# Introduction to R Programming

## Data Visualization with ggplot2

Pedro Fonseca

21 Abril 2020

ggplot2:
Build a data
MASTERPIECE
THEMES
GEOMS
aes
fill
color
ggANIMATE
plotly
HORST '18

# Introduction

- In lecture you will learn how to visualize data with the ggplot2 package.
- ggplot2 is one of the most elegant and versatile systems for making graphs.
- ggplot2 implements the grammar of graphics (Wickham 2010), a coherent system for describing and building graphs.

# Prerequisites

To access the datasets, help pages, and functions that we will use, load the ggplot2 package.

```
library(ggplot2)
```

# The mpg dataset

The mpg dataset contains information about 38 models of cars. Among the variables in mpg are:

- displ: engine size, in liters
- cyl: number of cylinders
- cty: city miles per gallon
- hwy: fuel efficiency on the highway, in miles per gallon (mpg).
- class: type of car

```
View(mpg)
```

For additional information see ?mpg.

# My first `ggplot()`

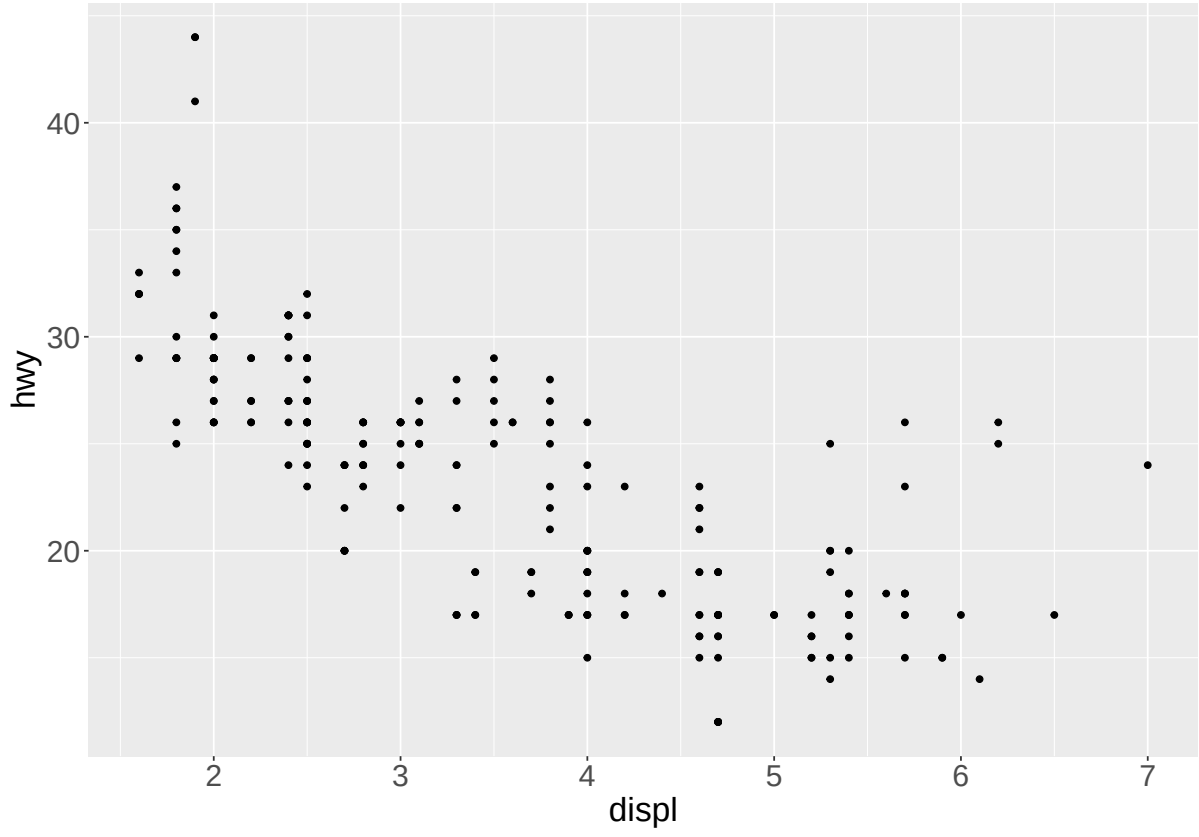
Let's build a graph to answer the following questions:

- Do cars with big engines use more fuel than cars with small engines?
- What does the relationship between engine size and fuel efficiency look like? Is it positive? Negative? Linear? Nonlinear?

We start by plotting engine size (`displ`) versus fuel efficiency (`hwy`).

# My first ggplot()

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



# My first `ggplot()`

- The plot shows a negative relationship between engine size and fuel efficiency.
- In other words: on average, cars with big engines use more fuel.

# A simple ggplot() template

```
ggplot(data = <DATA>) +
  <GEOM_FUNCTION>(mapping = aes(<MAPPINGS>))
```

- The first argument of ggplot() is a dataset
- We complete the graph by adding layers to ggplot()
- geom_point() adds a layer of points, creating scatterplot.
- ggplot2 has many geom functions that each add a different type of layer to a plot.

# A simple `ggplot()` template

- Each geom function takes a `mapping` argument.
- The `mapping` argument is always paired with `aes()`.
- The `x` and `y` arguments of `aes()` specify which variables to map to the `x` and `y` axes.

# Geometrical objects

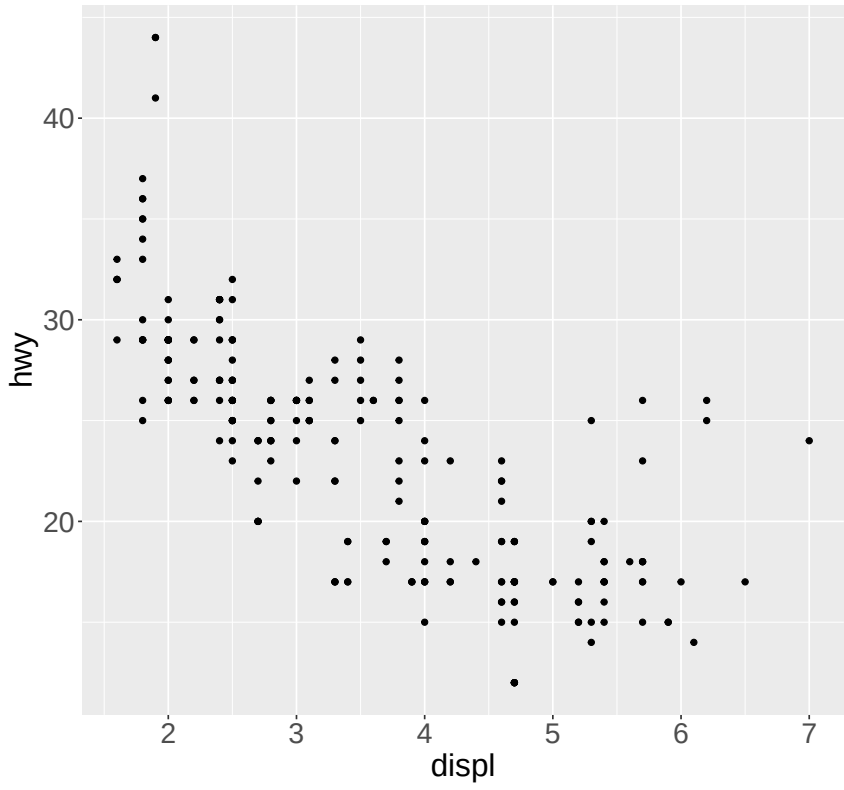
- A **geom** is the geometrical object that a plot uses to represent data (e.g. points, bars, lines. . . ).
- People often describe plots by the type of **geom** that it uses:
  - Bar charts use **bar** geoms
  - Line charts use **line** geoms
  - Boxplots use **boxplot** geom
  - . . .
- Scatterplots break the trend: they use the **point** geom.
- In ggplot2, we add geoms to a plot with **geom functions**.

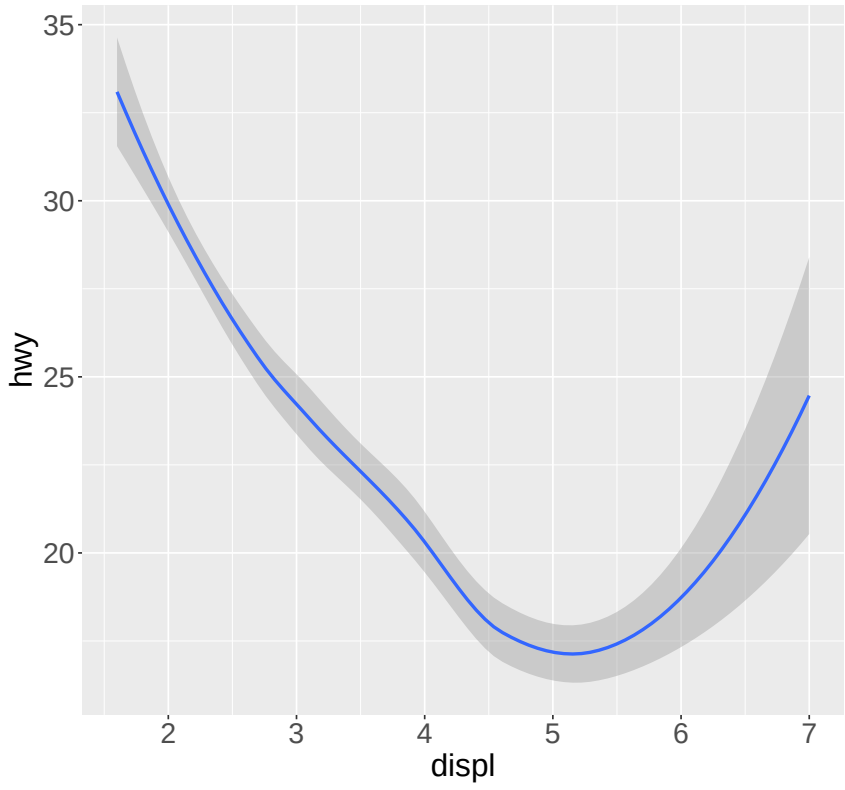
# Geometrical objects

Compare the next two plots. How are they similar?

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

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

# Geometrical objects



# Geometrical objects

Both plots:

- use the same data
- have the same `x` variable
- have the same `y` variable

But they are not identical:

- Each plot uses a different **geom**.
- The plot on the left uses the **point** geom.
- The plot on the right uses the **smooth** geom, a smooth line fitted to the data.

# The ggplot2 cheat sheet

- ggplot2 provides over 40 geoms
- The best way to get a comprehensive overview is the ggplot2 cheatsheet.

# Aesthetics

- **Aesthetics** are visual properties of the **geoms**.
- **Aesthetics** include things like the size, shape, and color of the points in a scatterplot.
- `aes()` builds **aesthetic mappings** that define how the variables in the dataset are mapped to aesthetics of the geoms.
- To map an aesthetic to a variable, associate the name of the aesthetic to the name of the variable inside `aes()`.
- Every geom function needs an aesthetic mapping, but not every aesthetic works with every geom, for example:
  - We can set the `shape` of a point, but not of a line.
  - We can set the `linetype` of a line, but not of a point.

# My first `ggplot()` revisited

One group of points (highlighted in red) seems to fall outside the linear trend. How can we explain these cars?

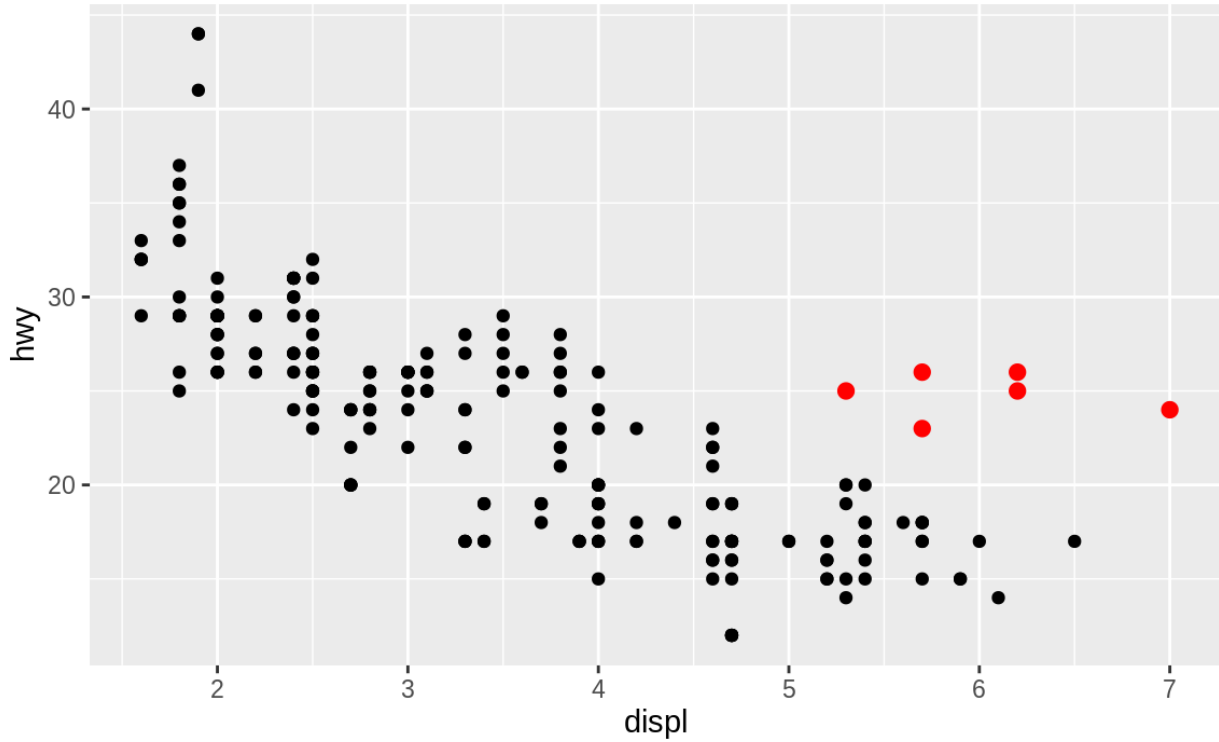



Figure 1: Some cars have a higher mileage than we might expect

# My first `ggplot()` revisited

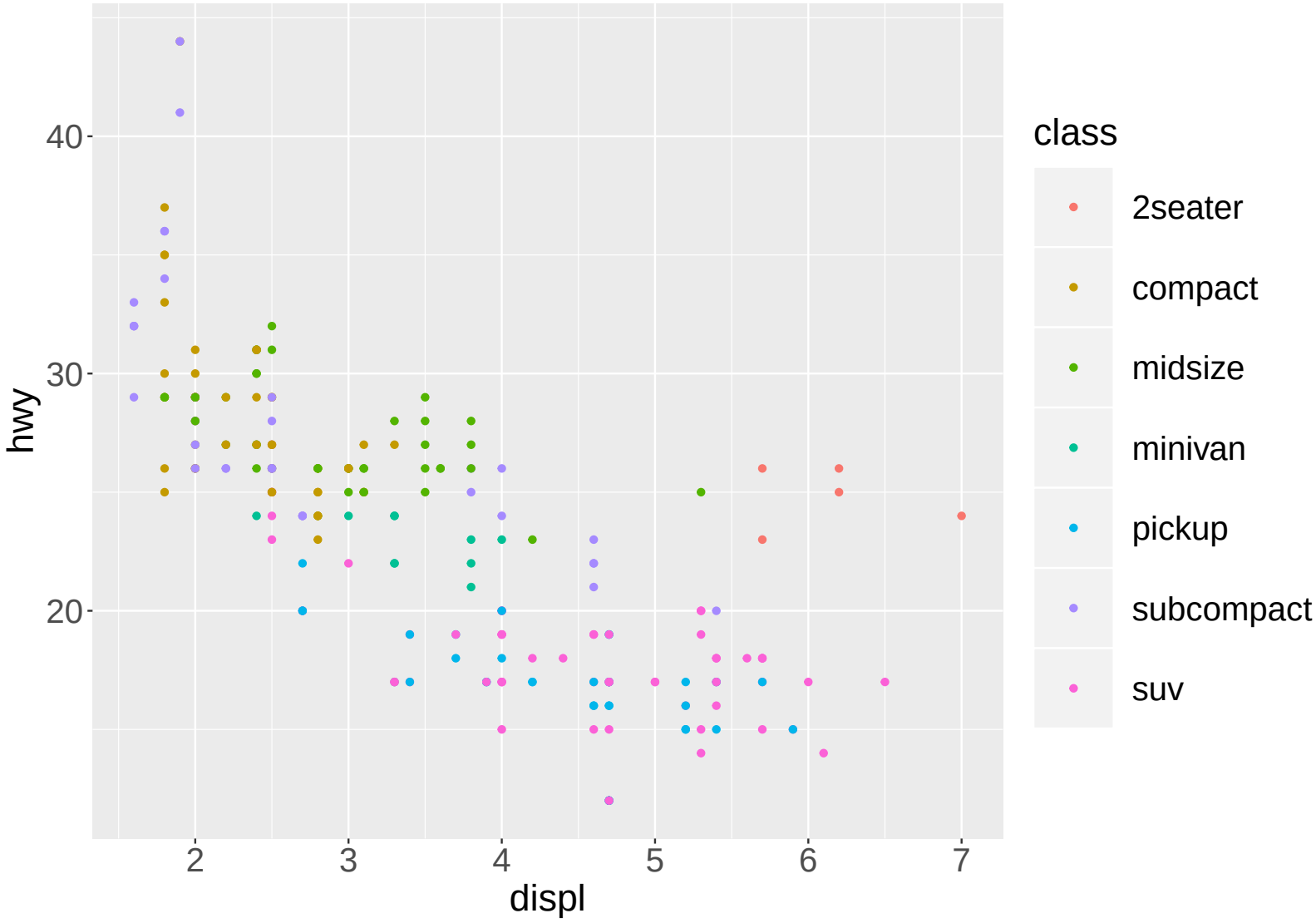
- The highlighted cars may have some common characteristic with respect to some other variable (e.g. they might all be hybrids).
- Lets try `class`, a variable that classifies cars into groups such as compact, midsize, and SUV.
- We can add a third variable to a two dimensional scatterplot by mapping it to an aesthetic.

# The color aesthetic

For example, we can map the color of the points to the `class` variable, so that the graph reveals the class of each car:

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

# The color aesthetic



# The color aesthetic

Now we know that all but one of the highlighted cars are two-seater cars! Let's find their model and manufacturer:

```
subset(mpg, class == "2seater",
       select = c("manufacturer", "model", "year"))
```

```
## # A tibble: 5 x 3
##   manufacturer model      year
##   <chr>        <chr>     <int>
## 1 chevrolet    corvette   1999
## 2 chevrolet    corvette   1999
## 3 chevrolet    corvette   2008
## 4 chevrolet    corvette   2008
## 5 chevrolet    corvette   2008
```

# The color aesthetic

- These cars are, in fact, sports cars!
- Sports cars have large engines like SUVs and pickup trucks, but small bodies like midsize and compact cars, which improves their gas mileage.

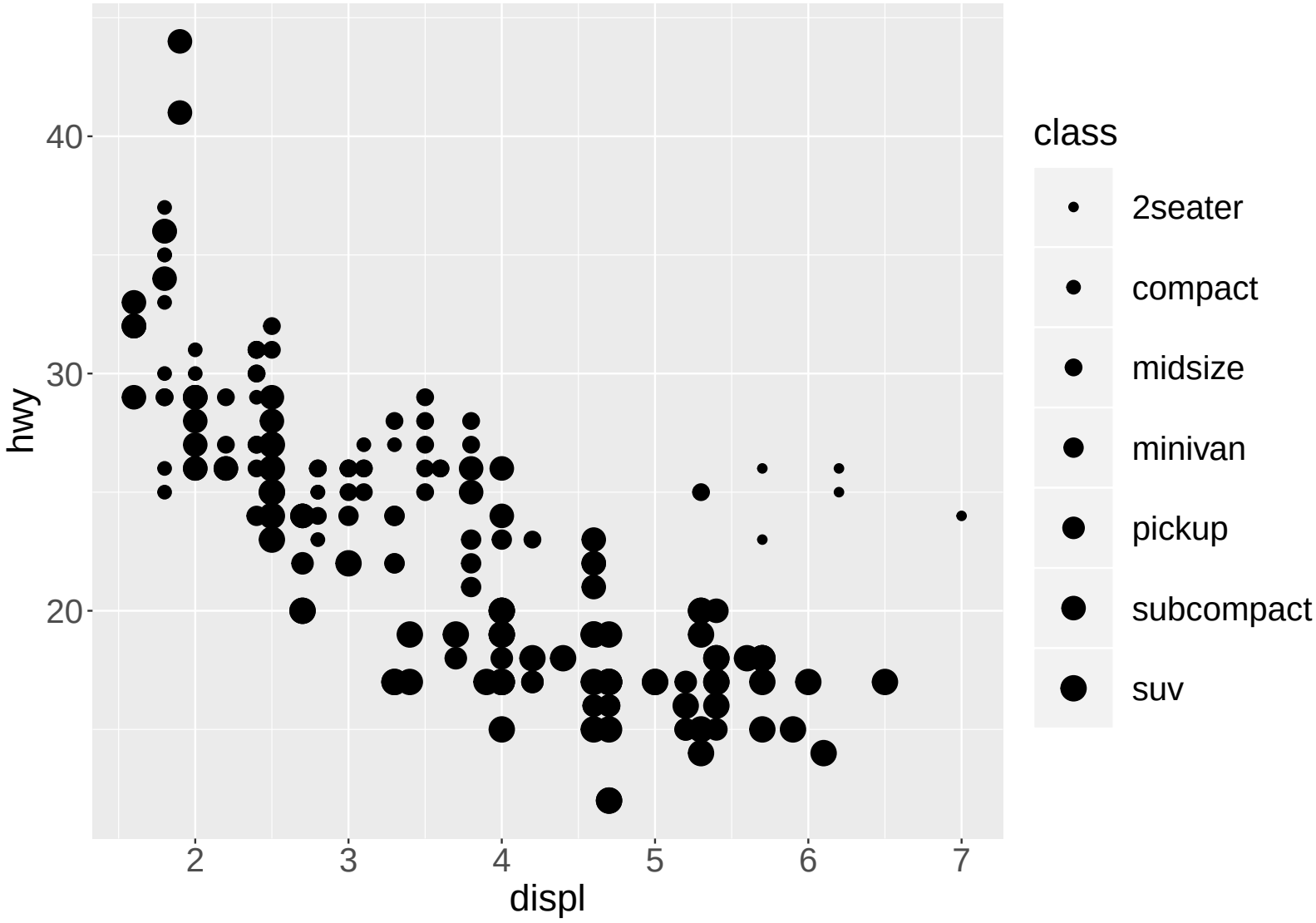
Figure 2: 2008 Chevrolet Corvette

# The size aesthetic

Now let´s map `class` to the size aesthetic:

