    Hobbit     2   2673
#> 6 The Return Of The King    Man     268   2459
#> 7 The Two Towers           Elf     331    513
#> 8 The Two Towers           Hobbit     0   2463
#> 9 The Two Towers           Man    401   3589
```

Quick practice 3: "long" or "wide" format?

Description: Word counts in LOTR trilogy

```
#> # A tibble: 15 × 4
#>   Film      Race Gender Word_Count
#>   <chr>    <chr> <chr>    <dbl>
#> 1 The Fellowship Of The Ring Elf      Female    1229
#> 2 The Fellowship Of The Ring Elf      Male      971
#> 3 The Fellowship Of The Ring Hobbit   Female     14
#> 4 The Fellowship Of The Ring Hobbit   Male    3644
#> 5 The Fellowship Of The Ring Man      Female      0
#> 6 The Fellowship Of The Ring Man      Male    1995
#> 7 The Return Of The King    Elf      Female    183
#> 8 The Return Of The King    Elf      Male     510
#> 9 The Return Of The King    Hobbit   Female      2
#> 10 The Return Of The King    Hobbit   Male    2673
#> 11 The Return Of The King    Man      Female    268
#> 12 The Return Of The King    Man      Male    2459
#> 13 The Two Towers          Elf      Female    331
#> 14 The Two Towers          Elf      Male     513
#> 15 The Two Towers          Hobbit   Female      0
```

Reshaping data with `pivot_longer()` and `pivot_wider()`

Reshaping data

```
pivot_longer()  
pivot_wider()
```

wide

id	x	y	z
1	a	c	e
2	b	d	f

From "long" to "wide" with `pivot_wider()`

long			wide			
id	key	val	id	key		
1	x	a	1	x	y	z
2	x	b	1	a	c	e
1	y	c	2	b	d	f
2	y	d				
1	z	e				
2	z	f				

From "long" to "wide" with `pivot_wider()`

```
head(fed_spend_long)
```

```
#> # A tibble: 6 × 3  
#>   department year rd_budget_mil  
#>   <chr>      <dbl>      <dbl>  
#> 1 DOD        1976      35696  
#> 2 NASA        1976      12513  
#> 3 DOE         1976      10882  
#> 4 HHS         1976       9226  
#> 5 NIH         1976       8025  
#> 6 NSF         1976       2372
```

```
fed_spend_wide <- fed_spend_long %>%  
  pivot_wider(  
    names_from = department,  
    values_from = rd_budget_mil  
  )  
head(fed_spend_wide)
```

```
#> # A tibble: 6 × 15  
#>   year  DOD  NASA  DOE  HHS  NIH  NSF  
#>   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <  
#> 1  1976 35696 12513 10882  9226  8025  2372  
#> 2  1977 37967 12553 13741  9507  8214  2395  
#> 3  1978 37022 12516 15663 10533  8802  2446  
#> 4  1979 37174 13079 15612 10127  9243  2404  
#> 5  1980 37005 13837 15226 10045  9093  2407  
#> 6  1981 41737 13276 14798  9644  8580  2300
```

From "wide" to "long" with `pivot_longer()`

wide					long		
id	x	y	z	key	id	key	val
1	a	c	e	val	1	x	a
2	b	d	f		2	x	b
					1	y	c
					2	y	d
					1	z	e
					2	z	f

From "wide" to "long" with `pivot_longer()`

```
head(fed_spend_wide)
```

```
#> # A tibble: 6 × 15  
#>   year   DOD   NASA   DOE   HHS   NI  
#>   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>  
#> 1  1976 35696 12513 10882  9226  802  
#> 2  1977 37967 12553 13741  9507  821  
#> 3  1978 37022 12516 15663 10533  880  
#> 4  1979 37174 13079 15612 10127  924  
#> 5  1980 37005 13837 15226 10045  909  
#> 6  1981 41737 13276 14798  9644  858
```

```
fed_spend_long <- fed_spend_wide %>%  
  pivot_longer(  
    names_to = "department",  
    values_to = "rd_budget_mil",  
    cols = DOD:Other  
  )
```

