Data Visualization in R with ggplot2

The Structure of ggplot2 (Part 1)

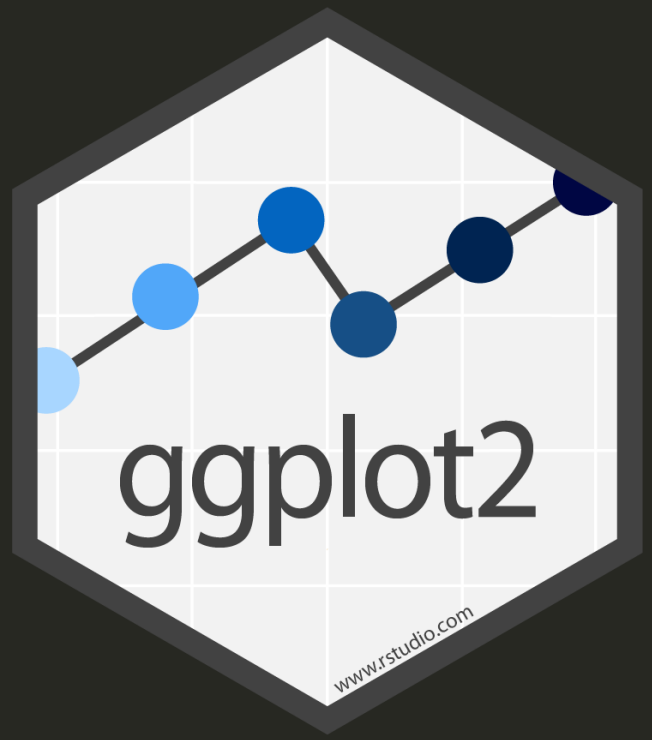
Cédric Scherer

Physalia Courses | November 9-13 2020

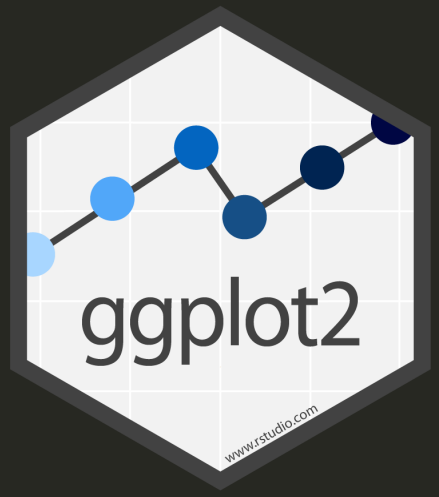
Photo by Richard Strozynski

Part 1

A Basic ggplot



The ggplot2 Package



`ggplot2` is a system for declaratively creating graphics, based on "The Grammar of Graphics" (Wilkinson, 2005).

You provide the data, tell **`ggplot2`** how to map variables to aesthetics, what graphical primitives to use, and it takes care of the details.

ggplot2 package description

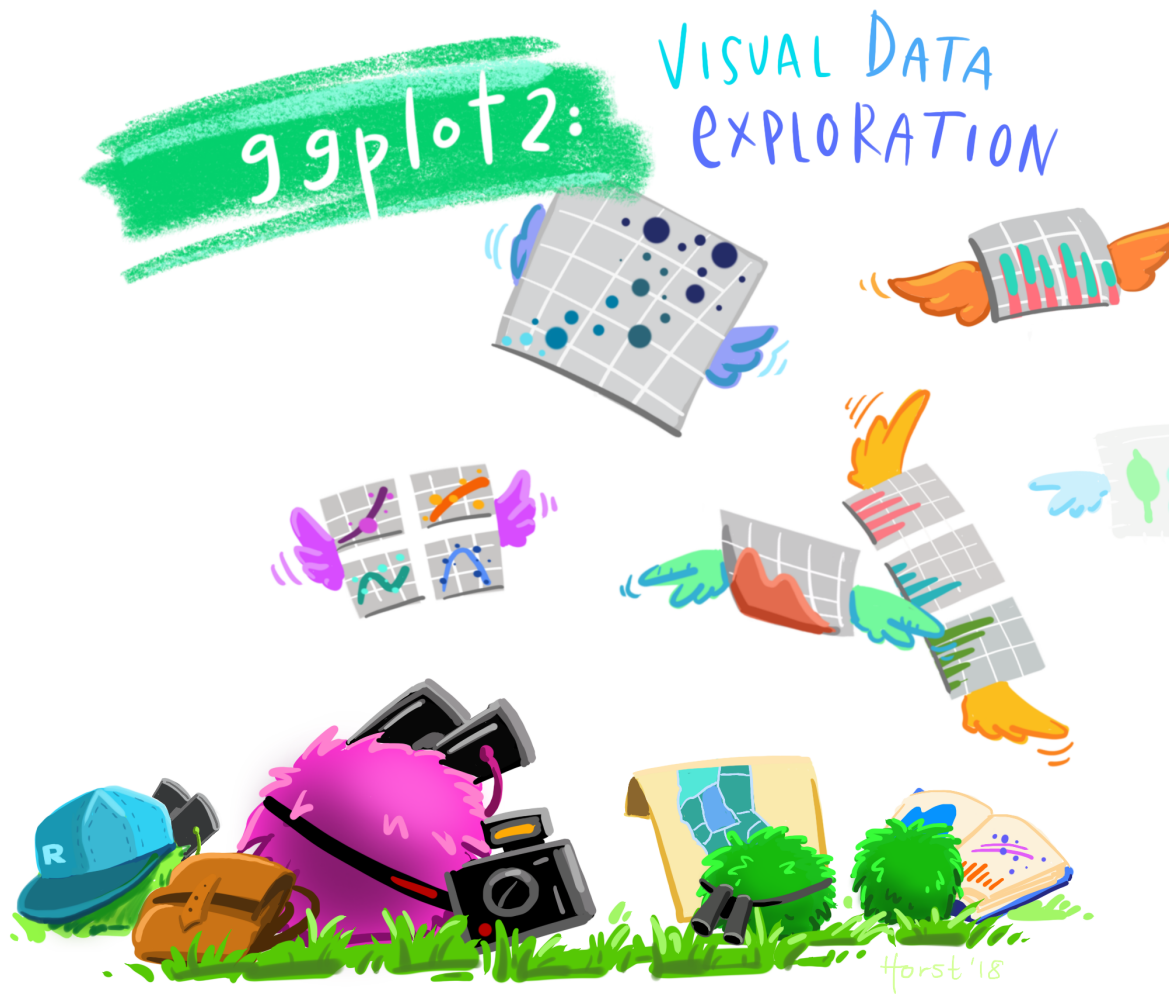
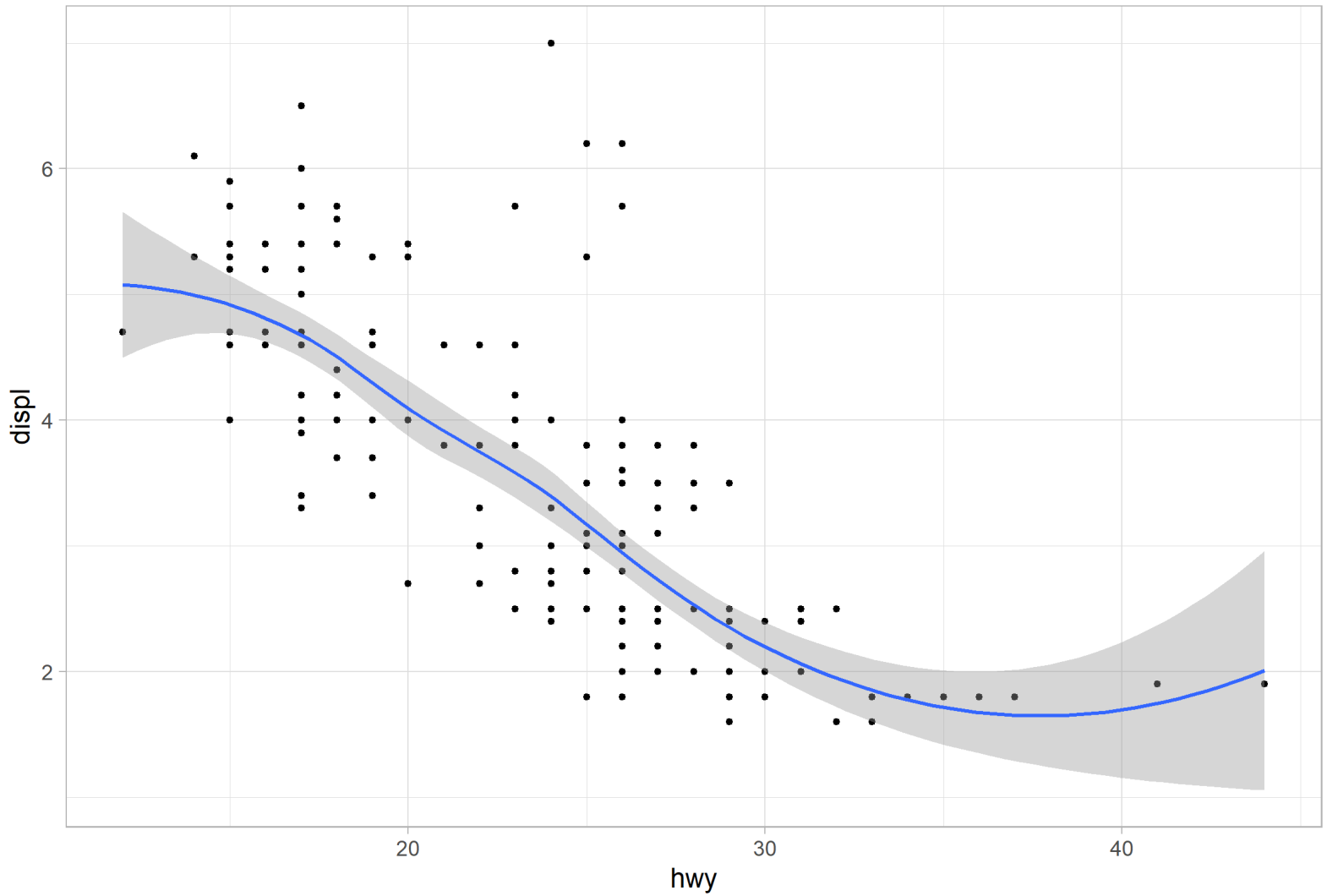


Illustration by Allison Horst (github.com/allisonhorst/stats-illustrations)

Advantages of `ggplot2`

- consistent underlying grammar of graphics (Wilkinson, 2005)
- very flexible, layered plot specification
- theme system for polishing plot appearance
- active and helpful community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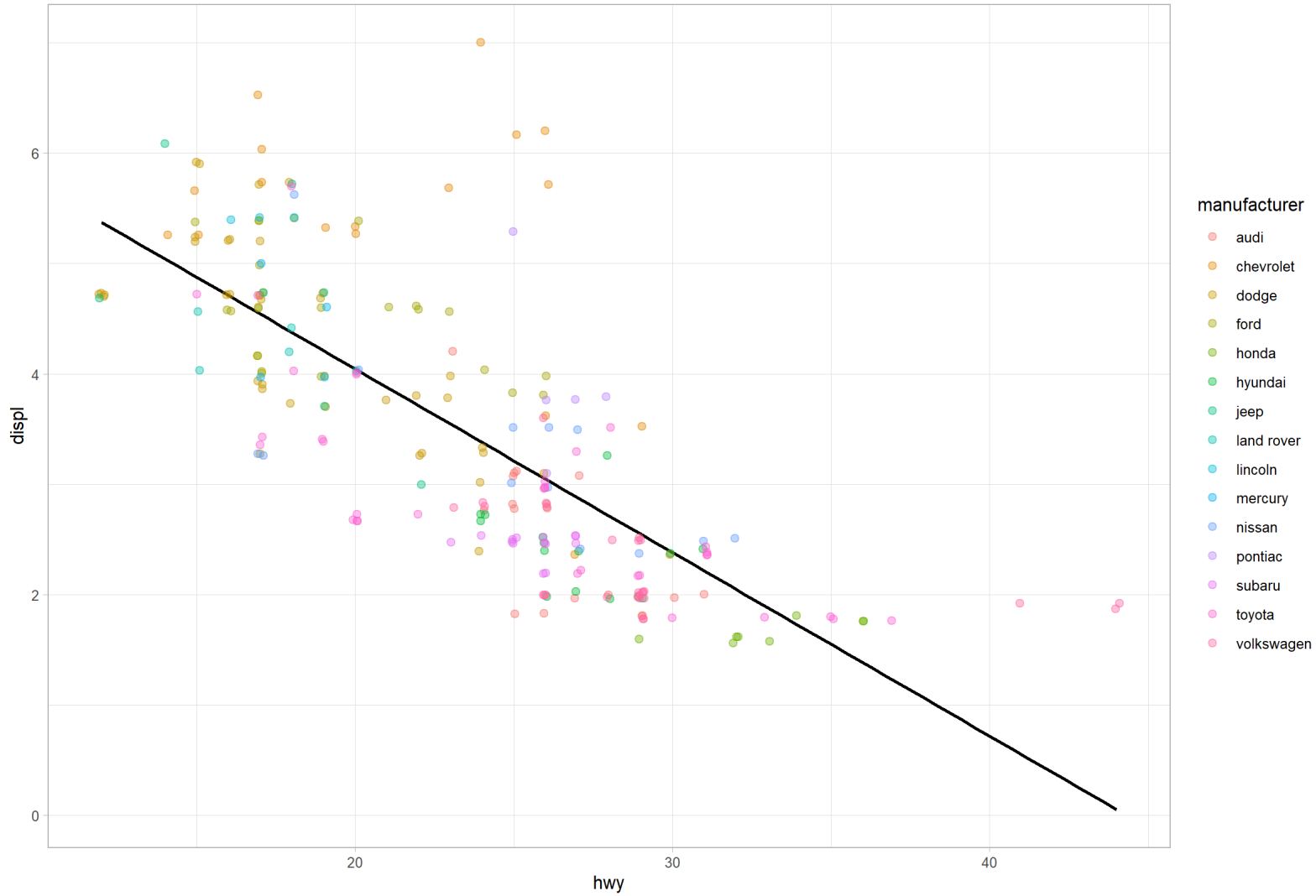
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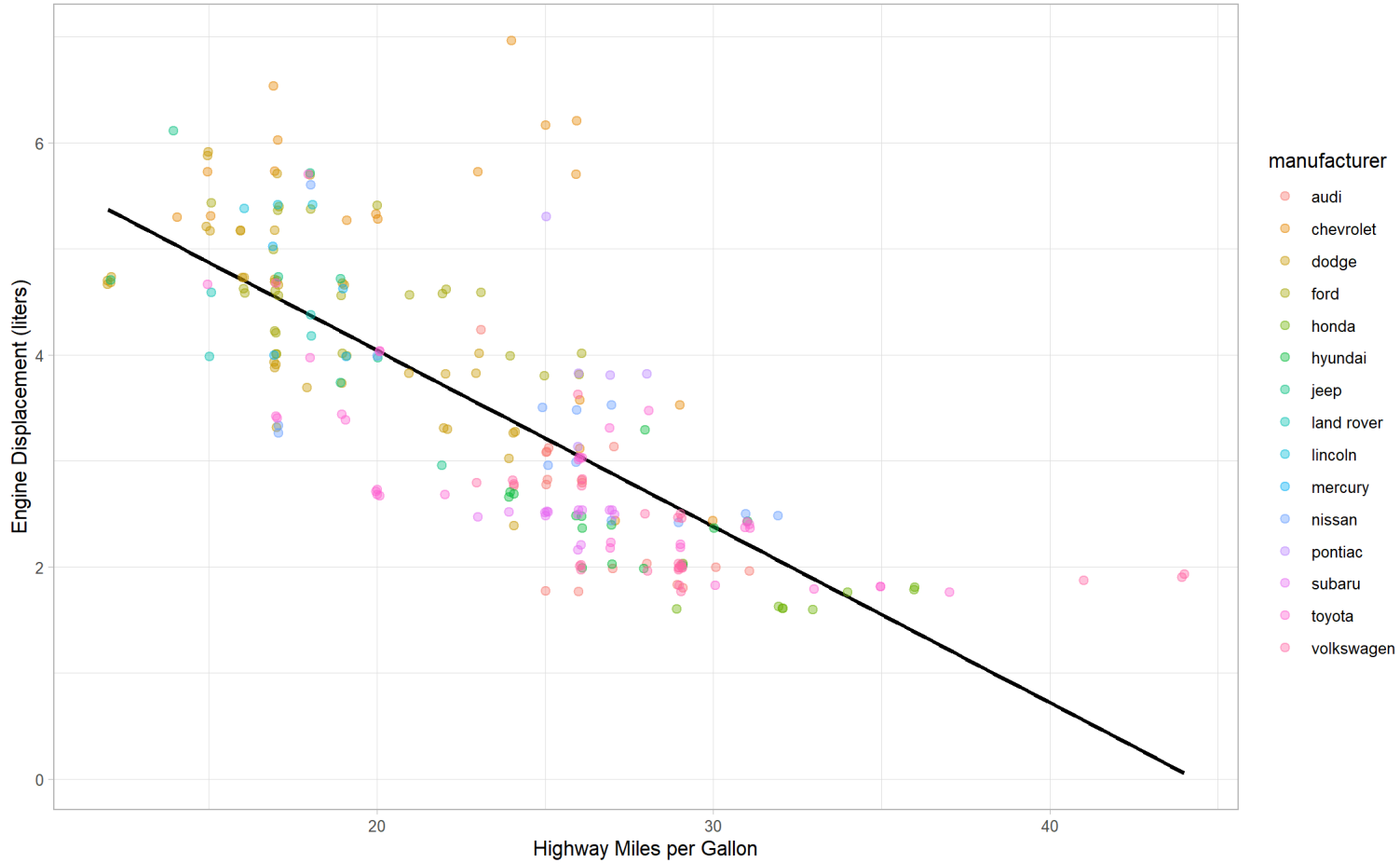
land rover
lincoln
mercury
nissan
pontiac
subaru
toyota
volkswagen

Fig 1:

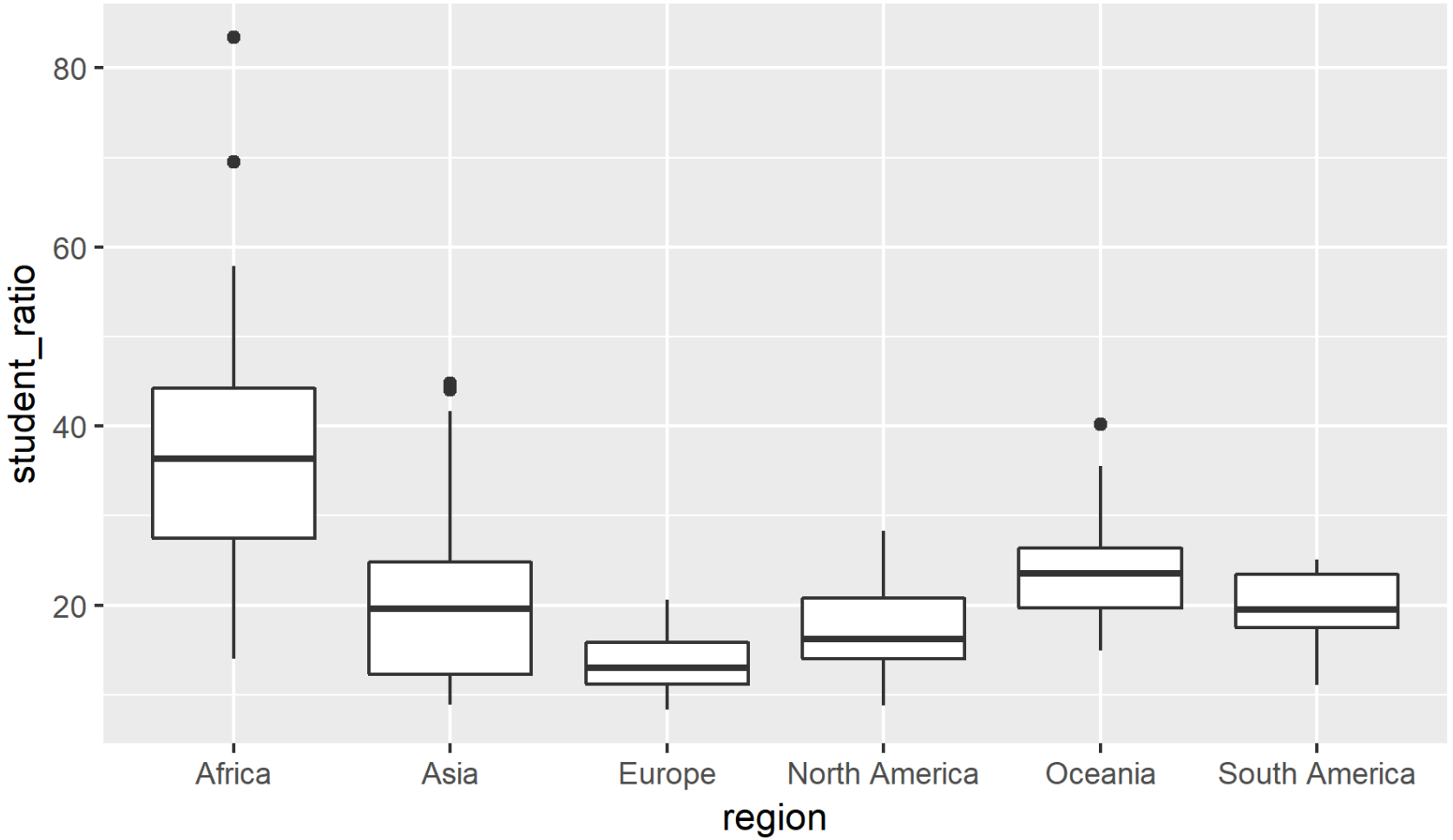
Weight and displacement by manufacturers of 38 popular models of cars

Simple linear regression of engine displacement (in liters) versus highway miles per gallon (MPG) for popular models of cars from 1999 to 2008.



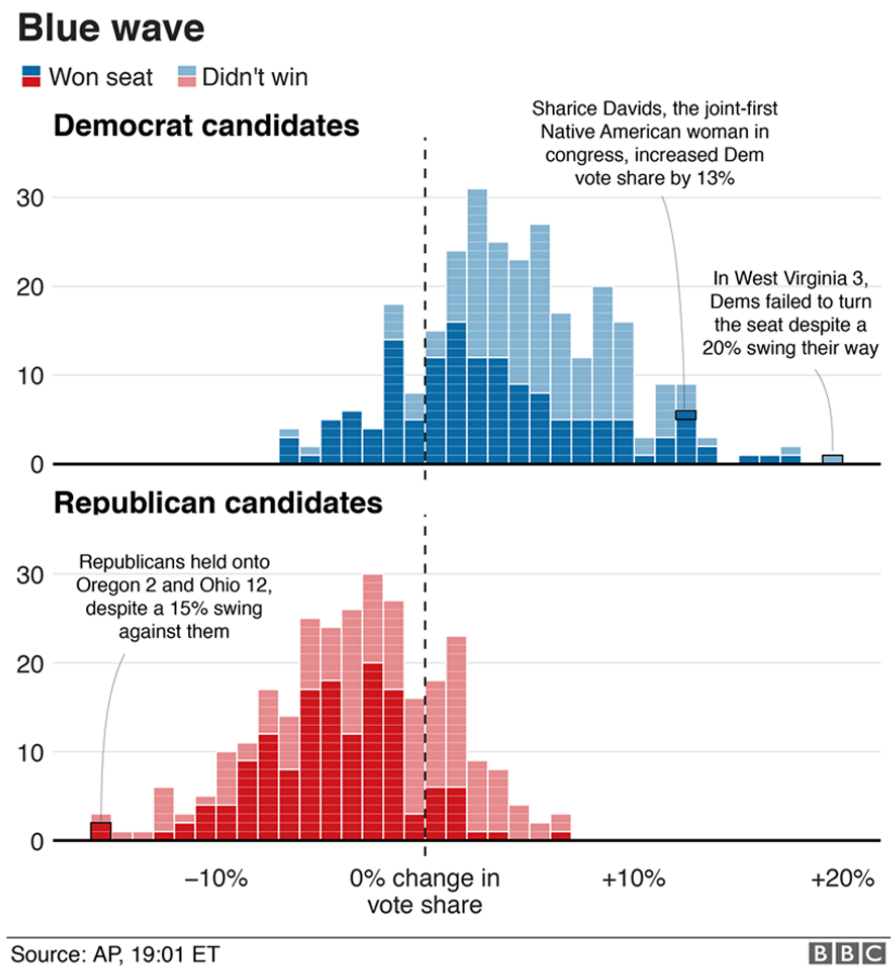
Data: EPA (www.fueleconomy.gov)

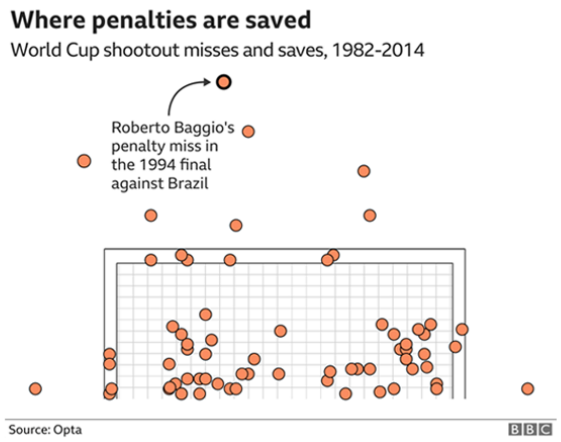
The Evolution of a ggplot

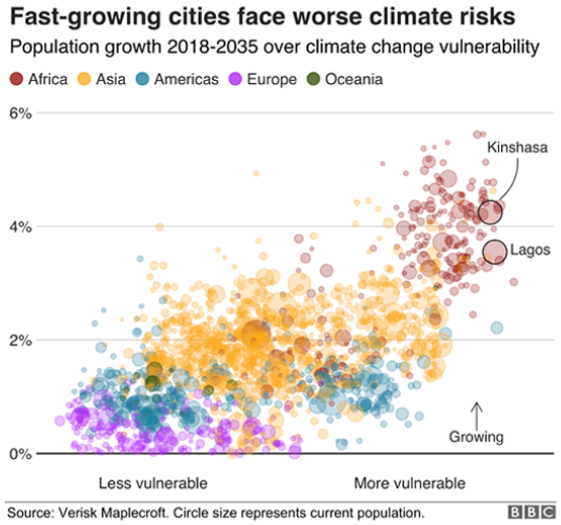


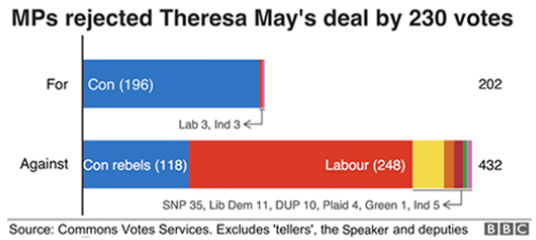
Data: UNESCO Institute for Statistics
Visualization by Cédric Scherer

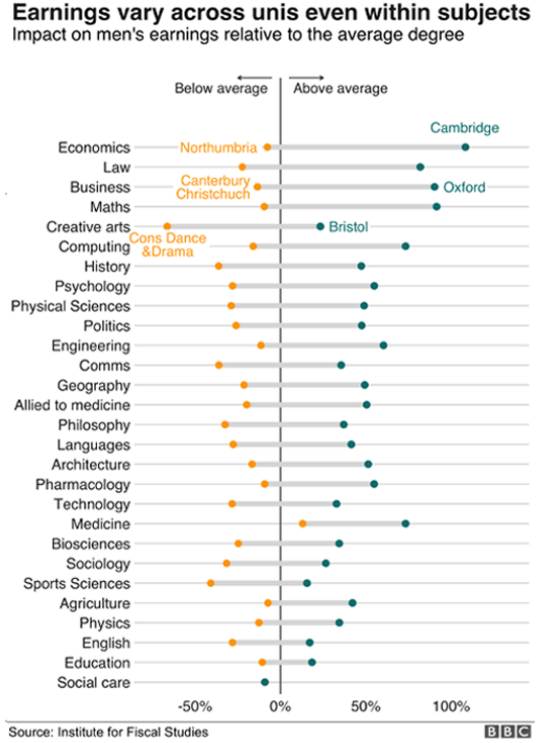
The ggplot2 Showcase









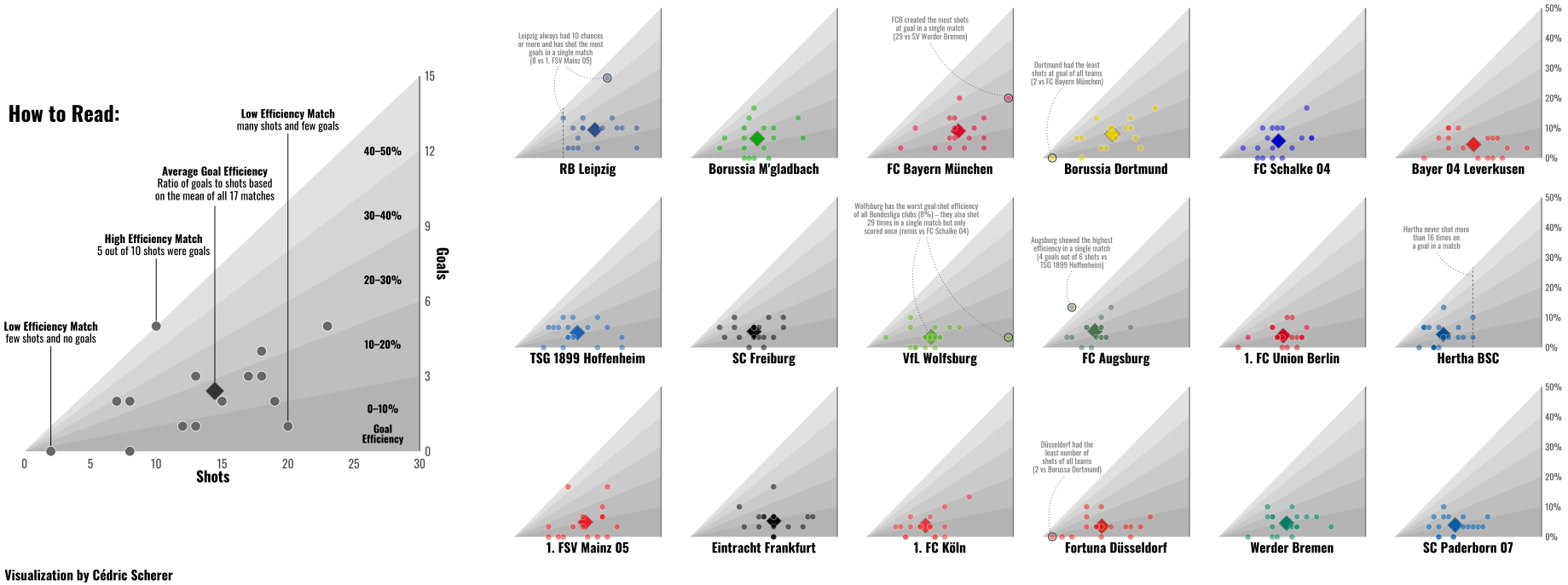


Collection of BBC Graphics

(modified from bbc.github.io/rcookbook)

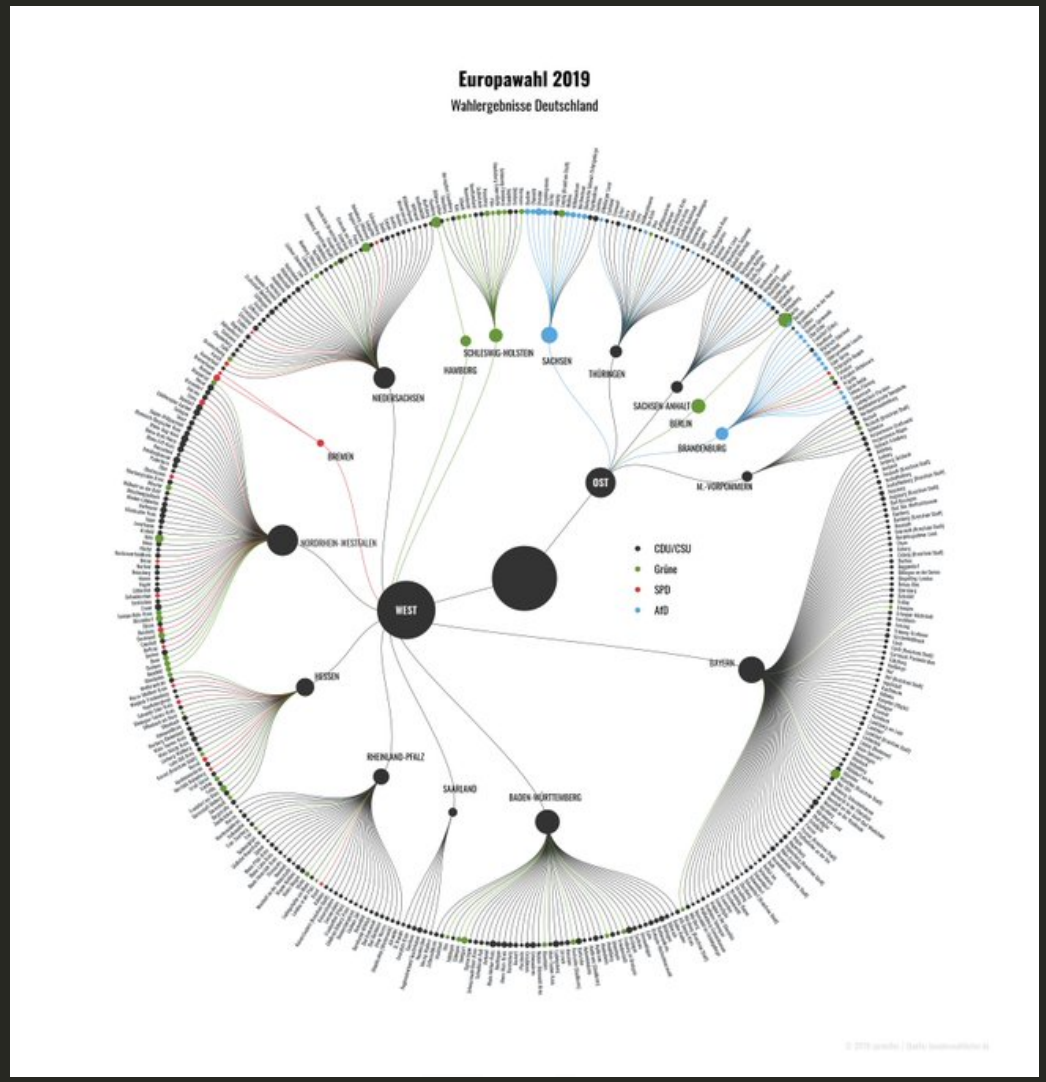
RB Leipzig and Borussia Dortmund Make the Most of Their Opportunities

The small multiples show each club's goal:shot efficiency in the first season 2019/2020 of the 1. Bundesliga. However, while Borussia Dortmund also had very bad matches with only 2 chances, the Autumn champion RB Leipzig always scored minimum one goal and shot at least ten times on the opponent's goal in all 17 matches! Of all Bundesliga clubs, RB Leipzig also shot the most goals – 8 against Mainz.



Visualization by Cédric Scherer

Contribution to #SWDchallenge

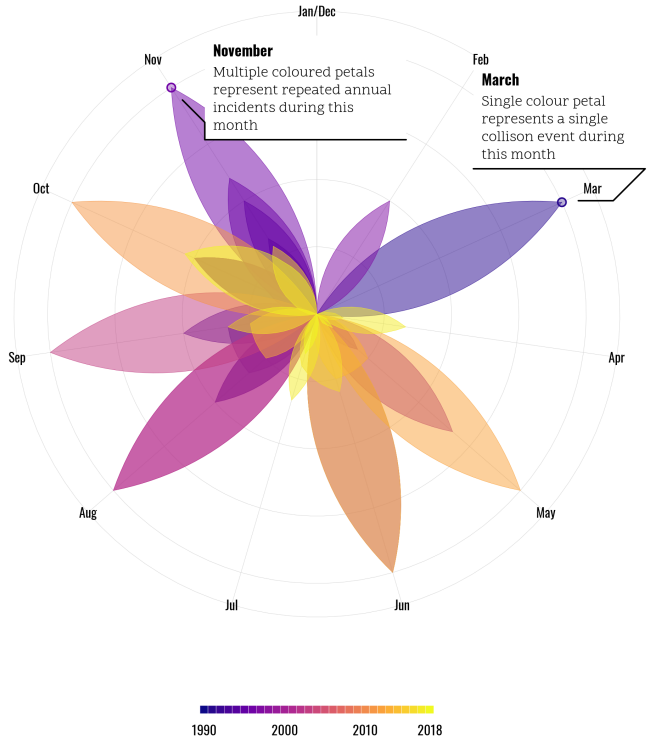


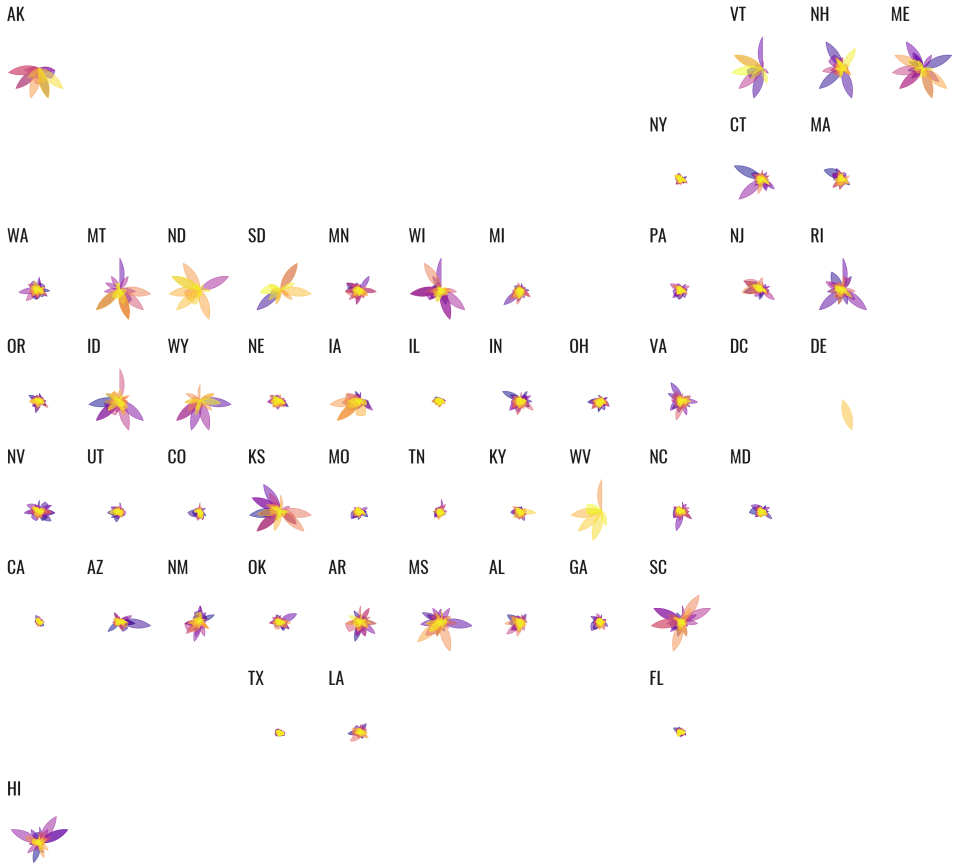
European Elections by Torsten Sprenger

(twitter.com/spren9er/status/1138000009306234880)

Seasonality of Wildlife-Aircraft Collisions by State

Presented below is a petal chart of of wildlife collisions with aircraft, with an inset legend showing assisting interpretation. Wildlife collisions by state are presented as small multiples, geographically arranged. Smaller compact flowers illustrate states with collisions occuring year round, while the bigger flowers tend to see single or concentrated spikes of collision activity. Flowers with diverse colours indicate repeated annual collisons while the single-hued flowers illustrate more sparse or isolated annual events.





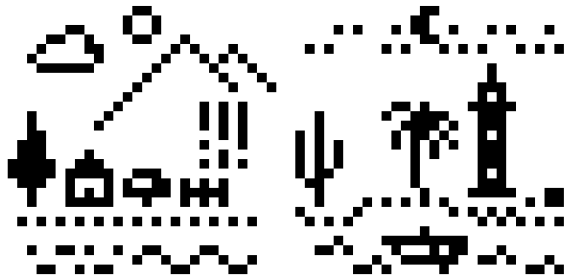
Data: FAA Wildlife Strike Database | Graphic: @jakekaupp

#TidyTuesday Contribution by Jake Kaupp

(github.com/jkaupp/tidytuesdays)

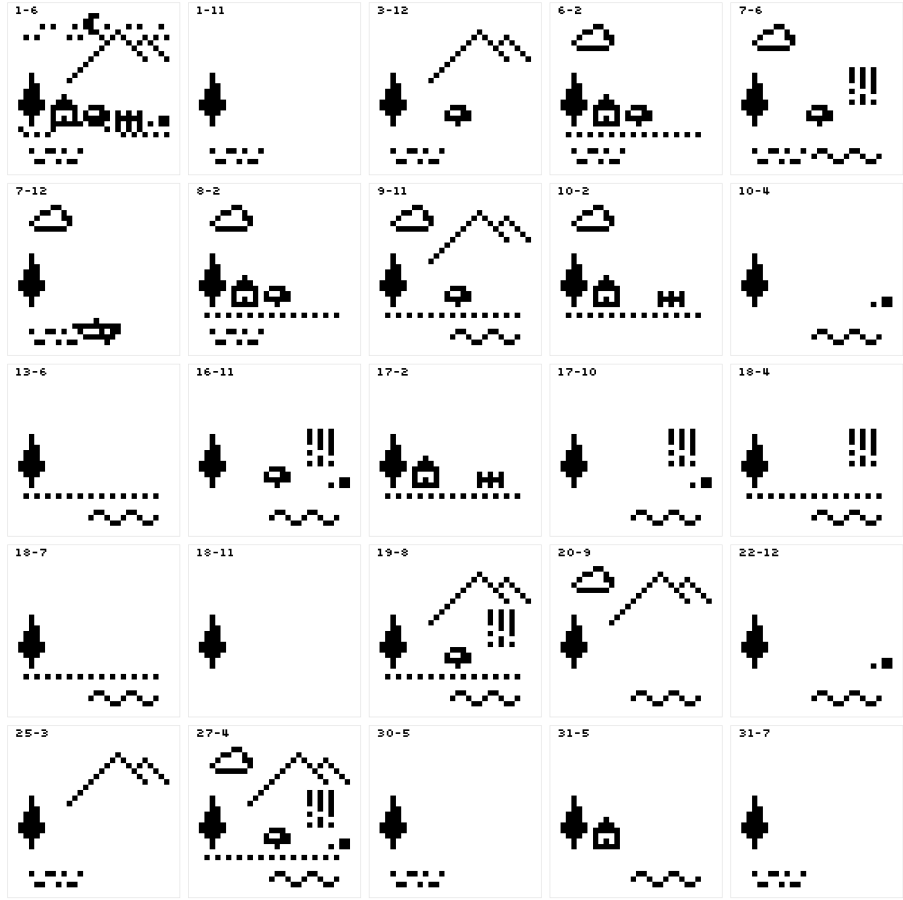
BOB ROSS - PAINTING BY THE ELEMENTS

GRAPHIC REPRESENTATIONS OF BOB ROSS' PAINTINGS WITH ELEMENTS IDENTIFIED IN THEM BY WALT HICKEY (FIVETHIRTYEIGHT). EACH ELEMENT REPRESENTS ONE OR MORE OCCURRENCES IN THE PAINTING. ONLY THE ELEMENTS IN THE LEGEND BELOW ARE DRAWN. TO THE RIGHT THERE ARE 25 RANDOM PAINTINGS THAT BOB PAINTED IN 'THE JOY OF PAINTING', WITH THE SEASON AND EPISODE NUMBER.



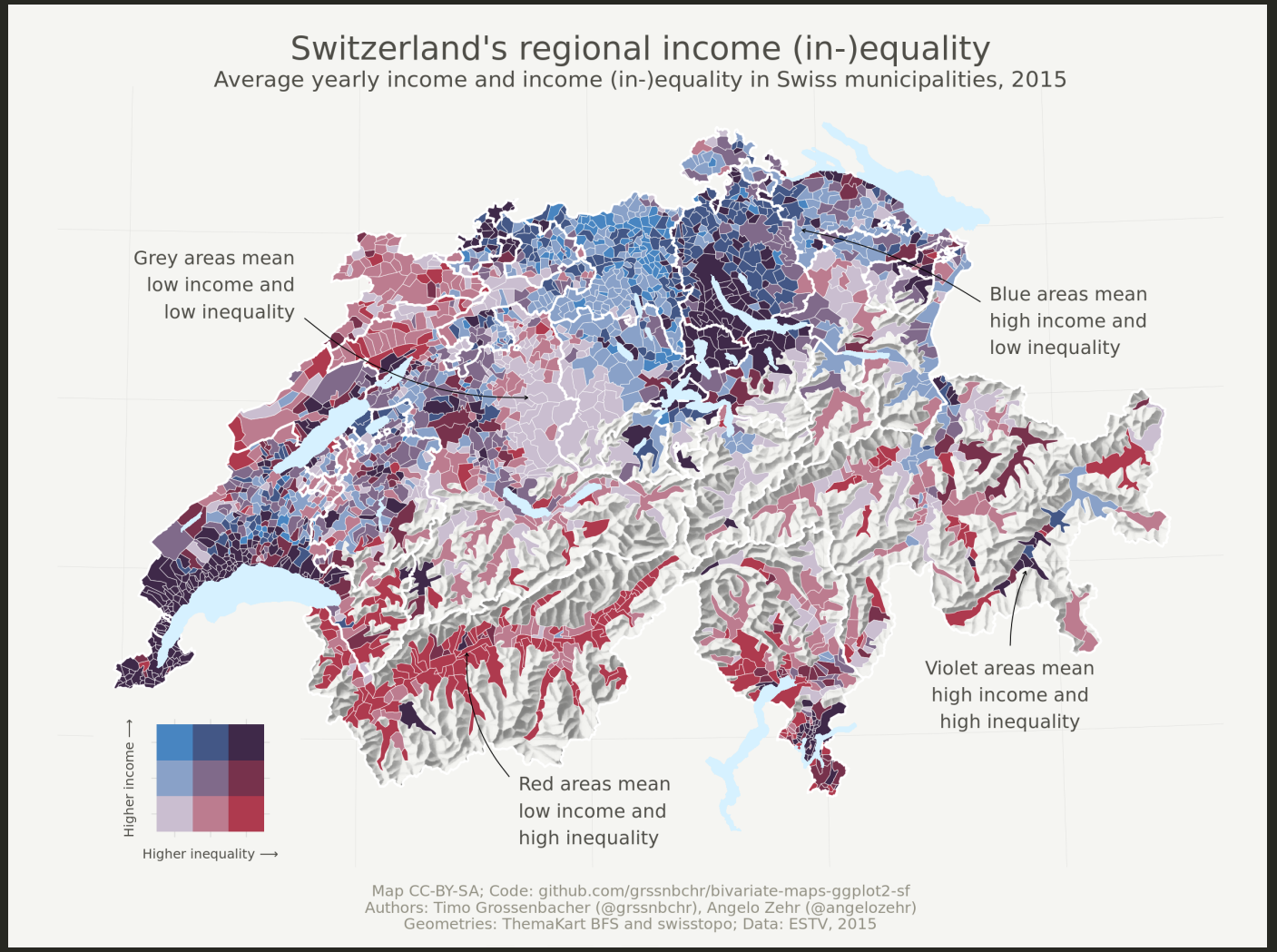
CLOUD (CIRRUS, CUMULUS), MOON, NIGHT, PALM TREE, SUN, MOUNTAIN (HILLS), CACTUS, LIGHTHOUSE, ROCKS, TREE (DECIDUOUS, CONIFER), BEACH, BOAT, CABIN (BARN, BUILDING, FARM), SEA (OCEAN, WAVES), BUSHES, FENCE, GRASS, WATERFALL, LAKE, RIVER

SOURCE: FIVETHIRTYEIGHT | PLOT: GEORGIOS KARAMANIS



#TidyTuesday Contribution by Georgos Karamanis

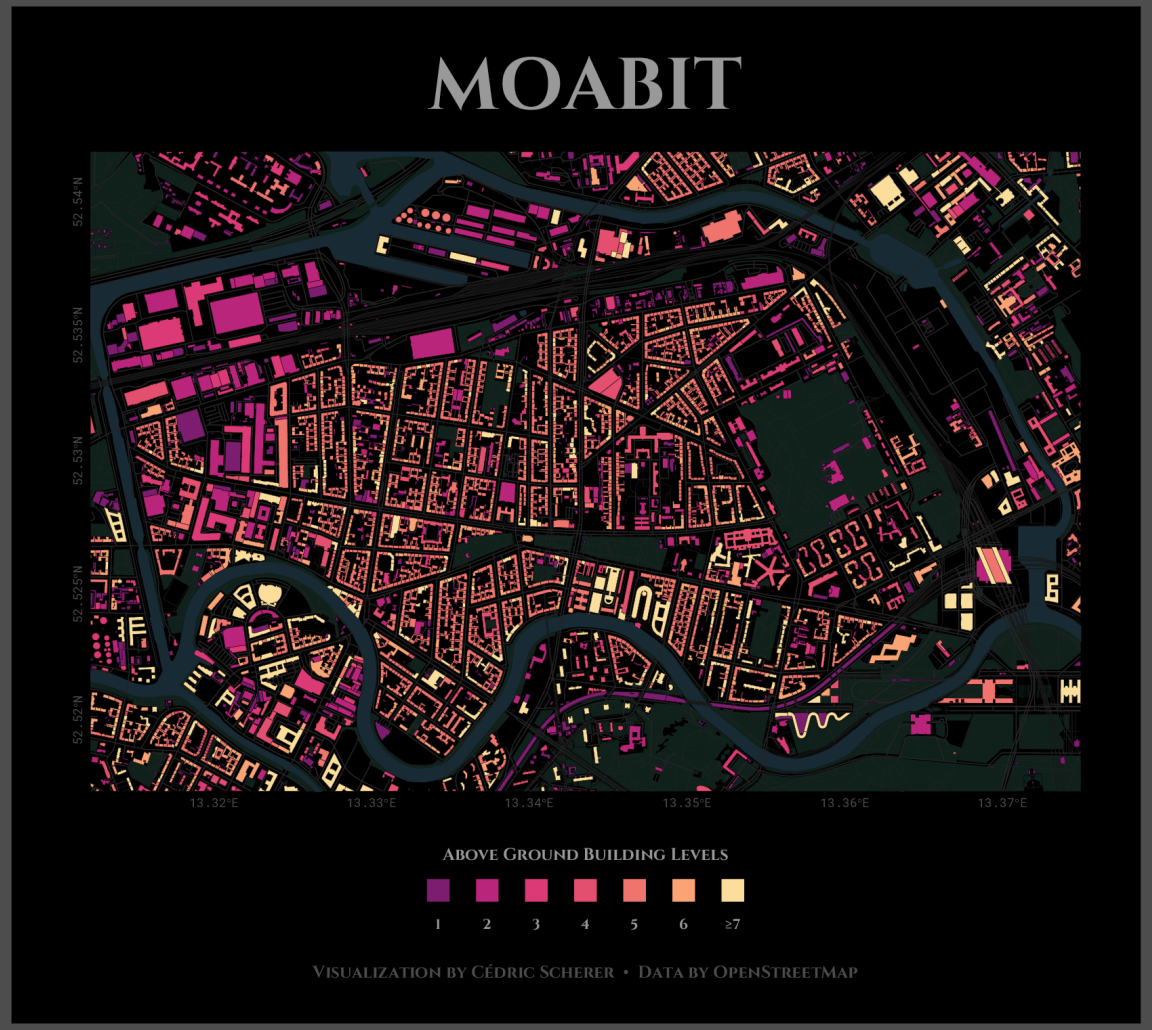
(github.com/gkaramanis/tidytuesday)



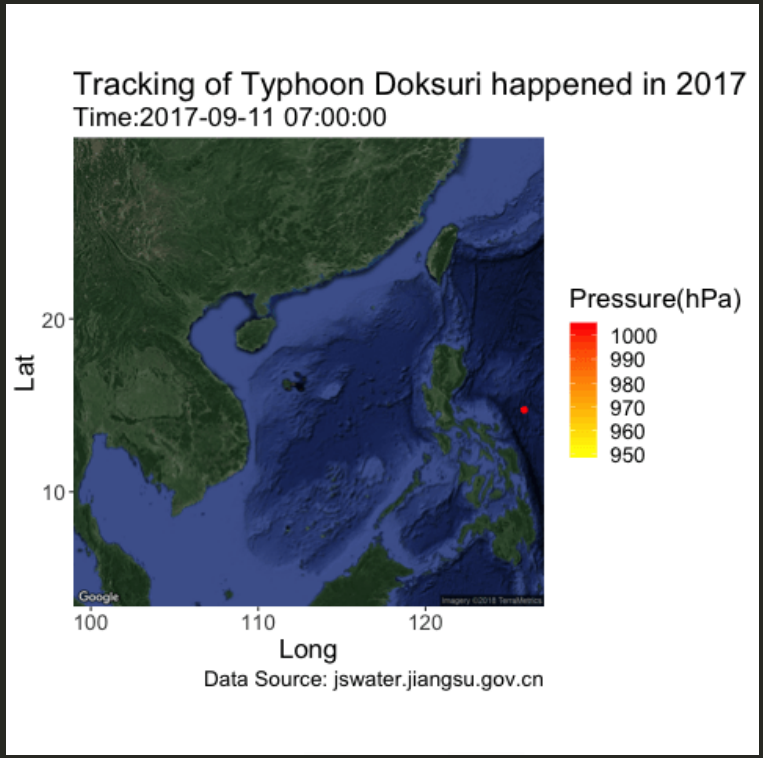
Bivariate Map by Timo Gossenbacher

(timogrossenbacher.ch/2019/04/bivariate-maps-with-ggplot2-and-sf)

Contribution to the #30DayMapChallenge

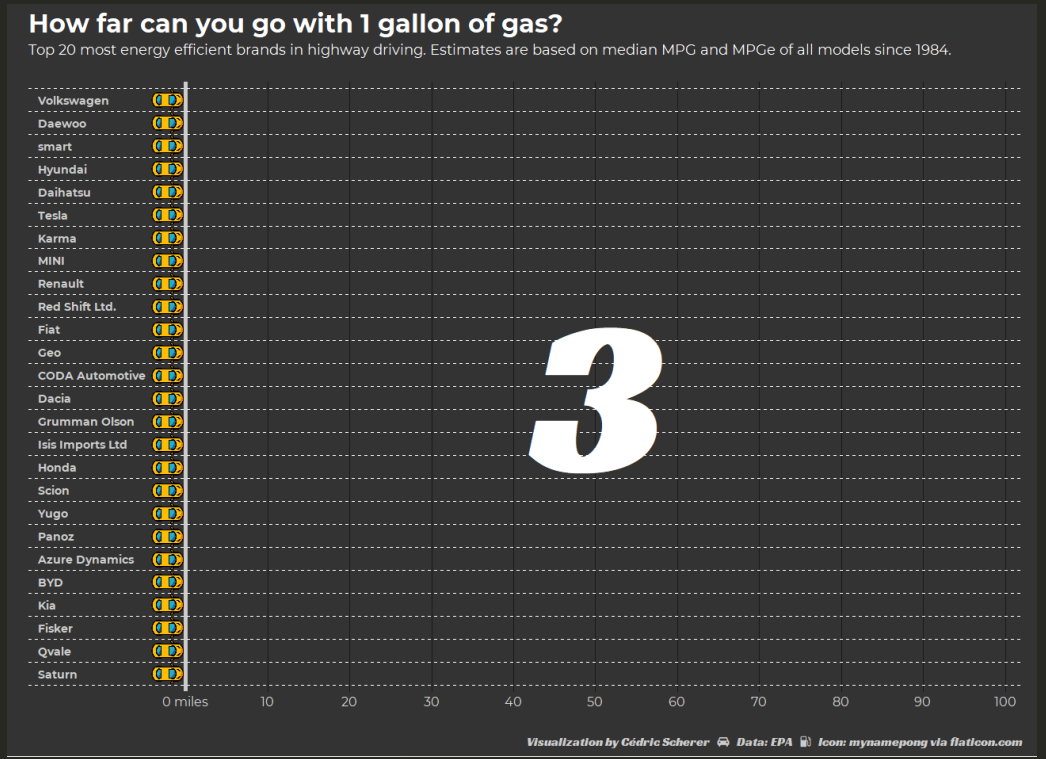


Contribution to the #30DayMapChallenge



Example of the {gganimate} Package

(github.com/thomasp85/gganimate/wiki)



Contribution to #TidyTuesday

The Setup

The package

ggplot2 is a **data visualization package** for the programming language **R** created by Hadley Wickham in 2005.

```
install.packages("ggplot2")
library(ggplot2)
```

ggplot2 is part of the **tidyverse**, a set of packages that work in harmony to manipulate and explore data.

```
install.packages("tidyverse")
library(tidyverse)
```

Source: dicook.org/files/rstudio/#3

The package

We are going to use the development version of **ggplot2**.

You can install the most recent version on GitHub using the package **devtools**:

```
install.packages("devtools")
devtools::install_github("tidyverse/ggplot2")
```

The data

We use data from the *National Morbidity and Mortality Air Pollution Study* (NMMAPS), filtered for the city of **Chicago** and the timespan **from January 1997 to December 2000**.

```
chic <- read_csv(
  "https://raw.githubusercontent.com/Z3tt/ggplot-courses/master/data/chicago-nmmaps.cs
  col_types = cols(season = col_factor(), year = col_factor())
)
tibble::glimpse(chic)
## Rows: 1,461
## Columns: 10
## $ city     <chr> "chic", "chic", "chic", "chic", "chic", "chic", "chic", "c...
## $ date     <date> 1997-01-01, 1997-01-02, 1997-01-03, 1997-01-04, 1997-01-0...
## $ death    <dbl> 137, 123, 127, 146, 102, 127, 116, 118, 148, 121, 110, 127...
## $ temp     <dbl> 36.0, 45.0, 40.0, 51.5, 27.0, 17.0, 16.0, 19.0, 26.0, 16.0...
## $ dewpoint <dbl> 37.500, 47.250, 38.000, 45.500, 11.250, 5.750, 7.000, 17.7...
## $ pm10     <dbl> 13.052268, 41.948600, 27.041751, 25.072573, 15.343121, 9.3...
## $ o3       <dbl> 5.659256, 5.525417, 6.288548, 7.537758, 20.760798, 14.9408...
## $ time     <dbl> 3654, 3655, 3656, 3657, 3658, 3659, 3660, 3661, 3662, 3663...
## $ season   <fct> Winter, Winter, Winter, Winter, Winter, Winter, Winter, Wi...
## $ year     <fct> 1997, 1997, 1997, 1997, 1997, 1997, 1997, 1997, 1997, 1997...
```

The Structure of `ggplot2`

"The Grammar of Graphics"

The Structure of `ggplot2`

Layer	Function	Explanation
Data	`ggplot(data)`	The raw data that you want to visualise.
Aesthetics	`aes()`	Aesthetic mappings of the geometric and statistical objects.
Layers	`geom_*()` and `stat_*()`	The geometric shapes and statistical summaries representing the data.

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Scales	`scale_*()`	Maps between the data and the aesthetic dimensions.
Coordinate System	`coord_*()`	Maps data into the plane of the data rectangle.
Facets	`facet_*()`	The arrangement of the data into a grid of plots.
Visual Themes	`theme()` and `theme_*()`	The overall visual defaults of a plot.

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Facets	`facet_*()`	The arrangement of the data into a grid of plots.
Visual Themes	`theme()` and `theme_*()`	The overall visual defaults of a plot.
Annotations	`annotate()`	Add additional labels, geometries or images to a plot.

Data

`ggplot(data)`

ggplot2::ggplot()

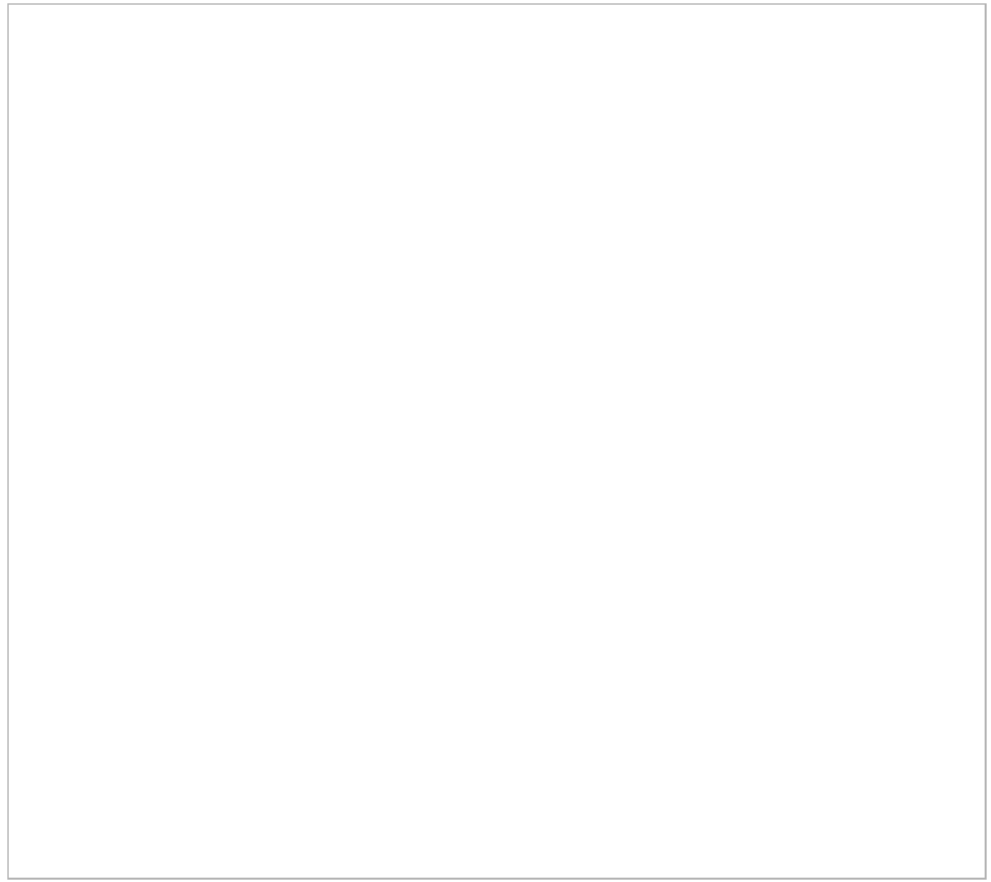
```
ggplot
## function (data = NULL, mapping = aes(), ..., environment = parent.frame())
## {
##     UseMethod("ggplot")
## }
## <bytecode: 0x0000000014b564d0>
## <environment: namespace:ggplot2>
```

ggplot(data)

We need to specify data in the `ggplot()` call:

```
ggplot(data = chic)
```

There is only an empty panel because `ggplot2` doesn't know **what** of the data it should plot.

