Graphics with ggplot2

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Learning Objectives

- ggplot2
- Basics of data visualization.
- Chapter 3 RDS

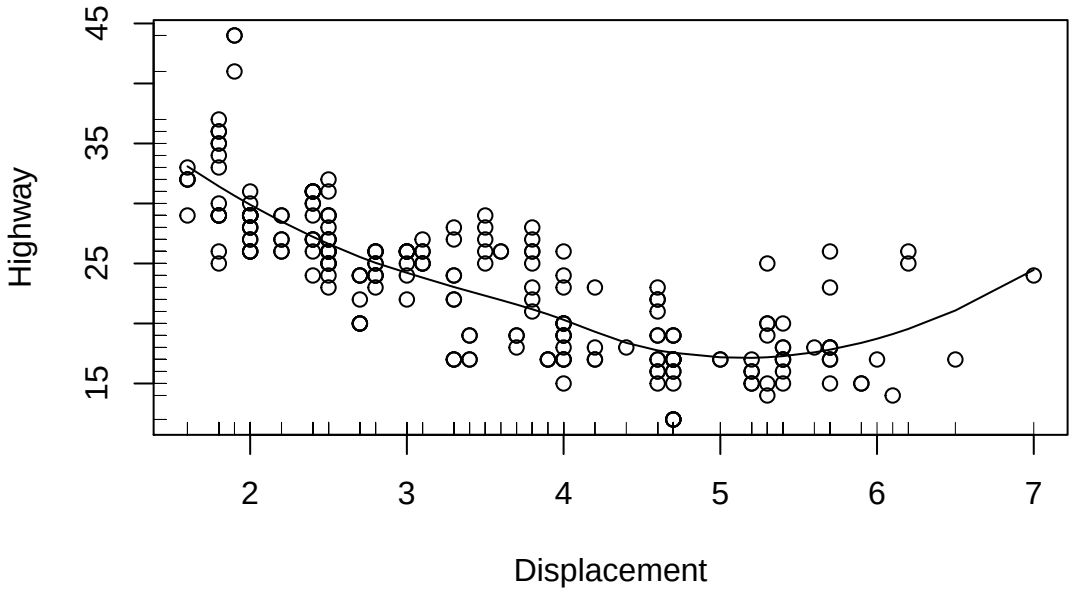
Background

- The three main plotting systems in R are base R, lattice, ggplot2 (from the tidyverse) (with base R-like syntax implemented in the `qplot()` function).
- In base R: start with a blank plot and build on it by adding elements — the "artist's canvas".
- In lattice: One function, specify everything at once.
- ggplot2: A "grammar of graphics". You map from variables to aesthetic attributes (size, color, shape) of geometic objects (lines, bars, points).
- Let's look at the three ways to make a scatterplot with a loess smoother and a rug plot.
  - Load data and packages:

```
library(ggplot2)
library(lattice)
data("mpg")
```

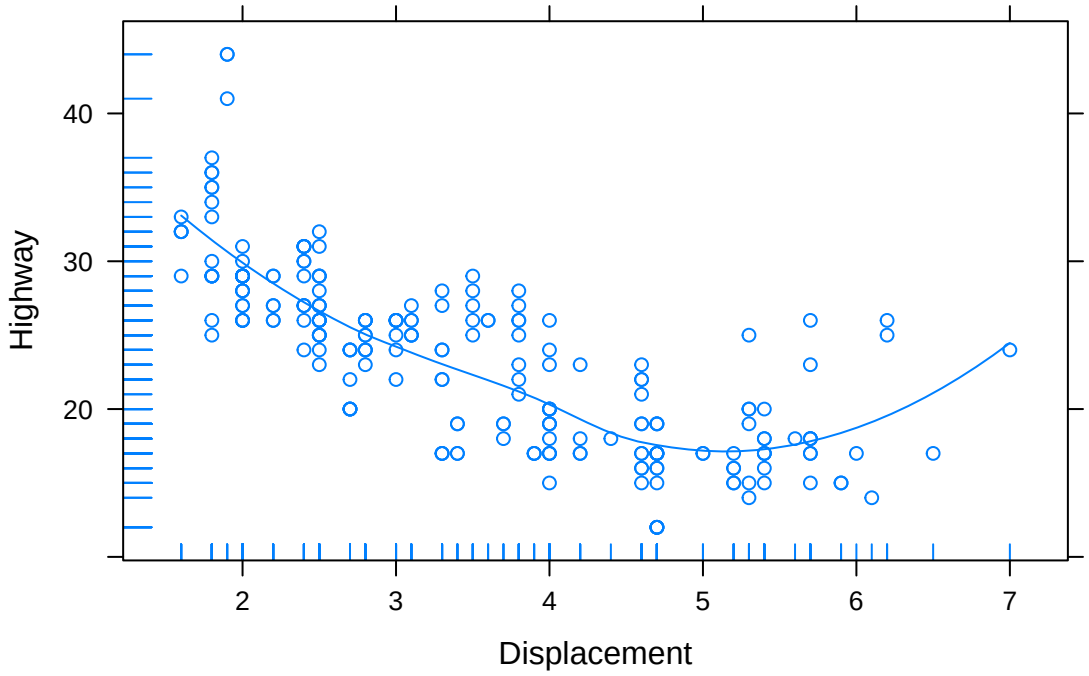
– base R: Everything is a separate non-connected function

```
## Make a scatterplot
plot(x = mpg$displ, y = mpg$hwy, xlab = "Displacement", ylab = "Highway")

## Add loess curve
lout <- loess(hwy ~ displ, data = mpg)
ord_x <- order(lout$x)
lines(lout$x[ord_x], lout$fitted[ord_x])

## Add two rug plots
rug(mpg$displ, side = 1)
rug(mpg$hwy, side = 2)
```



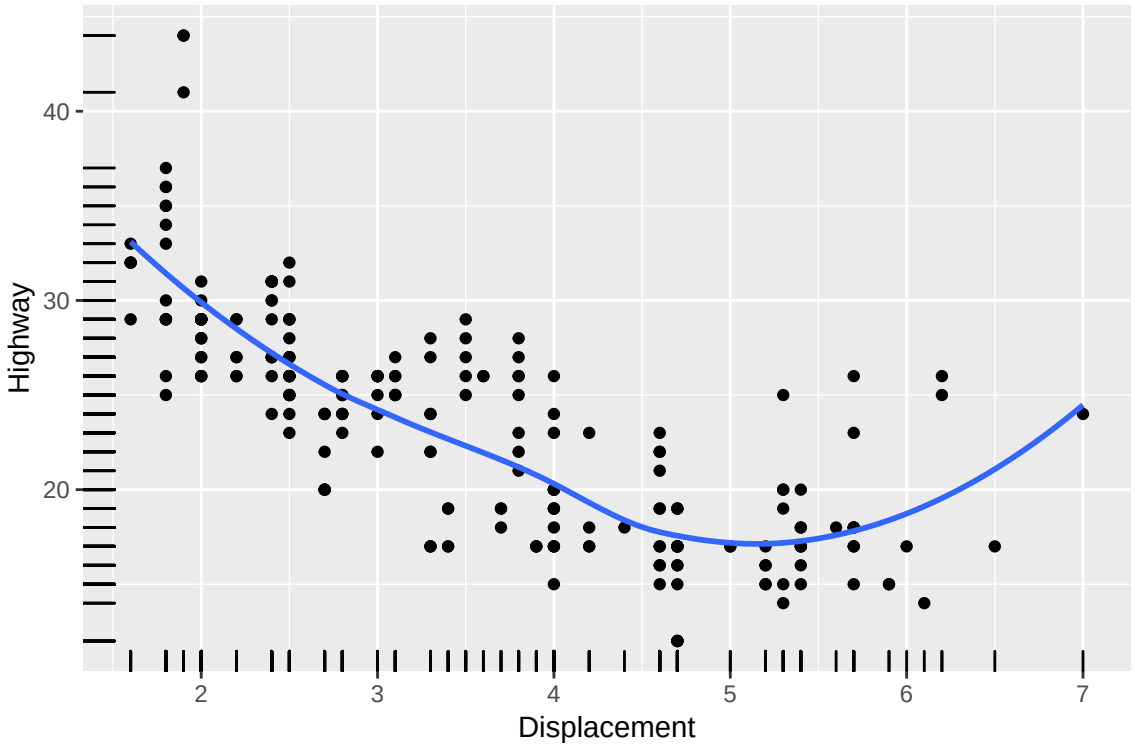
– lattice: Everything is done at once within some mega-function:

```
xyplot(hwy ~ displ, data = mpg,
       xlab = "Displacement", ylab = "Highway",
       panel = function(x, y) {
         panel.xyplot(x = x, y = y)                    ## Add scatterplot
         panel.loess(x = x, y = y, span = 0.75,
                     family = "gaussian", degree = 2) ## Add loess curve
         panel.rug(x = x, y = y)                       ## Add rug plot
       })
```



- ggplot2: Many connected functions

```
ggplot(mpg, mapping = aes(x = displ, y = hwy)) + ## set aesthetic maps
  geom_point() +                                 ## apply aesthetic maps to
                                                 ##     point objects
  geom_smooth(se = FALSE, method = loess) +      ## apply to smooth objects
  geom_rug() +                                   ## apply to rug objects
  xlab("Displacement") +
  ylab("Highway")
```



- lattice is the hardest to learn and the least used.
- base R is very flexible, but harder to use for most tasks.
- ggplot2 is very easy to use for most tasks, but very hard to use when you want to do something weird.

ggplot2 Foundation

- ggplot consists of the following elements:
  - **Data Frame** (`data`): Contains the variables that you want to plot.
  - Transformation (`stat`): Transforms data into a new data frame (e.g. by calculating the number of observational units in each bin for a histogram).
  - **Aesthetic Mapping** (`mapping`): Assign variables to be aesthetics (e.g. x-coordinate, y-coordinate, color, shape, transparency, line thickness, line type) of geometric objects.
  - **Geometric Objects** (`geom`): The type of plot you want (e.g. scatterplot, line plot, histogram, barplot)
  - Position Adjustment (`position`): Jitter objects, overlap histogram bins, etc..
  - **Facets**: Create multiple plots, one for each value of a categorical variable.
  - Coordinate systems: Cartesian/polar

- You can get most of your plotting done by understanding the basics of data frames, aesthetic mappings, geoms, and facets (the other aspects of the gramar of graphics are less often useful to modify).
- `ggplot()` creates a blank `gg` objects. It has two main arguments:
  - `data`: Must be a data frame. Contains the variables that you want to map onto aesthetics.
  - `mapping`: A definition for which variables map onto which aesthetics. You almost always use the `aes()` function to perform this mapping.
  - What is the output of the following?