```
head(fed_spend_long)
```

```
#> # A tibble: 6 × 3  
#>   year department rd_budget_mil  
#>   <dbl> <chr>          <dbl>  
#> 1  1976 DOD          35696  
#> 2  1976 NASA          12513  
#> 3  1976 DOE          10882  
#> 4  1976 HHS           9226  
#> 5  1976 NIH           8025  
#> 6  1976 NSF           2372
```

Can also set `cols` by selecting which columns *not* to use

```
names(fed_spend_wide)
```

```
#> [1] "year" "DOD" "NASA"
```

```
fed_spend_long <- fed_spend_wide %>%  
  pivot_longer(  
    names_to = "department",  
    values_to = "rd_budget_mil",  
    cols = -year  
  )
```

```
head(fed_spend_long)
```

```
#> # A tibble: 6 × 3  
#>   year department rd_budget_mil  
#>   <dbl> <chr>         <dbl>  
#> 1  1976 DOD          35696  
#> 2  1976 NASA          12513  
#> 3  1976 DOE          10882  
#> 4  1976 HHS           9226  
#> 5  1976 NIH           8025  
#> 6  1976 NSF           2372
```

Your turn: Reshaping Data

Open the `practice.qmd` file.

Run the code chunk to read in the following two data files:

- `pvc_cell_production.xlsx`: Data on solar photovoltaic cell production by country