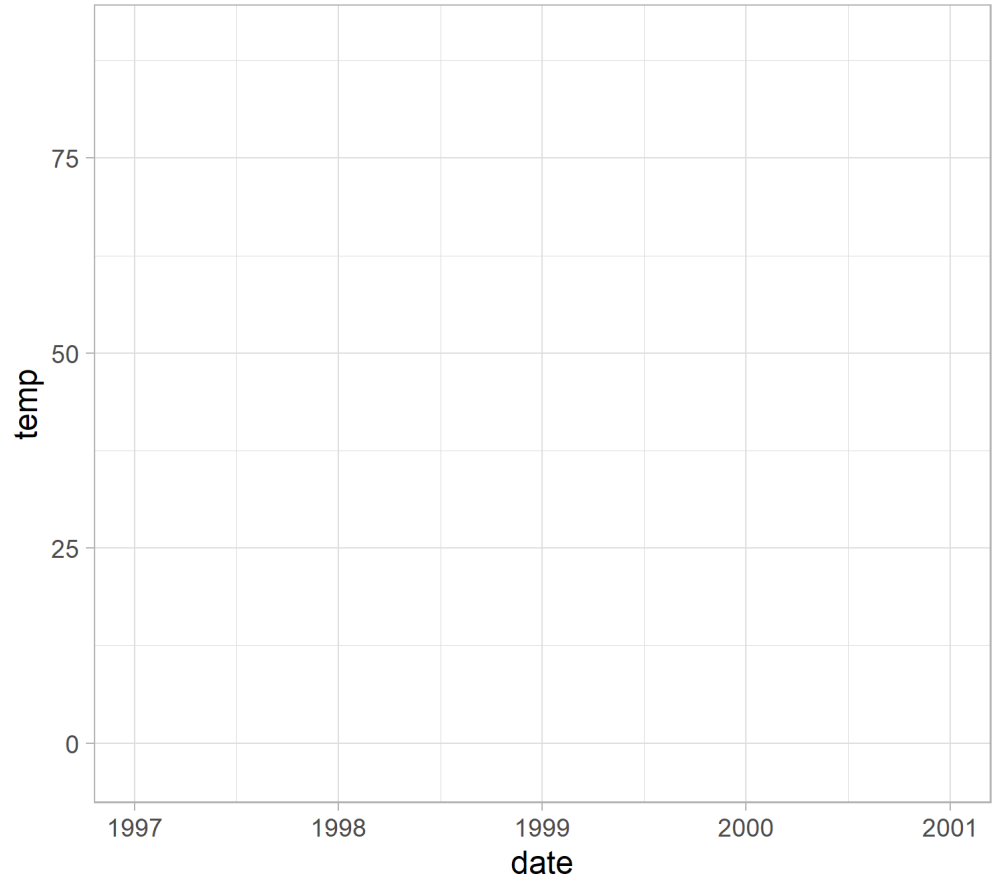


ggplot(data, aes(x, y))

We need to specify data and the two variables we want to plot as **aes**thetics of the **ggplot()** call:

```
ggplot(data = chic,
       mapping =
         aes(
          x = date,
          y = temp
         )
      )
```

There is only an empty panel because **ggplot2** doesn't know **how** it should plot the data.

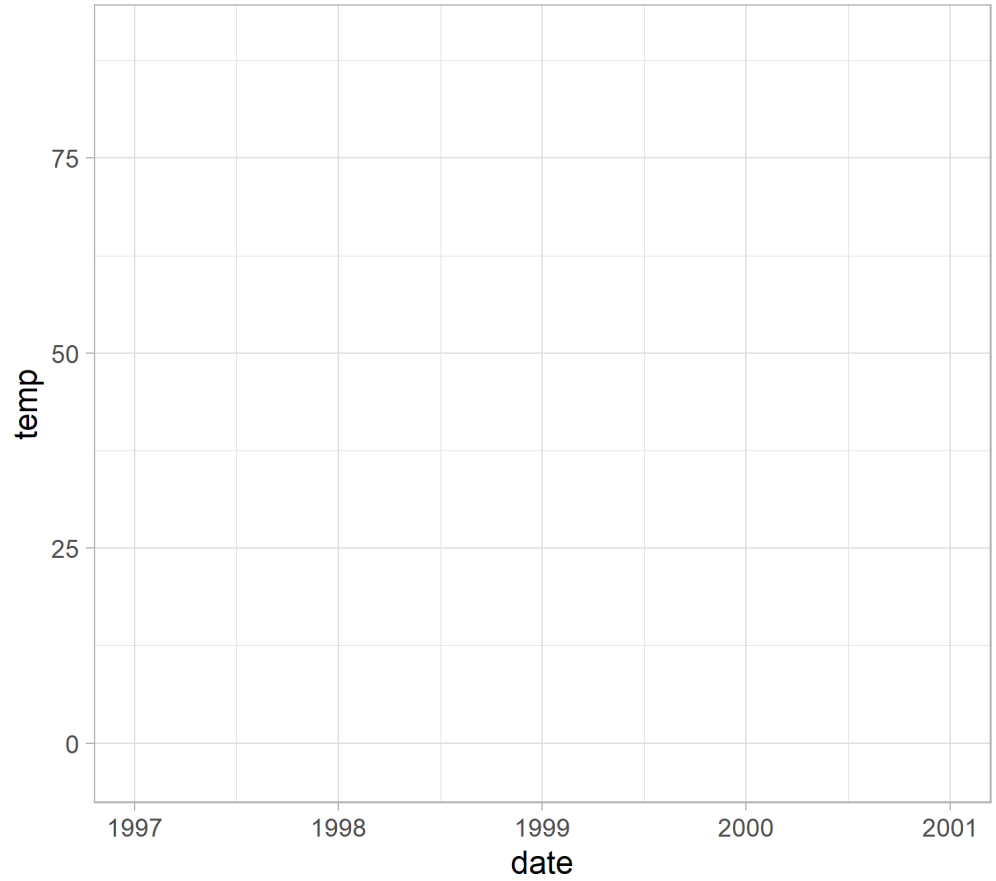


`ggplot(data, aes(x, y))`

We need to specify data and the two variables we want to plot as `aes`thetics of the `ggplot()` call:

Thanks to implicit matching of arguments in `ggplot(data, mapping)` and `aes(x, y)`, we can also write:

```
ggplot(chic, aes(date, temp))
```



ggplot(data) + aes(x, y)

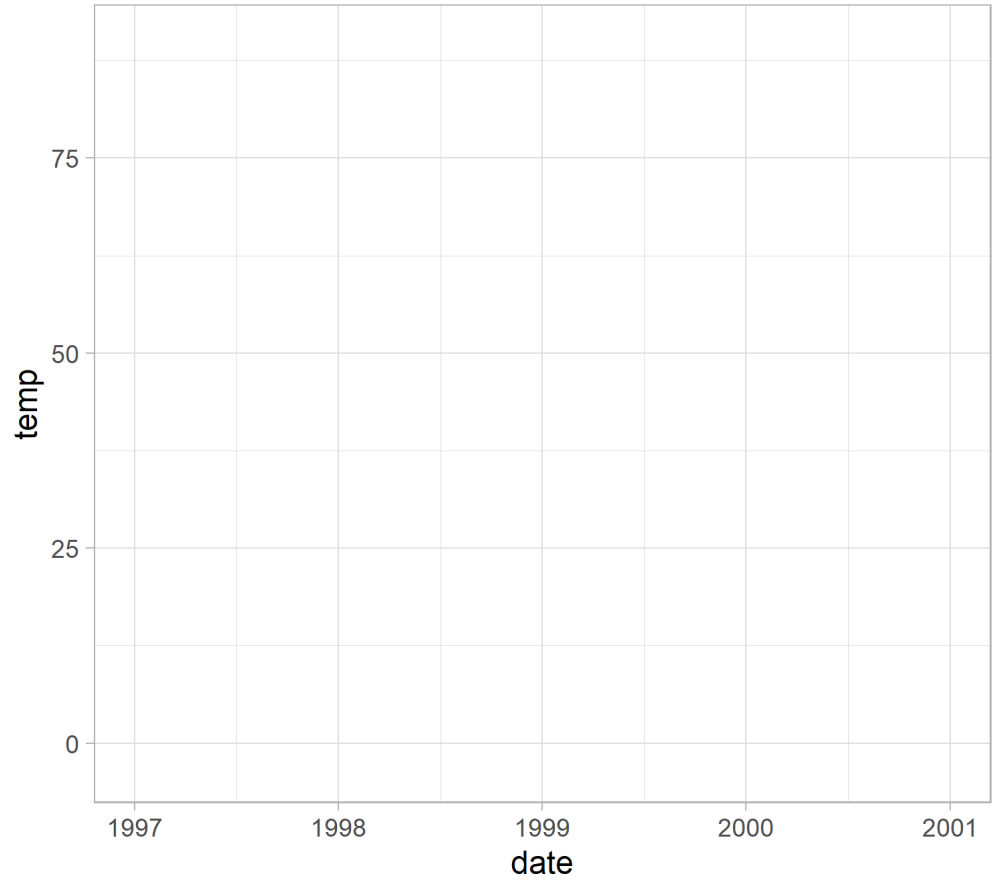
We need to specify data and the two variables we want to plot as **aes**thetics of the **ggplot()** call:

Since almost every **ggplot()** takes the same arguments (**data, mapping = aes(x, y)**), we can also write:

```
ggplot(chic, aes(date, temp))
```

... or add the **aes**thetics outside the **ggplot()** function:

```
ggplot(chic) +
  aes(date, temp)
```



Layers

`geom_*()` and `stat_*()`

`geom_*()` and `stat_*()`

By adding one or multiple layers we can tell `ggplot2` *how* to represent the data.

There are lots of build-in geometric elements (`geom's`) and statistical transformations (`stat's`):

Adapted from ggplot2.tidyverse.org/reference

... and several more in extension packages, e.g. `{ggforce}`, `{ggalt}`, `{ggridges}`, `{ggrepel}`, `{ggcorrplot}`, `{ggraph}`, `{ggdendro}` & `{ggalluvial}`.

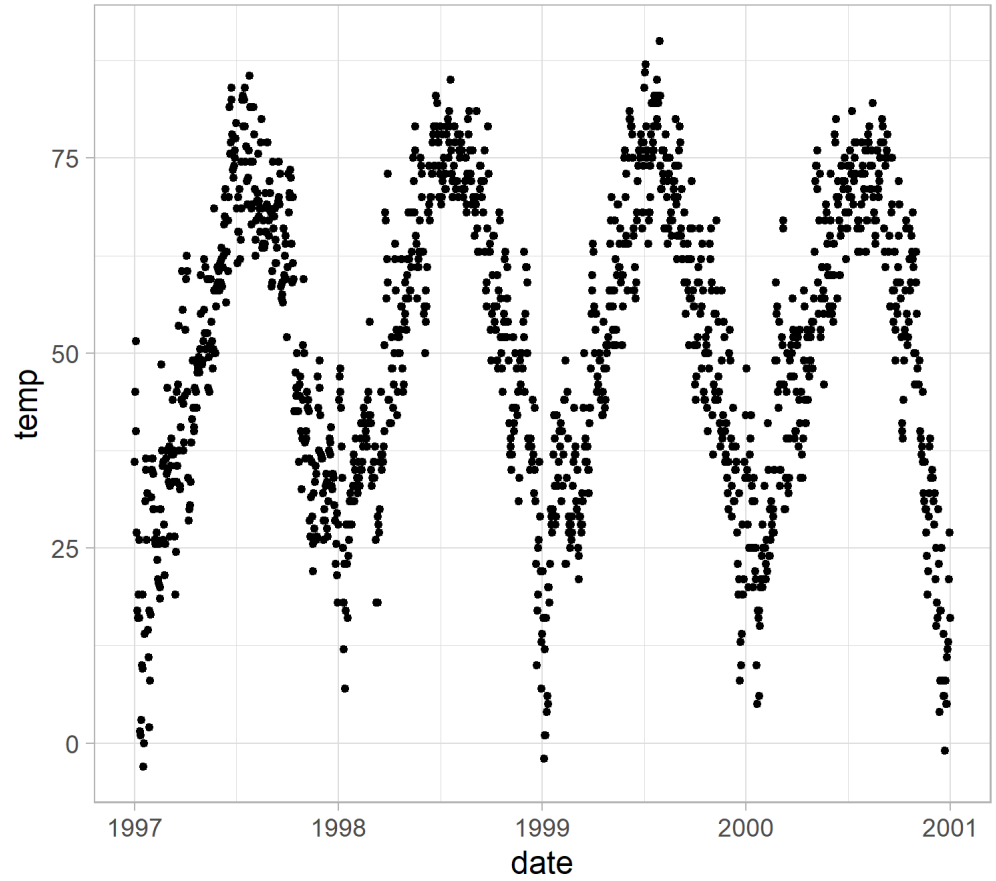
2. Layers

Geometric Layers: `geom_*()`

geom_point()

We can tell **ggplot2** to represent the data for example as a **scatter plot**:

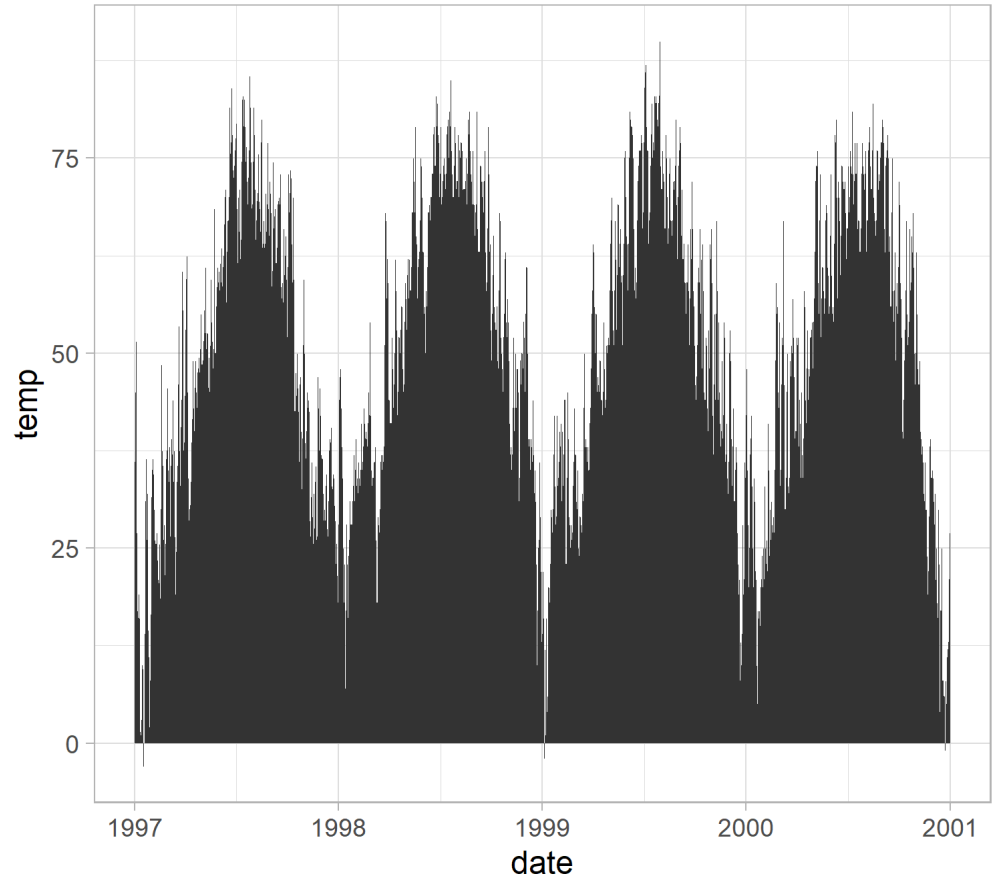
```
ggplot(chic, aes(date, temp)) +
  geom_point()
```



geom_area()

… or turn it for example into an area plot:

```
ggplot(chic, aes(date, temp)) +
  geom_area()
```



Spoiler: Themes!

The default theme of `ggplot2` is well known for it's beauty.

Even though Hadley ensures the design defaults were a

> deliberate choice because it puts the data forward while still making grid lines visible

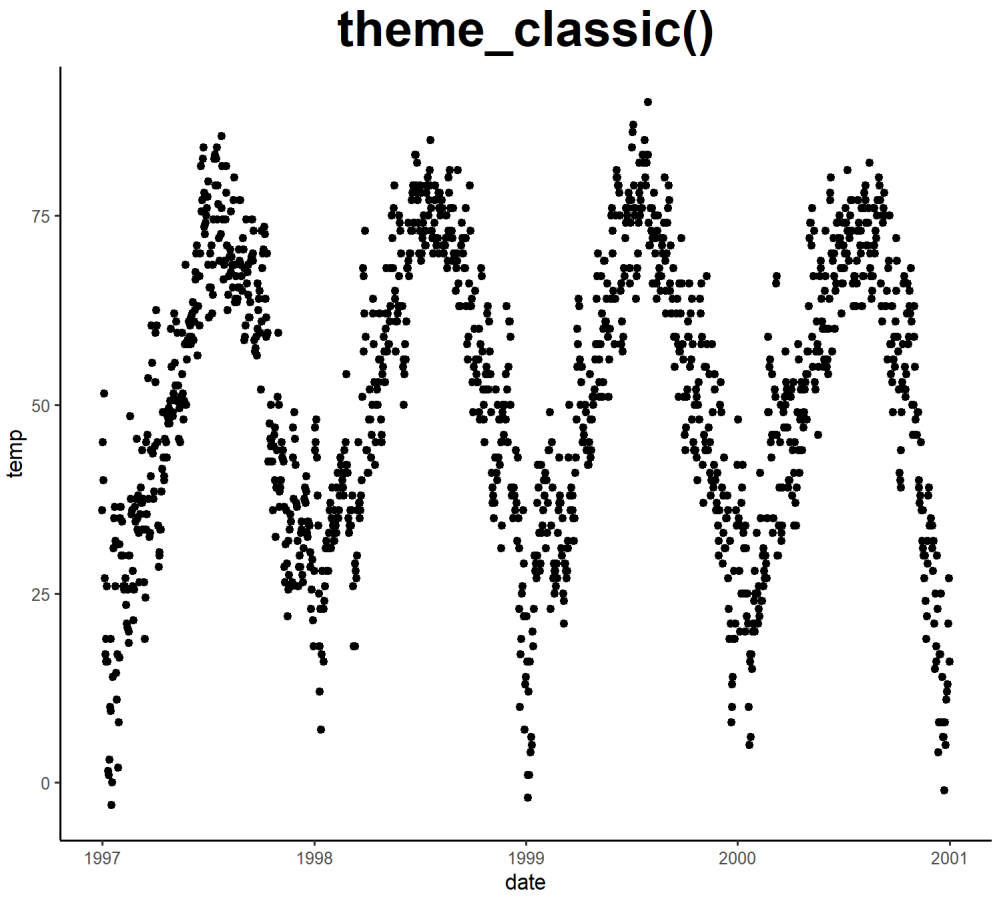
one of the first things I do is getting rid of it because I can't see it anymore.

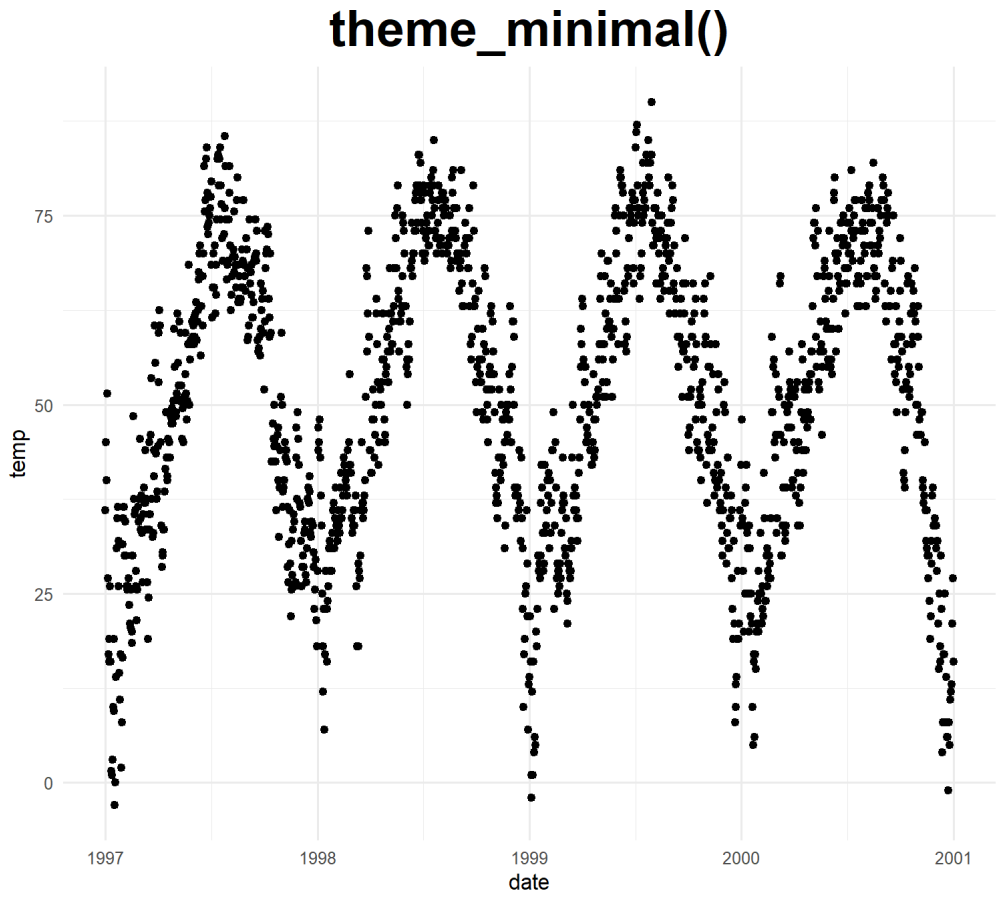
Also, I do not really agree with the reasoning:

> The white **grid lines are visible** (which is important because they significantly aid position judgements), but they have **little visual impact** and we can easily tune them out.
> The **grey background** gives the plot a **similar typographic colour to the text**, ensuring that the graphics fit in the with the flow of a document without jumping out wit a bright white background. Finally, the grey background **creates a continuous field of colour** which ensures that the plot is perceived as single visual entity.

Spoiler: Themes!

Luckily, there are several built-in themes in `ggplot2` (and many many more in extension packages):

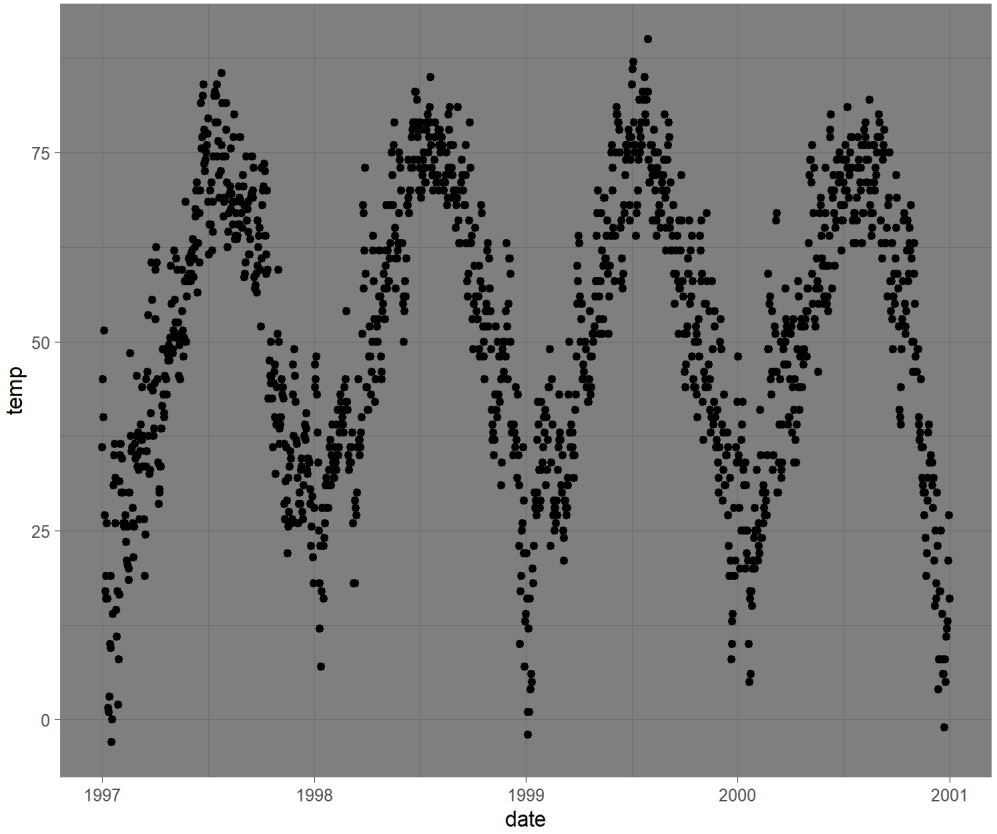




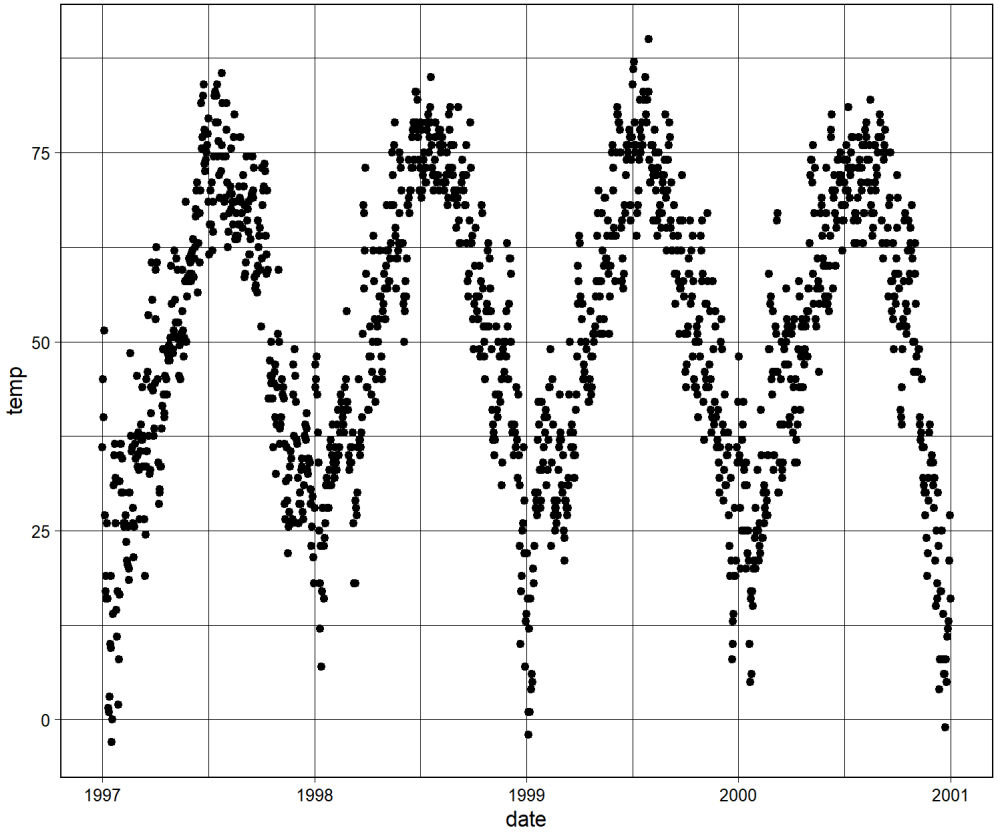
Spoiler: Themes!

Luckily, there are several built-in themes in `ggplot2` (and many many more in extension packages):

theme_dark()



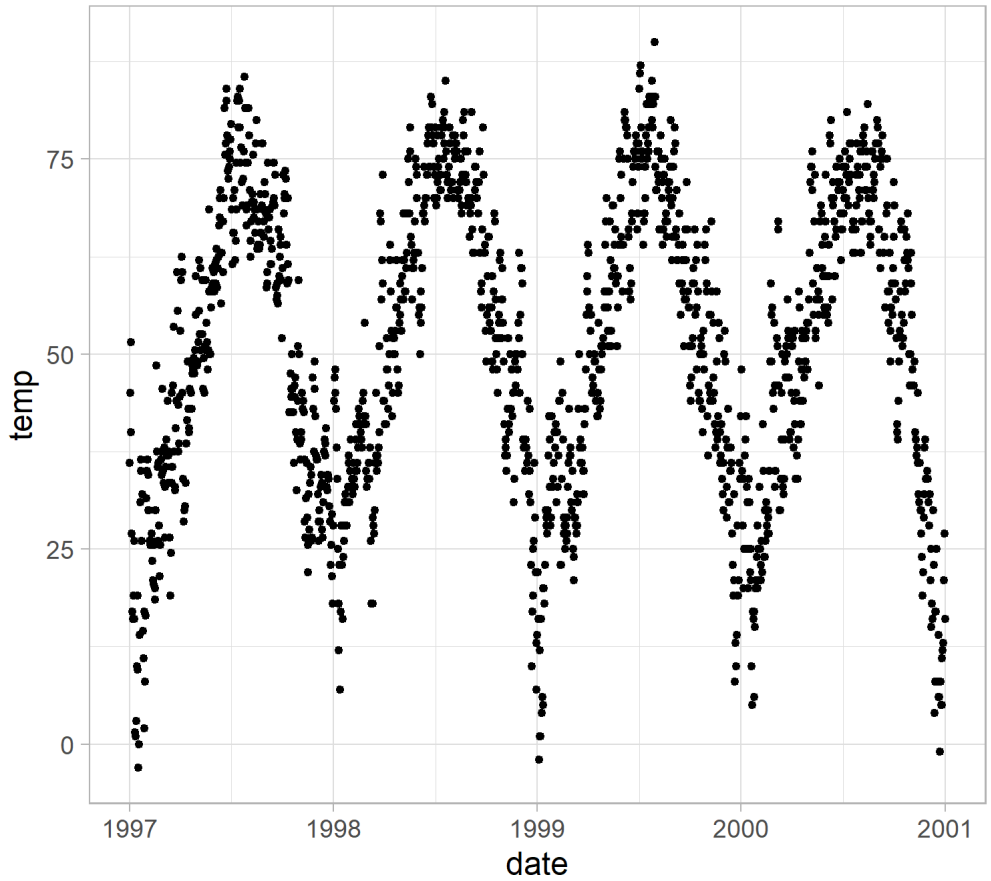
theme_linedraw()



Spoiler: Themes!

You can change the theme via `theme_set(theme_name())` - I am going to use `theme_light()` from now on:

```
theme_set(theme_light())

ggplot(chic, aes(date, temp)) +
  geom_point()
```



Your Turn!

- Turn our scatter plot into a line chart and into a bar chart!
- What's the difference between `geom_path()` and `geom_line()`?
- Create a box plot of temperature per date.
- What is the problem? How could you find out why this is happening?
- Try to create box plots as you would expect them.
- Bonus: Choose the built-in theme you like the most!

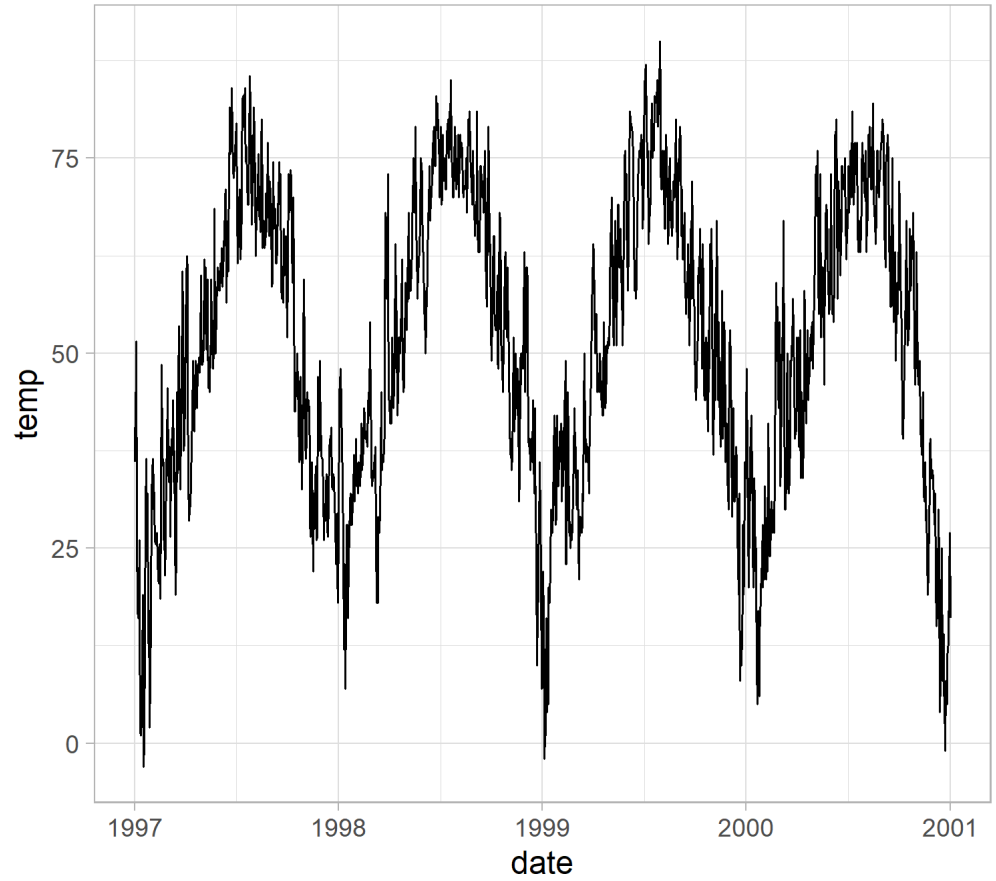
Your Turn!

- Turn our scatter plot into a line chart and into a bar chart!
- What's the difference between `geom_path()` and `geom_line()`?
- Create a box plot of temperature per date.
- What is the problem? How could you find out why this is happening?
- Try to create box plots as you would expect them.
- Hint: You need to specify one categorical variable!
- Bonus: Choose the built-in theme you like the most!

geom_line()

Our scatter plot as a **line plot**:

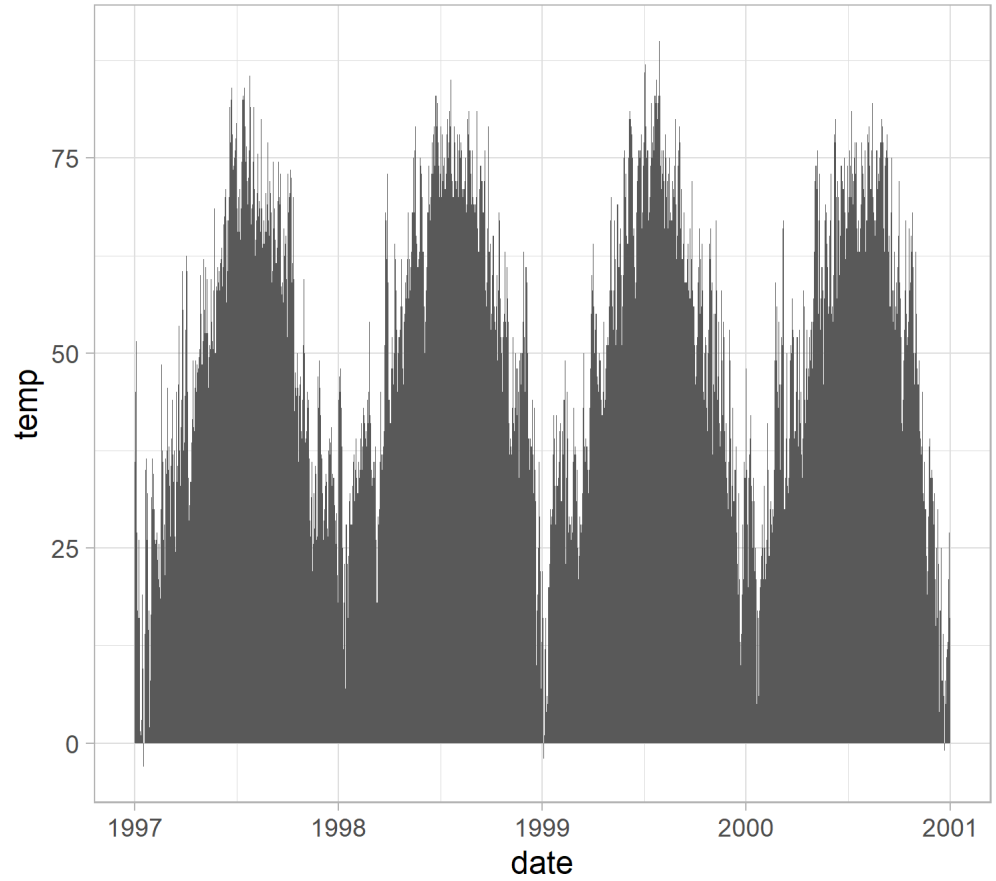
```
ggplot(chic, aes(date, temp)) +
  geom_line()
```



geom_line()

... or as a **bar plot**:

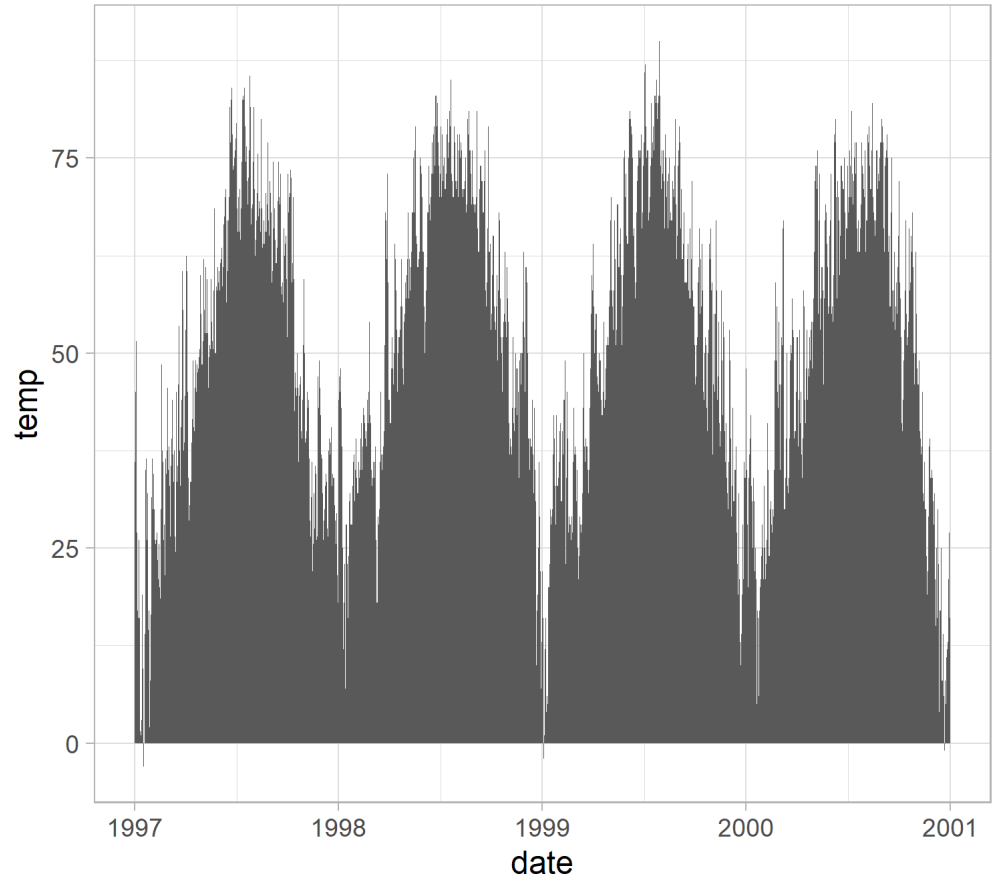
```
ggplot(chic, aes(date, temp)) +
  geom_bar(stat = "identity")
```



geom_line()

... or as a **bar plot**:

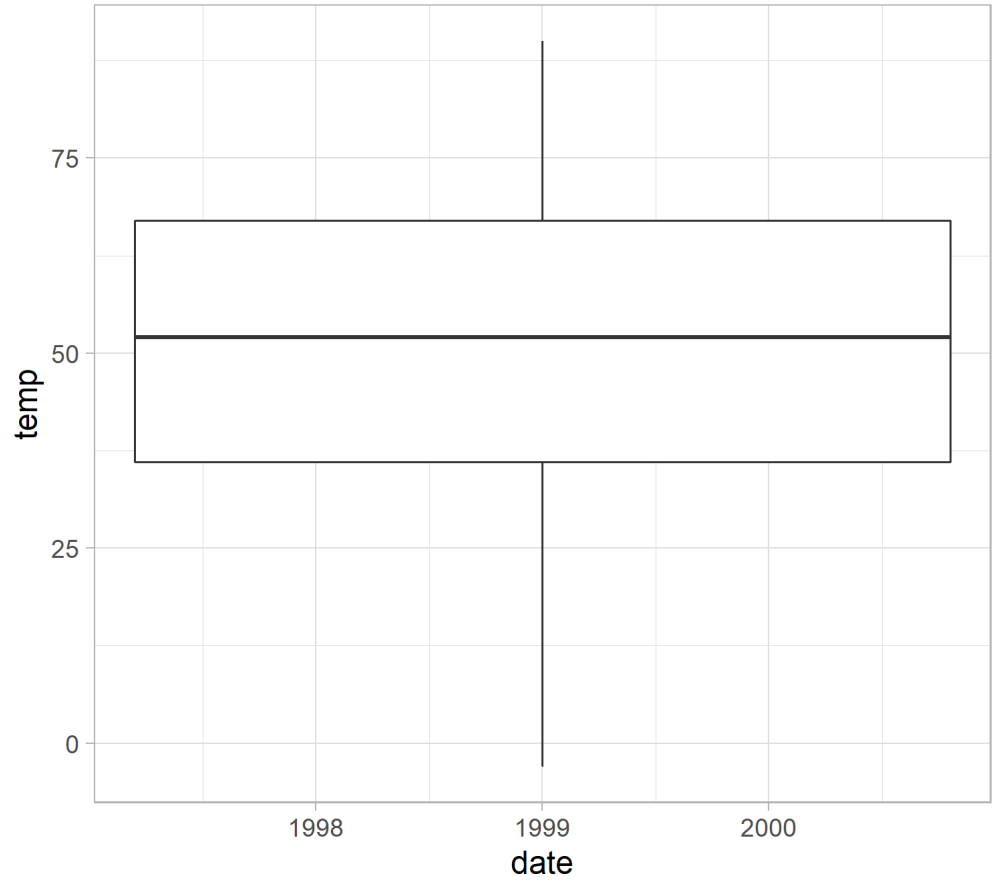
```
ggplot(chic, aes(date, temp)) +
  geom_col()
```



geom_boxplot()

... or a **box and whiskers plot**:

```
ggplot(chic, aes(date, temp)) +
  geom_boxplot()
```

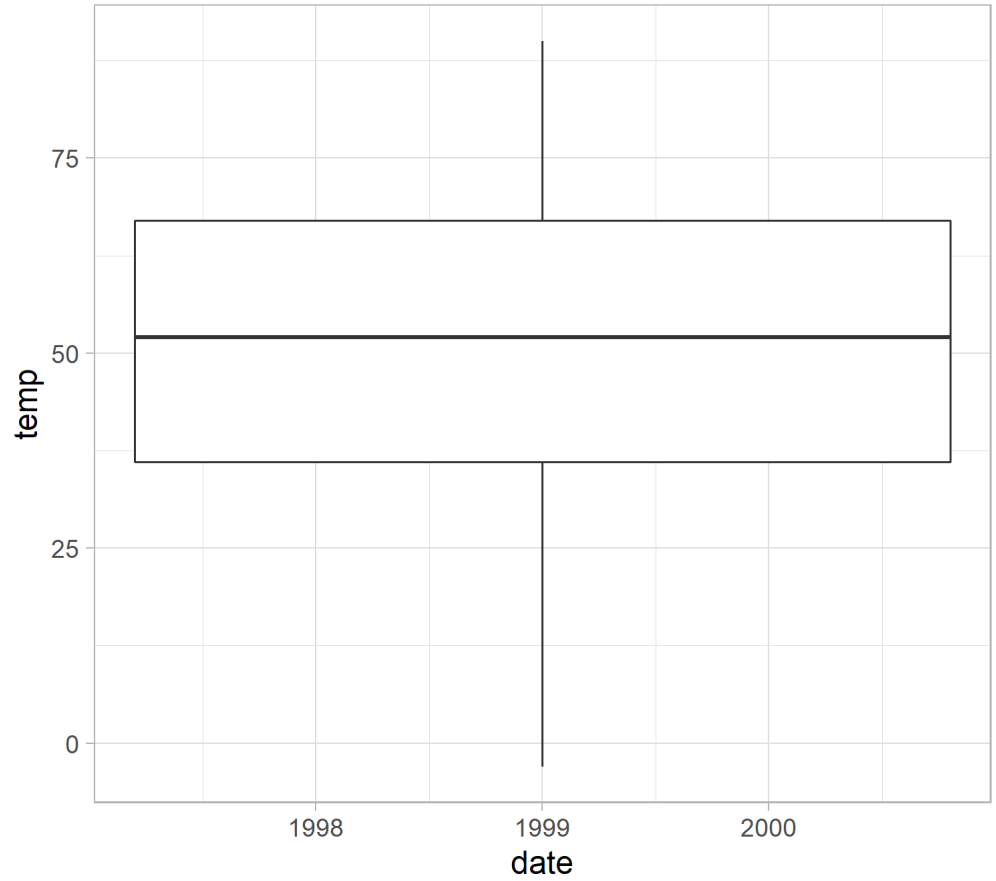


geom_boxplot()

... or a **box and whiskers plot**:

```
ggplot(chic, aes(date, temp)) +
  geom_boxplot()
```

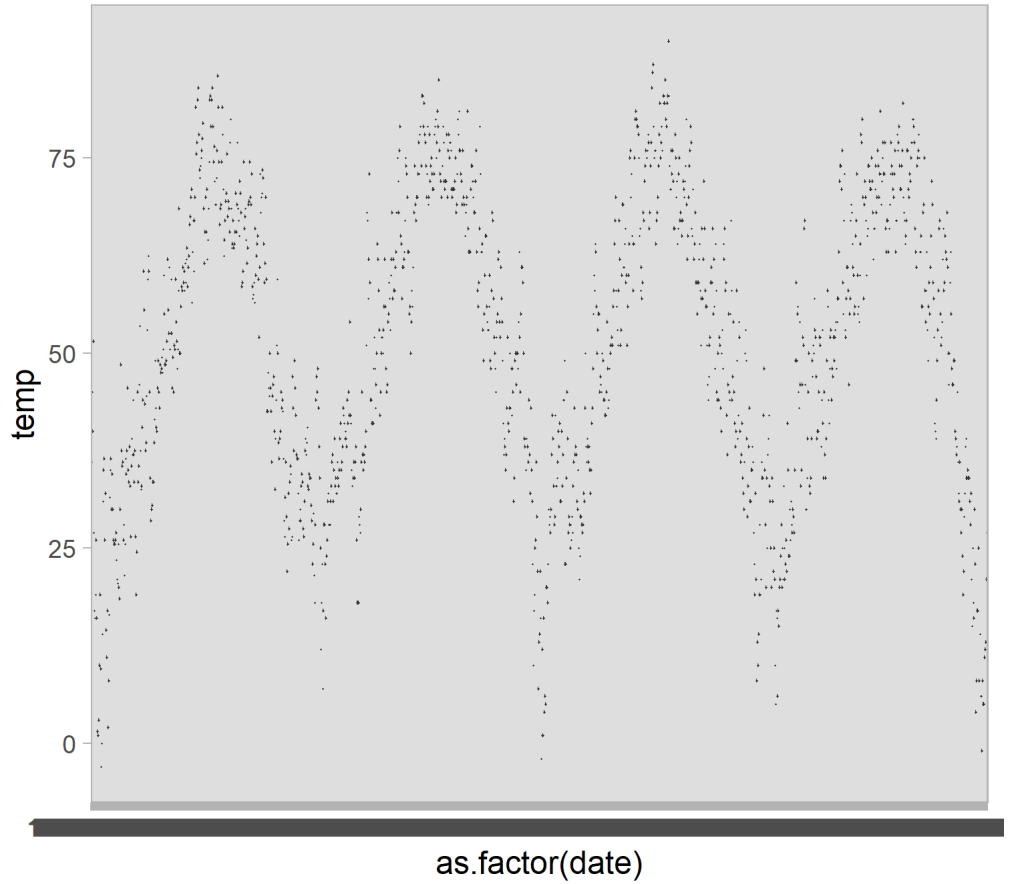
What's going on here?!



geom_boxplot()

We need to specify the variable as **categorial** (`as.factor(date)`), not as **continuous** (`date`):

```
ggplot(chic, aes(as.factor(date), temp)) +
    geom_boxplot()
```

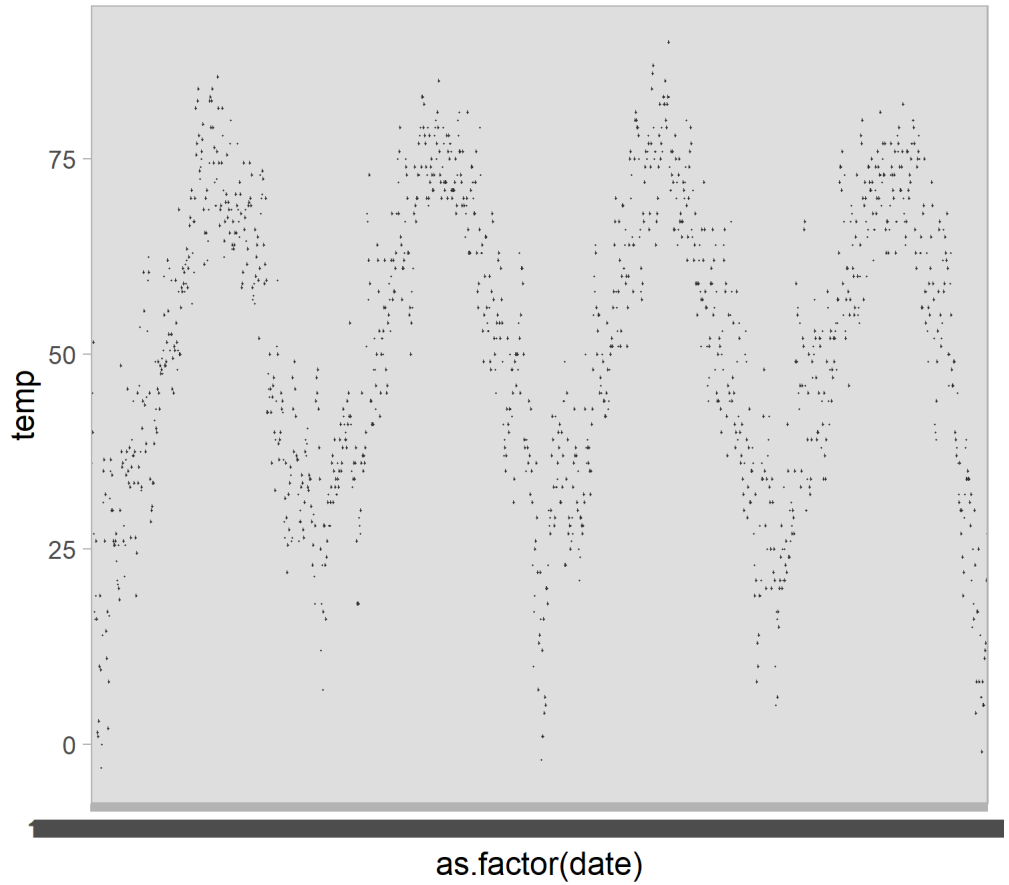


geom_boxplot()

We need to specify the variable as **categorial** (`as.factor(date)`), not as **continuous** (`date`):

```
ggplot(chic, aes(as.factor(date), temp)) +
    geom_boxplot()
```

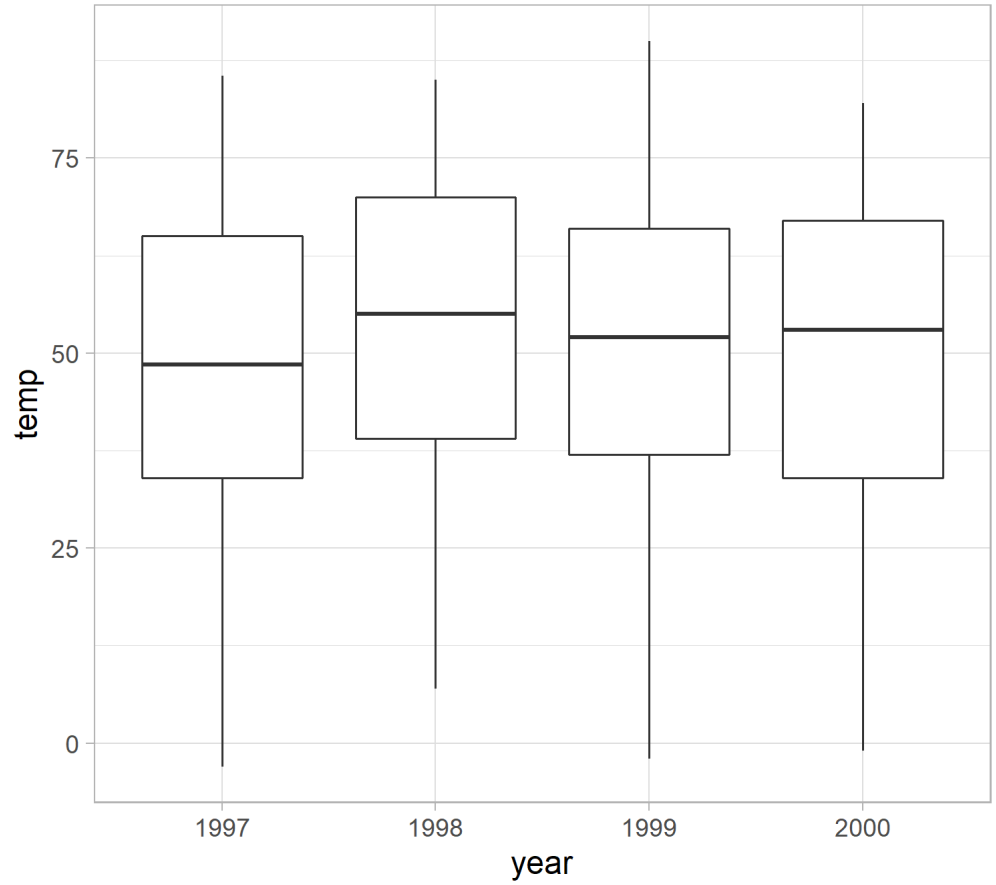
But - why are there no box plots?



geom_boxplot()

We need to specify the variable as **categorial** (e.g. `year` or `season`), not as **continuous** (`date`):

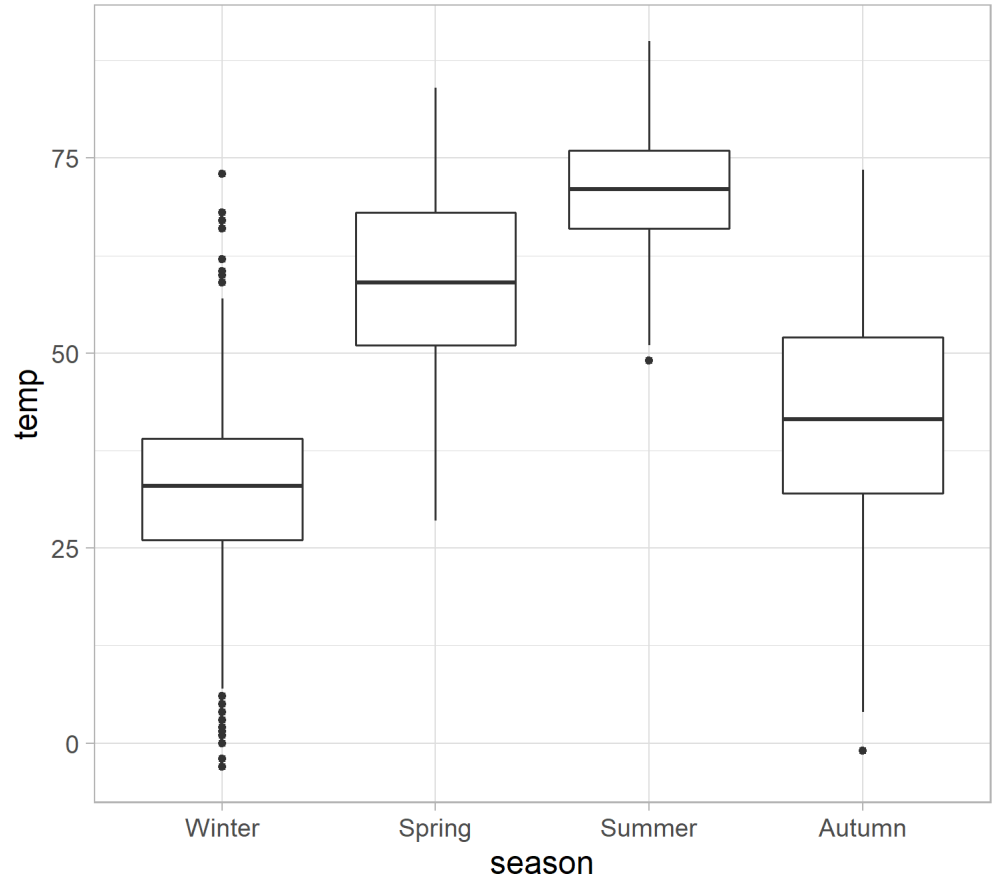
```
ggplot(chic, aes(year, temp)) +
    geom_boxplot()
```



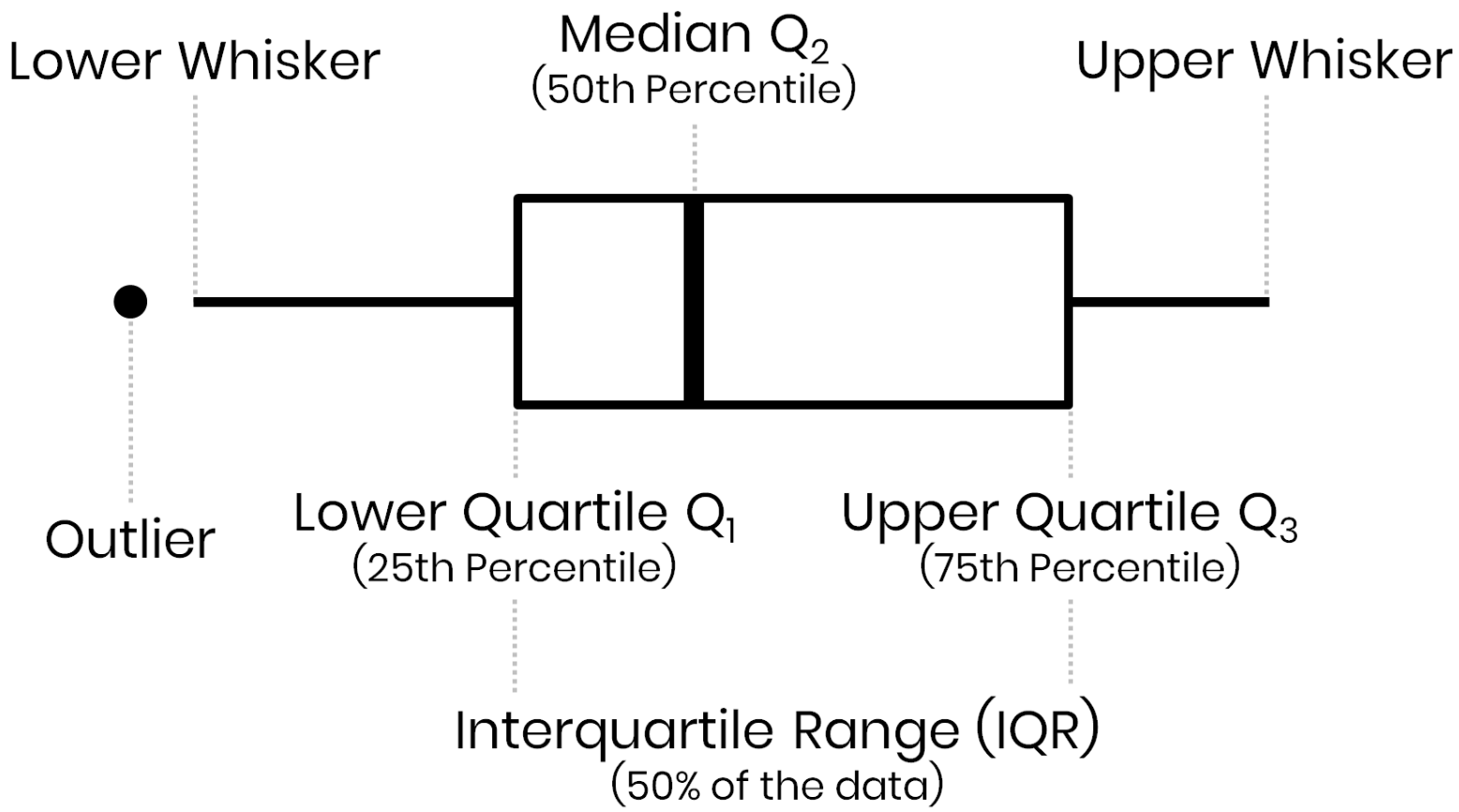
geom_boxplot()

We need to specify the variable as **categorial** (e.g. `year` or `season`), not as **continuous** (`date`):

```
ggplot(chic, aes(season, temp)) +
    geom_boxplot()
```