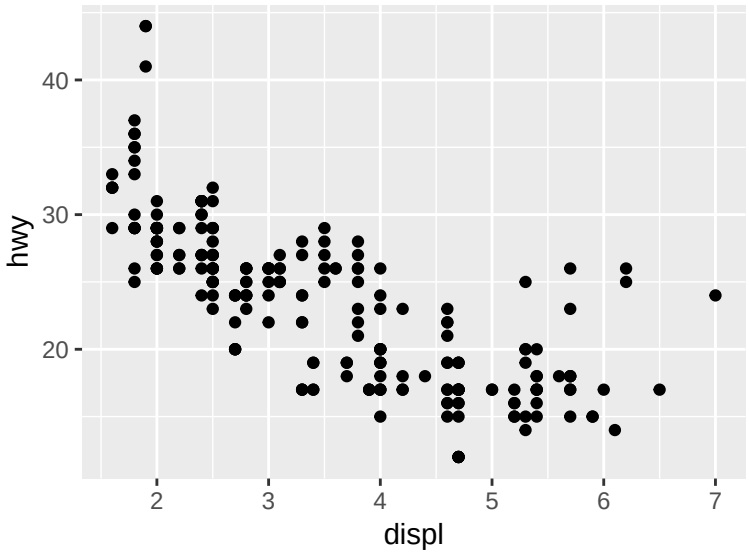
```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy))
```

- `ggplot()` is almost always followed by a `+` and then a `geom` argument to specify which geometic objects receive the aesthetic mapping. We will now go through many different types of geoms and the situations where they are useful:
- **Always make sure the + is at the end of a line and not at the beginning of a line.**
- To goet a list of the possible aesthetic mappings of a geom, look at the help page.

Comparing Two Quantitative Variables

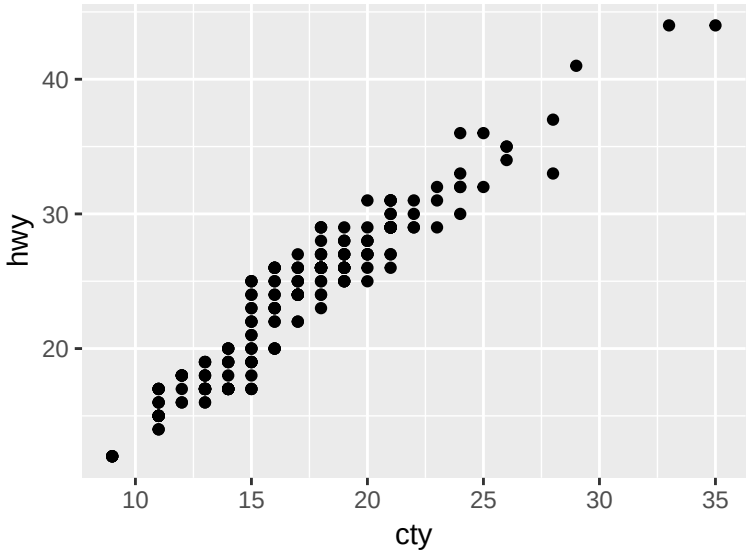
- A scatterplot is used to explore the relationship between two **quantitative** variables.
- "Qauntitative" means that arithmetic operations $(+/-/\times/\div)$ make sense on them.
- E.g. `hwy` and `displ` are two quantitative variables.
- Not all numeric variables are quantitative (e.g. phone numbers).
- Use `geom_point()` to create a scatterplot:

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy)) +
  geom_point()
```



- `displ` is mapped onto the `x` aesthetic and `hwy` is mapped onto the `y` aesthetic.
- The above indicates a **negative** relationship between `hwy` and `displ`
- The following indicates a **positive** relationship between `hwy` and `cty`

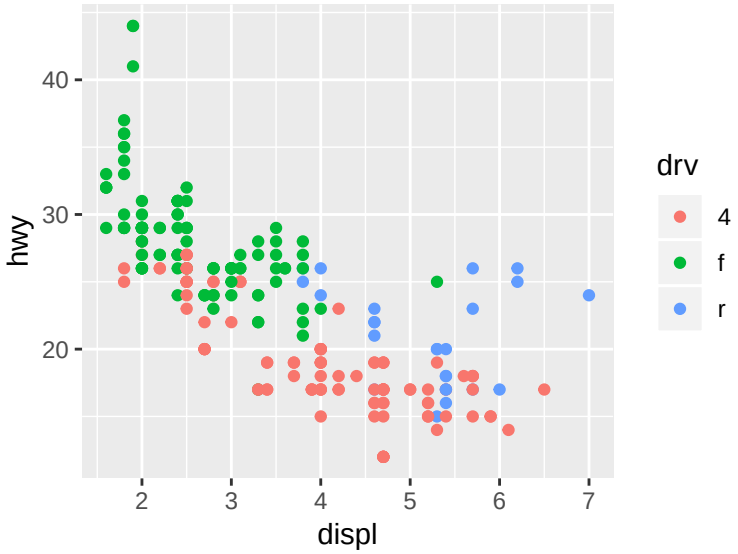
```
ggplot(data = mpg, mapping = aes(x = cty, y = hwy)) +
      geom_point()
```



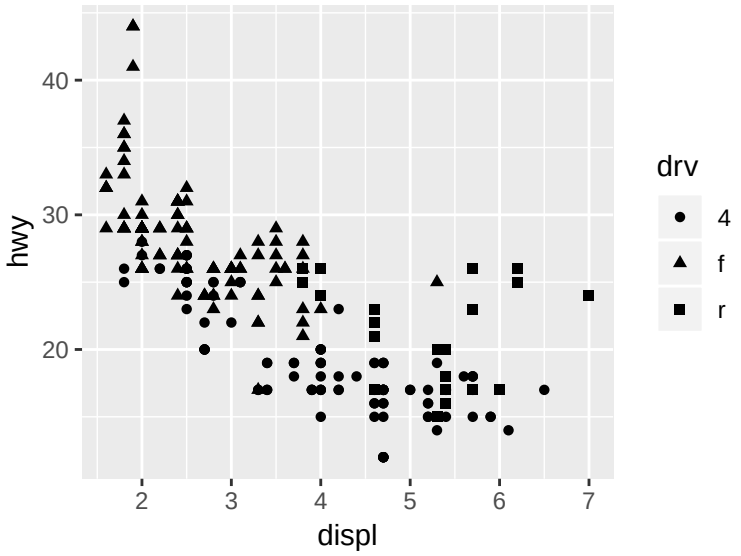
Annotating by a categorical variable

- We might be interested in the association of two quantitative variables at different values of a categorical variable.
- A **categorical** variable places observational units into different groups or categories based on the level of the categorical variable.
- We often map categorical variables to the `color` (better) or `shape` (worse) aesthetics:

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = drv)) +
      geom_point()
```



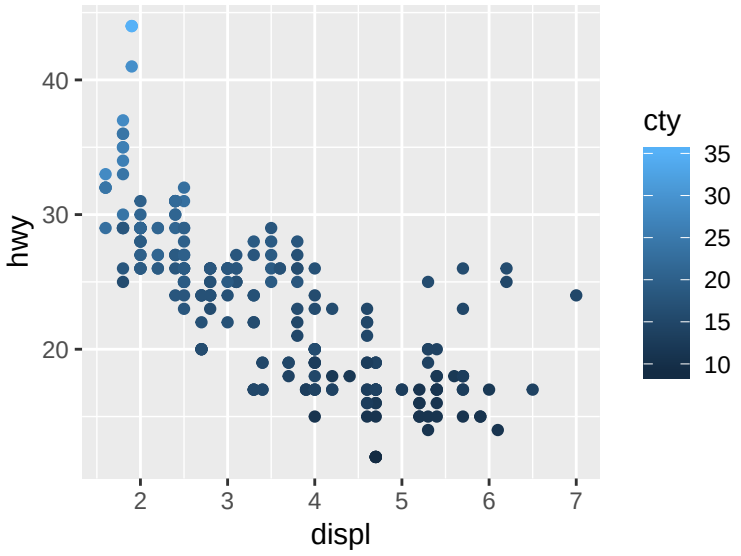

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, shape = drv)) +
      geom_point()
```



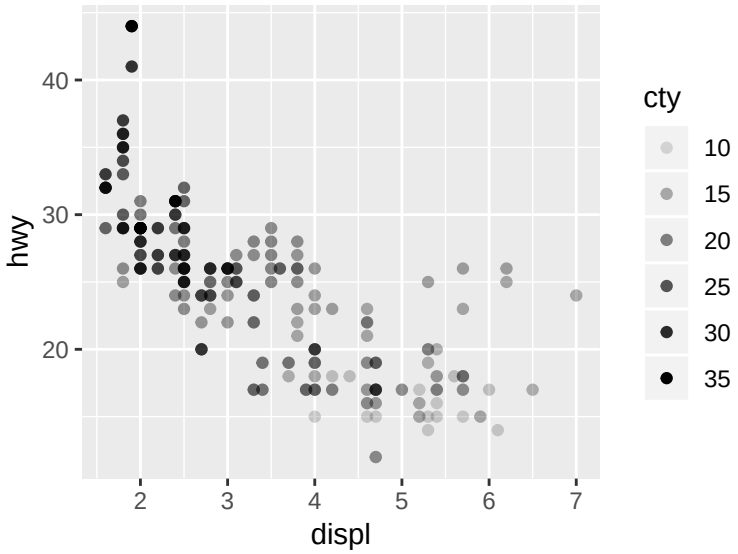
Annotating by a quantitative variable

- If we want to look at the association between two quantitative variables at different levels of a third quantitative variable, we can map that third quantitative variable to the `color` (good), `alpha` (good), or size (worst) aesthetic.

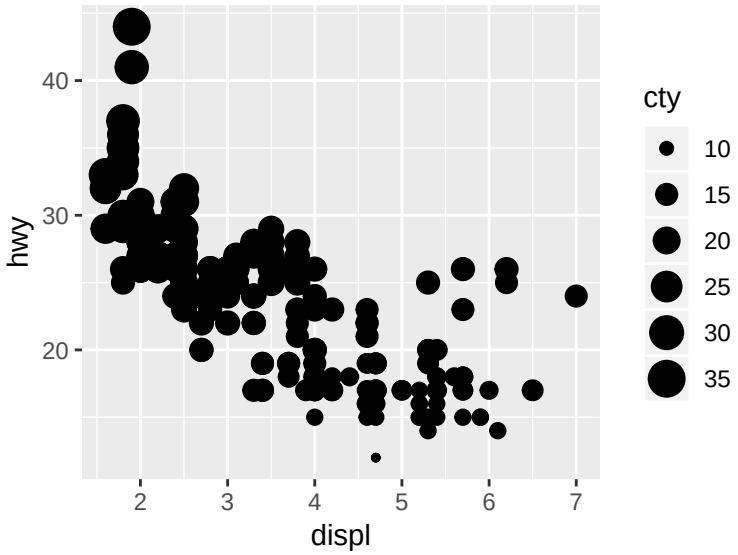
```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = cty)) +
          geom_point()
```




