EDA and data visualization

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29/01/24

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1 Overview

This week we will be going through some exploratory data analysis (EDA) and data visualization steps in R. The aim is to get you used to some possible steps and tools that you could take to understand the main characteristics and potential issues in a dataset.

We will be using the `opendatatoronto` R package, which interfaces with the City of Toronto Open Data Portal.

A good resource is part 1 (especially chapters 3 and 7) of 'R for Data Science' by Hadley Wickham, available for free here: https://r4ds.had.co.nz/.

1.1 What to hand in via GitHub

There are exercises at the end of this lab. Please make a new .Rmd/.qmd file with your answers, call it something sensible (e.g. `week_2_lab.qmd`), commit to your git repo from last week (ideally in a `labs` folder), and push to GitHub. Due on Monday by 9am.

1.2 A note on packages

You may need to install various packages used (using the `install.packages` function). Load in all the packages we need:

```
library(opendatatoronto)
library(tidyverse)
library(stringr)
library(skimr) # EDA
library(visdat) # EDA
library(janitor)
library(lubridate)
library(ggrepel)
```

2 TTC subway delays

This package provides an interface to all data available on the Open Data Portal provided by the City of Toronto.

Use the `list_packages` function to look whats available look at what's available

```
all_data <- list_packages(limit = 500)
head(all_data)
```

```
# A tibble: 6 x 11
  title             id    topics civic_issues publisher excerpt dataset_category
  <chr>             <chr> <chr>  <chr>        <chr>     <chr>   <chr>
1 Address Points (~ abed~ Locat~ <NA>         Informat~ "This ~ Map
2 Short Term Renta~ 2ab2~ Cultu~ <NA>         Municipa~ "This ~ Table
3 Building Permits~ 1e29~ Permi~ Climate cha~ Toronto ~ "Permi~ Table
4 Building Permits~ 5a19~ Devel~ <NA>         Toronto ~ "This ~ Table
5 Highrise Residen~ f816~ Publi~ <NA>         Fire Ser~ "Listi~ Table
6 Fire Incidents    64a2~ Locat~ <NA>         Fire Ser~ "This ~ Table
# i 4 more variables: num_resources <int>, formats <chr>, refresh_rate <chr>,
```

```
#   last_refreshed <date>
```

Let's download the data on TTC subway delays in 2022.

```
res <- list_package_resources("996cfe8d-fb35-40ce-b569-698d51fc683b") # obtained code from
res <- res |> mutate(year = str_extract(name, "202.?"))
delay_2022_ids <- res |> filter(year==2022) |> select(id) |> pull()

delay_2022 <- get_resource(delay_2022_ids)

# make the column names nicer to work with
delay_2022 <- clean_names(delay_2022)
```

Let's also download the delay code and readme, as reference.

```
# note: I obtained these codes from the 'id' column in the `res` object above
delay_codes <- get_resource("3900e649-f31e-4b79-9f20-4731bbfd94f7")
delay_data_codebook <- get_resource("ca43ac3d-3940-4315-889b-a9375e7b8aa4")
```

This dataset has a bunch of interesting variables. You can refer to the readme for descriptions. Our outcome of interest is `min_delay`, which give the delay in mins.

```
head(delay_2022)
```

```
# A tibble: 6 x 10
  date                time  day      station code  min_delay min_gap bound line
  <dttm>              <chr> <chr>    <chr>   <chr>     <dbl>   <dbl> <chr> <chr>
1 2022-01-01 00:00:00 15:59 Saturday LAWREN~ SRDP          0       0 N     SRT
2 2022-01-01 00:00:00 02:23 Saturday SPADIN~ MUIS          0       0 <NA>  BD
3 2022-01-01 00:00:00 22:00 Saturday KENNED~ MRO           0       0 <NA>  SRT
4 2022-01-01 00:00:00 02:28 Saturday VAUGHA~ MUIS          0       0 <NA>  YU
5 2022-01-01 00:00:00 02:34 Saturday EGLINT~ MUATC         0       0 S     YU
6 2022-01-01 00:00:00 05:40 Saturday QUEEN ~ MUNCA         0       0 <NA>  YU
# i 1 more variable: vehicle <dbl>
```

3 EDA and data viz

The following section highlights some tools that might be useful for you when you are getting used to a new dataset. There's no one way of exploration, but it's important to always keep in mind:

- what should your variables look like (type, values, distribution, etc)
- what would be surprising (outliers etc)
- what is your end goal (here, it might be understanding factors associated with delays, e.g. stations, time of year, time of day, etc)

In any data analysis project, if it turns out you have data issues, surprising values, missing data etc, it's important you **document** anything you found and the subsequent steps or **assumptions** you made before moving onto your data analysis / modeling.

3.1 Data checks

3.1.1 Sanity Checks

We need to check variables should be what they say they are. If they aren't, the natural next question is to what to do with issues (recode? remove?)

E.g. check days of week

```
unique(delay_2022$day)
```

```
[1] "Saturday"  "Sunday"    "Monday"    "Tuesday"   "Wednesday" "Thursday"
[7] "Friday"
```

Check lines: oh no. some issues here. Some have obvious recodes, others, not so much.

```
unique(delay_2022$line)
```

```
 [1] "SRT"             "BD"              "YU"              "YU/BD"
 [5] "SHP"             NA                "BD/YU"           "YU / BD"
 [9] "YU/ BD"          "B/D"             "Y/BD"            "YU/BD LINES"
[13] "YUS"             "YU & BD"         "YUS AND BD"      "YUS/BD"
[17] "69 WARDEN SOUTH" "YU/BD LINE"      "LINE 2 SHUTTLE"  "57 MIDLAND"
[21] "96 WILSON"       "506 CARLTON"
```

The `skimr` package might also be useful here

```
skim(delay_2022)
```

Table 1: Data summary

Name	delay_2022
Number of rows	19895
Number of columns	10
_____	
Column type frequency:	
character	6
numeric	3
POSIXct	1
_____	
Group variables	None

Variable type: character

skim_variable	n_missing	complete_rate	min	max	empty	n_unique	whitespace
time	0	1.00	5	5	0	1406	0
day	0	1.00	6	9	0	7	0
station	0	1.00	5	22	0	296	0
code	0	1.00	3	5	0	179	0
bound	5546	0.72	1	1	0	5	0
line	39	1.00	2	15	0	21	0

Variable type: numeric

skim_variable	n_missing	complete_rate	mean	sd	p0	p25	p50	p75	p100	hist
min_delay	0	1	3.67	12.00	0	0	0	4	458	
min_gap	0	1	5.33	12.66	0	0	0	8	463	
vehicle	0	1	3571.59	2646.62	0	0	5192	5701	8871	

Variable type: POSIXct

skim_variable	n_missing	complete_rate	min	max	median	n_unique
date	0	1	2022-01-01	2022-12-31	2022-06-29	365

3.1.2 Missing values

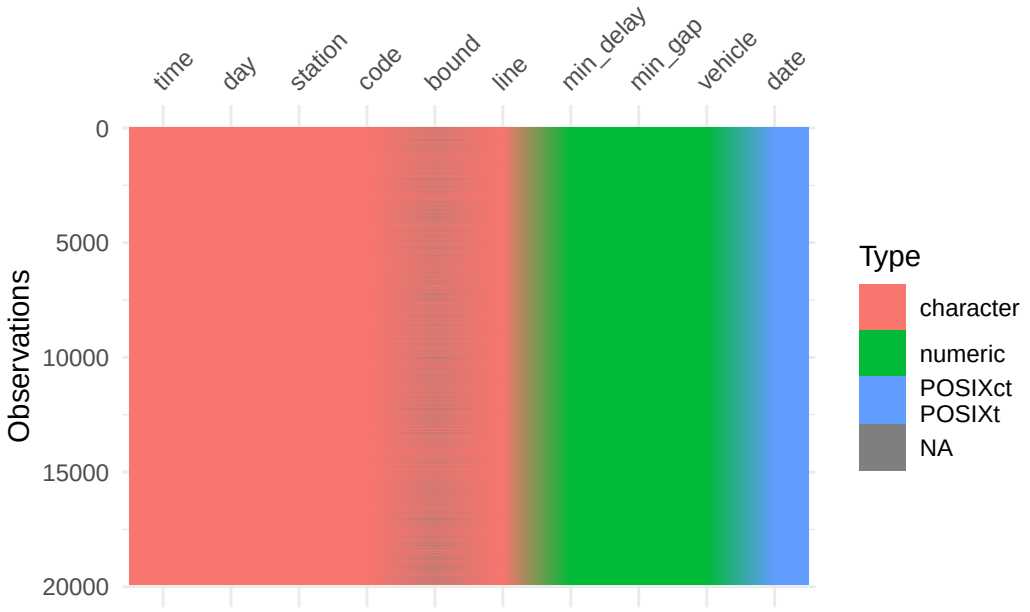
Calculate number of NAs by column

```
delay_2022 |>
  summarize(across(everything(), ~ sum(is.na(.x))))
```

```
# A tibble: 1 x 10
   date  time   day station  code min_delay min_gap bound  line vehicle
  <int> <int> <int>   <int> <int>     <int>   <int> <int> <int>   <int>
1     0     0     0       0     0         0       0  5546    39       0
```

The `visdat` package is useful here, particularly to see how missing values are distributed. (commented out because couldn't get pdf to render in quarto)

```
vis_dat(delay_2022)
```




```
#vis_miss(delay_2022)
```