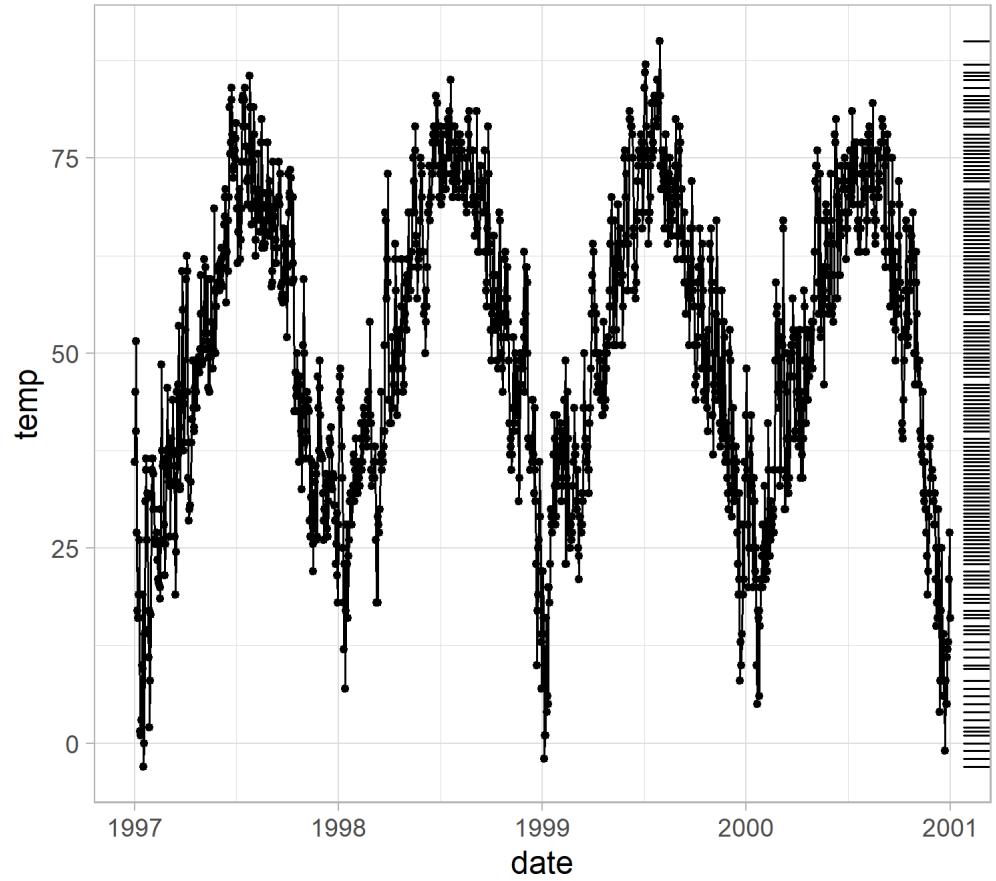
Box-and-Whisker Plots



Multiple `geom_*()`'s

Other layers can be added to an existing plot - a line and a rug representation for example:

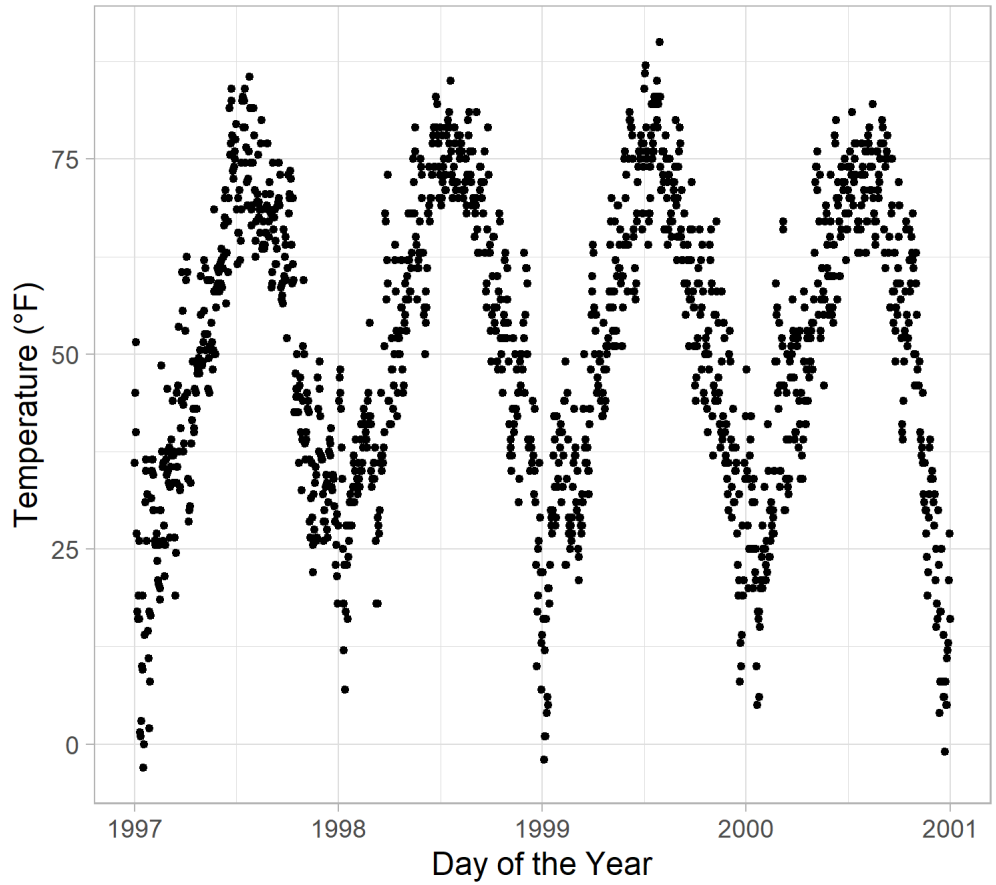
```
ggplot(chic, aes(date, temp)) +
  geom_point() +
  geom_line() +
  geom_rug(sides = "r")
```



Add Labels

You can change the axes titles by adding `xlab()` and `ylab()` to your ggplot:

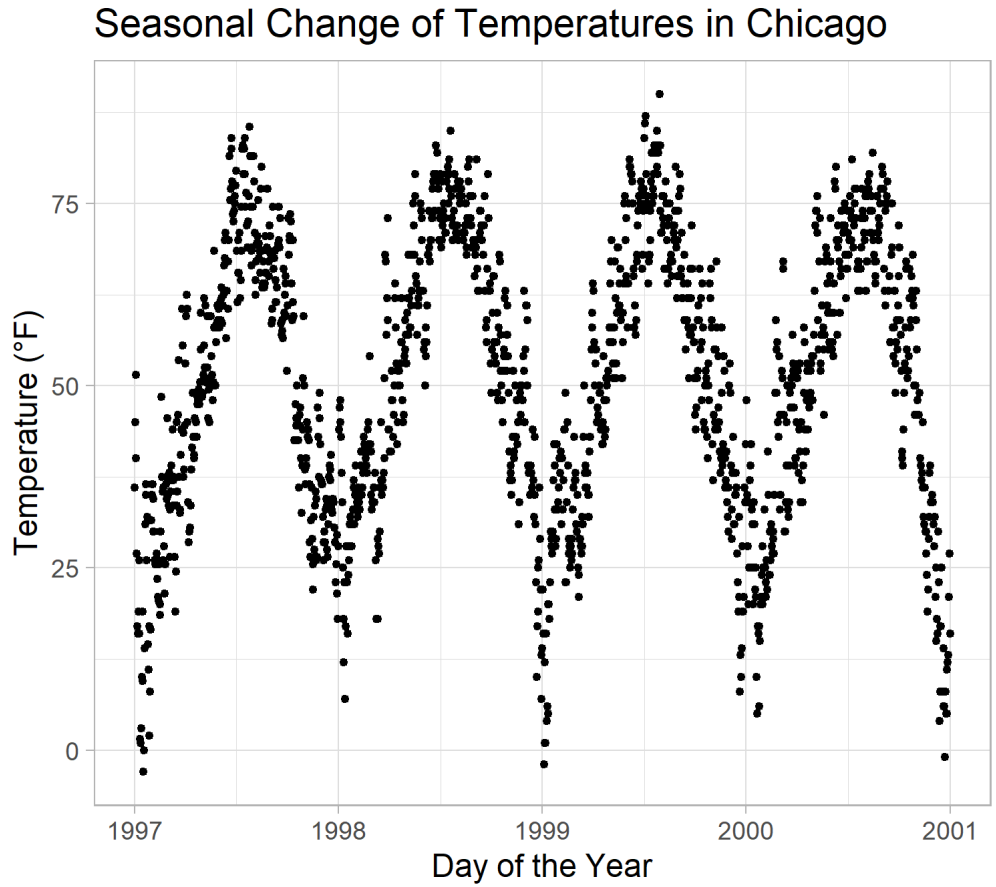
```
ggplot(chic, aes(date, temp)) +
  geom_point() +
  xlab("Day of the Year") +
  ylab("Temperature (°F)")
```



Add Labels

... and a title by adding `ggtitle()`:

```
ggplot(chic, aes(date, temp)) +
  geom_point() +
  xlab("Day of the Year") +
  ylab("Temperature (°F)") +
  ggtitle("Seasonal Change of Temperature
```

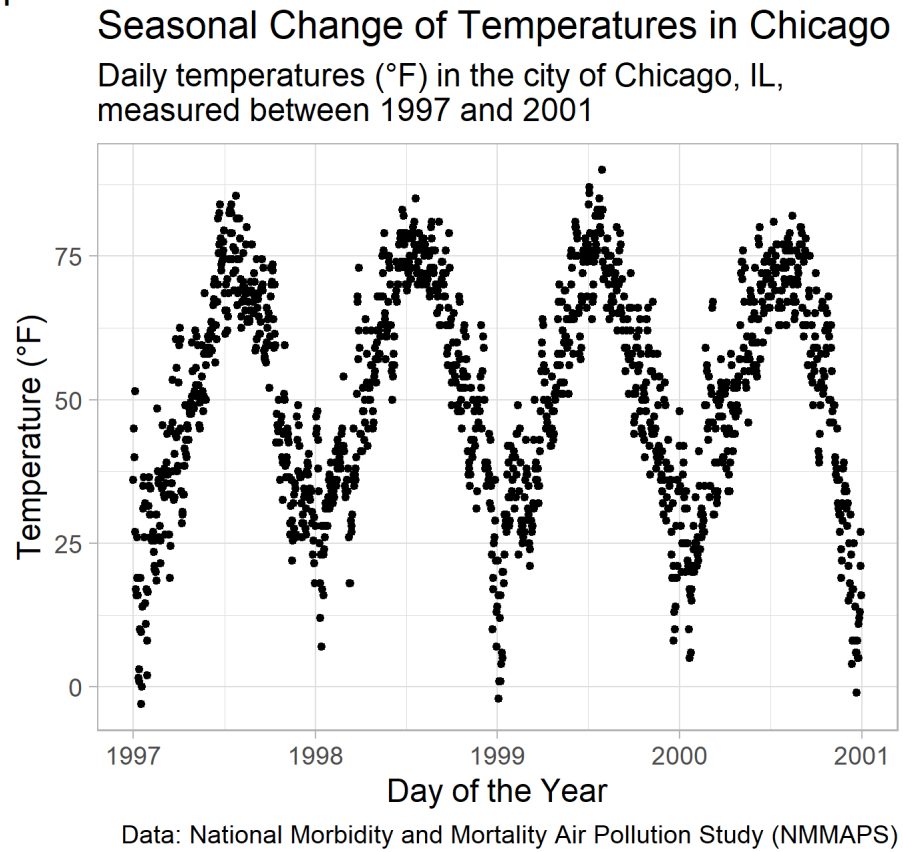


Add Labels

Using `labs()` you can also change all and more in one go:

```
ggplot(chic, aes(date, temp)) +
  geom_point() +
  labs(
    x = "Day of the Year",
    y = "Temperature (°F)",
    title = "Seasonal Change of Temperatu
    subtitle = "Daily temperatures (°F) i
    caption = "Data: National Morbidity a
    tag = "Fig. 1"
  )
```

Fig. 1

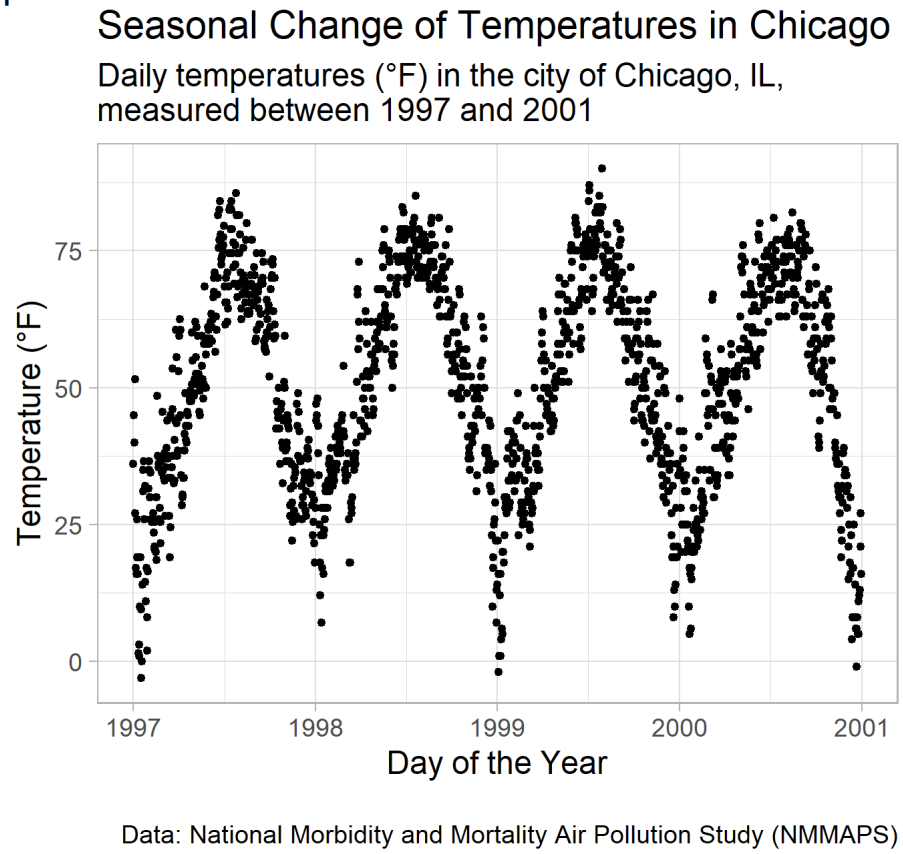


Add Labels

Using `labs()` you can also change all and more in one go:

```
ggplot(chic, aes(date, temp)) +
  geom_point() +
  labs(
    x = "Day of the Year",
    y = "Temperature (°F)",
    title = "Seasonal Change of Temperatu
    subtitle = "Daily temperatures (°F) i
    caption = "\nData: National Morbidity
    tag = "Fig. 1"
  )
```

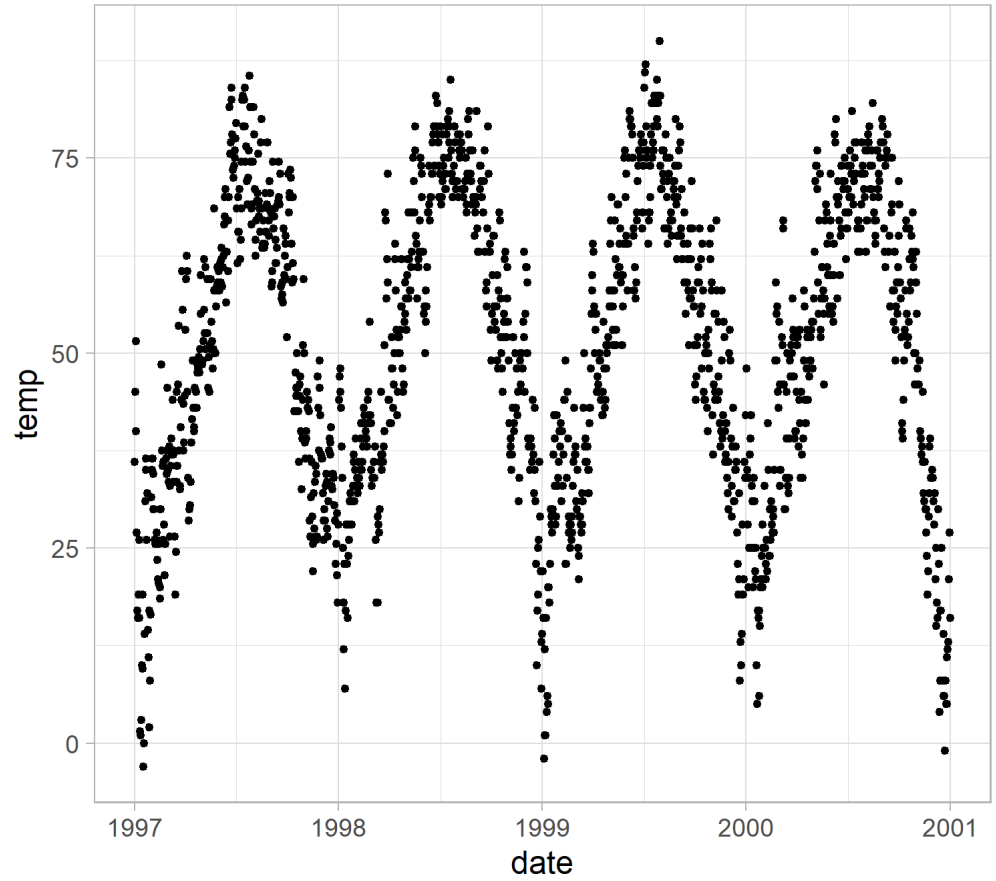
Fig. 1



ggplots as Object

You can assign ggplot to an object name:

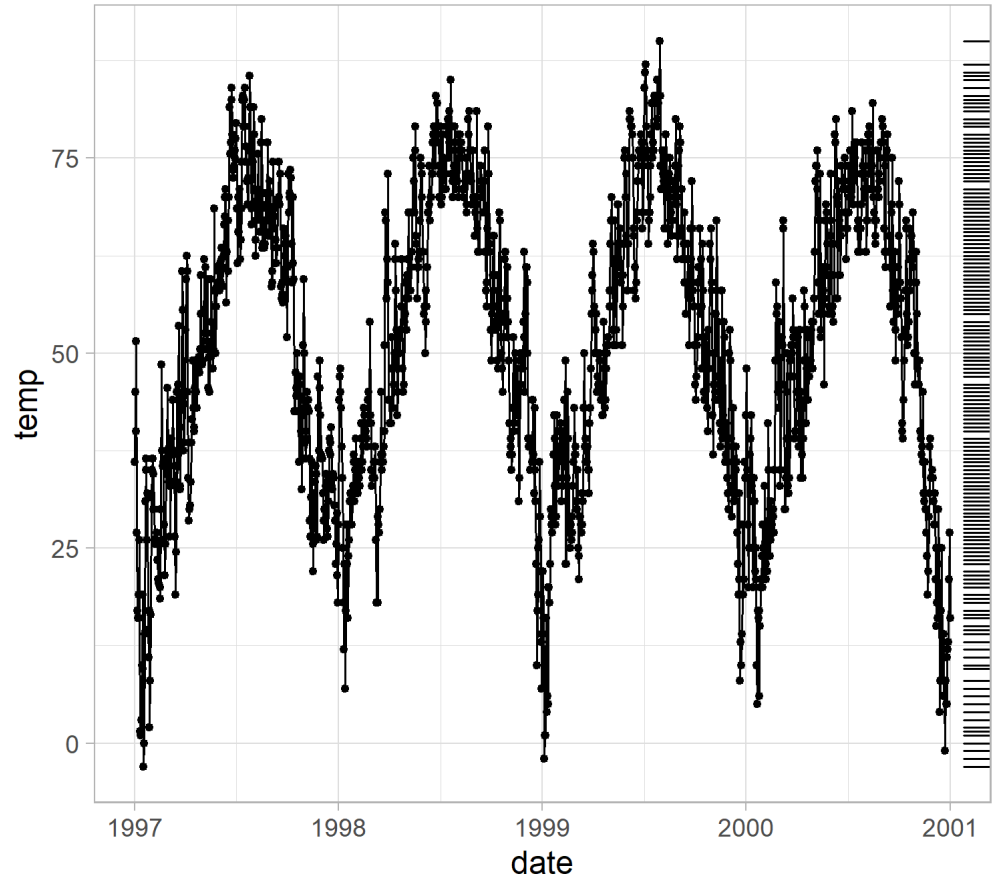
```
g <- ggplot(chic, aes(date, temp)) +
  geom_point()

g
```



ggplots as Object

... and add layers afterwards:

```
g <- ggplot(chic, aes(date, temp)) +
  geom_point()

g +
  geom_line() +
  geom_rug(sides = "r")
```



Saving a ggplot

You can export your plot via the `ggsave()` function:

```
ggsave(filename = "my_ggplot.pdf",
       width = 10, height = 7,
       device = cairo_pdf)

ggsave(filename = "my_ggplot.png",
       width = 10, height = 7,
       dpi = 700)
```

Source: canva.com

Your Turn!

- Import the data on password strength from *Information is Beautiful* from my GitHub repository:
  https://raw.githubusercontent.com/Z3tt/ggplot-courses/master/data/passwords.csv
- Have a look at the raw data (both in the browser and R)
- Investigate the data set via summary functions.
- Create two plots with geom's of your choice to answer the following:
  - Which password category is ranked the lowest and which the highest?
  - Is there a password category that is more common than others?
- Export the plot with a nice aspect ratio.

Your Turn!

```
passwords <- read_csv("https://raw.githubusercontent.com/rfordatascience/tidytuesday/m

glimpse(passwords)
## Rows: 507
## Columns: 9
## $ rank             <dbl> 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15...
## $ password         <chr> "password", "123456", "12345678", "1234", "qwerty...
## $ category         <chr> "password-related", "simple-alphanumeric", "simpl...
## $ value            <dbl> 6.91, 18.52, 1.29, 11.11, 3.72, 1.85, 3.72, 6.91,...
## $ time_unit        <chr> "years", "minutes", "days", "seconds", "days", "m...
## $ offline_crack_sec <dbl> 2.170e+00, 1.110e-05, 1.110e-03, 1.110e-07, 3.210...
## $ rank_alt         <dbl> 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15...
## $ strength         <dbl> 8, 4, 4, 4, 8, 4, 8, 4, 7, 8, 8, 1, 32, 9, 9, 8, ...
## $ font_size        <dbl> 11, 8, 8, 8, 11, 8, 11, 8, 11, 11, 11, 4, 23, 12,...
```

Your Turn!

```
#View(passwords)

summary(passwords[,c(1:6, 8)])
##       rank          password           category            value        
##  Min.   :  1.0   Length:507         Length:507         Min.   : 1.290  
##  1st Qu.:125.8   Class :character   Class :character   1st Qu.: 3.430  
##  Median :250.5   Mode  :character   Mode  :character   Median : 3.720  
##  Mean   :250.5                                         Mean   : 5.603  
##  3rd Qu.:375.2                                         3rd Qu.: 3.720  
##  Max.   :500.0                                         Max.   :92.270  
##  NA's   :7                                             NA's   :7       
##   time_unit         offline_crack_sec     strength    
##  Length:507         Min.   : 0.00000   Min.   : 0.000  
##  Class :character   1st Qu.: 0.00321   1st Qu.: 6.000  
##  Mode  :character   Median : 0.00321   Median : 7.000  
##                     Mean   : 0.50001   Mean   : 7.432  
##                     3rd Qu.: 0.08350   3rd Qu.: 8.000  
##                     Max.   :29.27000   Max.   :48.000  
##                     NA's   :7          NA's   :7
```

Your Turn!

```
range(passwords$rank)
## [1] NA NA
```

Your Turn!

```
range(passwords$rank)
## [1] NA NA

range(passwords$rank, na.rm = T)
## [1]   1 500
```

Your Turn!

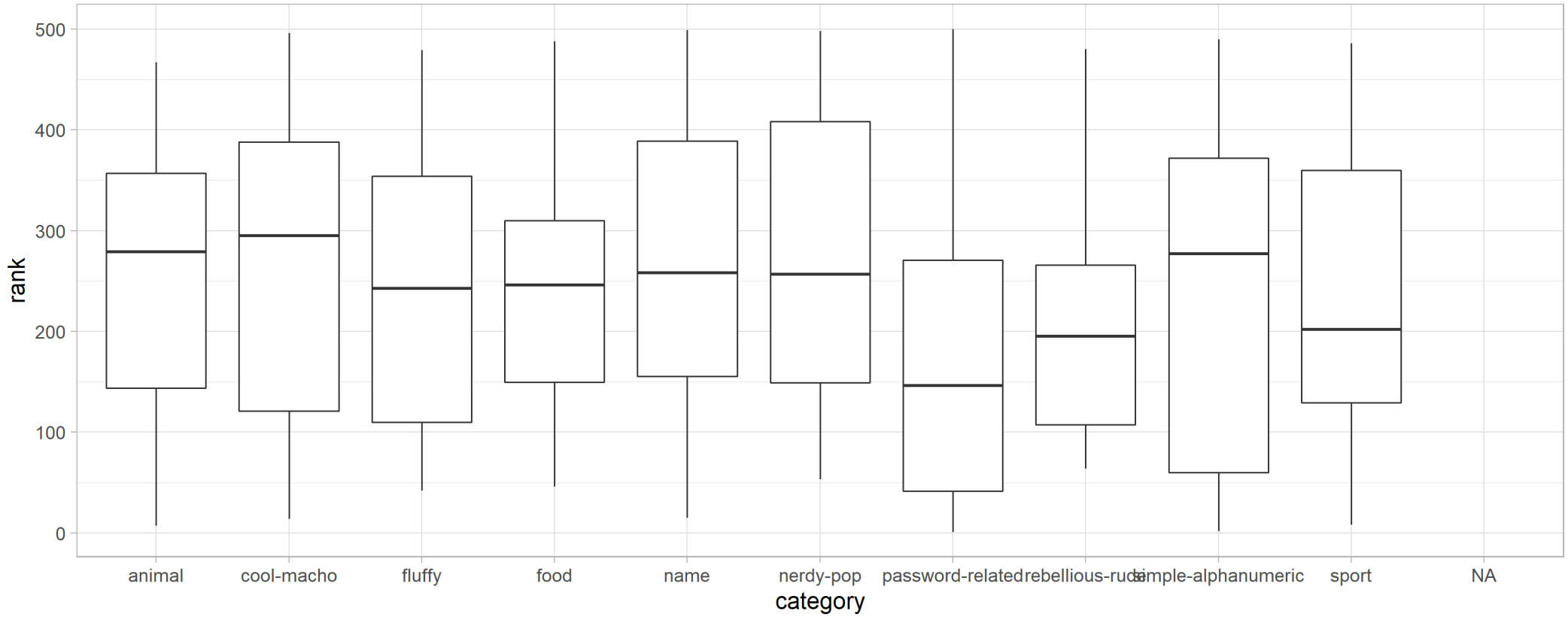
```
unique(passwords$category)
##  [1] "password-related"    "simple-alphanumeric" "animal"
##  [4] "sport"               "cool-macho"          "name"
##  [7] "fluffy"              "food"                "nerdy-pop"
## [10] "rebellious-rude"     NA
```

Your Turn!

```
unique(passwords$password)
##   [1] "password"  "123456"    "12345678"  "1234"      "qwerty"    "12345"
##   [7] "dragon"    "baseball"  "football"  "letmein"   "monkey"    "696969"
##  [13] "abc123"    "mustang"   "michael"   "shadow"    "master"    "jennifer"
##  [19] "111111"    "2000"      "jordan"    "superman"  "harley"    "1234567"
##  [25] "hunter"    "trustno1"  "ranger"    "buster"    "thomas"    "tigger"
##  [31] "robert"    "soccer"    "batman"    "test"      "pass"      "killer"
##  [37] "hockey"    "george"    "charlie"   "andrew"    "michelle"  "love"
##  [43] "sunshine"  "jessica"   "6969"      "pepper"    "daniel"    "access"
##  [49] "123456789" "654321"    "joshua"    "maggie"    "starwars"  "silver"
##  [55] "william"   "dallas"    "yankees"   "123123"    "ashley"    "666666"
##  [61] "hello"     "amanda"    "orange"    "biteme"    "freedom"   "computer"
##  [67] "sexy"      "thunder"   "nicole"    "ginger"    "heather"   "hammer"
##  [73] "summer"    "corvette"  "taylor"    "austin"    "1111"      "merlin"
##  [79] "matthew"   "121212"    "golfer"    "cheese"    "princess"  "martin"
##  [85] "chelsea"   "patrick"   "richard"   "diamond"   "yellow"    "bigdog"
##  [91] "secret"    "asdfgh"    "sparky"    "cowboy"    "camaro"    "anthony"
##  [97] "matrix"    "falcon"    "iloveyou"  "bailey"    "guitar"    "jackson"
## [103] "purple"    "scooter"   "phoenix"   "aaaaaa"    "morgan"    "tigers"
## [109] "porsche"   "mickey"    "maverick"  "cookie"    "nascar"    "peanut"
## [115] "justin"    "131313"    "money"     "samantha"  "panties"   "steelers"
## [121] "joseph"    "snoopy"    "boomer"    "whatever"  "iceman"    "smokey"
```

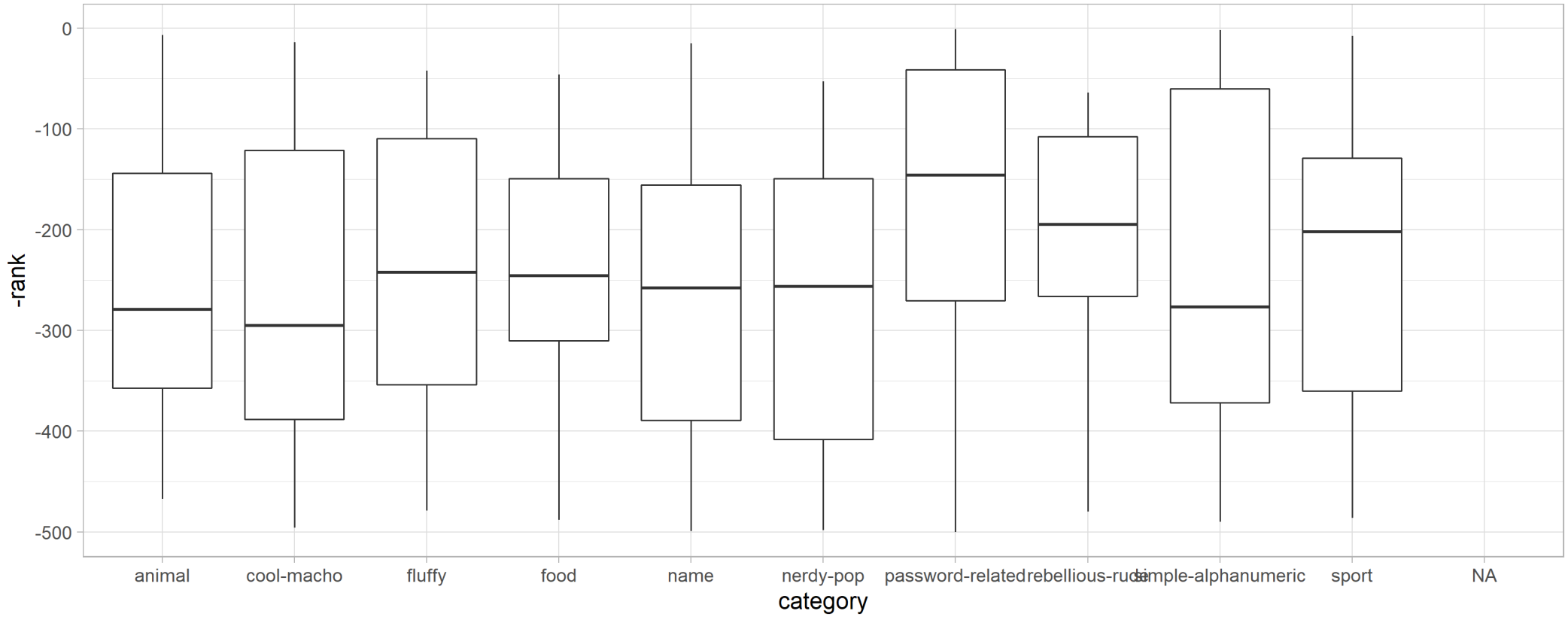
Your Turn!

```
ggplot(passwords, aes(category, rank)) +
  geom_boxplot()
```



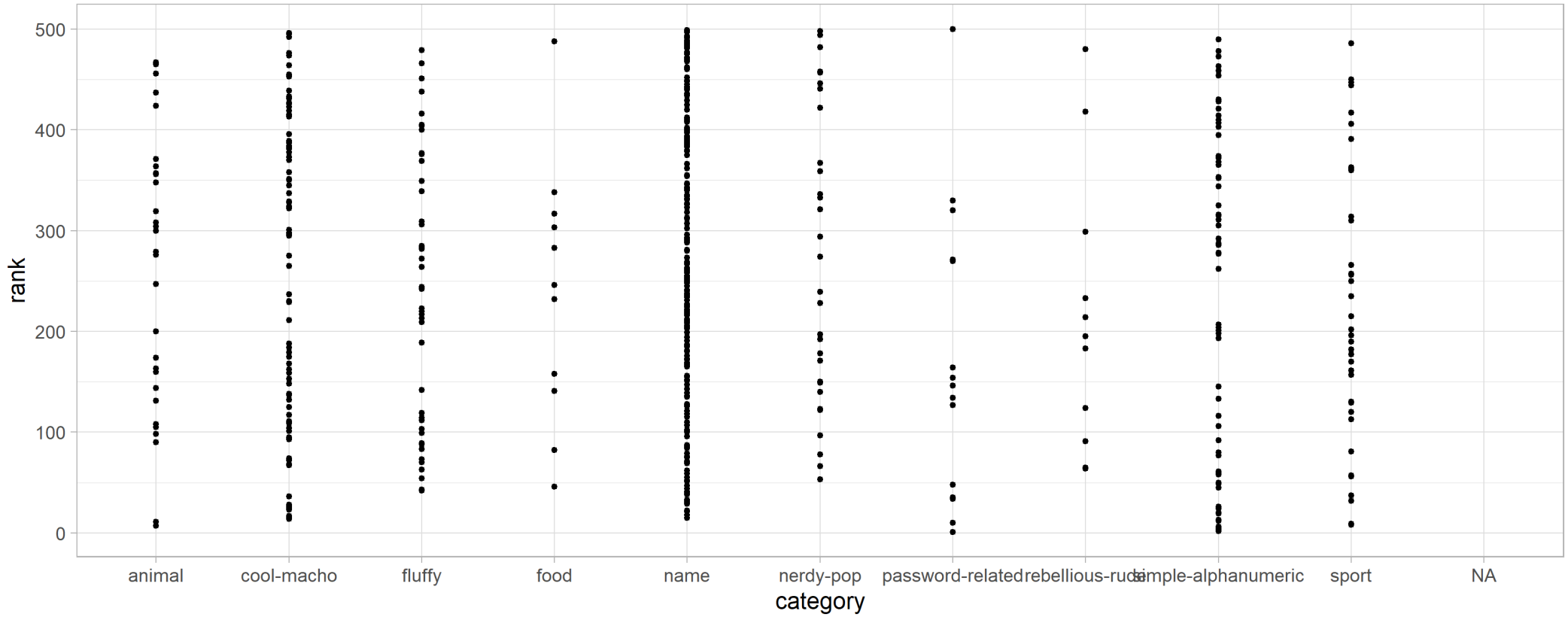
Your Turn!

```
ggplot(passwords, aes(category, -rank)) +
  geom_boxplot()
```



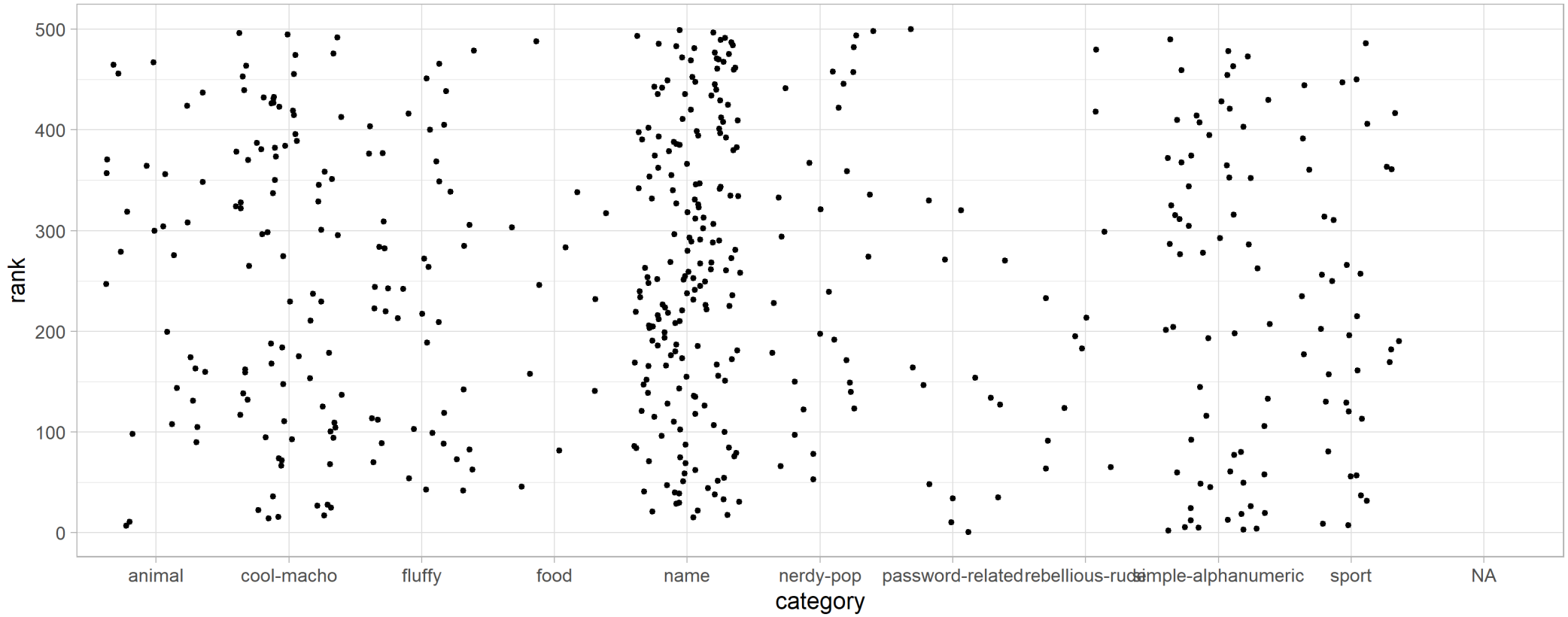
Your Turn!

```
ggplot(passwords, aes(category, rank)) +
  geom_point()
```



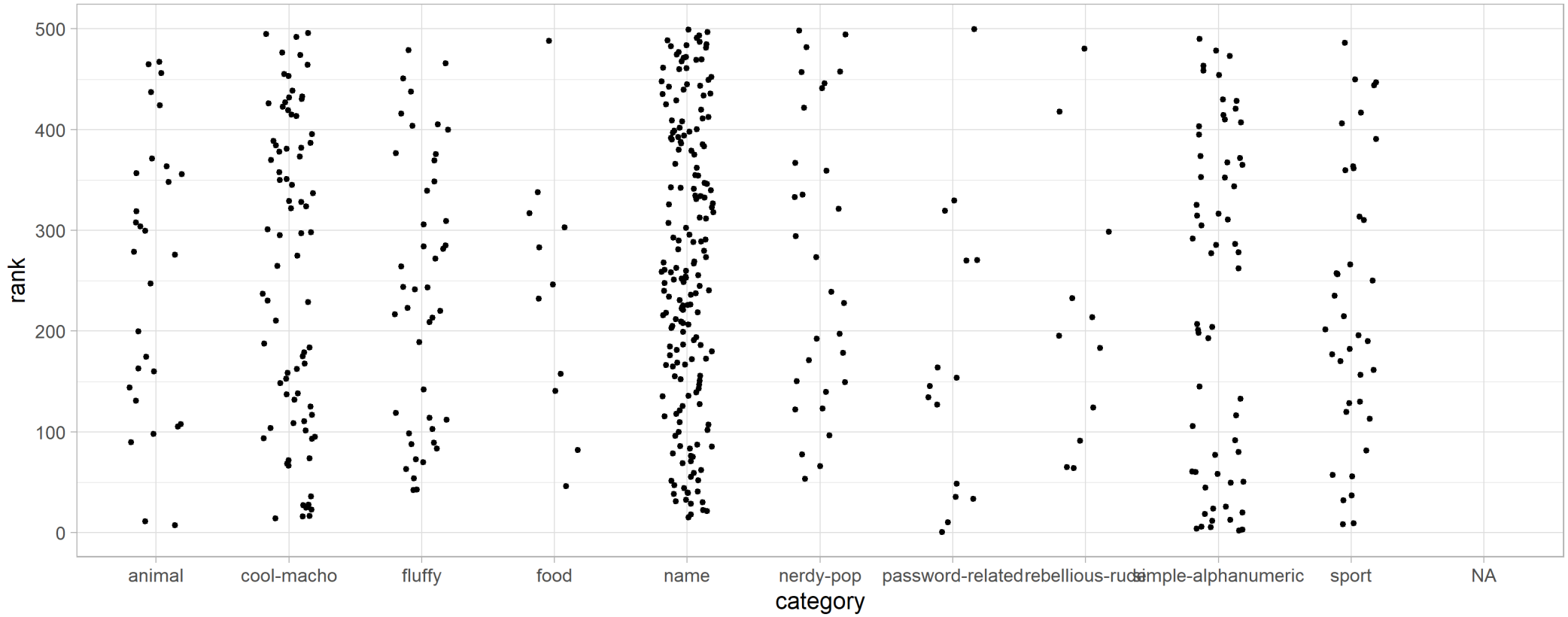
Your Turn!

```
ggplot(passwords, aes(category, rank)) +
  geom_jitter()
```



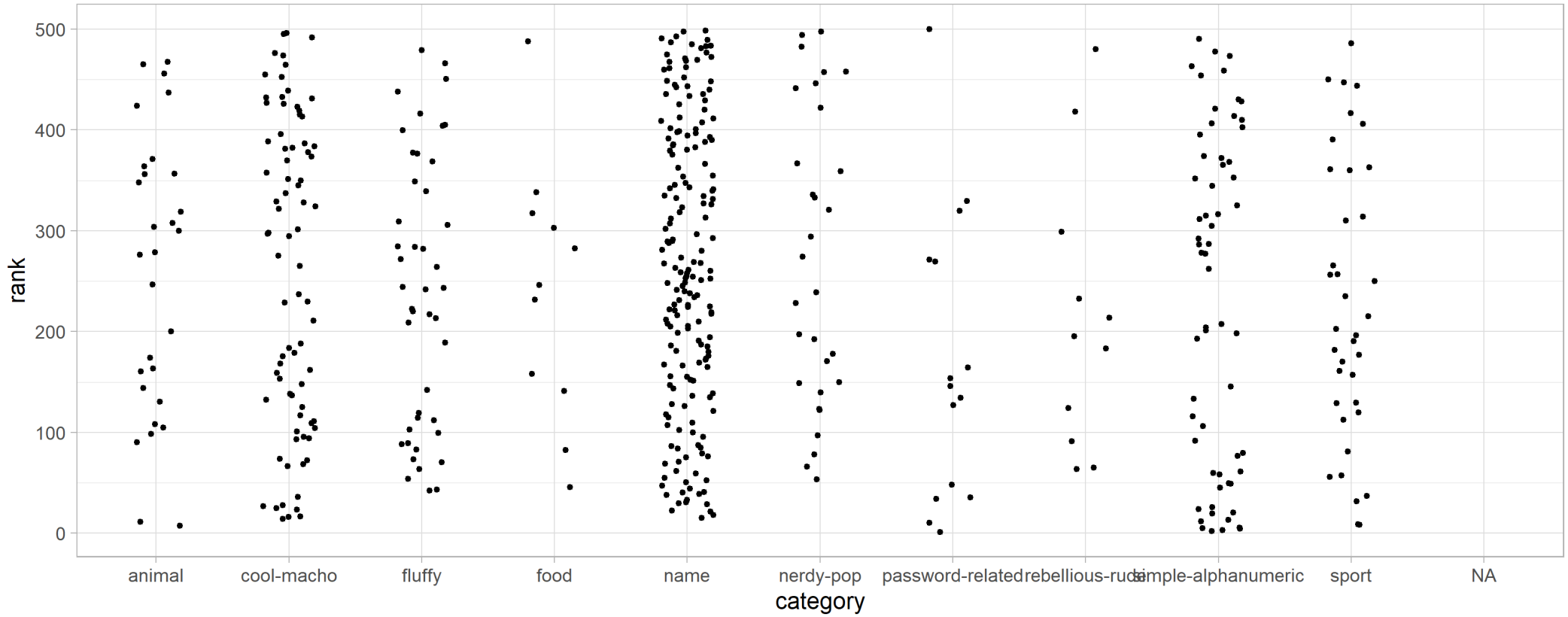
Your Turn!

```
ggplot(passwords, aes(category, rank)) +
  geom_jitter(width = .2)
```



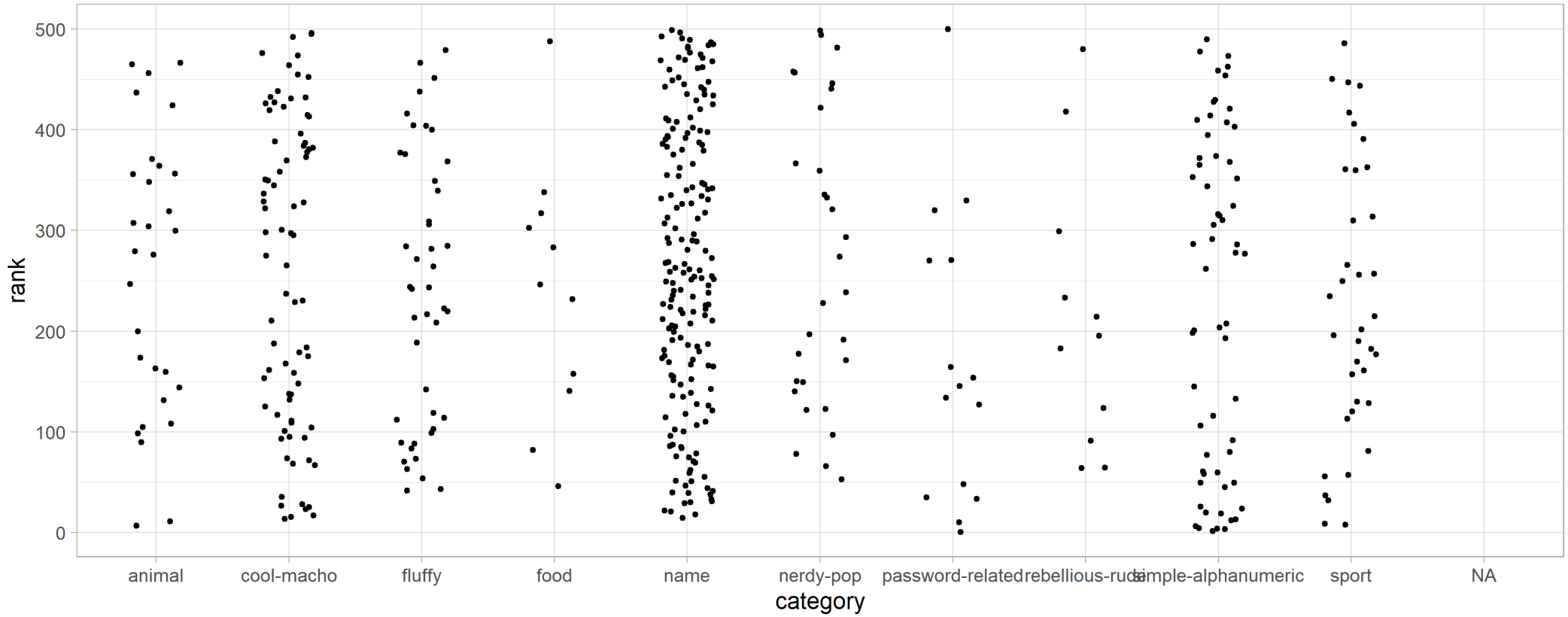
Your Turn!

```
ggplot(passwords, aes(category, rank)) +
  geom_jitter(position = position_jitter(width = .2, seed = 1))
```



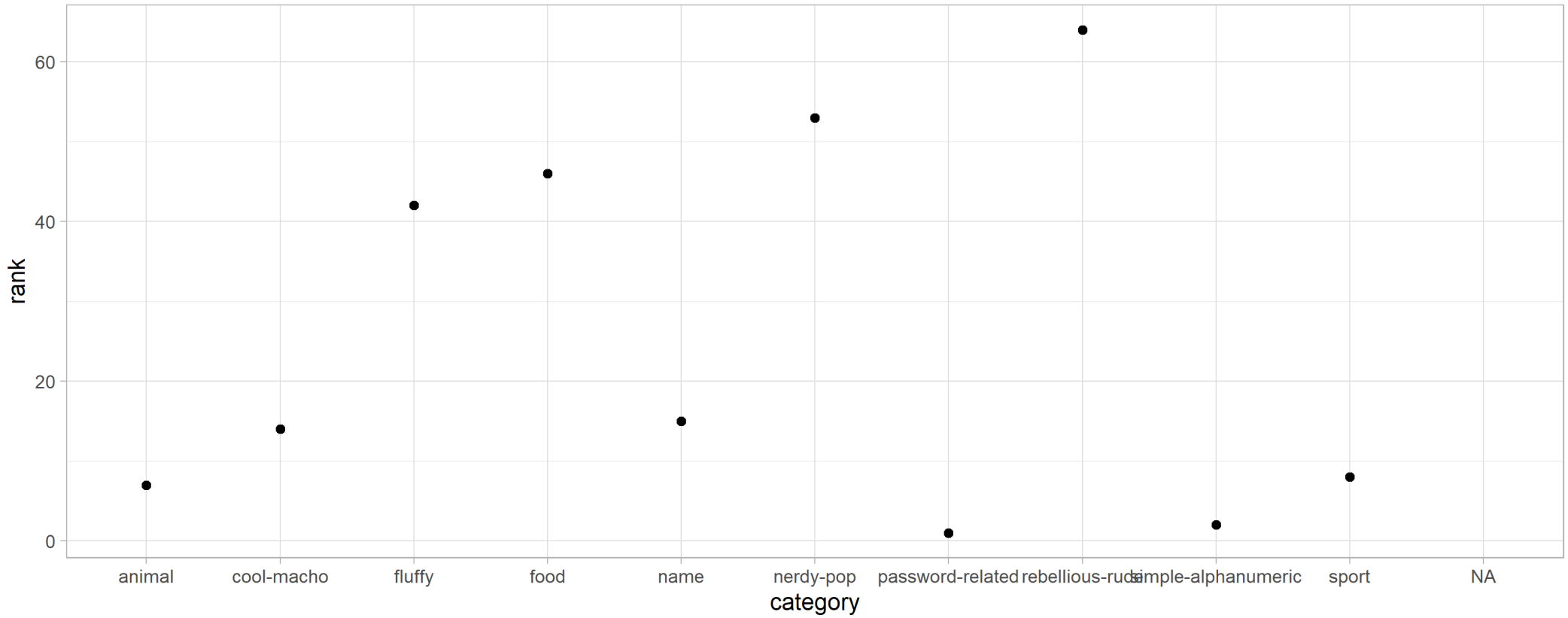
Your Turn!

```
ggplot(passwords, aes(category, rank)) +
  geom_jitter(position = position_jitter(width = .2, seed = 2020))
```



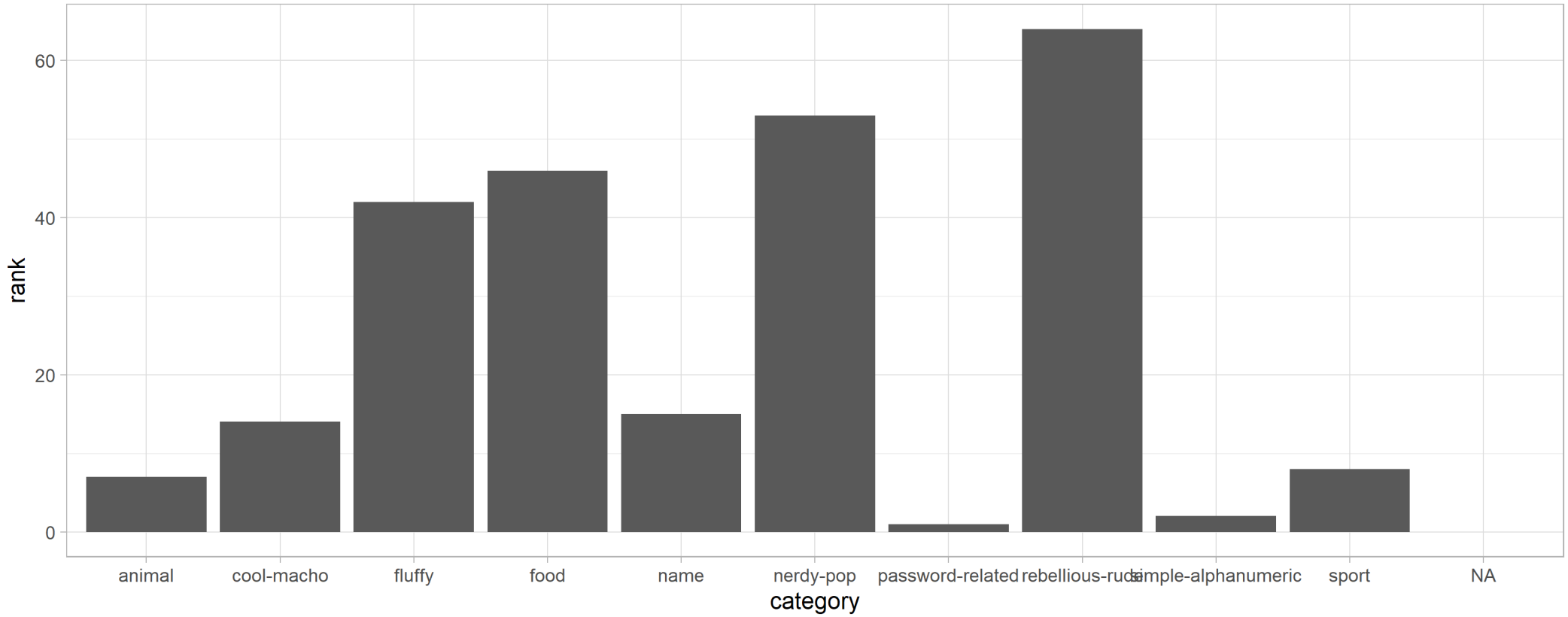
Your Turn!

```
ggplot(passwords, aes(category, rank)) +
  stat_summary(fun = min)
```



Your Turn!

```
ggplot(passwords, aes(category, rank)) +
  stat_summary(fun = min, geom = "col")
```



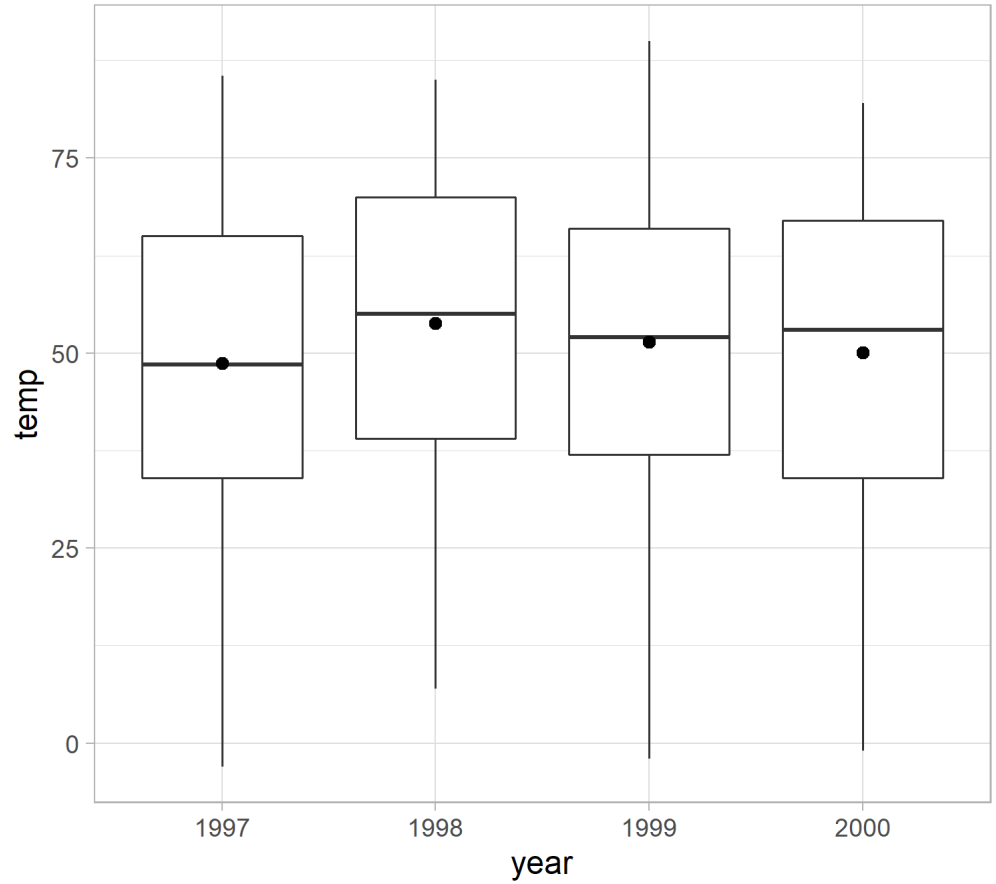
Layers

Statistical Layers: `stat_*()`

stat_*()

A handful of layers with attention to the statistical transformation rather than the visual appearance:

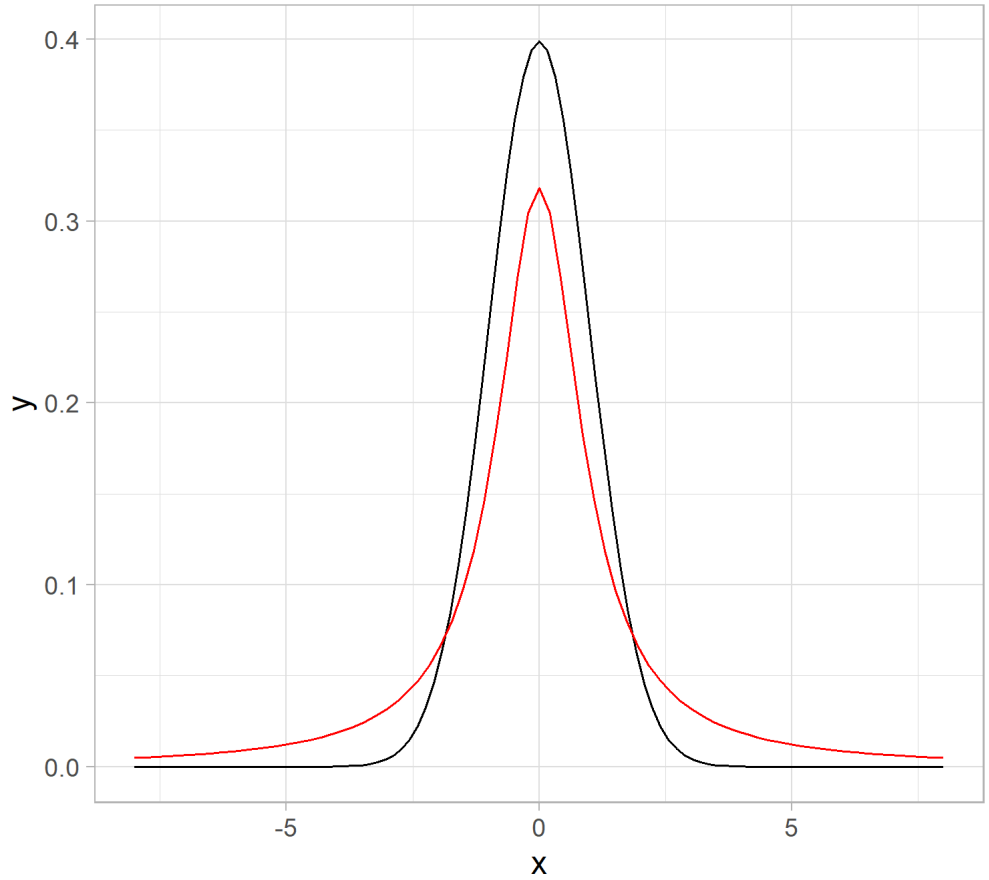
```
ggplot(chic, aes(year, temp)) +
  geom_boxplot() +
  stat_summary(fun = mean)
  ## fun.y in the current CRAN version
```



stat_function()

`stat_function()` makes it easy to add a function to a plot, either continuous or discrete:

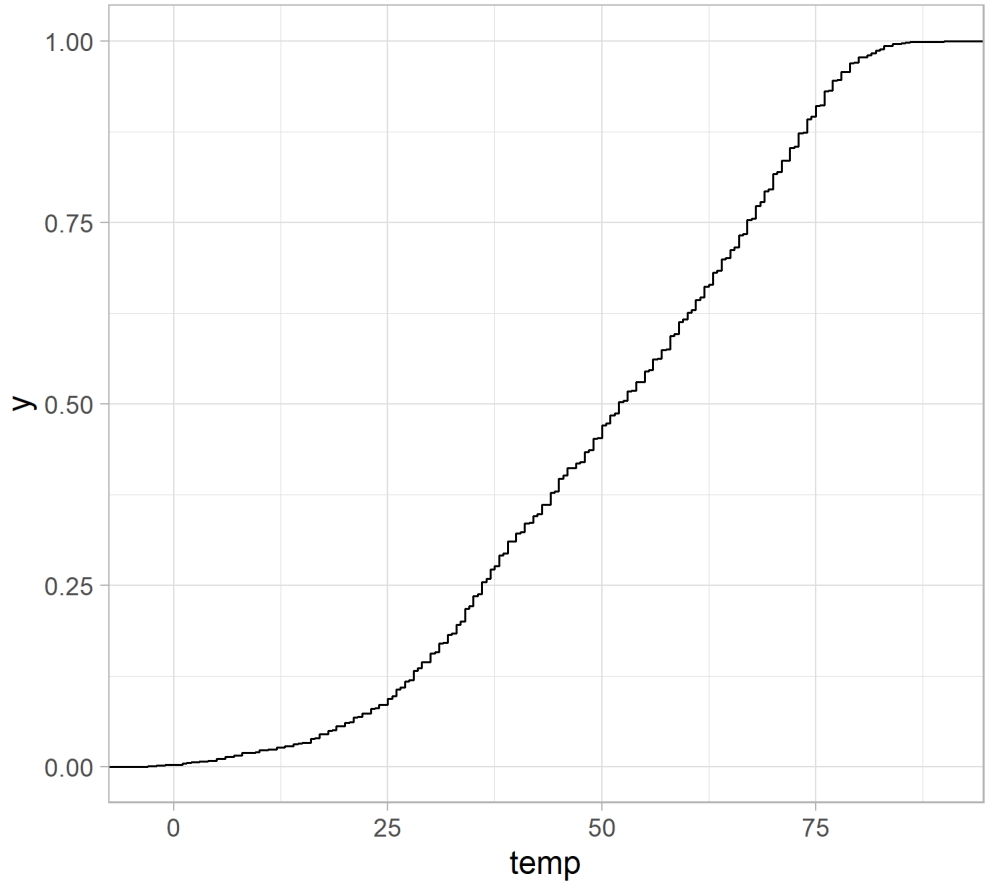
```
ggplot(tibble(x = c(-8, 8)), aes(x)) +
  stat_function(fun = dnorm) +
  stat_function(
    fun = dcauchy,
    color = "red",
    n = 75
  )
```



stat_ecdf()