```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, alpha = cty)) +
          geom_point()
```

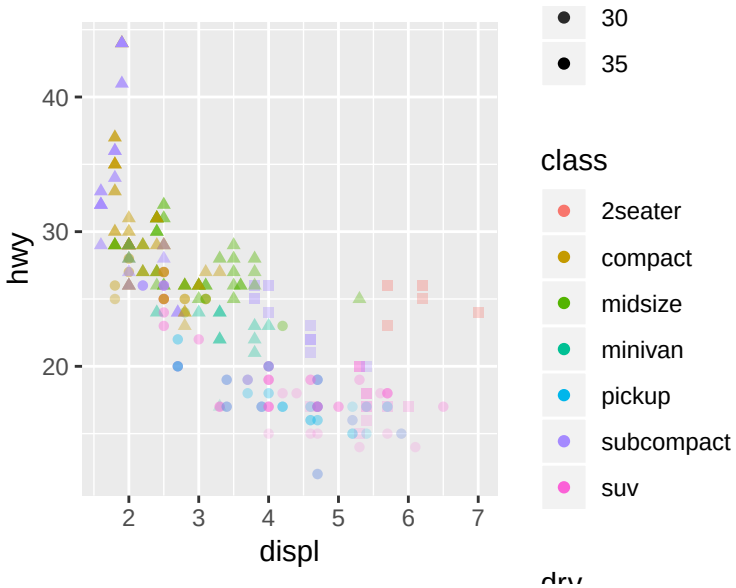



```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, size = cty)) +
              geom_point()
```



- We can map multiple variables to multiple aesthetics at the same time, but the resulting plot might get too complicated.

```
ggplot(data = mpg, mapping = aes(x = displ,
                                 y = hwy,
                                 alpha = cty,
                                 shape = drv,
                                 color = class)) +
         geom_point()
```

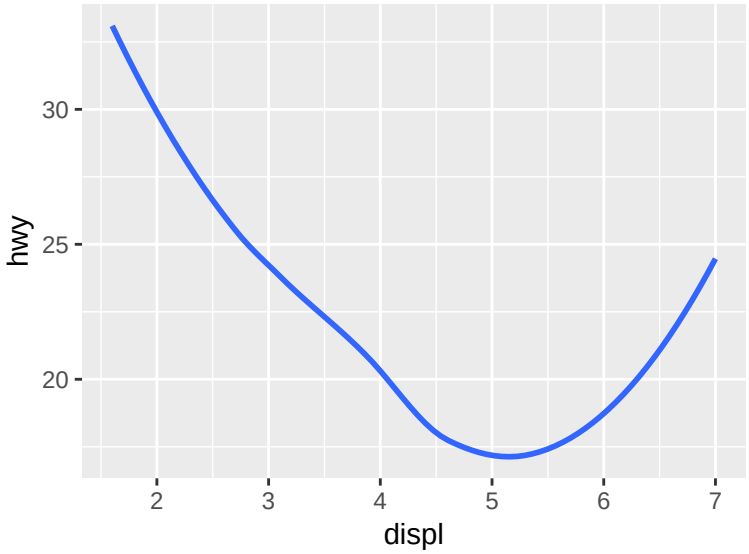


Smoothing

- `geom_smooth()` will create trend lines (either non-parametric or parametric) and plot these.

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy)) +
          geom_smooth(se = FALSE)
```

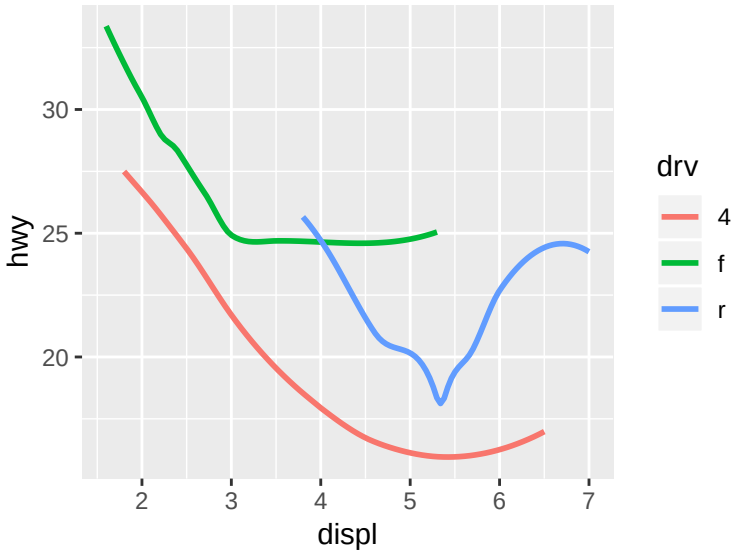
```
## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



- You can pass categorical variables to the `color` (best) or `linetype` (good) aesthetics

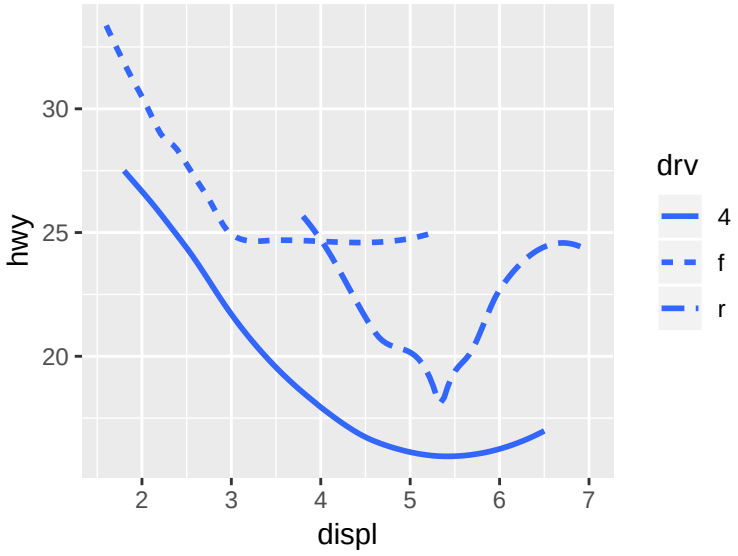
```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = drv)) +
          geom_smooth(se = FALSE)
```

```
## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



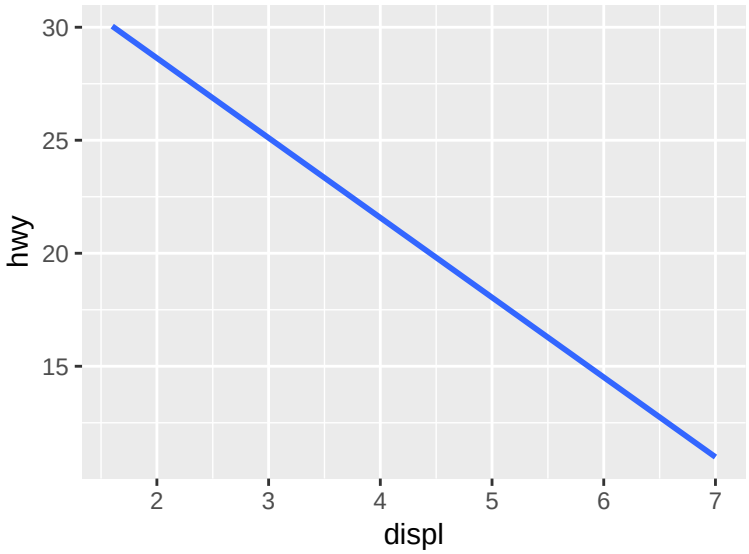

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, linetype = drv)) +
          geom_smooth(se = FALSE)
```

```
## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



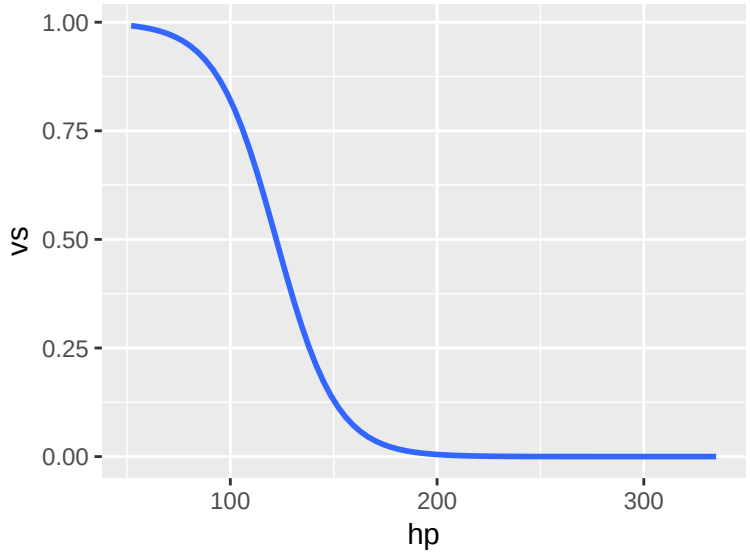
- The default for `geom_smooth()` is to calculate a loess smoother, but other options are available. For example, we can plot the OLS fit by changing the `method` argument.