- `milk_production.csv`: Data on milk production by state

Now modify the format of each:

- If the data are in "wide" format, convert it to "long" with `pivot_longer()`
- If the data are in "long" format, convert it to "wide" with `pivot_wider()`

Week 2: *Tidy Data*

1. Tidy Data

2. Tidy Data Wrangling

BREAK

3. Tidy Data Visualization

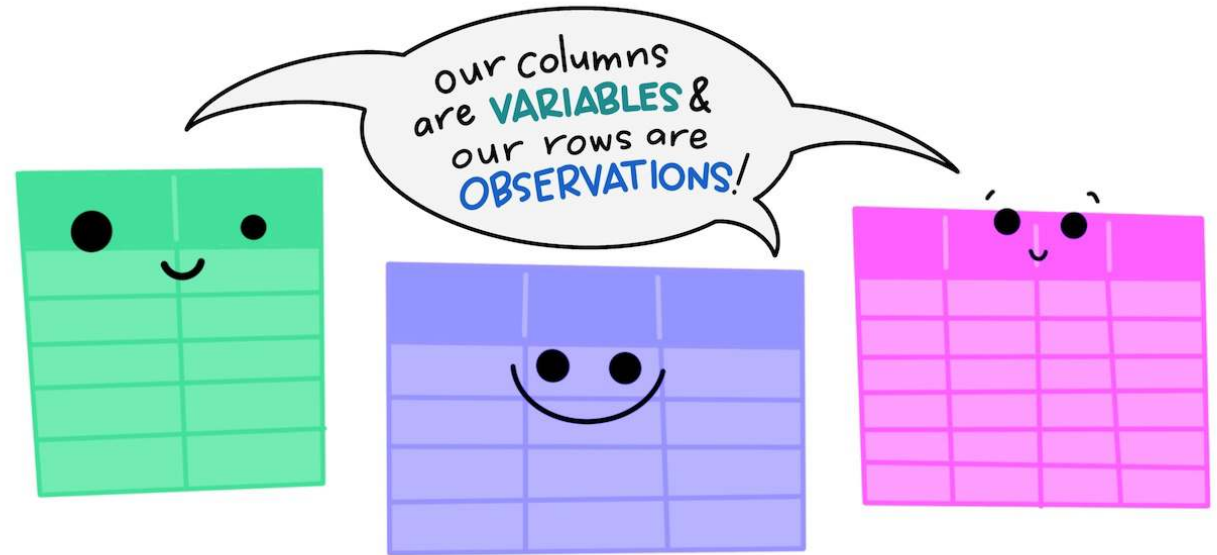
4. Data Provenance & Curation

5. Writing a Research Question

Why do we need tidy data?

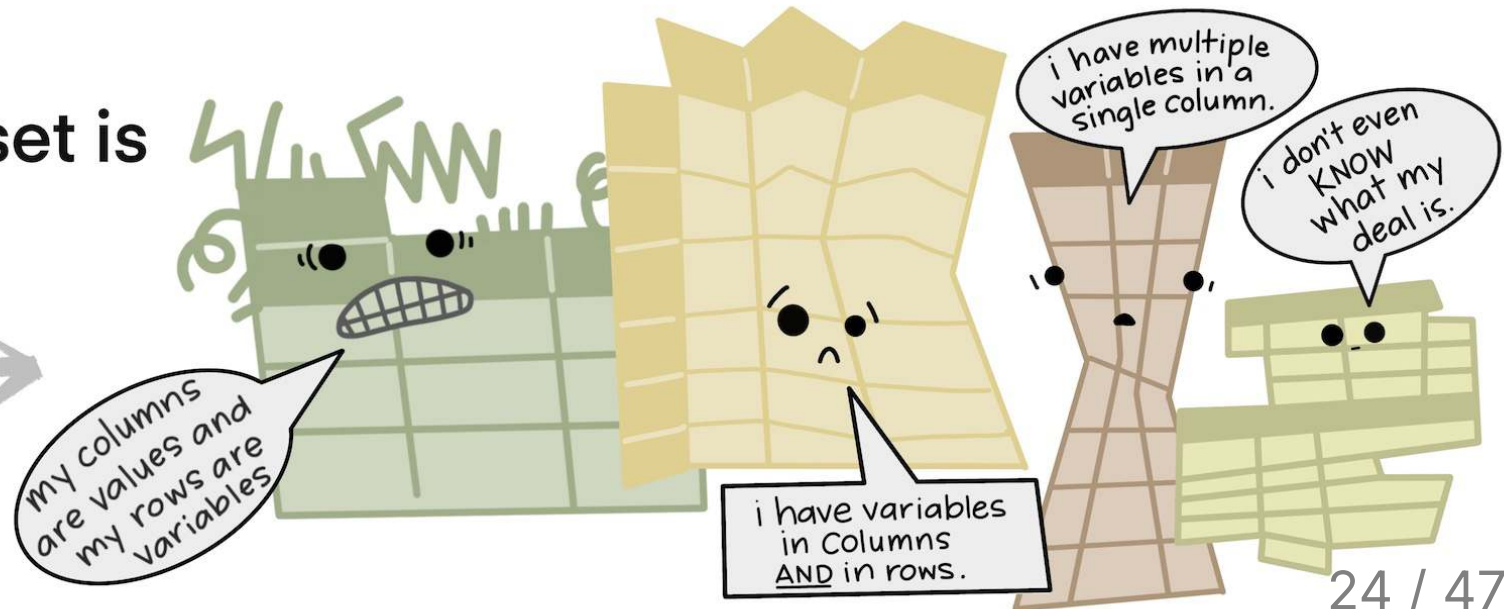
(a quick explanation with cute graphics, by [Allison Horst](#))

The standard structure of tidy data means that
"tidy datasets are all alike..."



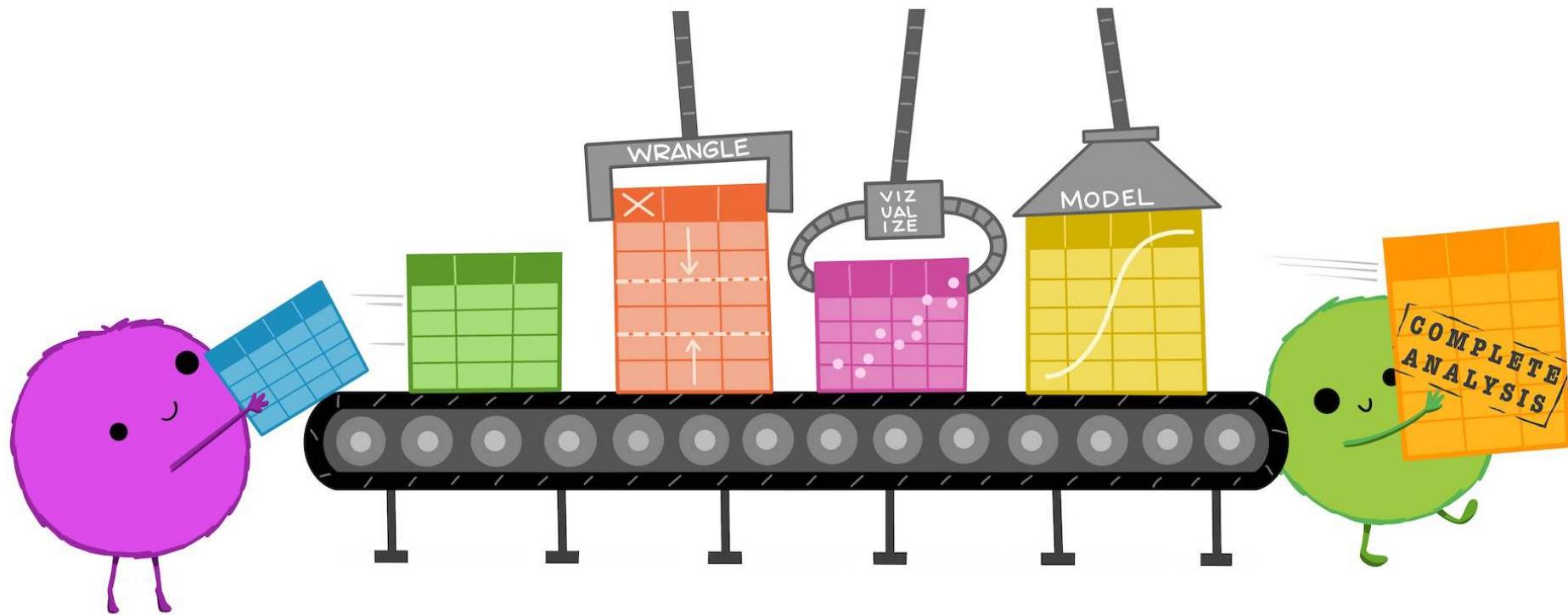
"...but every messy dataset is
messy in its own way."

—HADLEY WICKHAM



A green, round, fuzzy character with a smiling face, standing next to a wooden chair. The character has a large black eye, a small black dot for a nose, and a simple curved line for a smile. It has small green limbs. The background is a solid light blue.





Tidy data wrangling

Compute the total R&D spending in each year