You can also easily plot the empirical cumulative distribution function (ECDF) of a variable:

```
ggplot(chic, aes(temp)) +
  stat_ecdf()
```

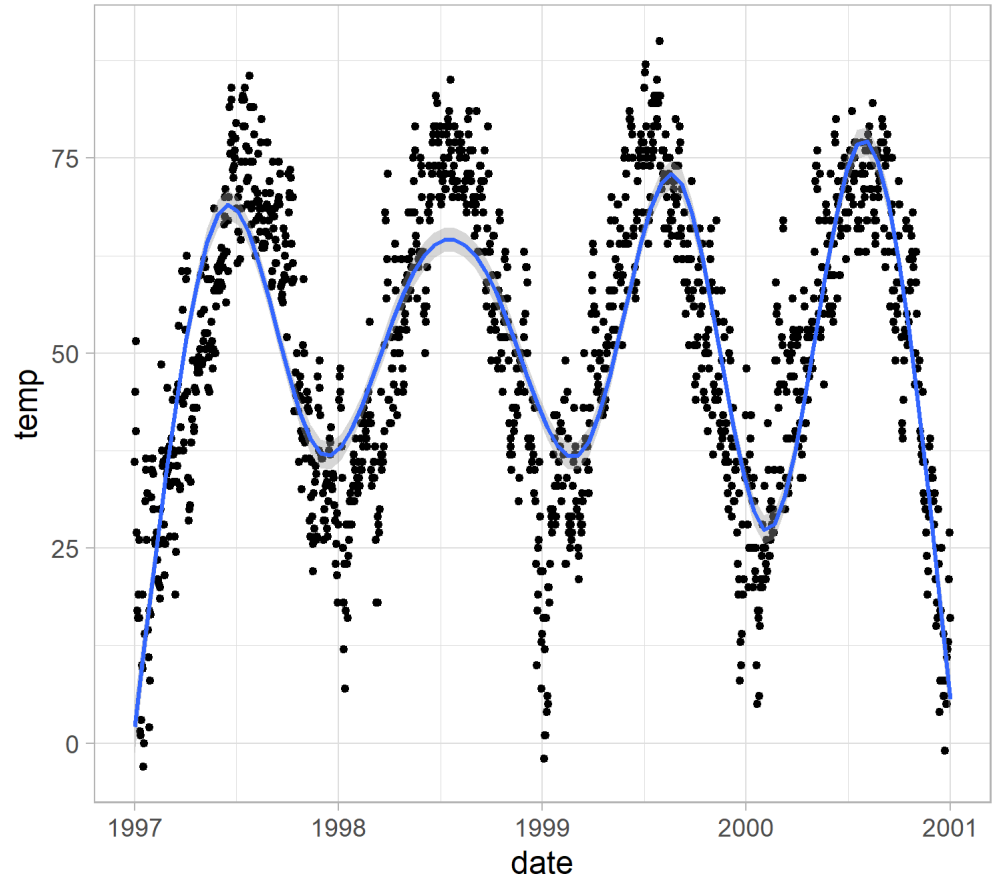


stat_smooth()

You can directly add smoothed conditional means:

```
ggplot(chic, aes(date, temp)) +
  geom_point() +
  stat_smooth()
```

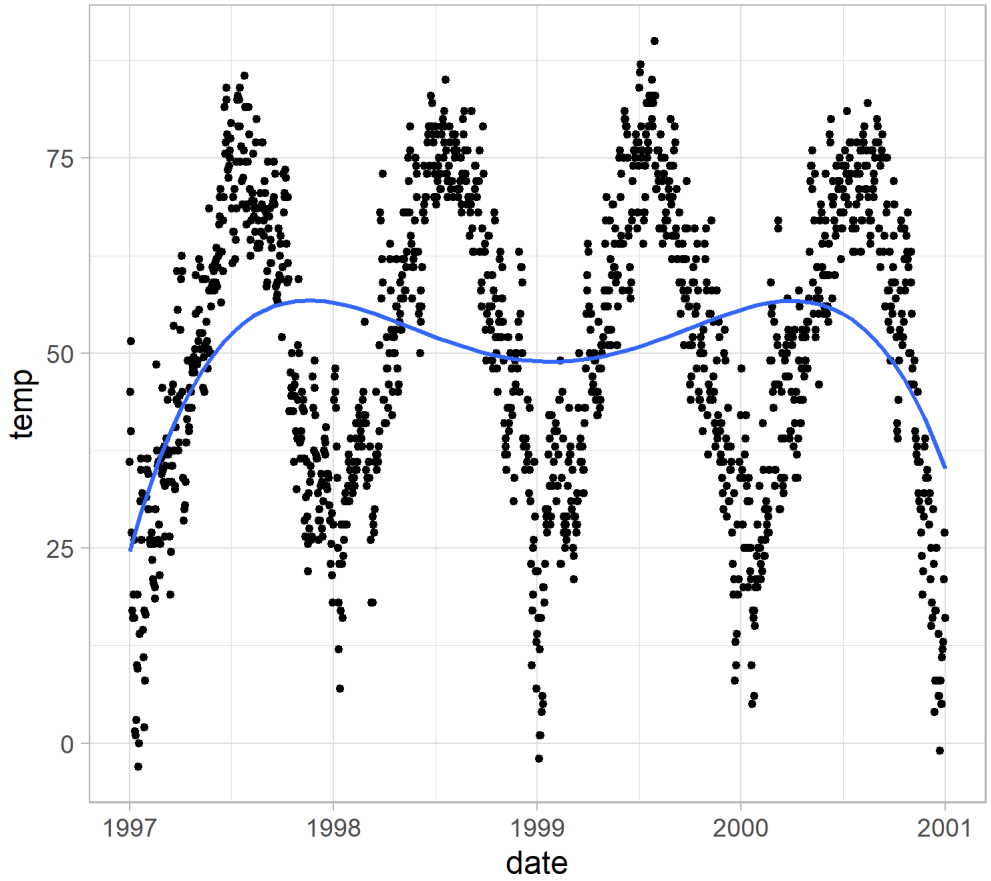
By default this adds a **LOESS** (locally weighted scatter plot smoothing, `method = "loess"`) or a **GAM** (generalized additive model, `method = "gam"`) depending on the number of data points (GAM in case of $\geq$ 1000 observations).



stat_smooth()

You can specify the fitting method and the formula:

```
ggplot(chic, aes(date, temp)) +
  geom_point() +
  stat_smooth(
    method = "lm",
    formula = y ~ x + I(x^2) +
                  I(x^3) + I(x^4),
    se = F
  )
```

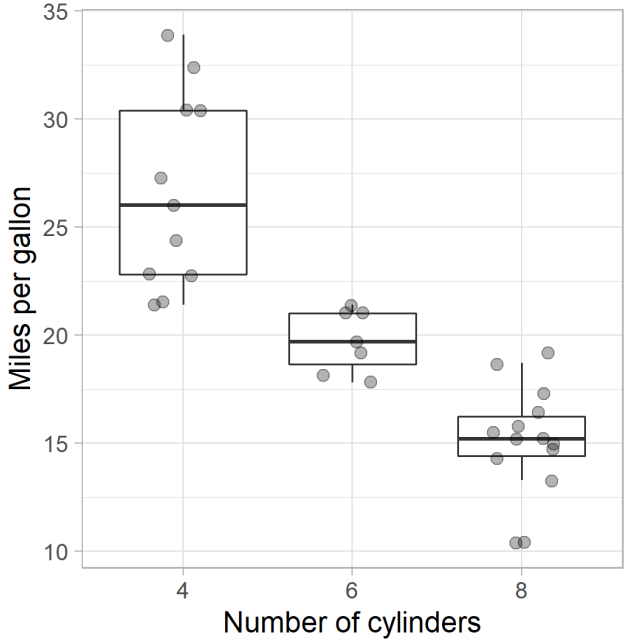


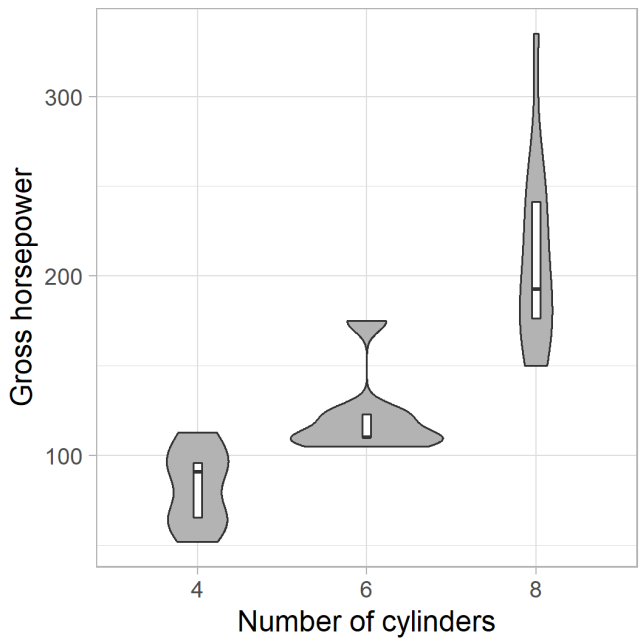
Other methods such as `method = "lm"` (without an explicit formula) for simple linear regressions and `method = "glm"` for generalized linear models are available as well.

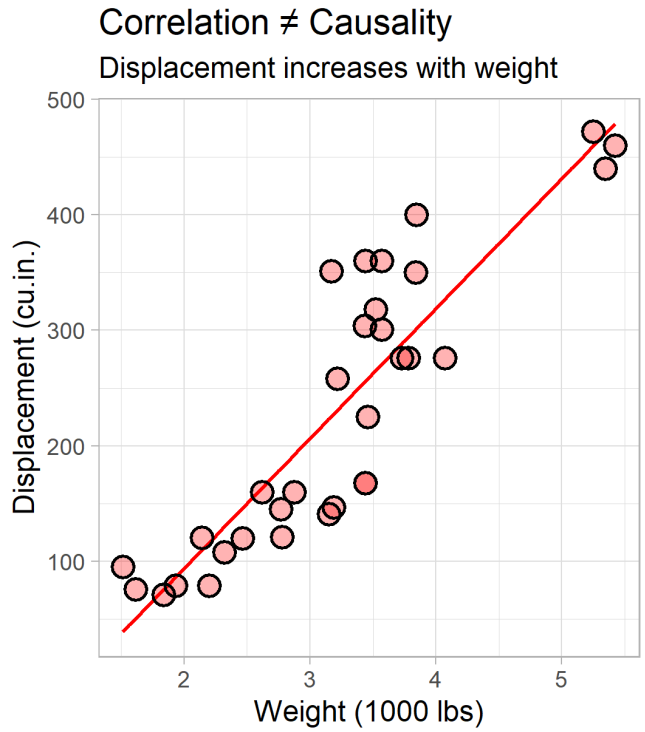
Your Turn!

A famous example datat set is `mtcars` which is pre-loaded in `R`.

- **Have a look at the data set and create the following three visualizations:**

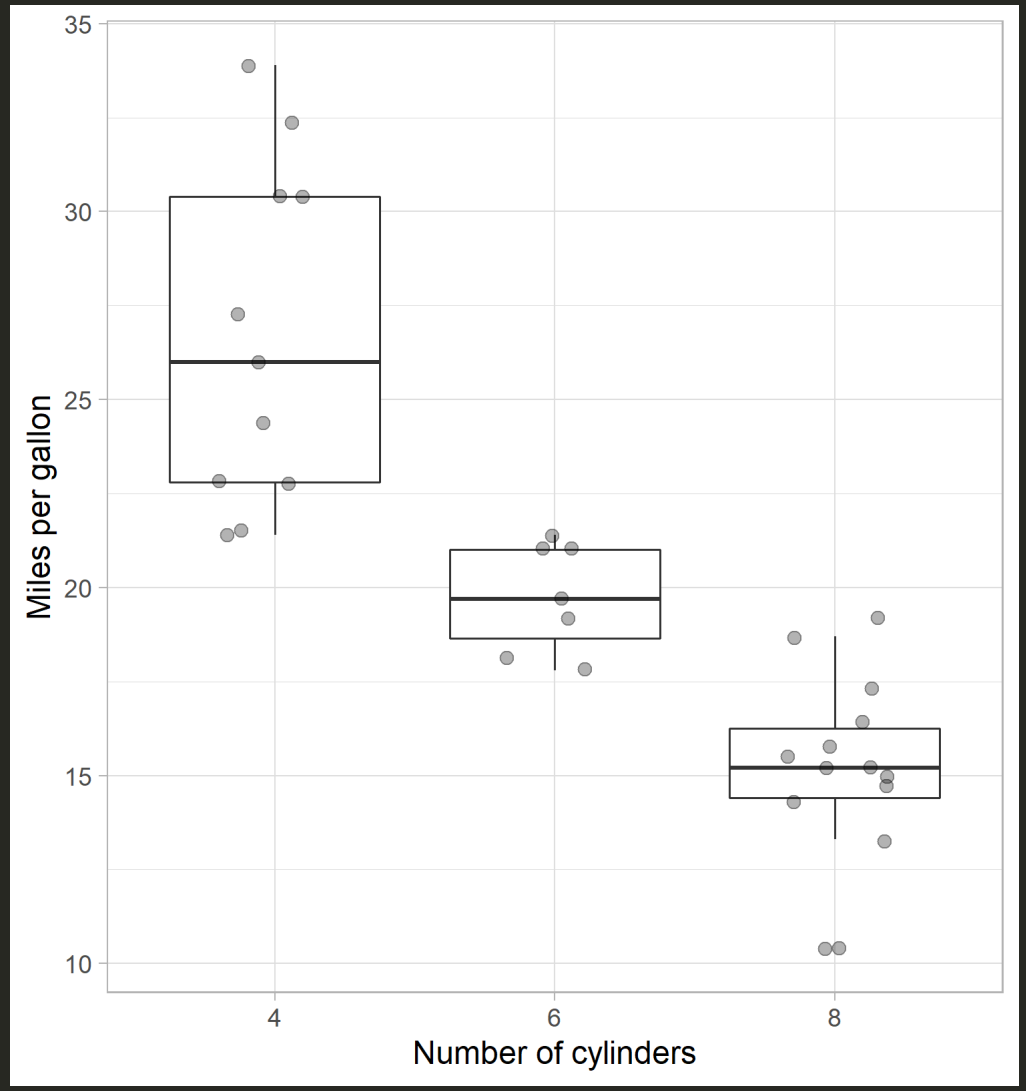




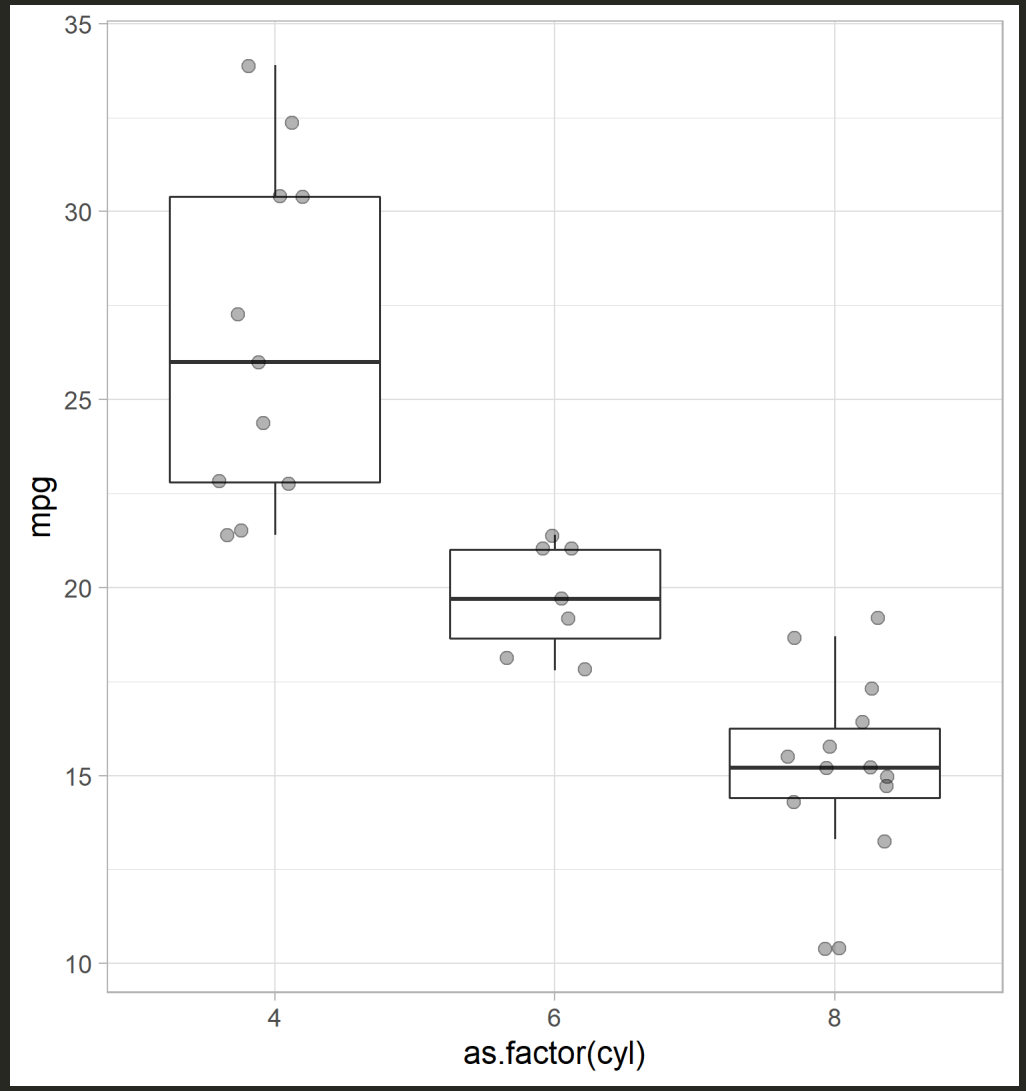


Data: 1974 "Motor Trend" US magazine

Your Turn: Create this Box Plot!

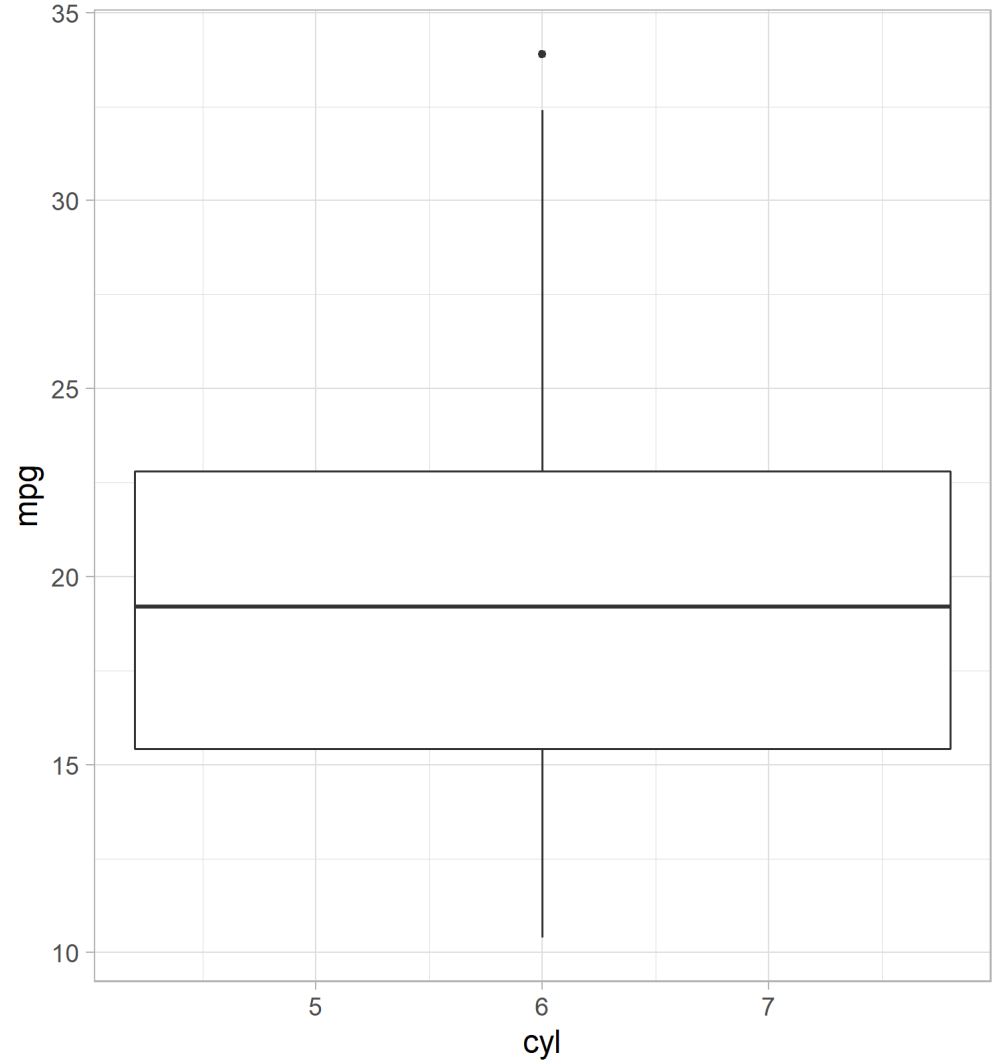


Your Turn: Create this Box Plot! (Less Mean)



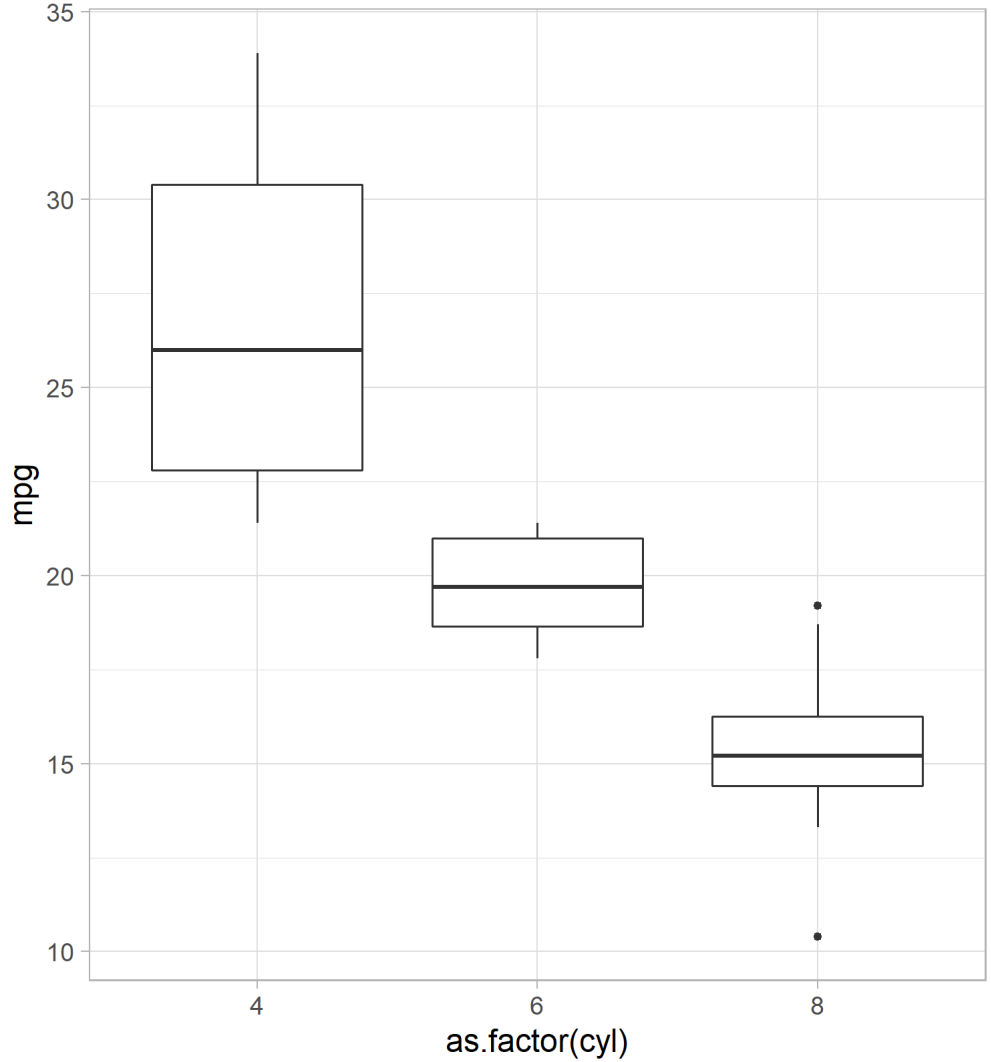
Your Turn: Box Plots with Raw Data

```
ggplot(
  mtcars,
  aes(cyl, mpg)
  ) +
  geom_boxplot()
```



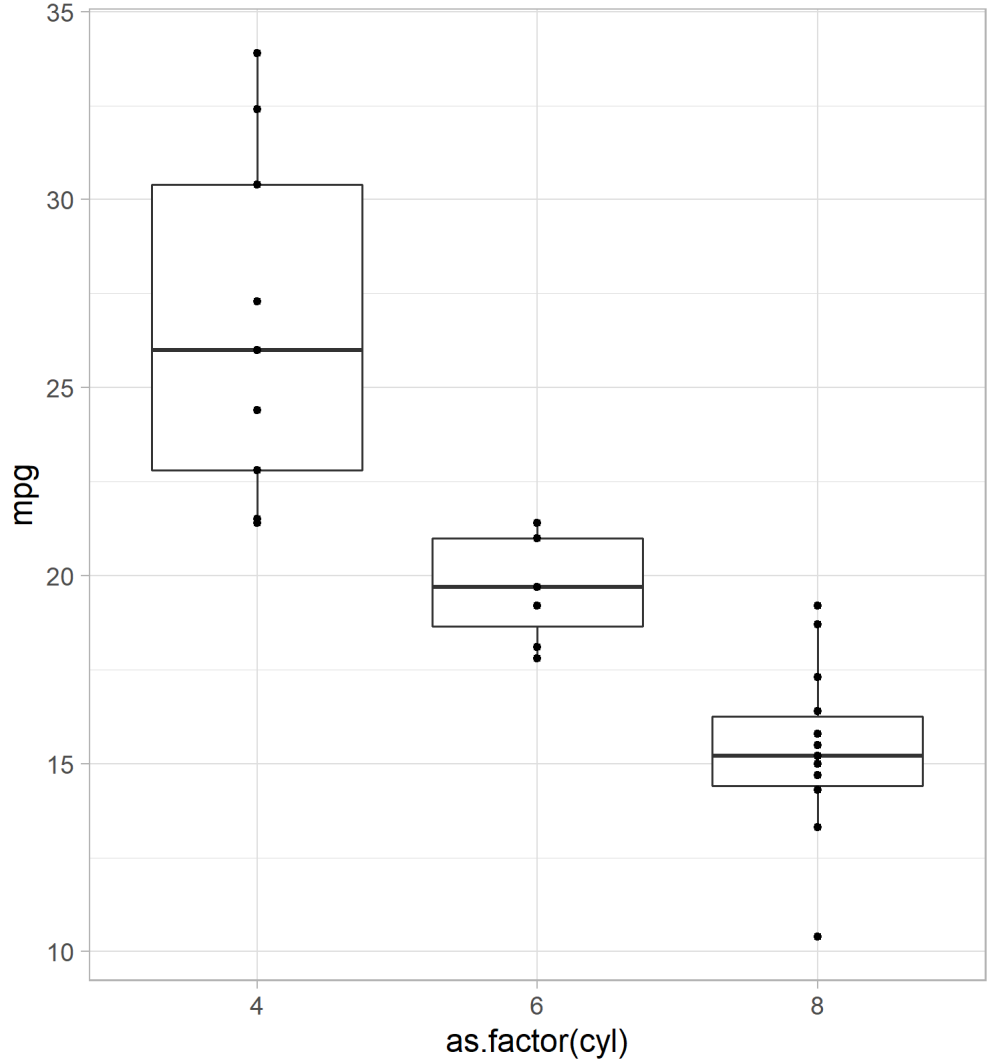
Your Turn: Box Plots with Raw Data

```
ggplot(
  mtcars,
  aes(as.factor(cyl), mpg)
  ) +
  geom_boxplot()
```



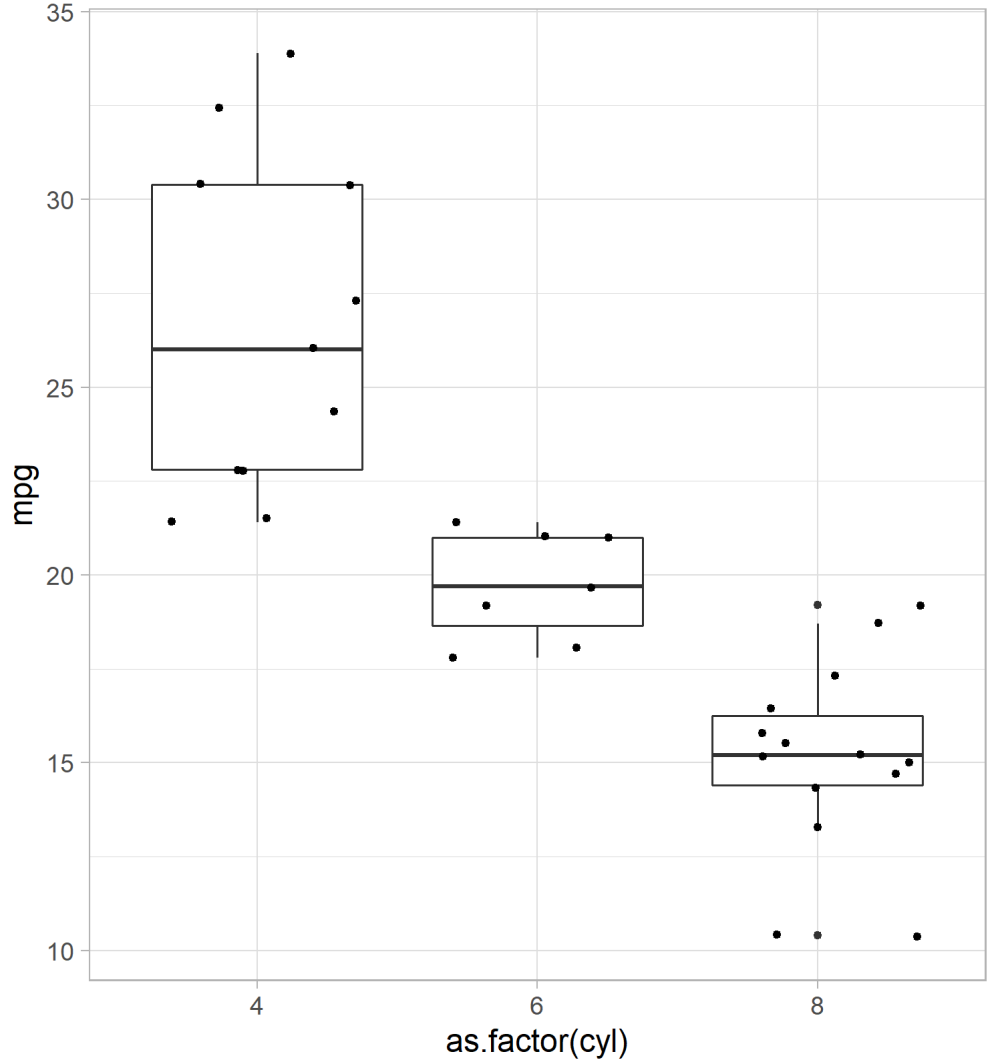
Your Turn: Box Plots with Raw Data

```
ggplot(
  mtcars,
  aes(as.factor(cyl), mpg)
  ) +
  geom_boxplot() +
  geom_point()
```



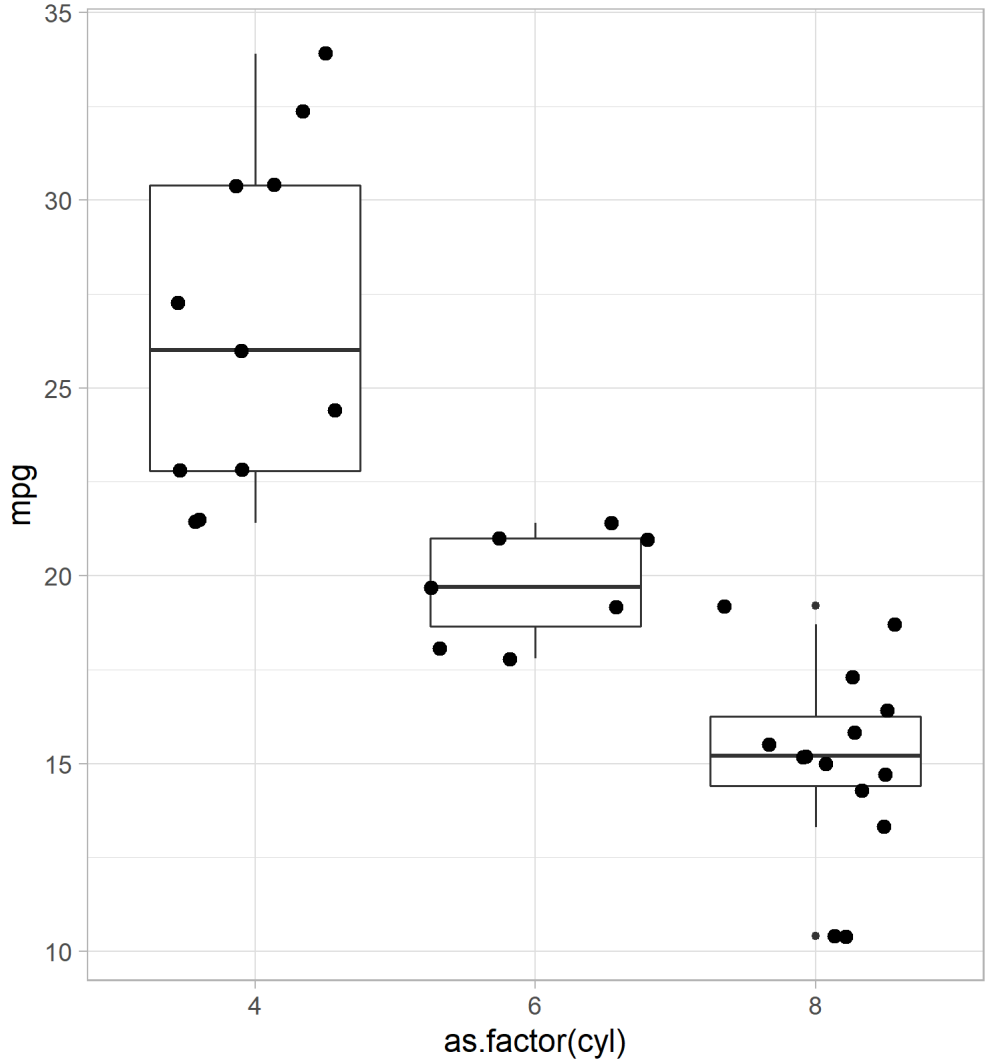
Your Turn: Box Plots with Raw Data

```
ggplot(
  mtcars,
  aes(as.factor(cyl), mpg)
  ) +
  geom_boxplot() +
  geom_jitter()
```



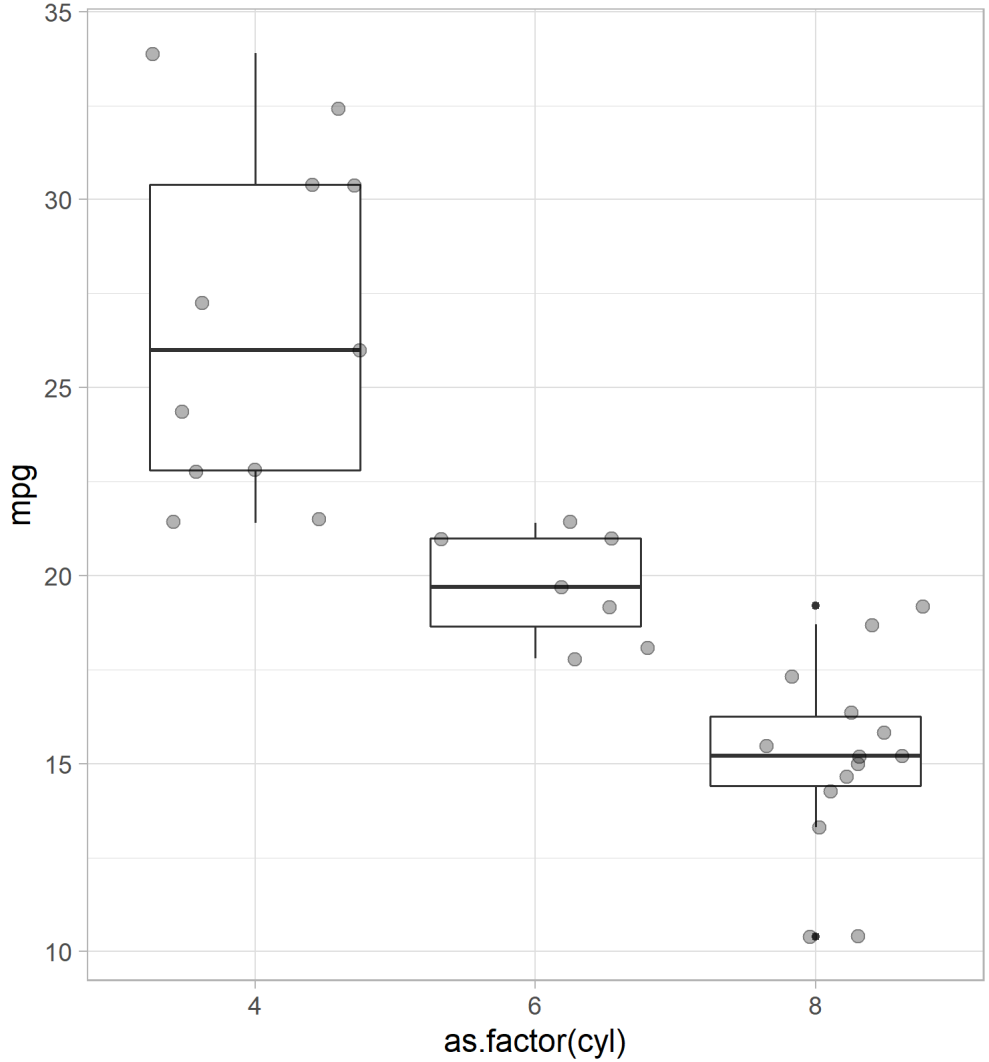
Your Turn: Box Plots with Raw Data

```
ggplot(
  mtcars,
  aes(as.factor(cyl), mpg)
  ) +
  geom_boxplot() +
  geom_jitter(
    size = 3
  )
```



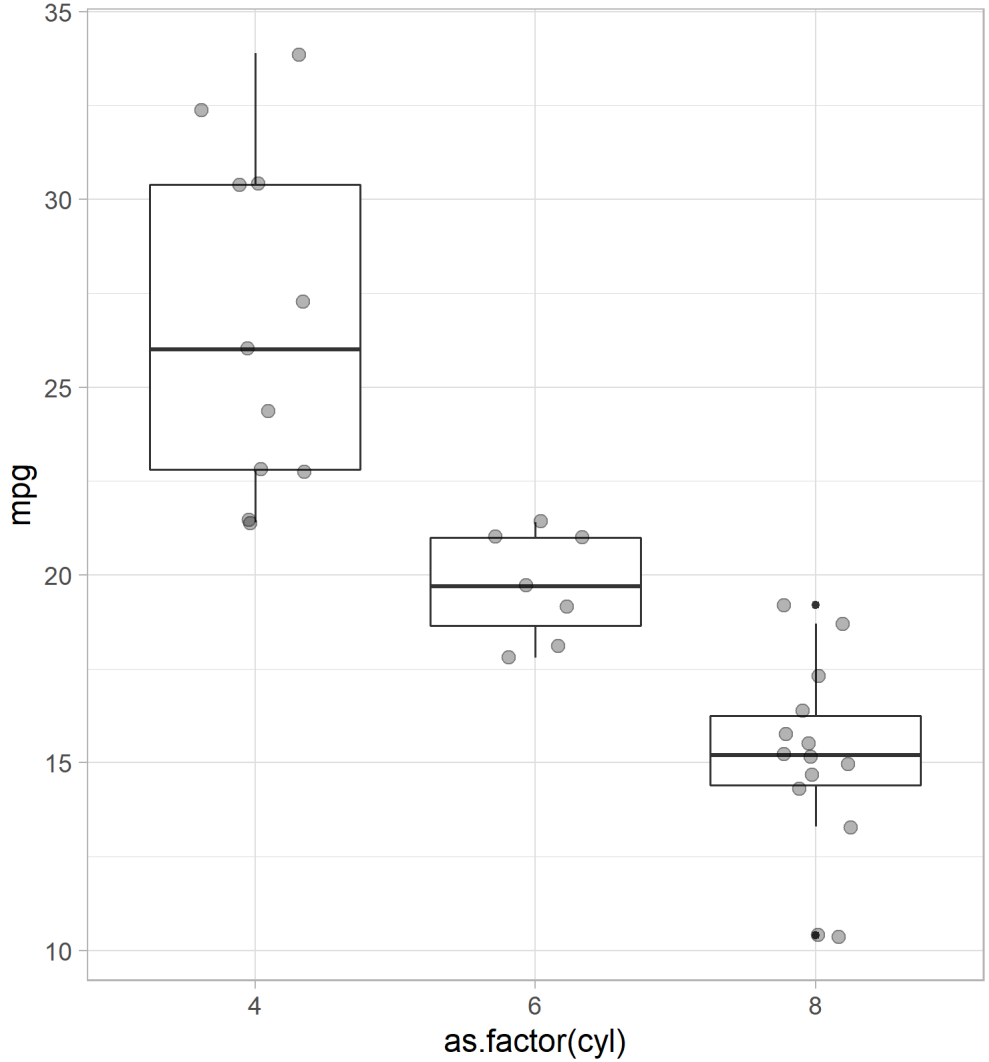
Your Turn: Box Plots with Raw Data

```
ggplot(
  mtcars,
  aes(as.factor(cyl), mpg)
  ) +
  geom_boxplot() +
  geom_jitter(
    size = 3,
    alpha = .3
  )
```



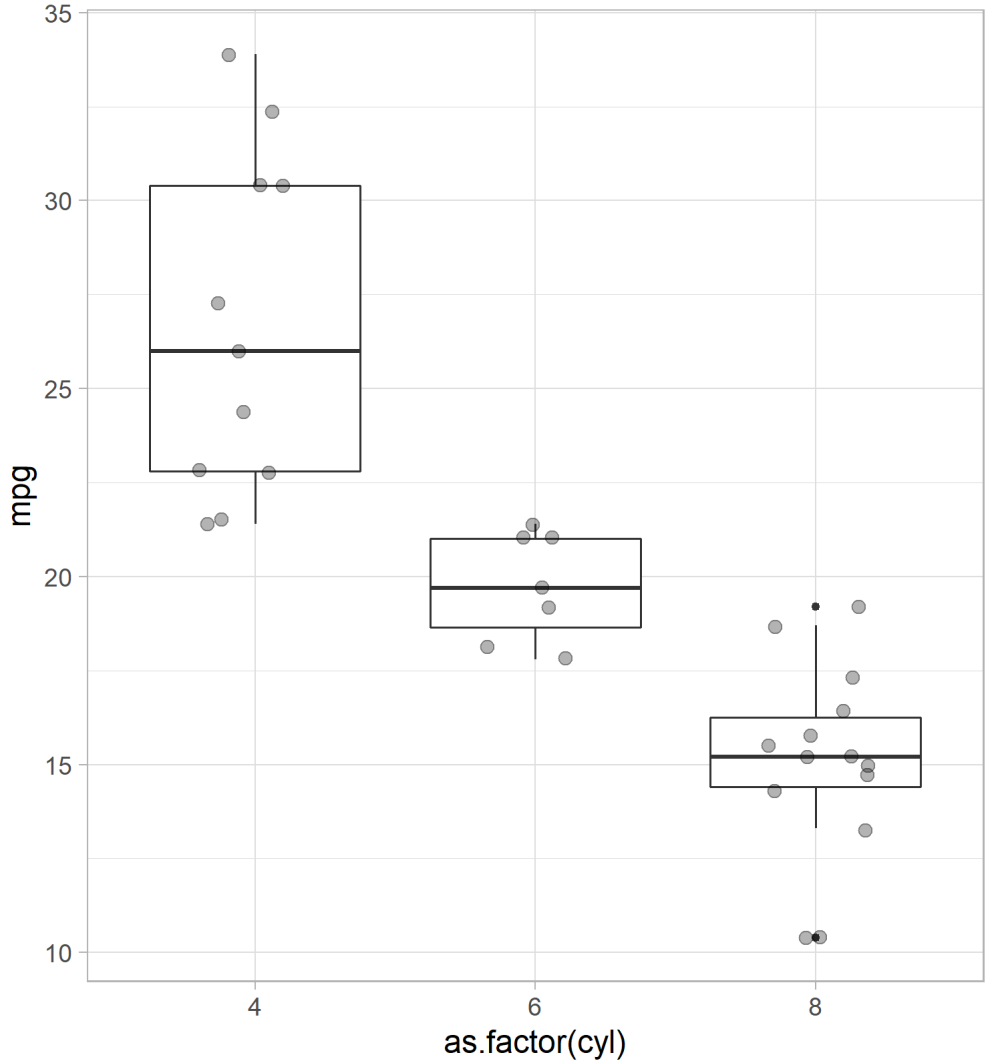
Your Turn: Box Plots with Raw Data

```
ggplot(
  mtcars,
  aes(as.factor(cyl), mpg)
  ) +
  geom_boxplot() +
  geom_jitter(
    size = 3,
    alpha = .3,
    width = .2
  )
```



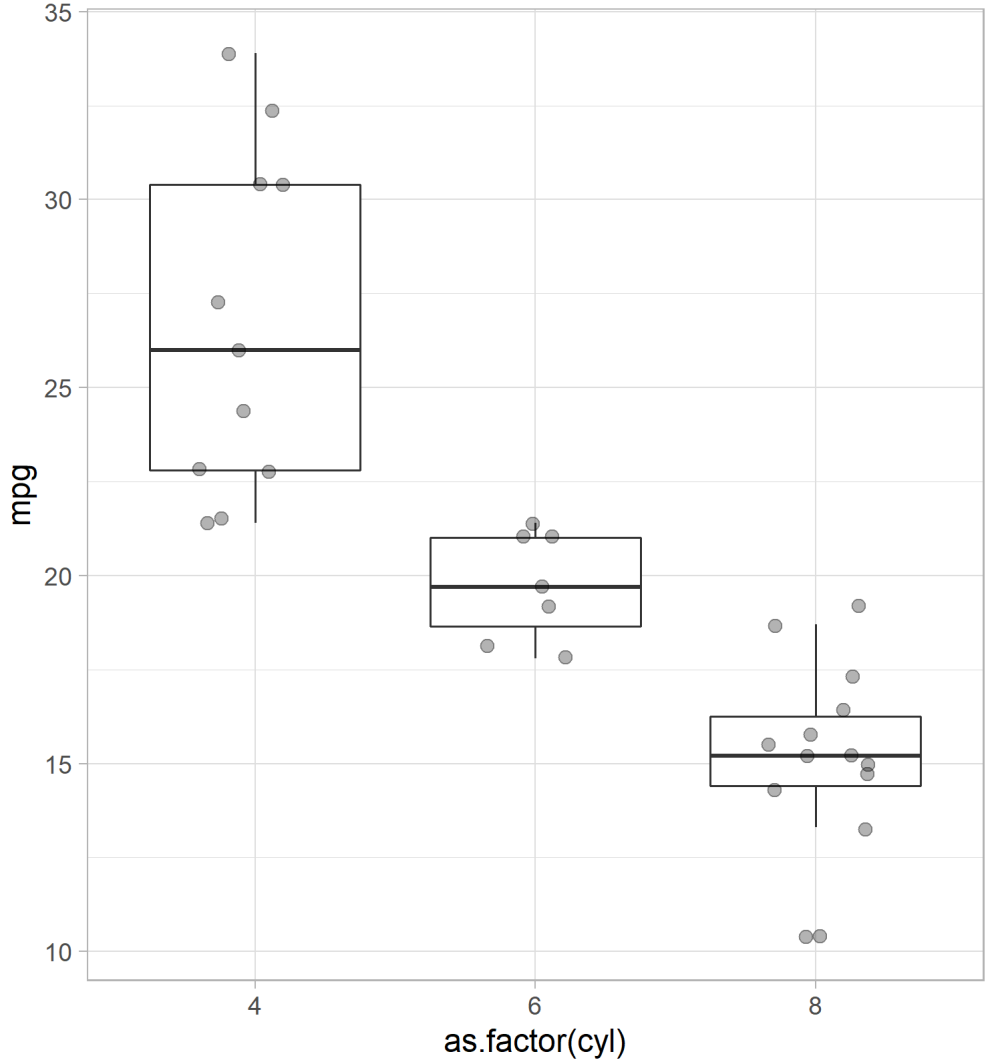
Your Turn: Box Plots with Raw Data

```
ggplot(
  mtcars,
  aes(as.factor(cyl), mpg)
  ) +
  geom_boxplot() +
  geom_jitter(
    size = 3,
    alpha = .3,
    position = position_jitter(
      width = .2,
      seed = 2020
    )
  )
```



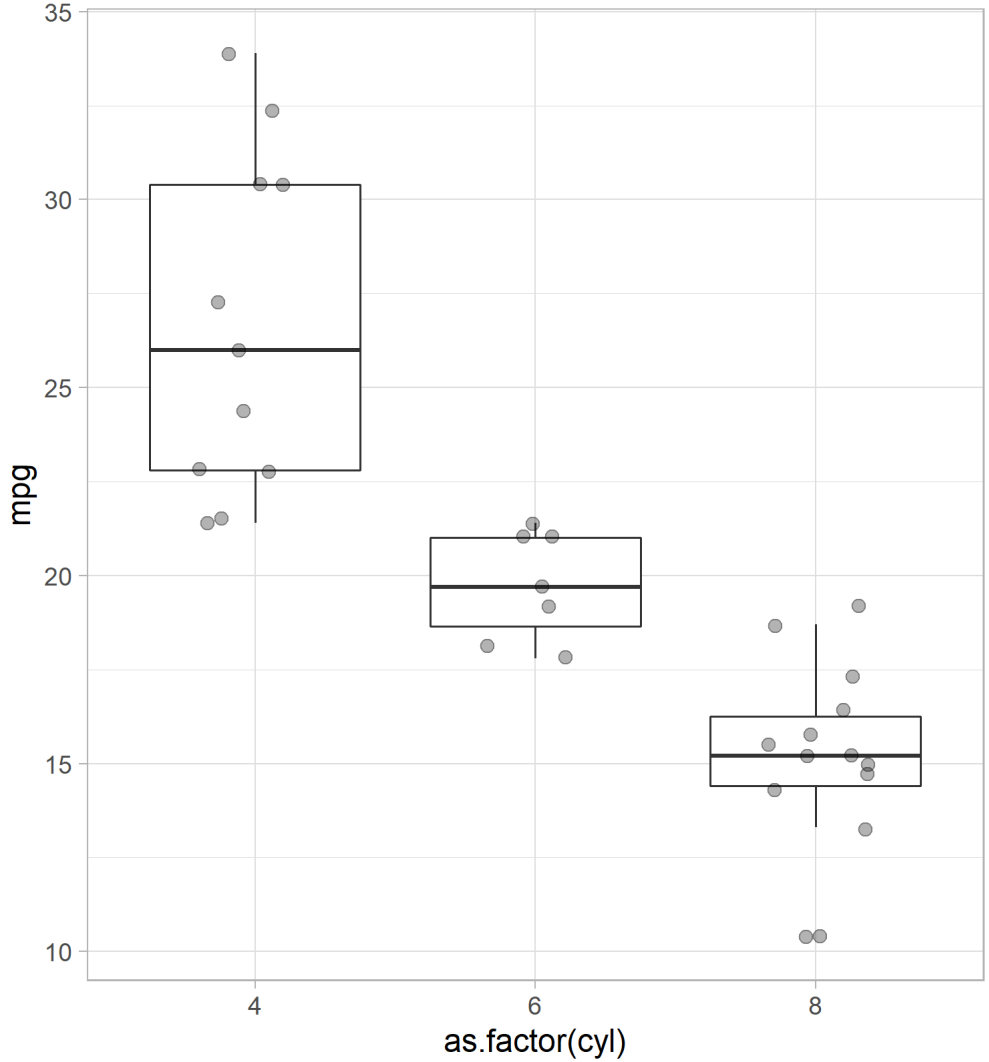
Your Turn: Box Plots with Raw Data

```
ggplot(
  mtcars,
  aes(as.factor(cyl), mpg)
  ) +
  geom_boxplot(
    outlier.alpha = 0
  ) +
  geom_jitter(
    size = 3,
    alpha = .3,
    position = position_jitter(
      width = .2,
      seed = 2020
    )
  )
```

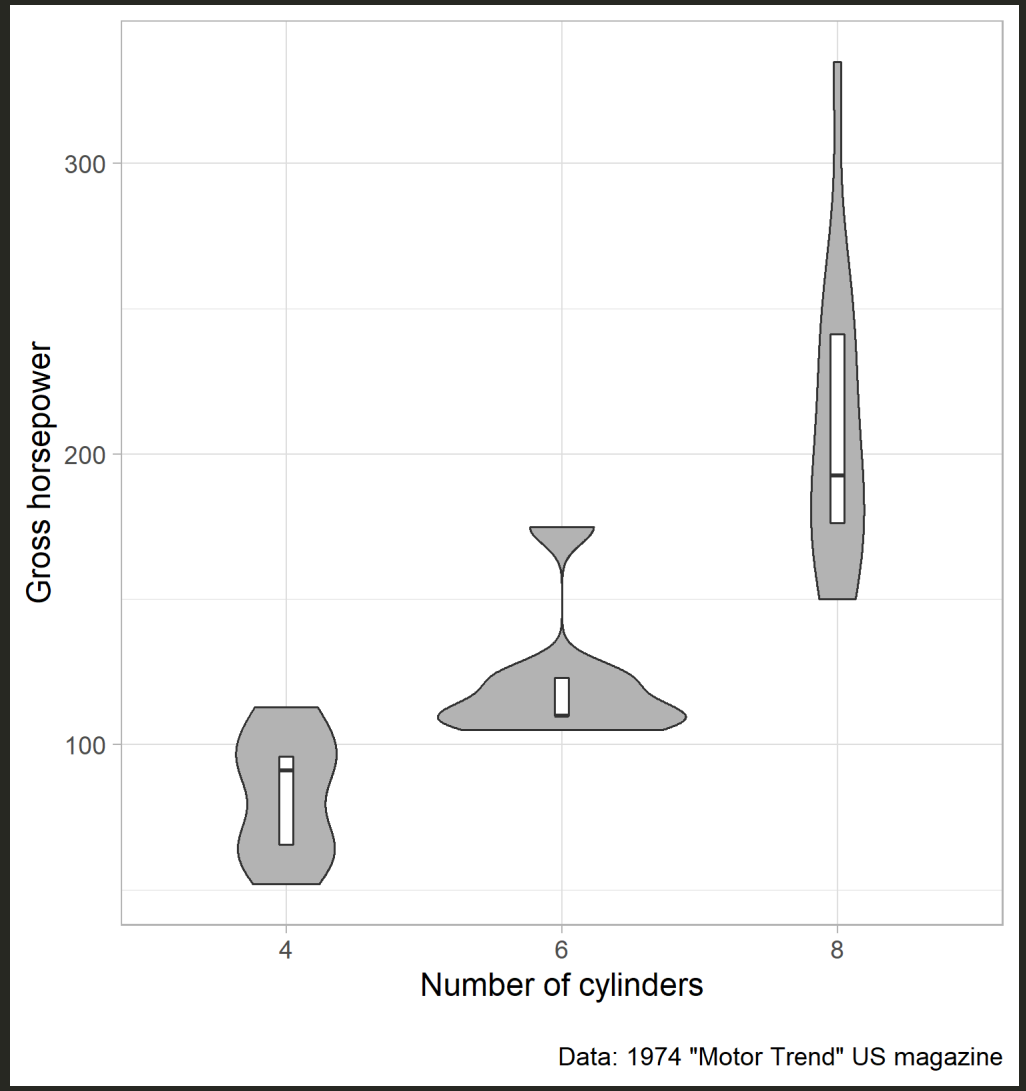


Your Turn: Box Plots with Raw Data

```
ggplot(
  mtcars,
  aes(as.factor(cyl), mpg
  )) +
  geom_boxplot(
    #outlier.alpha = 0,
    outlier.shape = NA
  ) +
  geom_jitter(
    size = 3,
    alpha = .3,
    position = position_jitter(
      width = .2,
      seed = 2020
    )
  )
```

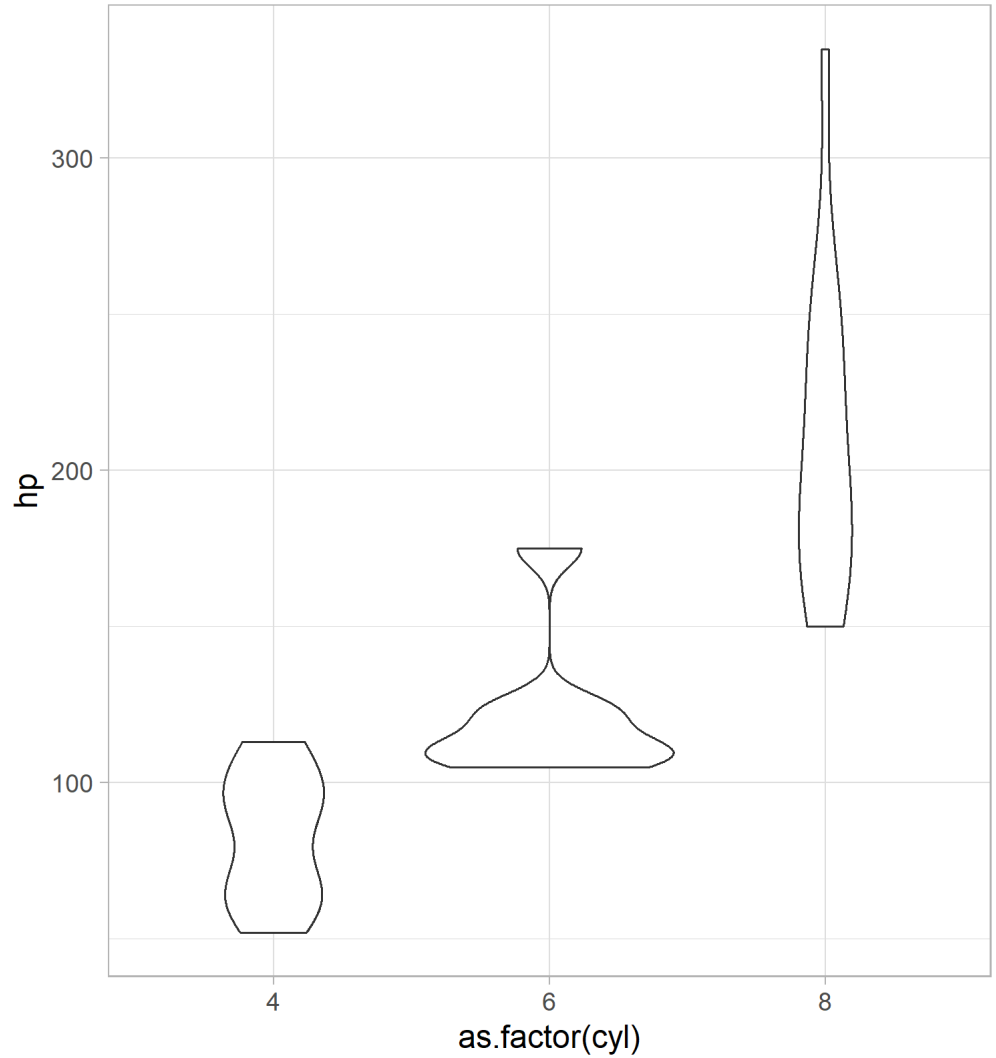


Your Turn: Create this Violin Plot!