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy)) +
          geom_smooth(se = FALSE, method = lm)
```



- If you have binary response data, you can plot the fitted logistic curves by

```
ggplot(data = mtcars, mapping = aes(x = hp, y = vs)) +
  geom_smooth(method = glm, method.args = list(family = "binomial"), se = FALSE)
```

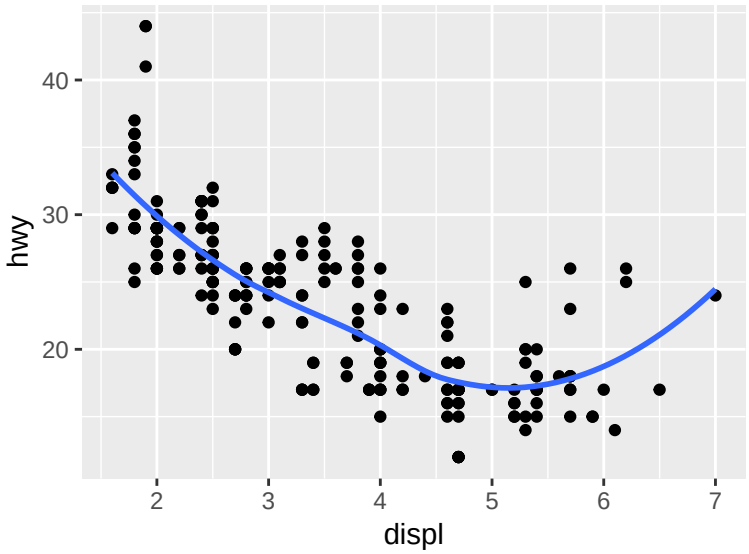


Layering Geoms:

- You can layer multiple geoms that use the same data and aesthetic map as defined in the `ggplot()` call:

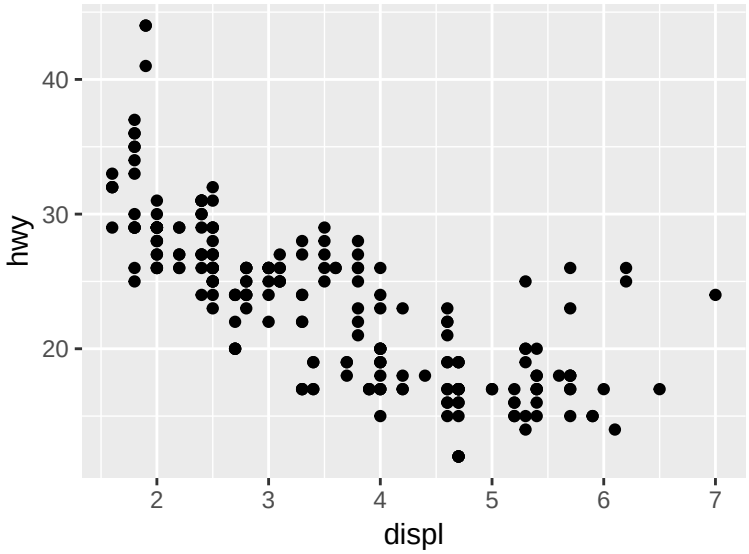
```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy)) +
  geom_point() +
  geom_smooth(se = FALSE)
```

```
## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



- You can equivilently define the aesthetics in the particular geom you are using. However, later geoms will not have access to these maps and you would have to redefine them.

```
ggplot(data = mpg) +
  geom_point(mapping = aes(x = displ, y = hwy))
```

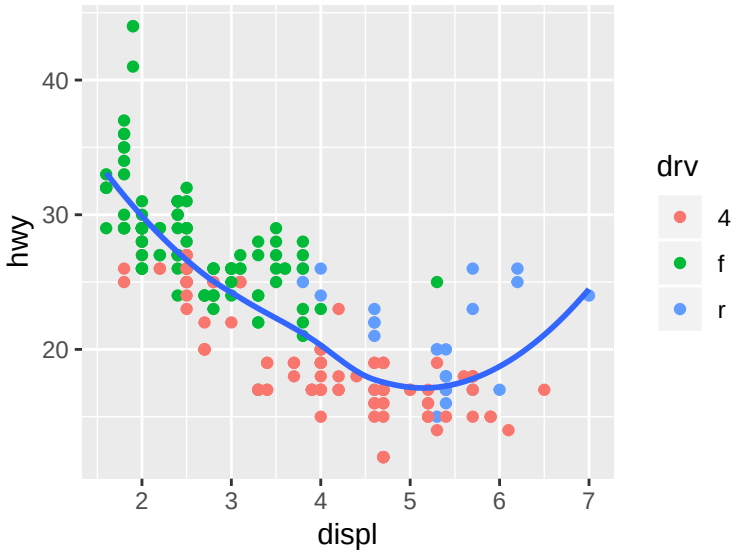



```
## Should produce an error
ggplot(data = mpg) +
  geom_point(mapping = aes(x = displ, y = hwy)) +
  geom_smooth()
```

- Place the aesthetic maps that are shared in the `ggplot()` call and place the geom-specific aesthetic maps within the `geom_` call

```
## Rug plot only on x-axis
ggplot(data = mpg, mapping = aes(x = displ, y = hwy)) +
  geom_point(mapping = aes(color = drv)) +
  geom_smooth(se = FALSE)
```

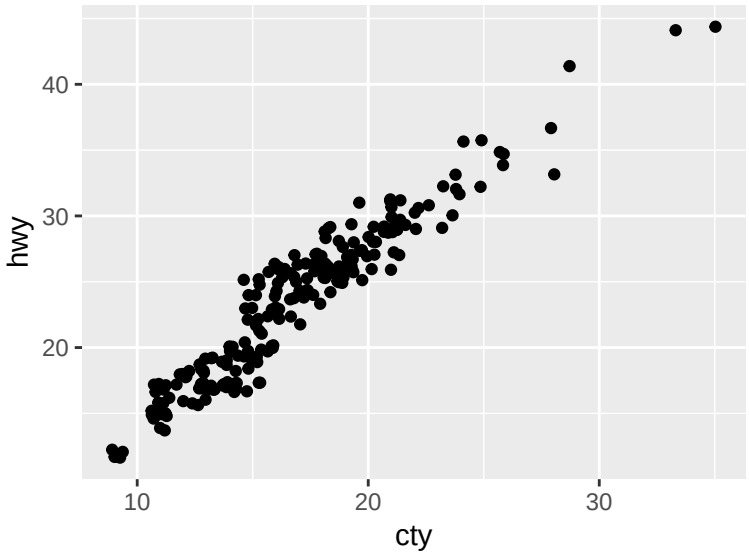
```
## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



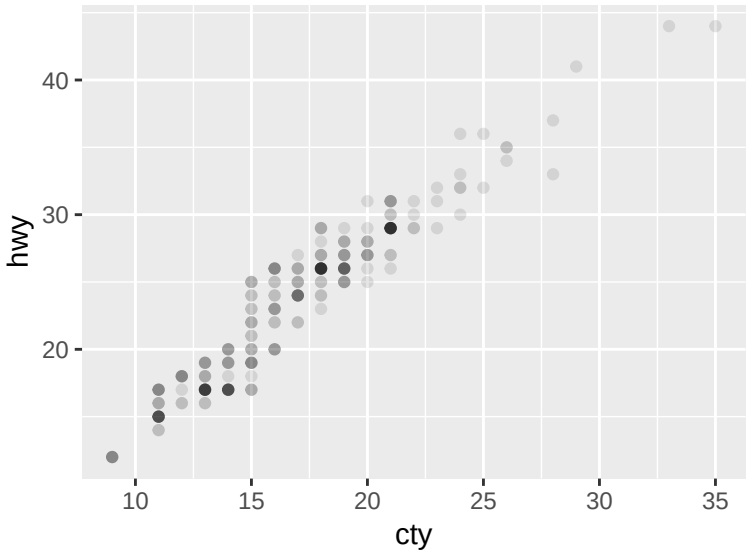
Overplotting

- The variables `cty` and `hwy` are rounded, so result in a lot of overlapping.
- Two ways to counteract this:
  1. If you have small data, use `geom_jitter()`
  2. If you have large data, set the transparency for all points to be low.

```
ggplot(data = mpg, mapping = aes(x = cty, y = hwy)) +
  geom_jitter()
```




```
ggplot(data = mpg, mapping = aes(x = cty, y = hwy)) +
  geom_point(alpha = 0.1)
```

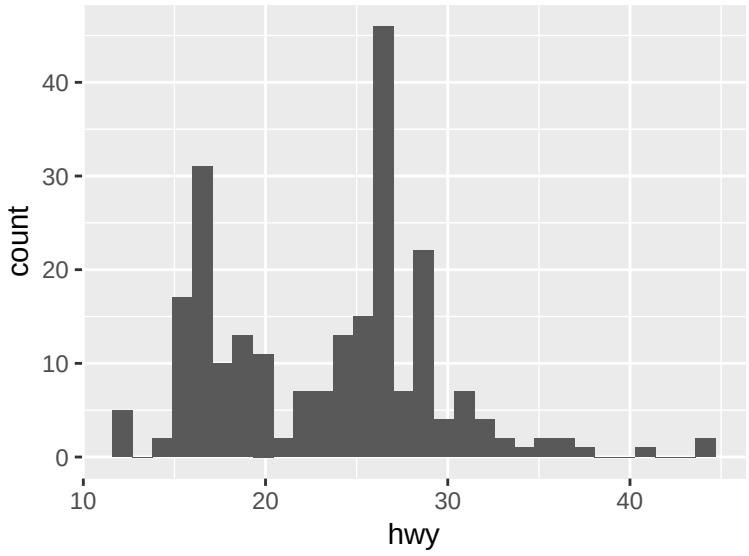


One Quantitative Variable

- A histogram allows us to explore the distribution of a quantitative variable.
- "Distribution" = what values a variable takes and how often it takes those values.
- Bins observations into bins of equal *width*, plots counts on y-axis and variable values on x-axis.

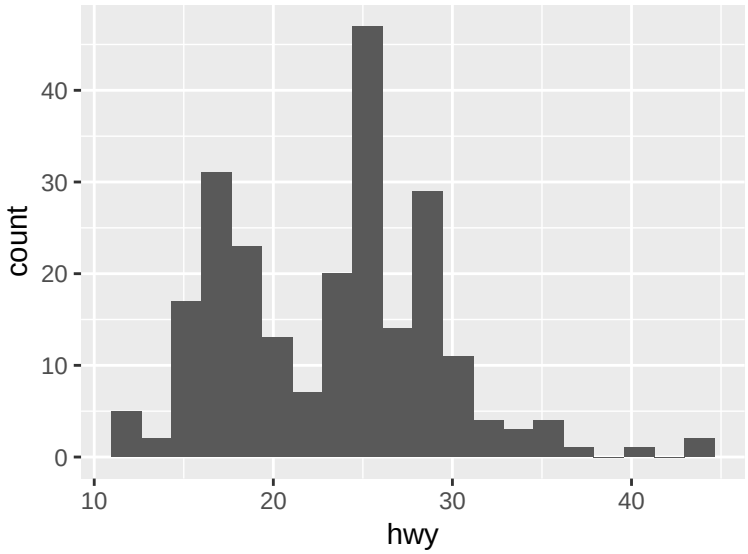
```
ggplot(data = mpg, mapping = aes(x = hwy)) +
  geom_histogram()
```