```
head(fed_spend_wide)
```

```
#> # A tibble: 6 × 15
#>   year  DOD  NASA  DOE  HHS  NIH  NSF  USDA Interior  DOT  EPA  DOC  DHS  V
#>   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>
#> 1  1976 35696 12513 10882  9226  8025  2372  1837    1152  1142   968   819     0  40
#> 2  1977 37967 12553 13741  9507  8214  2395  1796    1082  1095   966   837     0  37
#> 3  1978 37022 12516 15663 10533  8802  2446  1962    1125  1156  1175   871     0  35
#> 4  1979 37174 13079 15612 10127  9243  2404  2054    1176  1004  1102   952     0  35
#> 5  1980 37005 13837 15226 10045  9093  2407  1887    1082  1048   903   945     0  35
#> 6  1981 41737 13276 14798  9644  8580  2300  1964     990   978   901   829     0  38
```

Tidy data wrangling

Compute the total R&D spending in each year

Approach 1: Create new `total` by adding each variable

```
fed_spend_wide %>%  
  mutate(total = DHS + DOC + DOD + DOE + DOT + EPA + HHS + Interior + NASA + NIH + NSF + O  
  select(year, total)
```

```
#> # A tibble: 42 × 2  
#>   year total  
#>   <dbl> <dbl>  
#> 1  1976  86227  
#> 2  1977  91807  
#> 3  1978  94864  
#> 4  1979  96601  
#> 5  1980  96305  
#> 6  1981  98304  
#> 7  1982  95448  
#> 8  1983  95010  
#> 9  1984 105371
```

Tidy data wrangling

Compute the total R&D spending by department in each year

Approach 2: Reshape first, then summarise

```
fed_spend_long <- fed_spend_wide %>%  
  pivot_longer(  
    names_to = "department",  
    values_to = "rd_budget_mil",  
    cols = -year)  
  
head(fed_spend_long)
```

```
#> # A tibble: 6 × 3  
#>   year department rd_budget_mil  
#>   <dbl> <chr>         <dbl>  
#> 1  1976 DOD          35696  
#> 2  1976 NASA          12513  
#> 3  1976 DOE          10882  
#> 4  1976 HHS           9226  
#> 5  1976 NTH           8025
```