3.1.3 Duplicates?

The `get_dupes` function from the `janitor` package is useful for this.

```
  get_dupes(delay_2022)
```

```
# A tibble: 28 x 11
   date                time  day     station code  min_delay min_gap bound line
   <dttm>              <chr> <chr>   <chr>   <chr>     <dbl>   <dbl> <chr> <chr>
 1 2022-01-12 00:00:00 13:27 Wednes~ FINCH ~ TUNOA         3       6 S     YU
 2 2022-01-12 00:00:00 13:27 Wednes~ FINCH ~ TUNOA         3       6 S     YU
 3 2022-01-12 00:00:00 17:49 Wednes~ FINCH ~ TUNOA         3       6 S     YU
 4 2022-01-12 00:00:00 17:49 Wednes~ FINCH ~ TUNOA         3       6 S     YU
 5 2022-01-17 00:00:00 02:00 Monday  SCARBO~ TRST          0       0 <NA>  SRT
 6 2022-01-17 00:00:00 02:00 Monday  SCARBO~ TRST          0       0 <NA>  SRT
 7 2022-01-20 00:00:00 02:30 Thursd~ YONGE ~ TUST          0       0 <NA>  YU
 8 2022-01-20 00:00:00 02:30 Thursd~ YONGE ~ TUST          0       0 <NA>  YU
 9 2022-01-20 00:00:00 08:51 Thursd~ WILSON~ TUNOA         3       6 S     YU
10 2022-01-20 00:00:00 08:51 Thursd~ WILSON~ TUNOA         3       6 S     YU
# i 18 more rows
# i 2 more variables: vehicle <dbl>, dupe_count <int>
```

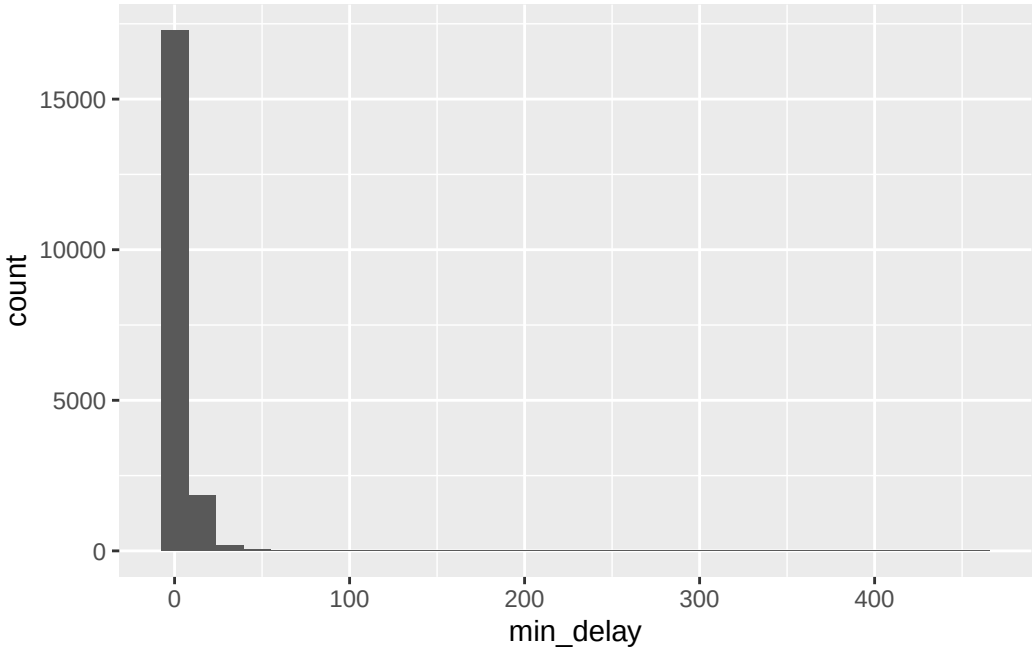
```
  delay_2022 <- delay_2022 |> distinct()
```

3.2 Visualizing distributions

Histograms, barplots, and density plots are your friends here.

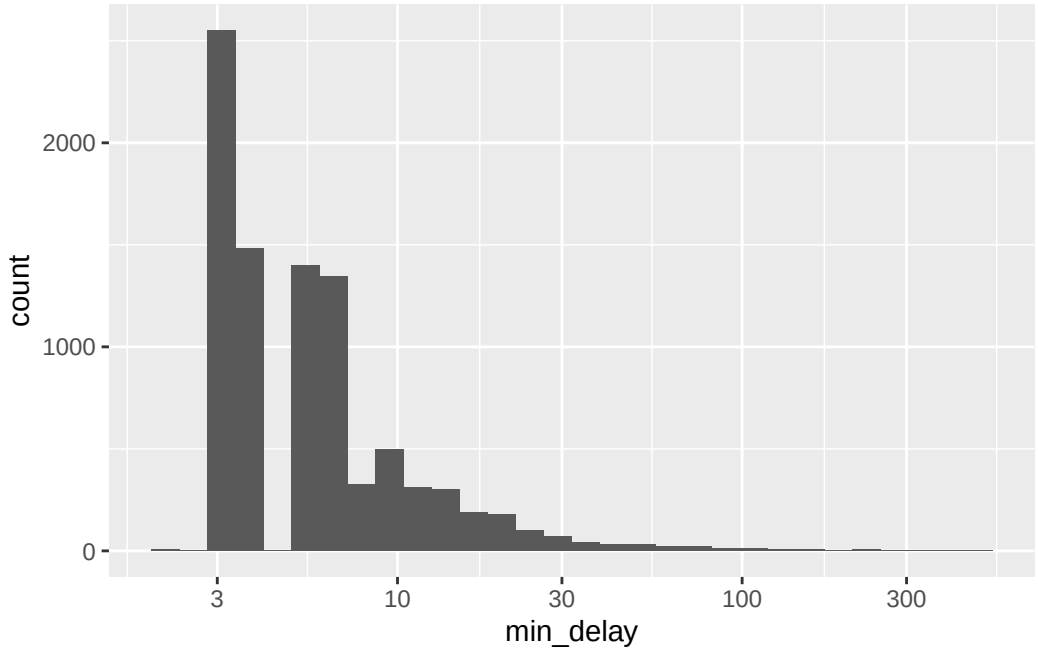
Let's look at the outcome of interest: `min_delay`. First of all just a histogram of all the data:

```
  ## Removing the observations that have non-standardized lines

  delay_2022 <- delay_2022 |> filter(line %in% c("BD", "YU", "SHP", "SRT"))

  ggplot(data = delay_2022) +
    geom_histogram(aes(x = min_delay))
```



To improve readability, could plot on logged scale:

```
ggplot(data = delay_2022) +
  geom_histogram(aes(x = min_delay)) +
  scale_x_log10()
```



Our initial EDA hinted at an outlying delay time, let's take a look at the largest delays below. Join the `delay_codes` dataset to see what the delay is. (Have to do some mangling as SRT has different codes).

```
delay_2022 <- delay_2022 |>
  left_join(delay_codes |> rename(code = `SUB RMENU CODE`, code_desc = `CODE DESCRIPTION..


delay_2022 <- delay_2022 |>
  mutate(code_srt = ifelse(line=="SRT", code, "NA")) |>
  left_join(delay_codes |> rename(code_srt = `SRT RMENU CODE`, code_desc_srt = `CODE DESCR
  mutate(code = ifelse(code_srt=="NA", code, code_srt),
         code_desc = ifelse(is.na(code_desc_srt), code_desc, code_desc_srt)) |>
  select(-code_srt, -code_desc_srt)
```

The largest delay is due to Fires.

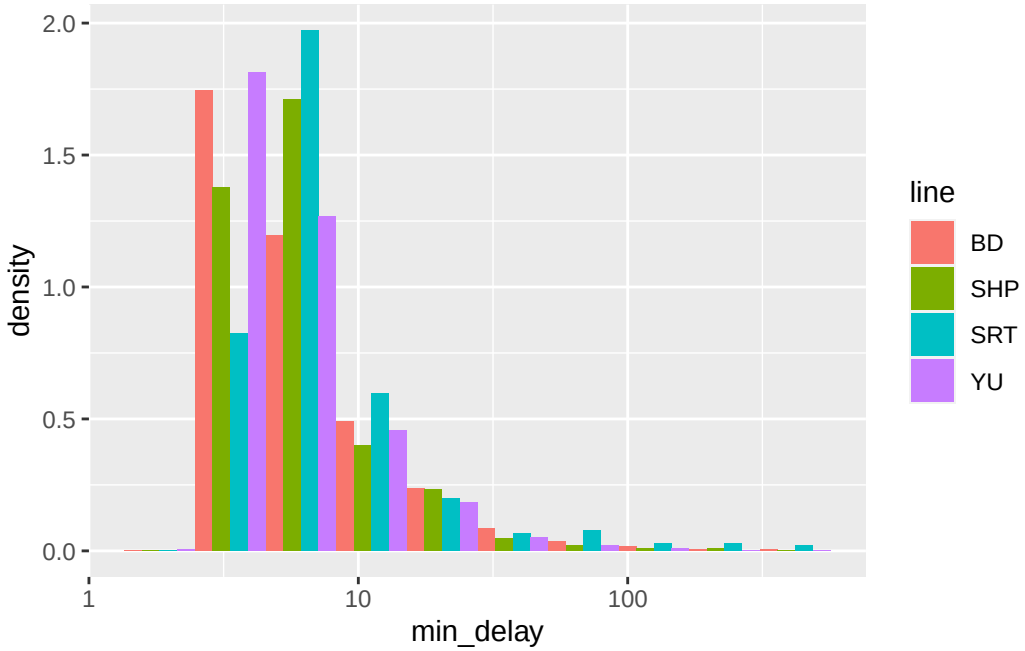
```
delay_2022 |>
  left_join(delay_codes |> rename(code = `SUB RMENU CODE`, code_desc = `CODE DESCRIPTION..
  arrange(-min_delay) |>
  select(date, time, station, line, min_delay, code, code_desc)
```

```
# A tibble: 19,460 x 7
   date                time  station             line  min_delay code  code_desc
   <dttm>              <chr> <chr>               <chr>     <dbl> <chr> <chr>
 1 2022-12-08 00:00:00 17:52 MIDLAND STATION     SRT         458 MRPLB Fire/Smo~
 2 2022-08-22 00:00:00 12:20 SRT LINE            SRT         451 PRSO  Signals ~
 3 2022-04-28 00:00:00 06:02 JANE STATION        BD          388 PUTR  Rail Rel~
 4 2022-07-26 00:00:00 07:06 YONGE BD STATION    BD          382 MUPLB Fire/Smo~
 5 2022-08-15 00:00:00 12:57 DUFFERIN STATION    BD          327 MUPR1 Priority~
 6 2022-01-26 00:00:00 20:15 KENNEDY SRT STATION SRT         315 MRWEA Weather ~
 7 2022-08-02 00:00:00 21:23 HIGHWAY 407 STATION YU          312 MUPR1 Priority~
 8 2022-01-17 00:00:00 21:30 SHEPPARD WEST TO U~ YU          291 MUFM  Force Ma~
 9 2022-01-25 00:00:00 21:03 SCARBOROUGH CTR ST~ SRT         285 PRSL  Loop Rel~
10 2022-06-17 00:00:00 12:25 KIPLING STATION     BD          241 SUUT  Unauthor~
# i 19,450 more rows
```