```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



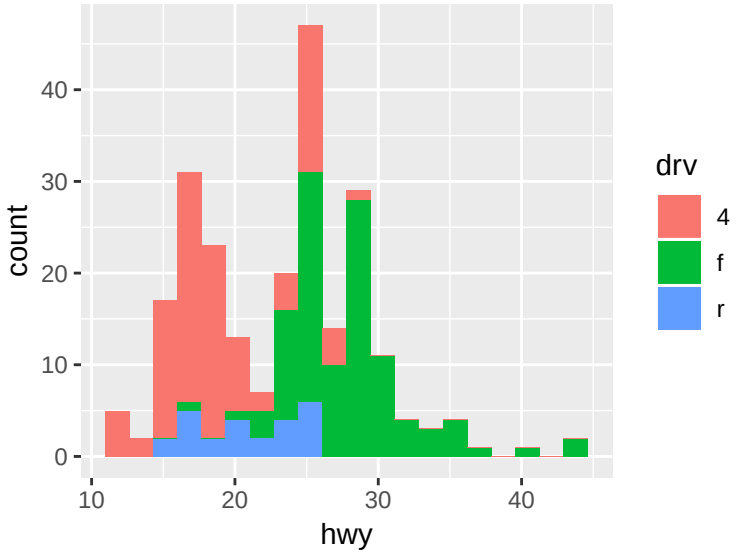
- Always play around with the `bins` argument until you get something nice-looking

```
ggplot(data = mpg, mapping = aes(x = hwy)) +
  geom_histogram(bins = 20)
```

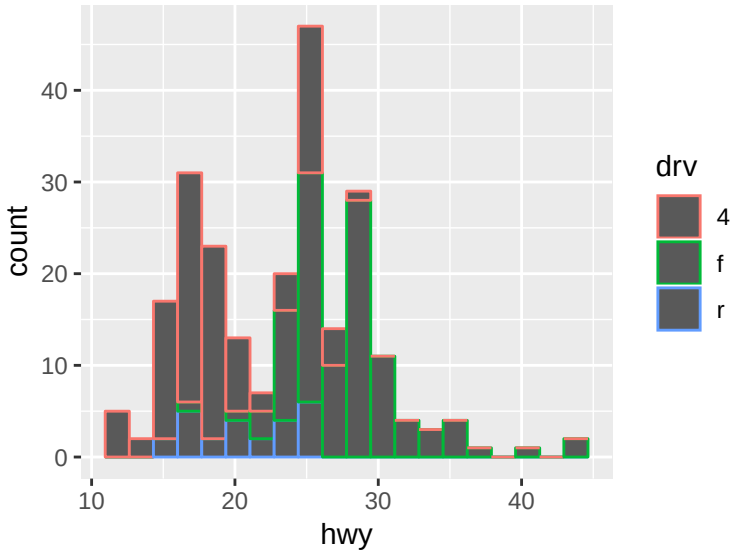


- You can annotate by a categorical variable by passing the `fill` (best) or `color` (worst) aesthetics.

```
ggplot(data = mpg, mapping = aes(x = hwy, fill = drv)) +
  geom_histogram(bins = 20)
```

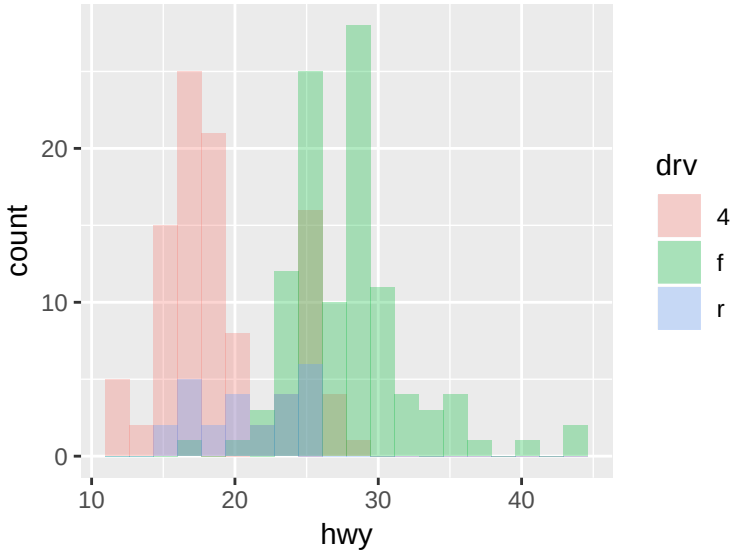



```
ggplot(data = mpg, mapping = aes(x = hwy, color = drv)) +
  geom_histogram(bins = 20)
```



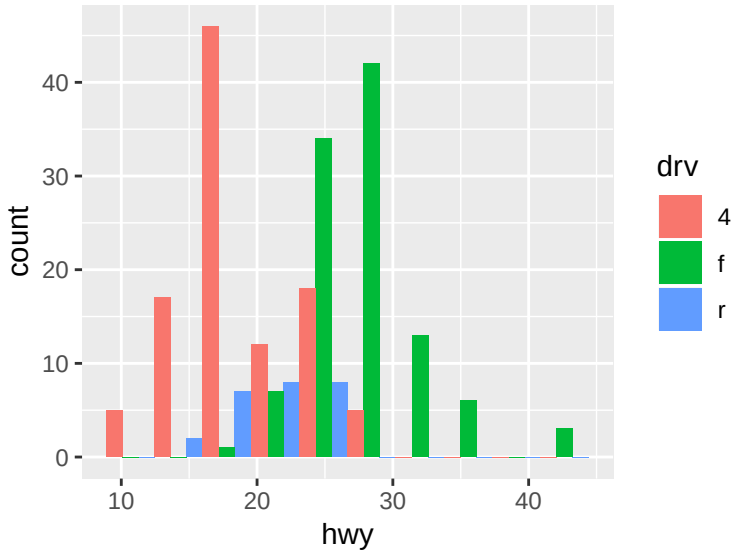
- Changing the `position` argument of `geom_histogram()` can help with seeing the histograms within all levels of the categorical variable.
- You can see all histograms by changing the transparency of the histograms in conjunction with `position = "identity"`.

```
ggplot(data = mpg, mapping = aes(x = hwy, fill = drv)) +
  geom_histogram(bins = 20, alpha = 0.3, position = "identity")
```



- `position = "dodge"` separates the bins for each category.

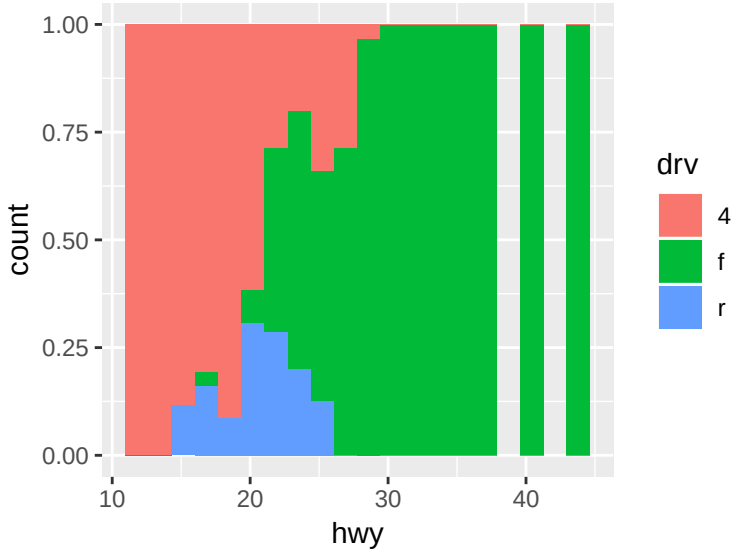
```
ggplot(data = mpg, mapping = aes(x = hwy, fill = drv)) +
  geom_histogram(bins = 10, position = "dodge")
```



- `position = "fill"` plots proportions of each category within a bin.

```
ggplot(data = mpg, mapping = aes(x = hwy, fill = drv)) +
  geom_histogram(bins = 20, position = "fill")
```

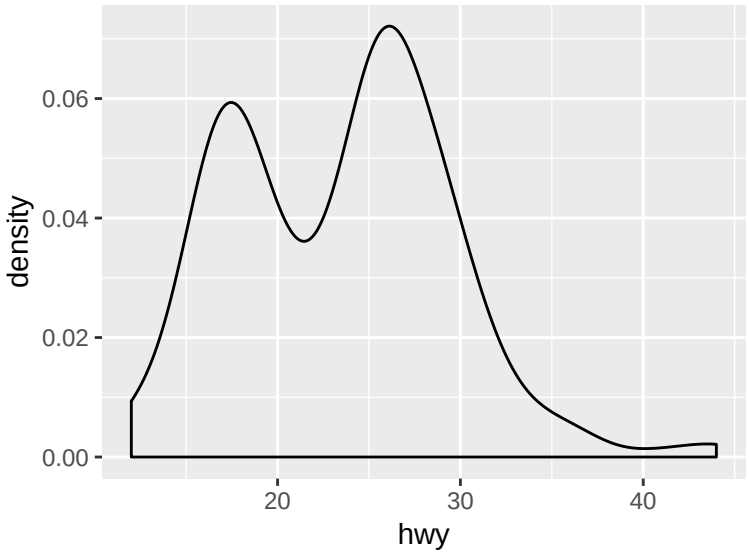
```
## Warning: Removed 6 rows containing missing values (geom_bar).
```