```
fed_spend_long %>%  
  group_by(year) %>%  
  summarise(total = sum(rd_budget_mil))
```

```
#> # A tibble: 42 × 2  
#>   year total  
#>   <dbl> <dbl>  
#> 1  1976 86227  
#> 2  1977 91807  
#> 3  1978 94864  
#> 4  1979 96601  
#> 5  1980 96305  
#> 6  1981 98304  
#> 7  1982 95448  
#> 8  1983 95010  
#> 9  1984 105371
```

Tidy data wrangling

Compute the total R&D spending by department in each year

Approach 2: Reshape first, then summarise

```
annual_spending <- fed_spend_wide %>%  
  pivot_longer(  
    names_to = "department",  
    values_to = "rd_budget_mil",  
    cols = -year  
  ) %>%  
  group_by(year) %>%  
  summarise(total = sum(rd_budget_mil))
```

```
head(annual_spending)
```

```
#> # A tibble: 6 × 2  
#>   year total  
#>   <dbl> <dbl>  
#> 1  1976 86227  
#> 2  1977 91807  
#> 3  1978 94864  
#> 4  1979 96601  
#> 5  1980 96305  
#> 6  1981 98304
```

Tidy data wrangling

Compute the total R&D spending by department in each year

Approach 2: Reshape first, then summarise

```
total <- fed_spend_wide %>%  
  pivot_longer(  
    names_to = "department",  
    values_to = "rd_budget_mil",  
    cols = -year) %>%  
  group_by(year) %>%  
  summarise(total = sum(rd_budget_mil))
```

```
head(total)
```

```
#> # A tibble: 6 × 2  
#>   year total  
#>   <dbl> <dbl>  
#> 1  1976 86227  
#> 2  1977 91807  
#> 3  1978 94864  
#> 4  1979 96601  
#> 5  1980 96305  
#> 6  1981 98304
```

Your turn: Tidy Data Wrangling

Open the `practice.qmd` file.

Run the code chunk to read in the following two data files:

- `gapminder.csv`: Life expectancy in different countries over time
- `gdp.csv`: GDP of different countries over time

Now convert the data into a tidy (long) structure, then create the following summary data frames:

- Mean life expectancy in each year.
- Mean GDP in each year.

Break

05 : 00

Week 2: *Tidy Data*

1. Tidy Data

2. Tidy Data Wrangling

BREAK

3. **Tidy Data Visualization**

4. Data Provenance & Curation

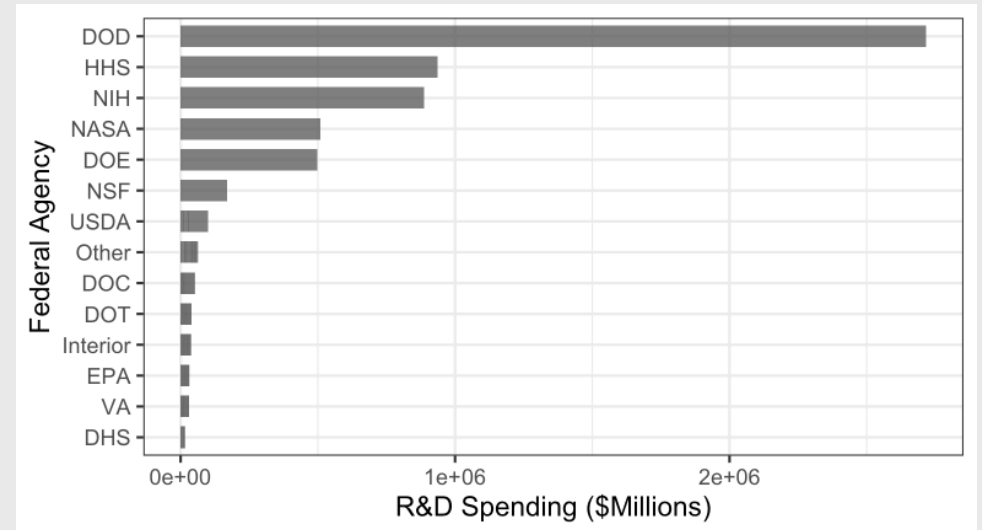
5. Writing a Research Question

Tidy data vizualization

Make a bar chart of total R&D spending by agency