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

# The size aesthetic



# The size aesthetic

- Each level of the `class` variable is assigned to a different size.
- This plot, however, came with a warning message:

```
#> Using size for a discrete variable is not advised.
```

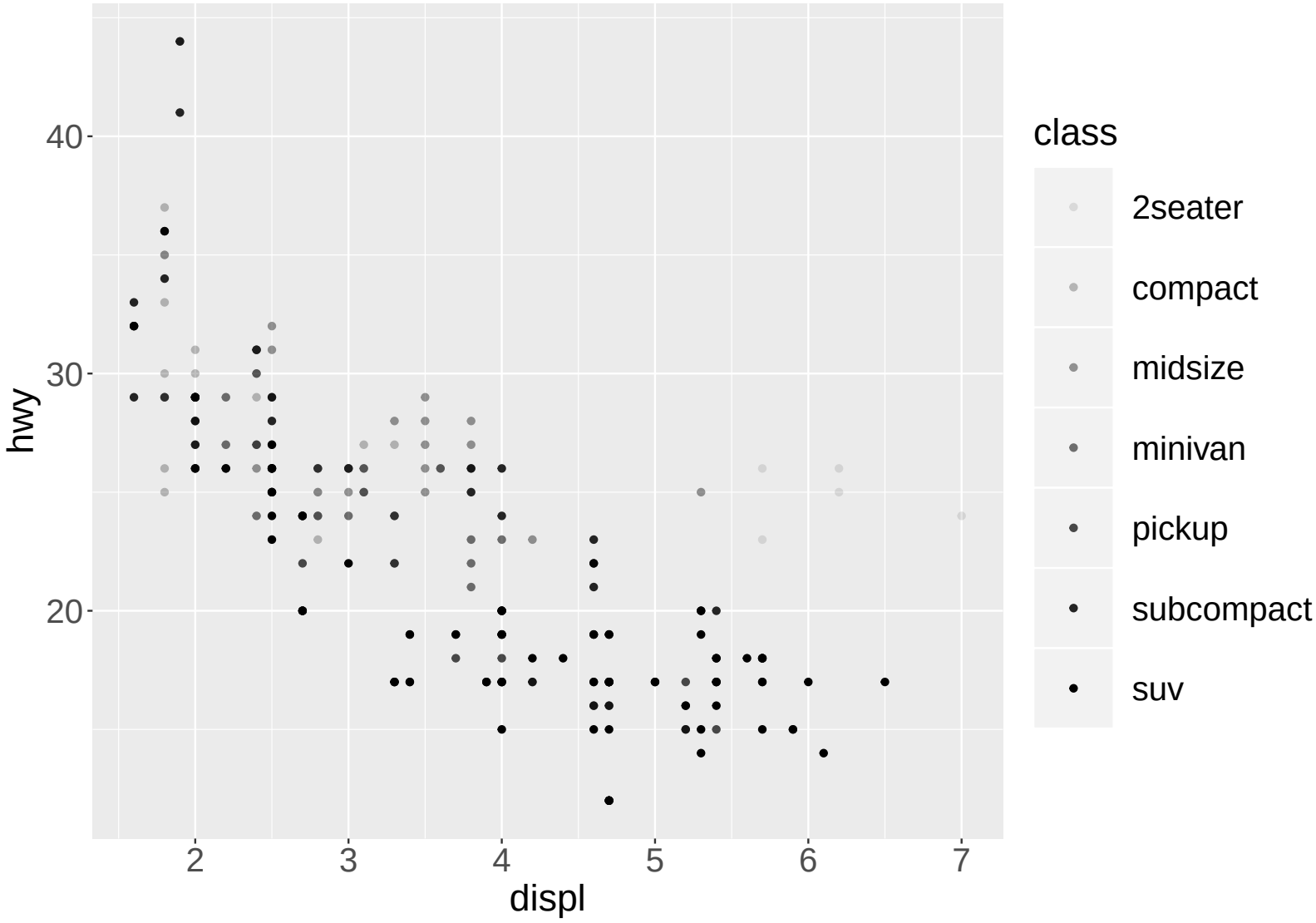
- This is because mapping an unordered variable (`class`) to ordered aesthetic (`size`) is not a good idea.
- Ordered aesthetics, like `size` and `alpha`, are more appropriate for continuous variables.

# The alpha aesthetic

The `alpha` aesthetic changes the transparency of the points:

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

# The alpha aesthetic



# The shape aesthetic

The `shape` aesthetic changes the shape of the points:

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

# The shape aesthetic

# The shape aesthetic

- What happened to the SUVs?
- By default ggplot2 uses only up to six shapes at a time.
- This is because points become difficult to discriminate if we use too many shapes.
- We can, however, use more than six shapes if we set them "manually" with `scale_shape_manual()`.

# The shape aesthetic

We can choose the following shapes of points by their number:

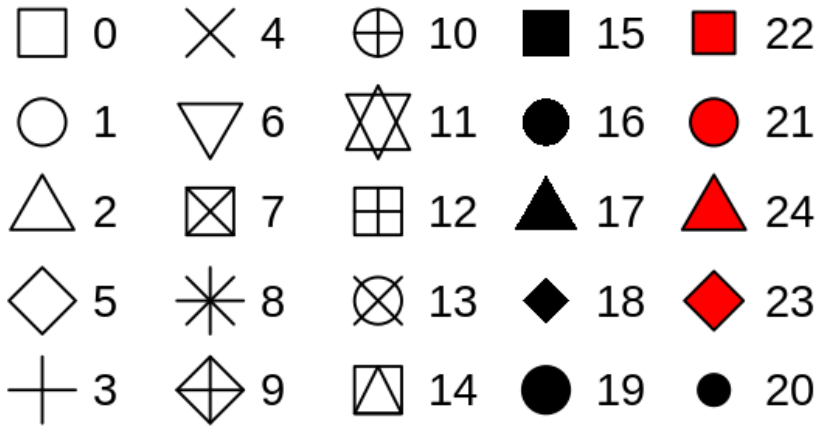


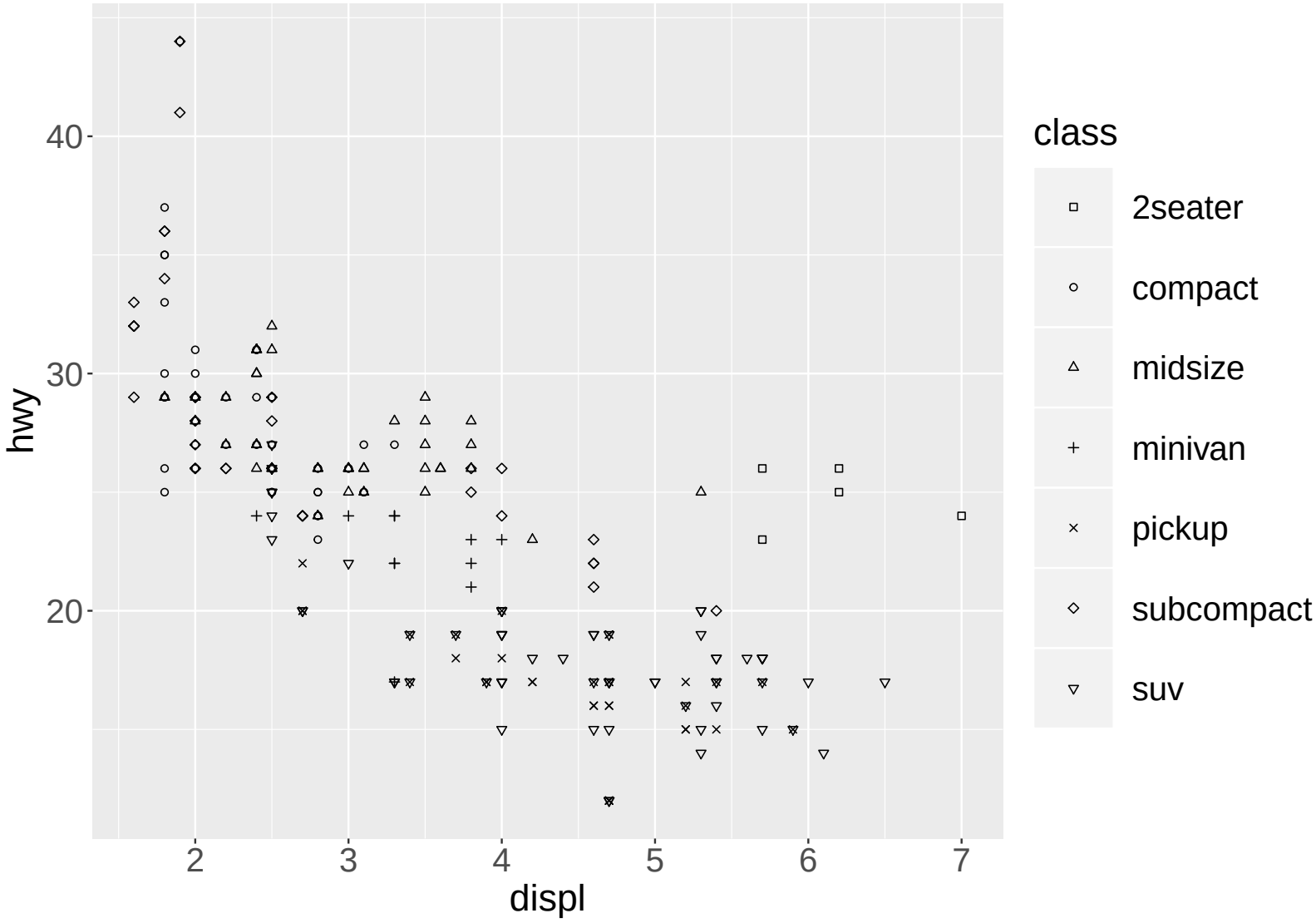

Figure 3: R Built in shapes

# The shape aesthetic

Let's choose the first 7 shapes:

```
ggplot(data = mpg) +
  geom_point(aes(x = displ, y = hwy, shape = class)) +
  scale_shape_manual(values = 0:6)
```

# The shape aesthetic

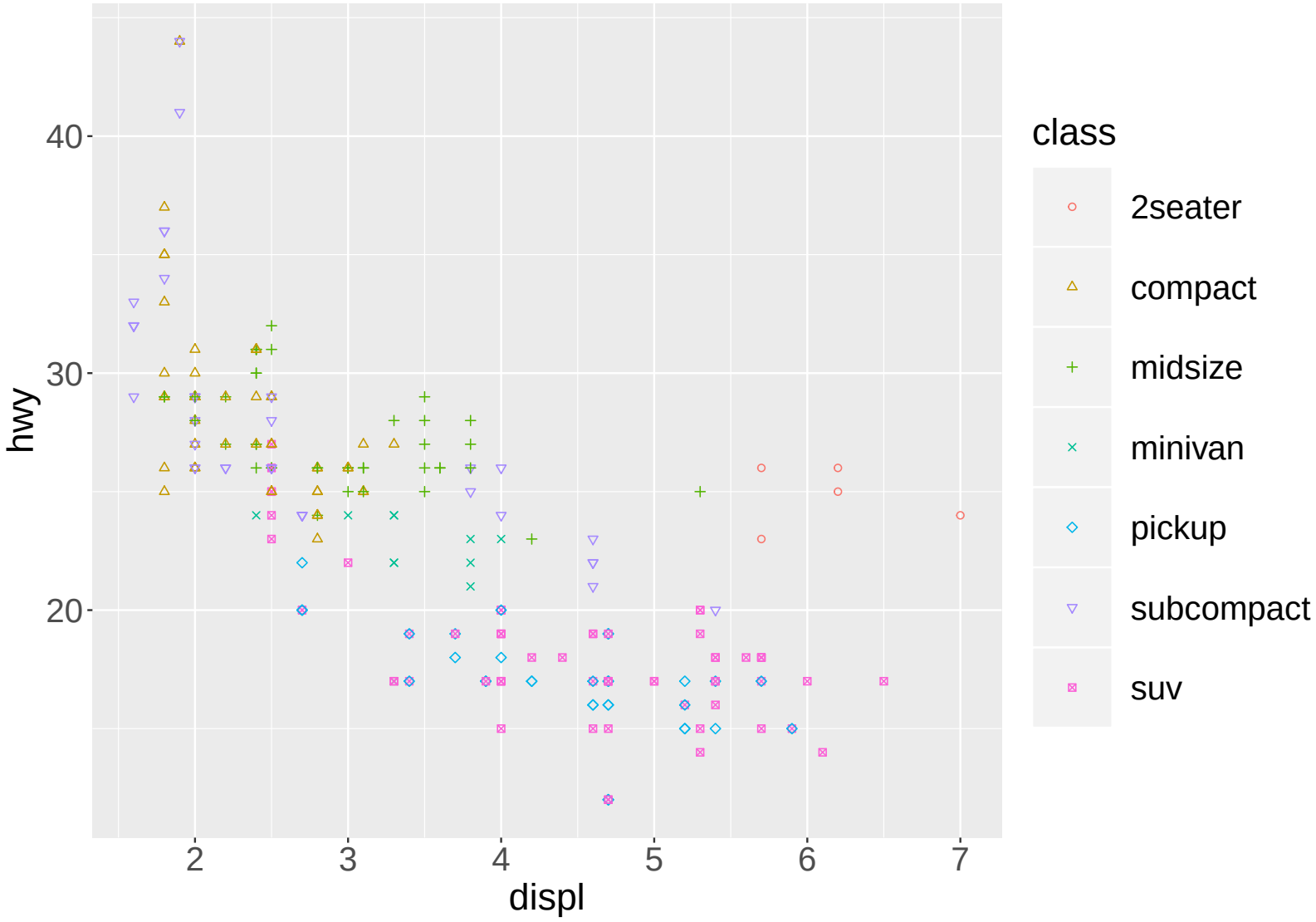


# Mapping one variable to two aesthetics

- Mapping a single variable to multiple aesthetics is redundant, and should be avoided in most cases.
- In this case, however, since we have many categories, it can improving visual discrimination.
- Let´s map `class` to `color` and `shape`:

```
ggplot(data = mpg) +
  geom_point(aes(x = displ, y = hwy,
                 shape = class, color = class)) +
  scale_shape_manual(values = 1:7)
```

# Mapping one variable to two aesthetics



# Mapping continuous variables to aesthetics

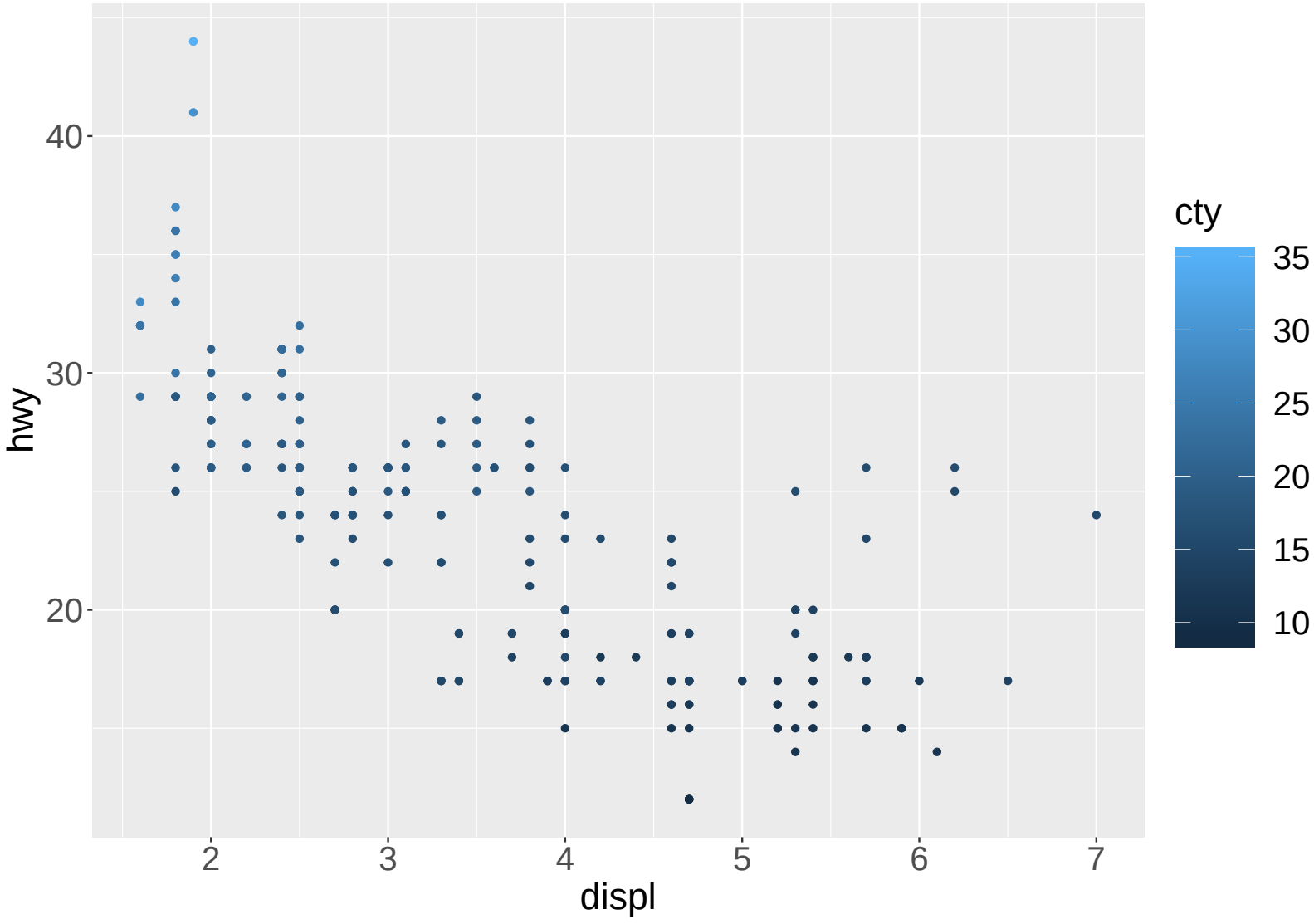
- So far we mapped `class`, a categorical variable, to the `color`, `size`, `shape` and `alpha` aesthetics of `geom_point()`.
- Now let´s map continuous variables to these aesthetics and see how they behaves differently for categorical versus continuous variables.
- The variable `cty` (city miles per gallon) is a continuous variable.

# Mapping continuous variables to aesthetics

Let's map `cty` to the `color` aesthetic:

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

# Mapping continuous variables to aesthetics

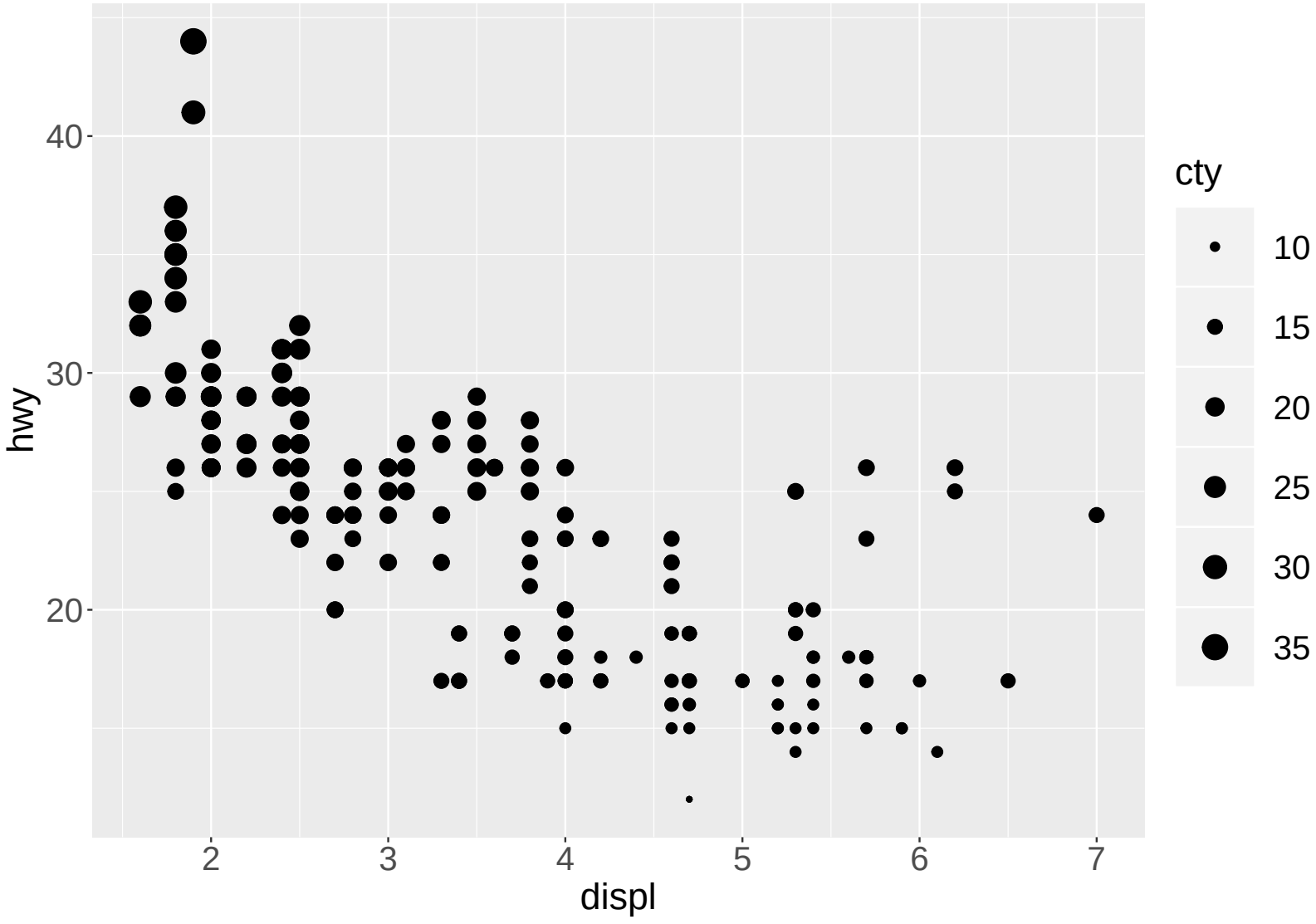


# Mapping continuous variables to aesthetics

Now let's map `cty` to the `size` aesthetic:

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

# Mapping continuous variables to aesthetics

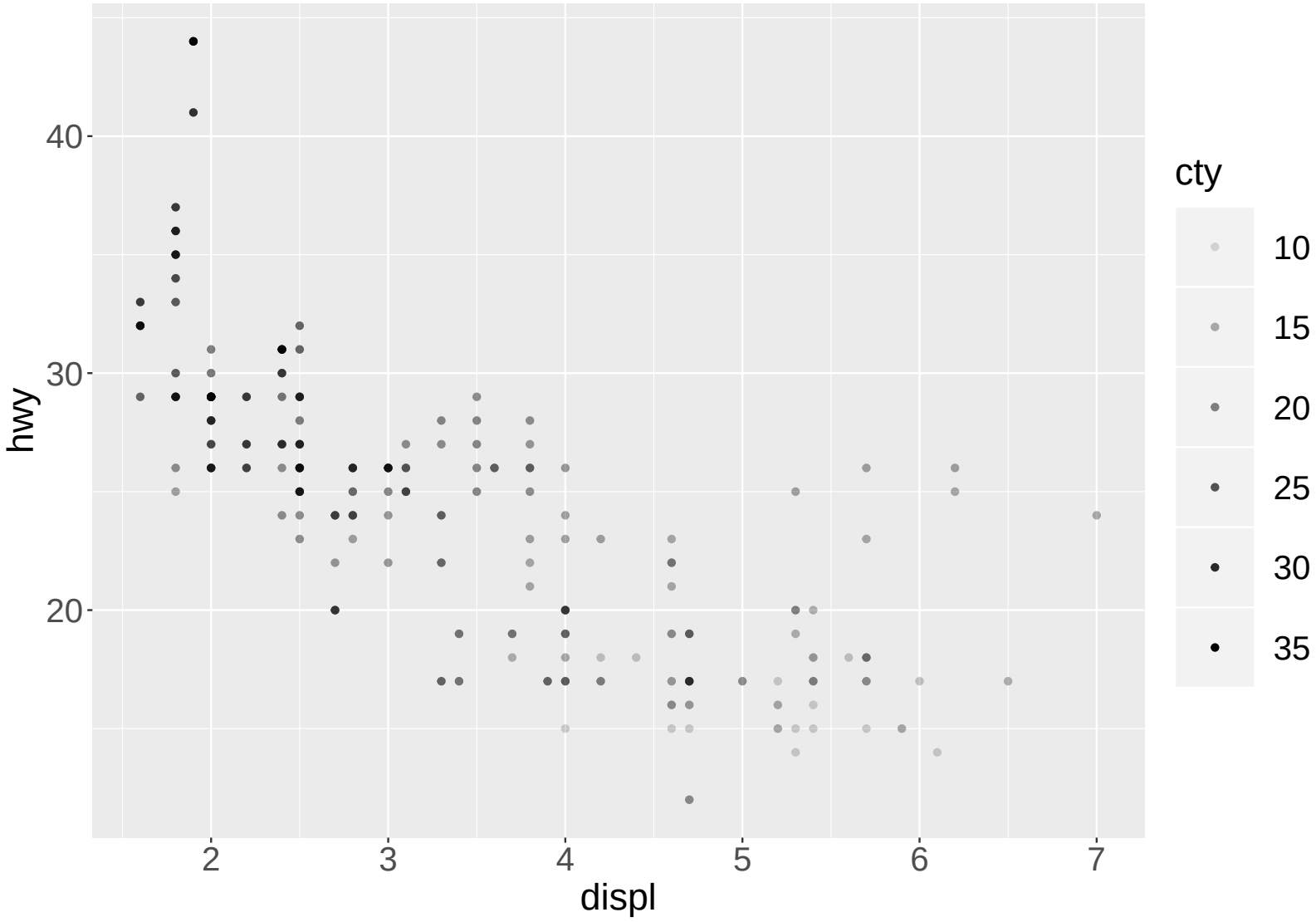


# Mapping continuous variables to aesthetics

Now let's map `cty` to the `alpha` aesthetic:

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

# Mapping continuous variables to aesthetics



# Mapping continuous variables to aesthetics

And finally let's map `cty` to the `shape` aesthetic:

```
ggplot(mpg) +
  geom_point(aes(x = displ, y = hwy, shape = cty))

#> Error: A continuous variable can not be mapped to
#> shape
```

# Aesthetic mappings: categorical vs continuous variables

**Color** and **alpha** aesthetics:

- Each level of a categorical variable is assigned to a different (discrete) color.
- The color of the points vary continuously from light to dark as a function of the values of a continuous variables.

**Size** aesthetic:

- Each level of a categorical variable is assigned to a different (discrete) size.
- The size of the points vary continuously as a function of the values of a continuous variables.

# Aesthetic mappings: categorical vs continuous variables

**Shape** aesthetic:

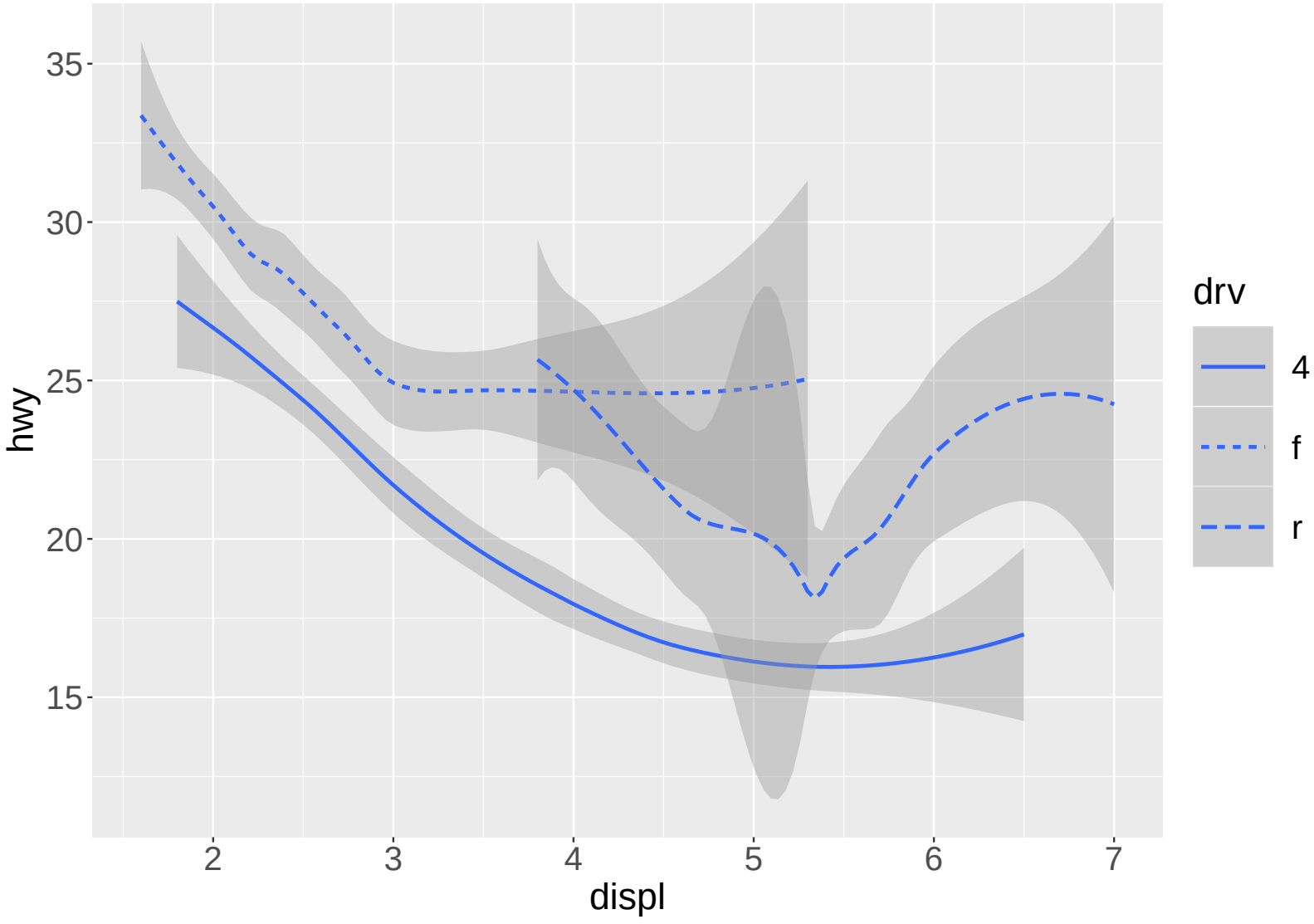
- A different shape is assigned to each level of a categorical value.
- The shape aesthetic can not be mapped to continuous variables.

# The `linetype` aesthetic

`geom_smooth()` draws a different type of line for each level of the variable that is mapped to the `linetype` aesthetic:

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

# The `linetype` aesthetic



# The `linetype` aesthetic

- The `linetype` aesthetic automatically adds a legend.
- The `linetype` aesthetic can not be mapped to continuous variables.

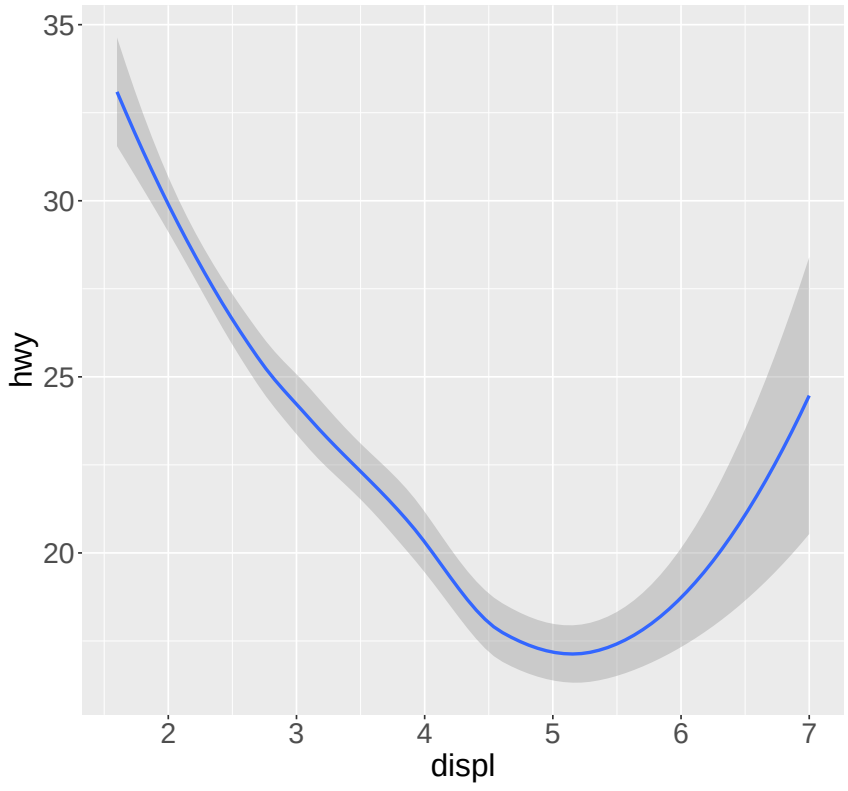
# The `group` aesthetic

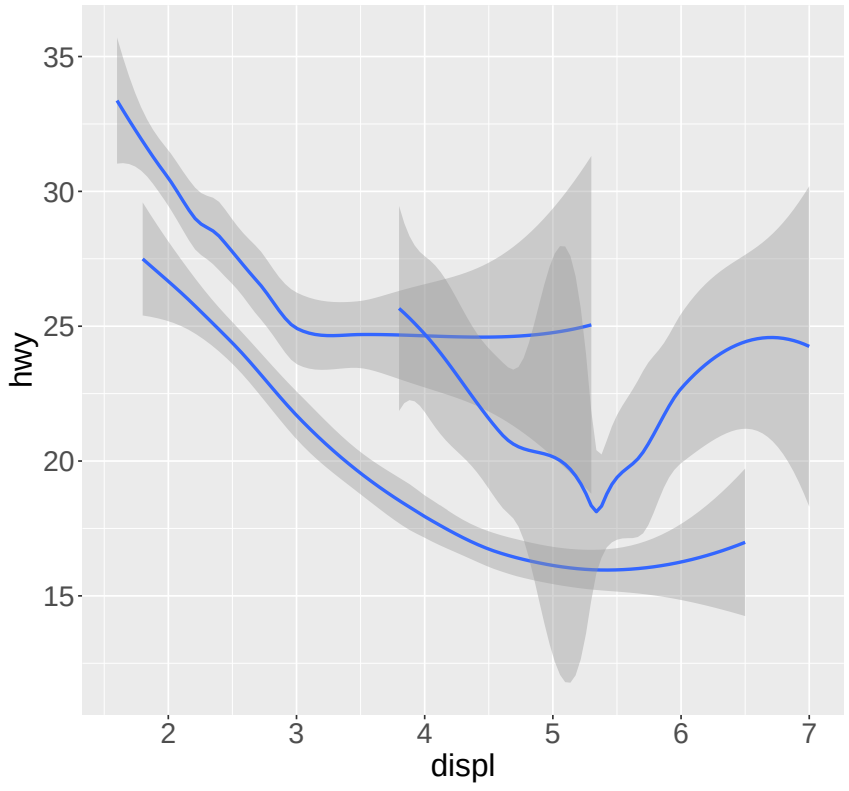
- The `group` aesthetic also draws a separate object for each level of a discrete variable.
- The `group` aesthetic does not add a legend or any other distinguishing feature.

# The group aesthetic

```
p1 <- ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy))

p2 <- ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy, group = drv))
```

# The group aesthetic

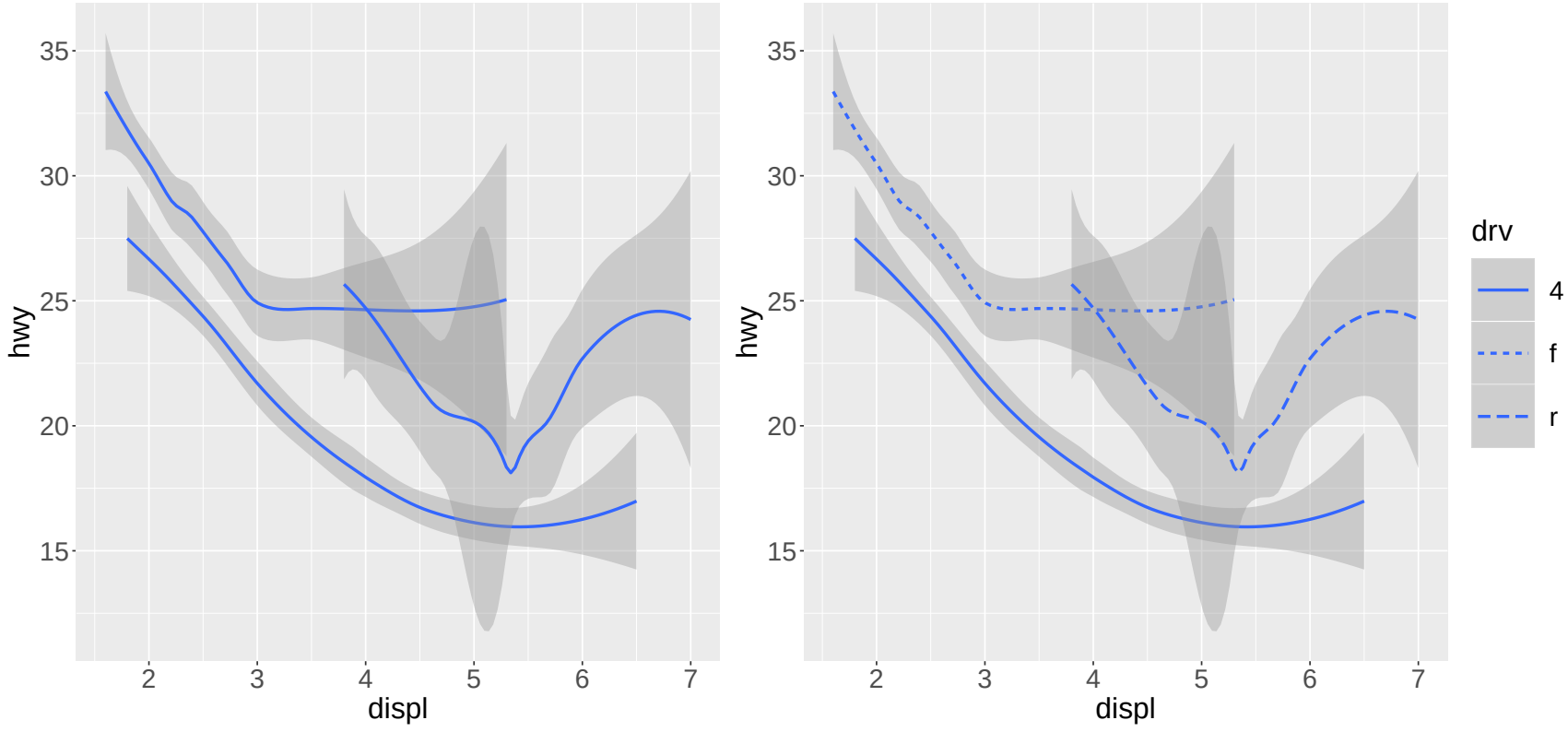


# group vs linetype

```
ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy, group = drv))

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

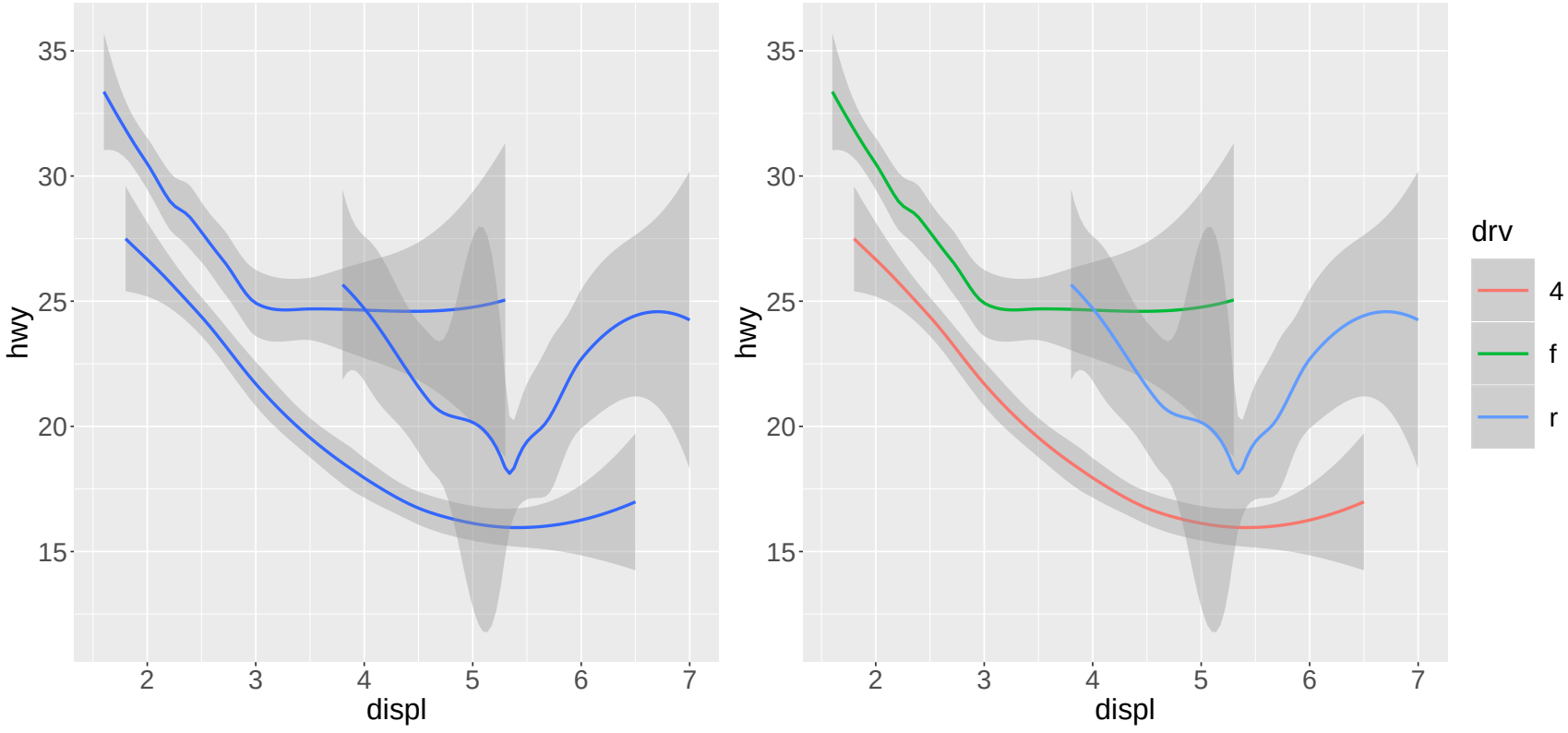
# group vs linetype



# group vs color

```
ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy, group = drv))

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

# group vs color



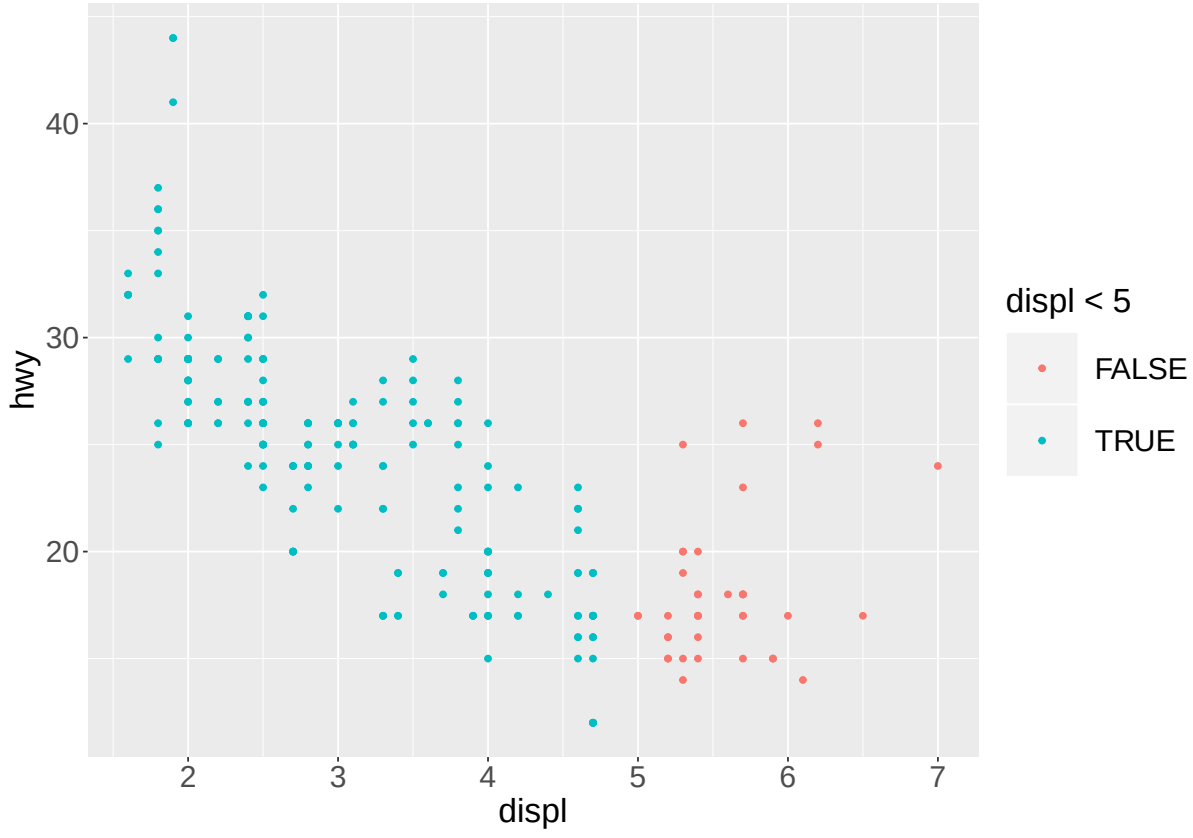
# Aesthetics and logical conditions

Aesthetics can be mapped to logical expressions. For example, if we map an aesthetic to `displ < 5`:

- `ggplot()` creates a temporary variable with values equal to the result `displ < 5`.
- The result of `displ < 5` is a logical variable.
- `ggplot()` then maps the aesthetic to the temporary variable.