Density Plot

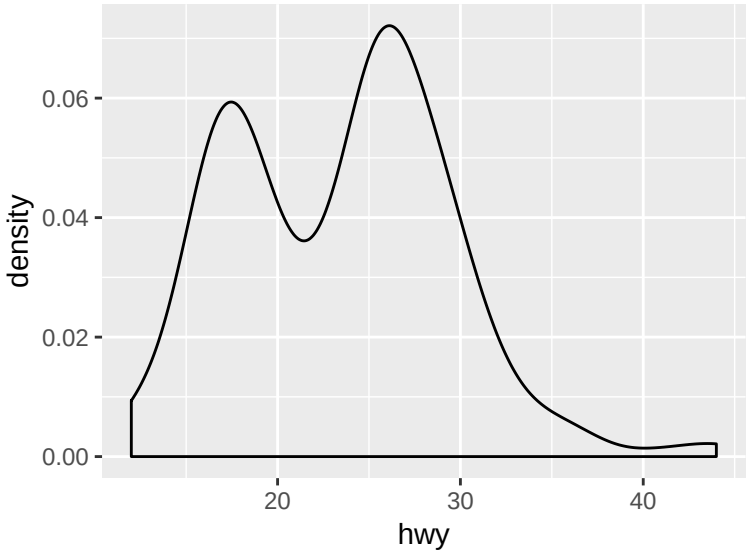
- A density is a "smoothed" histogram. It can be created with `geom_density()`
- Densities and histograms generally give us identical information.

```
ggplot(data = mpg, mapping = aes(x = hwy)) +
  geom_density()
```



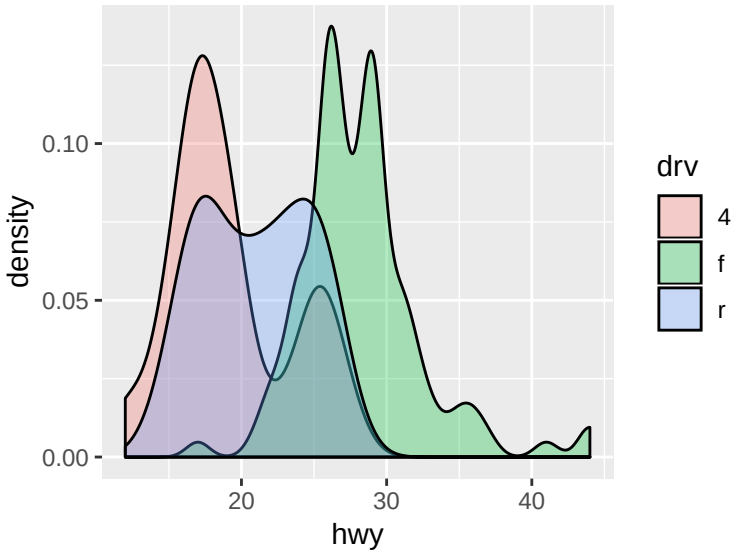
- You can plot the densities for the different lebvels of a categorical variable by mapping the `fill` aesthetic

```
ggplot(data = mpg, mapping = aes(x = hwy)) +
  geom_density(alpha = 0.3)
```



- You can change the transparency to see all densities.

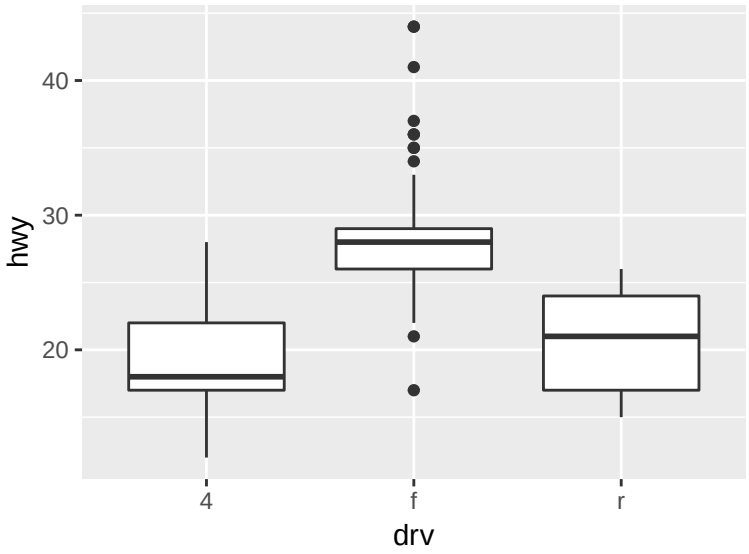
```
ggplot(data = mpg, mapping = aes(x = hwy, fill = drv)) +
  geom_density(alpha = 0.3)
```



One categorical variable, one quantitative variable.

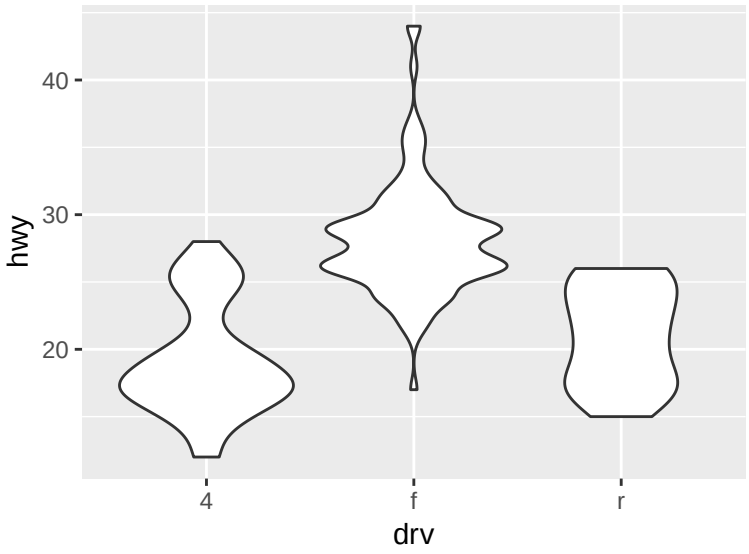
- The best plot for visualizing the association between a categorical and a quantitative variable is the boxplot. Use `geom_boxplot()` for this.

```
ggplot(data = mpg, mapping = aes(x = drv, y = hwy)) +
  geom_boxplot()
```



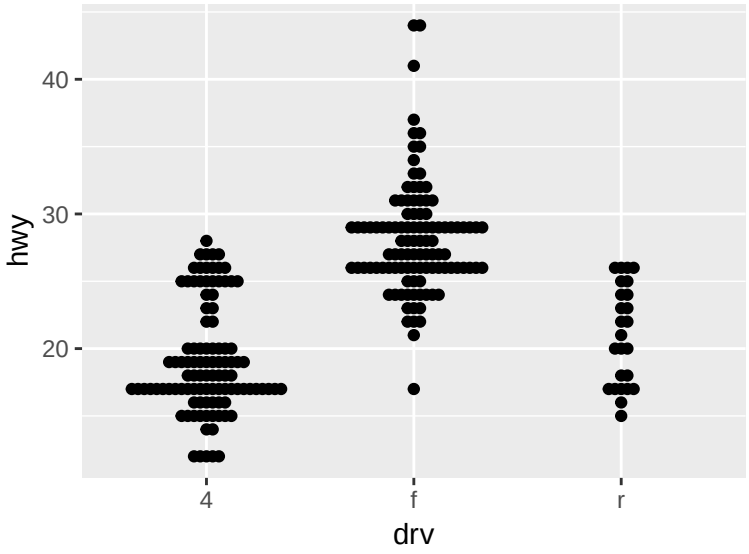
- An alternative is a violin plot:

```
ggplot(data = mpg, mapping = aes(x = drv, y = hwy)) +
  geom_violin()
```



- And the beeswarm plot from the package ggbeeswarm.

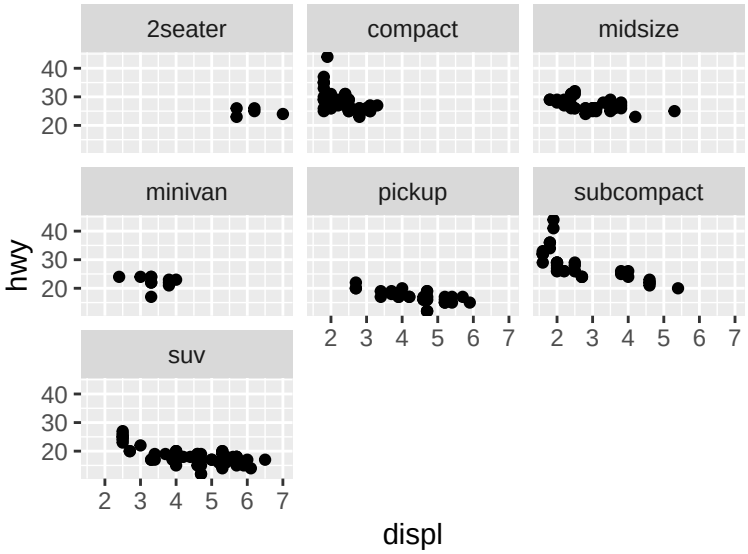
```
library(ggbeeswarm)
ggplot(data = mpg, mapping = aes(x = drv, y = hwy)) +
  geom_beeswarm()
```



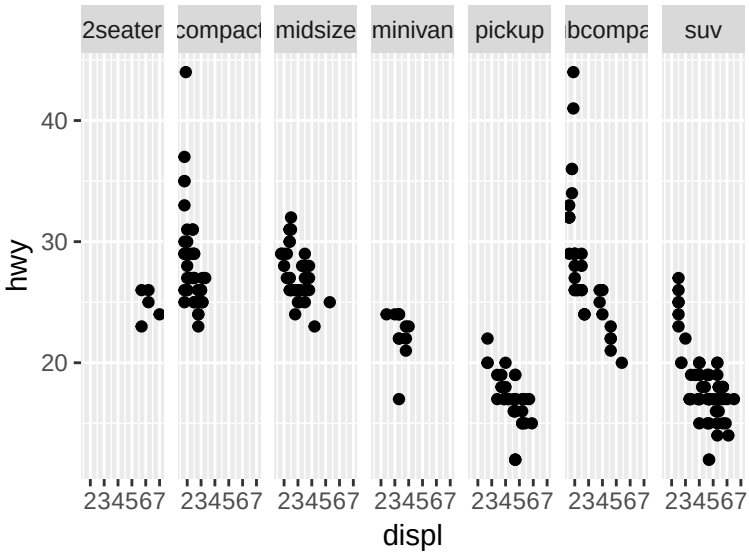
Facets

- If you want to create multiple plots from the same data, you can use the `facet_wrap()` or `facet_grid()` arguments.