3.2.0.1 Grouping and small multiples

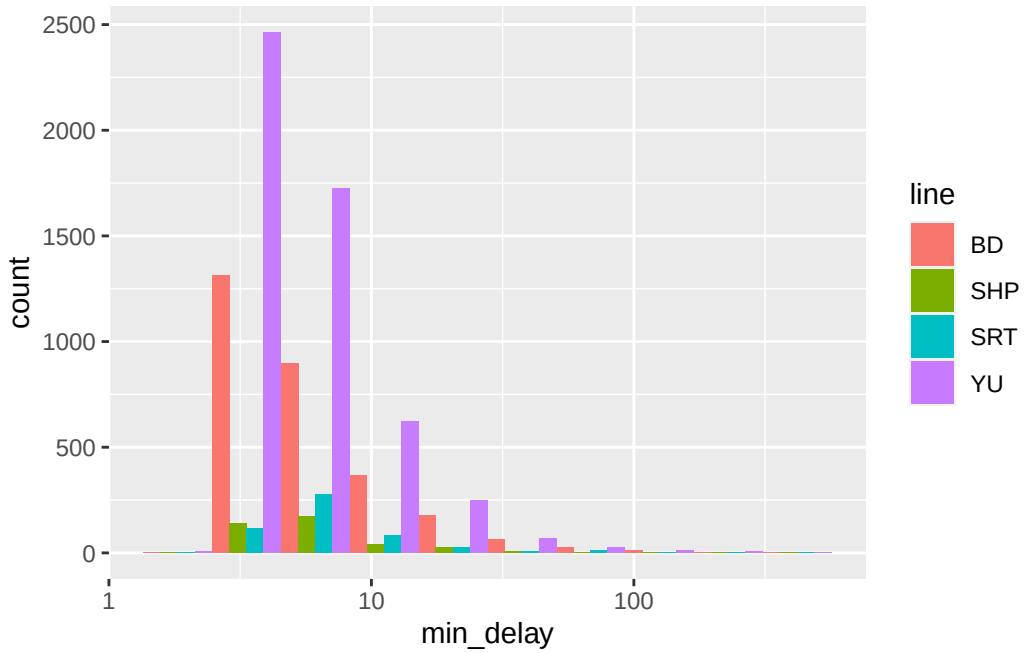
A quick and powerful visualization technique is to group the data by a variable of interest, e.g. `line`

```
ggplot(data = delay_2022) +
  geom_histogram(aes(x = min_delay, y = ..density.., fill = line), position = 'dodge', bin
  scale_x_log10()
```



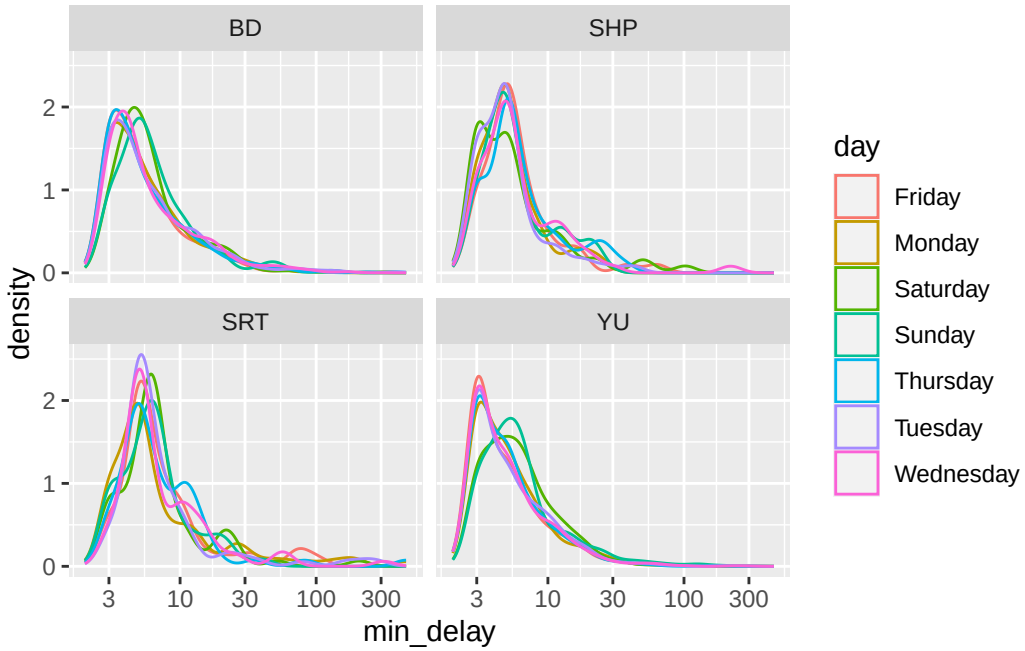
I switched to density above to look at the the distributions more comparably, but we should also be aware of differences in frequency, in particular, SHP and SRT have much smaller counts:

```
ggplot(data = delay_2022) +
  geom_histogram(aes(x = min_delay, fill = line), position = 'dodge', bins = 10) +
  scale_x_log10()
```



If you want to group by more than one variable, facets are good:

```
ggplot(data = delay_2022) +
  geom_density(aes(x = min_delay, color = day), bw = .08) +
  scale_x_log10() +
  facet_wrap(~line)
```



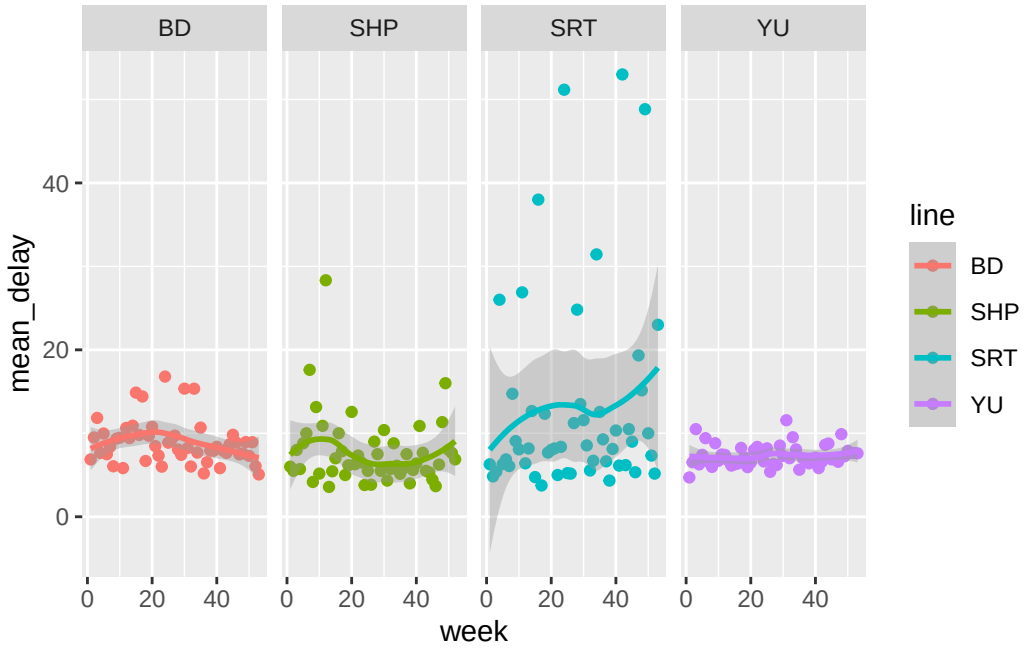
Side note: the station names are a mess. Try and clean up the station names a bit by taking just the first word (or, the first two if it starts with "ST"):

```
delay_2022 <- delay_2022 |>
  mutate(station_clean = ifelse(str_starts(station, "ST"), word(station, 1,2), word(statio
```