# Aesthetics and logical conditions

```
ggplot(mpg) +
  geom_point(aes(x = displ, y = hwy,
                 color = displ < 5))
```



# Aesthetics and logical conditions

```
ggplot(mpg) +
  geom_point(aes(x = displ, y = hwy,
                 color = class == "2seater"))
```

# Changing default aesthetic properties of geoms

- To change a default aesthetic property, set the aesthetic by name as an argument of the geom function.
  - Names of colors should be indicated as character strings.
  - Size of points should be indicated in mm.
  - Shapes are identified by the numbers in figure 3.

# Changing default aesthetic properties of geoms

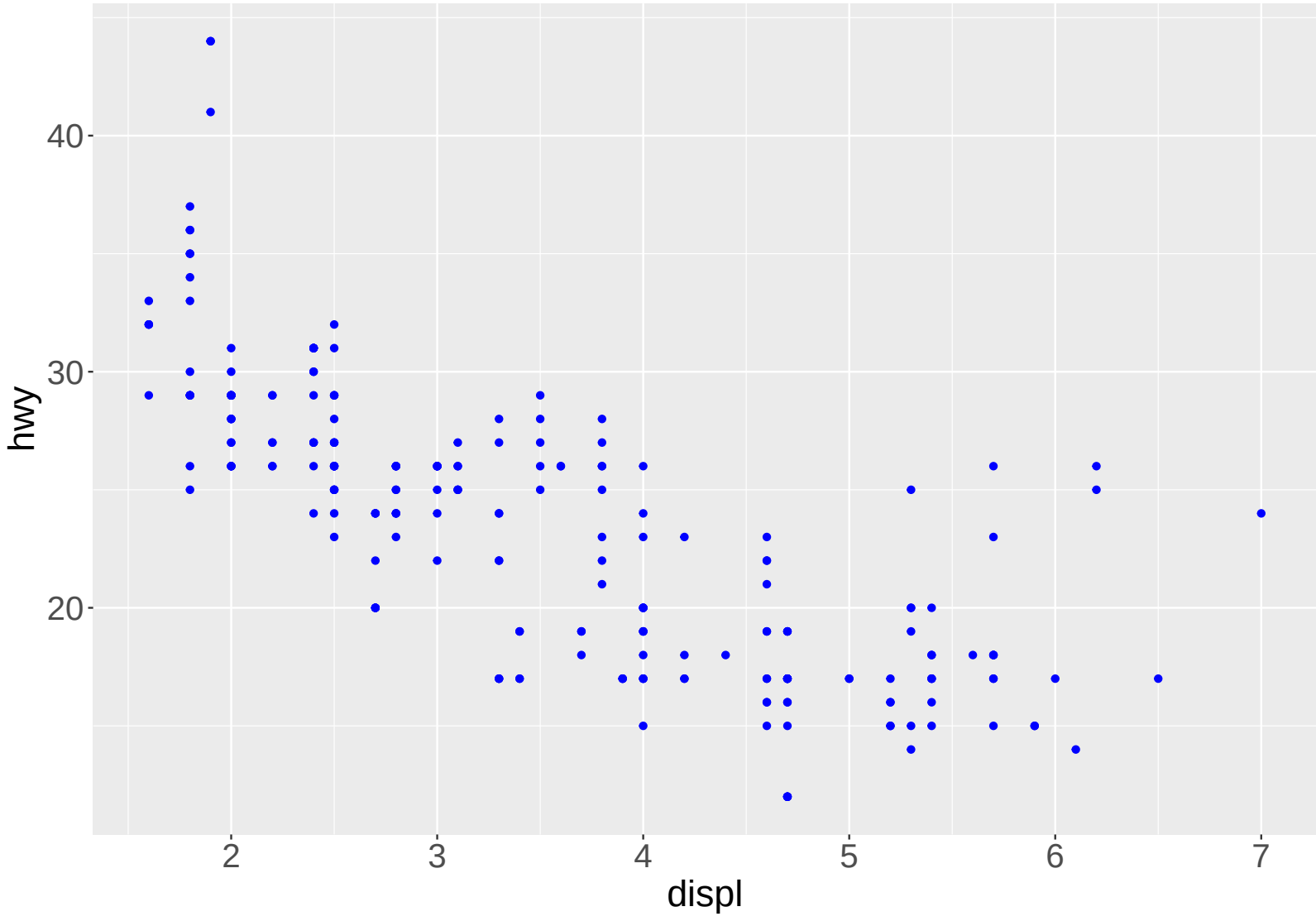
- There are some seeming duplicate shapes (e.g. 0, 15, and 22 are all squares).
- The difference comes from the interaction of the `color` and `fill` aesthetics:
  - The hollow shapes (0–14) have a border determined by the `color` aesthetic
  - The solid shapes (15–18) are filled with the color `aesthetic`
  - The filled shapes (21–24) have a border set by the `color` aesthetic and are filled with the `fill` aesthetic

# Changing default aesthetic properties of geoms

For example, we can make all of the points blue:

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

# Changing default aesthetic properties of geoms

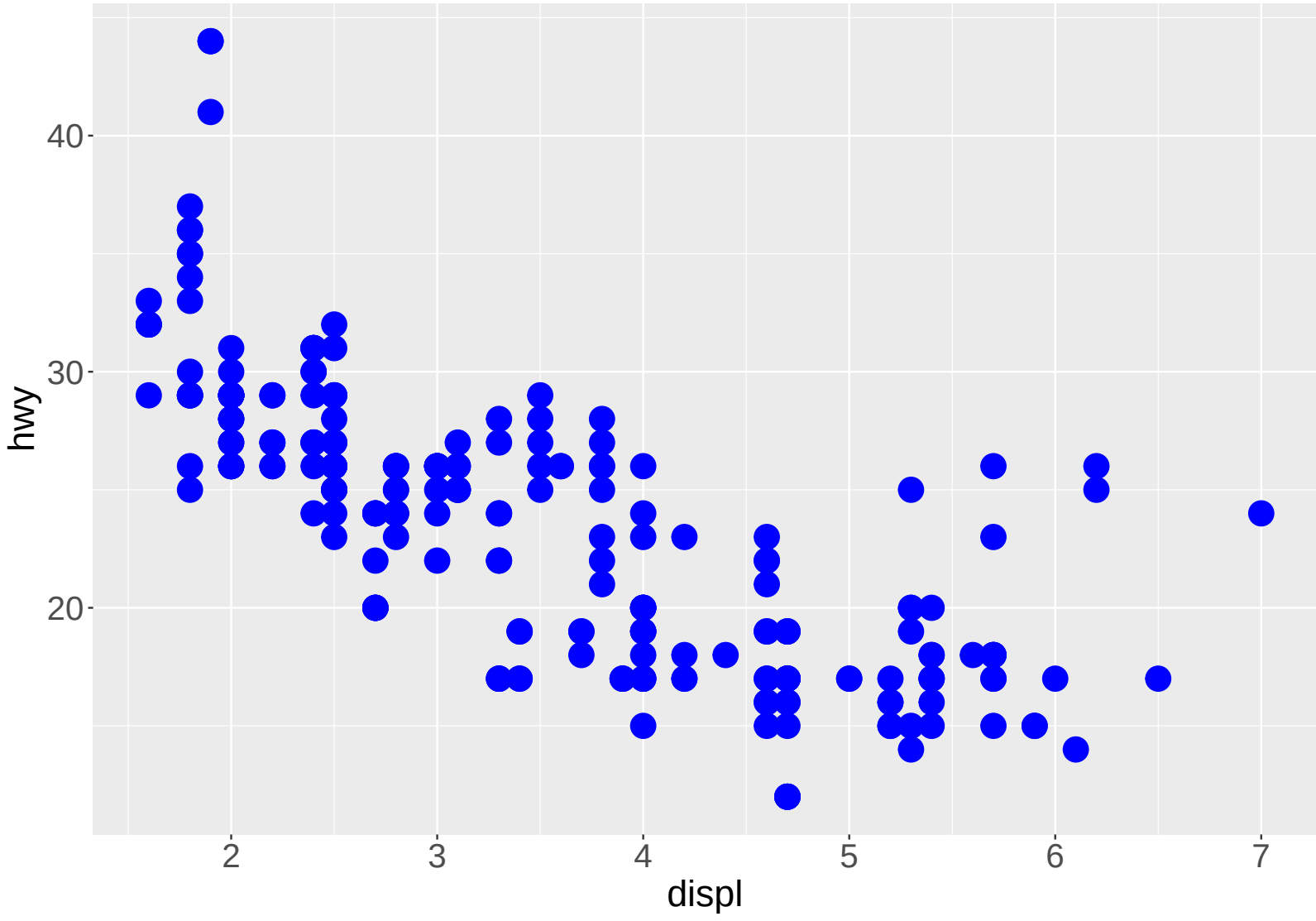


# Changing default aesthetic properties of geoms

Now let's change the size of the points:

```
ggplot(data = mpg) +
  geom_point(aes(x = displ, y = hwy),
    color = "blue",
    size = 6)
```

# Changing default aesthetic properties of geoms

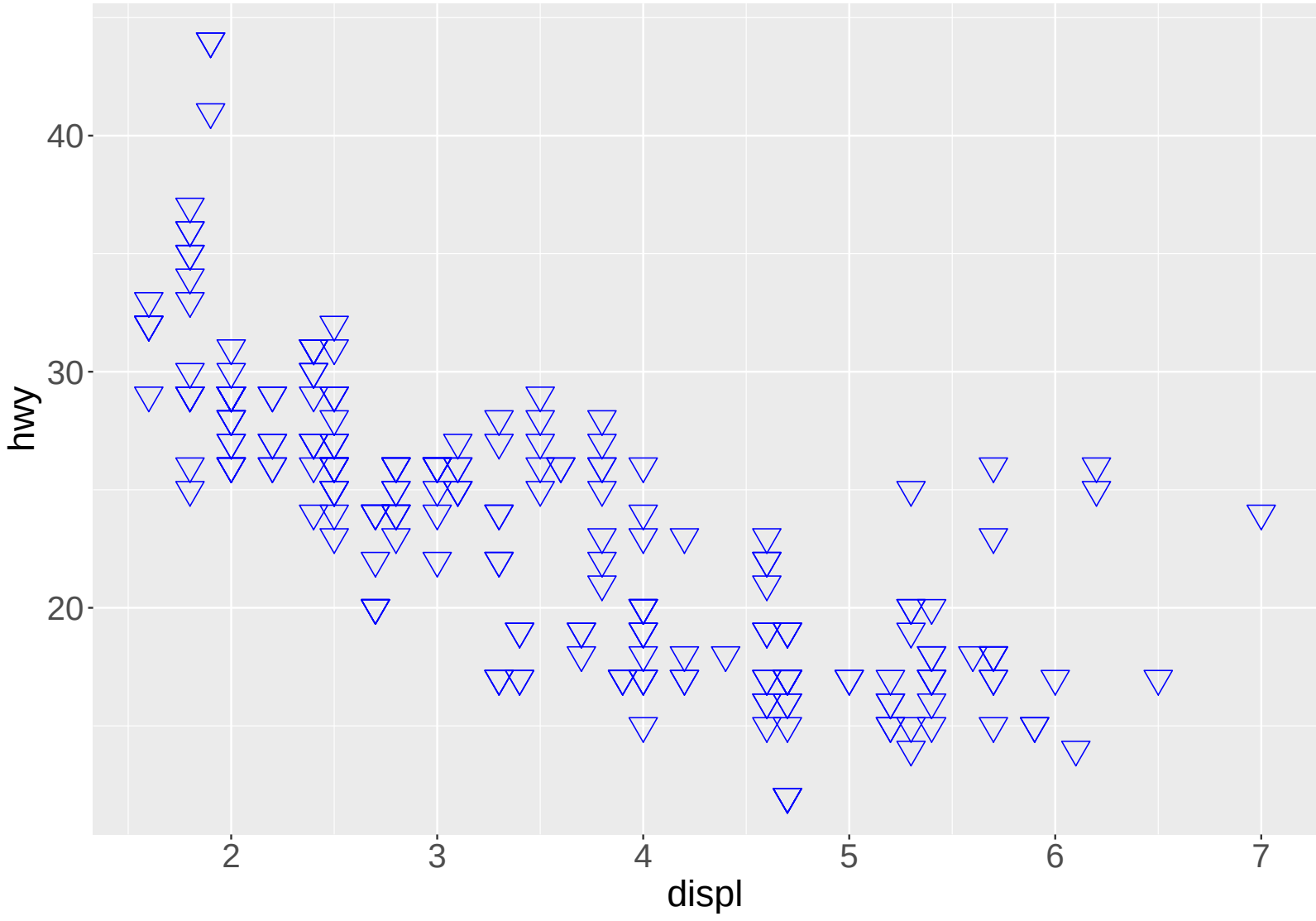


# Changing default aesthetic properties of geoms

We can also change the default shape of the points:

```
ggplot(data = mpg) +
  geom_point(aes(x = displ, y = hwy),
    color = "blue",
    size = 5,
    shape = 6)
```

# Changing default aesthetic properties of geoms

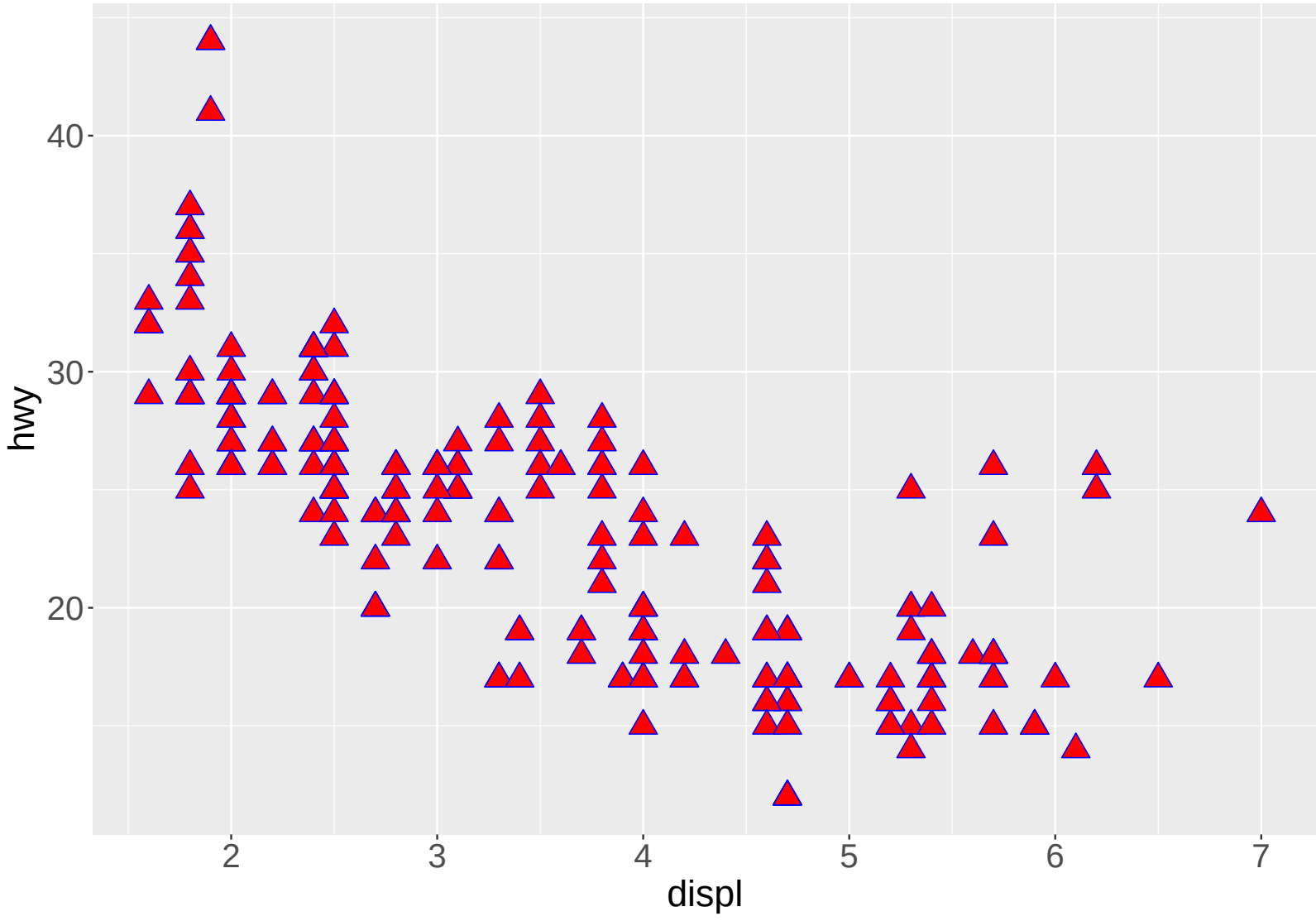


# Changing default aesthetic properties of geoms

- Shape 6 is a hollow shape, it interacts only with the `color` aesthetic.
- If we want triangles filled with color, we must use shape 24, which interacts both with the color and `fill` aesthetics:

```
ggplot(data = mpg) +
  geom_point(
    mapping = aes(x = displ, y = hwy),
    color = "blue",
    size = 5,
    shape = 24,
    fill = "red"
  )
```

# Changing default aesthetic properties of geoms

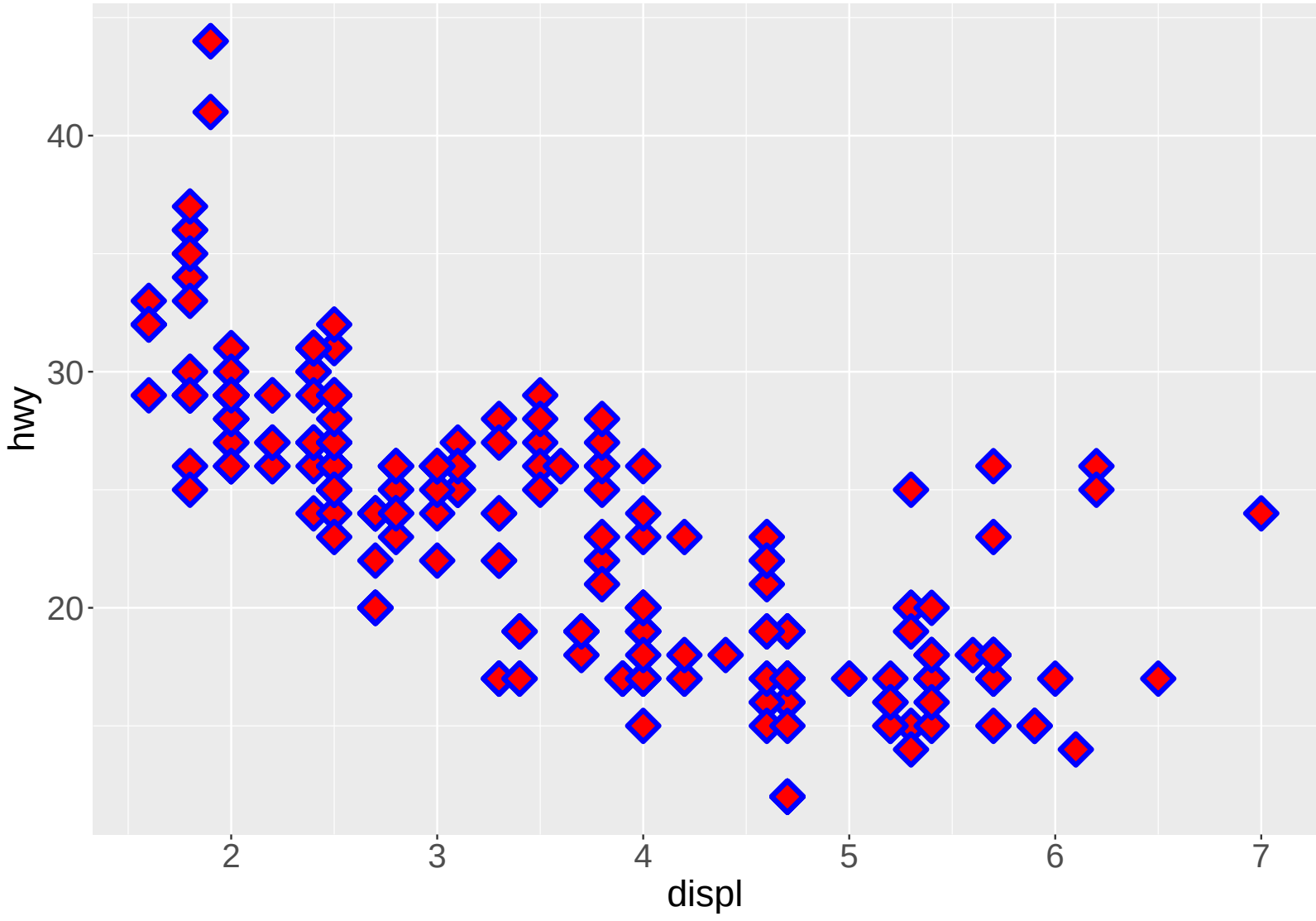


# Changing default aesthetic properties of geoms

The `stroke` aesthetic changes the thickness of the border of the points:

```
ggplot(data = mpg) +
  geom_point(aes(x = displ, y = hwy),
    color = "blue",
    size = 5,
    shape = 23,
    fill = "red",
    stroke = 2
  )
```