```
head(fed_spend_wide)
```

```
#> # A tibble: 6 × 15  
#>   year  DOD  NASA  DOE  HHS  NIH  NSF  
#>   <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>  
#> 1  1976 35696 12513 10882  9226  8025  2372  
#> 2  1977 37967 12553 13741  9507  8214  2395  
#> 3  1978 37022 12516 15663 10533  8802  2446  
#> 4  1979 37174 13079 15612 10127  9243  2404  
#> 5  1980 37005 13837 15226 10045  9093  2407  
#> 6  1981 41737 13276 14798  9644  8580  2300
```

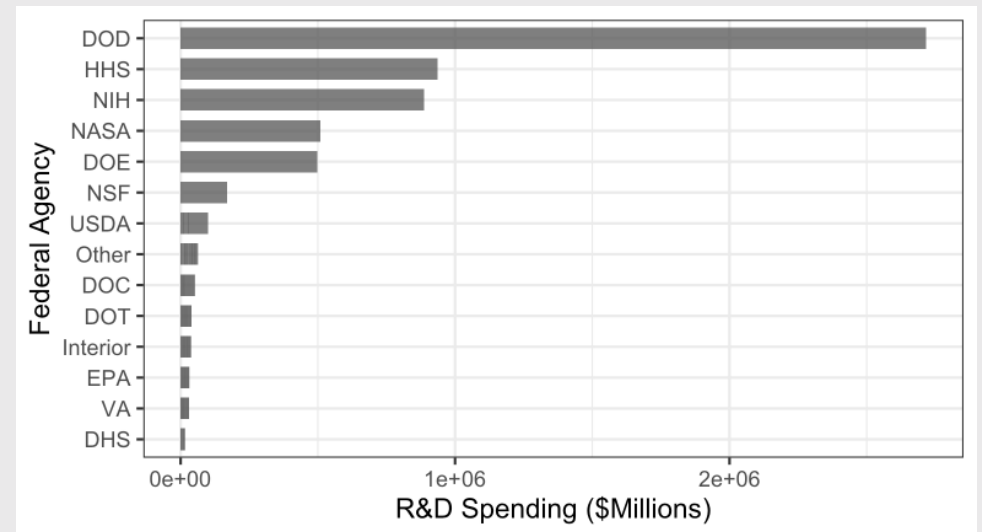


Tidy data vizualization

Make a bar chart of total R&D spending by agency