3.3 Visualizing time series

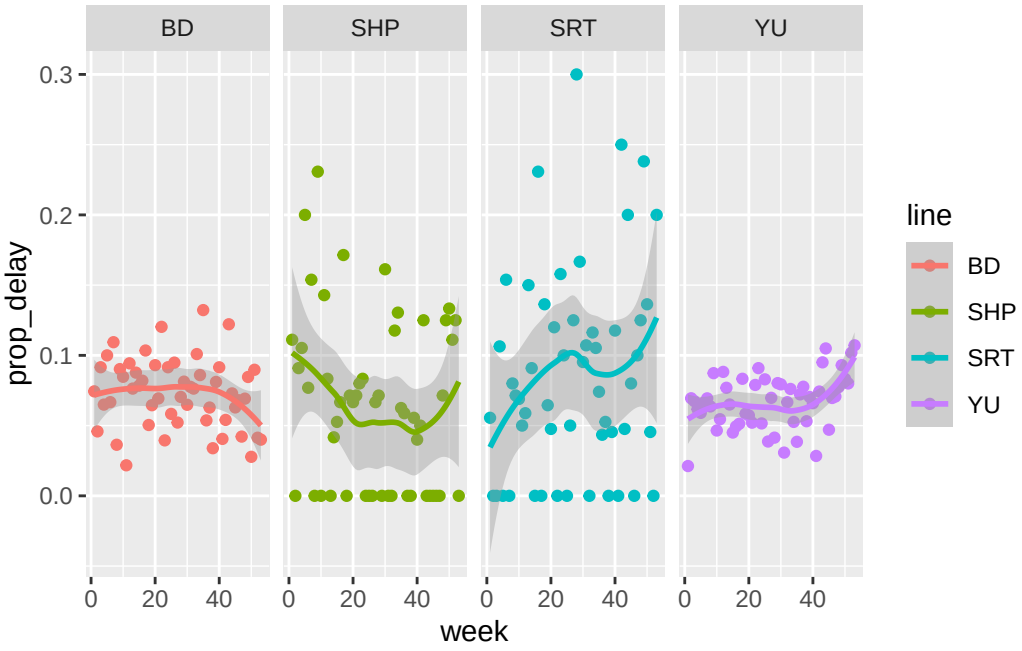
Daily plot is messy (you can check for yourself). Let's look by week to see if there's any seasonality. The `lubridate` package has lots of helpful functions that deal with date variables. First, mean delay (of those that were delayed more than 0 mins):

```
delay_2022 |>
  filter(min_delay>0) |>
  mutate(week = week(date)) |>
  group_by(week, line) |>
  summarise(mean_delay = mean(min_delay)) |>
  ggplot(aes(week, mean_delay, color = line)) +
  geom_point() +
  geom_smooth() +
  facet_grid(~line)
```



What about proportion of delays that were greater than 10 mins?

```
delay_2022 |>
  mutate(week = week(date)) |>
  group_by(week, line) |>
  summarise(prop_delay = sum(min_delay>10)/n()) |>
  ggplot(aes(week, prop_delay, color = line)) +
  geom_point() +
  geom_smooth() +
  facet_grid(~line)
```

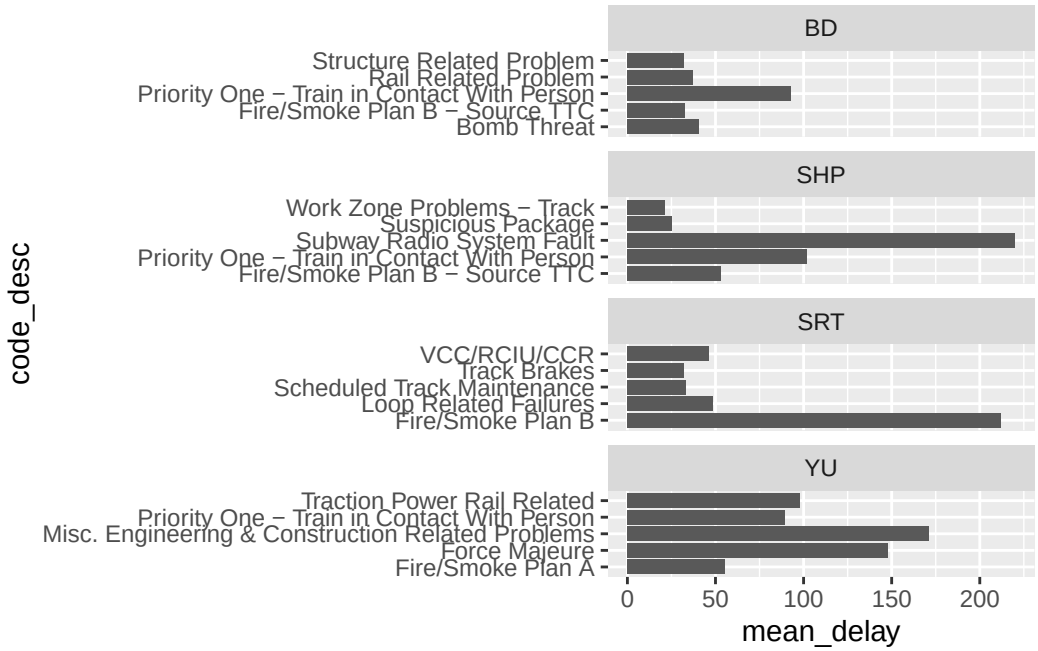


3.4 Visualizing relationships

Note that **scatter plots** are a good precursor to modeling, to visualize relationships between continuous variables. Nothing obvious to plot here, but easy to do with `geom_point`.

Look at top five reasons for delay by station. Do they differ? Think about how this could be modeled.

```
delay_2022 |>
  group_by(line, code_desc) |>
  summarise(mean_delay = mean(min_delay)) |>
  arrange(-mean_delay) |>
  slice(1:5) |>
  ggplot(aes(x = code_desc,
             y = mean_delay)) +
  geom_col() +
  facet_wrap(vars(line),
             scales = "free_y",
             nrow = 4) +
  coord_flip()
```



3.5 PCA (additional)

Principal components analysis is a really powerful exploratory tool, particularly when you have a lot of variables. It allows you to pick up potential clusters and/or outliers that can help to inform model building.

Let's do a quick (and imperfect) example looking at types of delays by station.

The delay categories are a bit of a mess, and there's hundreds of them. As a simple start, let's just take the first word:

```
delay_2022 <- delay_2022 |>
  mutate(code_red = case_when(
    str_starts(code_desc, "No") ~ word(code_desc, 1, 2),
    str_starts(code_desc, "Operator") ~ word(code_desc, 1,2),
    TRUE ~ word(code_desc,1))
         )
```

Let's also just restrict the analysis to causes that happen at least 50 times over 2022 To do the PCA, the dataframe also needs to be switched to wide format:

```
dwide <- delay_2022 |>
  group_by(line, station_clean) |>
  mutate(n_obs = n()) |>
  filter(n_obs>1) |>
  group_by(code_red) |>
  mutate(tot_delay = n()) |>
  arrange(tot_delay) |>
  filter(tot_delay>50) |>
  group_by(line, station_clean, code_red) |>
  summarise(n_delay = n()) |>
  pivot_wider(names_from = code_red, values_from = n_delay) |>
  mutate(
    across(everything(), ~ replace_na(.x, 0))
  )
```