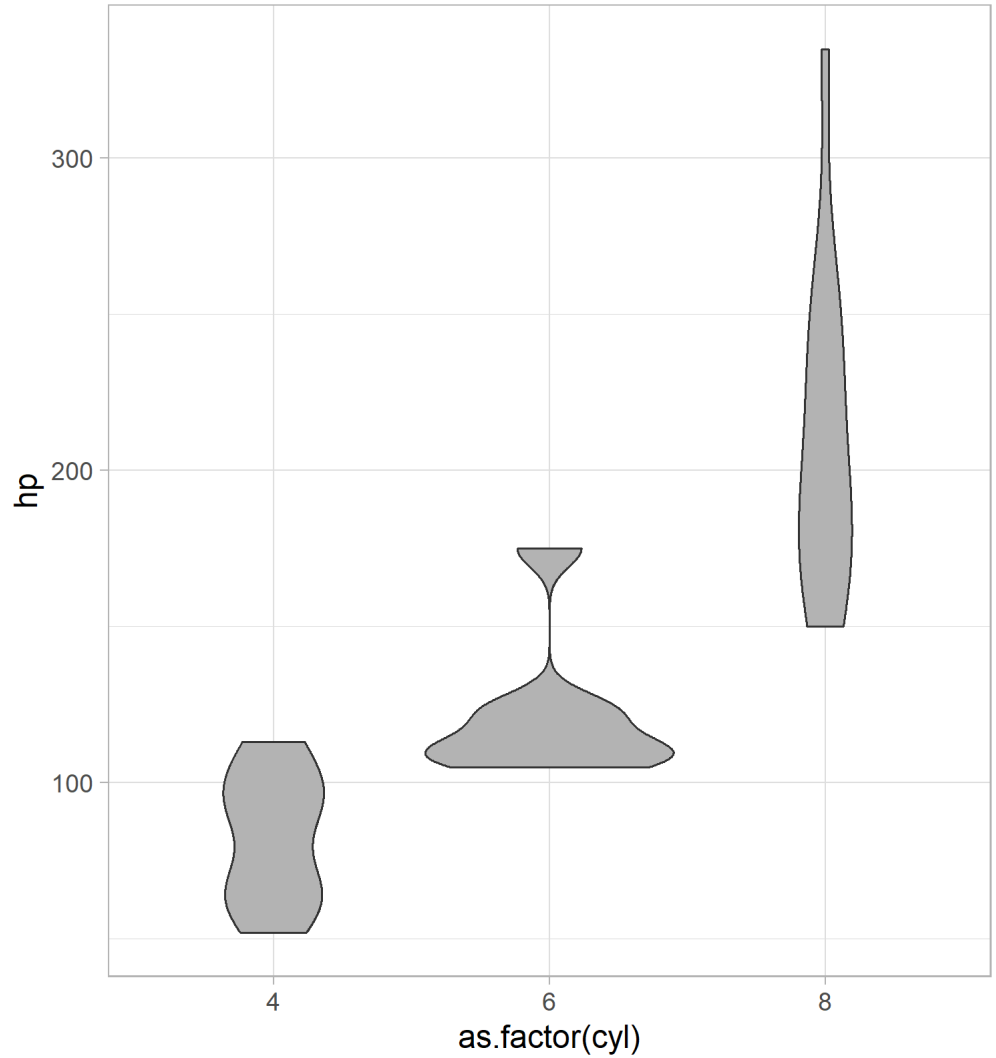
Your Turn: Violin Plot

```
ggplot(
  mtcars,
  aes(as.factor(cyl), hp)
  ) +
  geom_violin()
```



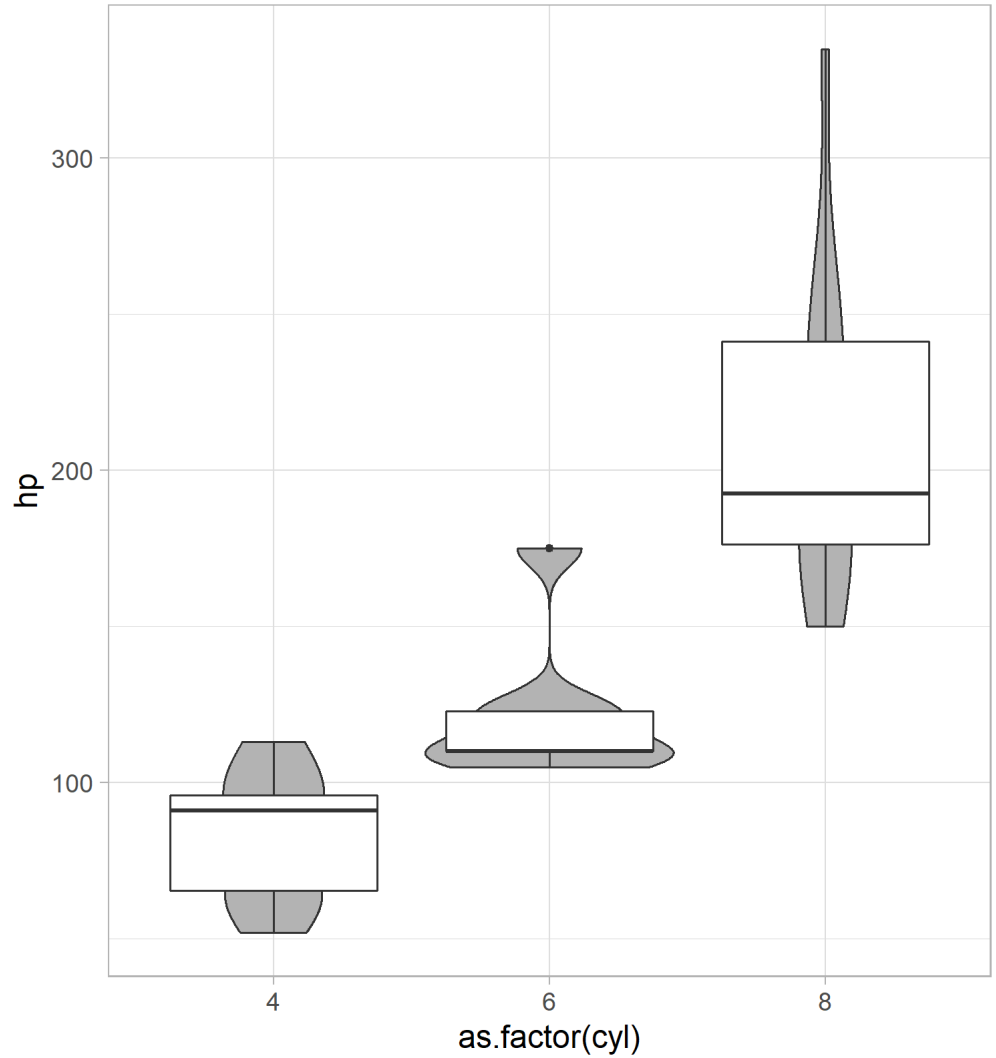
Your Turn: Violin Plot

```
ggplot(
  mtcars,
  aes(as.factor(cyl), hp)
  ) +
  geom_violin(
    fill = "grey70"
  )
```



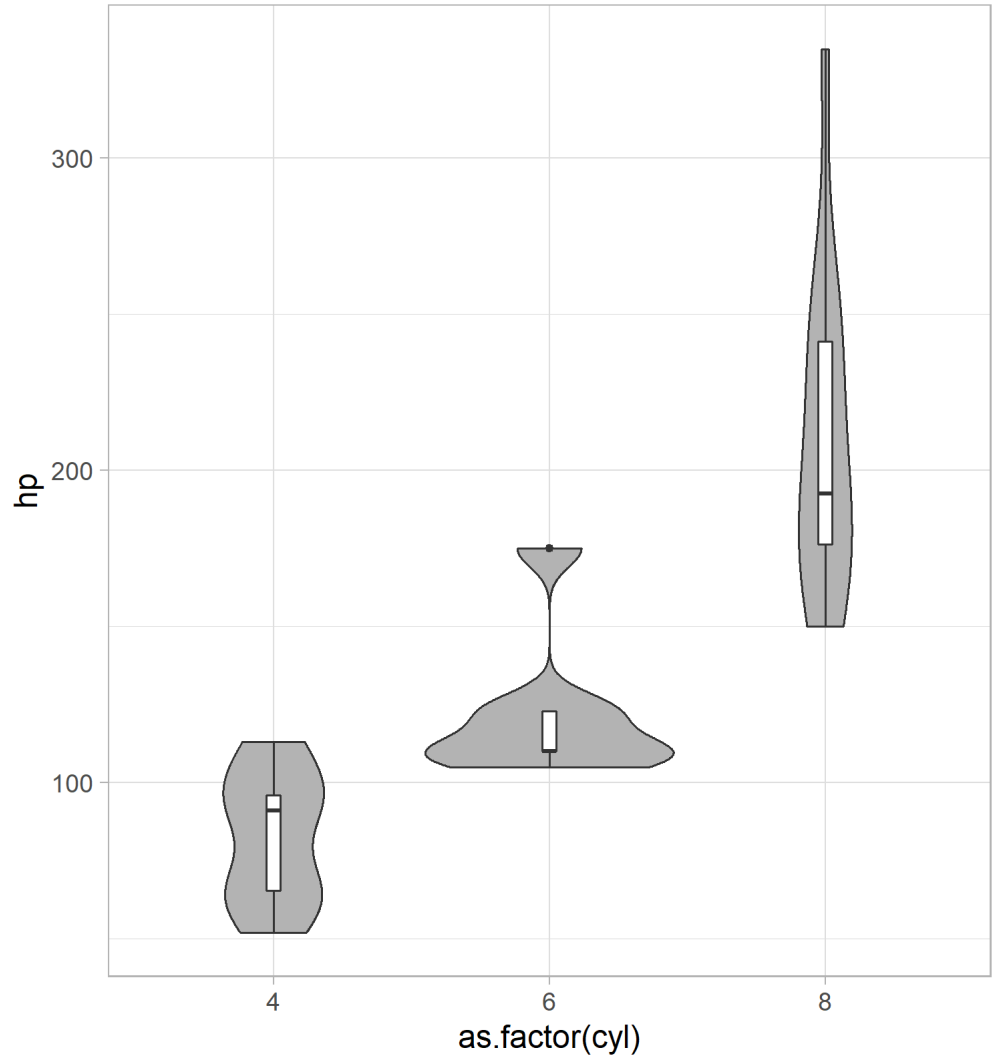
Your Turn: Violin Plot

```
ggplot(
  mtcars,
  aes(as.factor(cyl), hp)
  ) +
  geom_violin(
    fill = "grey70"
  ) +
  geom_boxplot()
```



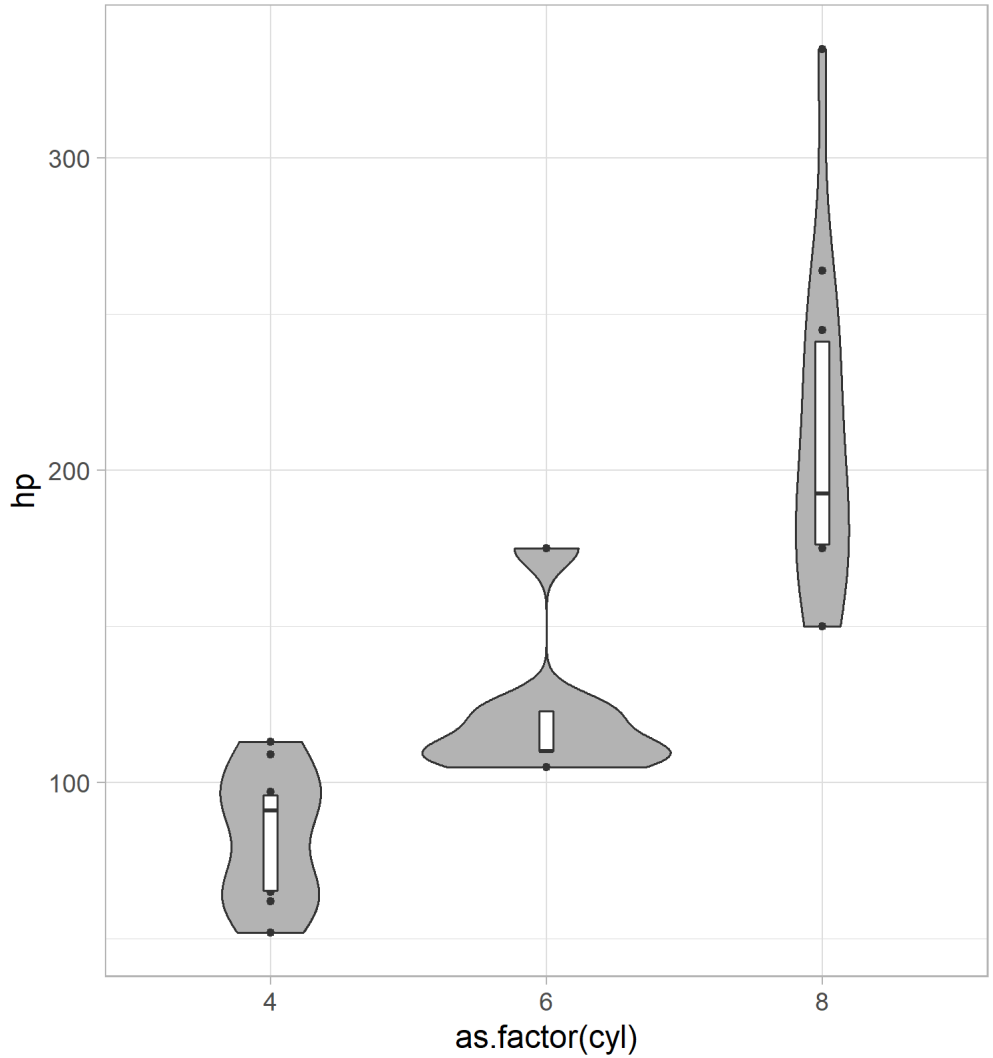
Your Turn: Violin Plot

```
ggplot(
  mtcars,
  aes(as.factor(cyl), hp)
  ) +
  geom_violin(
    fill = "grey70"
  ) +
  geom_boxplot(width = .05)
```



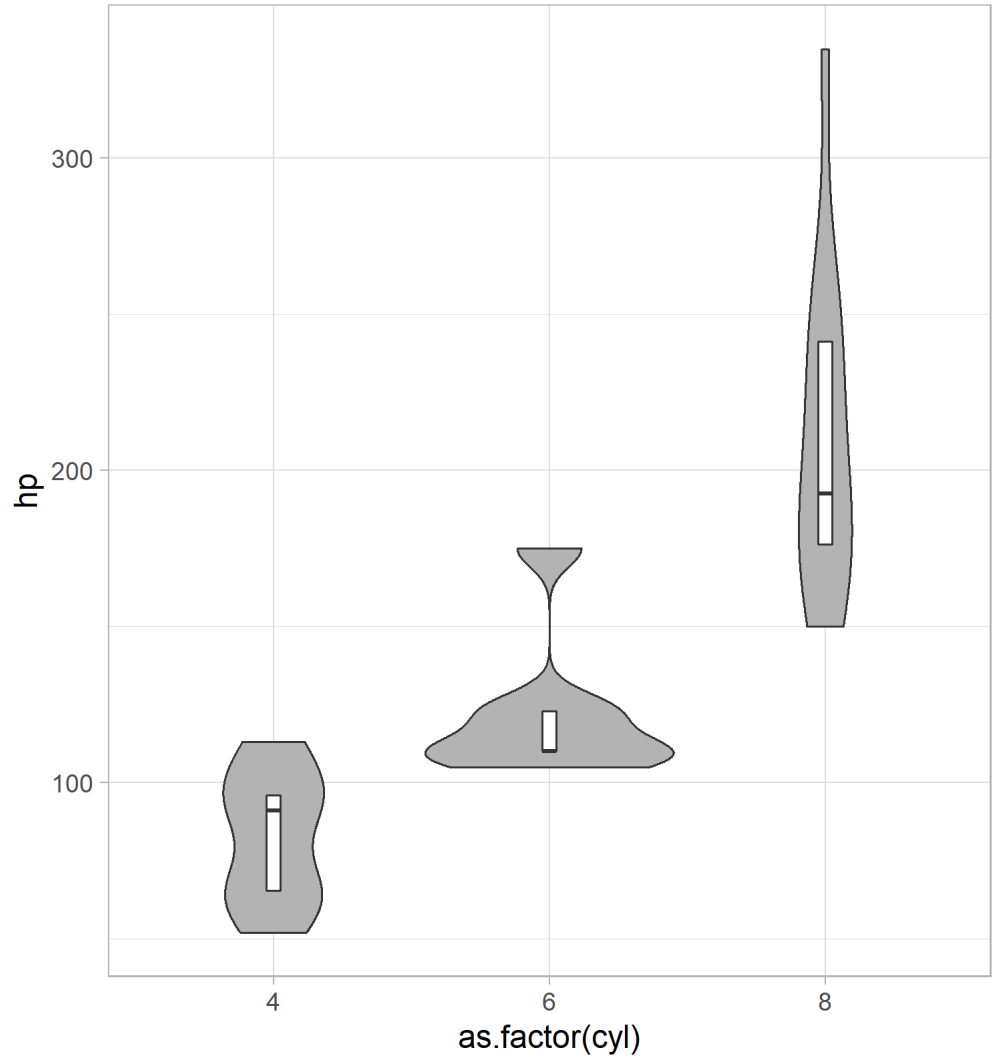
Your Turn: Violin Plot

```
ggplot(
  mtcars,
  aes(as.factor(cyl), hp)
  ) +
  geom_violin(
    fill = "grey70"
  ) +
  geom_boxplot(
    width = .05,
    coef = 0
  )
```



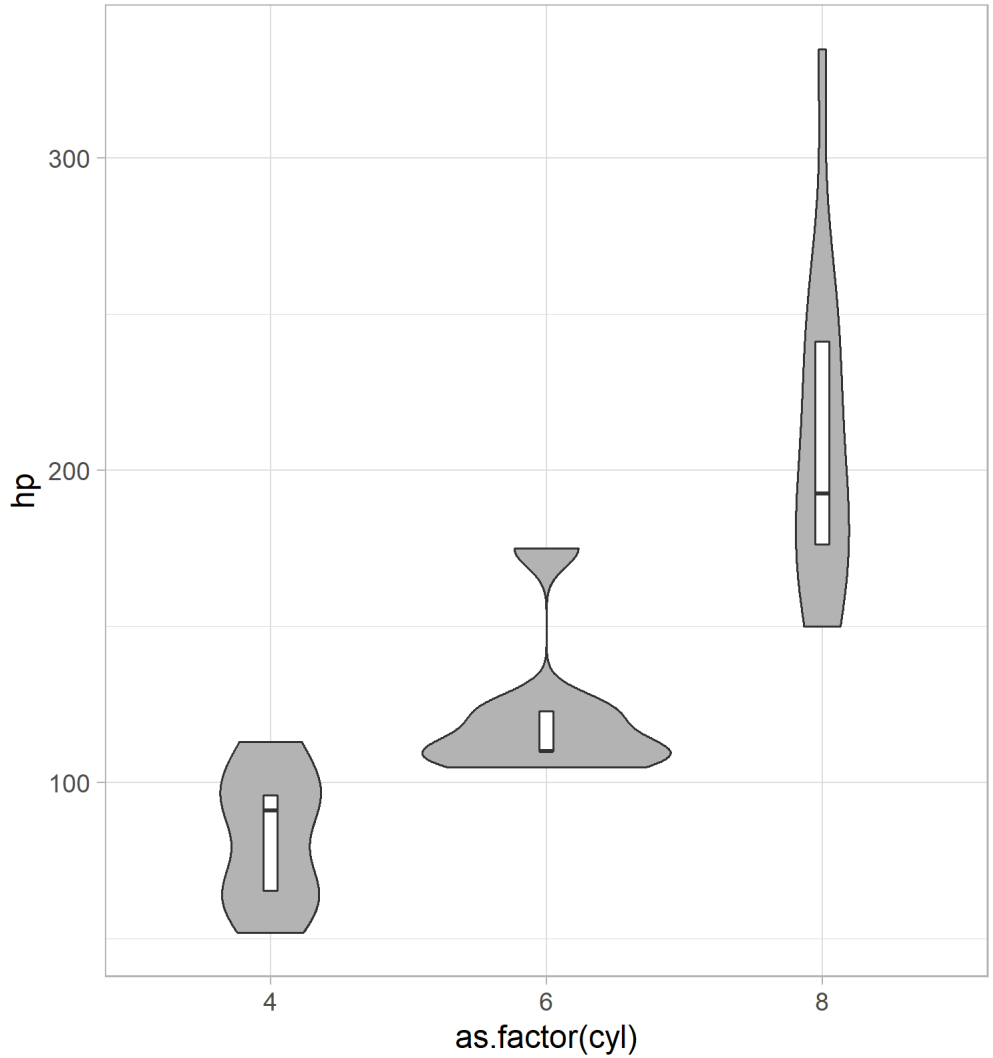
Your Turn: Violin Plot

```
ggplot(
  mtcars,
  aes(as.factor(cyl), hp)
  ) +
  geom_violin(
    fill = "grey70"
  ) +
  geom_boxplot(
    width = .05,
    coef = 0,
    outlier.shape = NA
  )
```



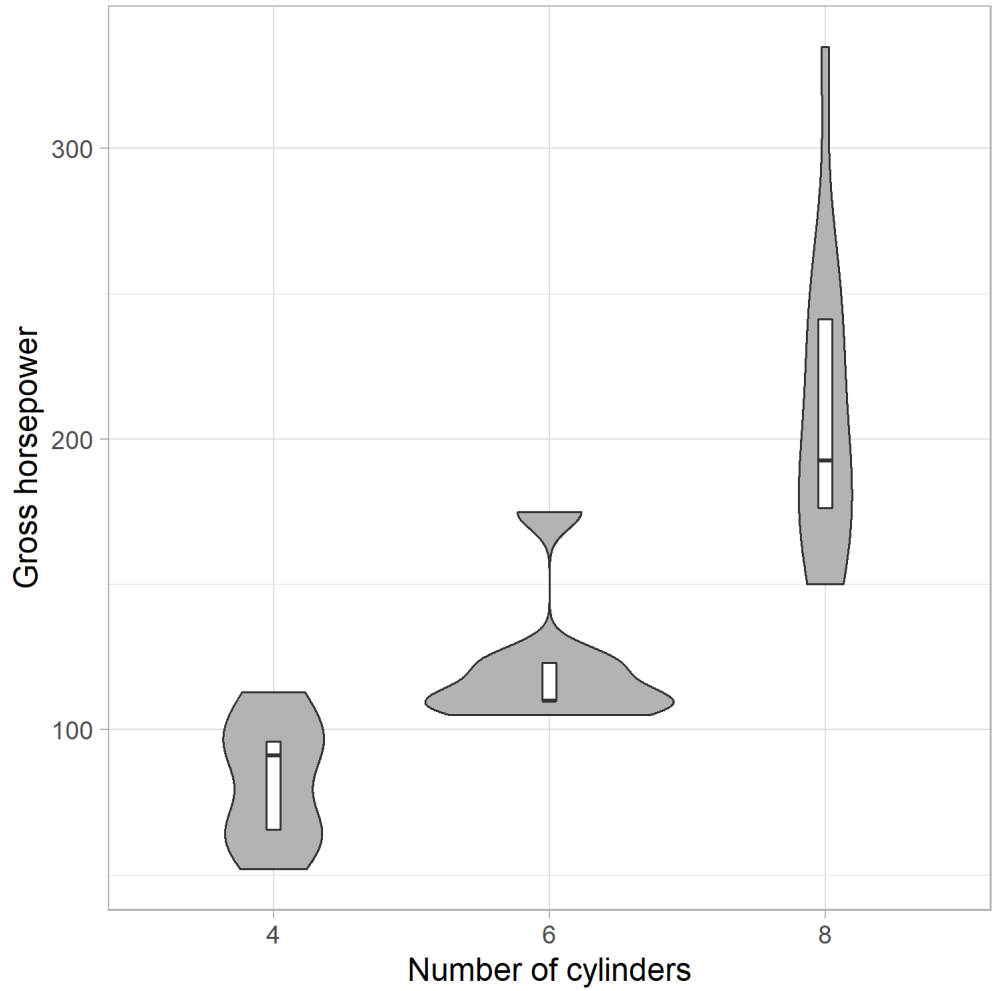
Your Turn: Violin Plot

```
ggplot(
  mtcars,
  aes(as.factor(cyl), hp)
  ) +
  geom_violin(
    fill = "grey70"
  ) +
  geom_boxplot(
    width = .05,
    coef = 0,
    #outlier.shape = NA
    outlier.alpha = 0
  )
```

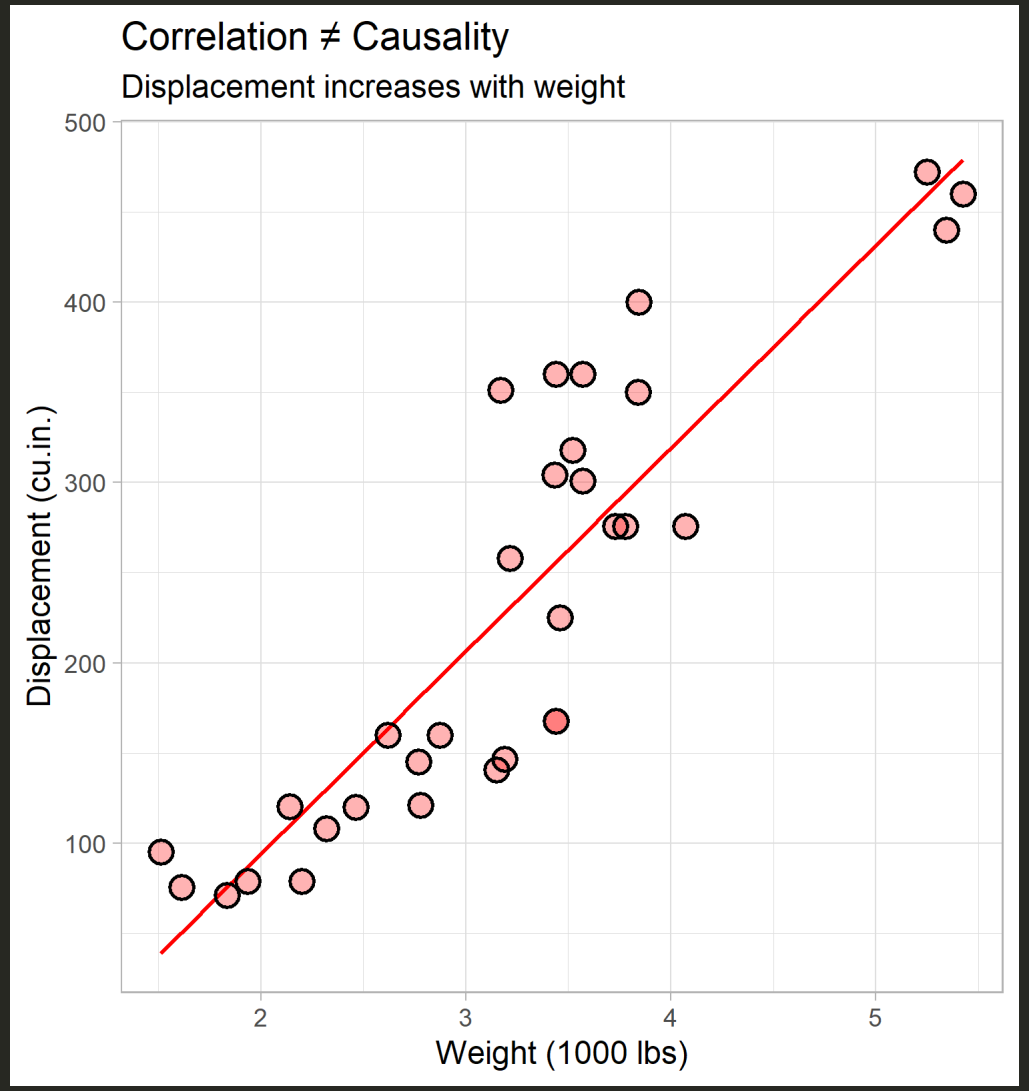


Your Turn: Violin Plot

```
ggplot(
  mtcars,
  aes(as.factor(cyl), hp)
  ) +
  geom_violin(
    fill = "grey70"
  ) +
  geom_boxplot(
    width = .05,
    coef = 0,
    #outlier.shape = NA
    outlier.alpha = 0
  ) +
  labs(
    x = "Number of cylinders",
    y = "Gross horsepower",
    caption = '\nData: 1974 "Motor Trend"
  )
```

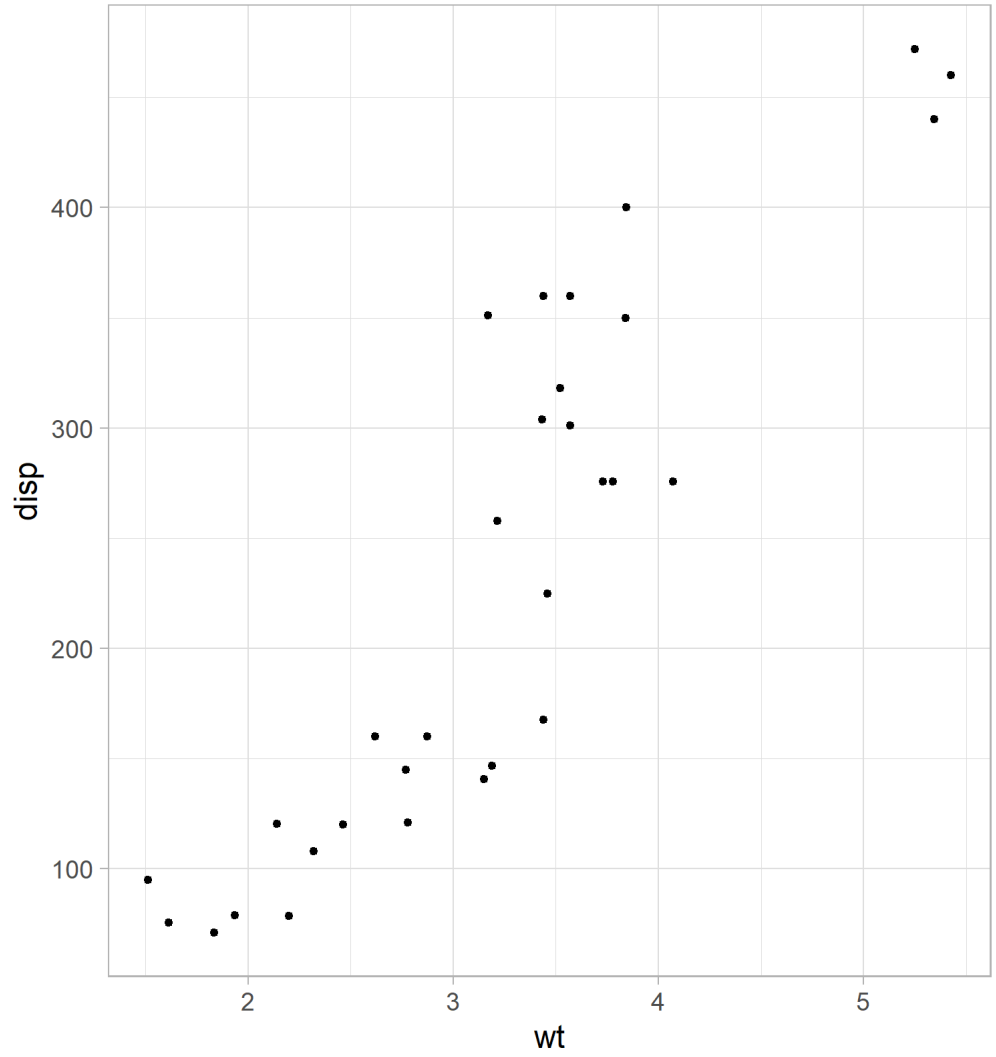


Your Turn: Create this Scatter Plot!



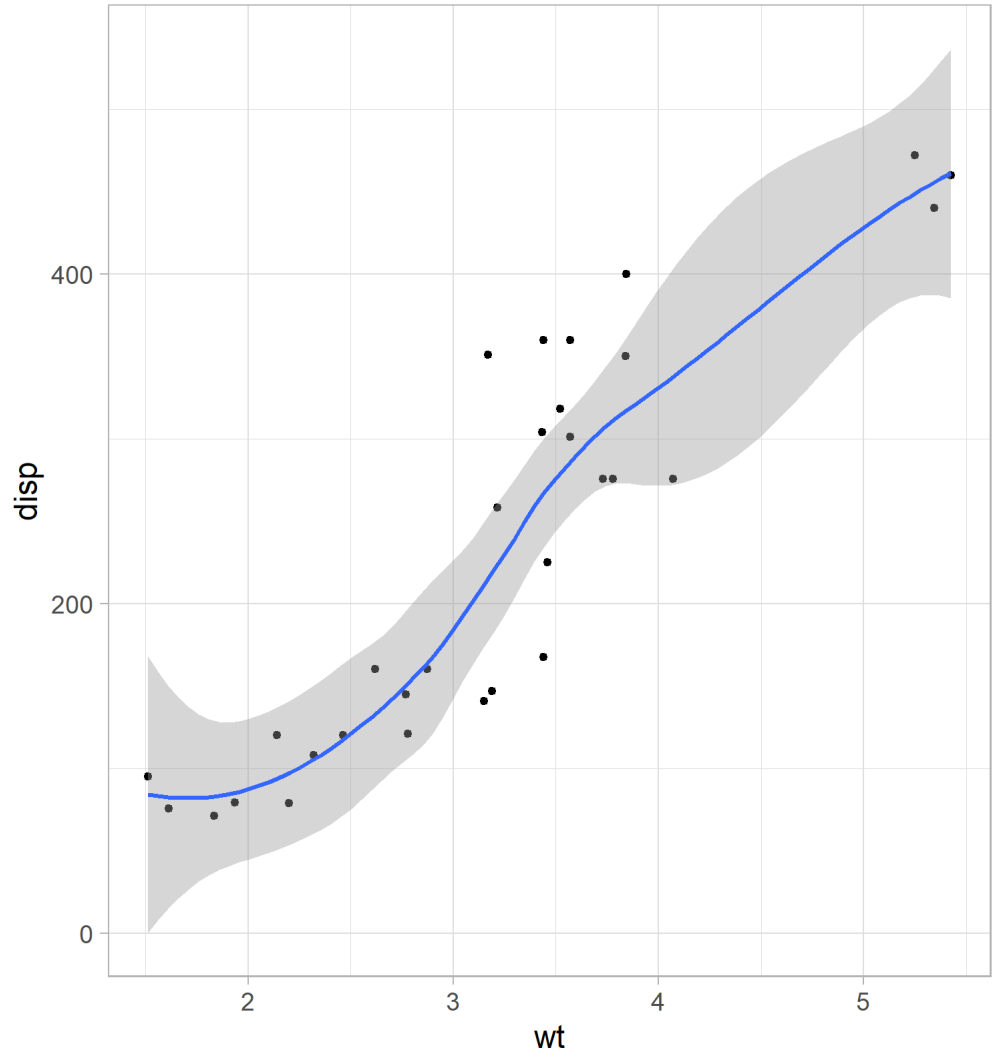
Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  geom_point()
```



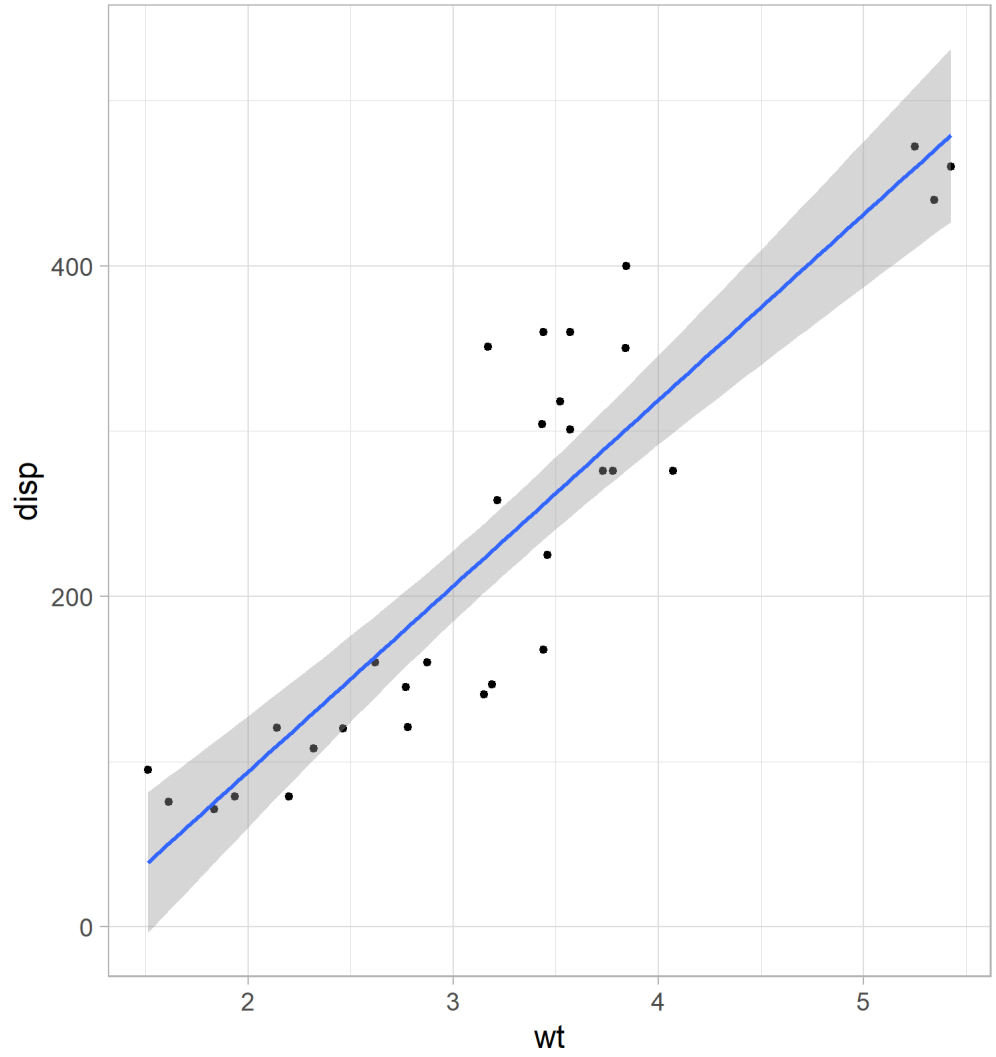
Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  geom_point() +
  stat_smooth()
```



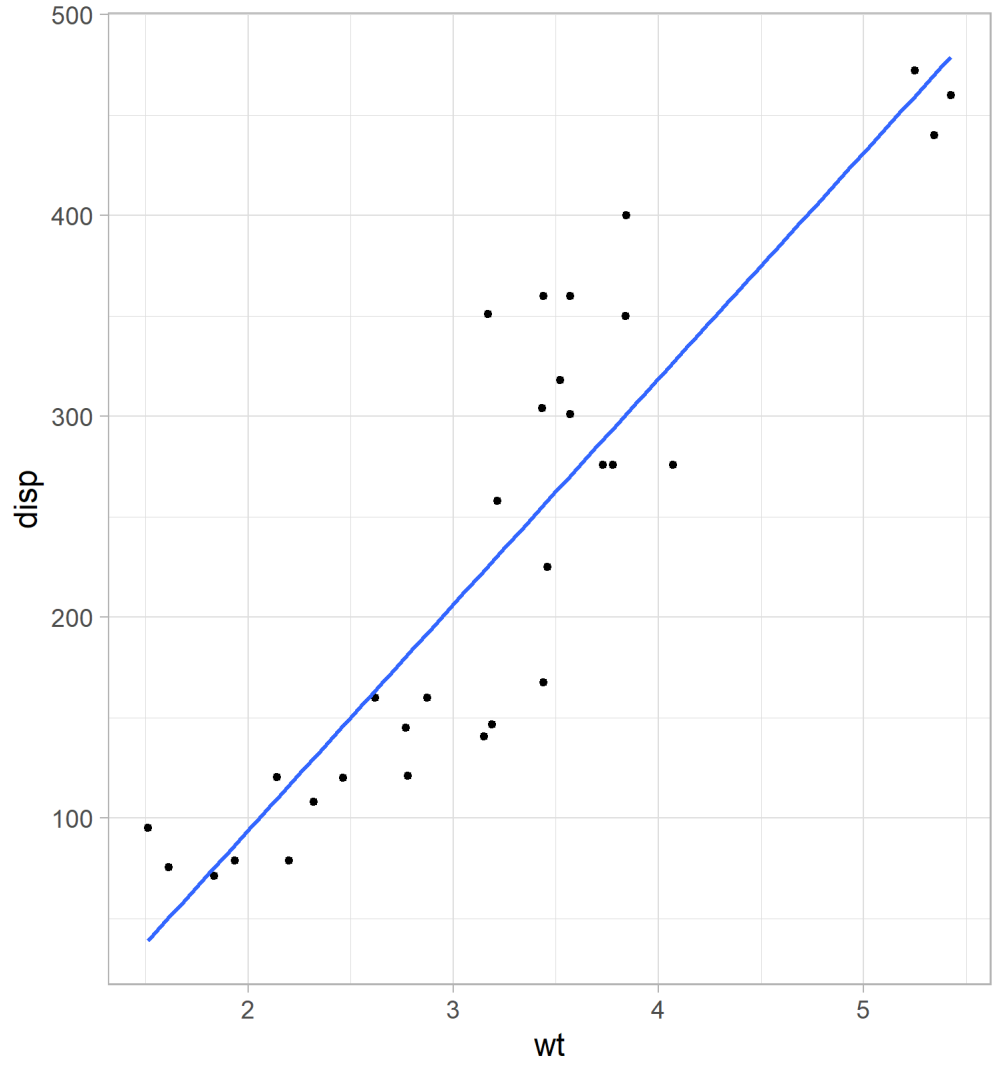
Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  geom_point() +
  stat_smooth(
    method = "lm"
  )
```



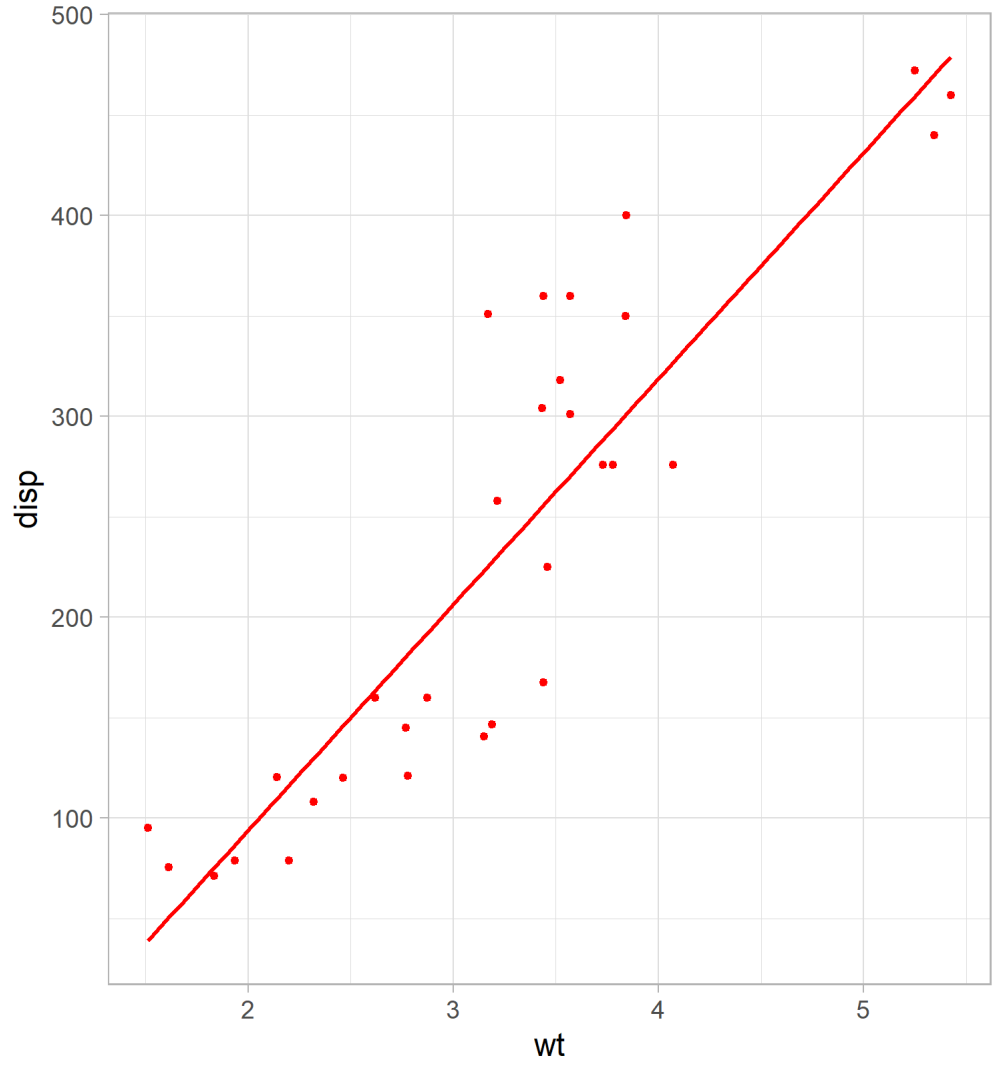
Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  geom_point() +
  stat_smooth(
    method = "lm",
    se = FALSE
  )
```



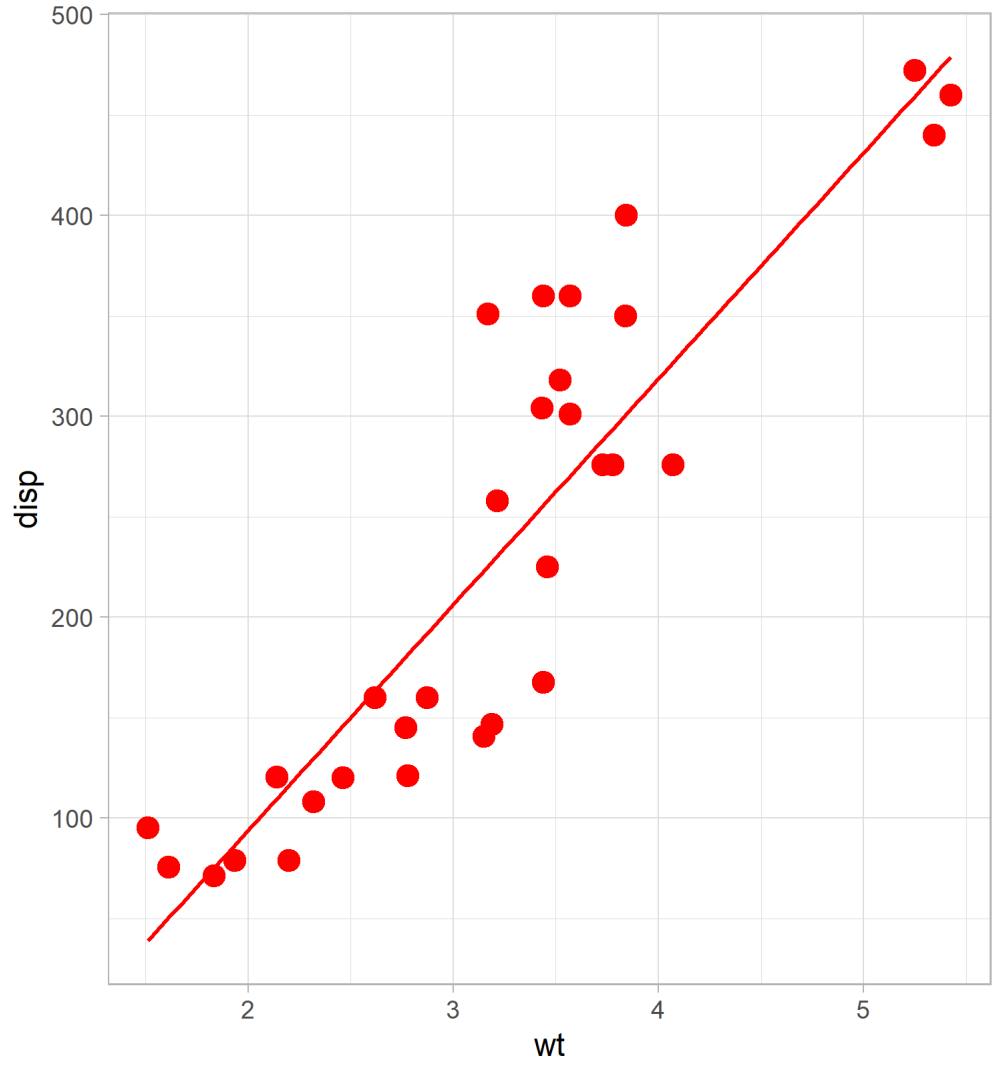
Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  geom_point(
    color = "red"
  ) +
  stat_smooth(
    method = "lm",
    se = FALSE,
    color = "red"
  )
```



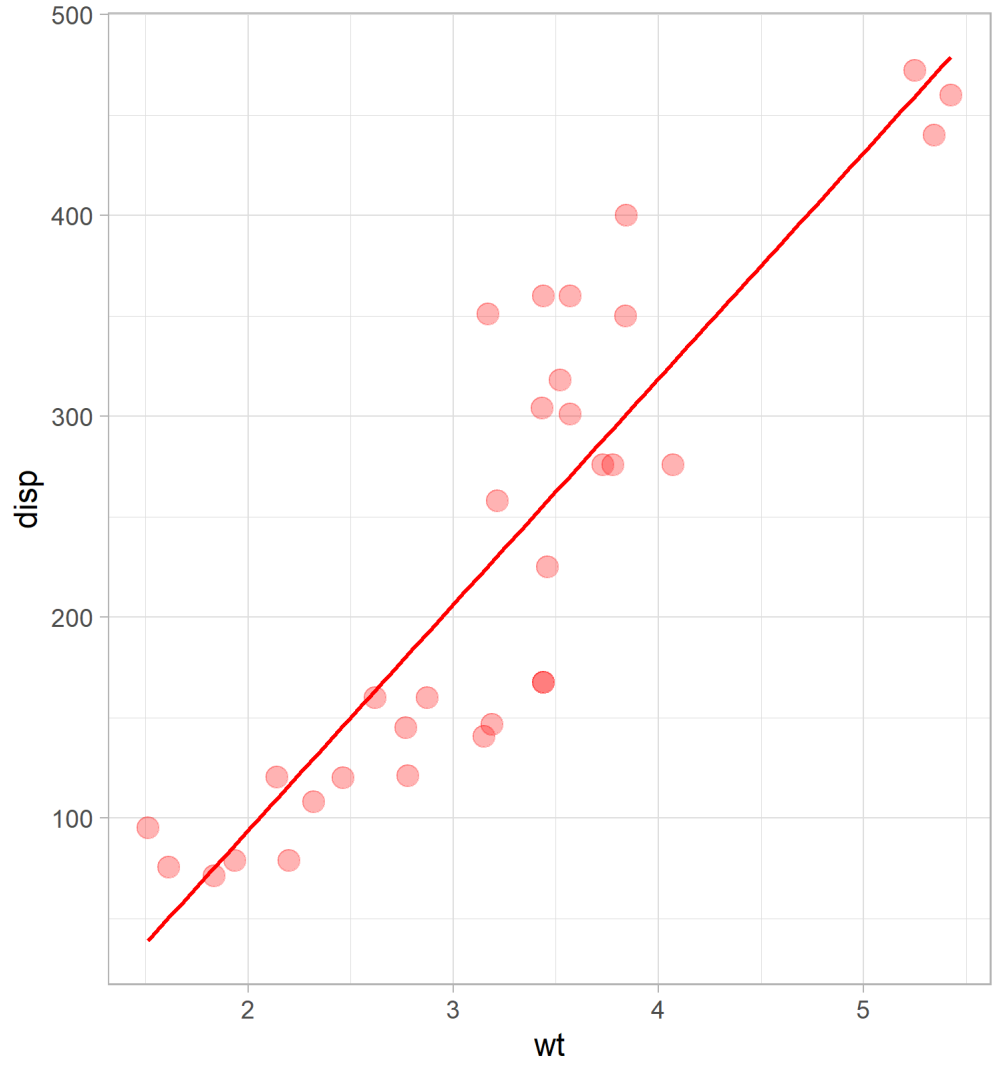
Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  geom_point(
    color = "red",
    size = 5
  ) +
  stat_smooth(
    method = "lm",
    se = FALSE,
    color = "red"
  )
```



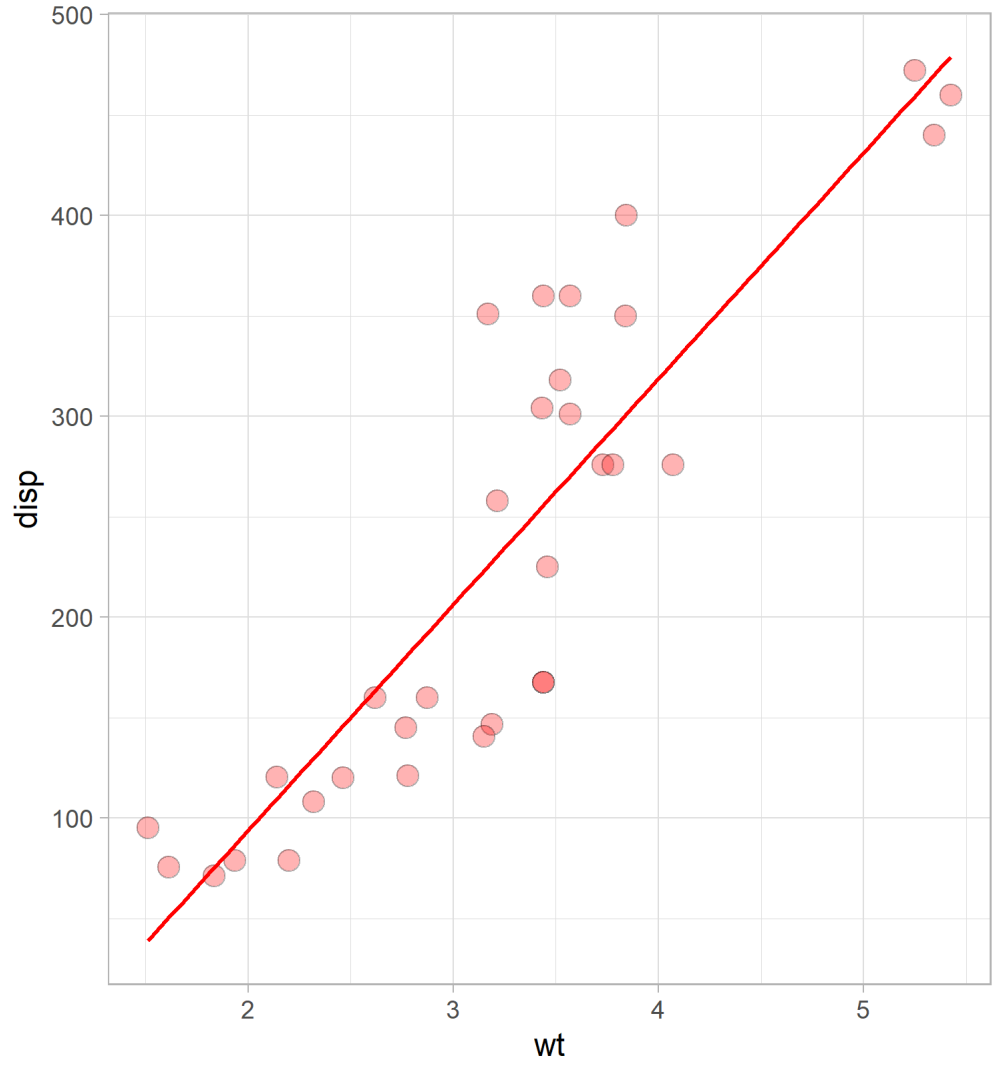
Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  geom_point(
    color = "red",
    size = 5,
    alpha = .3
  ) +
  stat_smooth(
    method = "lm",
    se = FALSE,
    color = "red"
  )
```

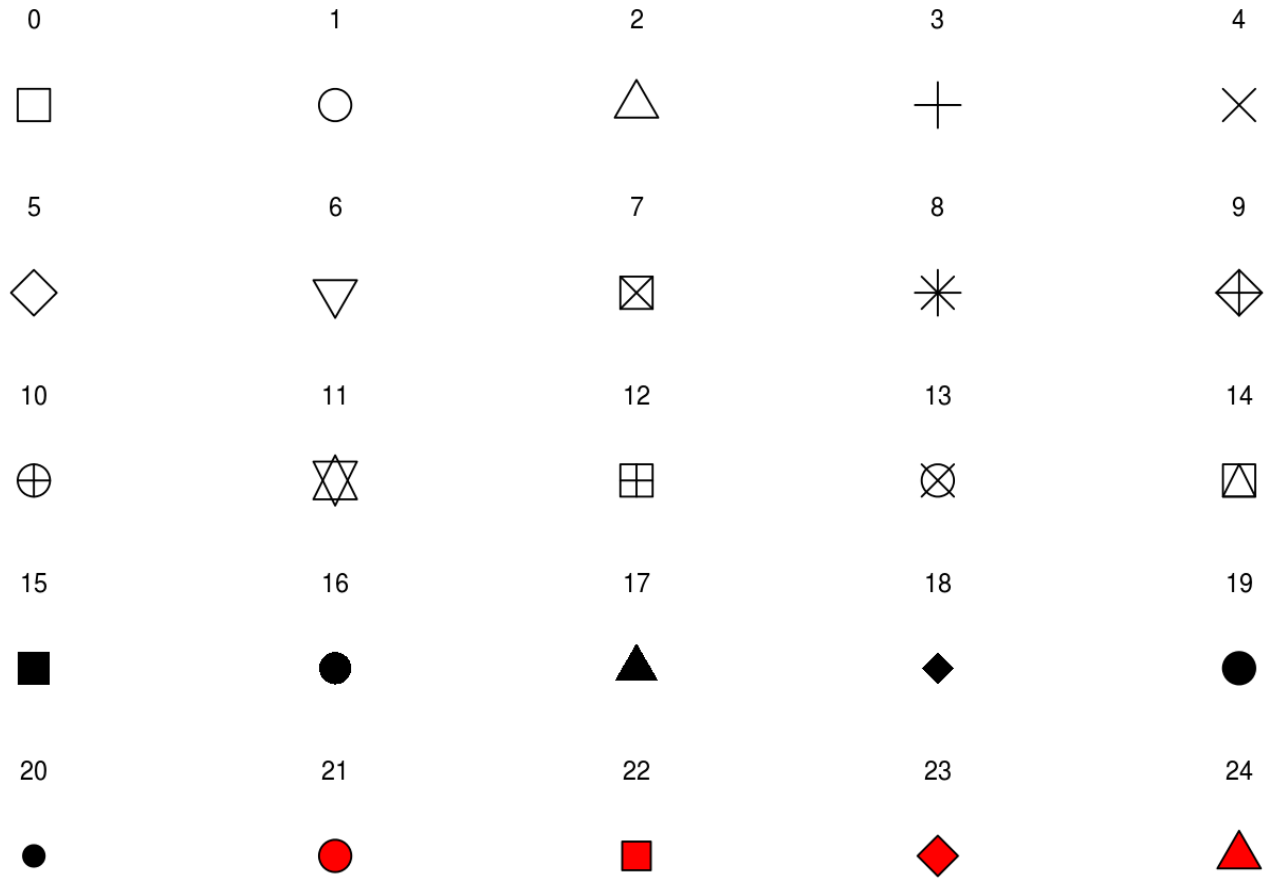


Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  geom_point(
    shape = 21,
    fill = "red",
    size = 5,
    alpha = .3
  ) +
  stat_smooth(
    method = "lm",
    se = FALSE,
    color = "red"
  )
```



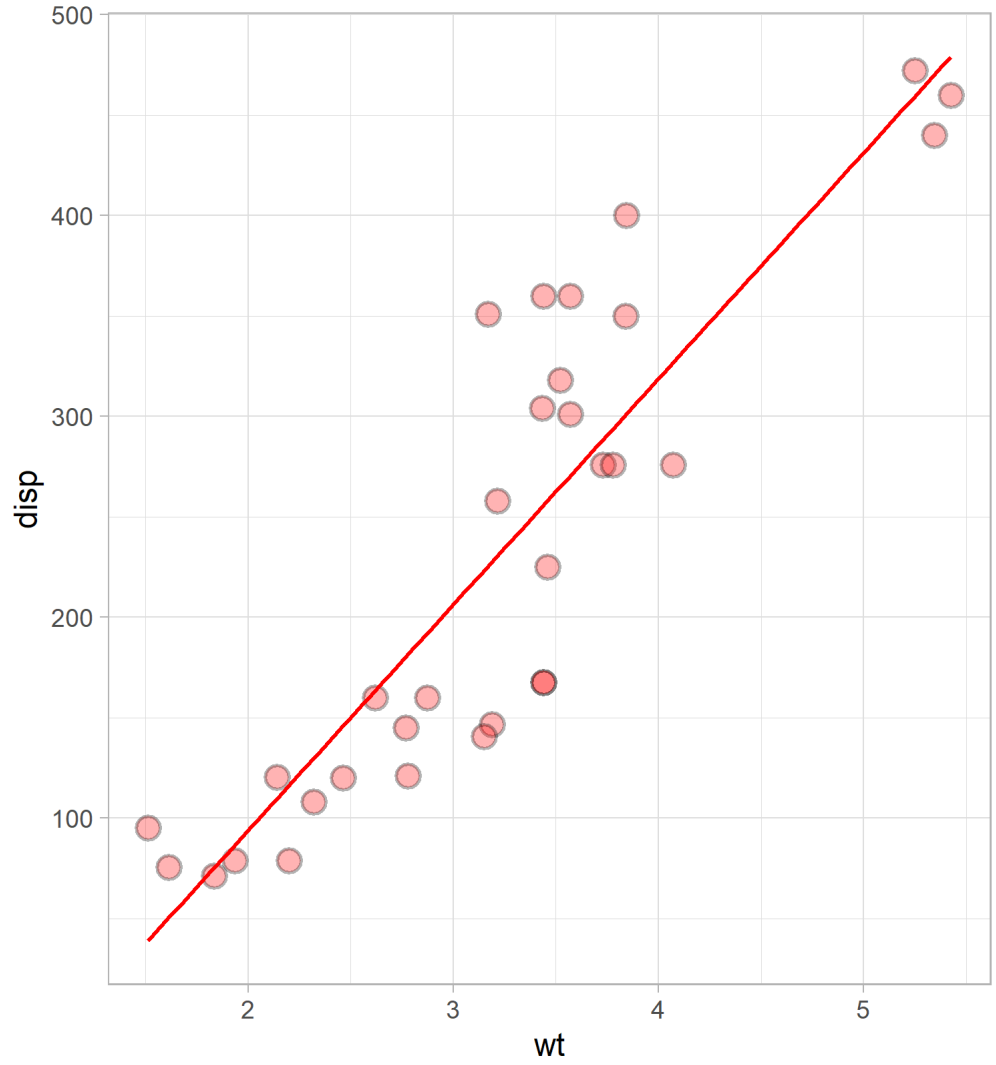
Your Turn: Scatter Plot with Linear Fitting