```
ggplot(fed_spend_wide) +  
  geom_col(aes(x = rd_budget_mil, y = department  
  theme_bw() +  
  labs(  
    x = "R&D Spending ($Millions)",  
    y = "Federal Agency"  
  )
```

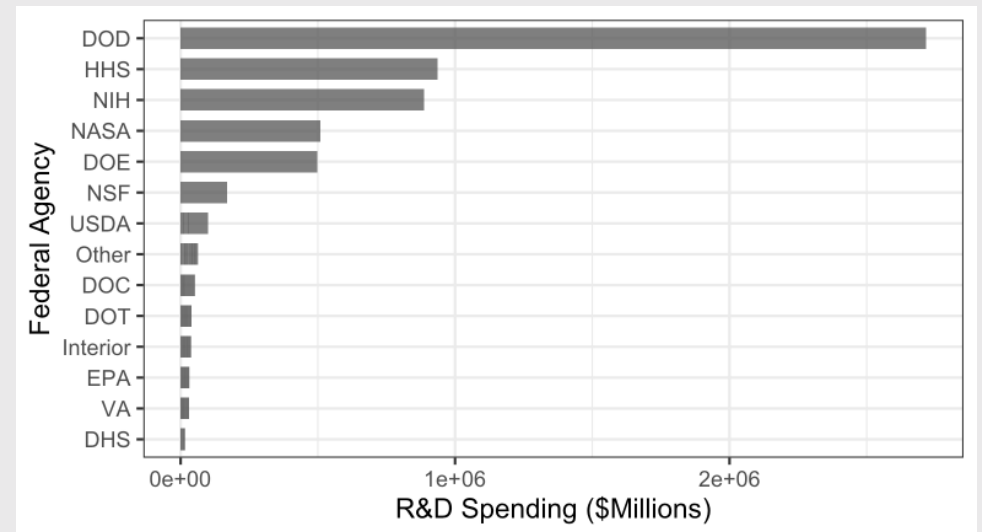
```
#> Error in `geom_col()`:  
#> ! Problem while computing aesthetics.  
#> i Error occurred in the 1st layer.  
#> Caused by error:  
#> ! object 'rd_budget_mil' not found
```



Tidy data vizualization

Make a bar chart of total R&D spending by agency

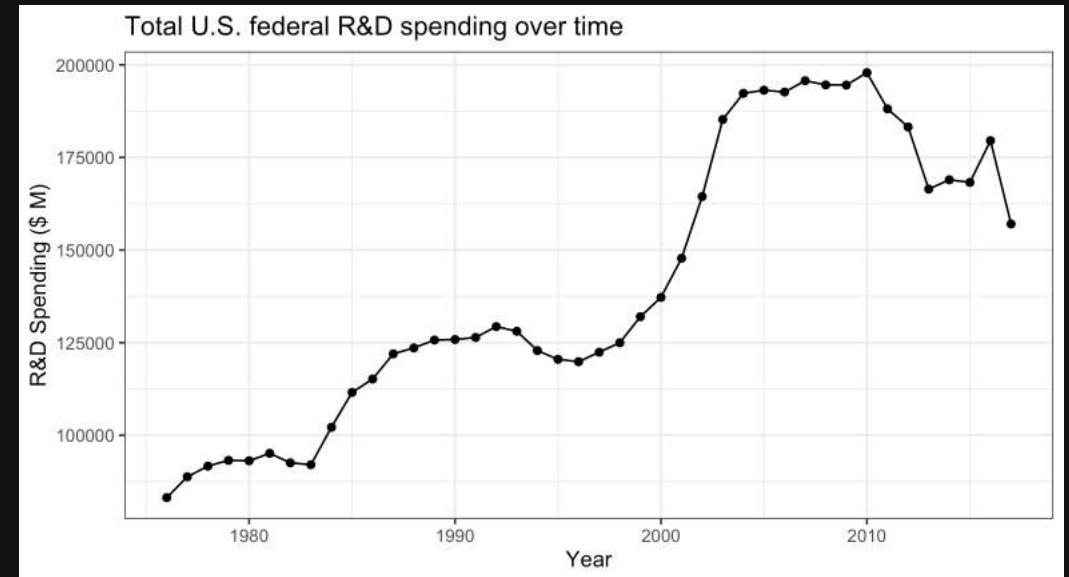
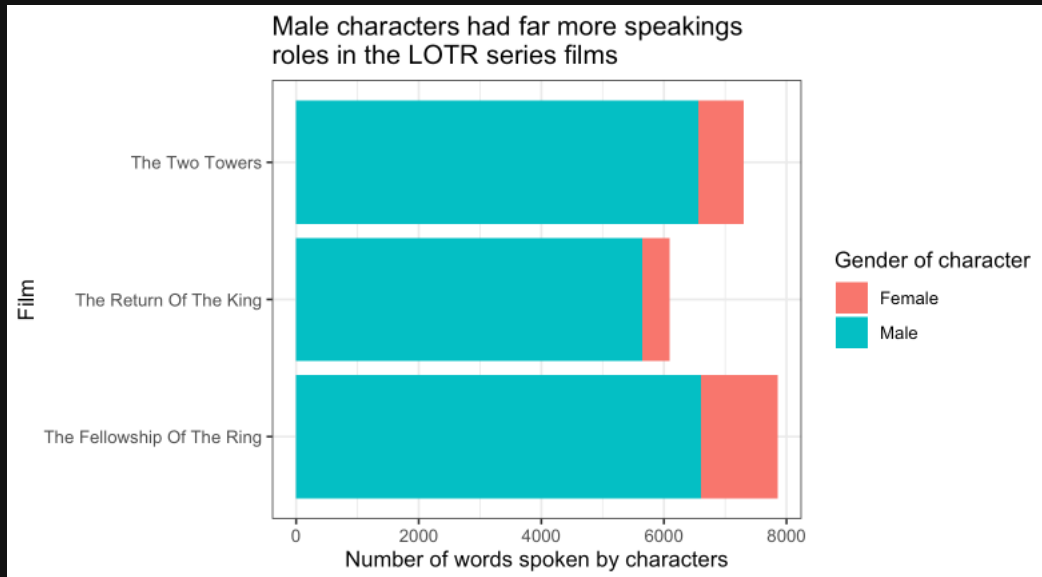
```
fed_spend_wide %>%  
  pivot_longer(  
    names_to = "department",  
    values_to = "rd_budget_mil",  
    cols = -year  
  ) %>%  
  ggplot() +  
    geom_col(aes(x = rd_budget_mil, y = department,  
    theme_bw() +  
    labs(  
      x = "R&D Spending ($Millions)",  
      y = "Federal Agency"  
    )
```



Your turn: Tidy Data Visualization

15:00

Run the code chunk to read in the two data files, then convert the data into a tidy (long) structure to create the following charts:



Week 2: *Tidy Data*

1. Tidy Data

2. Tidy Data Wrangling

BREAK

3. Tidy Data Visualization

4. Data Provenance & Curation

5. Writing a Research Question

Data provenance - It matters where you get your data

Validity:

- Is this data trustworthy? Is it authentic?
- Where did the data come from?
- How has the data been changed / managed over time?
- Is the data complete?

Comprehension:

- Is this data accurate?
- Can you explain your results?
- Is this the right data to answer your question?

Reproducibility:

- I should be able to fully replicate your results from your raw data and code.

🔍 Document your source like a museum curator

Example: View `README.md` file in the `data` folder

Whenever you download data, you should **at a minimum** record the following:

- The name of the file you are describing.
- The date you downloaded it.
- The original name of the downloaded file (in case you renamed it).
- The url to the site you downloaded it from.
- The source of the *original* data (sometimes different from the site you downloaded it from).
- A short description of the data, maybe how they were collected (if available).
- A dictionary for the data (e.g. a simple markdown table describing each variable).

Your turn