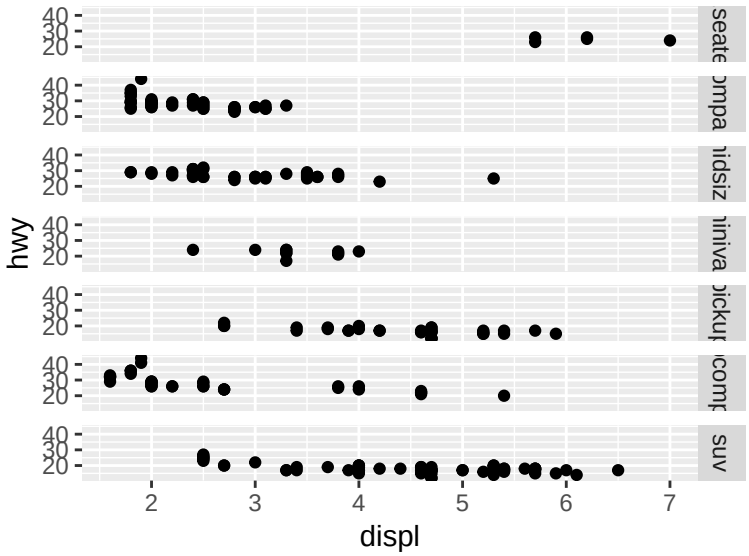
```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy)) +
  geom_point() +
  facet_wrap( ~ class)
```



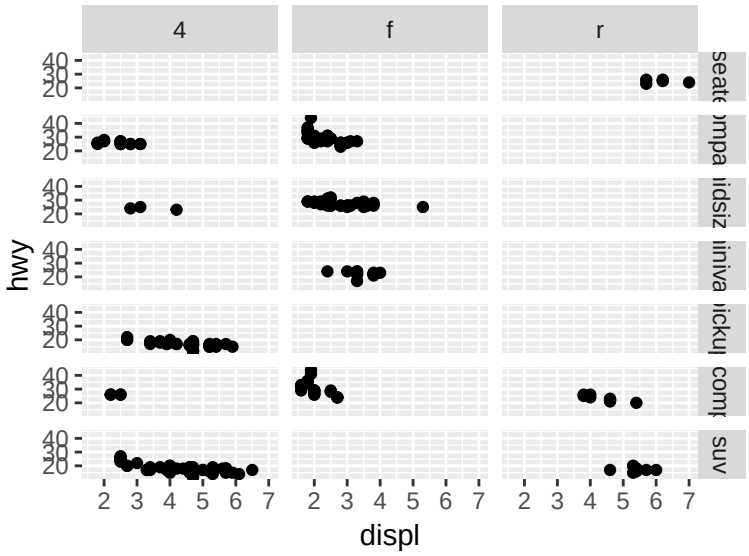

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy)) +
  geom_point() +
  facet_grid(. ~ class)
```




```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy)) +
  geom_point() +
  facet_grid(class ~ .)
```



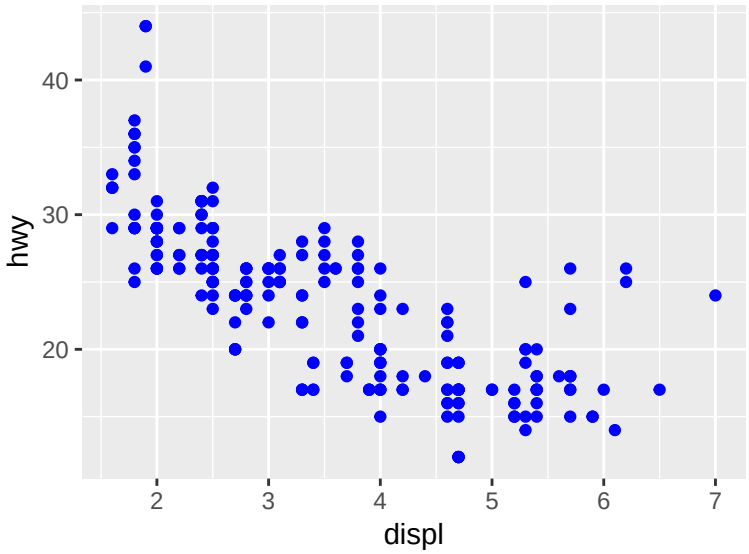

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy)) +
  geom_point() +
  facet_grid(class ~ drv)
```



Aesthetics for all objects.

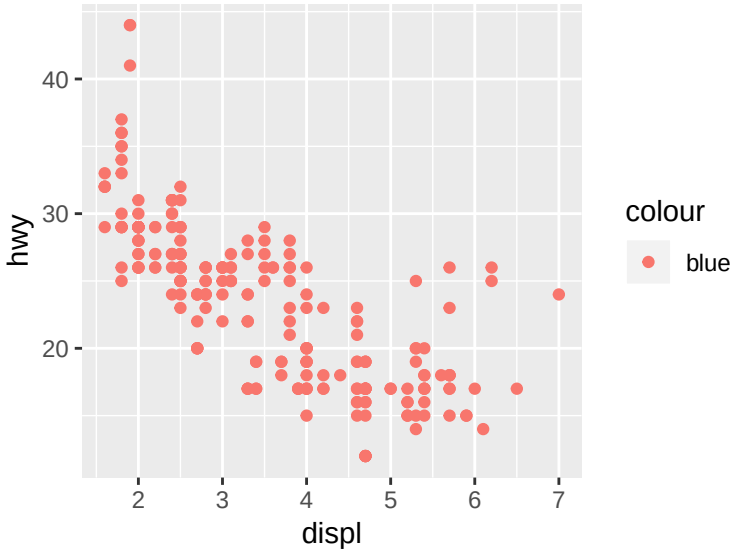
- Suppose we like scatterplots with blue points. The correct code to use is:

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy)) +
  geom_point(color = "blue")
```



- The `"blue"` must be outside of the `aes()` call. This tells ggplot2 to set the aesthetic manually, instead of via a map from a variable.
- If you put `"blue"` inside of the `aes()` call, then ggplot2 will assume that you are creating a categorical variable where every observational unit has the value `"blue"`.

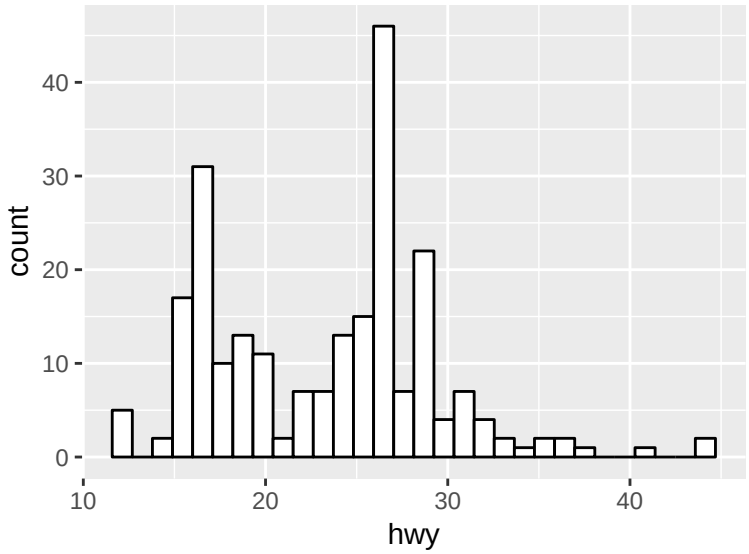
```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = "blue")) +
  geom_point()
```



- I often change the aesthetics for histograms.

```
ggplot(data = mpg, mapping = aes(x = hwy)) +
  geom_histogram(fill = "white", color = "black")
```

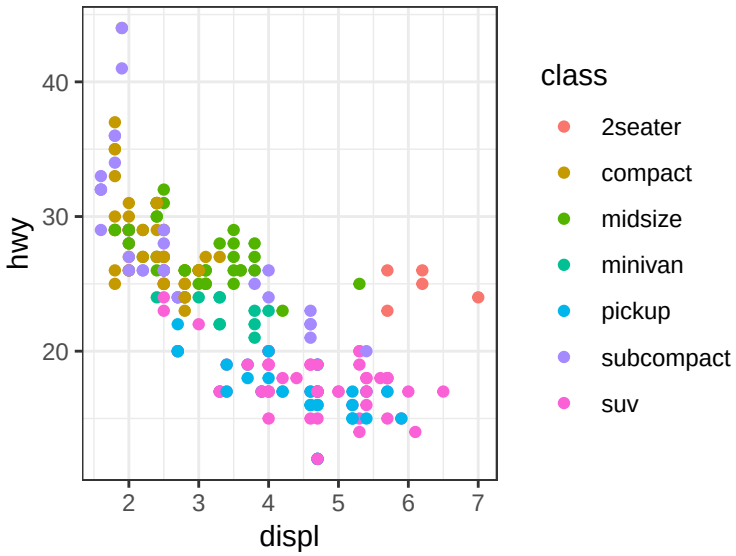
```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



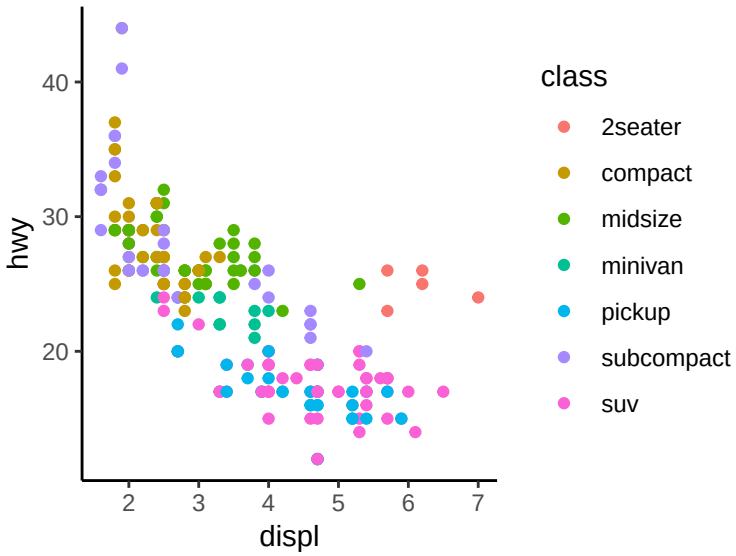
Themes

- The gray background is nice for presentations, but bad for publications. ggplot2 has a lot of themes that you can use. I think `theme_bw()` is the best.