Source: ggplot2.tidyverse.org/articles/ggplot2-specs.html

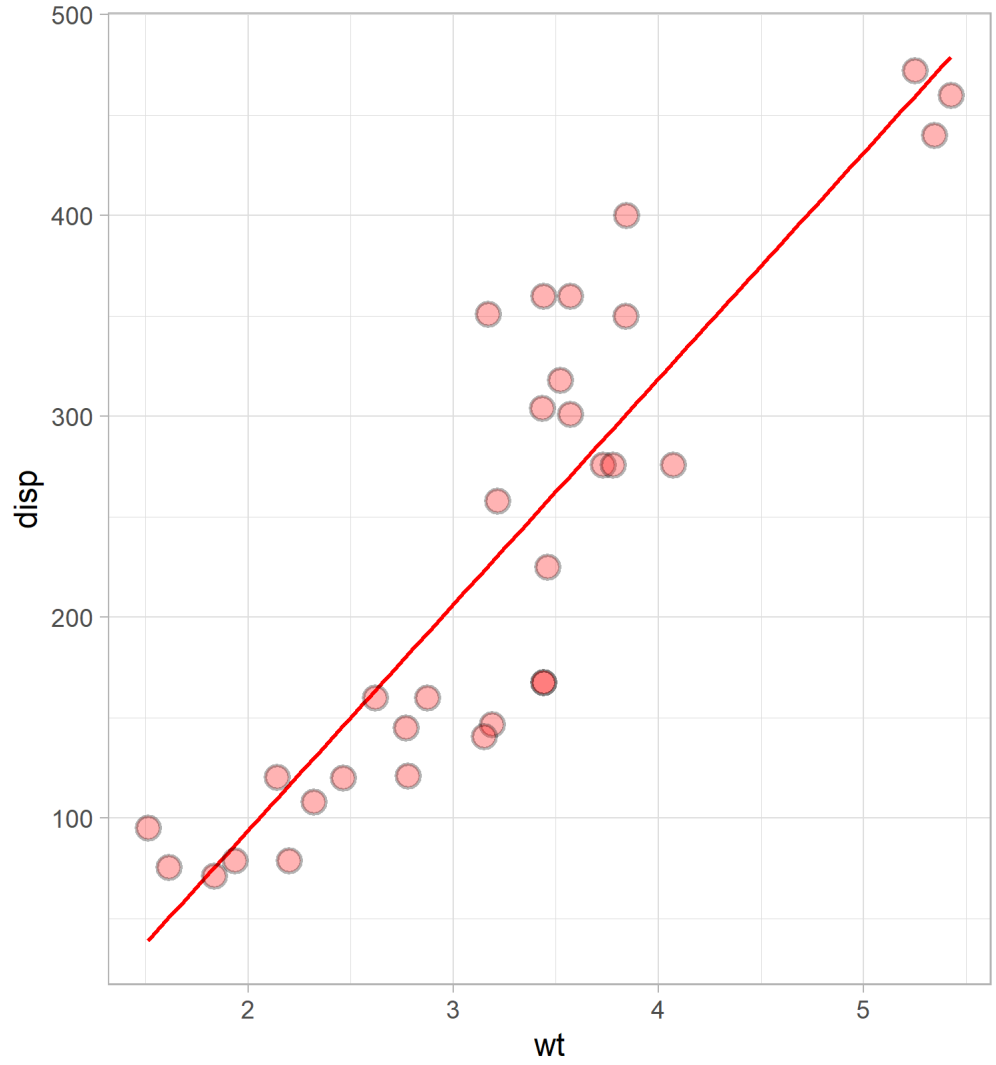
Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  geom_point(
    shape = 21,
    fill = "red",
    color = "black",
    stroke = 1.25,
    size = 5,
    alpha = .3
  ) +
  stat_smooth(
    method = "lm",
    se = FALSE,
    color = "red"
  )
```



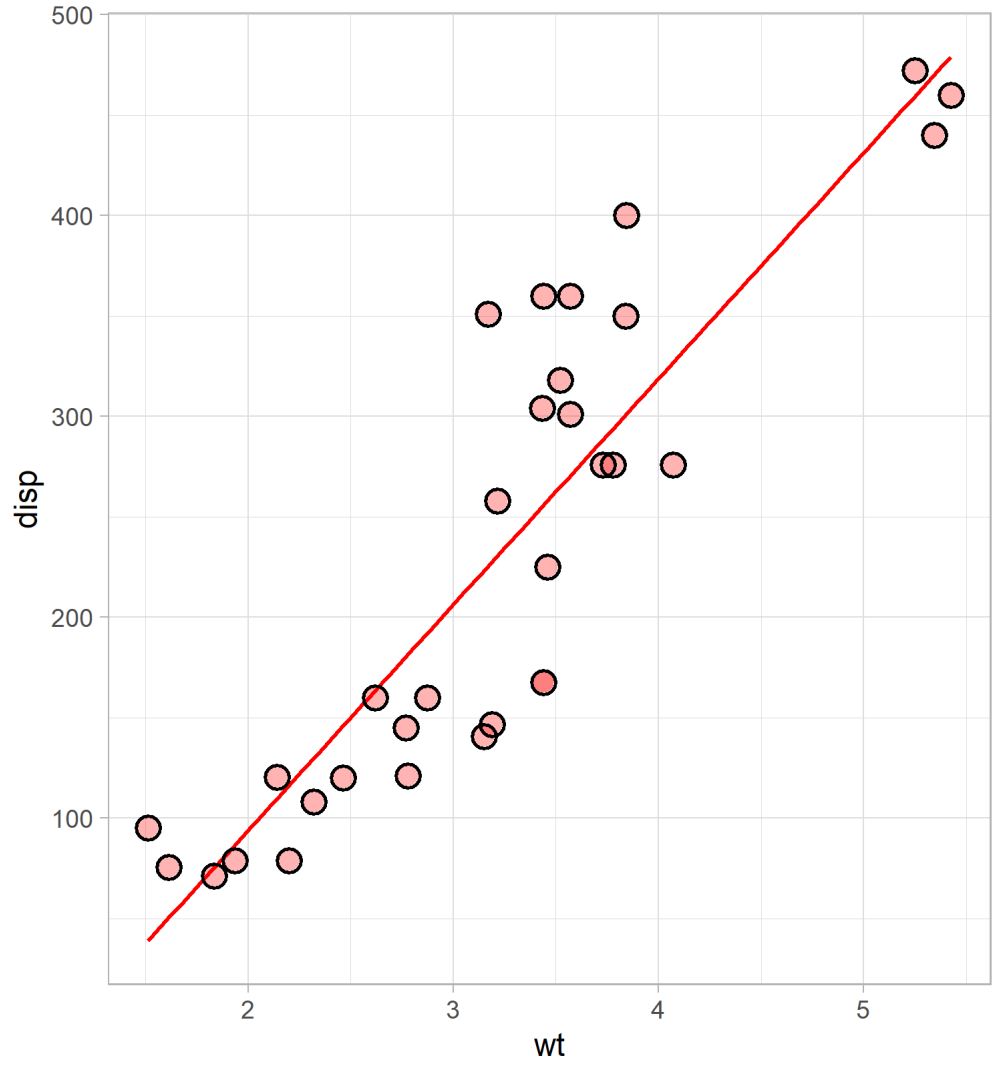
Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  stat_smooth(
    method = "lm",
    se = FALSE,
    color = "red"
  ) +
  geom_point(
    shape = 21,
    fill = "red",
    color = "black",
    stroke = 1.25,
    size = 5,
    alpha = .3
  )
```



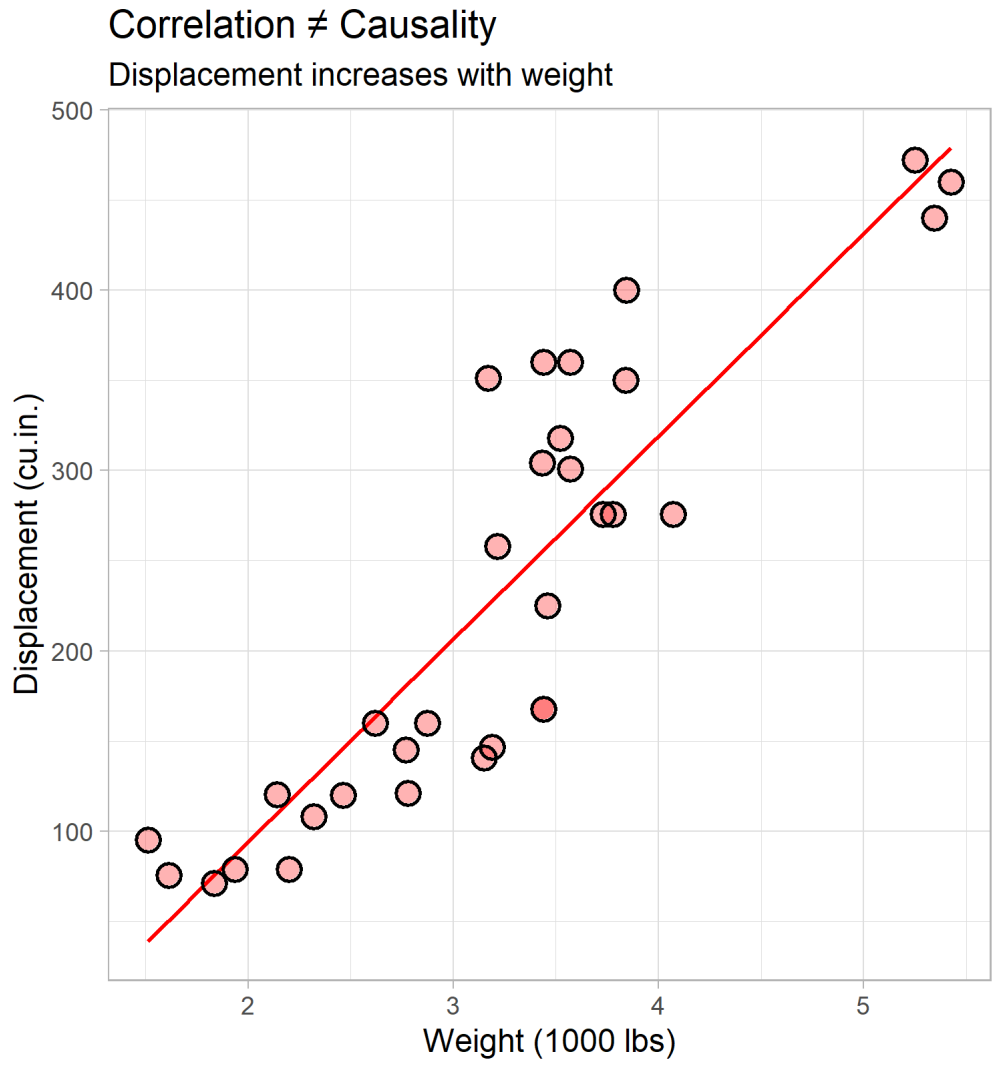
Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  stat_smooth(
    method = "lm",
    se = FALSE,
    color = "red"
  ) +
  geom_point(
    shape = 21,
    fill = "red",
    color = "transparent",
    size = 5,
    alpha = .3
  ) +
  geom_point(
    shape = 21,
    fill = "transparent",
    color = "black",
    stroke = 1.25,
    size = 5
  )
```



Your Turn: Scatter Plot with Linear Fitting

```
ggplot(mtcars, aes(wt, disp)) +
  stat_smooth(method = "lm",
              se = FALSE,
              color = "red") +
  geom_point(shape = 21,
             fill = "red",
             color = "transparent",
             size = 5,
             alpha = .3) +
  geom_point(shape = 21,
             fill = "transparent",
             color = "black",
             stroke = 1.25,
             size = 5) +
  labs(x = "Weight (1000 lbs)",
       y = "Displacement (cu.in.)",
       title = "Correlation \u2260 Causal
       subtitle = "Displacement increases
```



Aesthetics

aes()

`aes()`

Aesthetics of the geometric and statistical objects, such as

- **position** via `x`, `y`, `xmin`, `xmax`, `ymin`, `ymax`, ...
- **color** via `color` and `fill`
- **transparency** via `alpha`
- **size** via `size` and `width`
- **shape** via `shape` and `linetype`

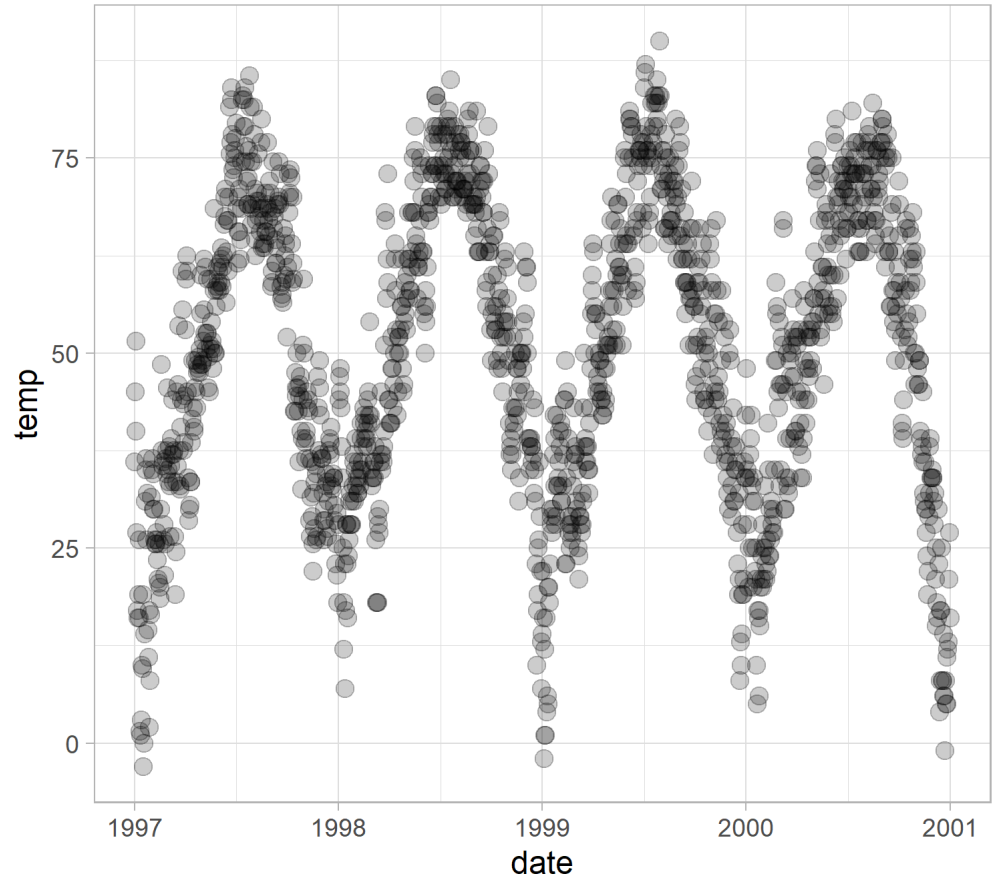
In general, everything which maps to the data needs to be wrapped in `aes()` (such as `x` and `y` in our previous examples) while static arguments are placed outside the `aes()` (such as `color` and `alpha` in our previous examples).

e.g.
`geom_point(color = "red")` to color all points in the same color
`geom_point(aes(color = season))` to color points based on the variable `season`

aes(color/fill/alpha/size/shape)

This way, we can enlarge all points and add some transparency:

```
ggplot(chic, aes(date, temp)) +
  geom_point(
    size = 4,
    alpha = .2
  )
```

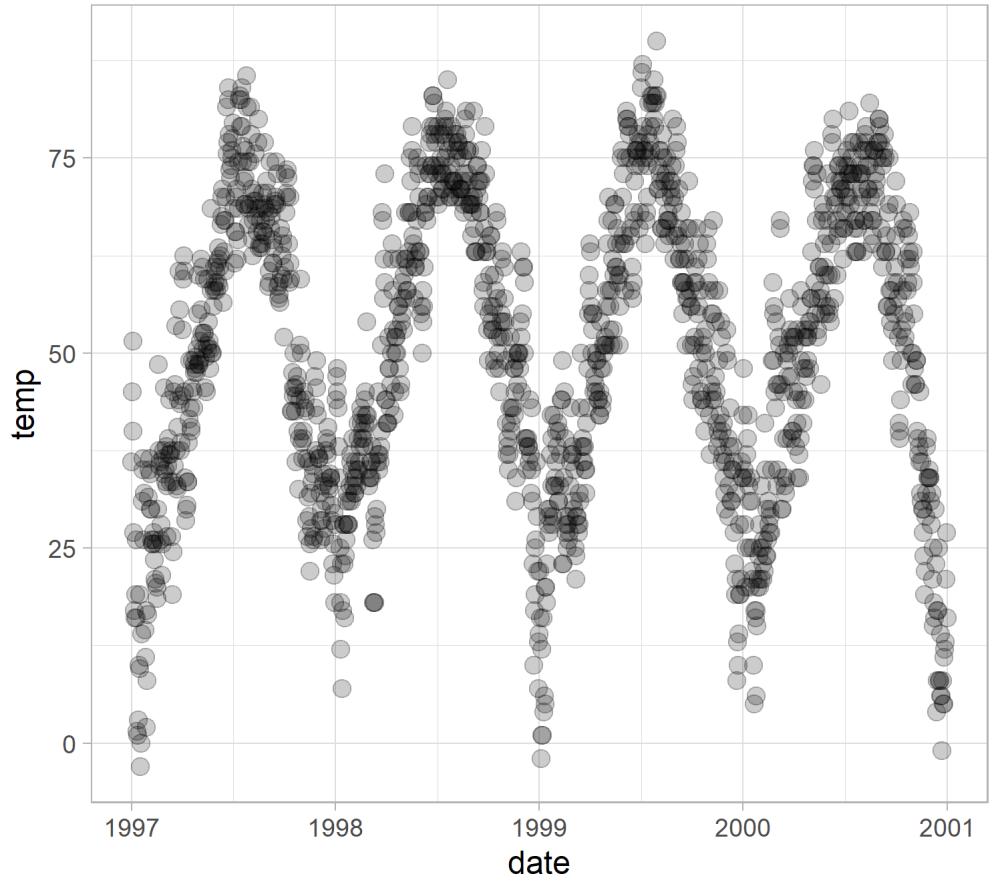


aes(color/fill/alpha/size/shape)

This way, we can enlarge all points and add some transparency:

```
ggplot(chic, aes(date, temp)) +
  geom_point(
    size = 4,
    alpha = .2
  )
```

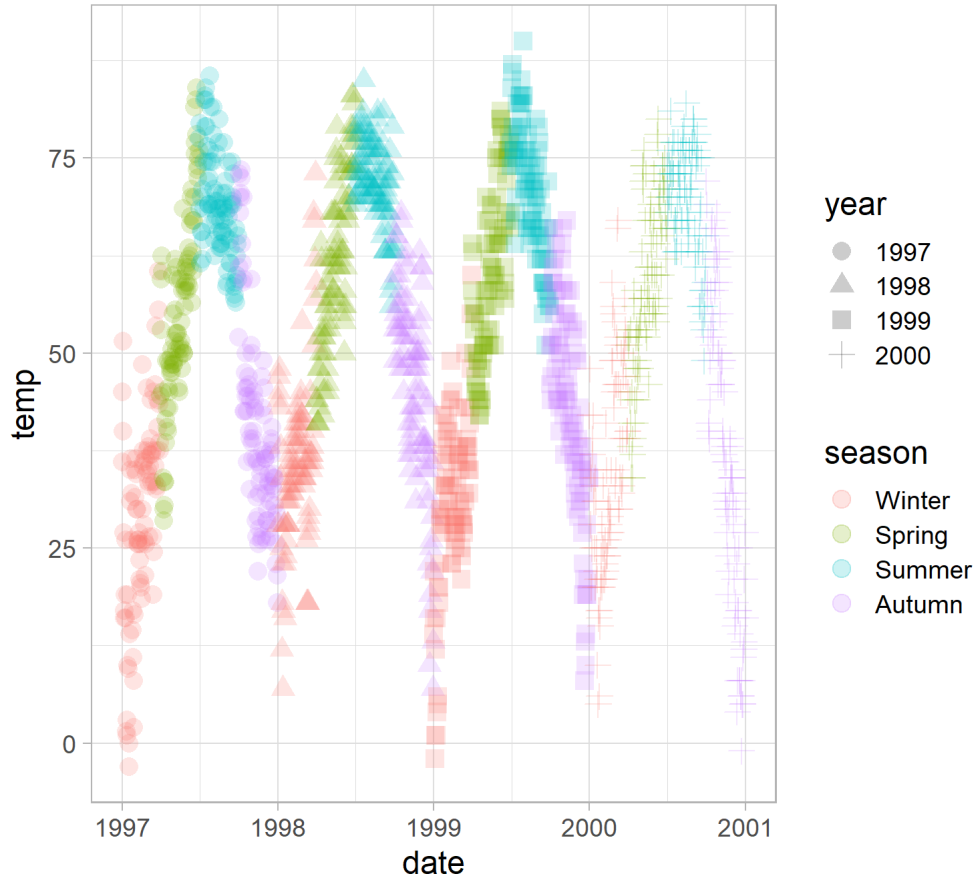
The changes in aesthetics are applied to all data points.



aes(color/fill/alpha/size/shape)

... and change the color and the shape based on **season** and **year**:

```
ggplot(chic, aes(date, temp)) +
  geom_point(
    aes(
      color = season,
      shape = year
    ),
    size = 4,
    alpha = .2
  )
```

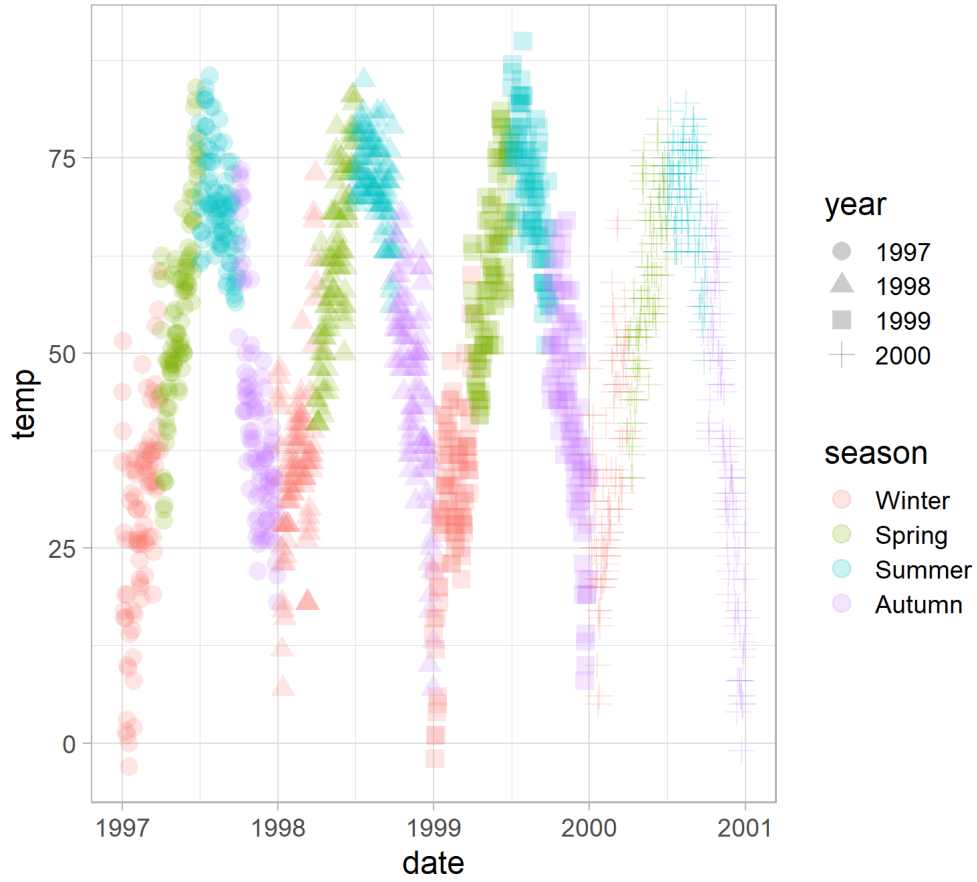


aes(color/fill/alpha/size/shape)

... and change the color and the shape based on **season** and **year**:

```
ggplot(chic, aes(date, temp)) +
  geom_point(
    aes(
      color = season,
      shape = year
    ),
    size = 4,
    alpha = .2
  )
```

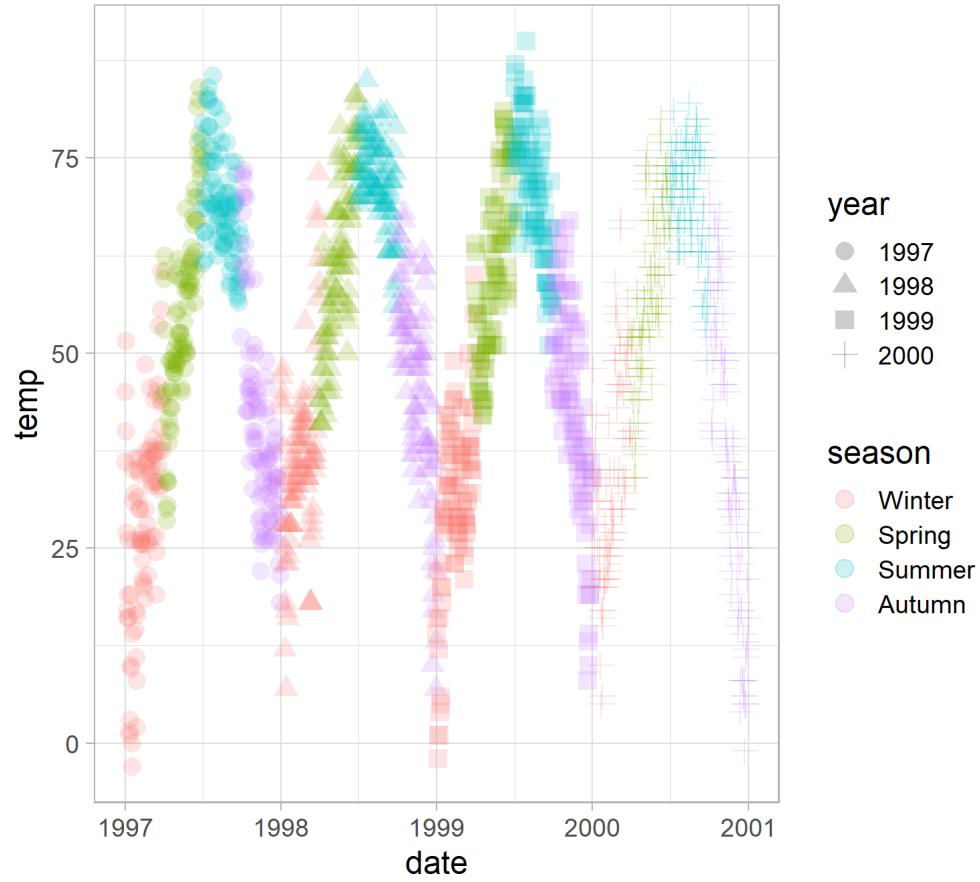
The changes in aesthetics are applied to each group.



Global `aes()`

Alternatively, all aesthetics can be grouped together (and are then applied to all `geom_*()` and `stats_*()`):

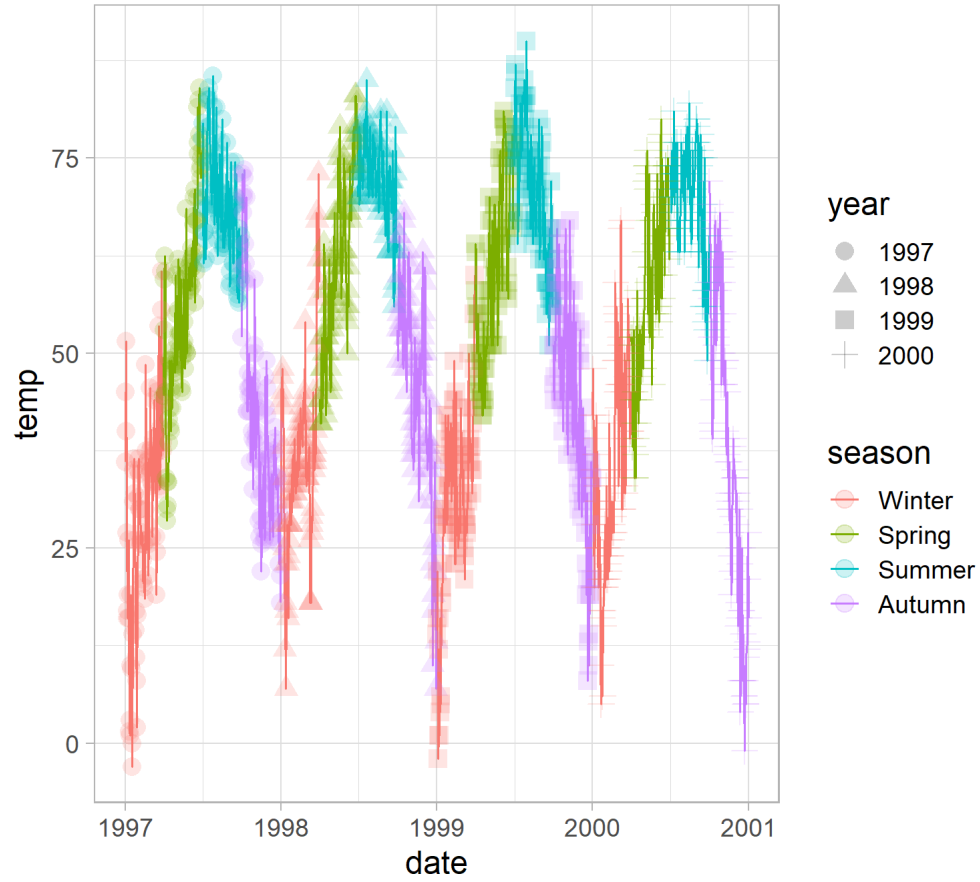
```
ggplot(
  chic,
  aes(date,
      temp,
      color = season,
      shape = year)
  ) +
  geom_point(
    size = 4,
    alpha = .2
  )
```



Global `aes()`

Alternatively, all aesthetics can be grouped together (and are then applied to all `geom_*()` and `stats_*()`):

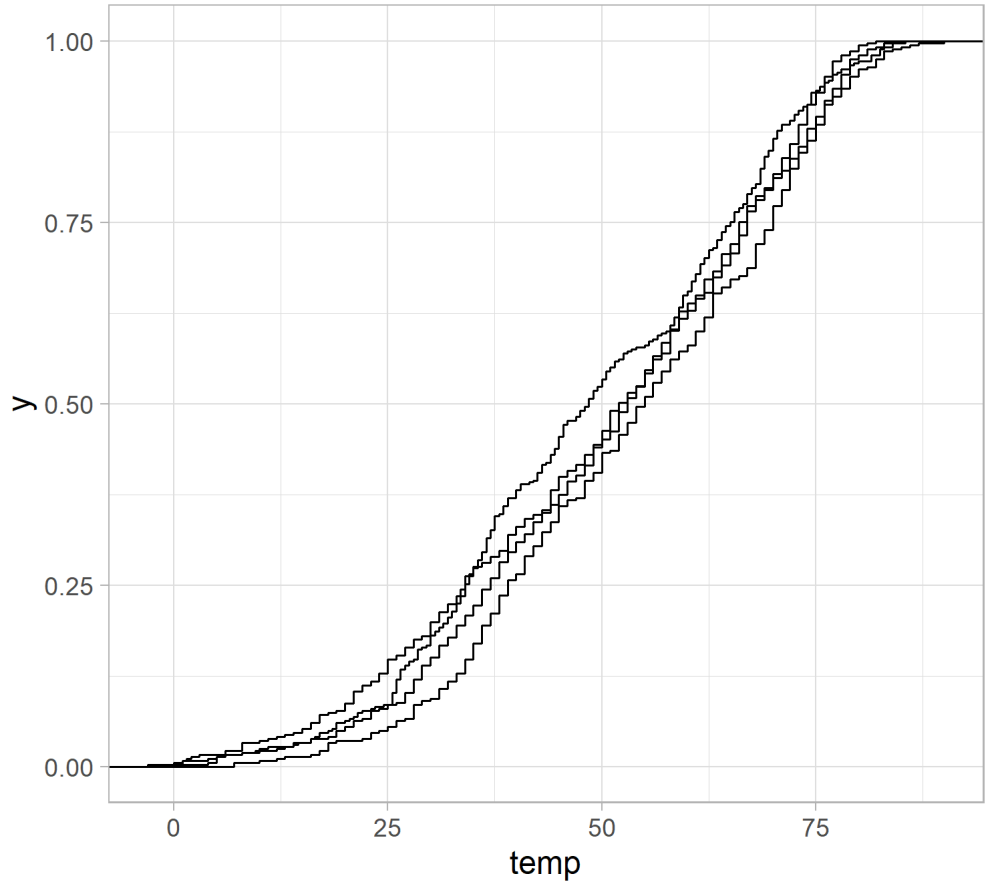
```
ggplot(
  chic,
  aes(date,
      temp,
      color = season,
      shape = year)
  ) +
  geom_line() +
  geom_point(
    size = 4,
    alpha = .2
  )
```



aes(group)

You can create subsets of the data by specifying a grouping variable via **group**:

```
ggplot(chic, aes(temp)) +
  stat_ecdf(aes(group = year))
```



However, for most applications you can simply specify the grouping using visual aesthetics (**color**, **fill**, **size**, **alpha**, **shape**, **linetype**).

Your Turn!

- Run the same code without the grouping. Guess first what's going to happen.
- Replace the

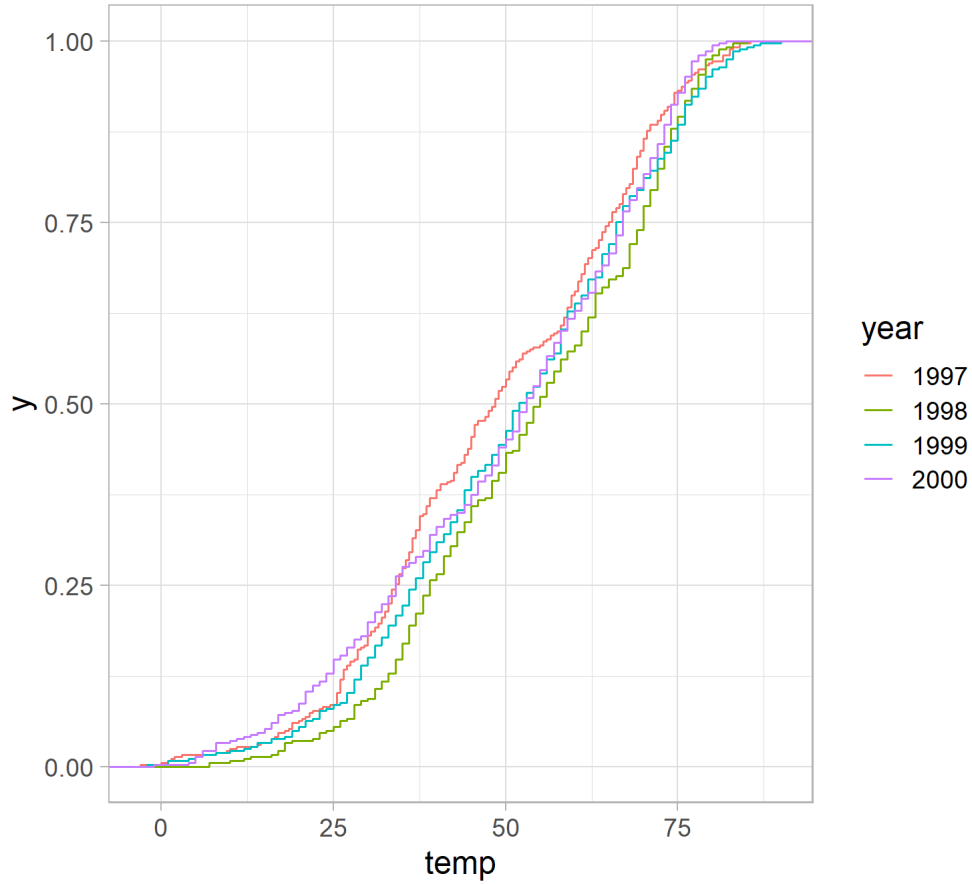
  `stat_ecdf(aes(grouop = year))` by `geom_boxplot(aes(group = year))`

  and run the code.How does this plot differ from previous ones?
- Replace the `group` argument by `color`, `linetype`, `shape` and `alpha`. What happens?

aes(color)

However, for most applications you can simply specify the grouping using visual aesthetics.

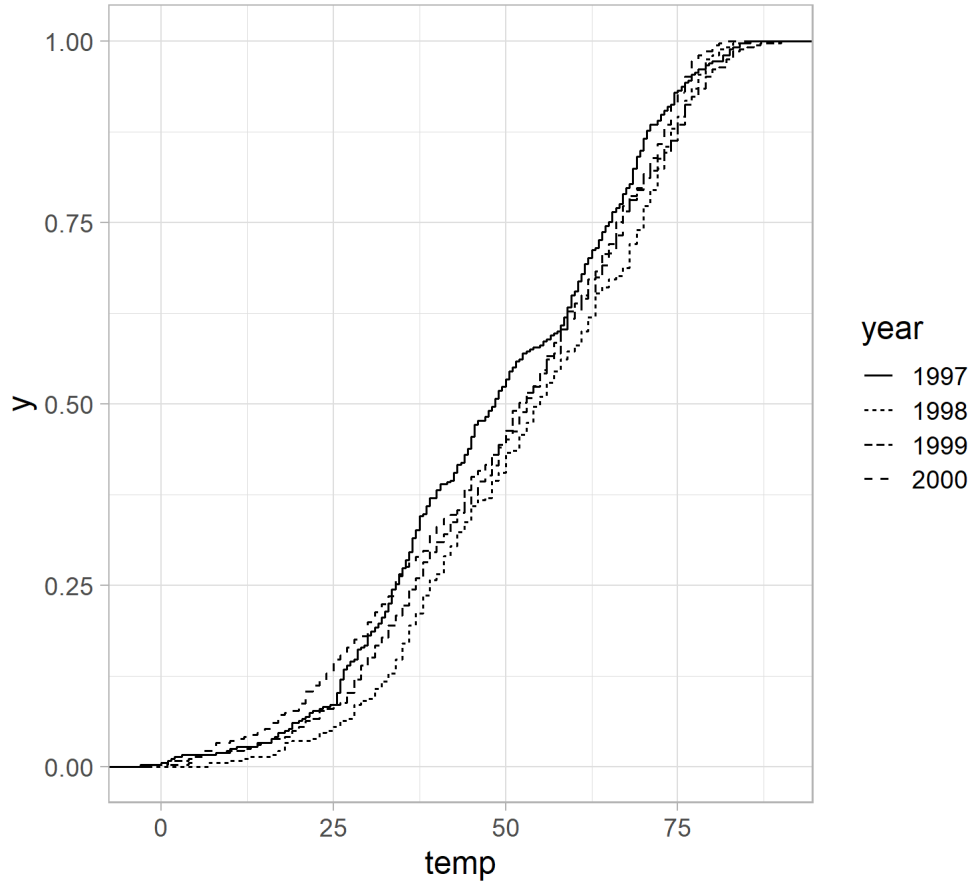
```
ggplot(chic, aes(temp)) +
  stat_ecdf(aes(color = year))
```



aes(linetype)

However, for most applications you can simply specify the grouping using visual aesthetics.

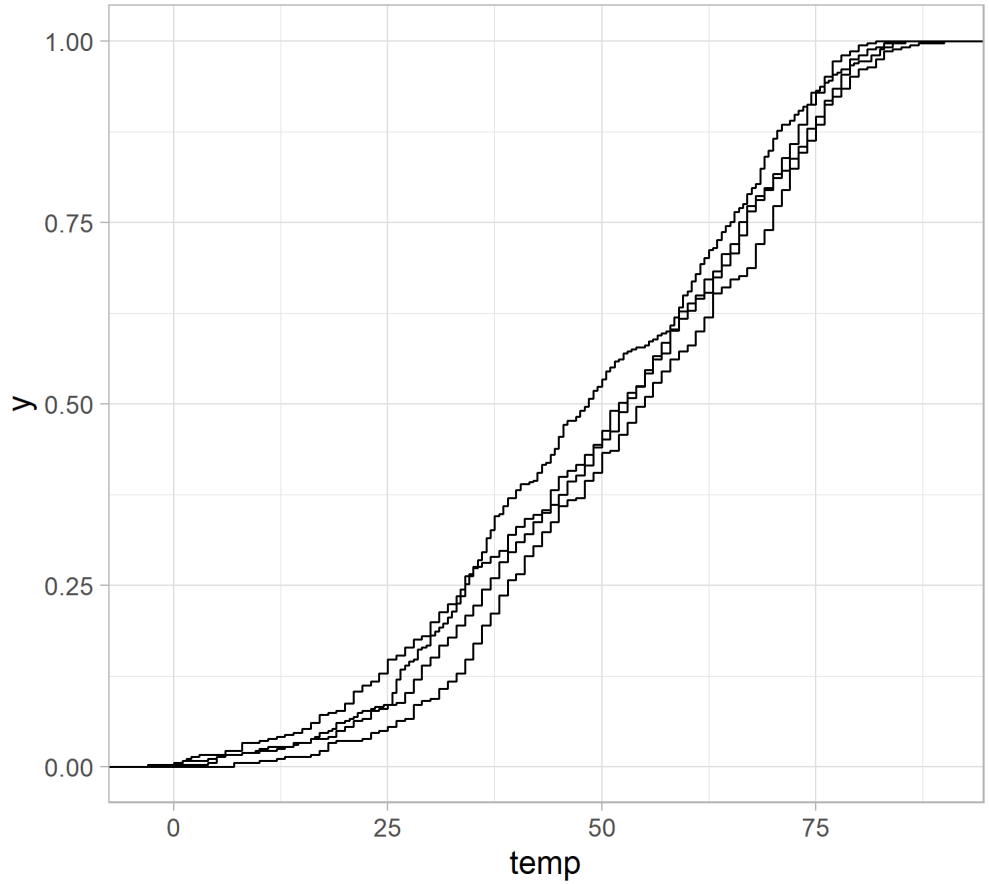
```
ggplot(chic, aes(temp)) +
  stat_ecdf(aes(linetype = year))
```



aes(shape)

However, for most applications you can simply specify the grouping using visual aesthetics.

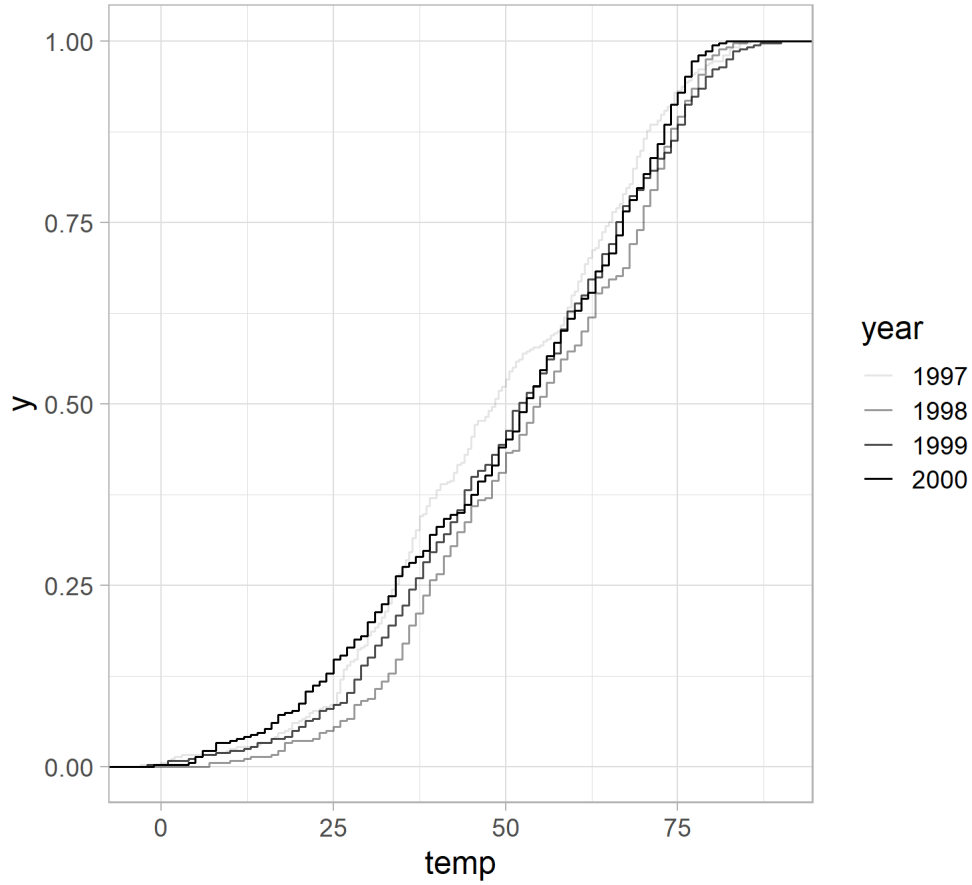
```
ggplot(chic, aes(temp)) +
  stat_ecdf(aes(shape = year))
```



aes(alpha)

However, for most applications you can simply specify the grouping using visual aesthetics.

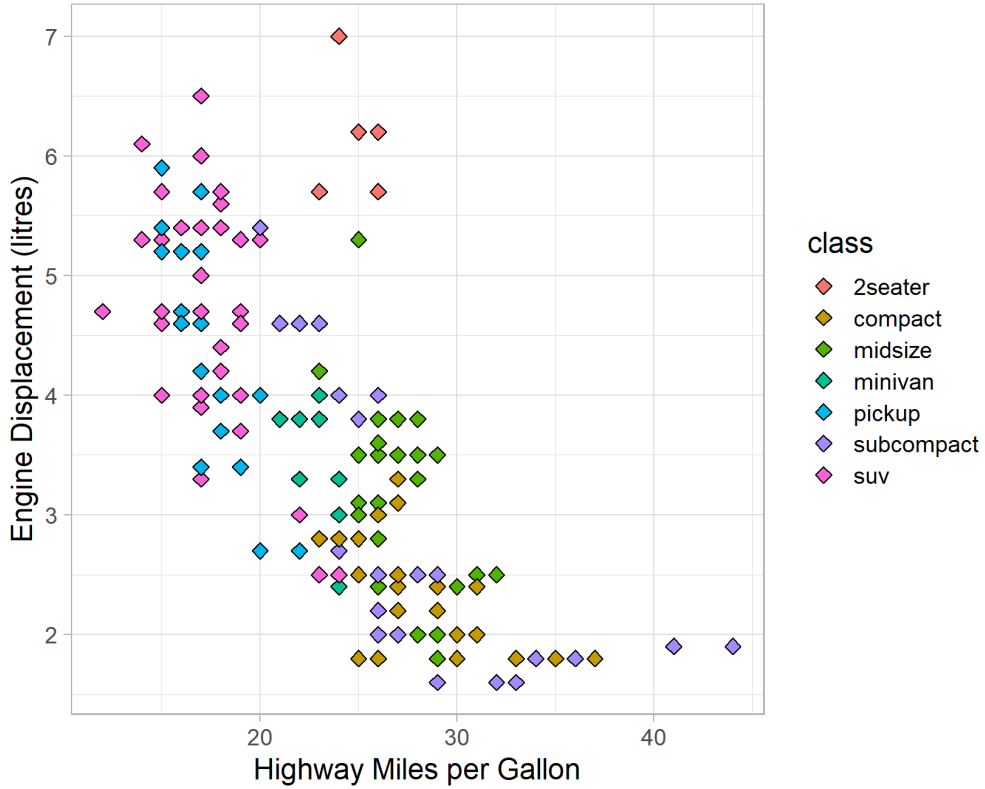
```
ggplot(chic, aes(temp)) +
  stat_ecdf(aes(alpha = year))
```

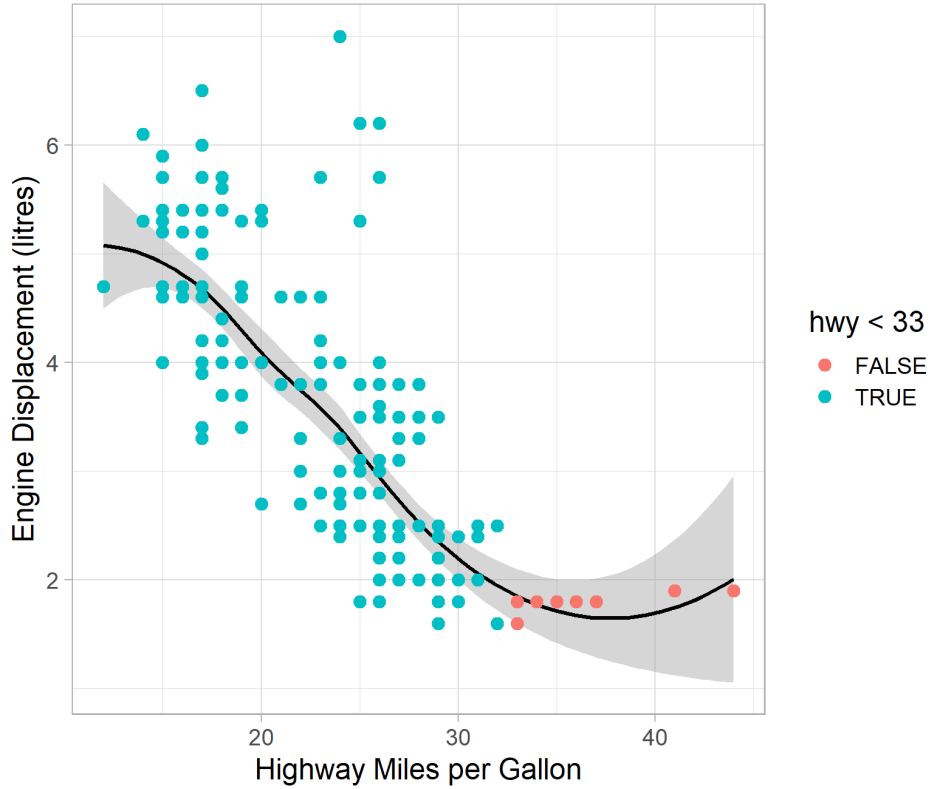


Your Turn!

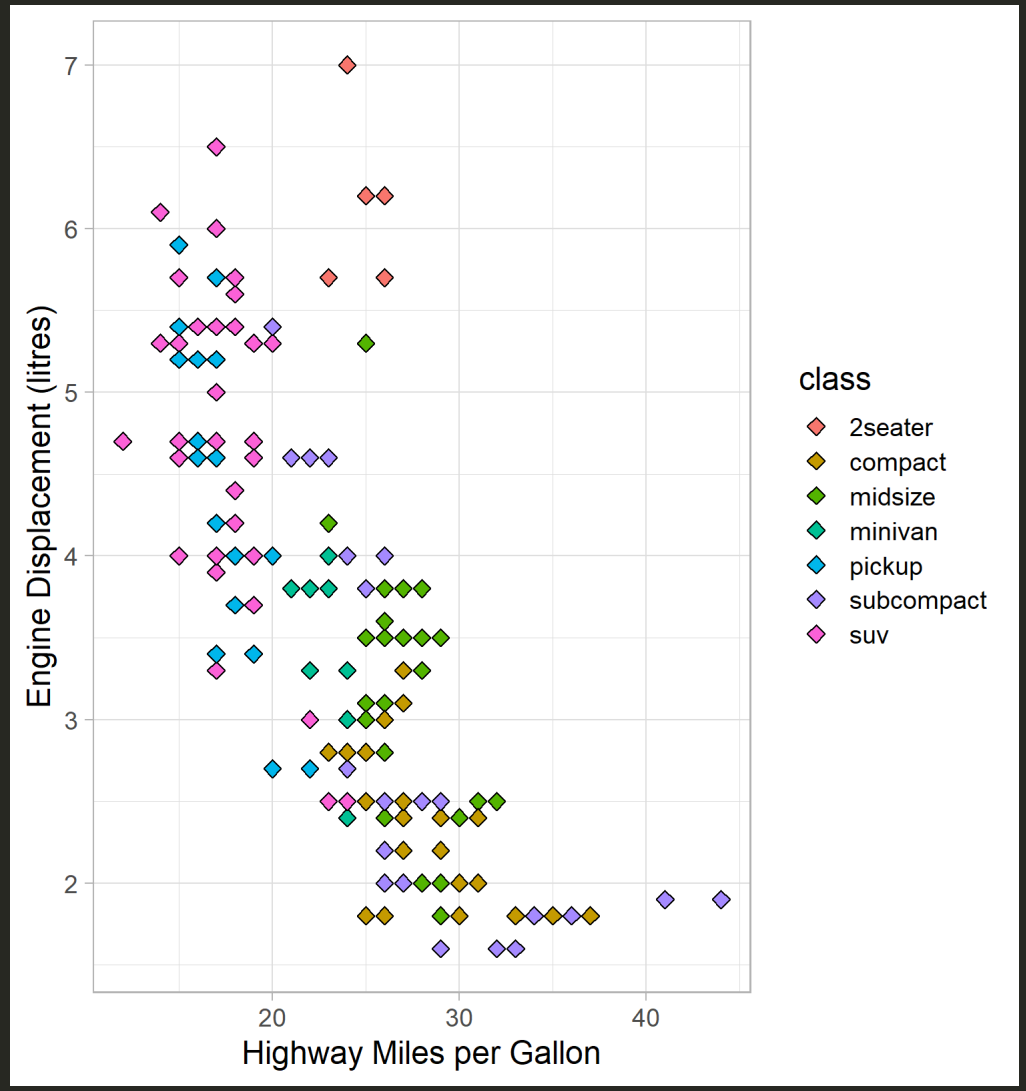
Another training data set focussing on cars comes with `ggplot2` and is called `mpg`:

- **Create the following visualizations:**



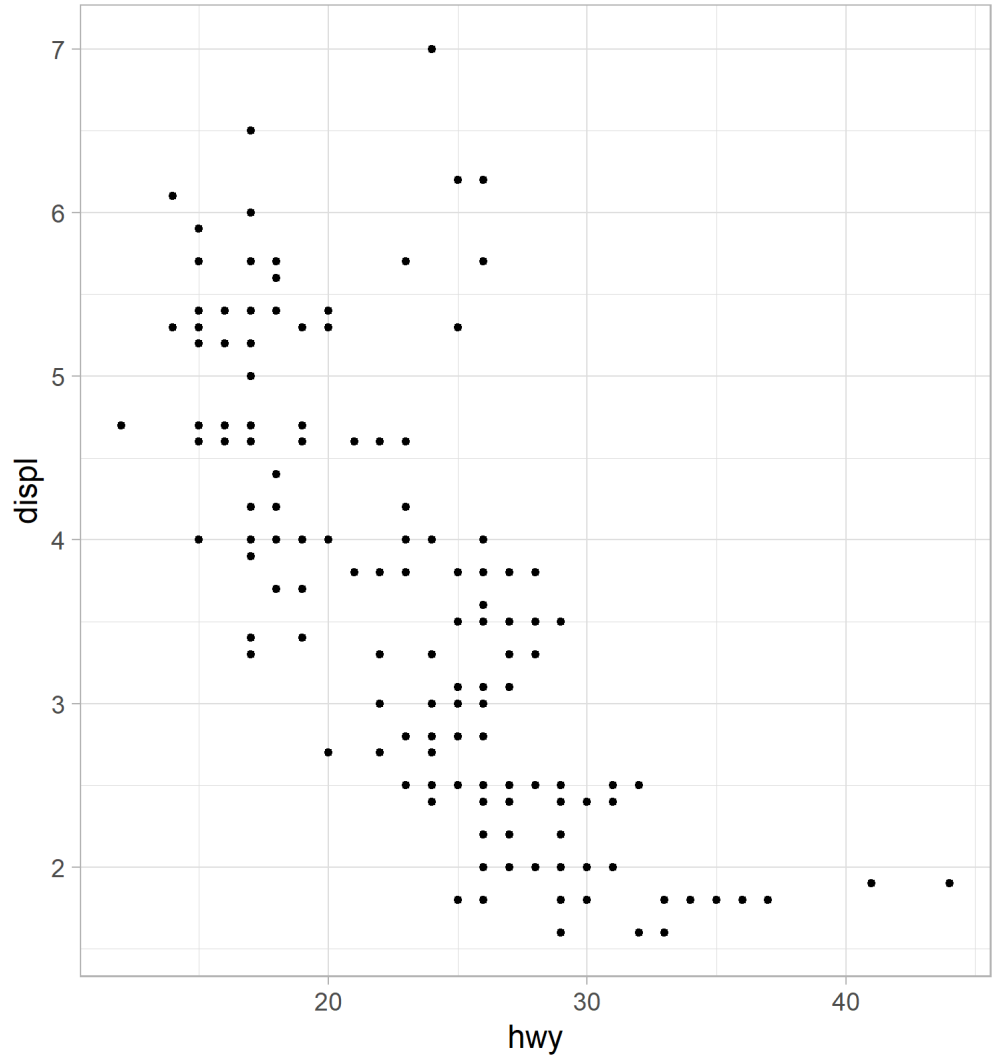


Your Turn: Create this Scatter Plot!



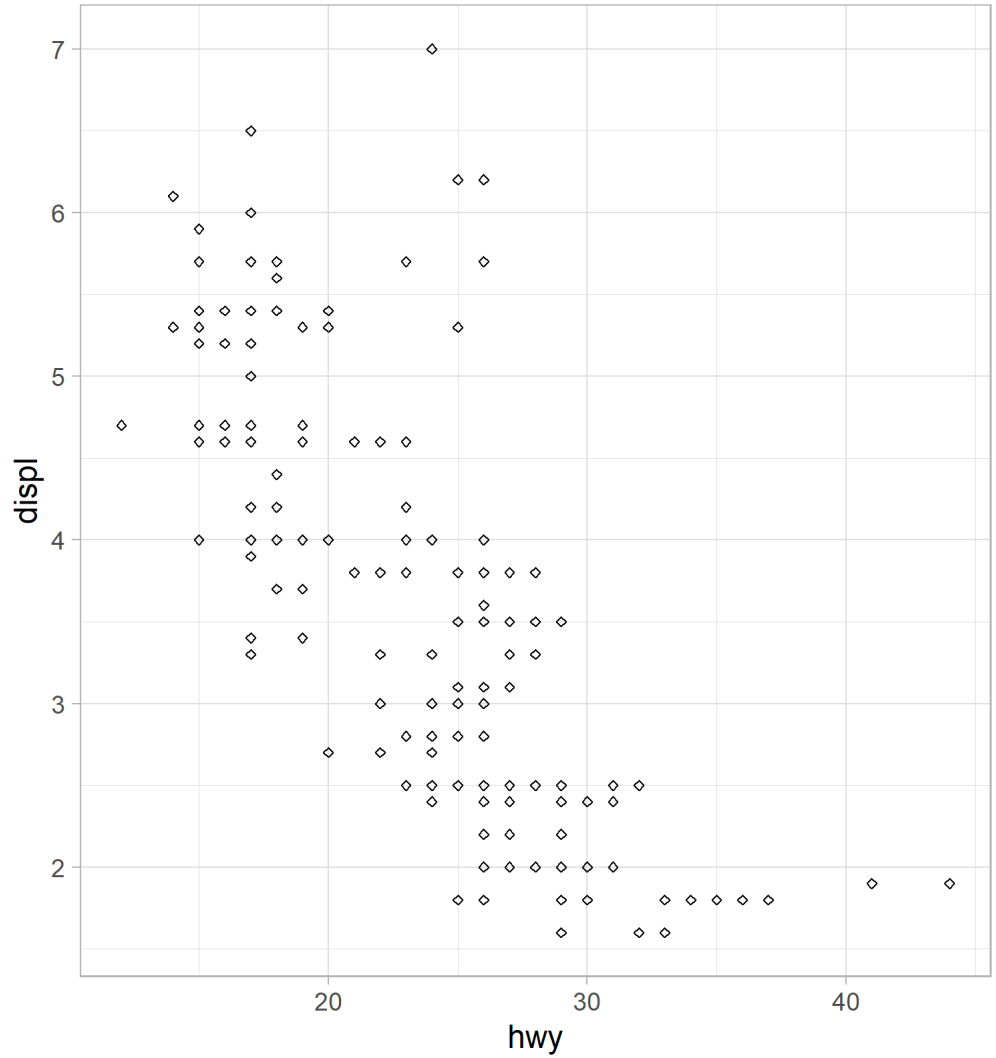
Your Turn: Scatter Plot with Diamonds

```
ggplot(mpg, aes(hwy, displ)) +
  geom_point()
```



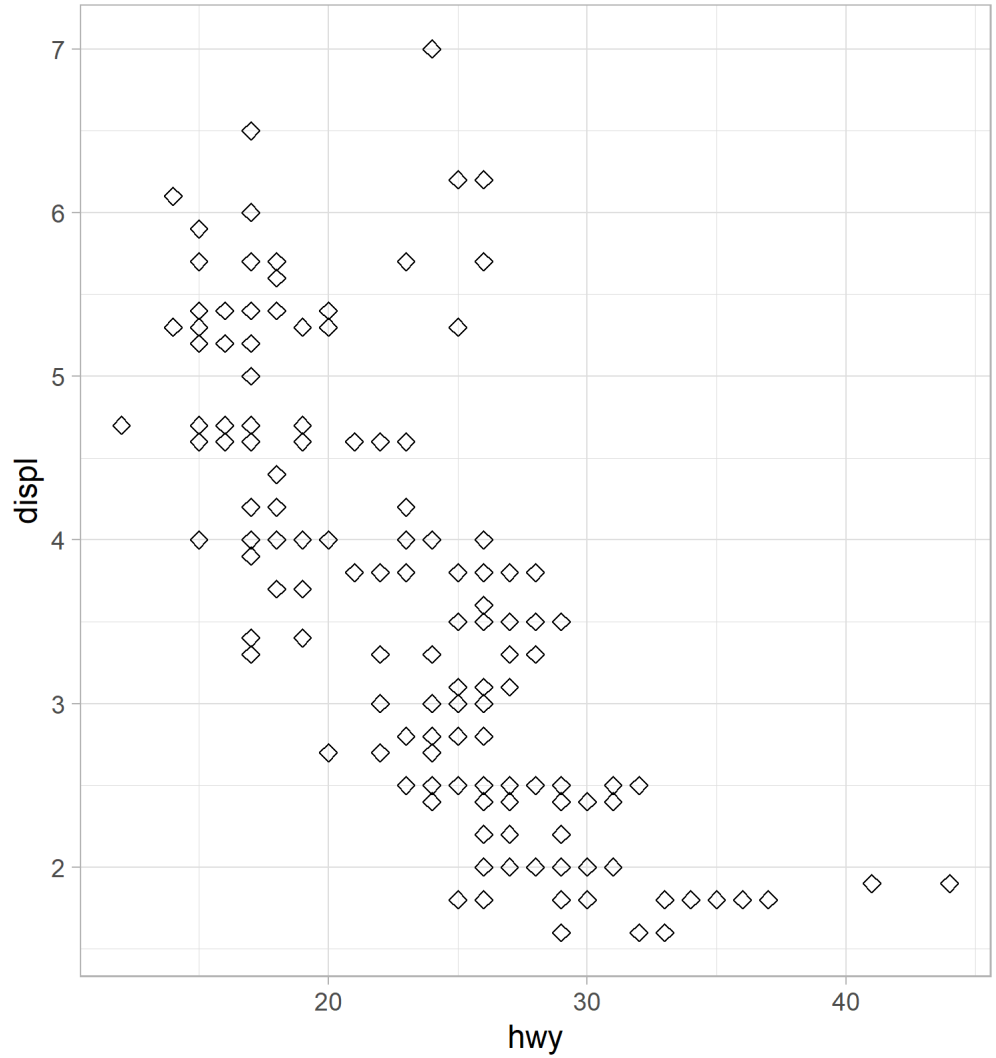
Your Turn: Scatter Plot with Diamonds