08:00

Documentation in the "data/README.md" file is missing for the following data sets:

- wildlife_impacts.csv: [source](#)
- north_america_bear_killings.txt: [source](#)
- uspto_clean_energy_patents.xlsx: [source](#)

Go to the above sites and add the following information to the "data/README.md" file:

- The name of the downloaded file.
- The web address to the site you downloaded the data from.
- The source of the *original* data (if different from the website).
- A short description of the data and how they were collected.
- A dictionary for the data (hint: the site might already have this!).

Week 2: *Tidy Data*

1. Tidy Data

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BREAK

3. Tidy Data Visualization

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5. Writing a Research Question

Writing a research question

Follow [these guidelines](#) - your question should be:

- **Clear:** your audience can easily understand its purpose without additional explanation.
- **Focused:** it is narrow enough that it can be addressed thoroughly with the data available and within the limits of the final project report.
- **Concise:** it is expressed in the fewest possible words.
- **Complex:** it is not answerable with a simple "yes" or "no," but rather requires synthesis and analysis of data.
- **Arguable:** its potential answers are open to debate rather than accepted facts (do others care about it?)

Writing a research question

Bad question: Why are social networking sites harmful?

- Unclear: it does not specify *which* social networking sites or state what harm is being caused; assumes that "harm" exists.

Improved question: How are online users experiencing or addressing privacy issues on social networking sites such as Facebook and Twitter?

- Specifies the sites (Facebook and Twitter), type of harm (privacy issues), and who is harmed (online users).

Writing a research question

Example from previous classes:

- [Genders in the Workforce](#): How has the US gender wage gap changed over time for different occupations and age groups?
- [NFL Suspensions](#): What factors contribute to the severity of disciplinary actions towards NFL players from 2002-2014?

Other good examples: See the [Example Projects](#) page

Use [this link](#) to form teams