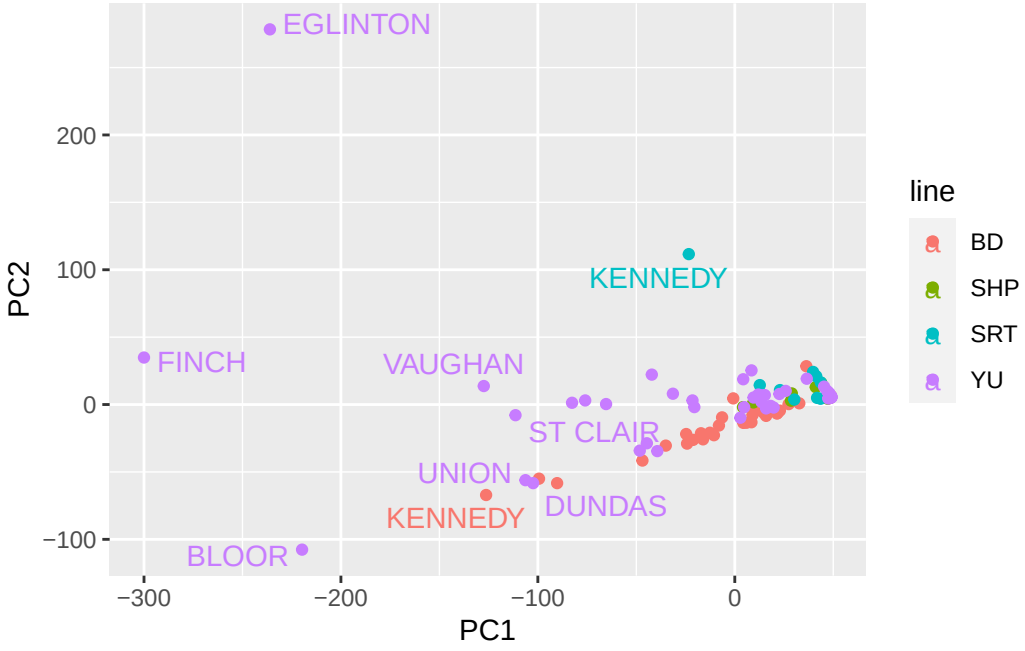
Do the PCA:

```
delay_pca <- prcomp(dwide[,3:ncol(dwide)])

df_out <- as_tibble(delay_pca$x)
df_out <- bind_cols(dwide |> select(line, station_clean), df_out)
head(df_out)
```

```
# A tibble: 6 x 41
# Groups:   line, station_clean [6]
  line  station_clean     PC1    PC2    PC3   PC4    PC5    PC6    PC7    PC8
  <chr> <chr>           <dbl>  <dbl>  <dbl> <dbl>  <dbl>  <dbl>  <dbl>  <dbl>
1 BD    BATHURST       -16.4  -24.2  -6.53  10.6  -3.13   5.31  -3.21  -8.76
2 BD    BAY              8.46 -13.1  -6.37   8.08  0.929  0.379  6.06   0.302
3 BD    BLOOR           36.3   28.4  34.5   14.6   9.64   7.72  -4.50   1.11
4 BD    BLOOR-DANFORTH  48.8    6.37 -0.508  1.55 -9.19   3.76  -0.656  0.426
5 BD    BROADVIEW      -22.7  -26.0  -6.29  11.7   4.28  -2.67   4.42   7.65
6 BD    CASTLE          15.9   -8.41 -3.27   6.67 -3.58   0.351  0.626 -3.93
# i 31 more variables: PC9 <dbl>, PC10 <dbl>, PC11 <dbl>, PC12 <dbl>,
#   PC13 <dbl>, PC14 <dbl>, PC15 <dbl>, PC16 <dbl>, PC17 <dbl>, PC18 <dbl>,
#   PC19 <dbl>, PC20 <dbl>, PC21 <dbl>, PC22 <dbl>, PC23 <dbl>, PC24 <dbl>,
#   PC25 <dbl>, PC26 <dbl>, PC27 <dbl>, PC28 <dbl>, PC29 <dbl>, PC30 <dbl>,
#   PC31 <dbl>, PC32 <dbl>, PC33 <dbl>, PC34 <dbl>, PC35 <dbl>, PC36 <dbl>,
#   PC37 <dbl>, PC38 <dbl>, PC39 <dbl>
```

Plot the first two PCs, and label some outlying stations:

```
ggplot(df_out,aes(x=PC1,y=PC2,color=line )) + geom_point() + geom_text_repel(data = df_out
```



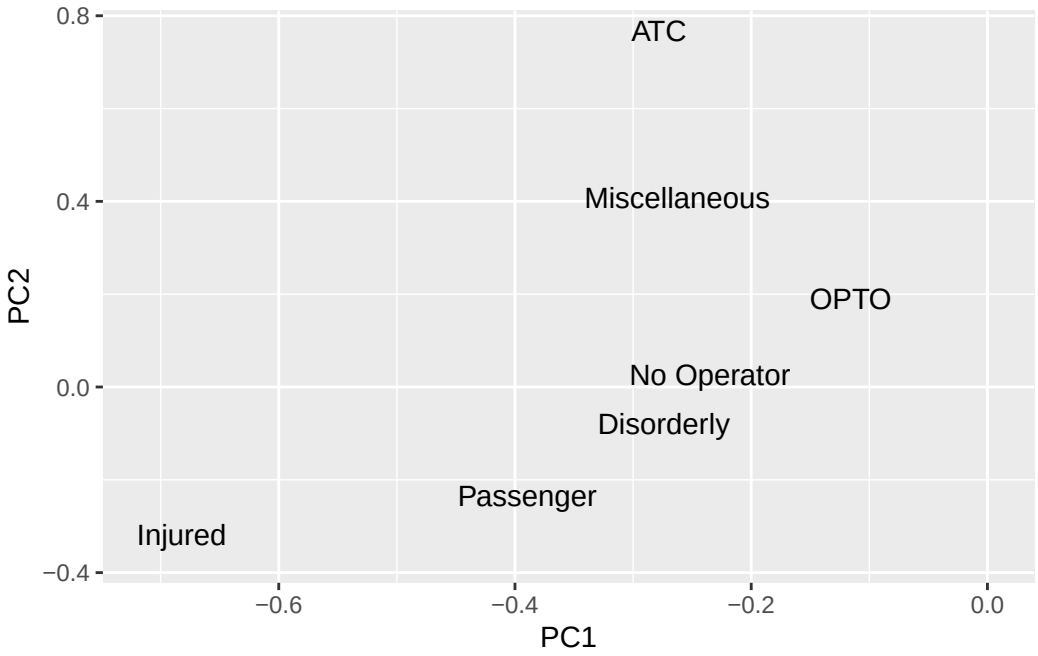
Plot the factor loadings. Some evidence of public v operator?

```
df_out_r <- as_tibble(delay_pca$rotation)
df_out_r$feature <- colnames(dwide[,3:ncol(dwide)])

df_out_r
```

```
# A tibble: 39 x 40
       PC1      PC2       PC3      PC4      PC5      PC6      PC7      PC8      PC9
     <dbl>    <dbl>     <dbl>    <dbl>    <dbl>    <dbl>    <dbl>    <dbl>    <dbl>
 1 -0.127  -0.0379  -0.0174     0.0269   0.0395 -0.0422  0.121   -0.0234   0.161
 2 -0.305  -0.126   -0.0746     0.0452   0.104  -0.184   0.191   -0.652   -0.485
 3 -0.0531 -0.0116   0.0384     0.0378   0.0574 -0.0448 -0.0616  -0.116    0.252
 4 -0.0135 -0.0170  -0.0118    -0.00289  0.0459 -0.0371  0.0135   0.0179 -0.0706
 5 -0.0119 -0.00468  0.000237   0.00866 -0.0176 -0.0466 -0.0313  -0.0949   0.0600
 6 -0.0904 -0.0248   0.0513    -0.0165  -0.0337 -0.0660  0.0728   0.205    0.263
 7 -0.0161 -0.00184 -0.00127    0.00539  0.0137 -0.0363  0.0141   0.0363 -0.0393
 8 -0.713  -0.366   -0.0129     0.0887  -0.166   0.272  -0.433    0.211   -0.0557
 9 -0.232   0.457    0.706      0.259    0.378   0.0680 -0.0673   0.0102 -0.0670
```

```
10 -0.0401  0.00653  0.100    -0.0386  -0.0932 -0.510   0.00136  0.300  -0.101
# i 29 more rows
# i 31 more variables: PC10 <dbl>, PC11 <dbl>, PC12 <dbl>, PC13 <dbl>,
#   PC14 <dbl>, PC15 <dbl>, PC16 <dbl>, PC17 <dbl>, PC18 <dbl>, PC19 <dbl>,
#   PC20 <dbl>, PC21 <dbl>, PC22 <dbl>, PC23 <dbl>, PC24 <dbl>, PC25 <dbl>,
#   PC26 <dbl>, PC27 <dbl>, PC28 <dbl>, PC29 <dbl>, PC30 <dbl>, PC31 <dbl>,
#   PC32 <dbl>, PC33 <dbl>, PC34 <dbl>, PC35 <dbl>, PC36 <dbl>, PC37 <dbl>,
#   PC38 <dbl>, PC39 <dbl>, feature <chr>
```

```
ggplot(df_out_r,aes(x=PC1,y=PC2,label=feature )) + geom_text_repel()
```



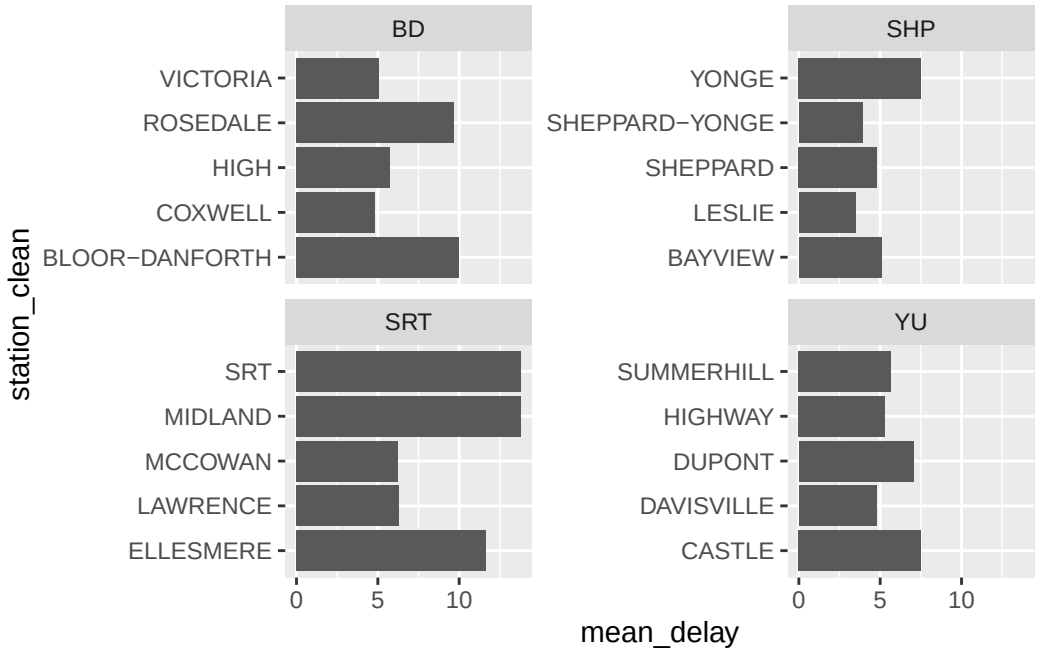
4 Lab Exercises

To be handed in via submission of quarto file (and rendered pdf) to GitHub.