```
ggplot(mpg, aes(hwy, displ)) +
  geom_point(
    shape = 23
  )
```



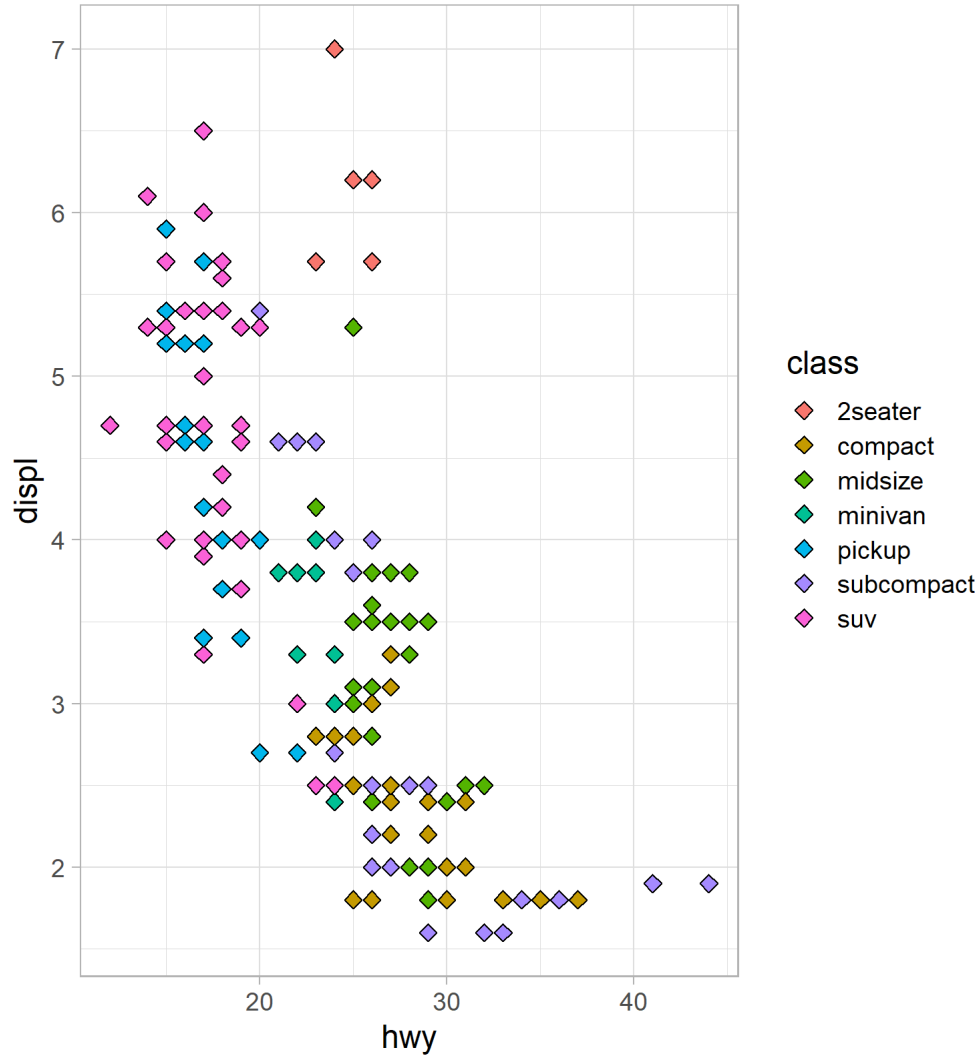
Your Turn: Scatter Plot with Diamonds

```
ggplot(mpg, aes(hwy, displ)) +
  geom_point(
    shape = 23,
    size = 3
  )
```



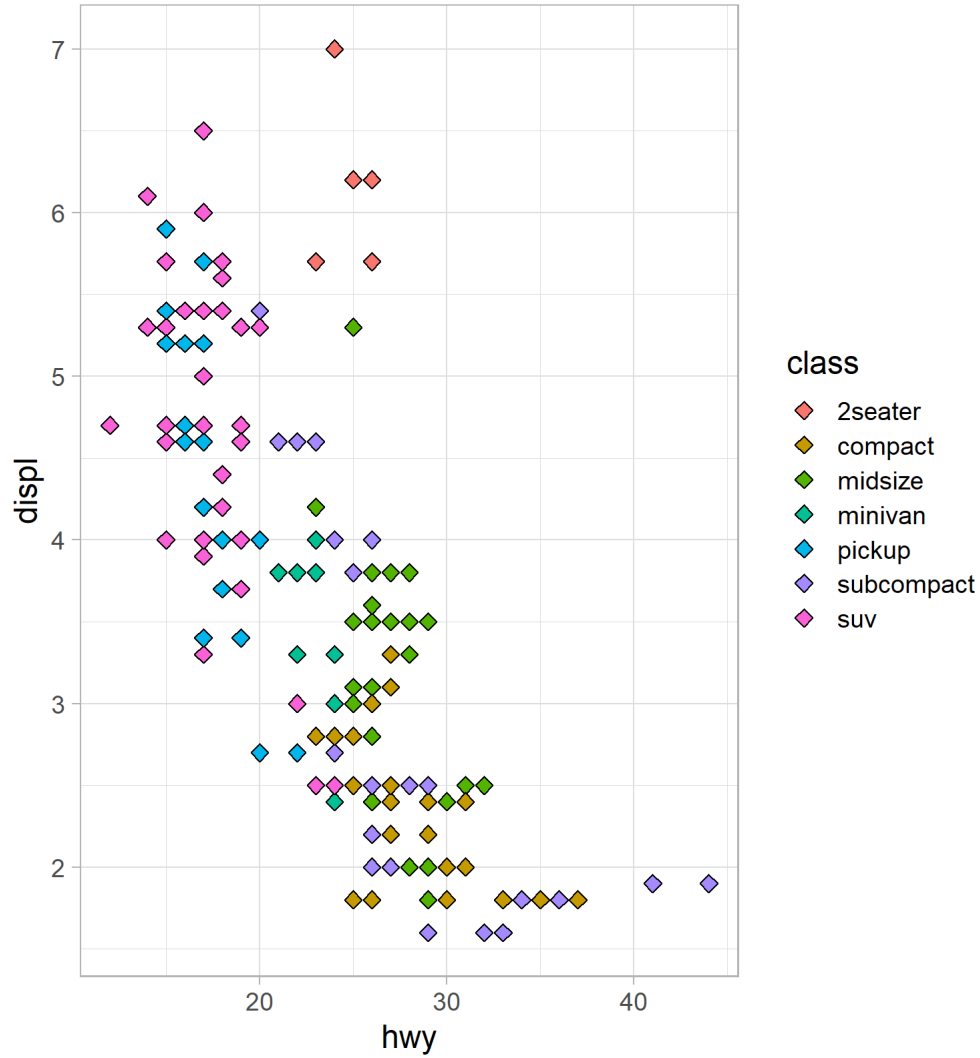
Your Turn: Scatter Plot with Diamonds

```
ggplot(mpg, aes(hwy, displ)) +
  geom_point(
    mapping = aes(fill = class),
    shape = 23,
    size = 3
  )
```



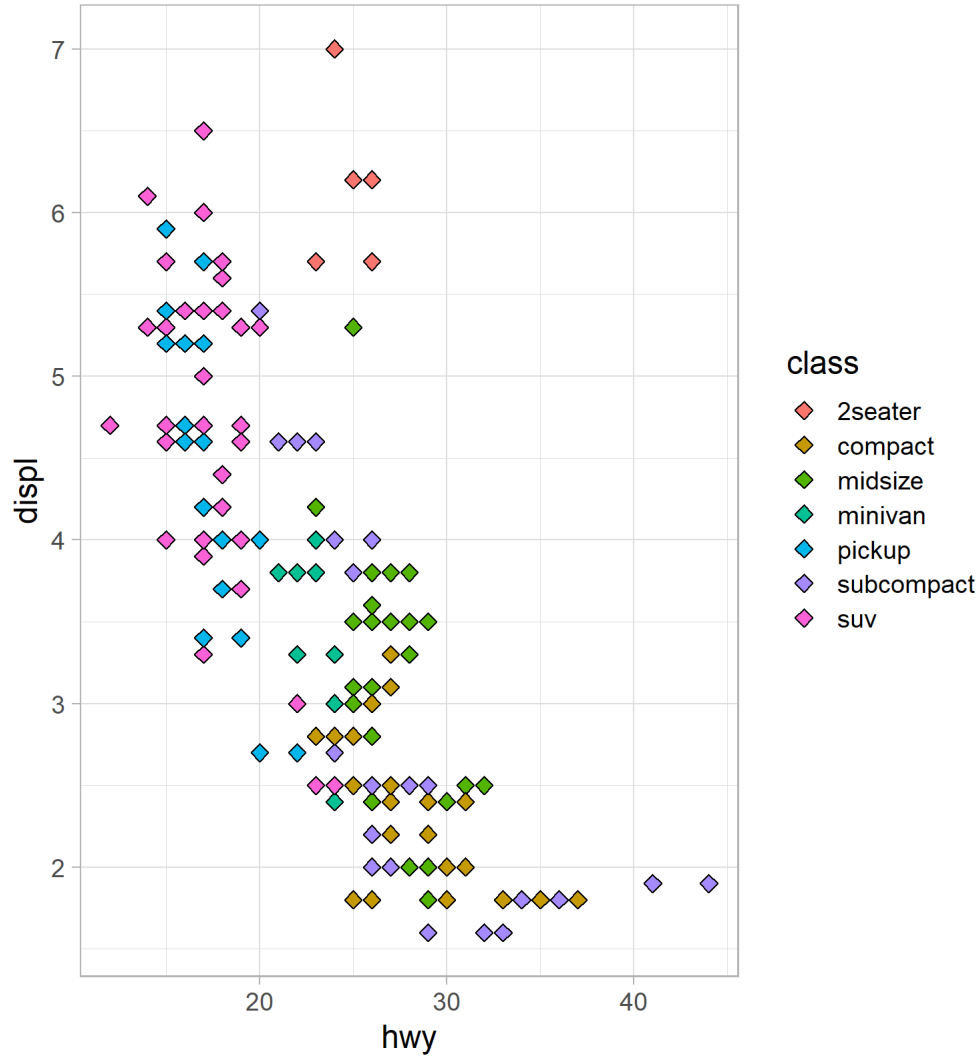
Your Turn: Scatter Plot with Diamonds

```
ggplot(mpg, aes(hwy, displ)) +
  geom_point(
    aes(fill = class),
    shape = 23,
    size = 3
  )
```



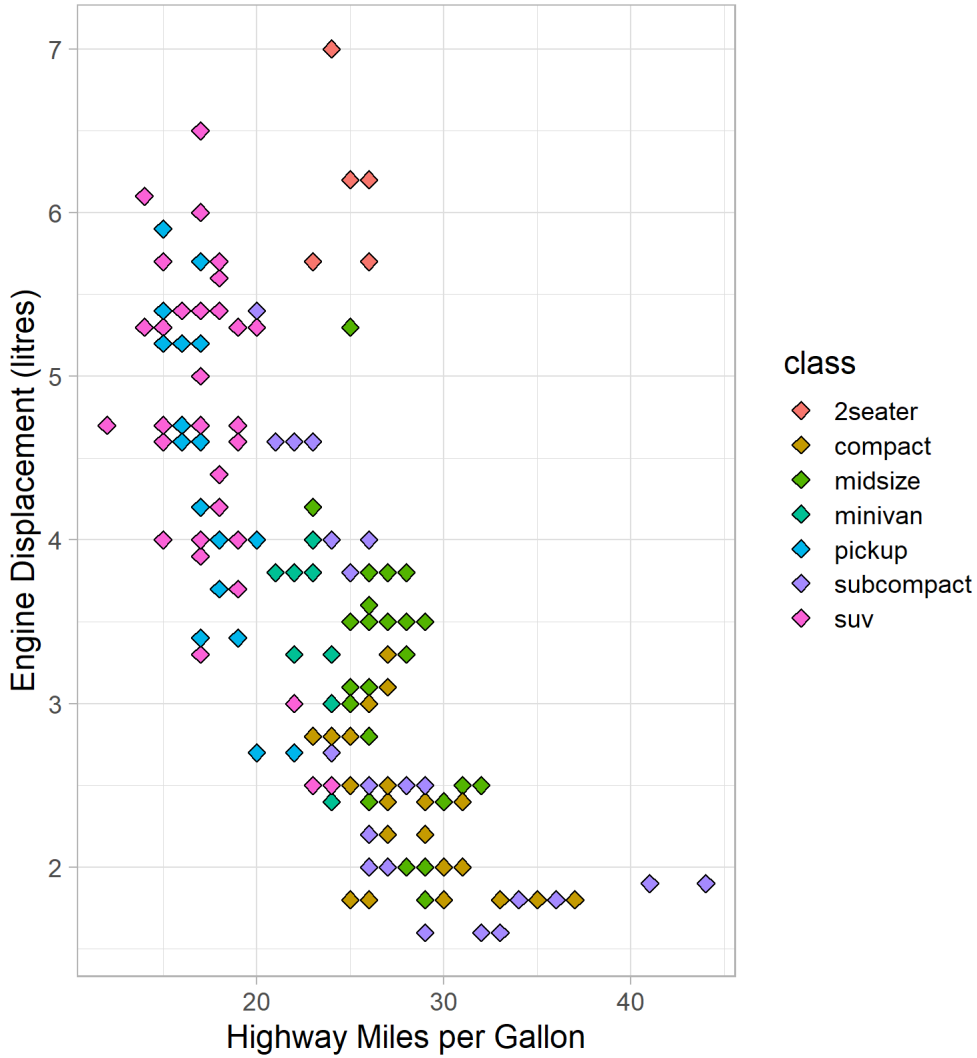
Your Turn: Scatter Plot with Diamonds

```
ggplot(
  mpg,
  aes(
    hwy,
    displ,
    fill = class
  )) +
  geom_point(
    shape = 23,
    size = 3
  )
```

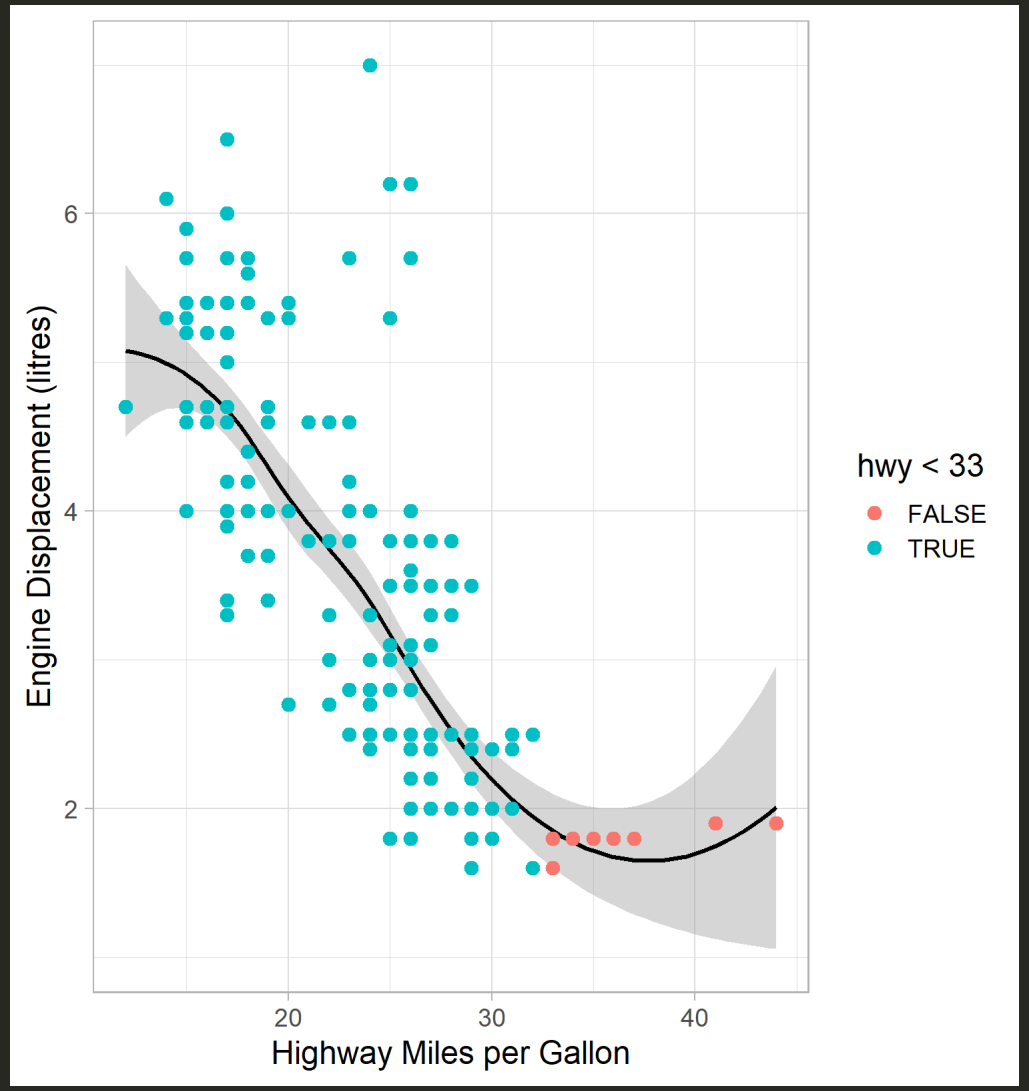


Your Turn: Scatter Plot with Diamonds

```
ggplot(
  mpg,
  aes(
    hwy,
    displ,
    fill = class
  )) +
  geom_point(
    shape = 23,
    size = 3
  ) +
  labs(
    x = "Highway Miles per Gallon",
    y = "Engine Displacement (litres)"
  )
```

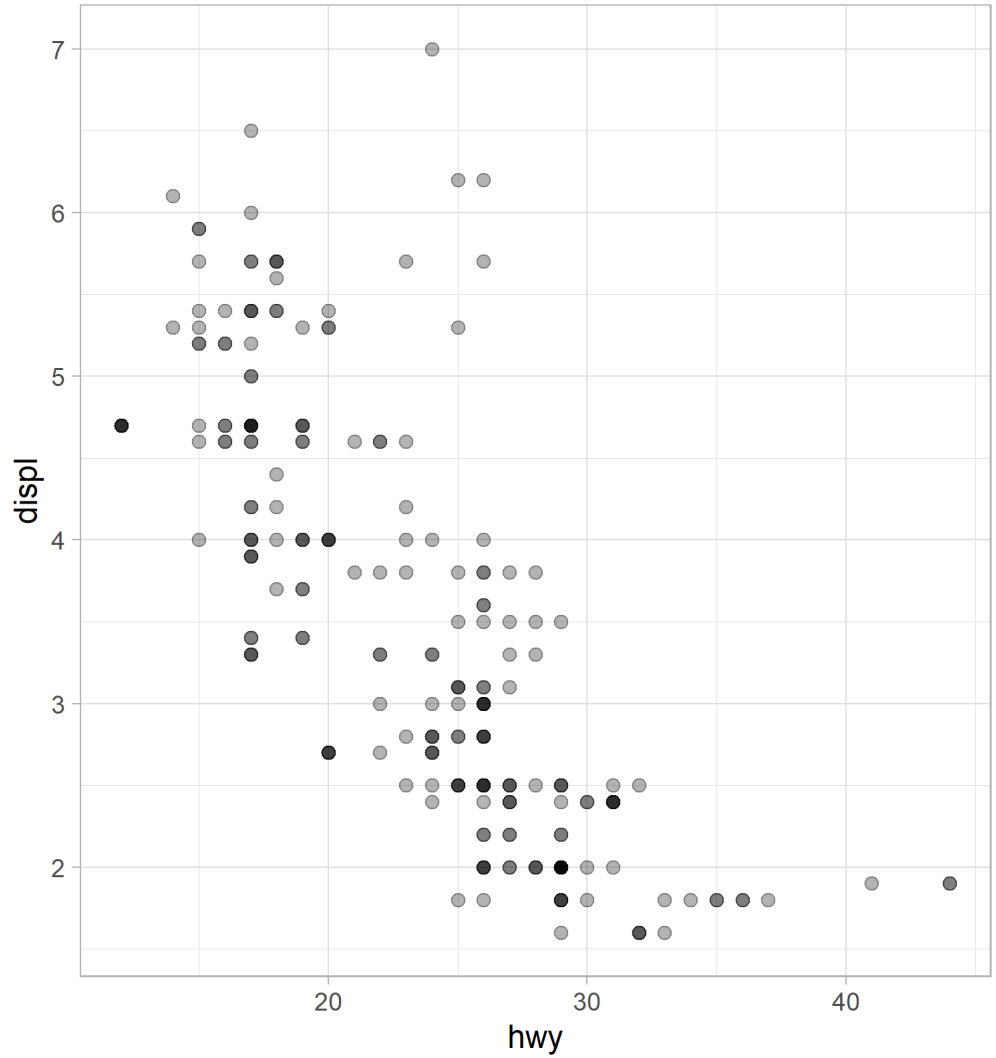


Your Turn: Create this Scatter Plot!



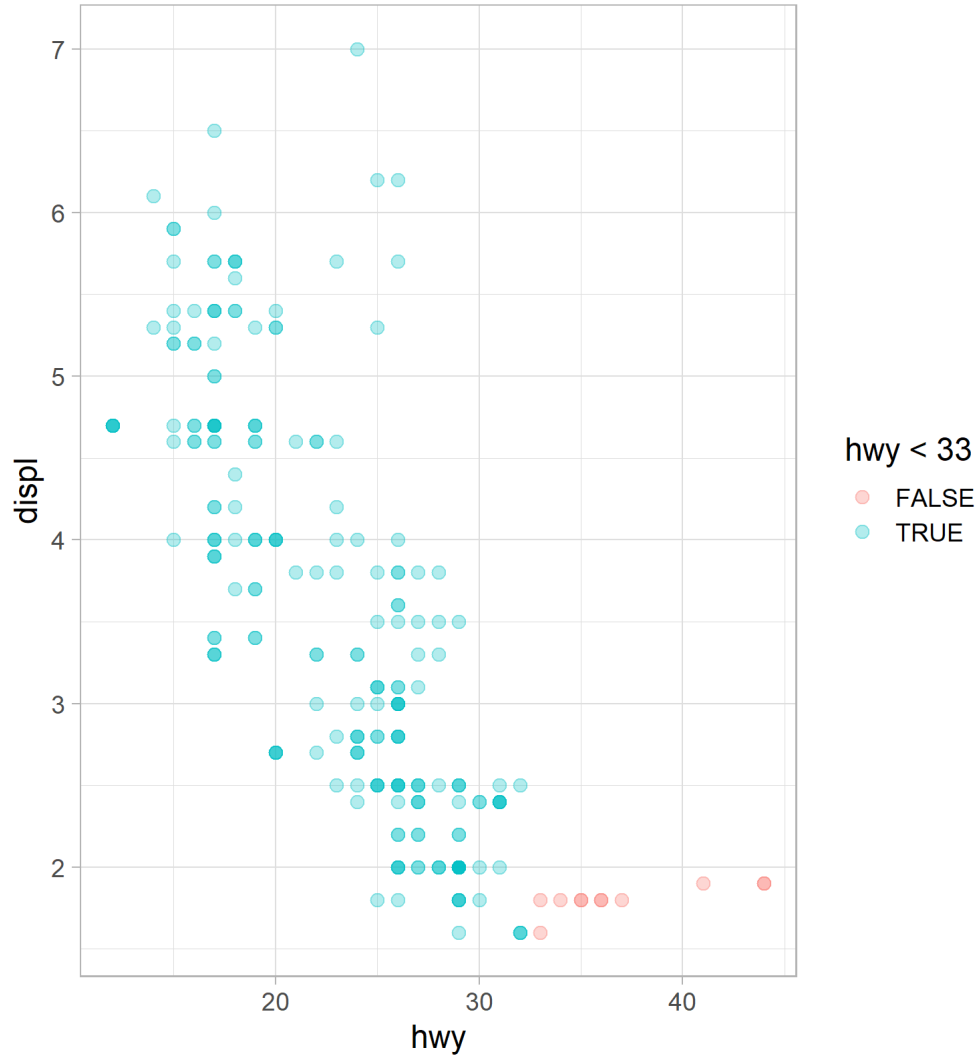
Your Turn: Scatter Plot with Highlights

```
ggplot(mpg, aes(hwy, displ)) +
  geom_point(
    size = 3,
    alpha = .3
  )
```



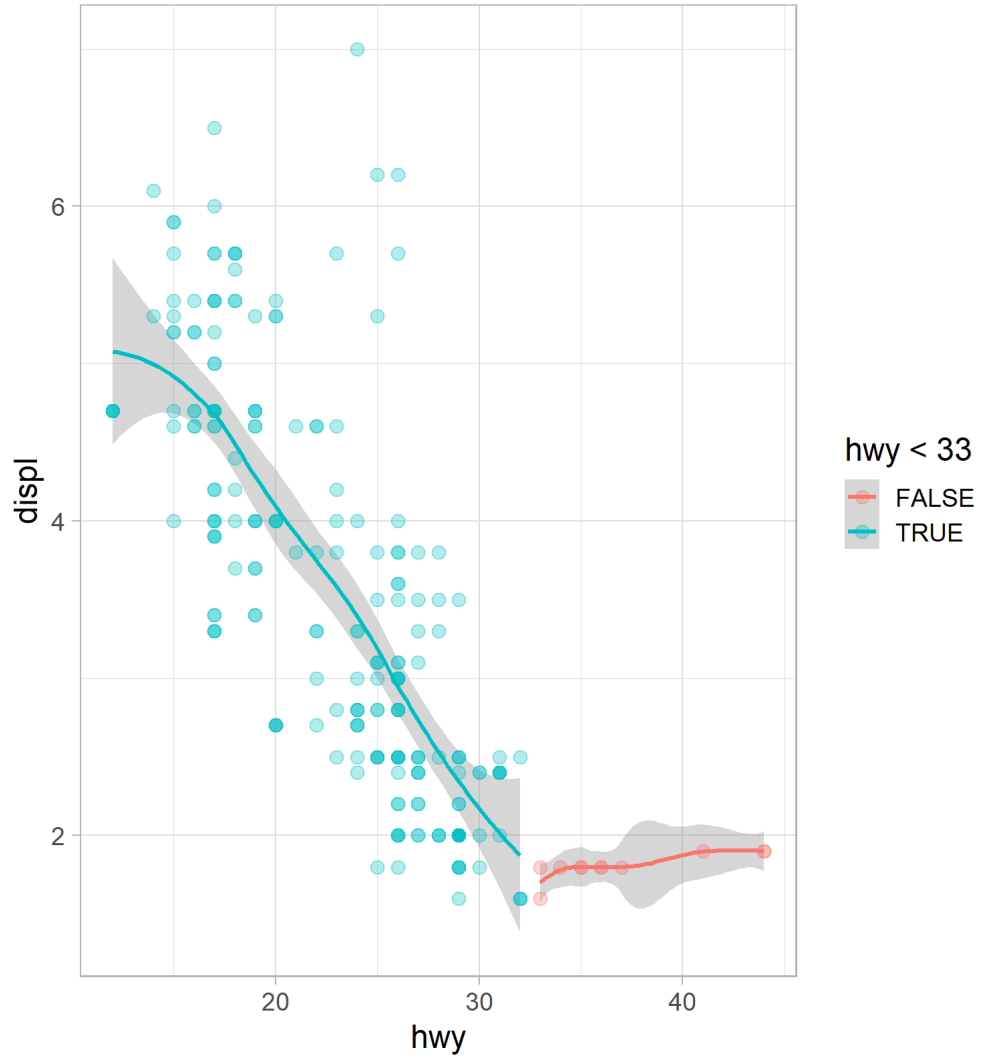
Your Turn: Scatter Plot with Highlights

```
ggplot(
  mpg,
  aes(
    hwy,
    displ,
    color = hwy < 33
  )) +
  geom_point(
    size = 3,
    alpha = .3
  )
```



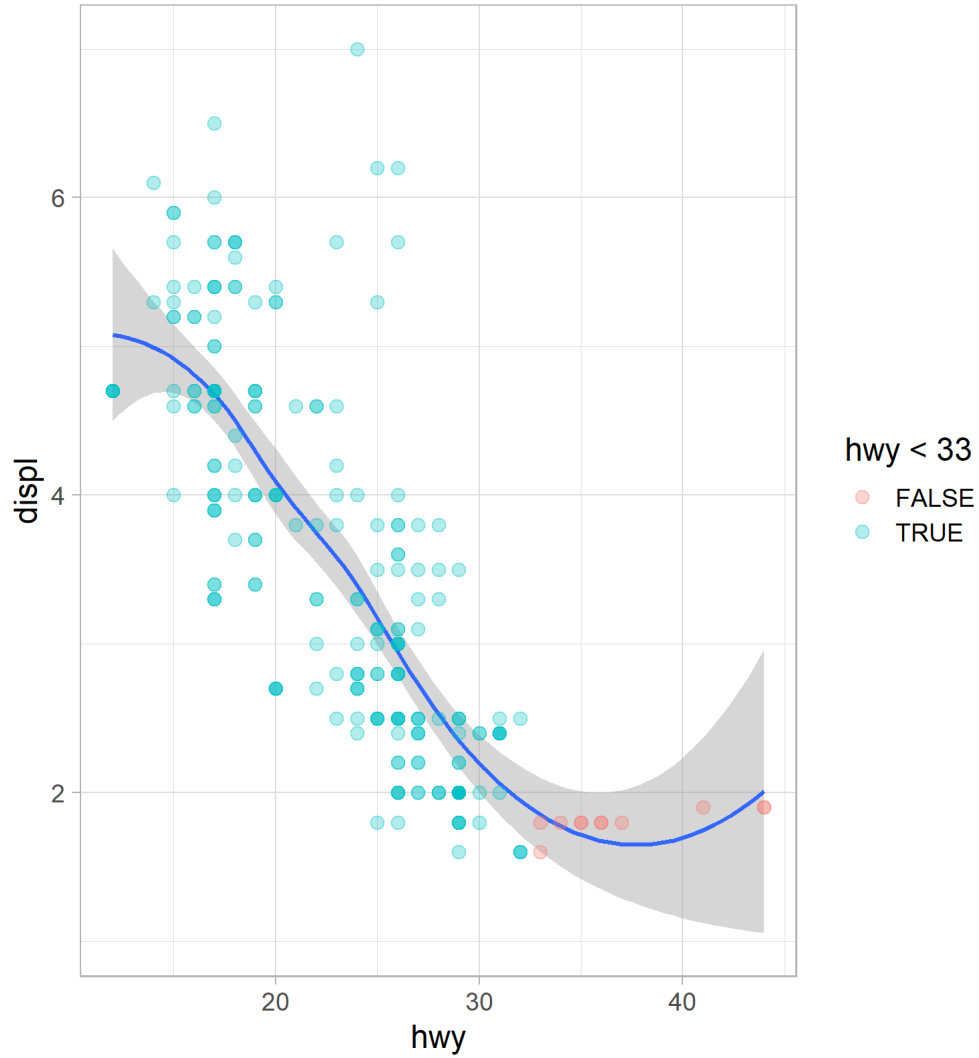
Your Turn: Scatter Plot with Highlights

```
ggplot(
  mpg,
  aes(
    hwy,
    displ,
    color = hwy < 33
  )) +
  stat_smooth() +
  geom_point(
    size = 3,
    alpha = .3
  )
```



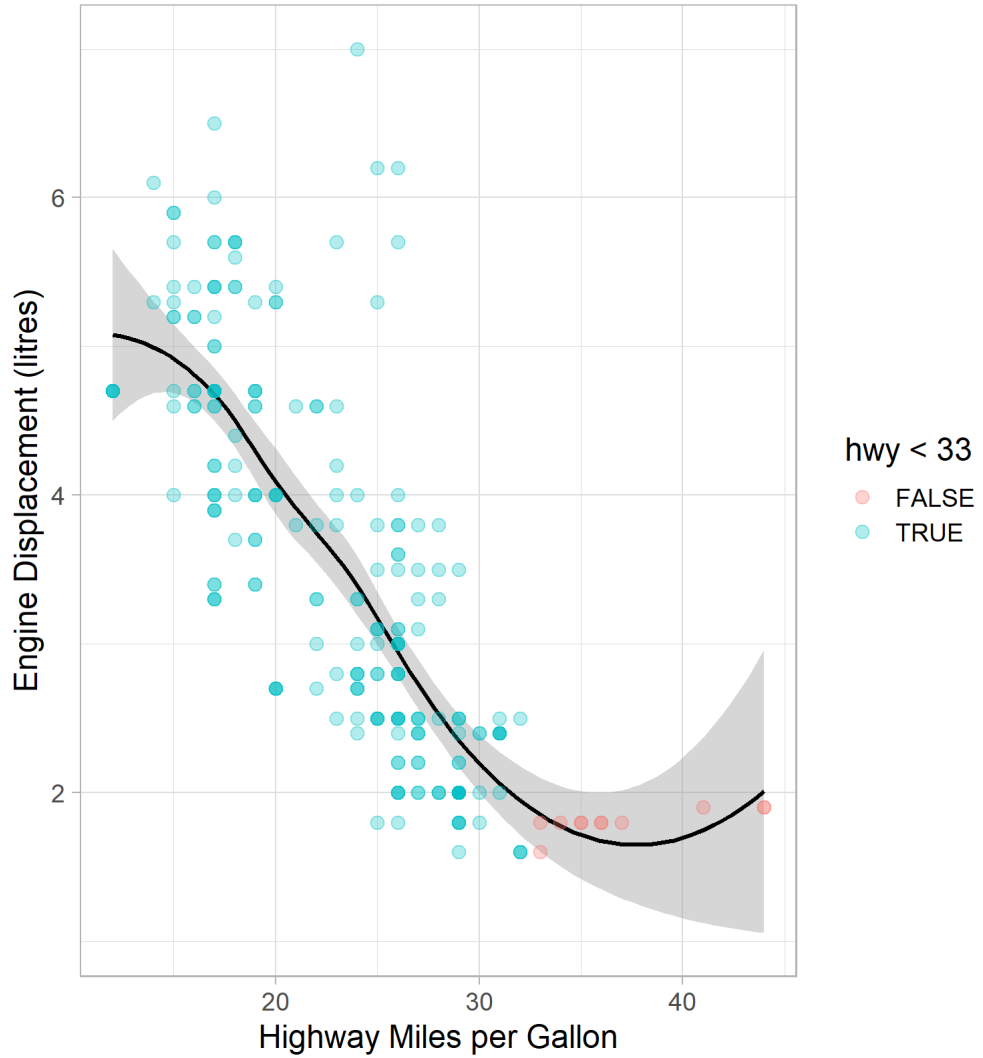
Your Turn: Scatter Plot with Highlights

```
ggplot(
  mpg,
  aes(
    hwy,
    displ
  )) +
  stat_smooth() +
  geom_point(
    aes(color = hwy < 33),
    size = 3,
    alpha = .3
  )
```



Your Turn: Scatter Plot with Highlights