# Changing default aesthetic properties of geoms

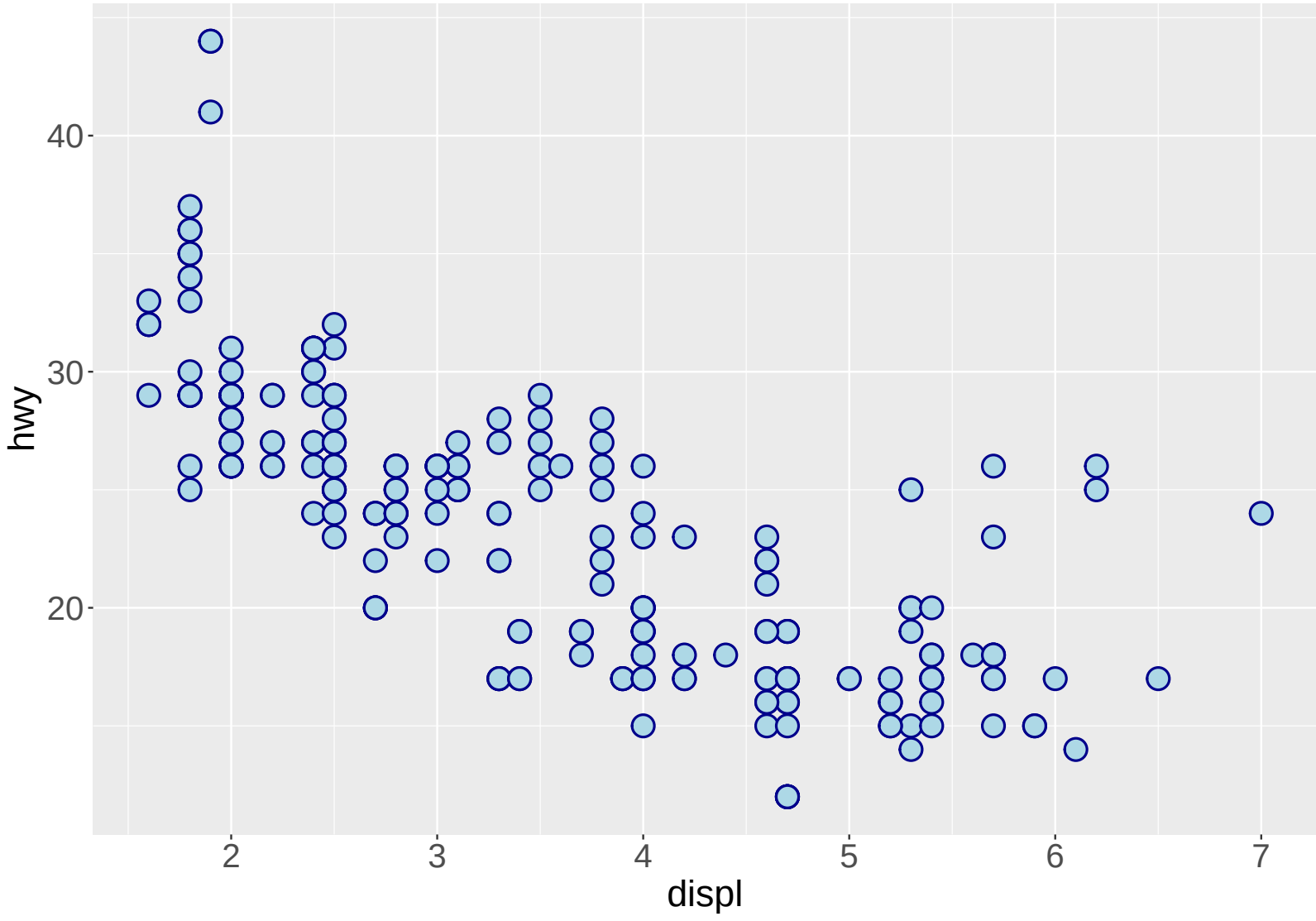


# Changing default aesthetic properties of geoms

We can also use colors like dark blue and light blue:

```
ggplot(data = mpg) +
  geom_point(aes(x = displ, y = hwy),
    color = "darkblue",
    fill = "lightblue",
    shape = 21,
    size = 5,
    stroke = 1
  )
```

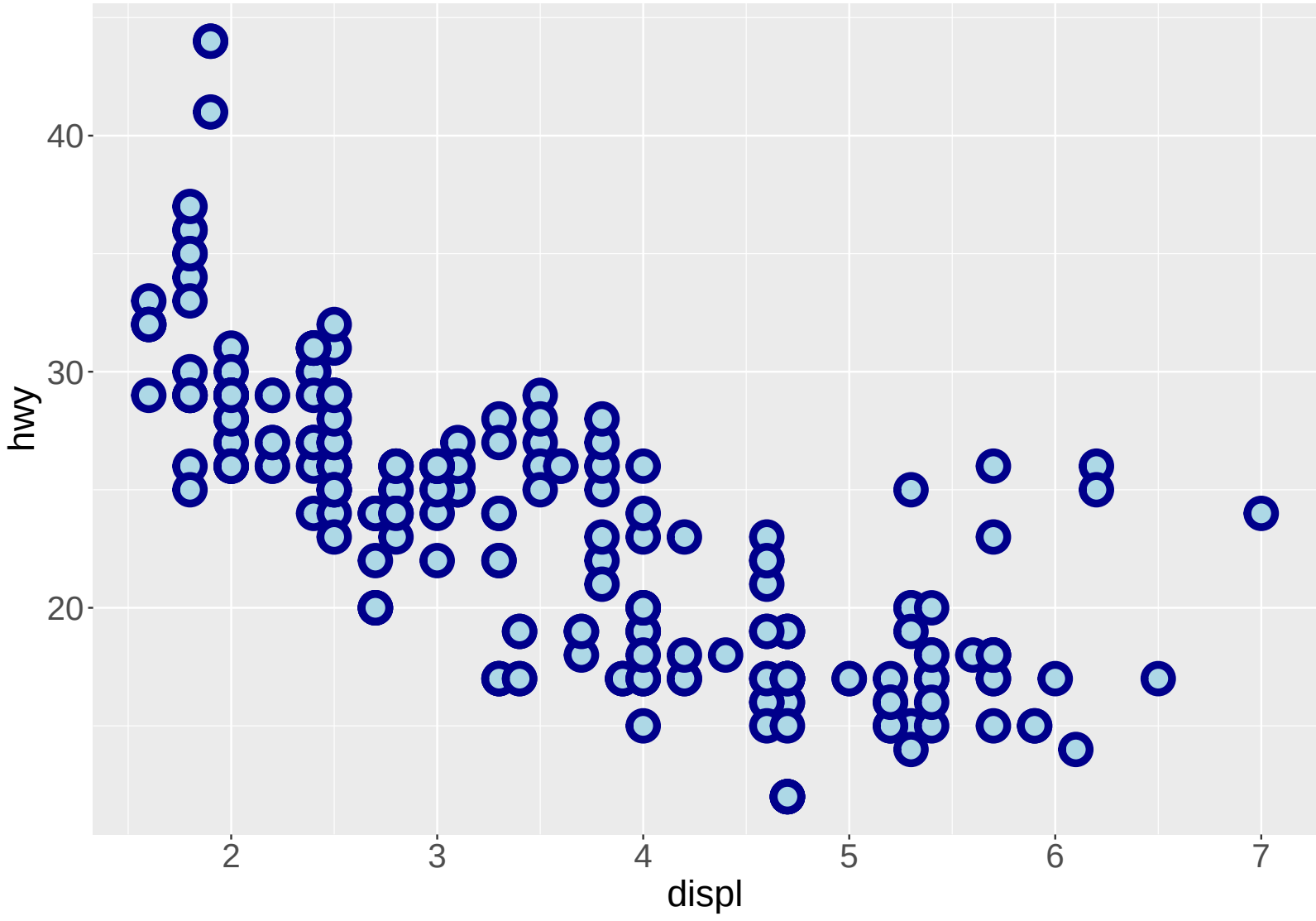
# Changing default aesthetic properties of geoms



# Changing default aesthetic properties of geoms

```
ggplot(data = mpg) +
  geom_point(aes(x = displ, y = hwy),
    color = "darkblue",
    fill = "lightblue",
    shape = 21,
    size = 5,
    stroke = 3
  )
```

# Changing default aesthetic properties of geoms



# Changing default aesthetic properties of geoms

- For a list of available colors and their names see: http://sape.inf.usi.ch/quick-reference/ggplot2/color

# Changing default aesthetic properties of geoms

- Alternatively, we can use RGB codes.
- The RGB model reproduces a broad array of colors by mixing together red, green, and blue in different proportions.
- We can specify colors like in HTML/CSS, using the hexadecimal values (00 to FF) for red, green, and blue, concatenated into a string, prefixed with a "#".
- A pure red color this is represented with "#FF0000".

See:

- https://www.rapidtables.com/web/color/RGB_Color.html
- https://htmlcolorcodes.com

# Changing default aesthetic properties of geoms

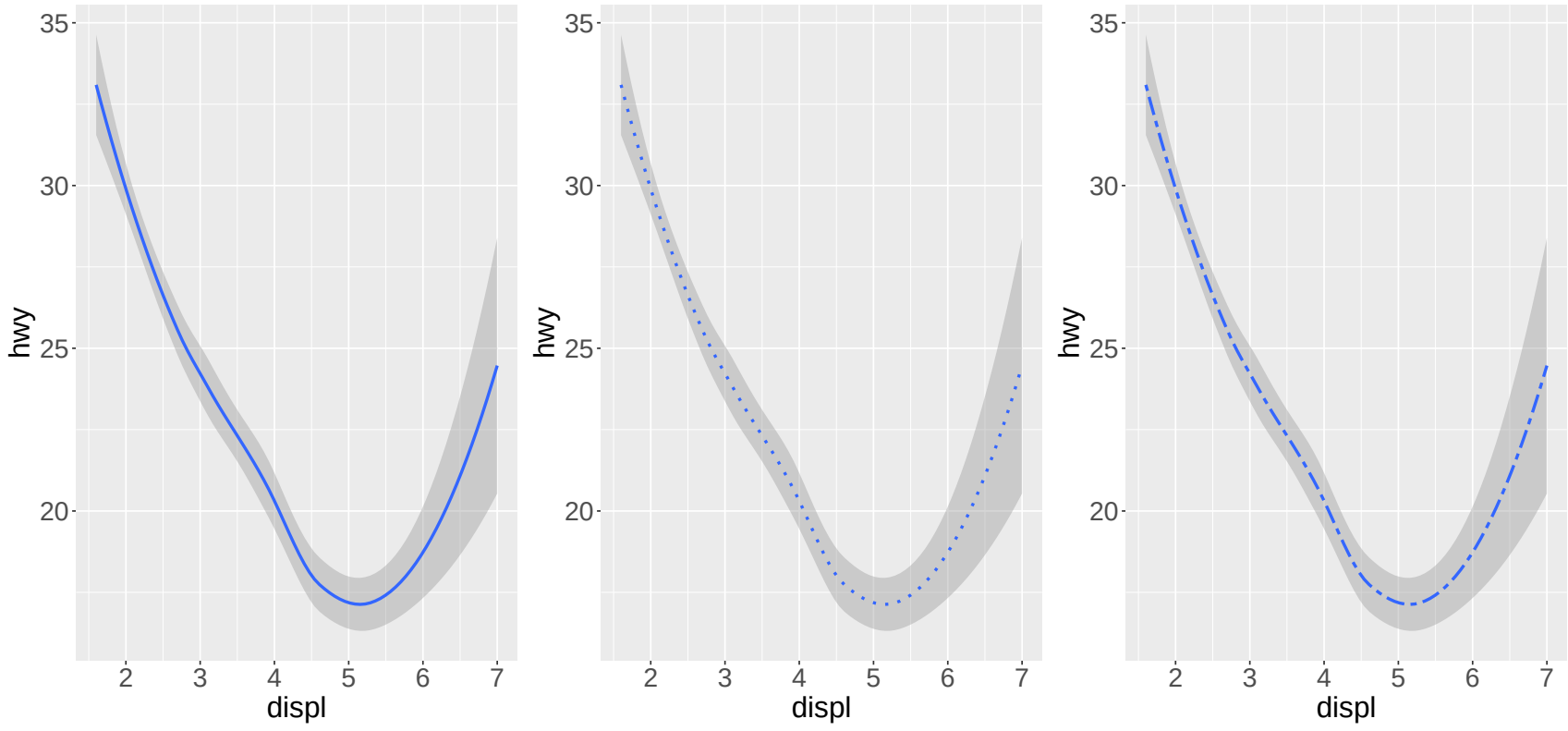
We can change the default line type of geom functions like `geom_smooth()`.

Figure 4: Built in line types

# Changing default aesthetic properties of geoms

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

ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy),
    linetype = "dotted")

ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy),
    linetype = "twodash")
```

# Changing default aesthetic properties of geoms

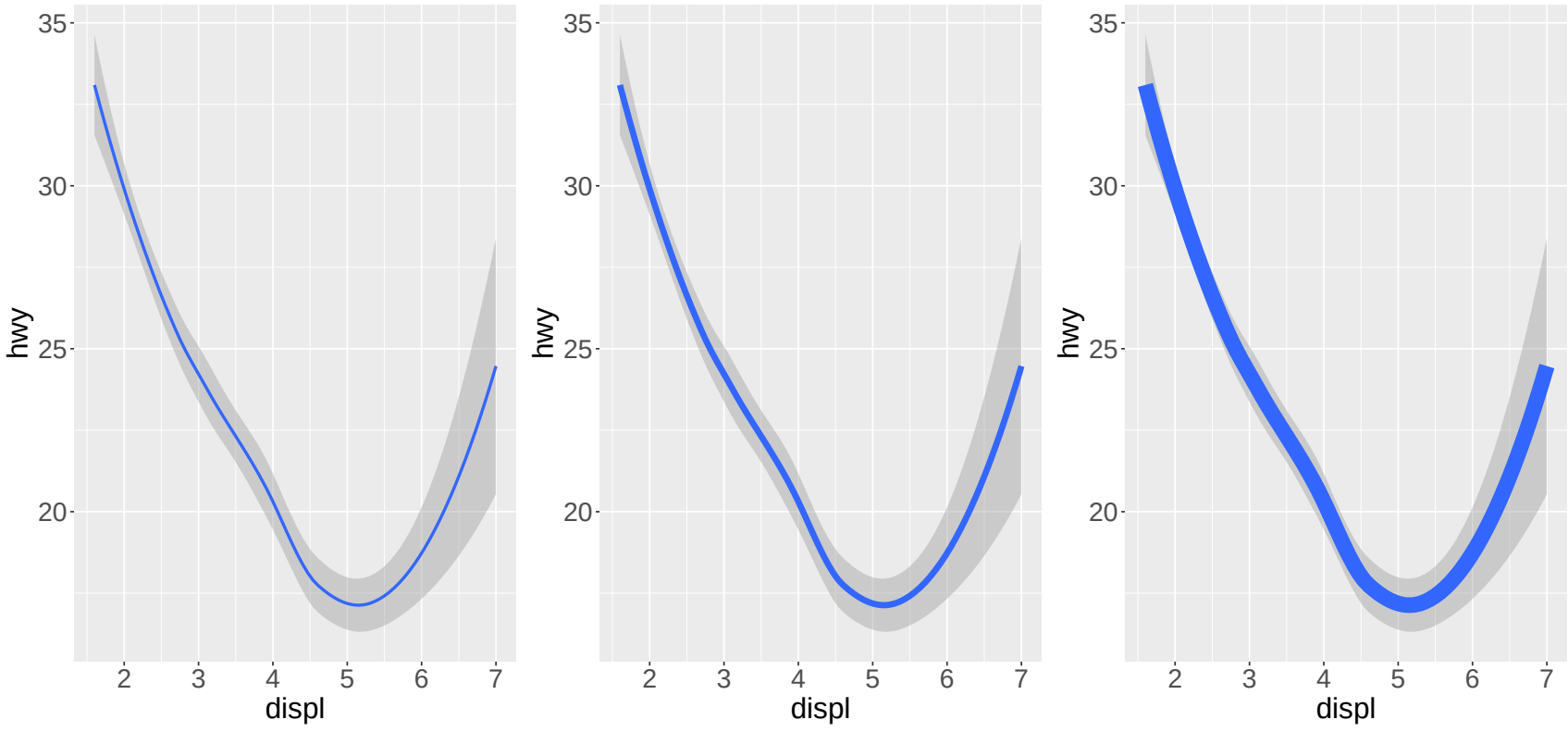


# Changing default aesthetic properties of geoms

We can also change the thickness of the lines:

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

ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy), size = 2)

ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy), size = 5)
```

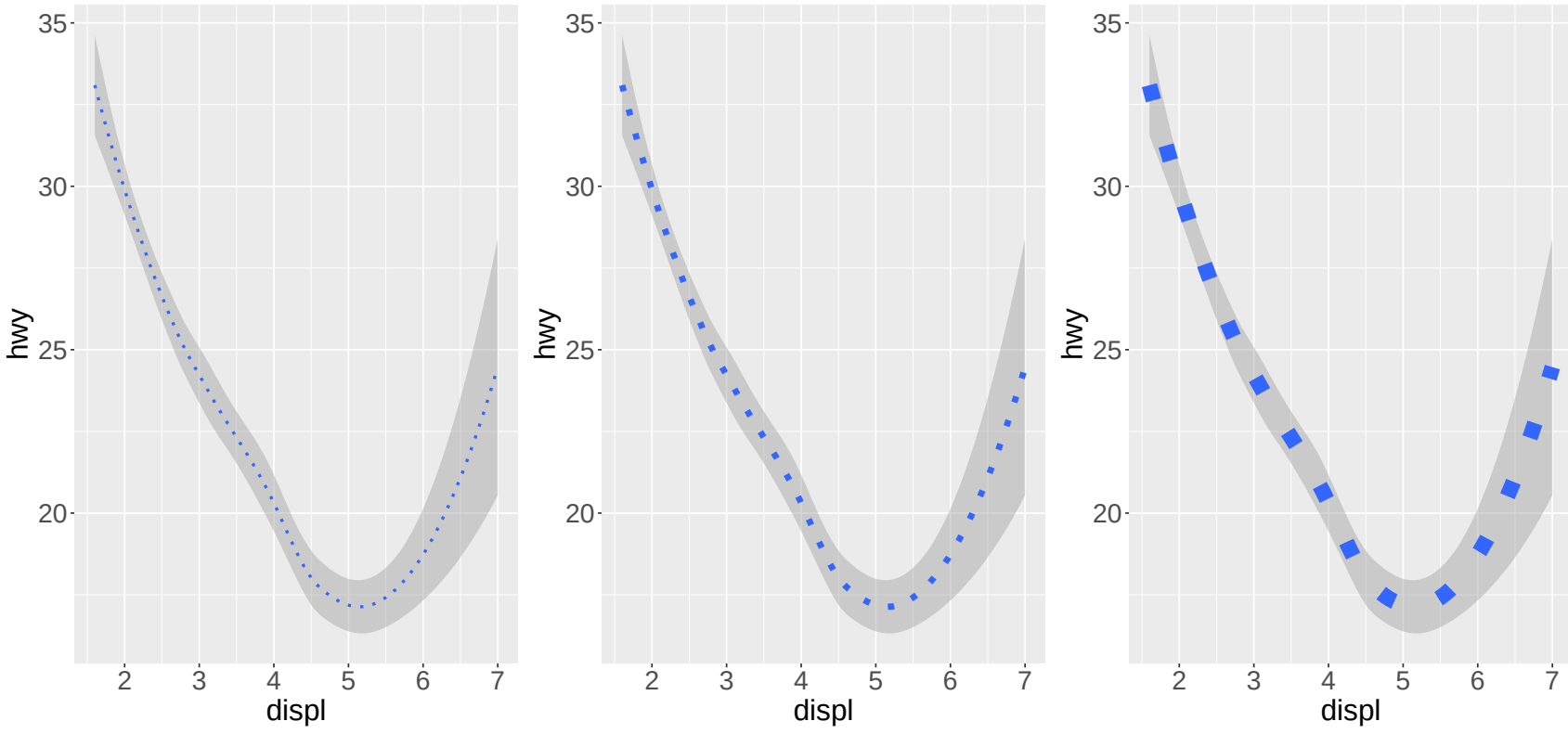
# Changing default aesthetic properties of geoms



# Changing default aesthetic properties of geoms

```
ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy),
              linetype = "dotted")

ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy),
              linetype = "dotted", size = 2)

ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy),
              linetype = "dotted", size = 5)
```