1. Using the `delay_2022` data, plot the five stations with the highest mean delays. Facet the graph by `line`

```
delay_2022 |>
  group_by(line, station_clean) |>
```

```
  summarise(mean_delay = mean(min_delay), n_obs = n()) |>
  filter(n_obs>1) |>
  arrange(line, -mean_delay) |>
  slice(1:5) |>
  ggplot(aes(station_clean, mean_delay)) +
  geom_col() +
  coord_flip() +
  facet_wrap(~line, scales = "free_y")
```



2. Restrict the `delay_2022` to delays that are greater than 0 and to only have delay reasons that appear in the top 50% of most frequent delay reasons. Perform a regression to study the association between delay minutes, and two covariates: line and delay reason. It's up to you how to specify the model, but make sure it's appropriate to the data types. Comment briefly on the results, including whether results generally agree with the exploratory data analysis above.

```
dr <- delay_2022 |>
  filter(min_delay>0) |>
  group_by(code_desc) |>
  mutate(n_delays = n())
```

```r
summary(dr$n_delays)
```

```
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
    1.0   108.0   295.0   382.2   703.0   963.0
```

```r
summary(lm(log(min_delay)~line+code_desc, data = dr |> filter(n_delays>295)))
```

```
Call:
lm(formula = log(min_delay) ~ line + code_desc, data = filter(dr,
    n_delays > 295))

Residuals:
    Min      1Q  Median      3Q     Max
-1.4699 -0.3443 -0.0768  0.2803  3.2161

Coefficients:
                                                                 Estimate
(Intercept)                                                      1.571708
lineSHP                                                          0.157935
lineSRT                                                          0.299851
lineYU                                                          -0.007852
code_descDisorderly Patron                                       0.122365
code_descInjured or ill Customer (On Train) - Medical Aid Refused  0.225360
code_descNo Operator Immediately Available                      -0.216807
code_descOPTO (COMMS) Train Door Monitoring                     -0.120926
code_descPassenger Assistance Alarm Activated - No Trouble Found  -0.257274
code_descPassenger Other                                         0.553718
code_descUnauthorized at Track Level                             0.696973
                                                                Std. Error
(Intercept)                                                       0.028361
lineSHP                                                           0.047458
lineSRT                                                           0.061990
lineYU                                                            0.020500
code_descDisorderly Patron                                        0.027142
code_descInjured or ill Customer (On Train) - Medical Aid Refused   0.036017
code_descNo Operator Immediately Available                        0.031962
code_descOPTO (COMMS) Train Door Monitoring                       0.027731
code_descPassenger Assistance Alarm Activated - No Trouble Found    0.030356
code_descPassenger Other                                          0.035197
code_descUnauthorized at Track Level                              0.032918
```

```
                                                                t value
(Intercept)                                                      55.418
lineSHP                                                           3.328
lineSRT                                                           4.837
lineYU                                                           -0.383
code_descDisorderly Patron                                        4.508
code_descInjured or ill Customer (On Train) - Medical Aid Refused  6.257
code_descNo Operator Immediately Available                       -6.783
code_descOPTO (COMMS) Train Door Monitoring                      -4.361
code_descPassenger Assistance Alarm Activated - No Trouble Found -8.475
code_descPassenger Other                                         15.732
code_descUnauthorized at Track Level                             21.173
                                                                Pr(>|t|)
(Intercept)                                                      < 2e-16 ***
lineSHP                                                         0.000882 ***
lineSRT                                                         1.36e-06 ***
lineYU                                                          0.701712
code_descDisorderly Patron                                      6.70e-06 ***
code_descInjured or ill Customer (On Train) - Medical Aid Refused 4.29e-10 ***
code_descNo Operator Immediately Available                      1.33e-11 ***
code_descOPTO (COMMS) Train Door Monitoring                     1.33e-05 ***
code_descPassenger Assistance Alarm Activated - No Trouble Found  < 2e-16 ***
code_descPassenger Other                                          < 2e-16 ***
code_descUnauthorized at Track Level                              < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.5196 on 4470 degrees of freedom
Multiple R-squared:  0.2516,    Adjusted R-squared:  0.2499
F-statistic: 150.3 on 10 and 4470 DF,  p-value: < 2.2e-16
```

```r
# or with interaction
summary(lm(log(min_delay)~line+code_desc+line*code_desc, data = dr |> filter(n_delays>295)))
```

```
Call:
lm(formula = log(min_delay) ~ line + code_desc + line * code_desc,
    data = filter(dr, n_delays > 295))

Residuals:
    Min      1Q  Median      3Q     Max
-1.5847 -0.3472 -0.0837  0.2733  3.1769
```

```
Coefficients: (5 not defined because of singularities)
                                                                        Estimate
(Intercept)                                                              1.63273
lineSHP                                                                  0.48203
lineSRT                                                                 -0.29811
lineYU                                                                  -0.06887
code_descDisorderly Patron                                               0.06037
code_descInjured or ill Customer (On Train) - Medical Aid Refused        0.18434
code_descNo Operator Immediately Available                              -0.29662
code_descOPTO (COMMS) Train Door Monitoring                             -0.11808
code_descPassenger Assistance Alarm Activated - No Trouble Found        -0.35303
code_descPassenger Other                                                 0.46917
code_descUnauthorized at Track Level                                     0.67515
lineSHP:code_descDisorderly Patron                                      -0.43426
lineSRT:code_descDisorderly Patron                                       0.73657
lineYU:code_descDisorderly Patron                                        0.06315
lineSHP:code_descInjured or ill Customer (On Train) - Medical Aid Refused -0.42701
lineSRT:code_descInjured or ill Customer (On Train) - Medical Aid Refused -0.07377
lineYU:code_descInjured or ill Customer (On Train) - Medical Aid Refused  0.03866
lineSHP:code_descNo Operator Immediately Available                      -0.14140
lineSRT:code_descNo Operator Immediately Available                       0.66310
lineYU:code_descNo Operator Immediately Available                        0.07932
lineSHP:code_descOPTO (COMMS) Train Door Monitoring                     -0.41809
lineSRT:code_descOPTO (COMMS) Train Door Monitoring                           NA
lineYU:code_descOPTO (COMMS) Train Door Monitoring                            NA
lineSHP:code_descPassenger Assistance Alarm Activated - No Trouble Found -0.39590
lineSRT:code_descPassenger Assistance Alarm Activated - No Trouble Found  0.51431
lineYU:code_descPassenger Assistance Alarm Activated - No Trouble Found   0.11346
lineSHP:code_descPassenger Other                                        -0.11558
lineSRT:code_descPassenger Other                                         0.87953
lineYU:code_descPassenger Other                                          0.06328
lineSHP:code_descUnauthorized at Track Level                                 NA
lineSRT:code_descUnauthorized at Track Level                                 NA
lineYU:code_descUnauthorized at Track Level                                  NA
                                                                        Std. Error
(Intercept)                                                               0.05479
lineSHP                                                                   0.16093
lineSRT                                                                   0.16093
lineYU                                                                    0.05118
code_descDisorderly Patron                                                0.06095
code_descInjured or ill Customer (On Train) - Medical Aid Refused         0.07143
code_descNo Operator Immediately Available                                0.08145
```

```
code_descOPTO (COMMS) Train Door Monitoring                                    0.02803
code_descPassenger Assistance Alarm Activated - No Trouble Found               0.07178
code_descPassenger Other                                                       0.06874
code_descUnauthorized at Track Level                                           0.03926
lineSHP:code_descDisorderly Patron                                             0.19123
lineSRT:code_descDisorderly Patron                                             0.20013
lineYU:code_descDisorderly Patron                                              0.06190
lineSHP:code_descInjured or ill Customer (On Train) - Medical Aid Refused      0.23427
lineSRT:code_descInjured or ill Customer (On Train) - Medical Aid Refused      0.40300
lineYU:code_descInjured or ill Customer (On Train) - Medical Aid Refused       0.07877
lineSHP:code_descNo Operator Immediately Available                             0.28861
lineSRT:code_descNo Operator Immediately Available                             0.21525
lineYU:code_descNo Operator Immediately Available                              0.08390
lineSHP:code_descOPTO (COMMS) Train Door Monitoring                            0.17397
lineSRT:code_descOPTO (COMMS) Train Door Monitoring                                 NA
lineYU:code_descOPTO (COMMS) Train Door Monitoring                                  NA
lineSHP:code_descPassenger Assistance Alarm Activated - No Trouble Found       0.21737
lineSRT:code_descPassenger Assistance Alarm Activated - No Trouble Found       0.24830
lineYU:code_descPassenger Assistance Alarm Activated - No Trouble Found        0.07397
lineSHP:code_descPassenger Other                                               0.21977
lineSRT:code_descPassenger Other                                               0.20438
lineYU:code_descPassenger Other                                                0.07691
lineSHP:code_descUnauthorized at Track Level                                        NA
lineSRT:code_descUnauthorized at Track Level                                        NA
lineYU:code_descUnauthorized at Track Level                                         NA
                                                                            t value
(Intercept)                                                                  29.799
lineSHP                                                                       2.995
lineSRT                                                                      -1.852
lineYU                                                                       -1.346
code_descDisorderly Patron                                                    0.990
code_descInjured or ill Customer (On Train) - Medical Aid Refused             2.581
code_descNo Operator Immediately Available                                   -3.642
code_descOPTO (COMMS) Train Door Monitoring                                  -4.213
code_descPassenger Assistance Alarm Activated - No Trouble Found             -4.918
code_descPassenger Other                                                      6.825
code_descUnauthorized at Track Level                                         17.198
lineSHP:code_descDisorderly Patron                                           -2.271
lineSRT:code_descDisorderly Patron                                            3.680
lineYU:code_descDisorderly Patron                                             1.020
lineSHP:code_descInjured or ill Customer (On Train) - Medical Aid Refused    -1.823
lineSRT:code_descInjured or ill Customer (On Train) - Medical Aid Refused    -0.183
lineYU:code_descInjured or ill Customer (On Train) - Medical Aid Refused      0.491
```

```
lineSHP:code_descNo Operator Immediately Available                          -0.490
lineSRT:code_descNo Operator Immediately Available                           3.081
lineYU:code_descNo Operator Immediately Available                            0.945
lineSHP:code_descOPTO (COMMS) Train Door Monitoring                         -2.403
lineSRT:code_descOPTO (COMMS) Train Door Monitoring                             NA
lineYU:code_descOPTO (COMMS) Train Door Monitoring                              NA
lineSHP:code_descPassenger Assistance Alarm Activated - No Trouble Found    -1.821
lineSRT:code_descPassenger Assistance Alarm Activated - No Trouble Found     2.071
lineYU:code_descPassenger Assistance Alarm Activated - No Trouble Found      1.534
lineSHP:code_descPassenger Other                                            -0.526
lineSRT:code_descPassenger Other                                             4.303
lineYU:code_descPassenger Other                                              0.823
lineSHP:code_descUnauthorized at Track Level                                    NA
lineSRT:code_descUnauthorized at Track Level                                    NA
lineYU:code_descUnauthorized at Track Level                                     NA
                                                                         Pr(>|t|)
(Intercept)                                                               < 2e-16
lineSHP                                                                  0.002758
lineSRT                                                                  0.064036
lineYU                                                                   0.178498
code_descDisorderly Patron                                               0.322046
code_descInjured or ill Customer (On Train) - Medical Aid Refused        0.009892
code_descNo Operator Immediately Available                               0.000274
code_descOPTO (COMMS) Train Door Monitoring                              2.57e-05
code_descPassenger Assistance Alarm Activated - No Trouble Found         9.06e-07
code_descPassenger Other                                                 9.96e-12
code_descUnauthorized at Track Level                                      < 2e-16
lineSHP:code_descDisorderly Patron                                       0.023200
lineSRT:code_descDisorderly Patron                                       0.000236
lineYU:code_descDisorderly Patron                                        0.307712
lineSHP:code_descInjured or ill Customer (On Train) - Medical Aid Refused 0.068407
lineSRT:code_descInjured or ill Customer (On Train) - Medical Aid Refused 0.854762
lineYU:code_descInjured or ill Customer (On Train) - Medical Aid Refused  0.623587
lineSHP:code_descNo Operator Immediately Available                       0.624203
lineSRT:code_descNo Operator Immediately Available                       0.002079
lineYU:code_descNo Operator Immediately Available                        0.344502
lineSHP:code_descOPTO (COMMS) Train Door Monitoring                      0.016294
lineSRT:code_descOPTO (COMMS) Train Door Monitoring                            NA
lineYU:code_descOPTO (COMMS) Train Door Monitoring                             NA
lineSHP:code_descPassenger Assistance Alarm Activated - No Trouble Found  0.068630
lineSRT:code_descPassenger Assistance Alarm Activated - No Trouble Found  0.038387
lineYU:code_descPassenger Assistance Alarm Activated - No Trouble Found   0.125167
lineSHP:code_descPassenger Other                                         0.598988
```

```
lineSRT:code_descPassenger Other                                          1.72e-05
lineYU:code_descPassenger Other                                           0.410666
lineSHP:code_descUnauthorized at Track Level                                    NA
lineSRT:code_descUnauthorized at Track Level                                    NA
lineYU:code_descUnauthorized at Track Level                                     NA

(Intercept)                                                               ***
lineSHP                                                                   **
lineSRT                                                                   .
lineYU
code_descDisorderly Patron
code_descInjured or ill Customer (On Train) - Medical Aid Refused         **
code_descNo Operator Immediately Available                                ***
code_descOPTO (COMMS) Train Door Monitoring                               ***
code_descPassenger Assistance Alarm Activated - No Trouble Found          ***
code_descPassenger Other                                                  ***
code_descUnauthorized at Track Level                                      ***
lineSHP:code_descDisorderly Patron                                        *
lineSRT:code_descDisorderly Patron                                        ***
lineYU:code_descDisorderly Patron
lineSHP:code_descInjured or ill Customer (On Train) - Medical Aid Refused .
lineSRT:code_descInjured or ill Customer (On Train) - Medical Aid Refused
lineYU:code_descInjured or ill Customer (On Train) - Medical Aid Refused
lineSHP:code_descNo Operator Immediately Available
lineSRT:code_descNo Operator Immediately Available                        **
lineYU:code_descNo Operator Immediately Available
lineSHP:code_descOPTO (COMMS) Train Door Monitoring                       *
lineSRT:code_descOPTO (COMMS) Train Door Monitoring
lineYU:code_descOPTO (COMMS) Train Door Monitoring
lineSHP:code_descPassenger Assistance Alarm Activated - No Trouble Found  .
lineSRT:code_descPassenger Assistance Alarm Activated - No Trouble Found  *
lineYU:code_descPassenger Assistance Alarm Activated - No Trouble Found
lineSHP:code_descPassenger Other
lineSRT:code_descPassenger Other                                          ***
lineYU:code_descPassenger Other
lineSHP:code_descUnauthorized at Track Level
lineSRT:code_descUnauthorized at Track Level
lineYU:code_descUnauthorized at Track Level
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.5185 on 4454 degrees of freedom
Multiple R-squared:  0.2576,    Adjusted R-squared:  0.2533
```

```
F-statistic: 59.44 on 26 and 4454 DF,  p-value: < 2.2e-16
```