```
ggplot(
  mpg,
  aes(
    hwy,
    displ
  )) +
  stat_smooth(
    color = "black"
  ) +
  geom_point(
    aes(color = hwy < 33),
    size = 3,
    alpha = .3
  ) +
  labs(
    x = "Highway Miles per Gallon",
    y = "Engine Displacement (litres)"
  )
```

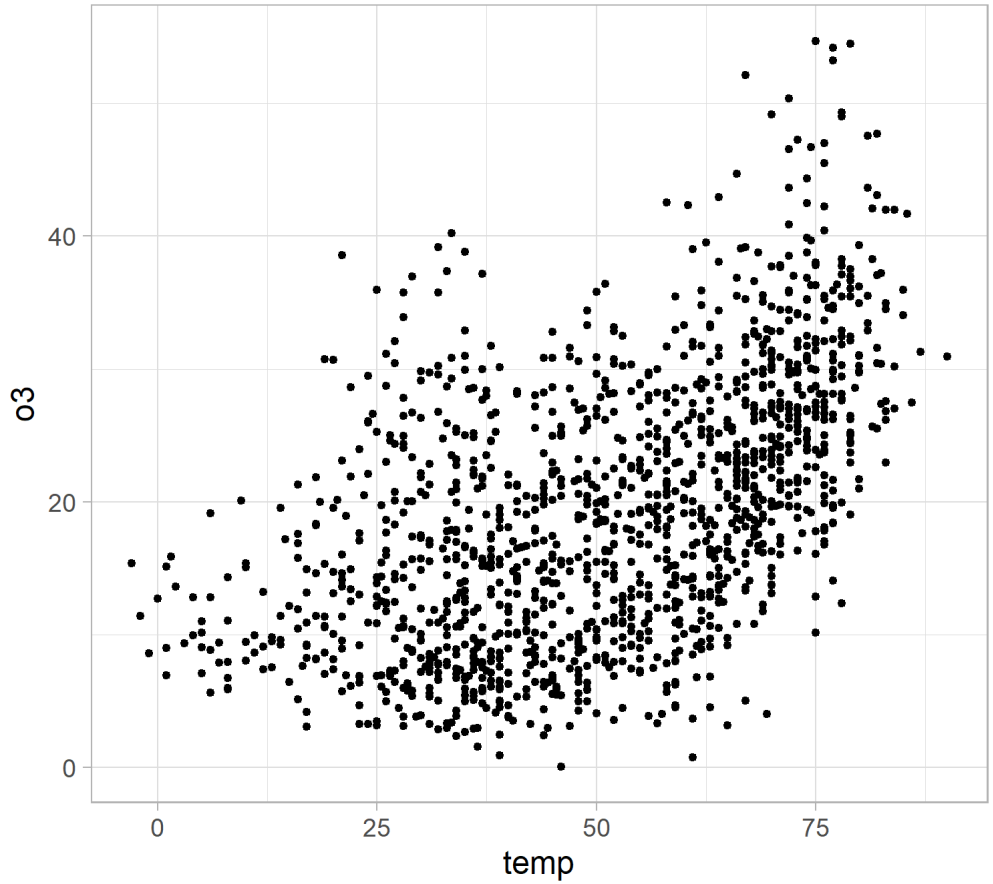


More `geom`'s!

`geom_*()` and `stat_*()`

You can displa your data via `geom_point()` as scatter plot...

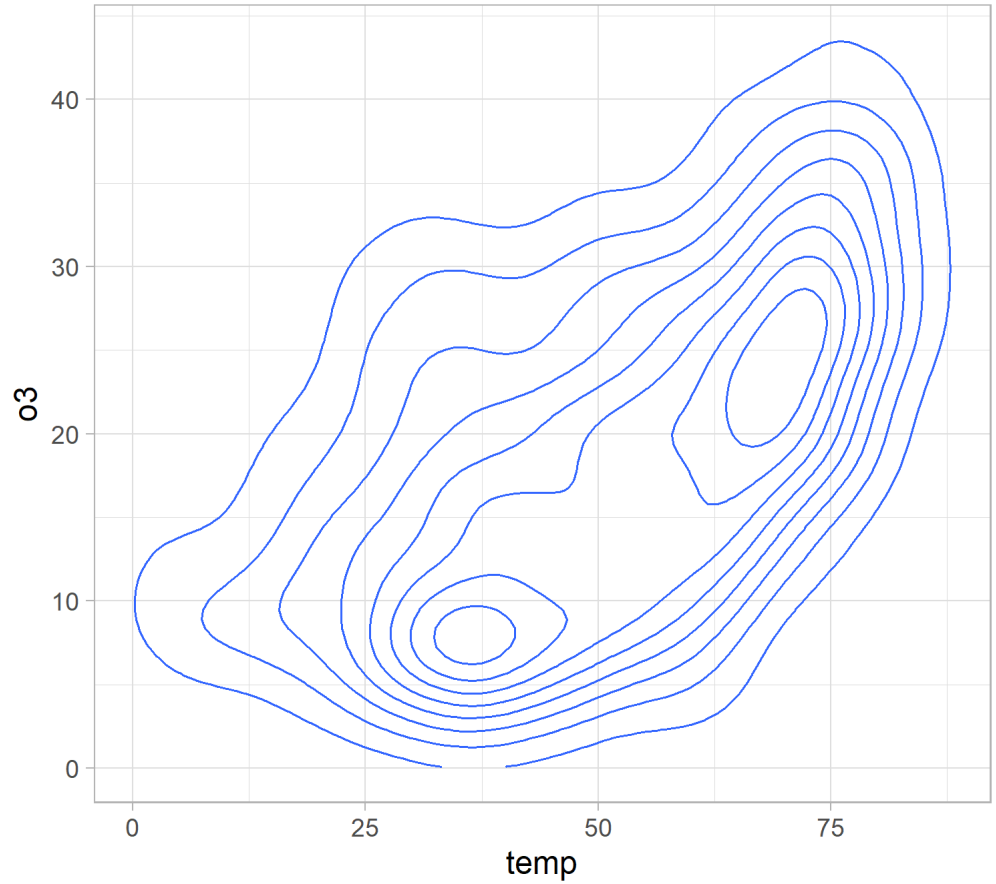
```
ggplot(chic, aes(temp, o3)) +
  geom_point()
```



geom_*() and stat_*()

You can displa your data via `geom_point()` as scatter plot but there are also other built-in options:

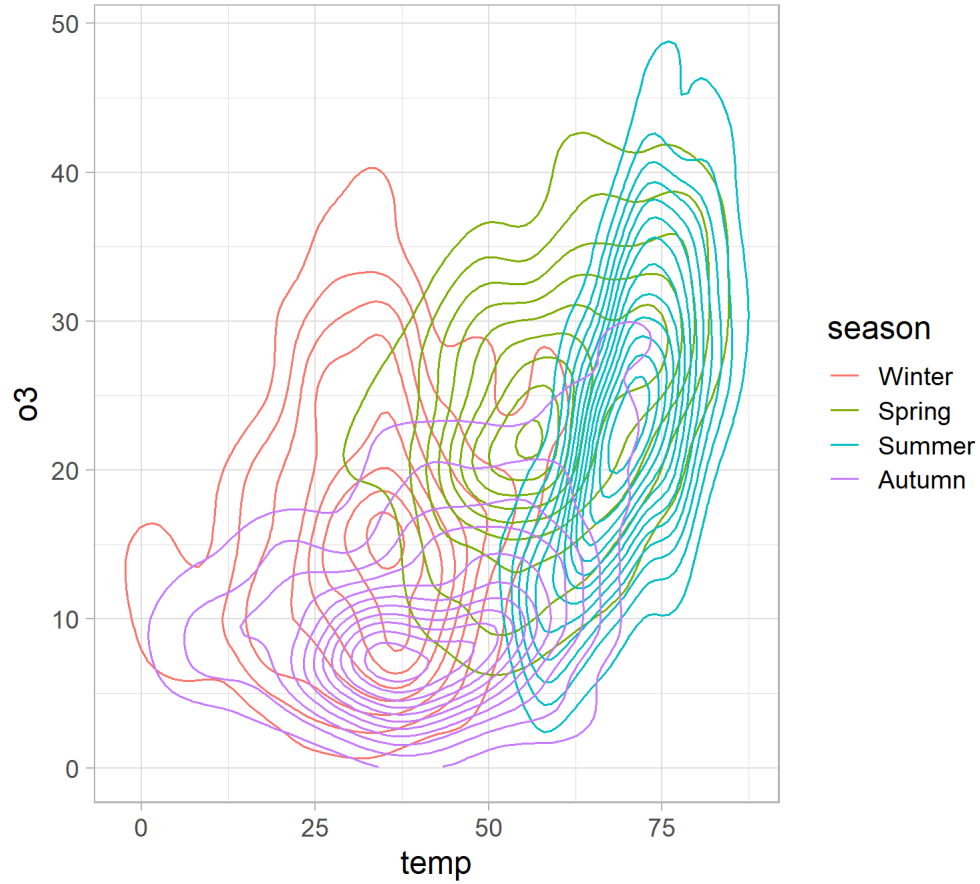
```
ggplot(chic, aes(temp, o3)) +
  geom_density2d()
```



`geom_*()` and `stat_*()`

You can displa your data via `geom_point()` as scatter plot but there are also other built-in options:

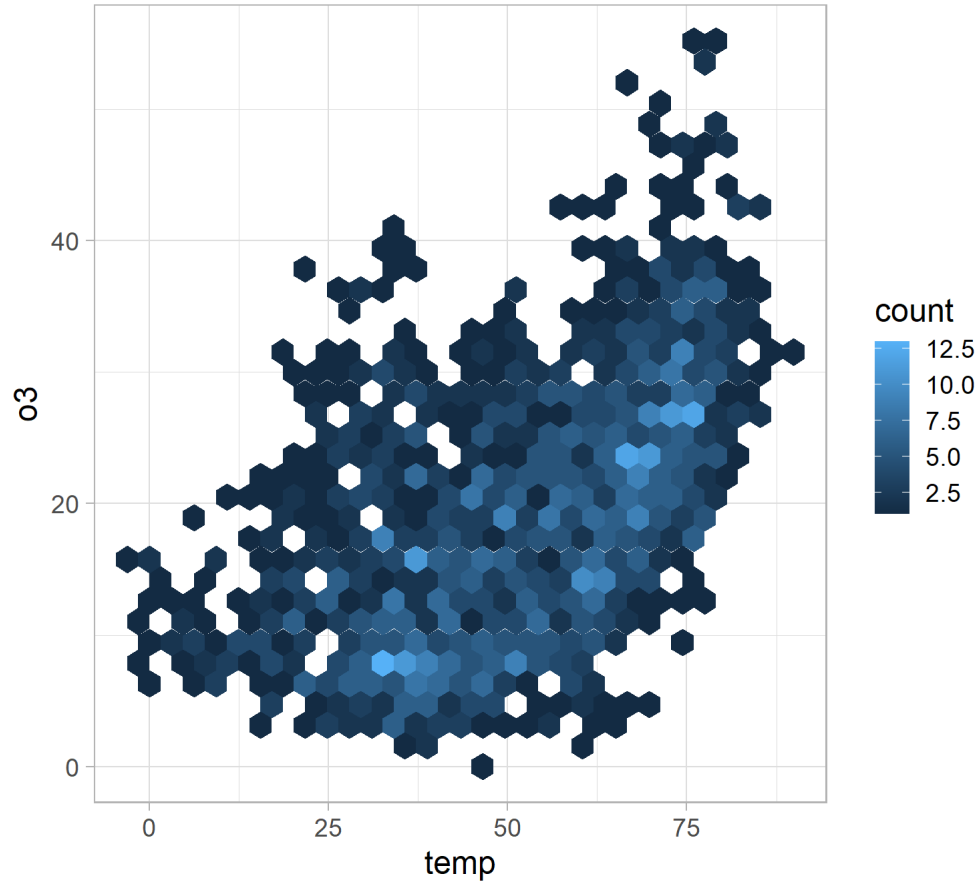
```
ggplot(chic, aes(temp, o3)) +
  geom_density2d(
    aes(color = season)
  )
```



geom_*() and stat_*()

You can displa your data via `geom_point()` as scatter plot but there are also other built-in options:

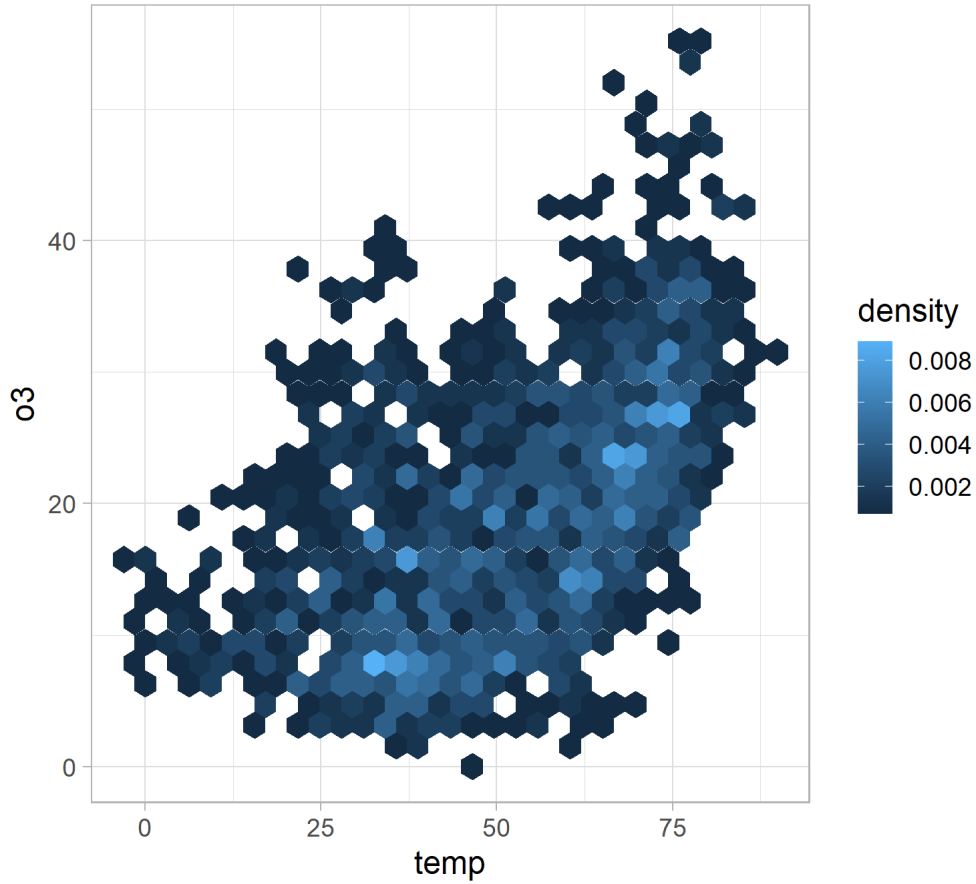
```
ggplot(chic, aes(temp, o3)) +
  geom_hex()
```



`geom_*()` and `stat_*()`

You can displa your data via `geom_point()` as scatter plot but there are also other built-in options:

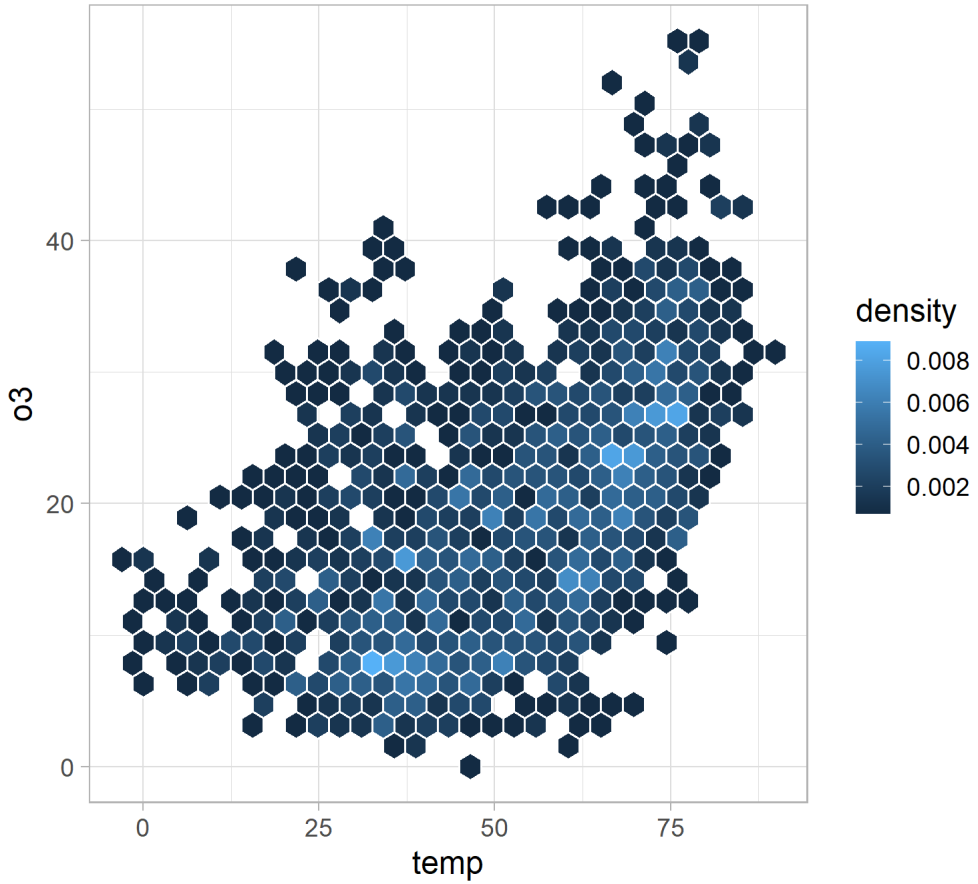
```
ggplot(chic, aes(temp, o3)) +
  geom_hex(
    aes(fill = ..density..)
  )
```



`geom_*()` and `stat_*()`

You can displa your data via `geom_point()` as scatter plot but there are also other built-in options:

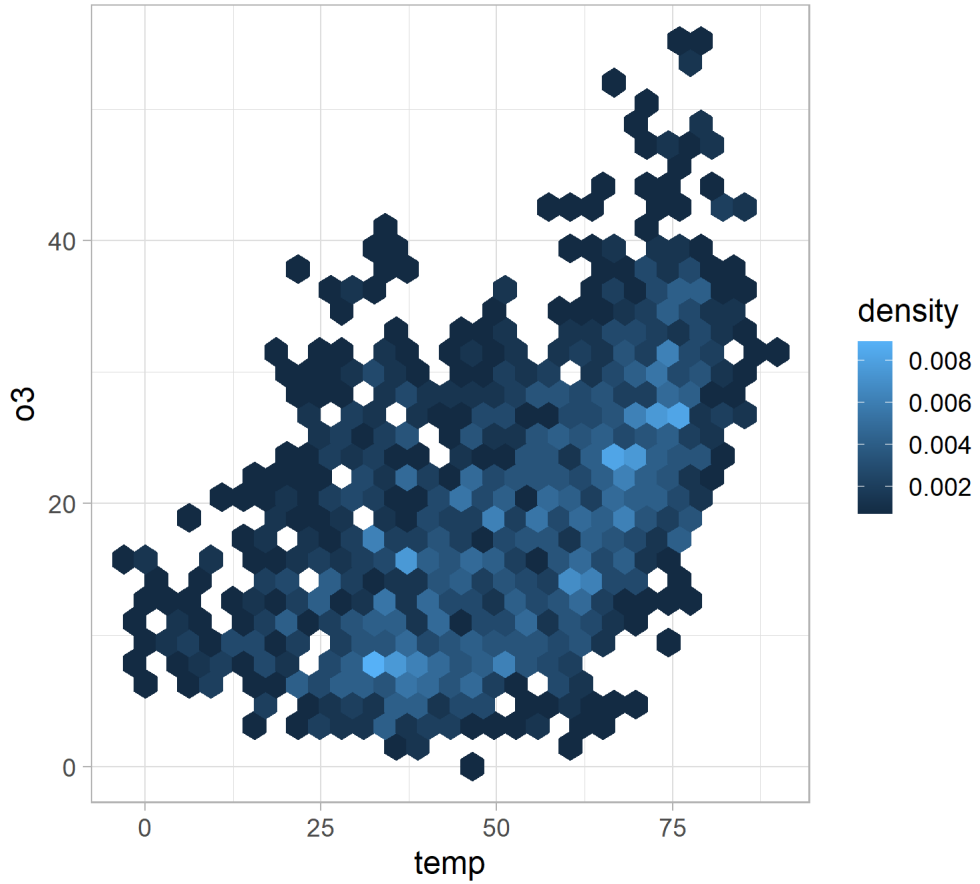
```
ggplot(chic, aes(temp, o3)) +
  geom_hex(
    aes(
      fill = ..density..
    ),
      color = "white"
  )
```



`geom_*()` and `stat_*()`

You can displa your data via `geom_point()` as scatter plot but there are also other built-in options:

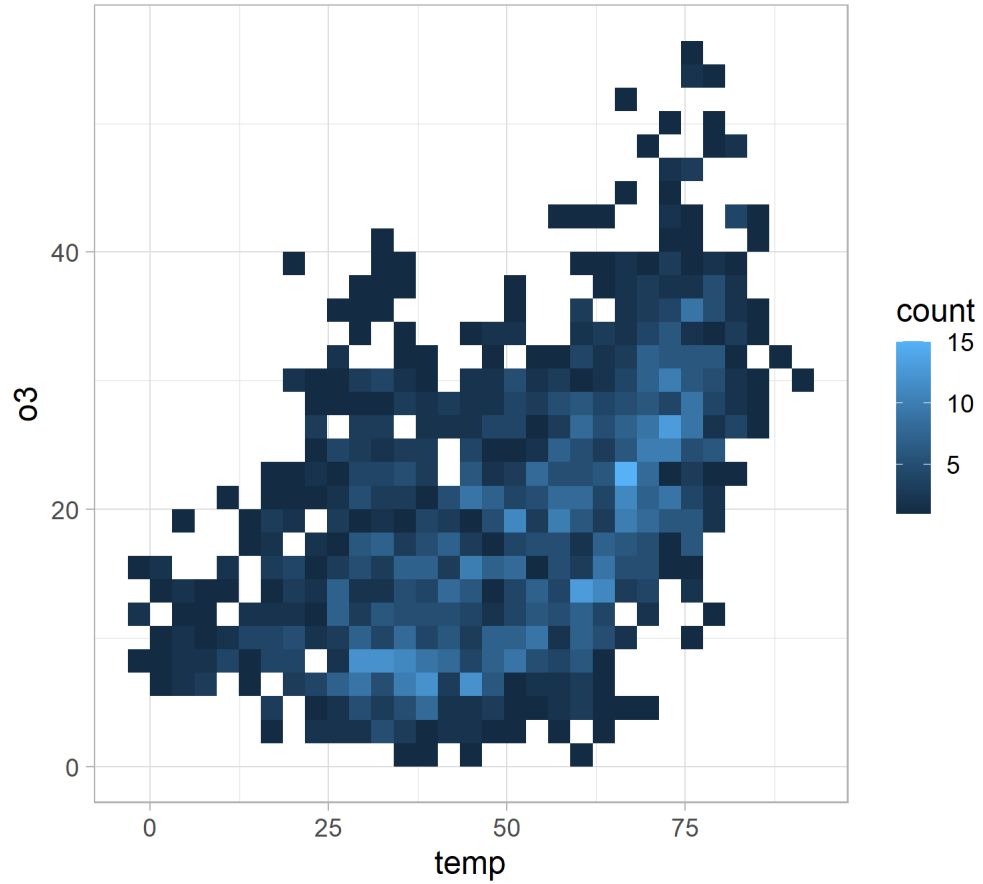
```
ggplot(chic, aes(temp, o3)) +
  geom_hex(
    aes(
      fill = ..density..,
      color = ..density..
    )
  )
```



`geom_*()` and `stat_*()`

You can displa your data via `geom_point()` as scatter plot but there are also other built-in options:

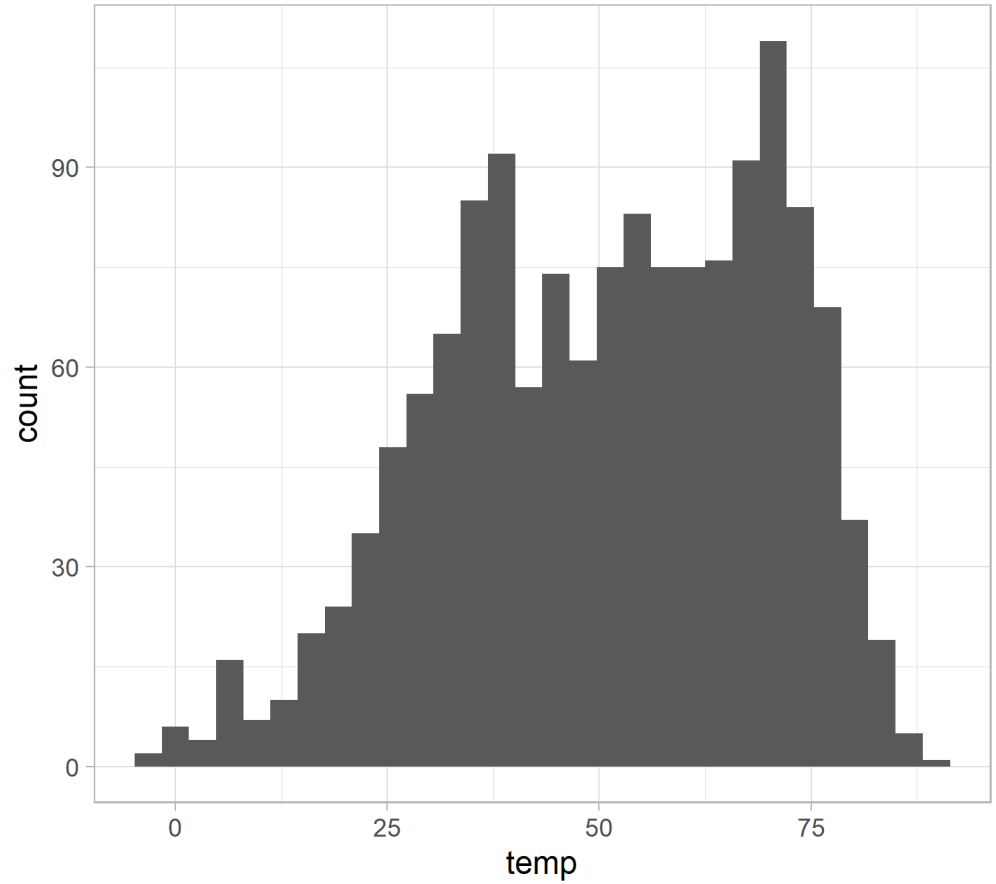
```
ggplot(chic, aes(temp, o3)) +
  geom_bin2d()
```



`geom_*()` and `stat_*()`

Until now, we have mostly focussed on **geoms showing the relation between two variables** - but some only need **one**:

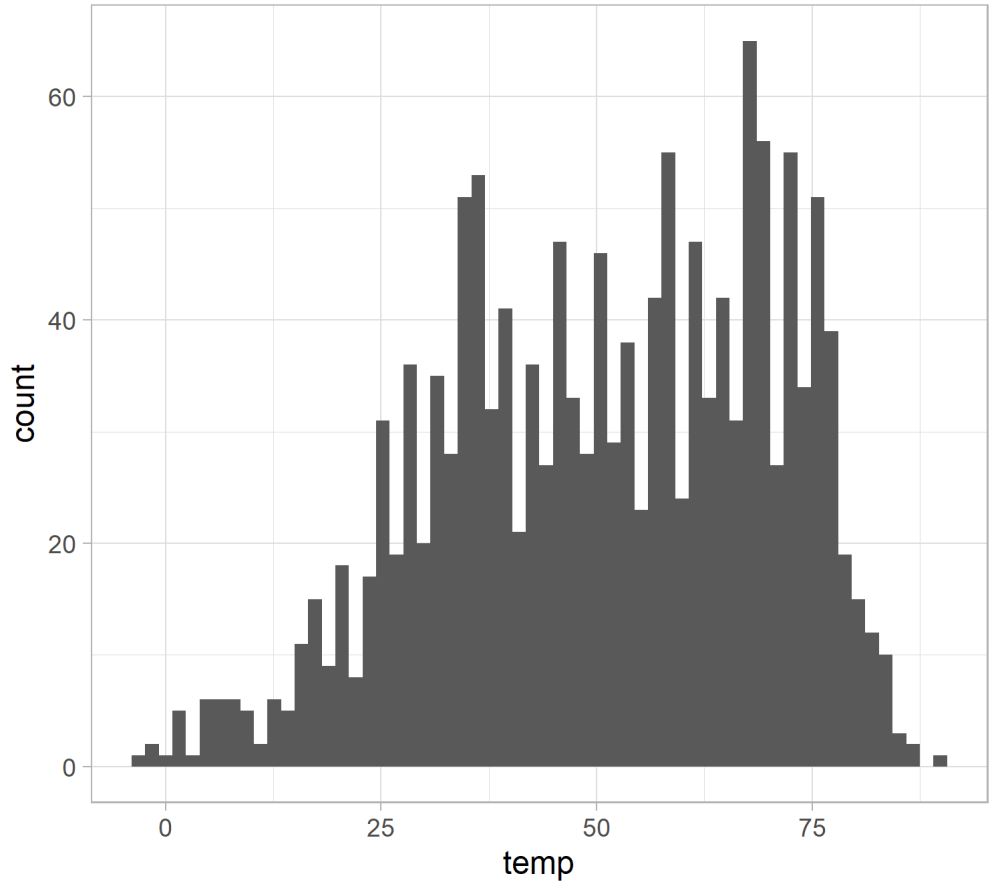
```
ggplot(chic, aes(temp)) +
  geom_histogram()
```



geom_*() and stat_*()

Until now, we have mostly focussed on **geoms showing the relation between two variables** - but some only need **one**:

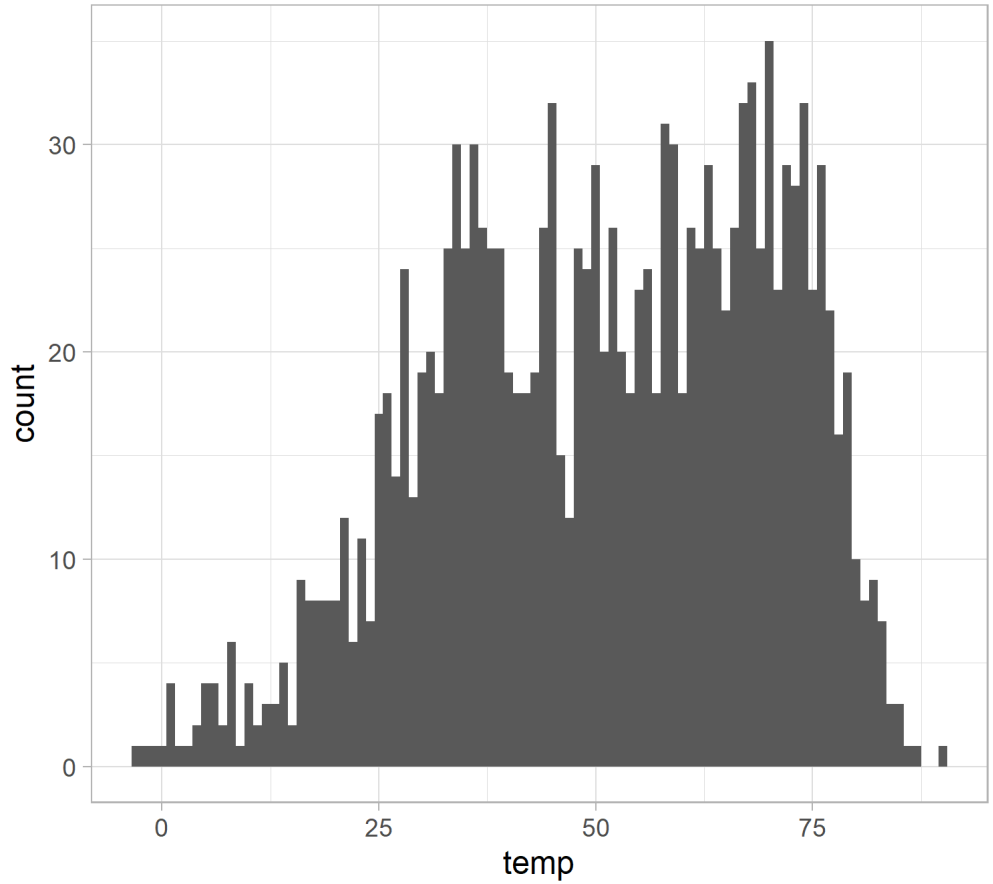
```
ggplot(chic, aes(temp)) +
  geom_histogram(
    bins = 60
  )
```



geom_*() and stat_*()

Until now, we have mostly focussed on **geoms showing the relation between two variables** - but some only need **one**:

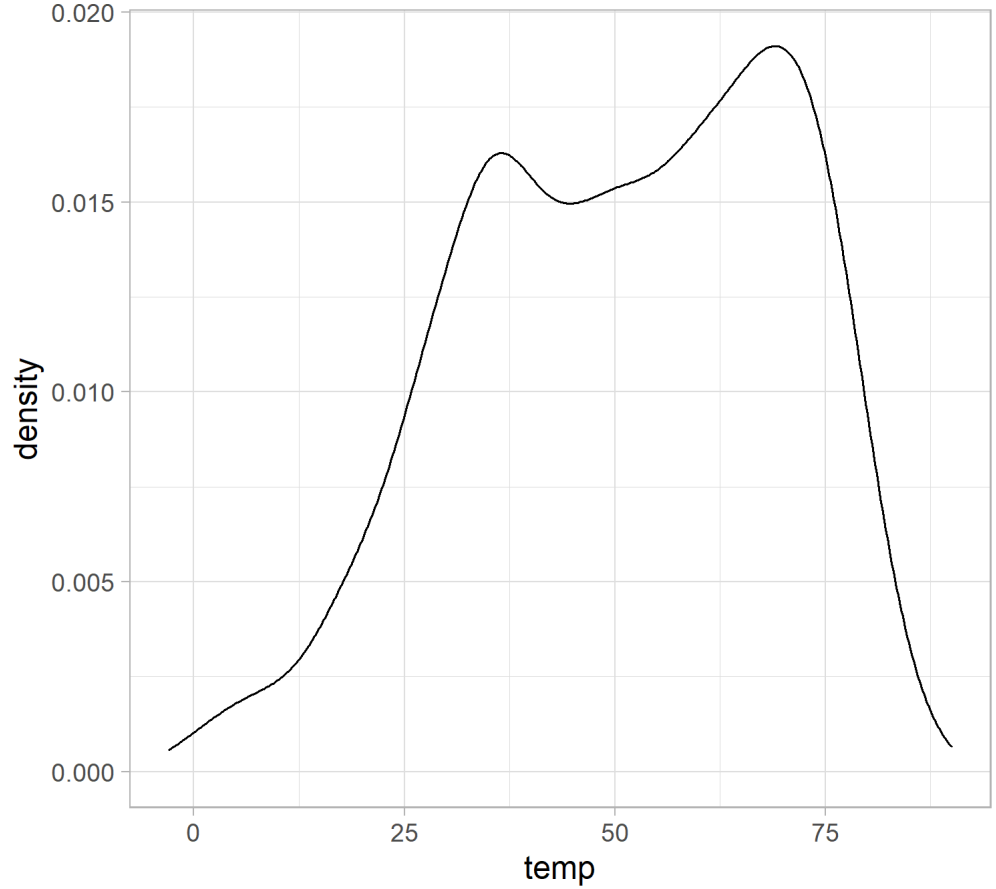
```
ggplot(chic, aes(temp)) +
  geom_histogram(
    binwidth = 1
  )
```



geom_*() and stat_*()

Until now, we have mostly focussed on **geoms showing the relation between two variables** - but some only need **one**:

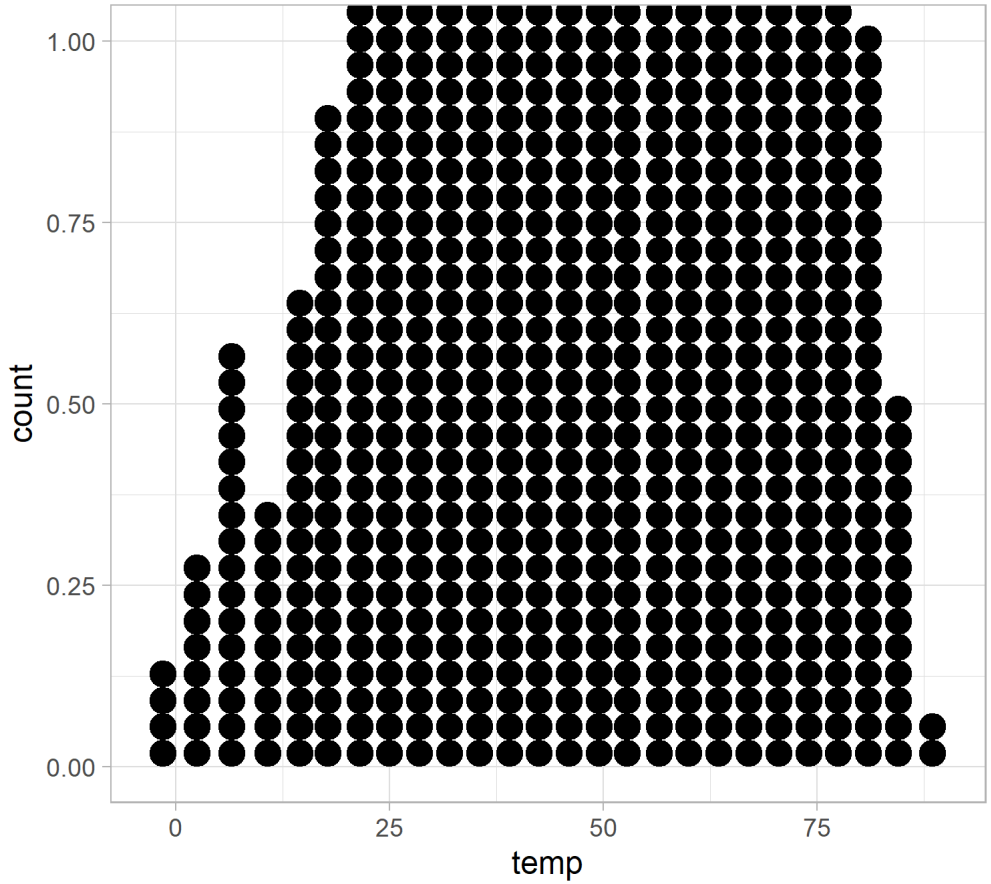
```
ggplot(chic, aes(temp)) +
  geom_density()
```



geom_*() and stat_*()

Until now, we have mostly focussed on **geoms showing the relation between two variables** - but some only need **one**:

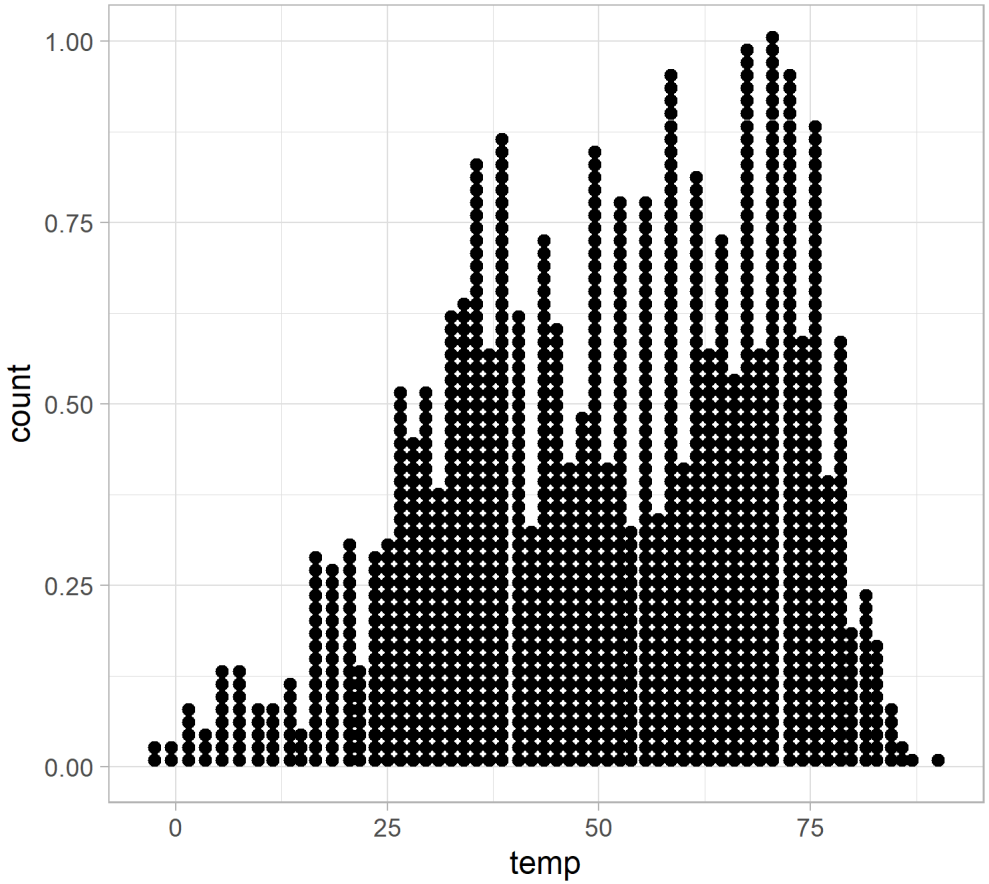
```
ggplot(chic, aes(temp)) +
  geom_dotplot()
```



geom_*() and stat_*()

Until now, we have mostly focussed on **geoms showing the relation between two variables** - but some only need **one**:

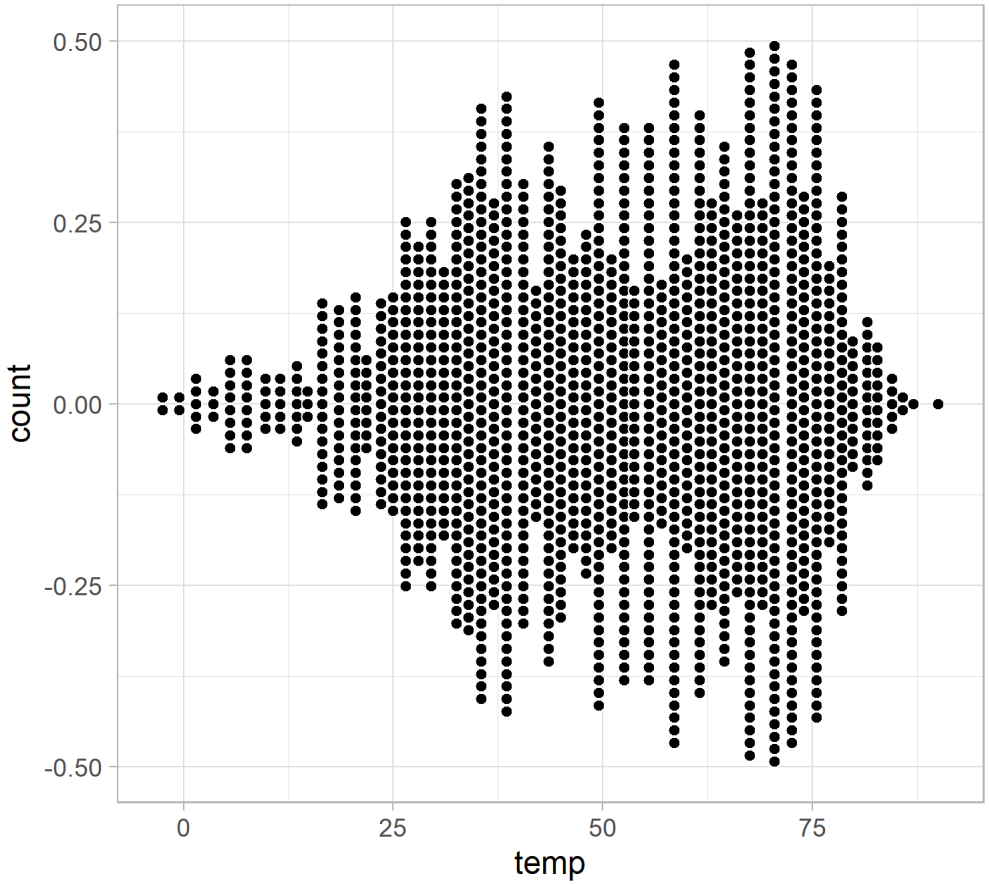
```
ggplot(chic, aes(temp)) +
  geom_dotplot(
    binwidth = 1.5
  )
```



geom_*() and stat_*()

Until now, we have mostly focussed on **geoms showing the relation between two variables** - but some only need **one**:

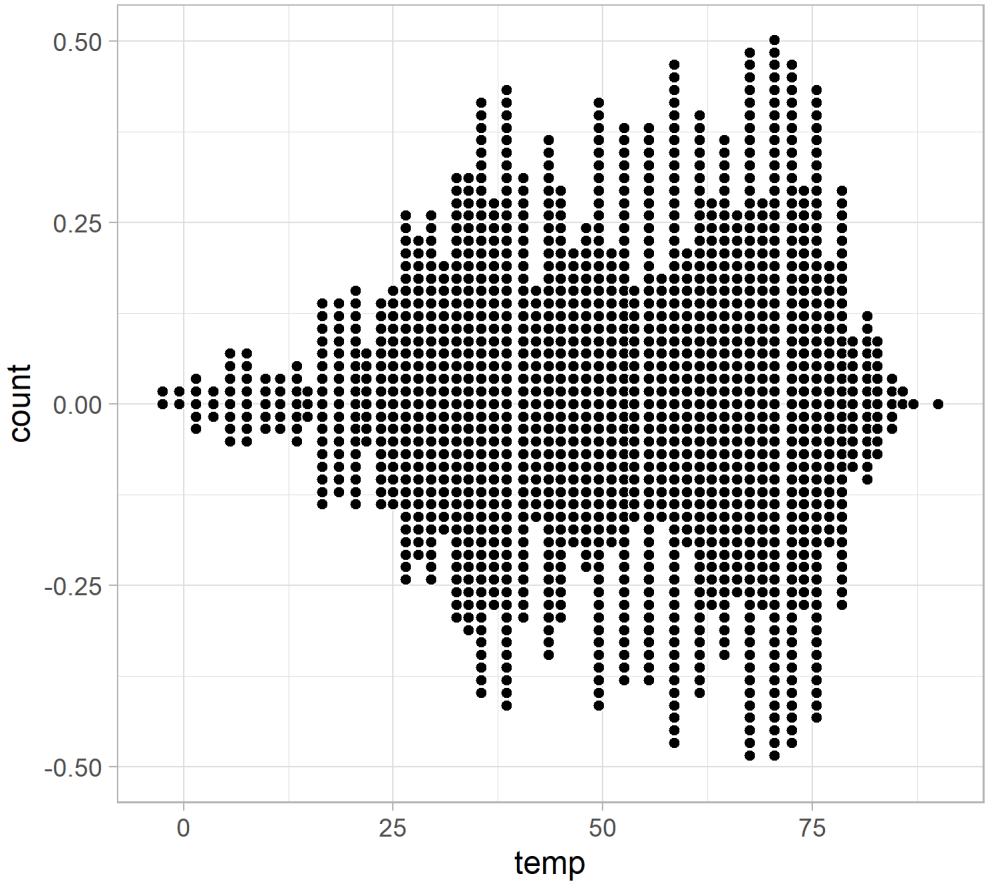
```
ggplot(chic, aes(temp)) +
  geom_dotplot(
    binwidth = 1.5,
    color = "white",
    stackdir = "center"
  )
```



geom_*() and stat_*()

Until now, we have mostly focussed on **geoms showing the relation between two variables** - but some only need **one**:

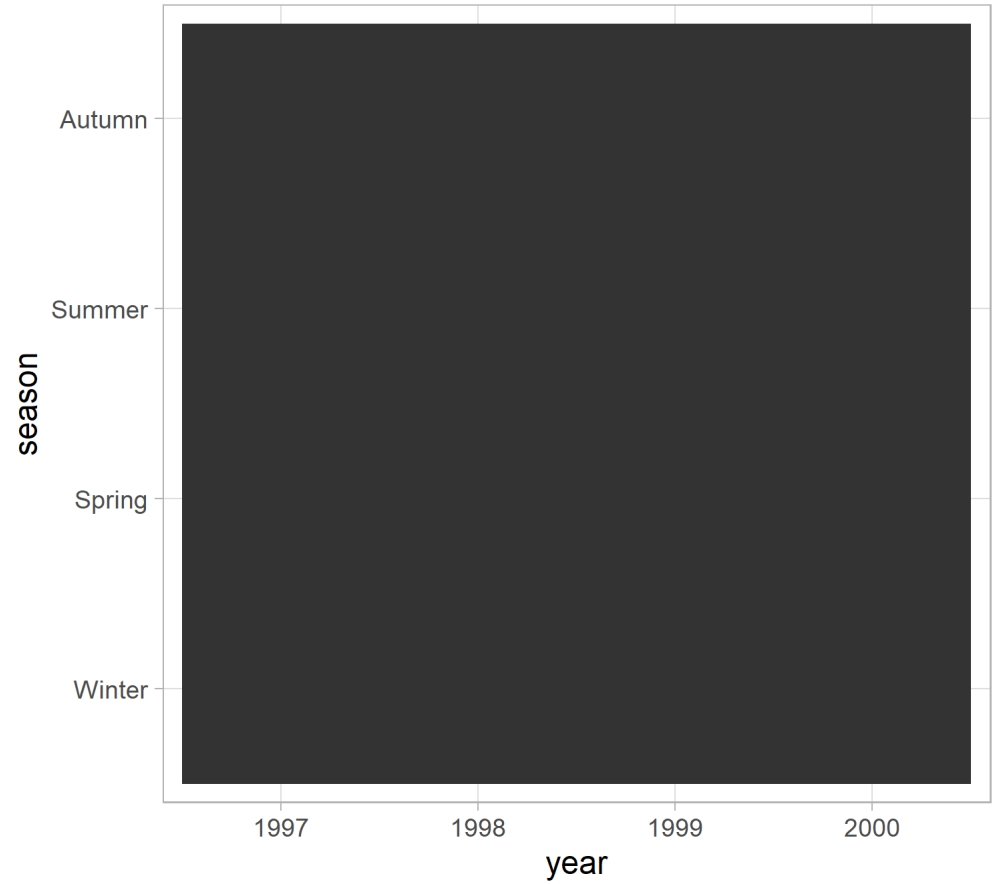
```
ggplot(chic, aes(temp)) +
  geom_dotplot(
    binwidth = 1.5,
    color = "white",
    stackdir = "centerwhole"
  )
```



`geom_*()` and `stat_*()`

... and some which make only sense with **three variables**:

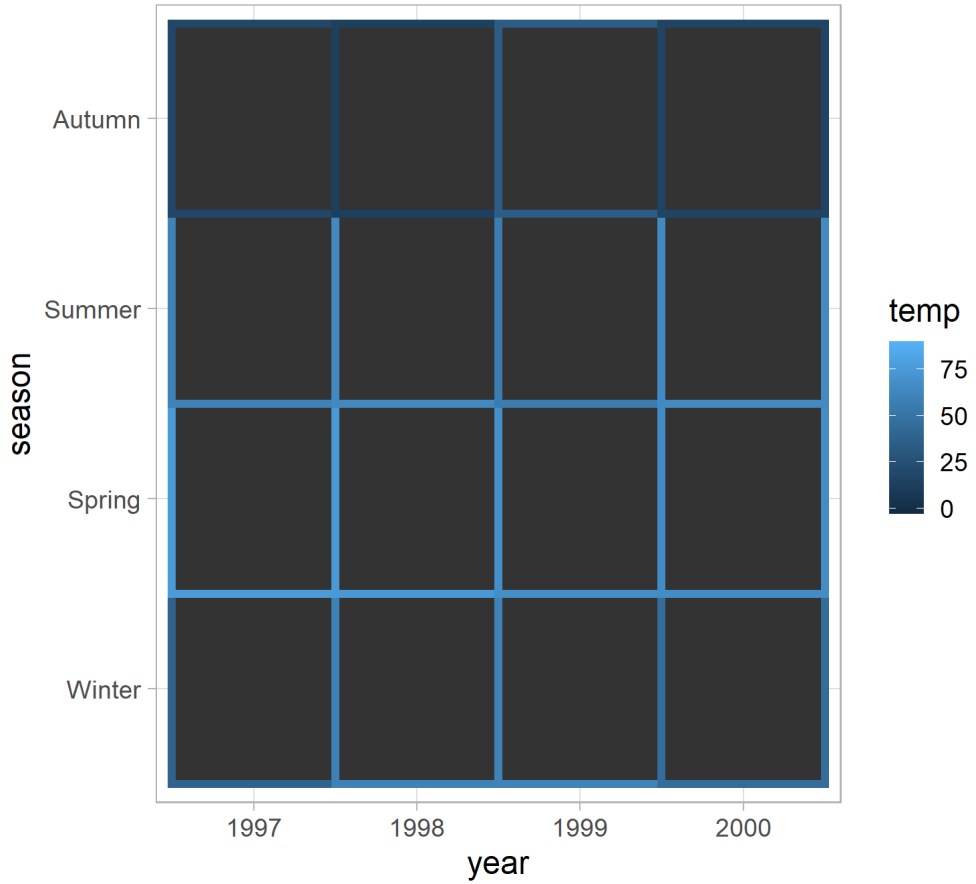
```
ggplot(chic, aes(year, season)) +
  geom_tile()
```



geom_*() and stat_*()

... and some which make only sense with **three variables**:

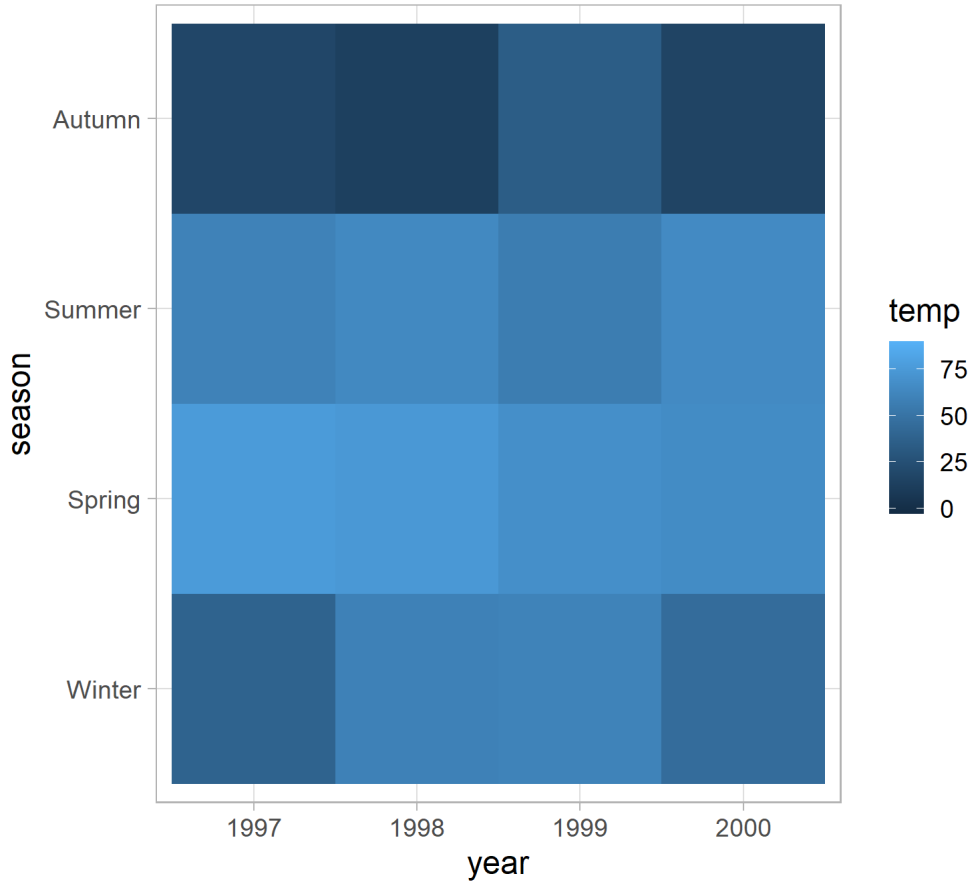
```
ggplot(chic, aes(year, season)) +
  geom_tile(
    aes(color = temp),
    size = 2
  )
```



geom_*() and stat_*()

... and some which make only sense with **three variables**:

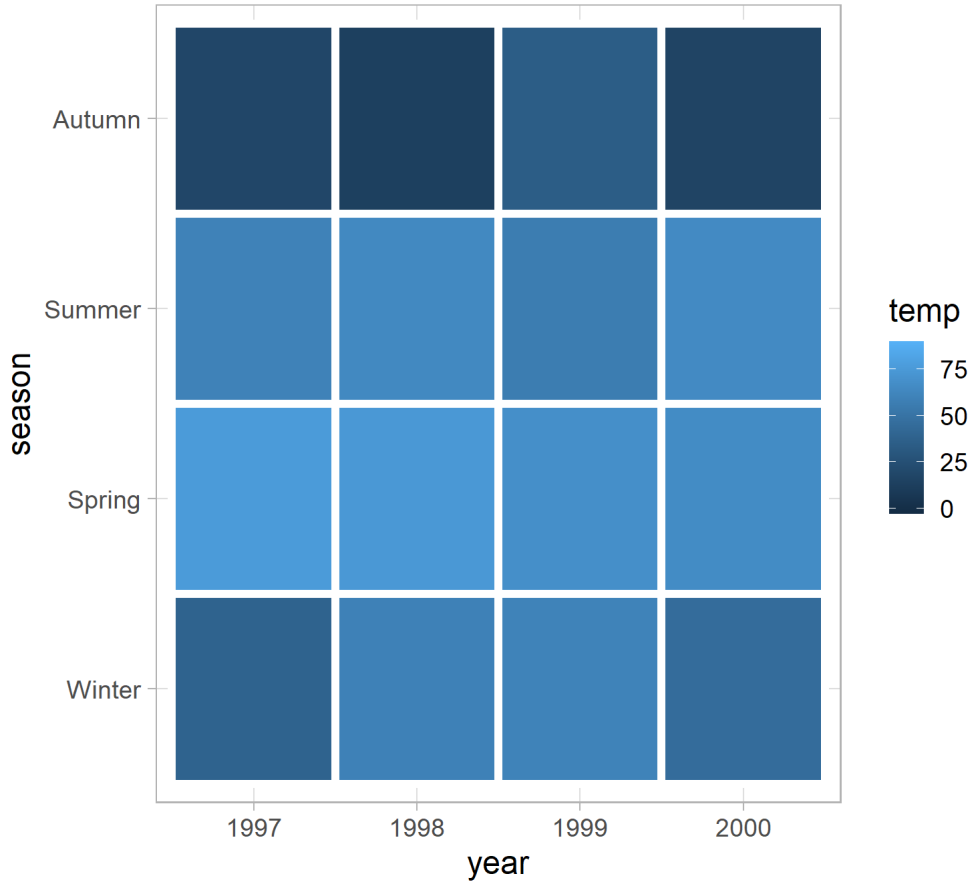
```
ggplot(chic, aes(year, season)) +
  geom_tile(
    aes(fill = temp)
  )
```



geom_*() and stat_*()

... and some which make only sense with **three variables**:

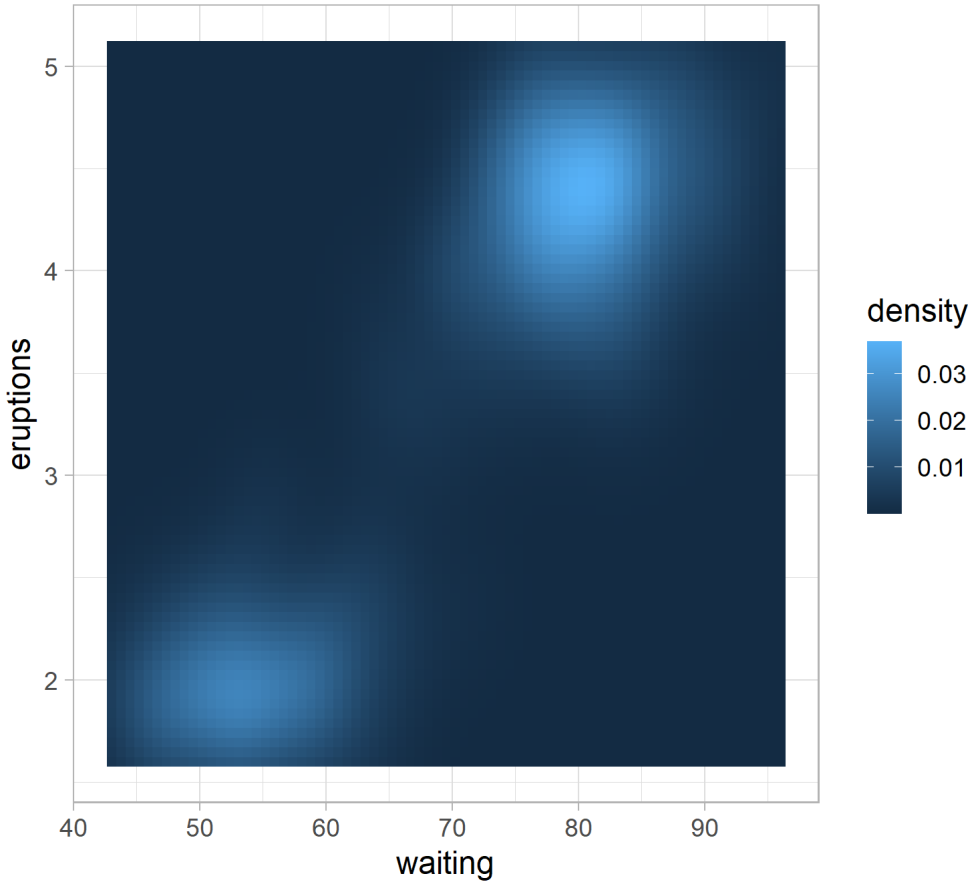
```
ggplot(chic, aes(year, season)) +
  geom_tile(
    aes(fill = temp),
    color = "white",
    size = 2
  )
```



`geom_*()` and `stat_*()`

... and some which make only sense with **three variables**:

```
ggplot(
  faithfuld,
  aes(
    waiting,
    eruptions
  )) +
  geom_raster(
    aes(fill = density)
  )
```

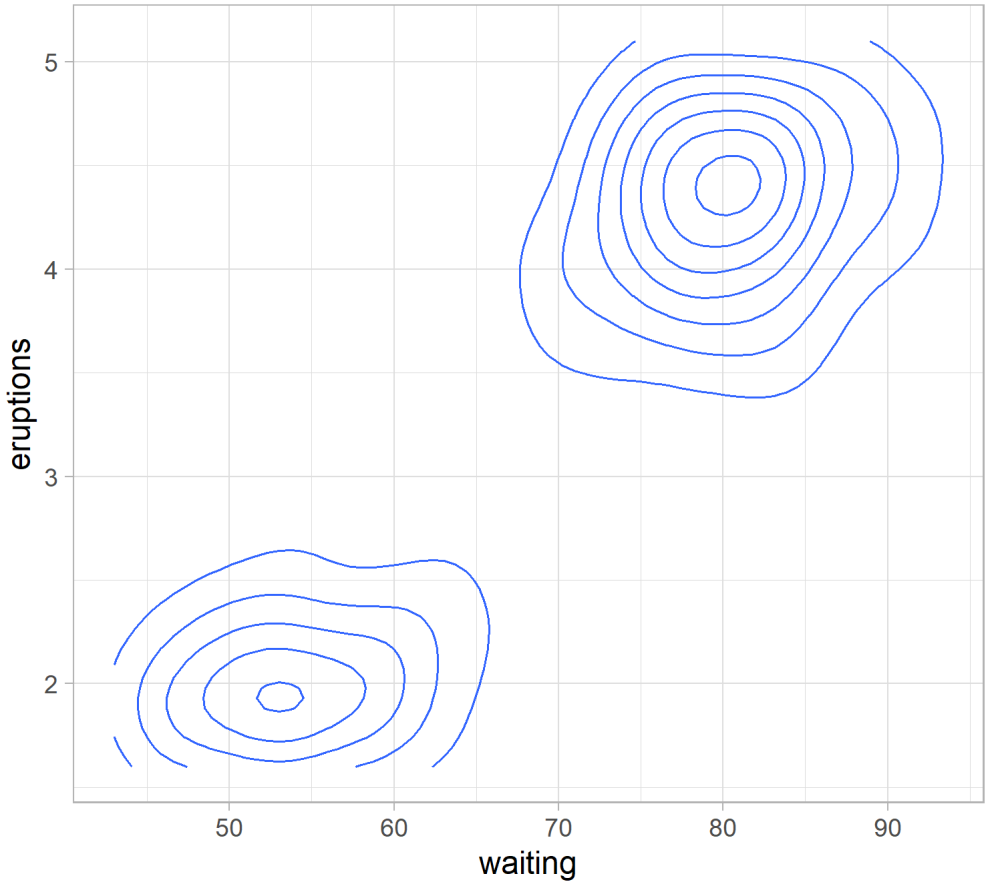


`geom_raster()` does more or less the same as `geom_tile()` but is is a "high performance special case for when\nall the tiles are the same size".

geom_*() and stat_*()

... and some which make only sense with **three variables**:

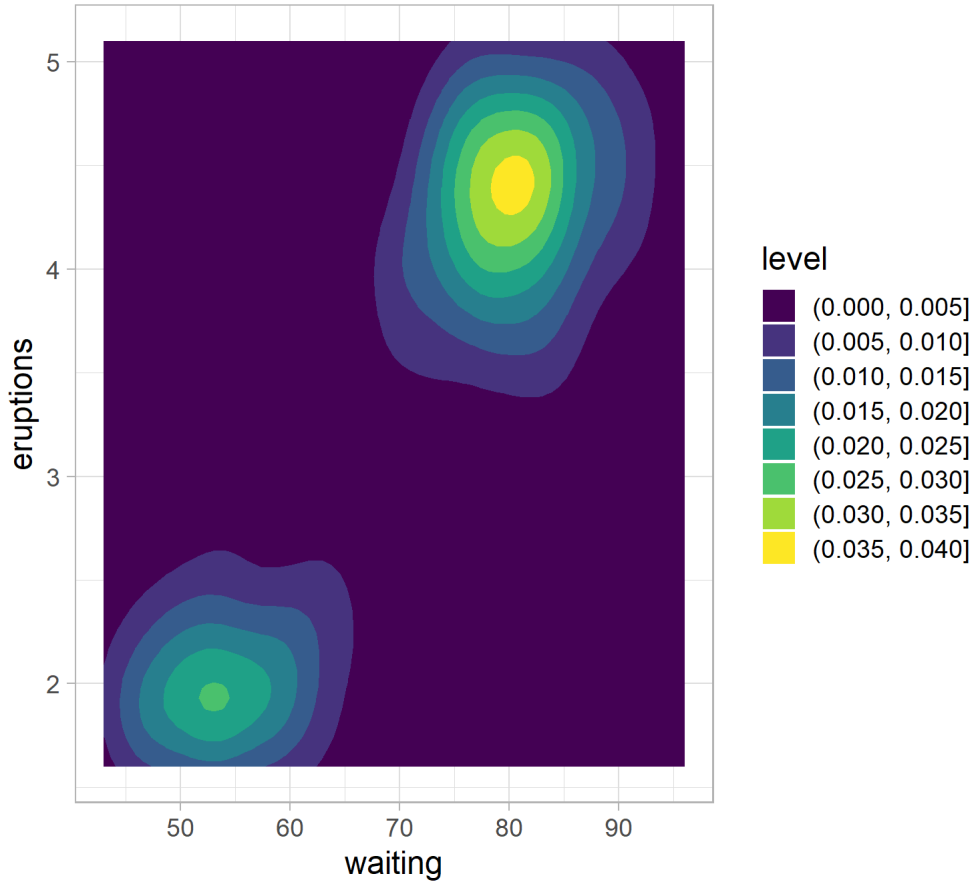
```
ggplot(
  faithfuld,
  aes(
    waiting,
    eruptions,
    z = density
  )) +
  geom_contour()
```



geom_*() and stat_*()

... and some which make only sense with **three variables**:

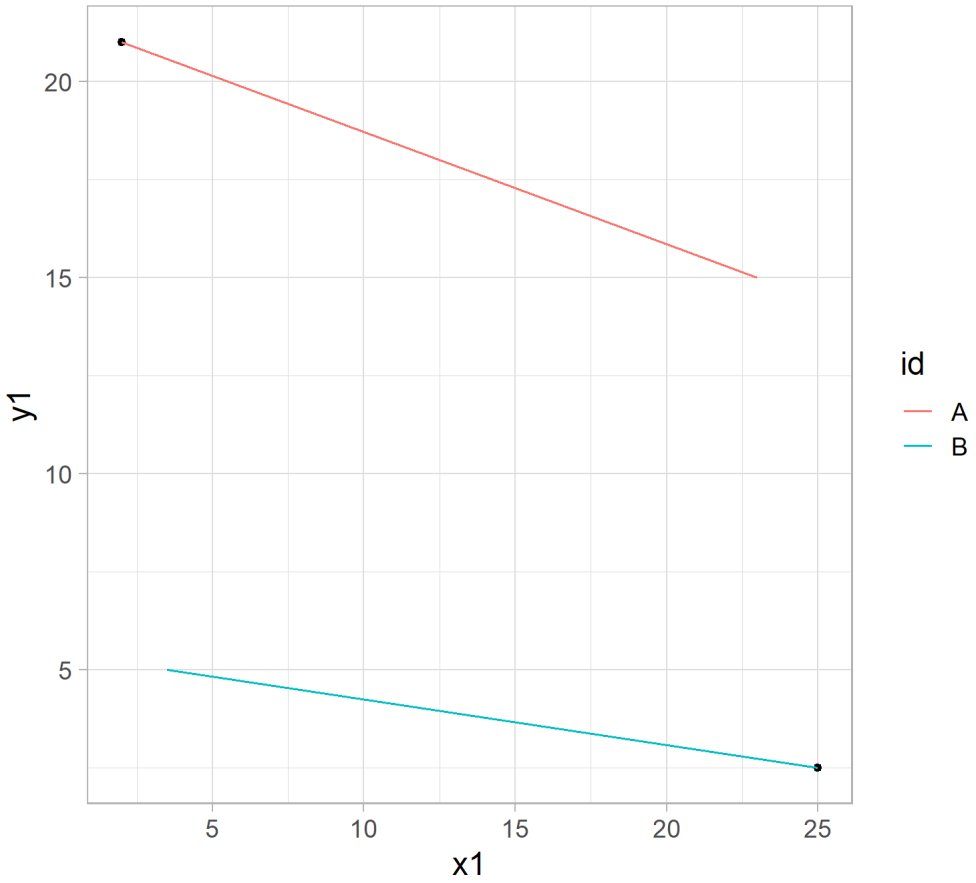
```
ggplot(
  faithfuld,
  aes(
    waiting,
    eruptions,
    z = density
  )) +
  geom_contour_filled()
```



geom_*() and stat_*()

Some need even more inputs:

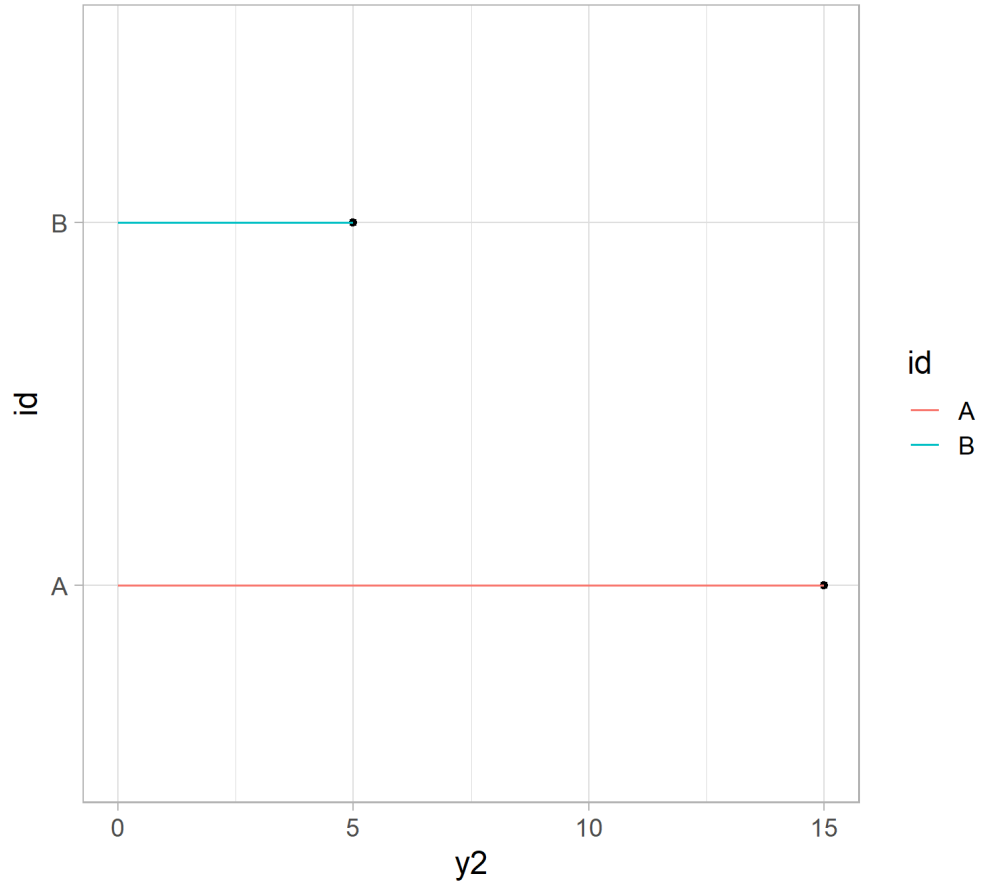
```
points <- tibble(
  x1 = c(2, 25),
  x2 = c(23, 3.5),
  y1 = c(21, 2.5),
  y2 = c(15, 5),
  id = c("A", "B")
)

ggplot(points, aes(x1, y1)) +
  geom_point() +
  geom_segment(
    aes(
      xend = x2,
      yend = y2,
      color = id
    )
  )
```



geom_*() and stat_*()

Some need even more inputs:

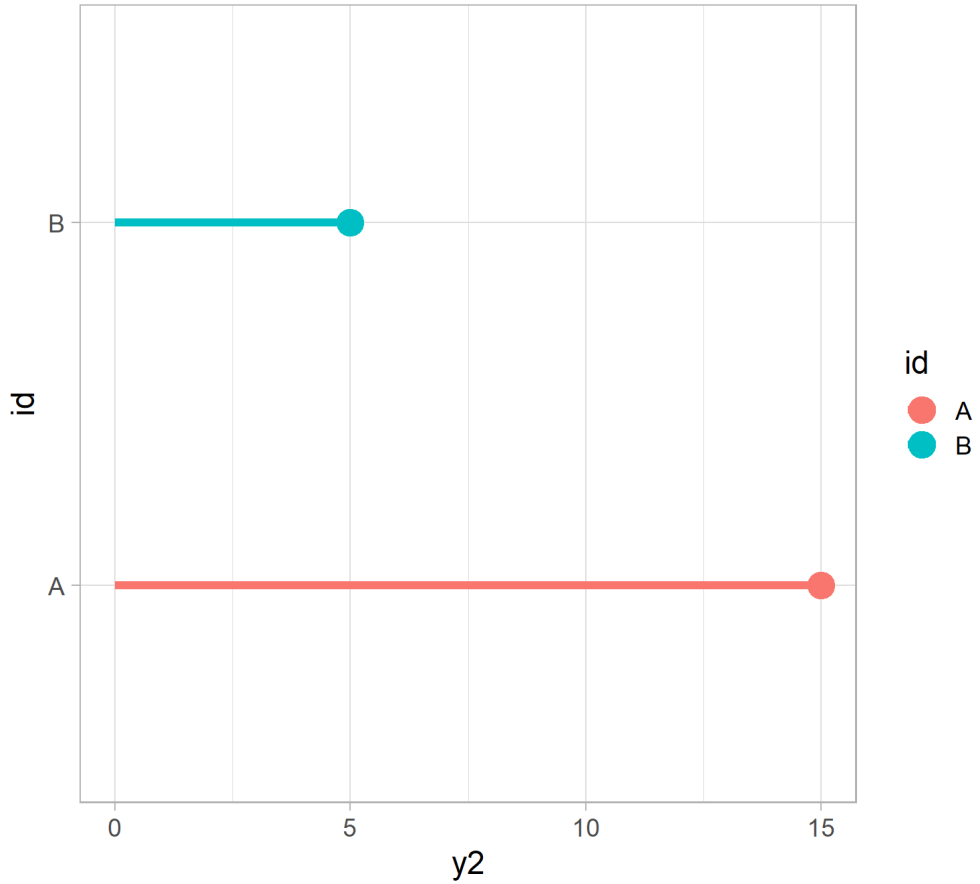
```
ggplot(points, aes(y2, id)) +
  geom_point() +
  geom_segment(
    aes(
      xend = 0,
      yend = id,
      color = id
    )
  )
```



geom_*() and stat_*()

Some need even more inputs:

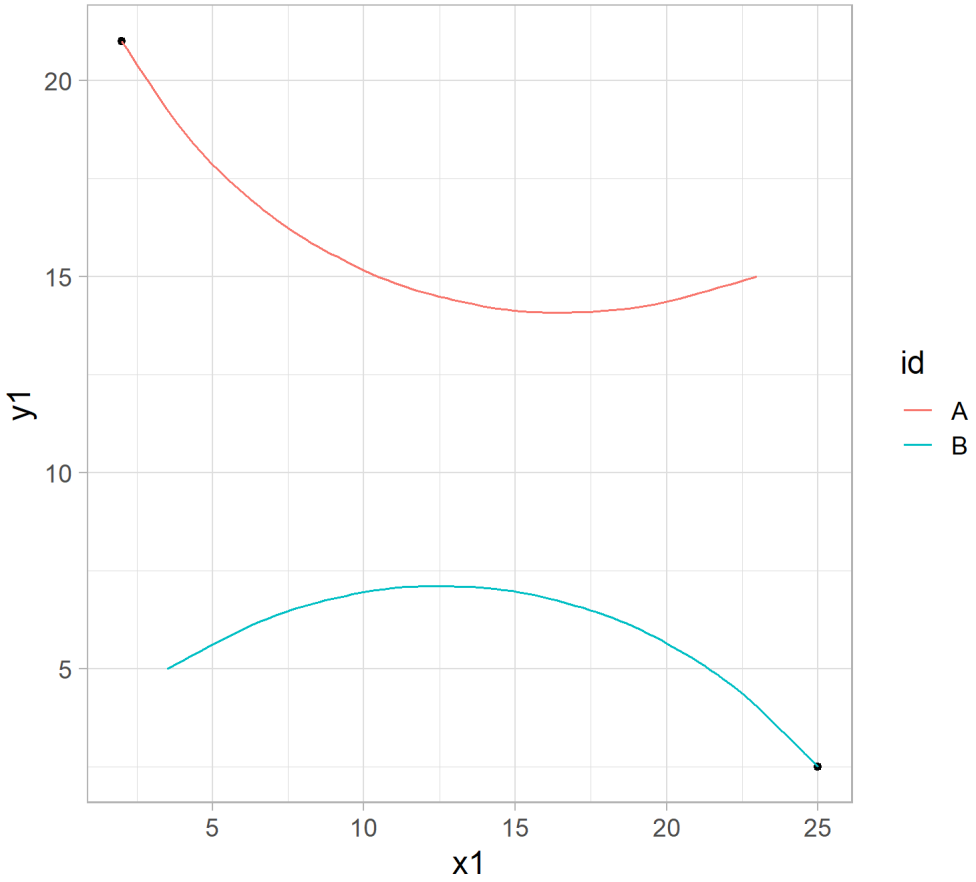
```
ggplot(
  points,
  aes(
    y2,
    id,
    color = id
  )) +
  geom_point(size = 6) +
  geom_segment(
    aes(
      xend = 0,
      yend = id
    ),
    size = 2
  )
```



geom_*() and stat_*()

Some need even more inputs:

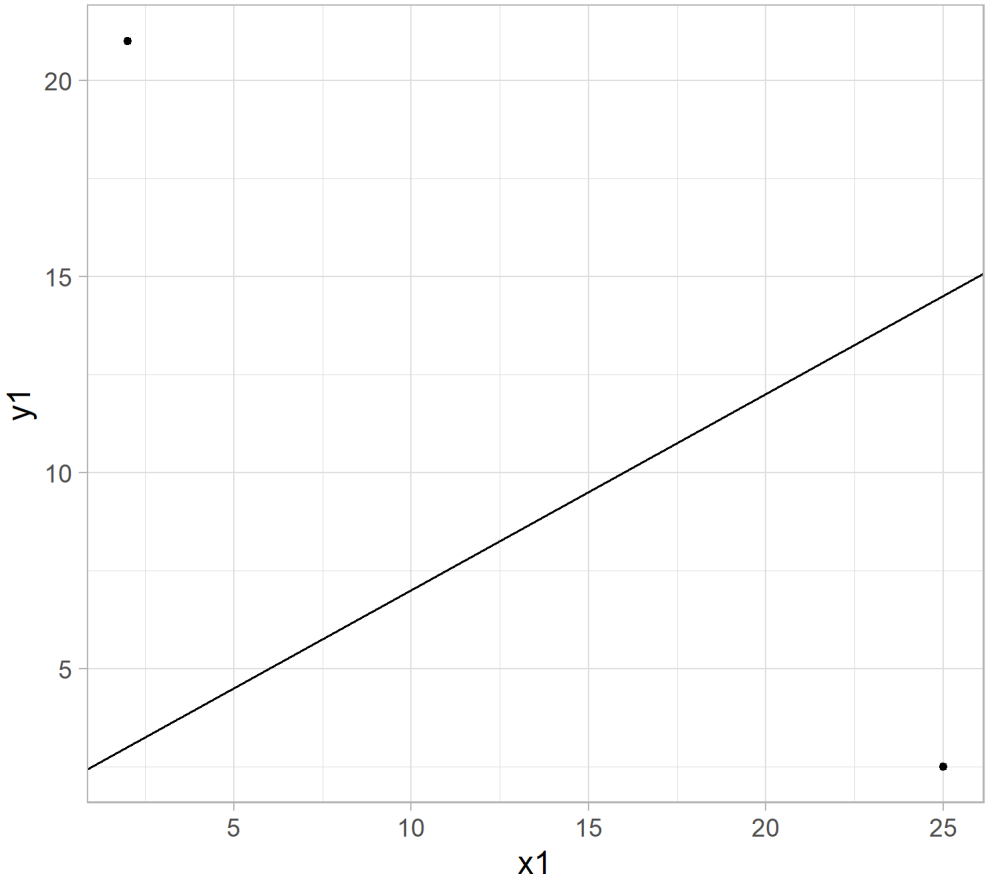
```
ggplot(points, aes(x1, y1)) +
  geom_point() +
  geom_curve(
    aes(
      xend = x2,
      yend = y2,
      color = id
    ),
    curvature = .4,
    arrow = arrow(
      length = unit(0.03, "pt")
    )
  )
```



geom_*() and stat_*()

... or very different input compared to the other geom's:

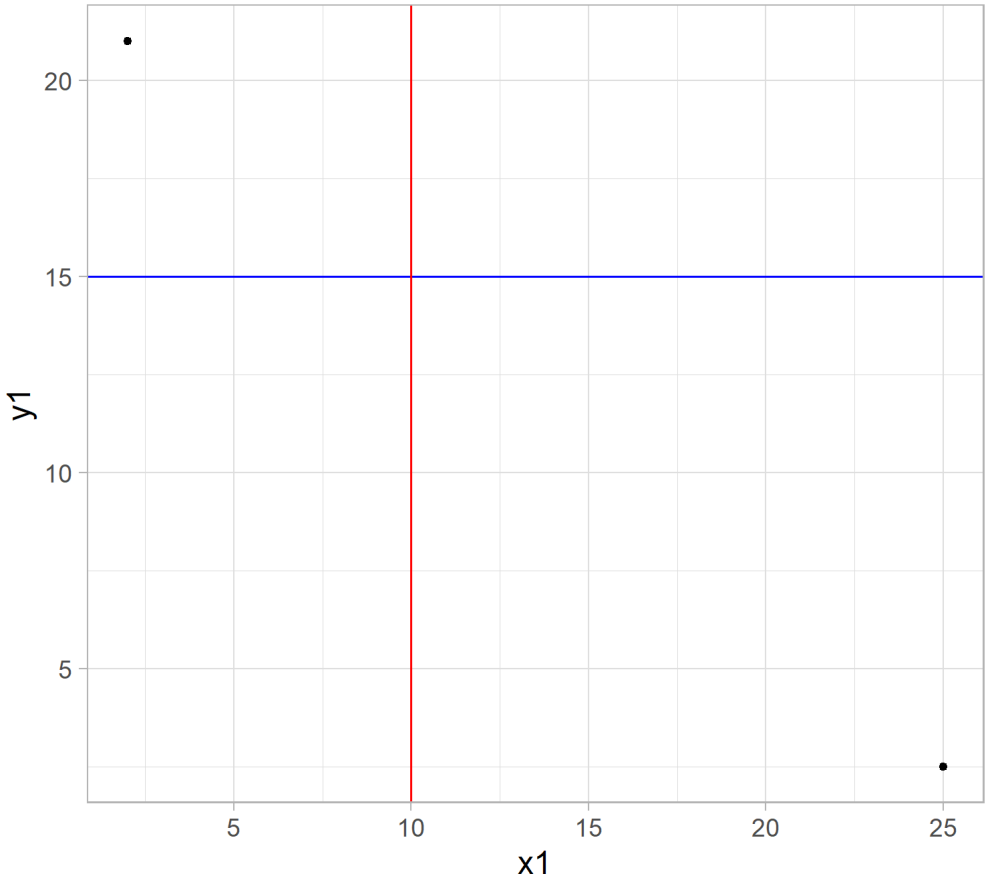
```
ggplot(points, aes(x1, y1)) +
  geom_point() +
  geom_abline(
    slope = .5,
    intercept = 2
  )
```



geom_*() and stat_*()

... or very different input compared to the other geom's:

```
ggplot(points, aes(x1, y1)) +
  geom_point() +
  geom_hline(
    yintercept = 15,
    color = "blue"
  ) +
  geom_vline(
    xintercept = 10,
    color = "red"
  )
```



geom_*() and stat_*()

... or very different input compared to the other geom's:

```
ggplot(points, aes(x1, y1)) +
  geom_point() +
  geom_rect(
    aes(
      xmin = x1,
      xmax = x2,
      ymin = y1,
      ymax = y2,
      fill = id
    ),
    color = "black"
  )
```

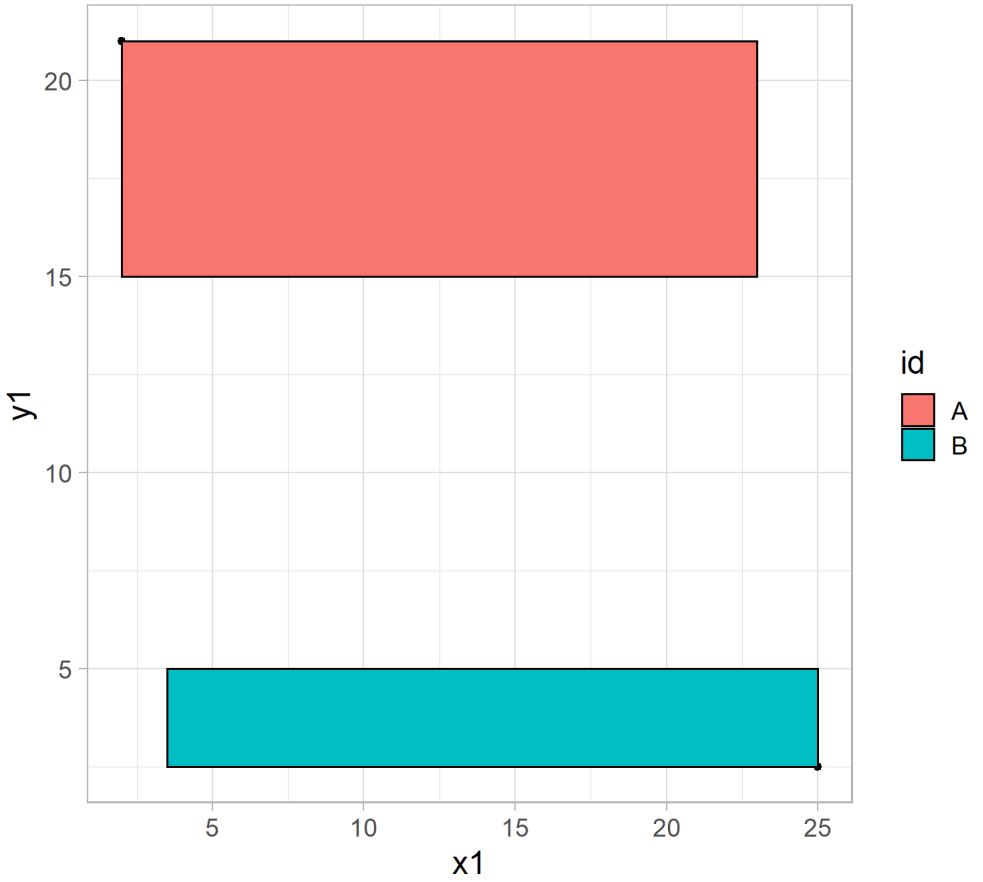


Illustration by Allison Horst (github.com/allisonhorst/stats-illustrations)