# Changing default aesthetic properties of geoms

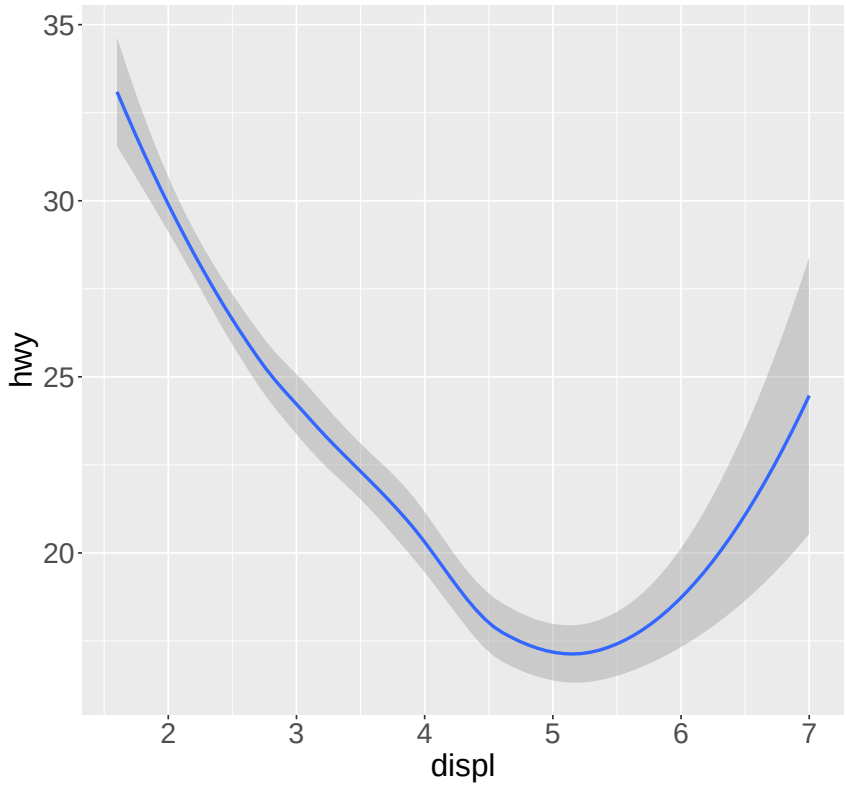


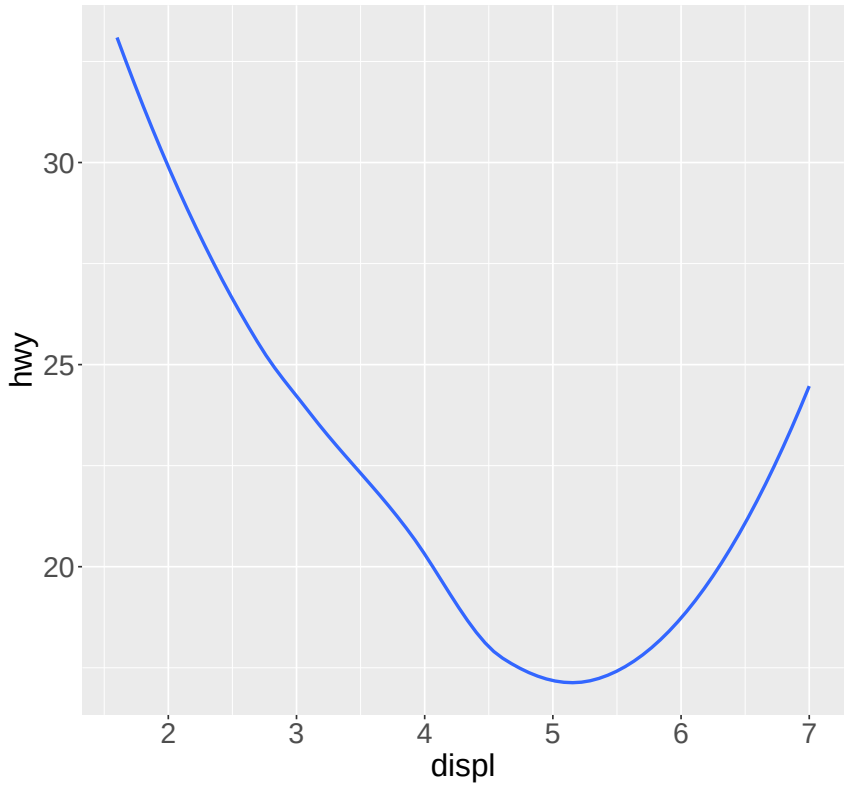
# Changing default aesthetic properties of geoms

- By default, `geom_smooth()` displays confidence intervals around the smoothed line.
- Confidence intervals may be disabled by setting the `se` (standard error) aesthetic to `FALSE`:

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

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

# Changing default aesthetic properties of geoms

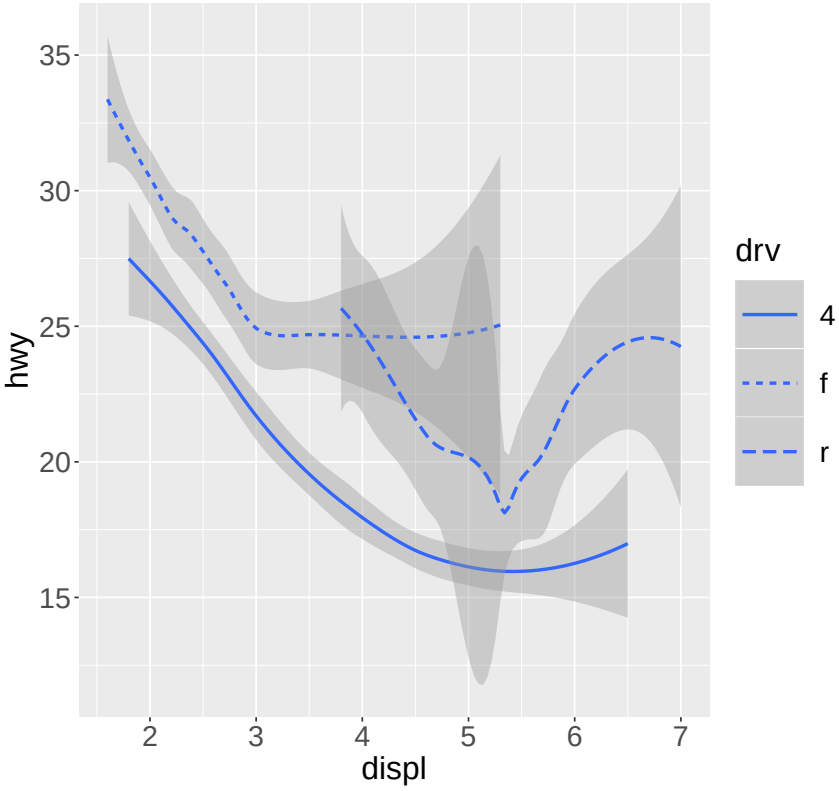


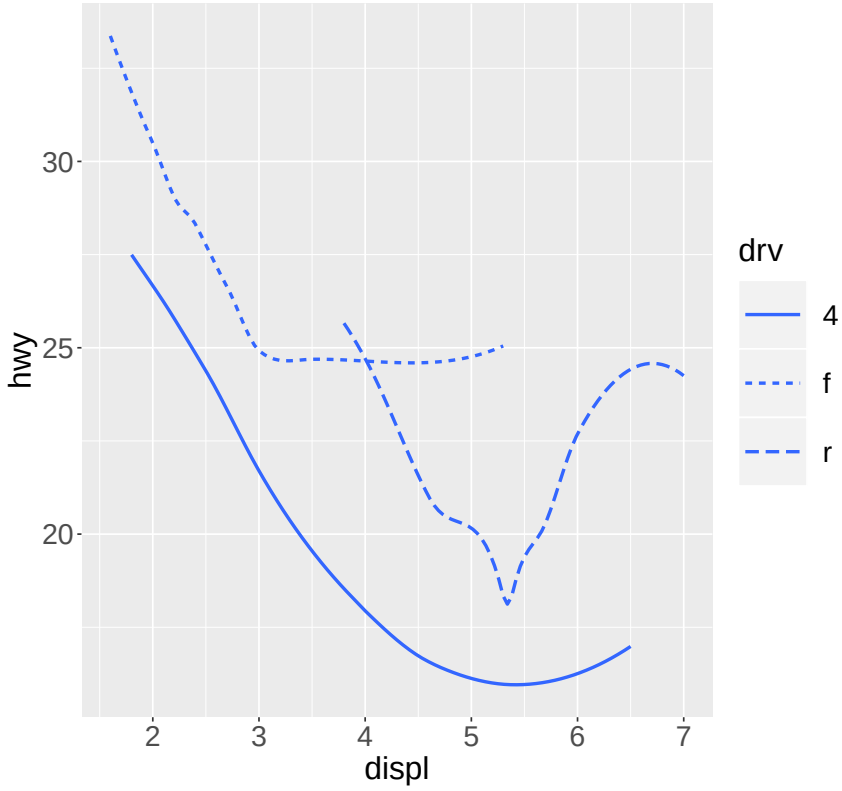



# Changing default aesthetic properties of geoms

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

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

# Changing default aesthetic properties of geoms

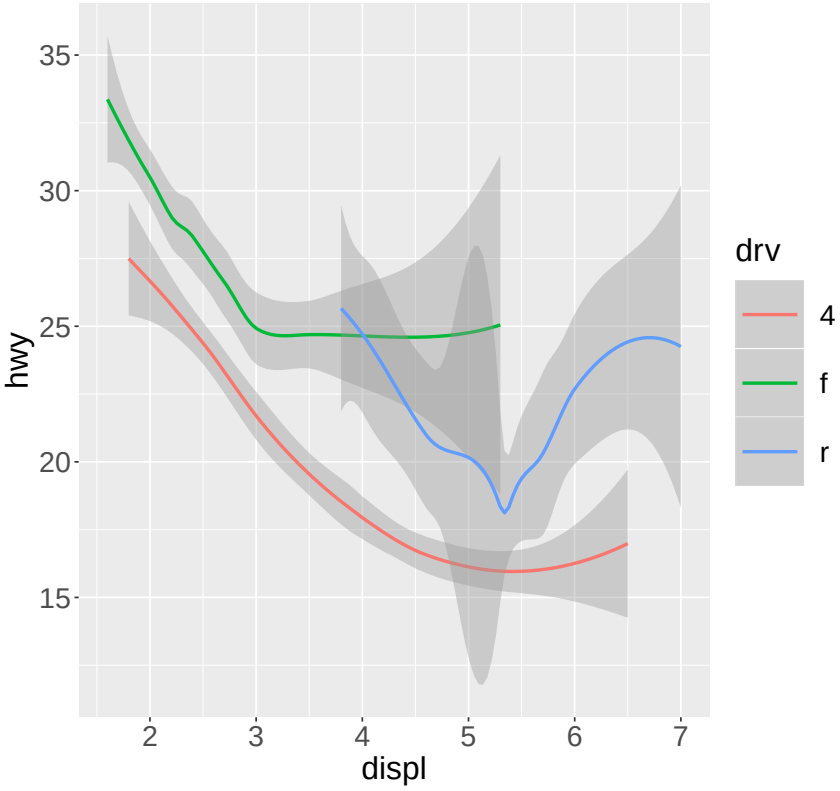


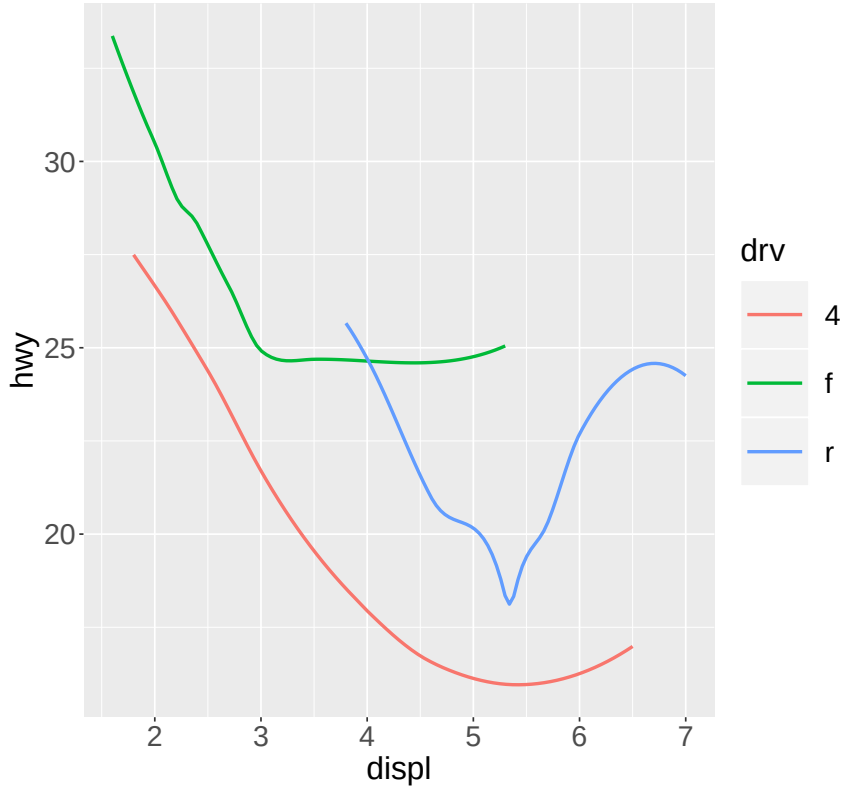



# Changing default aesthetic properties of geoms

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

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

# Changing default aesthetic properties of geoms



# Changing default aesthetic properties of geoms

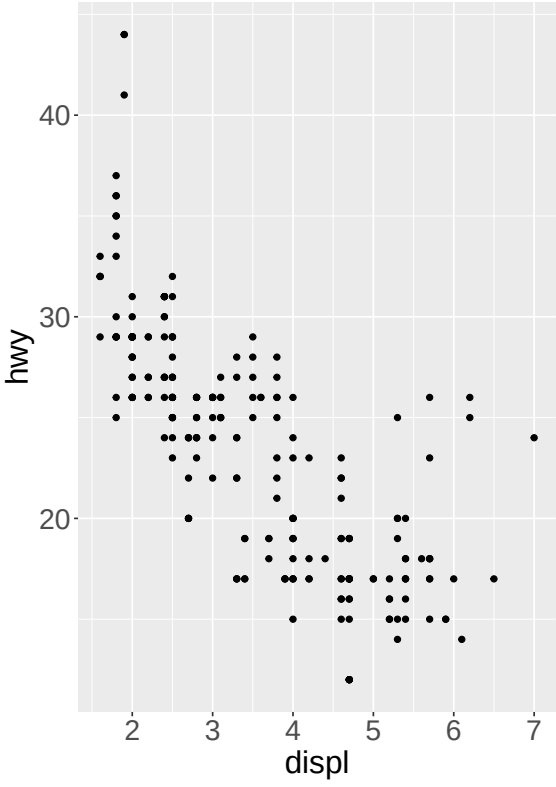
- The default smoothing method of `geom_smooth` can be changed.
- The default method (`"auto"`) depends on the size of the largest group.
- For less than 1000 observations the method is `"loess"` (a local polynomial regression).
- Admissible methods are: `"auto"`, `"lm"`, `"glm"`, `"gam"` and `"loess"`.

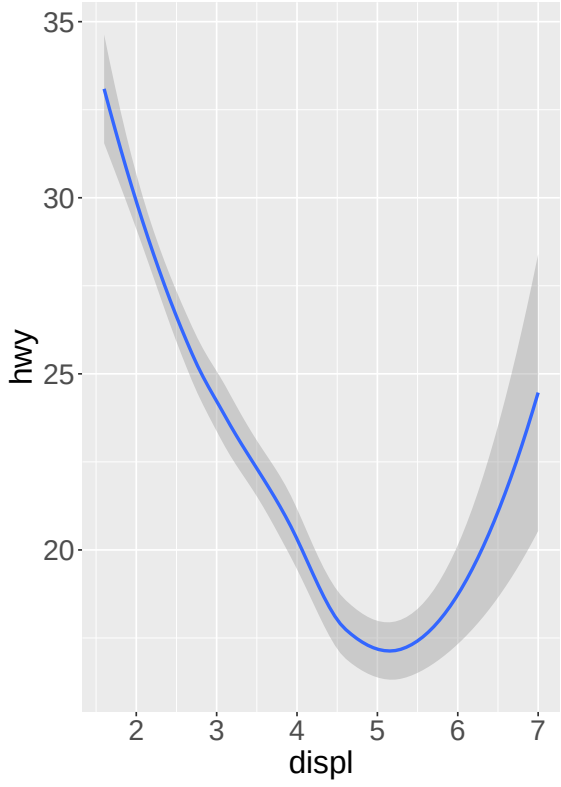
# Changing default aesthetic properties of geoms

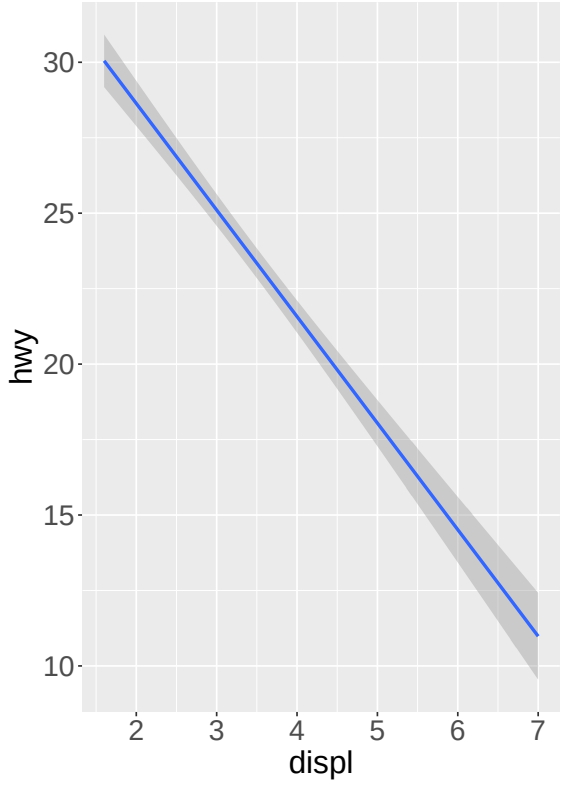
To add a linear regression line use `method = "lm"`:

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

ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = hwy))

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

# Changing default aesthetic properties of geoms



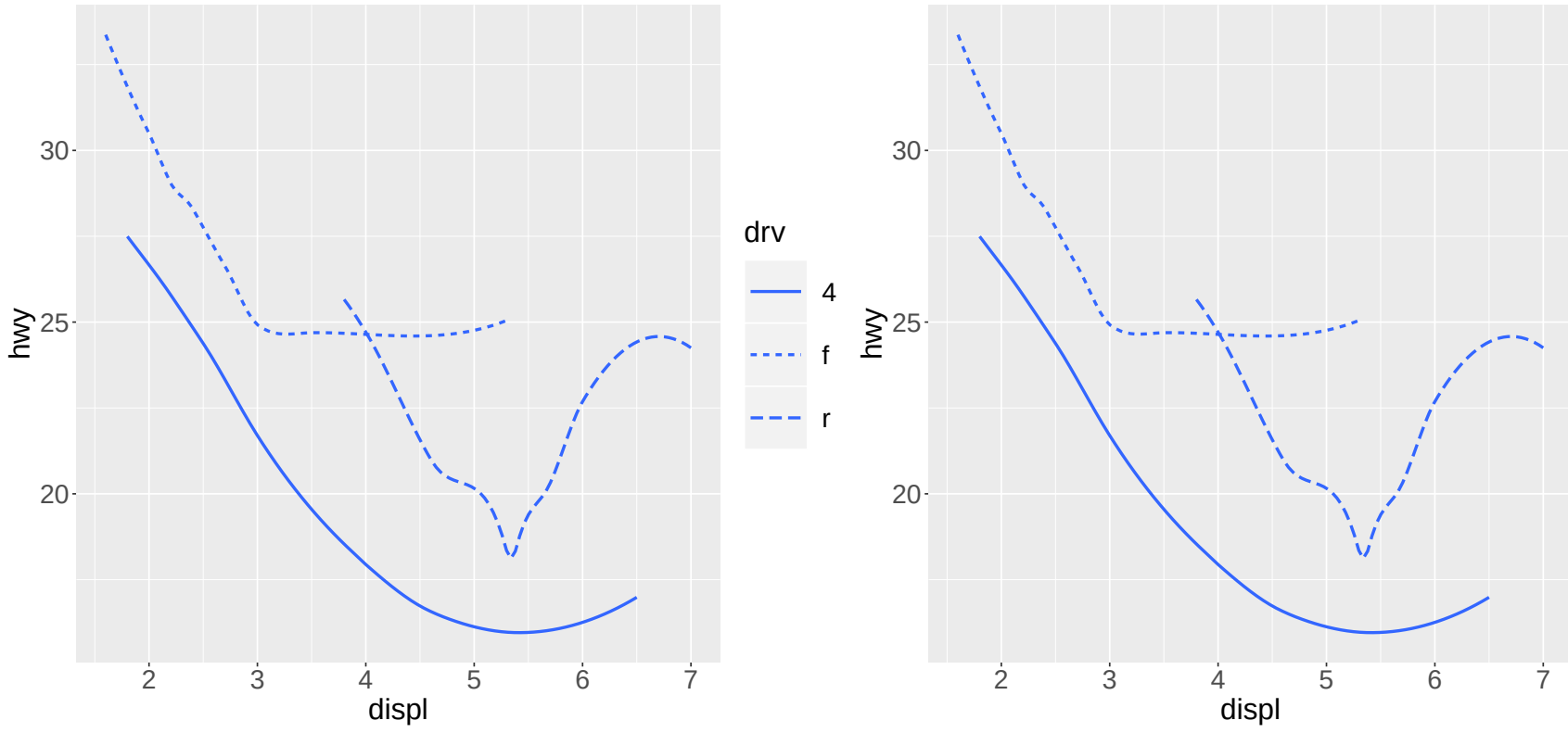



# Changing default aesthetic properties of geoms

Legends can also be disabled:

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

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

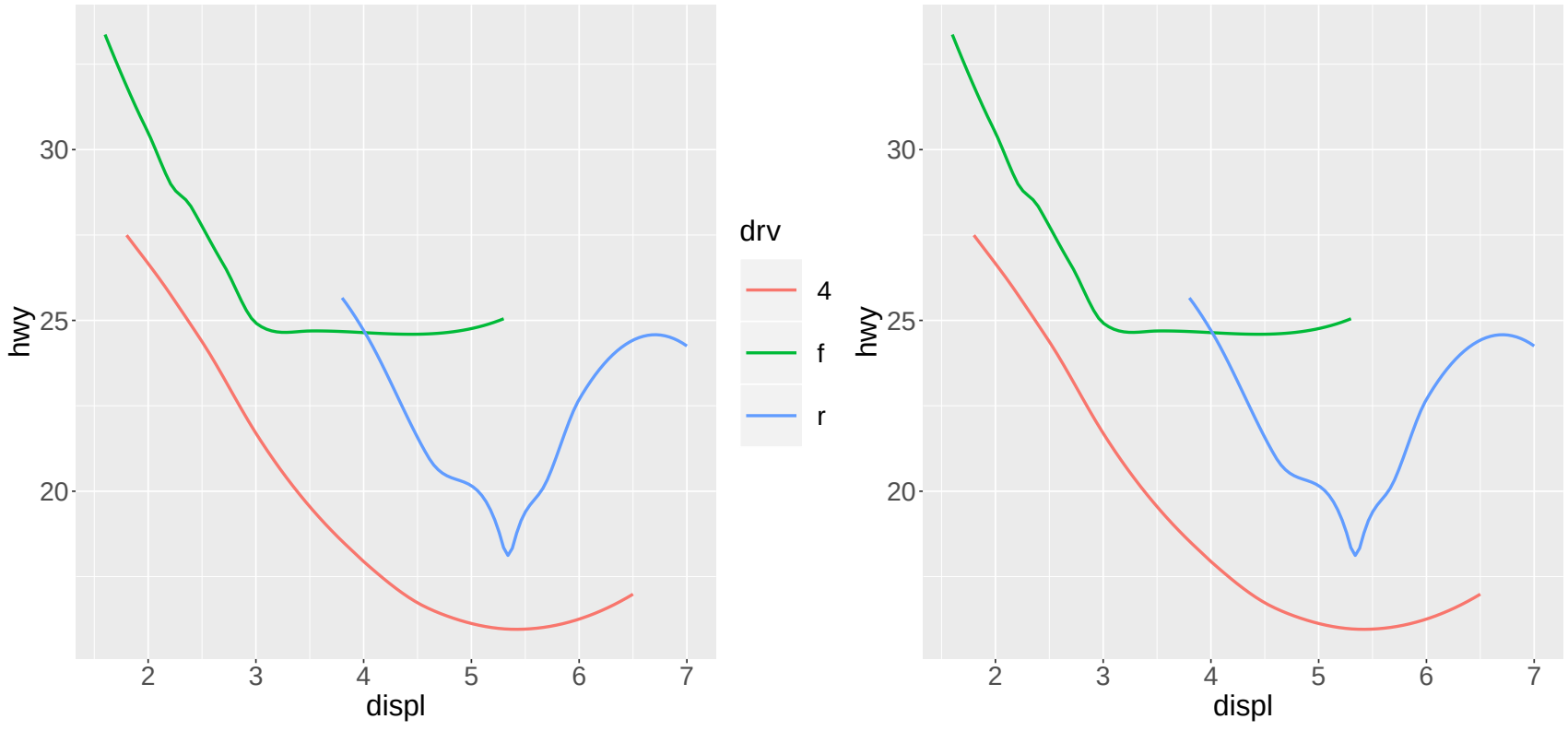
# Changing default aesthetic properties of geoms