3. Using the `opendatatoronto` package, download the data on mayoral campaign contributions for 2014 and clean it up. Hints:

   - find the ID code you need for the package you need by searching for 'campaign' in the `all_data` tibble above
   - you will then need to `list_package_resources` to get ID for the data file
   - note: the 2014 file you will get from `get_resource` has a bunch of different campaign contributions, so just keep the data that relates to the Mayor election
   - clean up the data format (fixing the parsing issue and standardizing the column names using `janitor`)

   ::: {.cell}

   ```
   list_package_resources("e869d365-2c15-4893-ad2a-744ca867be3b")
   ```

   ::: {.cell-output .cell-output-stdout} # A tibble: 4 x 4   name   ic
   format last_modified   <chr>   <chr>   <chr>
   <date>   1 Campaign Contributions 2018 Data   5f54ab3d-44d7-4e5c-9c~
   ZIP   2023-04-26   2 Campaign Contributions 2018 Readme eea9eecd-75ba-4a27-9f~
   XLSX   2023-04-26   3 Campaign Contributions 2014 Data   8b42906f-c894-4e93-a9~
   ZIP   2023-04-26   4 Campaign Contributions 2014 Readme 10158522-4f3b-4957-9f~
   XLS   2023-04-26 :::

   ```
   all_campaigns <- get_resource("8b42906f-c894-4e93-a98e-acac200f34a4")
   df <- all_campaigns[[2]]
   df <- df |>
     janitor::row_to_names(1) |>
     janitor::clean_names()
   ```

   :::

4. Summarize the variables in the dataset. Are there missing values, and if so, should we be worried about them? Is every variable in the format it should be? If not, create new variable(s) that are in the right format.

```
skim(df)
```