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = class)) +
  geom_point() +
  theme_bw()
```

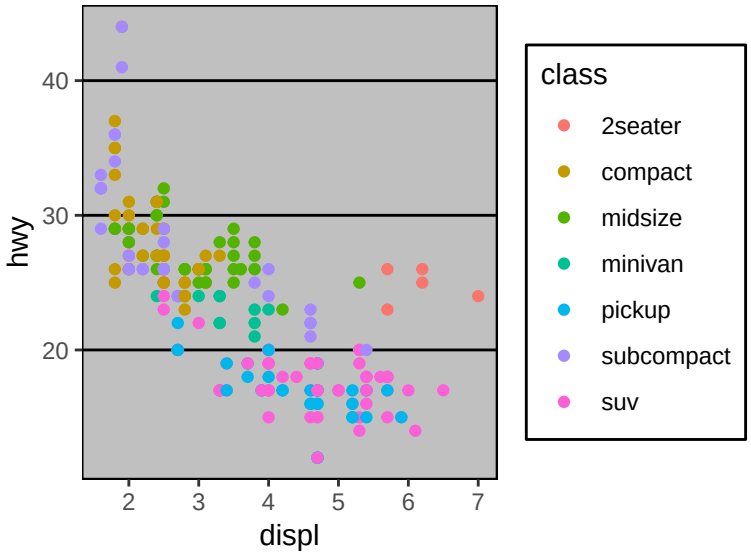



```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = class)) +
  geom_point() +
  theme_classic()
```

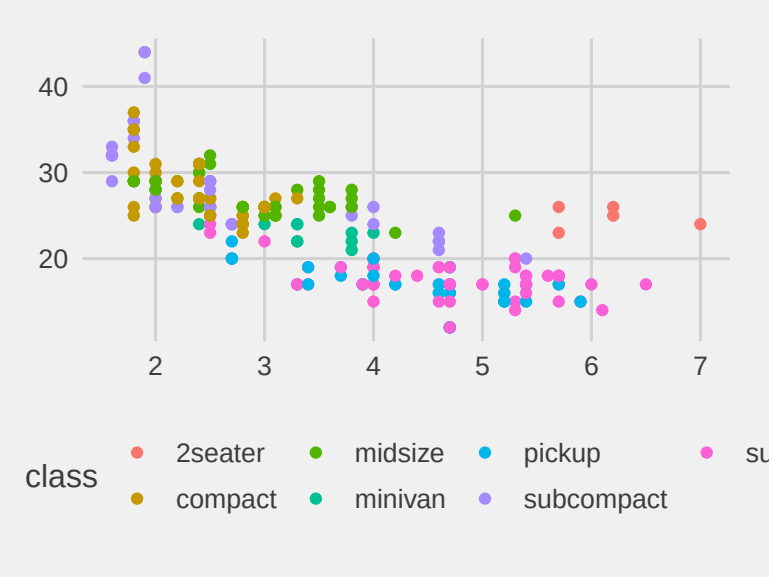


- Even more themes are available in the ggthemes package.

```
library(ggthemes)
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = class)) +
  geom_point() +
  theme_excel()
```



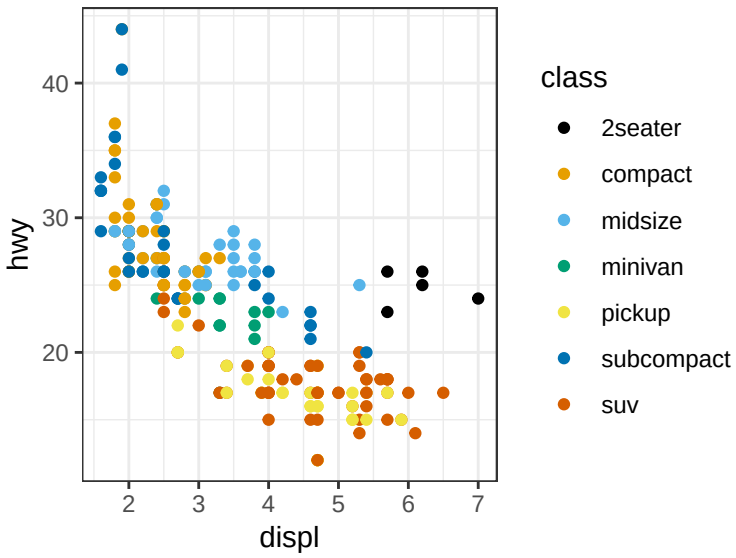

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = class)) +
  geom_point() +
  theme_fivethirtyeight()
```



Colorblind safe pallettes

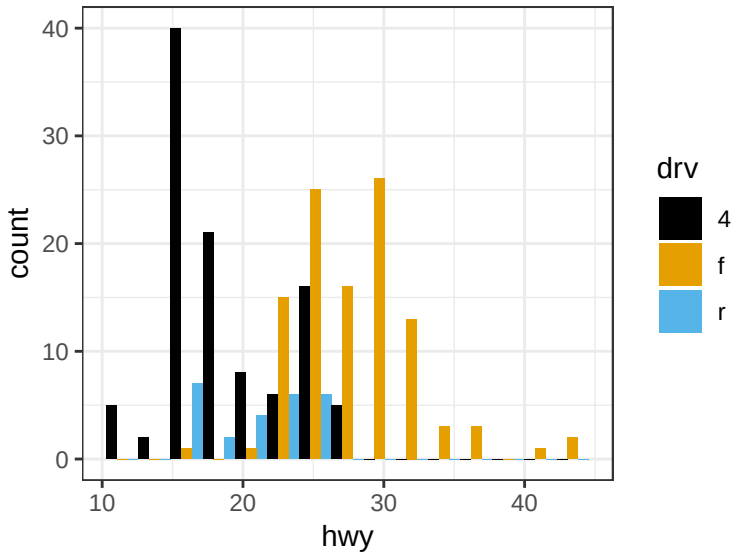
- When you publish, it's polite to use colorblind safe palletes. You can do this easily with the ggthemes package.

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = class)) +
  geom_point() +
  theme_bw() +
  scale_color_colorblind()
```



- Use `scale_color_colorblind()` to change the scale of the `color` aesthetic. Use `scale_fill_colorblind()` to change the scale of the `fill` aesthetic, etc...

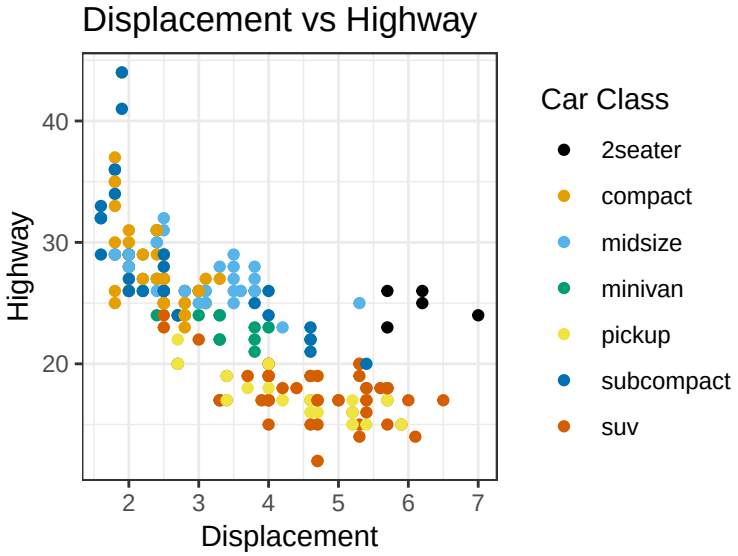
```
ggplot(data = mpg, mapping = aes(x = hwy, fill = drv)) +
  geom_histogram(position = "dodge", bins = 15) +
  theme_bw() +
  scale_fill_colorblind()
```



Labels

- You can set the axis labels manually with `xlab()` and `ylab()`.
- Titles may be added with `ggtitle()`.
- Legend titles need to be modified with a scale argument.

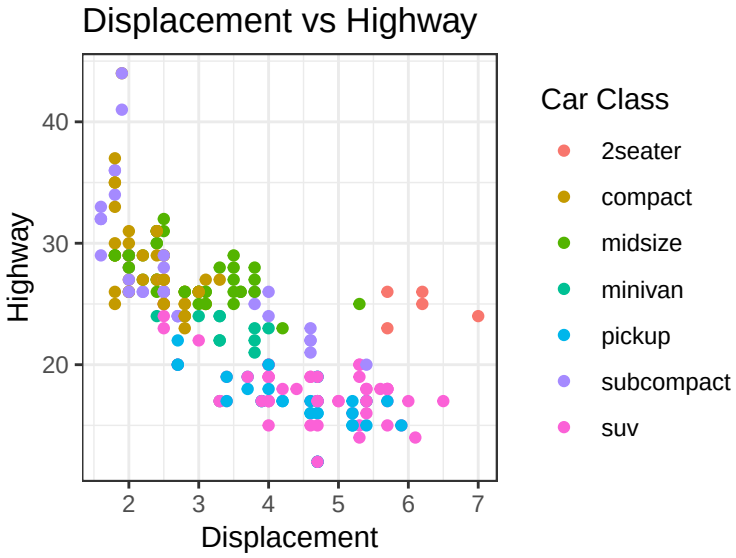
```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = class)) +
  geom_point() +
  theme_bw() +
  scale_color_colorblind(name = "Car Class") +
  xlab("Displacement") +
  ylab("Highway") +
  ggtitle("Displacement vs Highway")
```



- If you don't want colorblind scale, you can use `scale_color_discrete()` or `scale_fill_discrete()`

or `scale_color_continuous()` or `scale_fill_continuous()` etc...

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = class)) +
  geom_point() +
  theme_bw() +
  scale_color_discrete(name = "Car Class") +
  xlab("Displacement") +
  ylab("Highway") +
  ggtitle("Displacement vs Highway")
```



Saving Plots

- To save a plot, you can either print it and then use the RStudio functionality.

```
ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color = class)) +
  geom_point() +
  theme_bw() +
  scale_color_colorblind() ->
  pl
```

- It's better to automatic this process using the `ggsave()` function

```
ggsave(filename = "my_first_plot.pdf",
       plot = pl,
       device = pdf(),
       width = 6,
       height = 4,
       family = "Times")
```

- You can also do this manually using `pdf()`:

```
pdf(file = "my_second_plot.pdf", width = 6, height = 4, family = "Times")
print(pl)
dev.off()
```

```
## pdf
##   2
```

- `pdf()` opens up a connection to a new pdf file. `print(pl)` prints our saved `gg` object to that pdf file (instead of the R graphics device). `dev.off()` closes the connection.