# Changing default aesthetic properties of geoms

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

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

# Changing default aesthetic properties of geoms



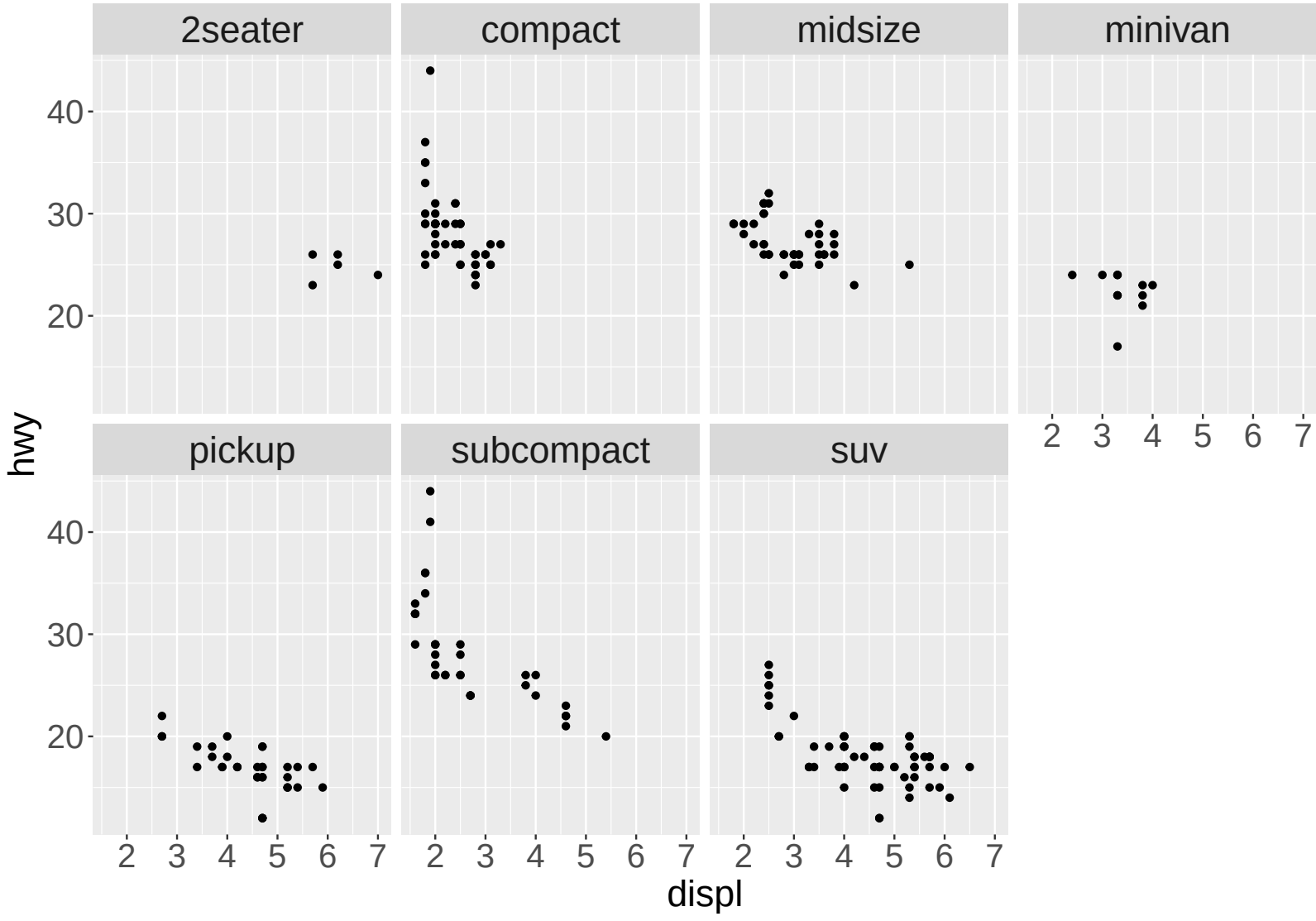
# Facets

- One way to add additional variables to a plot is with **aesthetics**.
- Another way, particularly useful for categorical variables, is to split the plot into **facets**, subplots that each display one subset of the data.
- To facet a plot by a single variable, use `facet_wrap()`.
- The first argument of `facet_wrap()` should be `"~"` followed the name of a variable.

# Facets

```
ggplot(data = mpg) +
  geom_point(aes(x = displ, y = hwy)) +
  facet_wrap(~ class, nrow = 2)
```

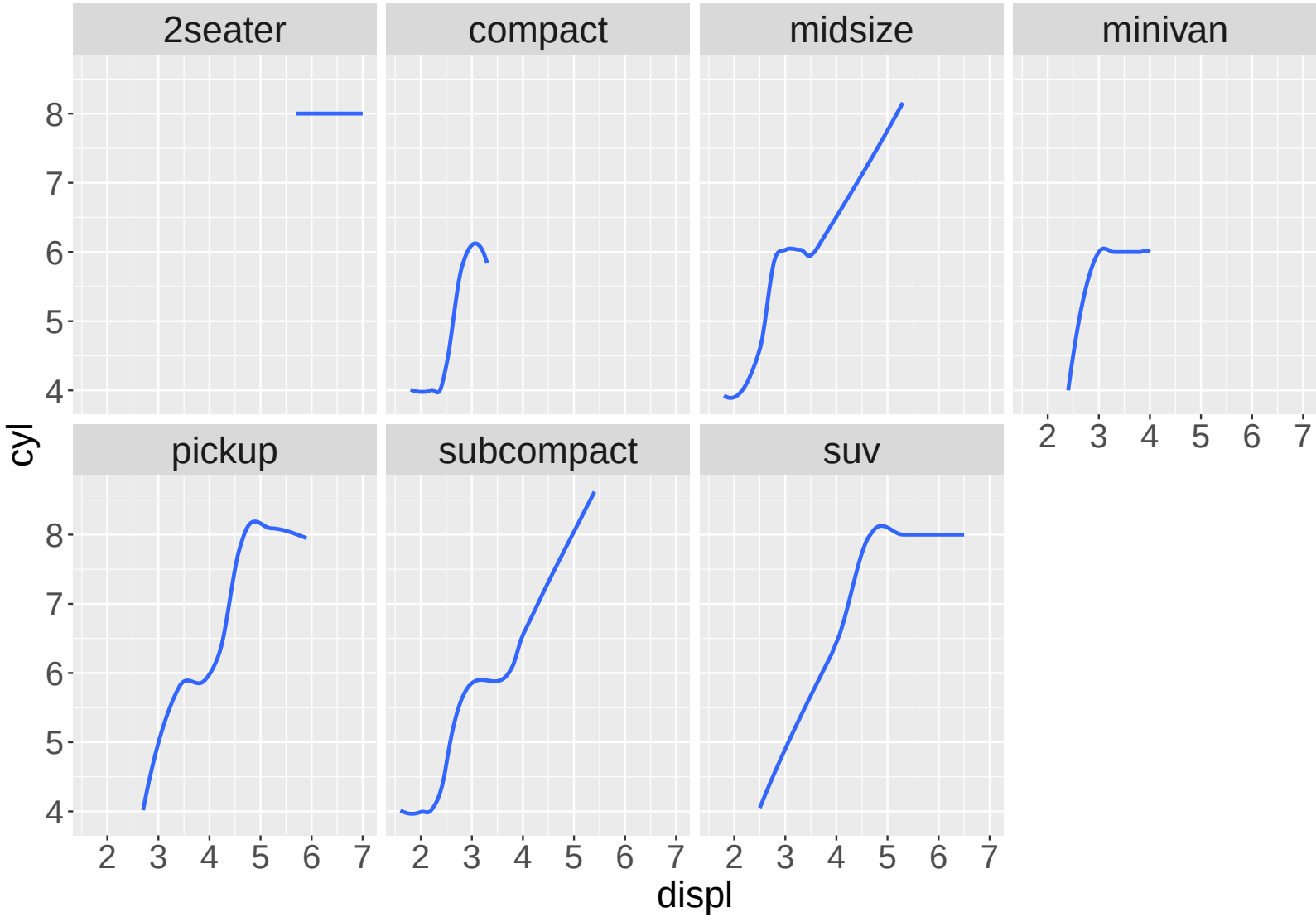
# Facets


2seater
compact
midsize
minivan
pickup
subcompact
suv
hwy
displ
40
30
20
2
3
4
5
6
7

# Facets

```
ggplot(data = mpg) +
  geom_smooth(aes(x = displ, y = cyl), se = FALSE) +
  facet_wrap(~class, nrow = 2)
```

# Facets

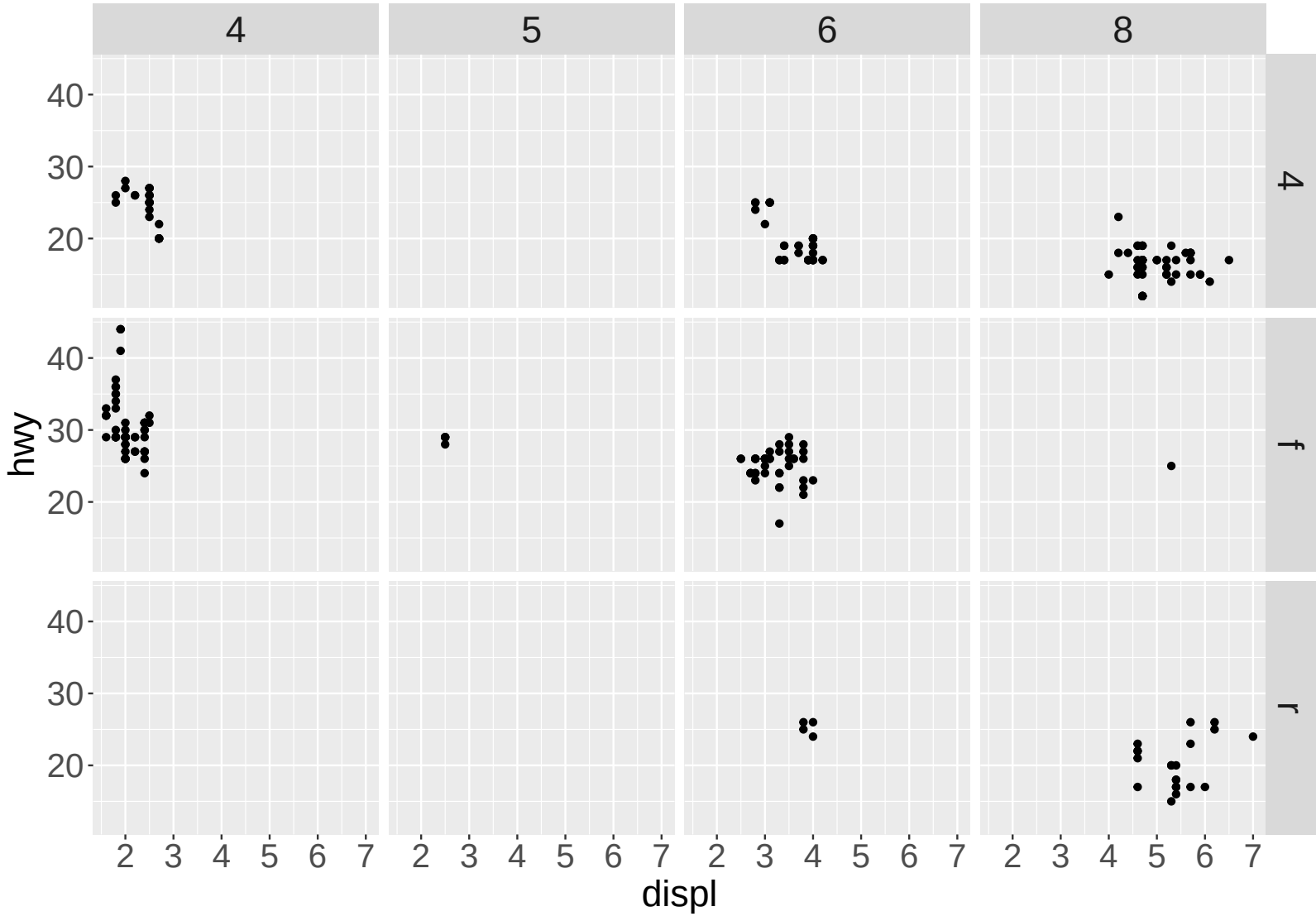

2seater
compact
midsize
minivan
pickup
subcompact
suv
cyl
displ
4
5
6
7
8
2
3
4
5
6
7

# Facets

- To facet a plot on the combination of two variables, use `facet_grid()`.
- The first argument of `facet_grid()` should contain the two variable names separated by `"~"`.

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

# Facets

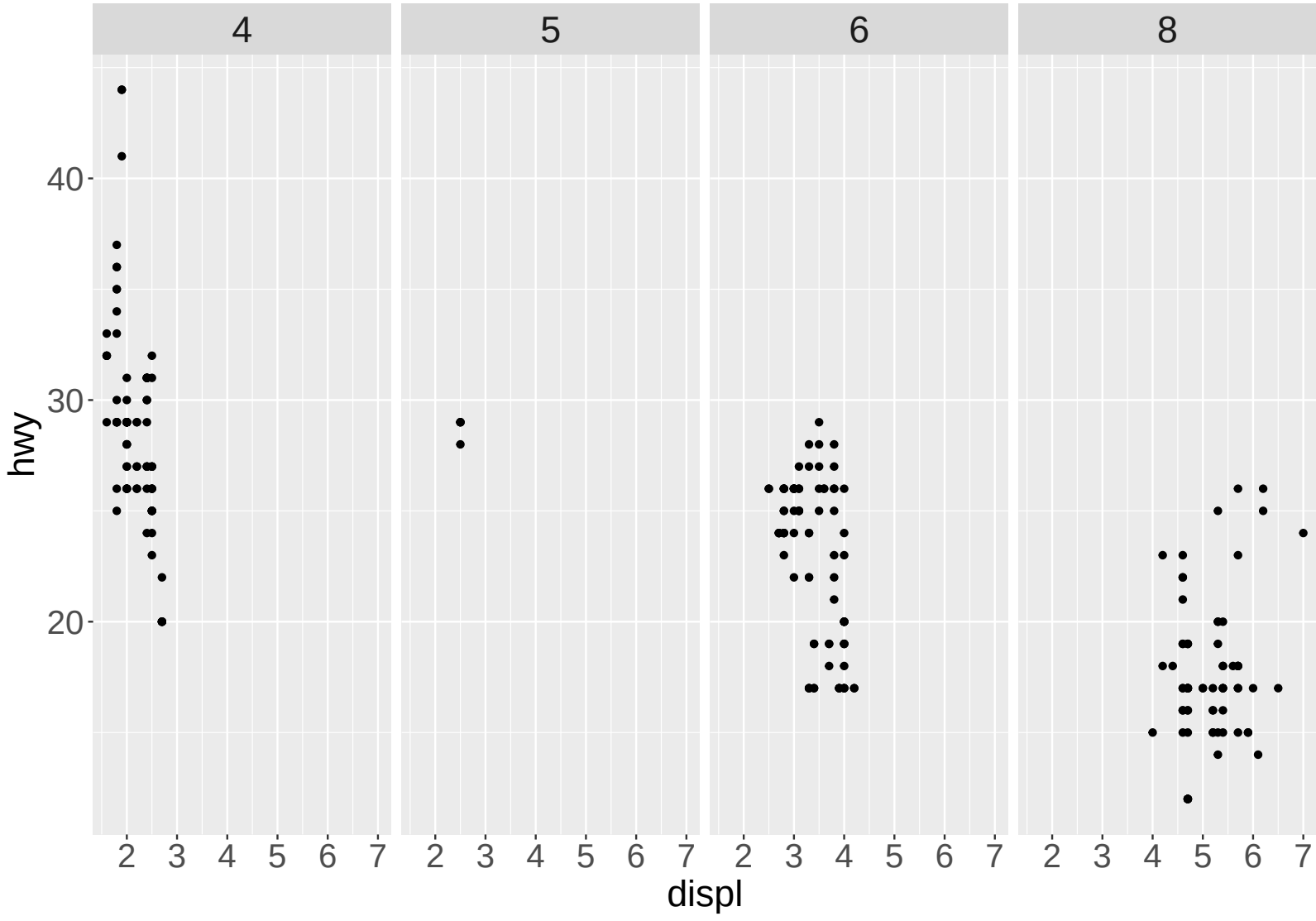


# Facets

If we prefer to not facet in the rows (or columns), we can use a "." instead of a variable name:

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

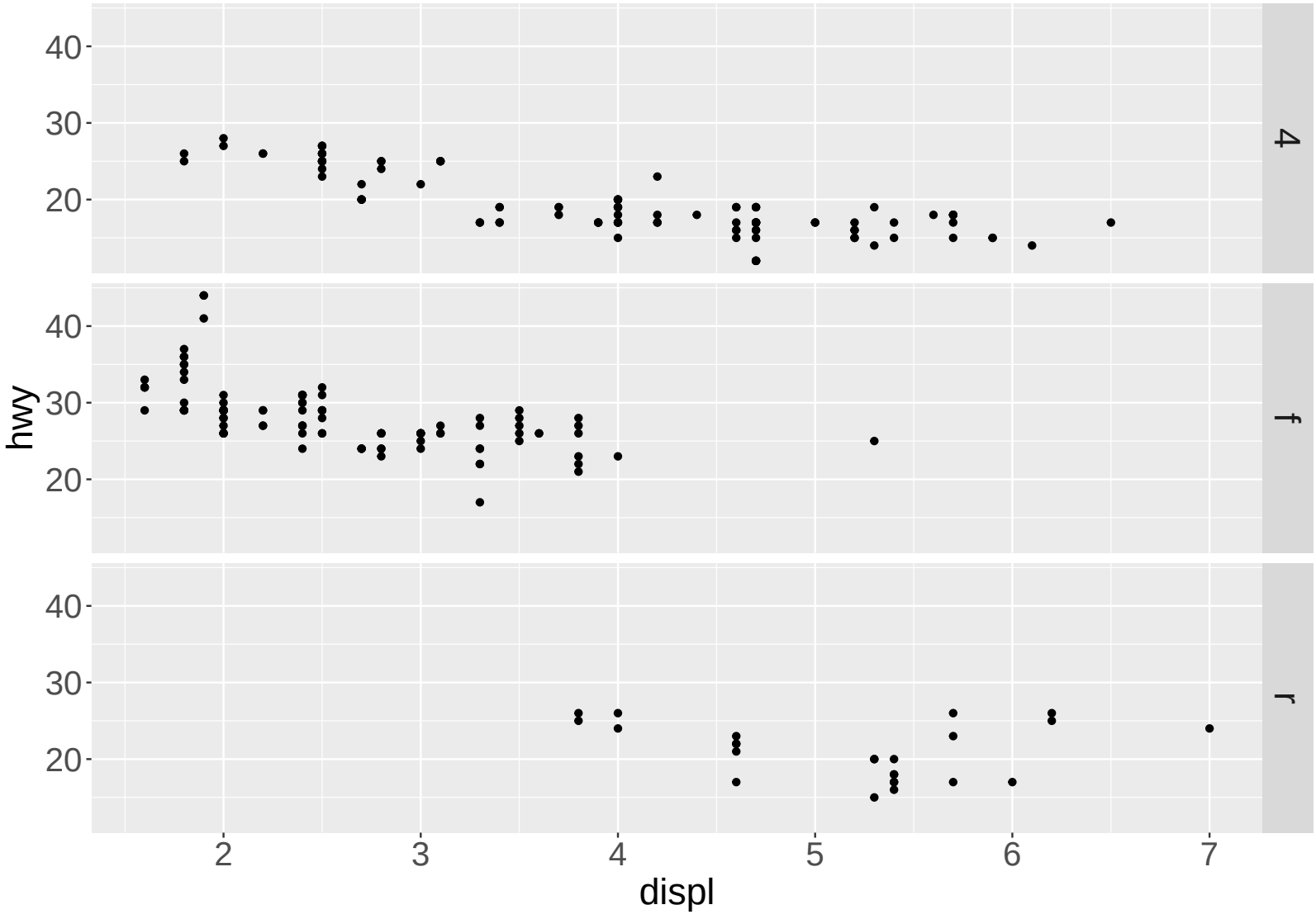
# Facets



# Facets

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

# Facets

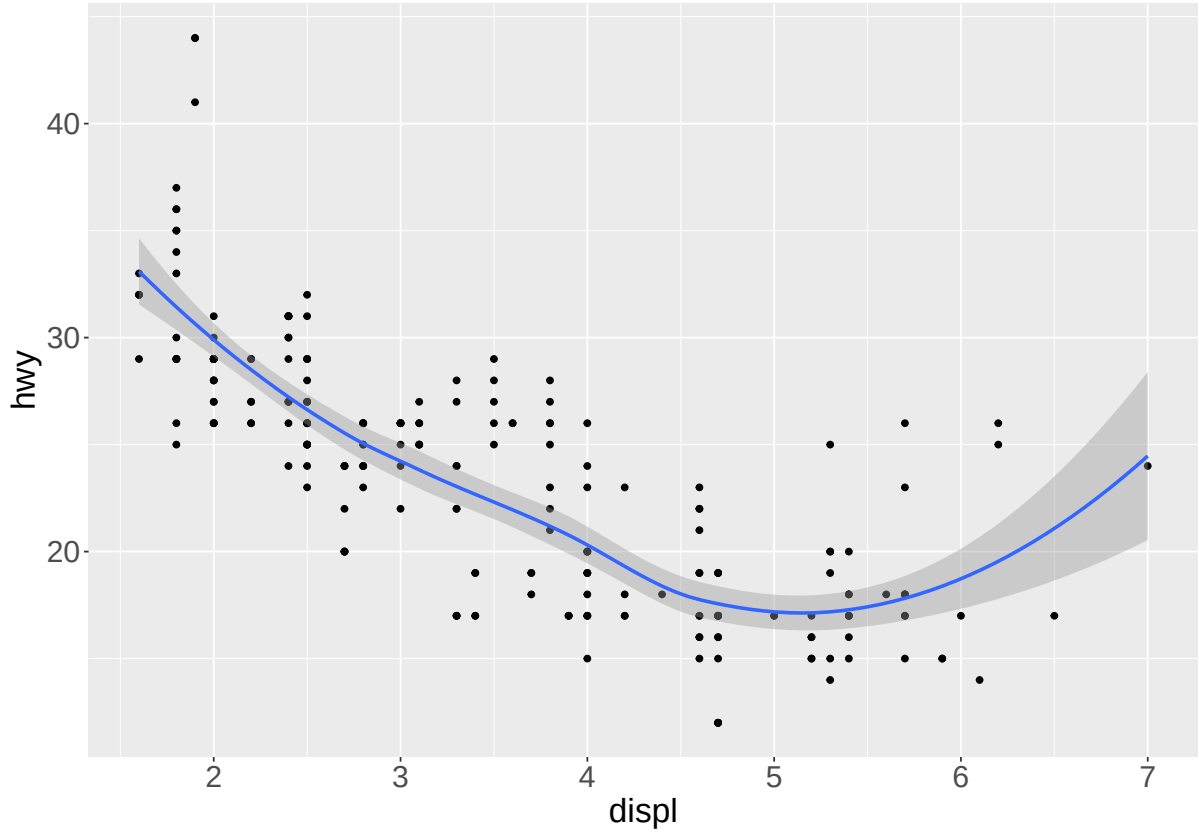


# Multiple geoms

- We can add multiple geoms to the same graph.
- For example, we can overlap points and lines.
- This is archived by adding multiple geom functions to `ggplot()`.