Table 5: Data summary

Name	df
Number of rows	10199

Number of columns	13
Column type frequency:	
character	13
Group variables	None

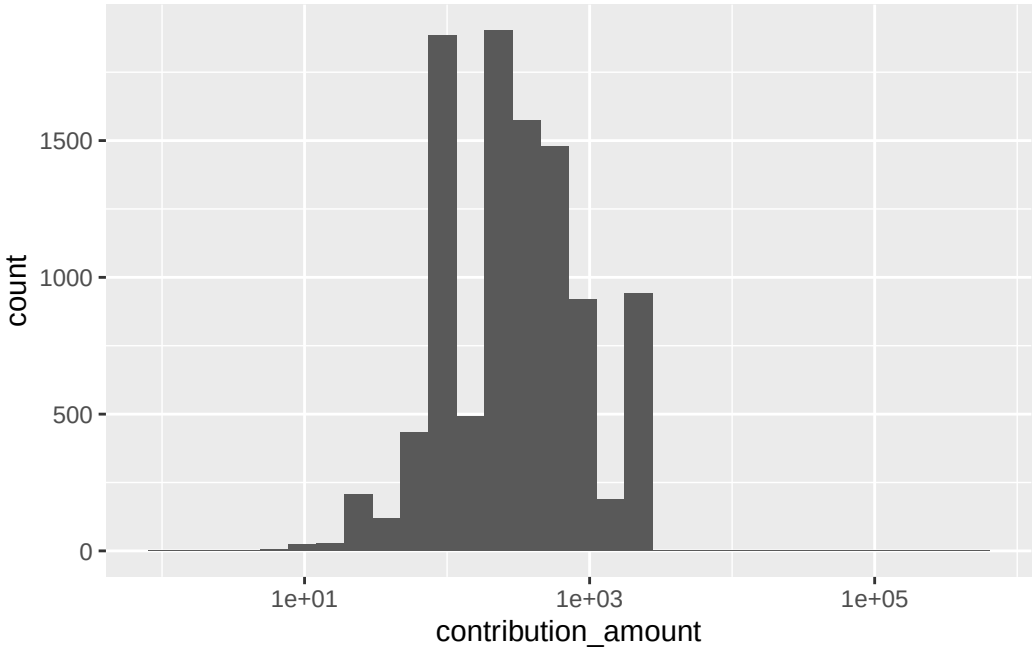
Variable type: character

skim_variable	n_missing	complete_rate	min	max	empty	n_unique	whitespace
contributors_name	0	1	4	31	0	7545	0
contributors_address	10197	0	24	26	0	2	0
contributors_postal_code	0	1	7	7	0	5284	0
contribution_amount	0	1	1	18	0	209	0
contribution_type_desc	0	1	8	14	0	2	0
goods_or_service_desc	10188	0	11	40	0	9	0
contributor_type_desc	0	1	10	11	0	2	0
relationship_to_candidate	10166	0	6	9	0	2	0
president_business_manager	10197	0	13	16	0	2	0
authorized_representative	10197	0	13	16	0	2	0
candidate	0	1	9	18	0	27	0
office	0	1	5	5	0	1	0
ward	10199	0	NA	NA	0	0	0

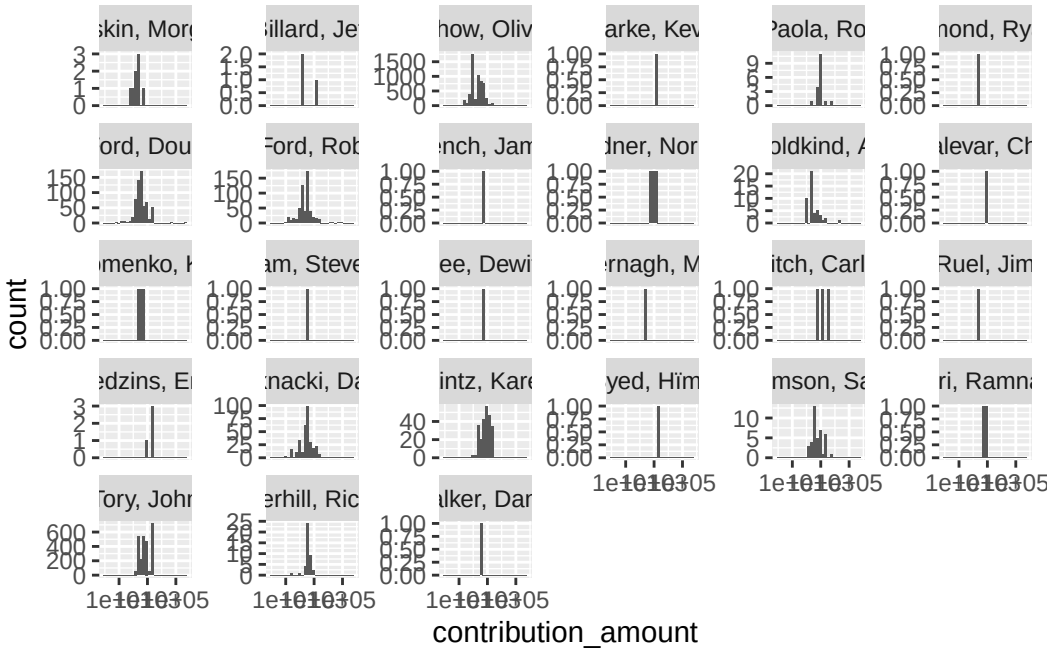
```
df <- df |>
  mutate(contribution_amount = as.numeric(contribution_amount))
```

5. Visually explore the distribution of values of the contributions. What contributions are notable outliers? Do they share a similar characteristic(s)? It may be useful to plot the distribution of contributions without these outliers to get a better sense of the majority of the data.

```
df |>
  ggplot(aes(contribution_amount)) + geom_histogram() + scale_x_log10()
```




```
df |>
  ggplot(aes(contribution_amount)) + geom_histogram() + scale_x_log10() + facet_wrap(~cand
```



```
# The big outliers are from Fords to Fords
```

6. List the top five candidates in each of these categories:
    - total contributions
    - mean contribution
    - number of contributions

```
# total contributions
df |>
  group_by(candidate) |>
  summarise(total_contr = sum(contribution_amount)) |>
  arrange(-total_contr)
```

```
# A tibble: 27 x 2
   candidate          total_contr
   <chr>                    <dbl>
 1 Tory, John            2767869.
 2 Chow, Olivia          1638266.
 3 Ford, Doug             889897.
 4 Ford, Rob              387648.
 5 Stintz, Karen          242805
 6 Soknacki, David        132431
 7 Goldkind, Ari           41125.
 8 Thomson, Sarah          34628.
 9 Di Paola, Rocco         21126
10 Underhill, Richard      15660
# i 17 more rows
```

```
# mean contributions
df |>
  group_by(candidate) |>
  summarise(mean_contr = mean(contribution_amount)) |>
  arrange(-mean_contr)
```

```
# A tibble: 27 x 2
   candidate        mean_contr
   <chr>                 <dbl>
 1 Sniedzins, Erwin      2025
 2 Syed, Hïmy            2018
 3 Ritch, Carlie         1887.
```

```
 4 Ford, Doug            1456.
 5 Clarke, Kevin         1200
 6 Di Paola, Rocco       1174.
 7 Tory, John            1064.
 8 Gardner, Norman       1000
 9 Stintz, Karen          995.
10 Kalevar, Chai          900
# i 17 more rows
```

```
# number
df |>
  group_by(candidate) |>
  tally() |>
  arrange(-n)
```

```
# A tibble: 27 x 2
   candidate              n
   <chr>              <int>
 1 Chow, Olivia        5708
 2 Tory, John          2602
 3 Ford, Doug           611
 4 Ford, Rob            538
 5 Soknacki, David      314
 6 Stintz, Karen        244
 7 Goldkind, Ari         47
 8 Underhill, Richard    41
 9 Thomson, Sarah        40
10 Di Paola, Rocco       18
# i 17 more rows
```

7. Repeat 6 but without contributions from the candidates themselves.

```
df_not_to_self <- df |>
  filter(contributors_name!=candidate)


df_not_to_self |>
  group_by(candidate) |>
  summarise(total_contr = sum(contribution_amount)) |>
  arrange(-total_contr)
```

```
# A tibble: 17 x 2
   candidate          total_contr
   <chr>                    <dbl>
 1 Tory, John            2765369.
 2 Chow, Olivia          1634766.
 3 Ford, Doug             331173.
 4 Stintz, Karen          242805
 5 Ford, Rob              174510.
 6 Soknacki, David        132431
 7 Thomson, Sarah          27702.
 8 Goldkind, Ari           17501
 9 Underhill, Richard      15660
10 Di Paola, Rocco         15126
11 Ritch, Carlie            5660
12 Sniedzins, Erwin         5600
13 Gardner, Norman          3000
14 Baskin, Morgan           1550
15 Billard, Jeff            1486.
16 Tiwari, Ramnarine        1000
17 Lam, Steven               300
```

```r
# mean contributions
df_not_to_self |>
  group_by(candidate) |>
  summarise(mean_contr = mean(contribution_amount)) |>
  arrange(-mean_contr)
```

```
# A tibble: 17 x 2
   candidate          mean_contr
   <chr>                   <dbl>
 1 Ritch, Carlie           1887.
 2 Sniedzins, Erwin        1867.
 3 Tory, John              1063.
 4 Gardner, Norman         1000
 5 Tiwari, Ramnarine       1000
 6 Stintz, Karen            995.
 7 Di Paola, Rocco          890.
 8 Thomson, Sarah           729.
 9 Ford, Doug               545.
10 Billard, Jeff            496.
11 Soknacki, David          422.
```

```
12 Underhill, Richard       382.
13 Goldkind, Ari            380.
14 Ford, Rob                329.
15 Lam, Steven              300
16 Chow, Olivia             286.
17 Baskin, Morgan           194.
```

```
# number
df_not_to_self |>
  group_by(candidate) |>
  tally() |>
  arrange(-n)
```

```
# A tibble: 17 x 2
   candidate              n
   <chr>              <int>
 1 Chow, Olivia        5706
 2 Tory, John          2601
 3 Ford, Doug           608
 4 Ford, Rob            531
 5 Soknacki, David      314
 6 Stintz, Karen        244
 7 Goldkind, Ari         46
 8 Underhill, Richard    41
 9 Thomson, Sarah        38
10 Di Paola, Rocco       17
11 Baskin, Morgan         8
12 Billard, Jeff          3
13 Gardner, Norman        3
14 Ritch, Carlie          3
15 Sniedzins, Erwin       3
16 Lam, Steven            1
17 Tiwari, Ramnarine      1
```

8. How many contributors gave money to more than one candidate?

```
df |>
  group_by(contributors_name) |>
  distinct(candidate) |>
  tally() |>
  filter(n>1) |>
```

```
  nrow()
```

```
[1] 184
```

```
# OR

df |>
  group_by(contributors_name, candidate) |>
  tally() |>
  group_by(contributors_name) |>
  tally() |>
  filter(n>1) |> nrow()
```

```
[1] 184
```