# Multiple geoms

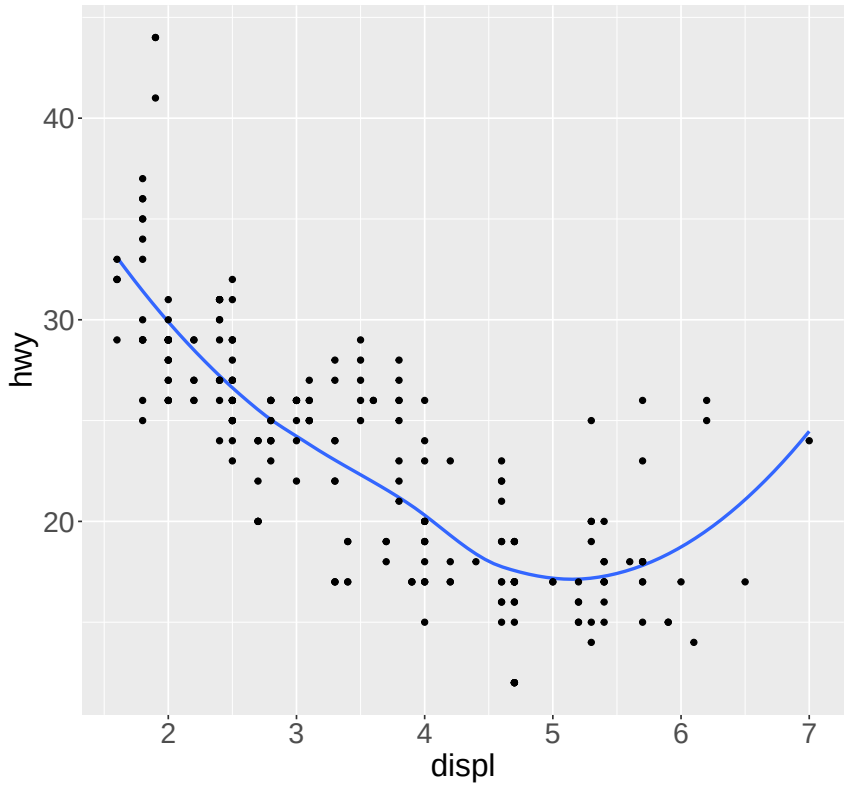
```
ggplot(data = mpg) +
  geom_point(aes(x = displ, y = hwy)) +
  geom_smooth(aes(x = displ, y = hwy))
```

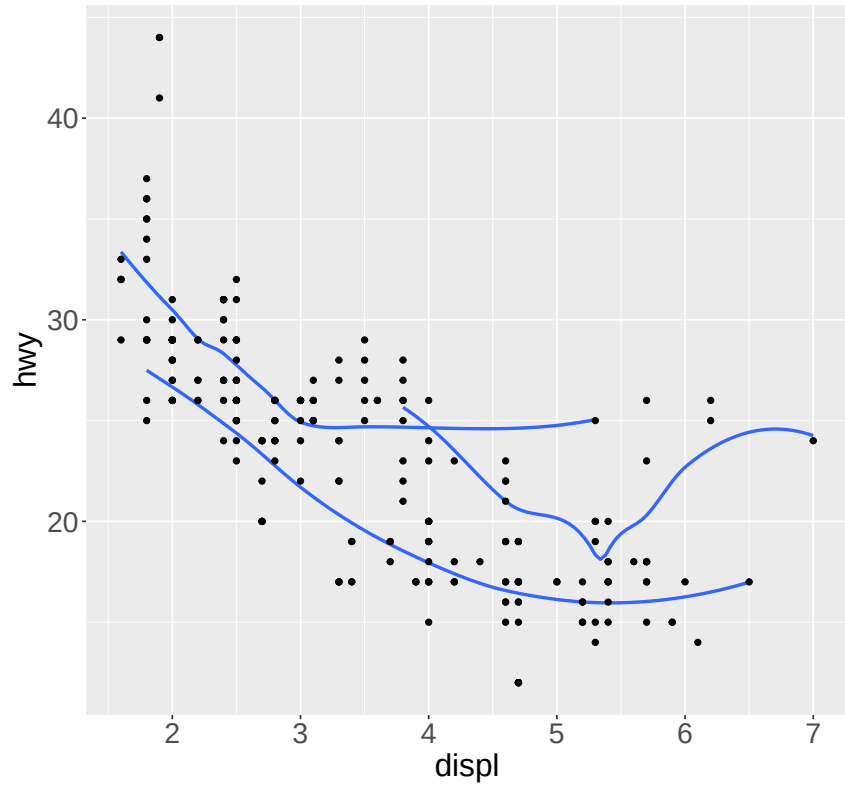


# Multiple geoms

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

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

# Multiple geoms



# Multiple geoms

- This, however, induces duplication in our code.
- We built the same aesthetic mapping twice in each graph.
- We can avoid this type of repetition by passing a set of mappings to `ggplot()`.
- ggplot2 will treat these mappings as global mappings that apply to each geom in the graph.

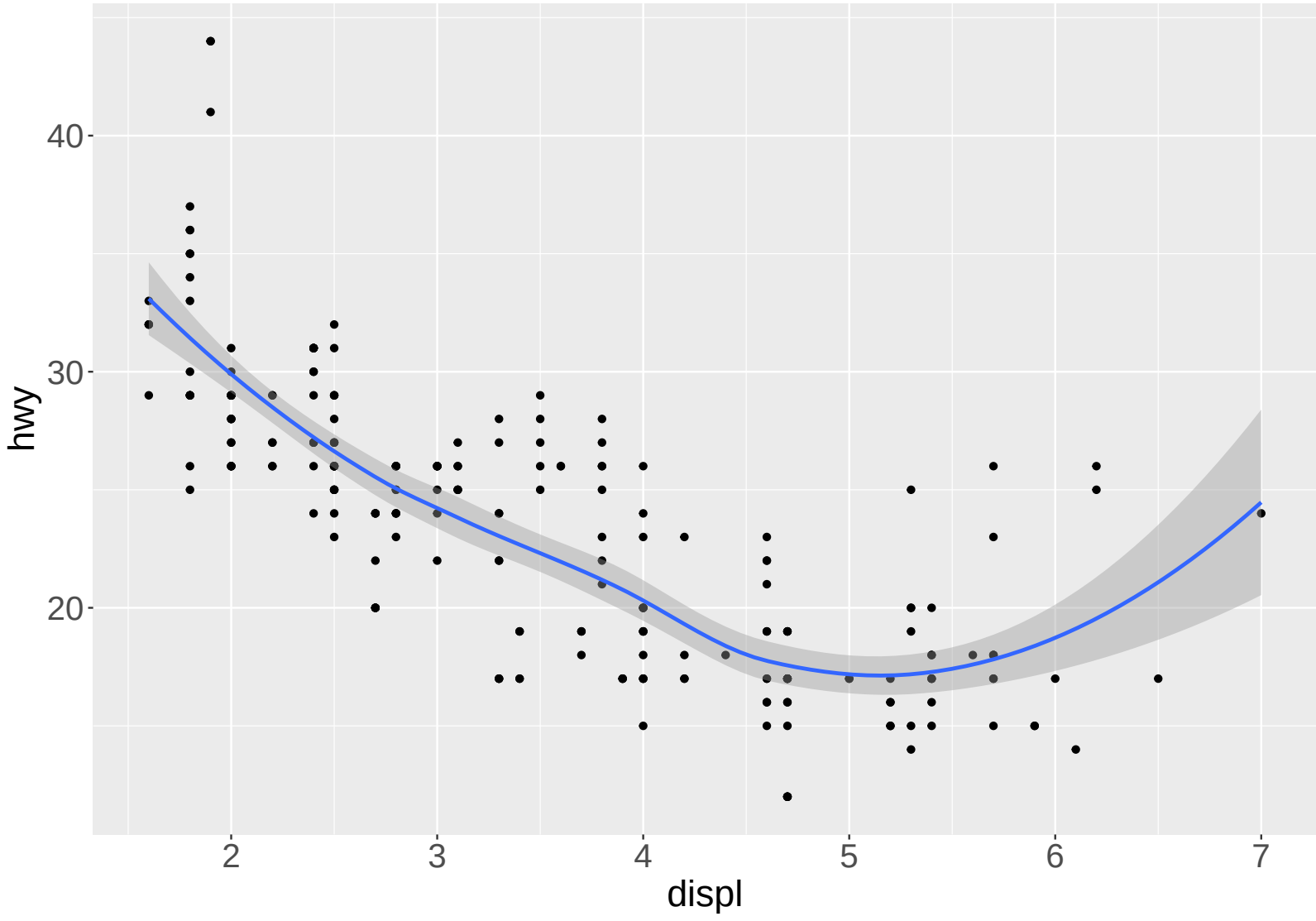
# Multiple geoms

These two chunks of code result in the same plot:

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

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

# Multiple geoms



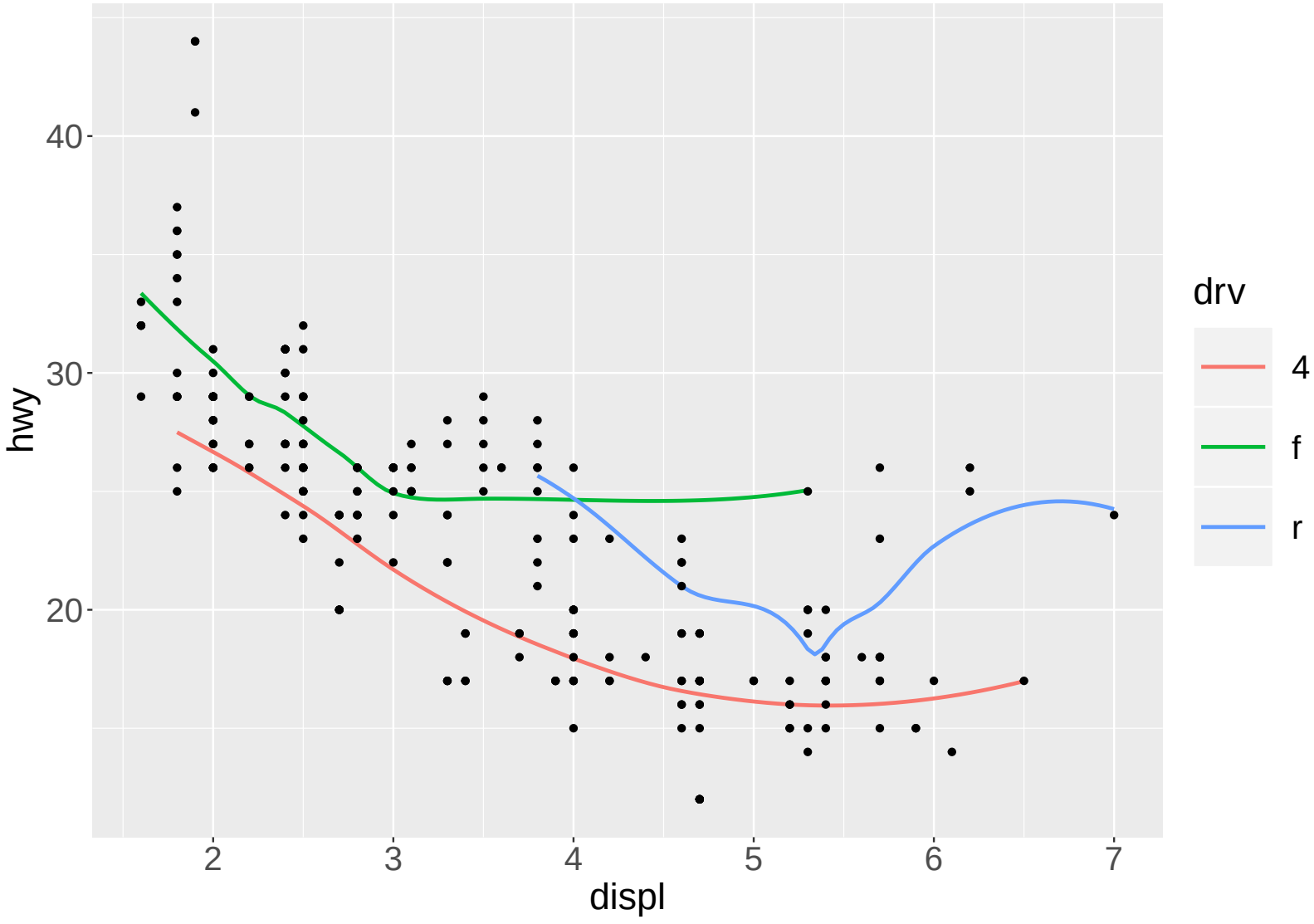
# Multiple geoms

- If we place mappings in a geom function, ggplot2 will treat them as local mappings for that layer.
- It will use these mappings to extend or overwrite the global mappings for that layer only.
- This makes it possible to display different aesthetics in different layers.

# Multiple geoms

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

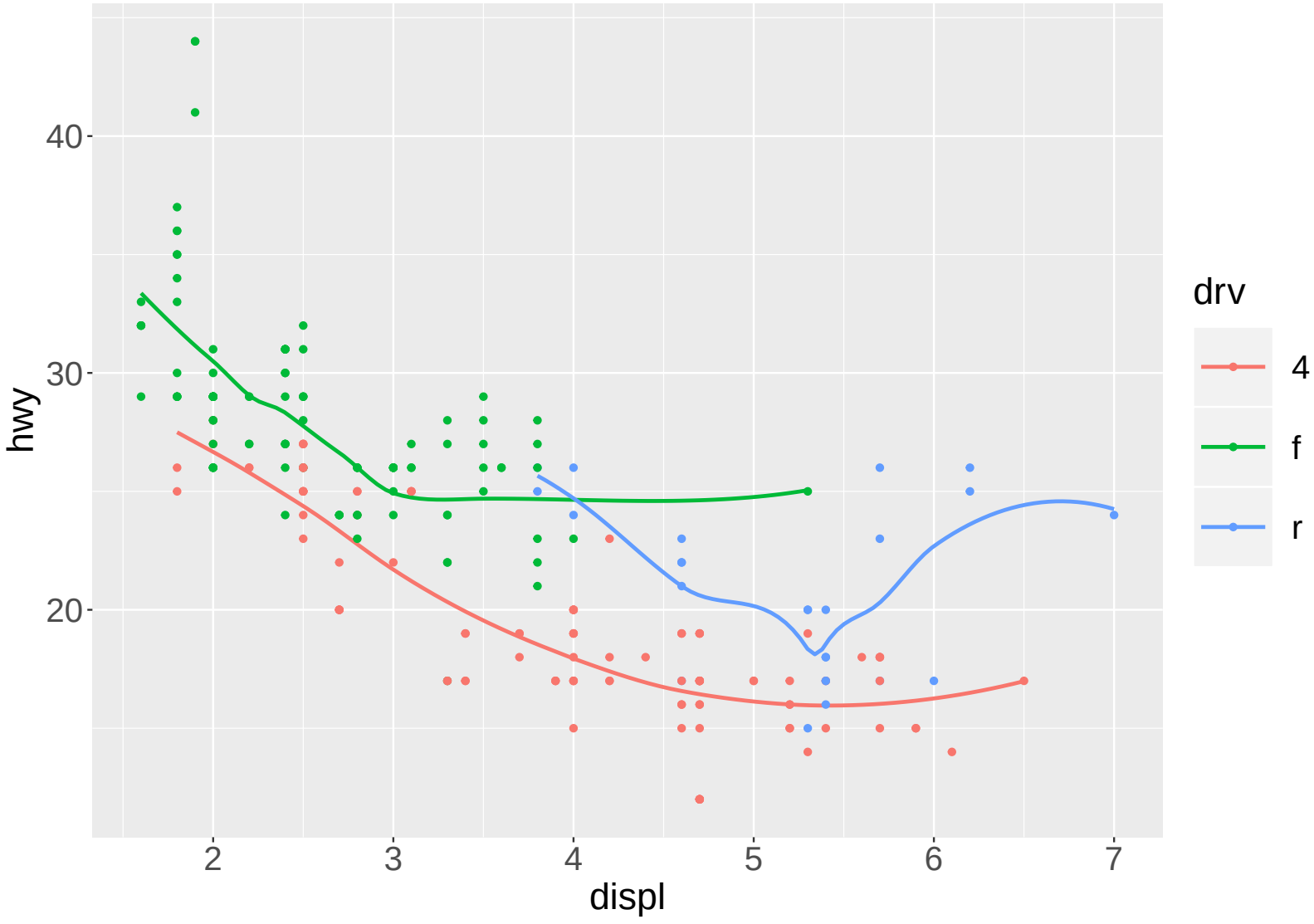
# Multiple geoms



# Multiple geoms

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

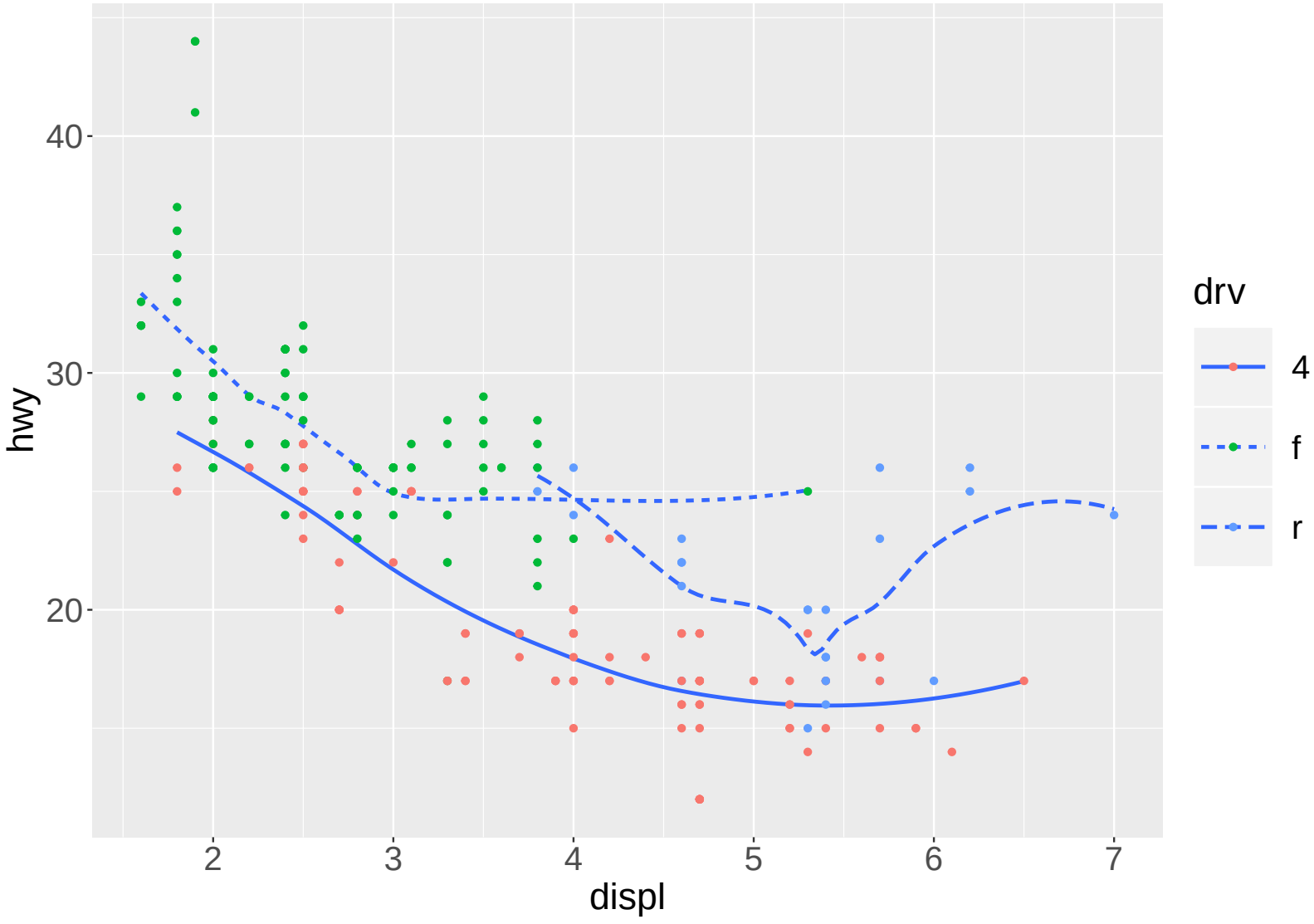
# Multiple geoms



# Multiple geoms

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

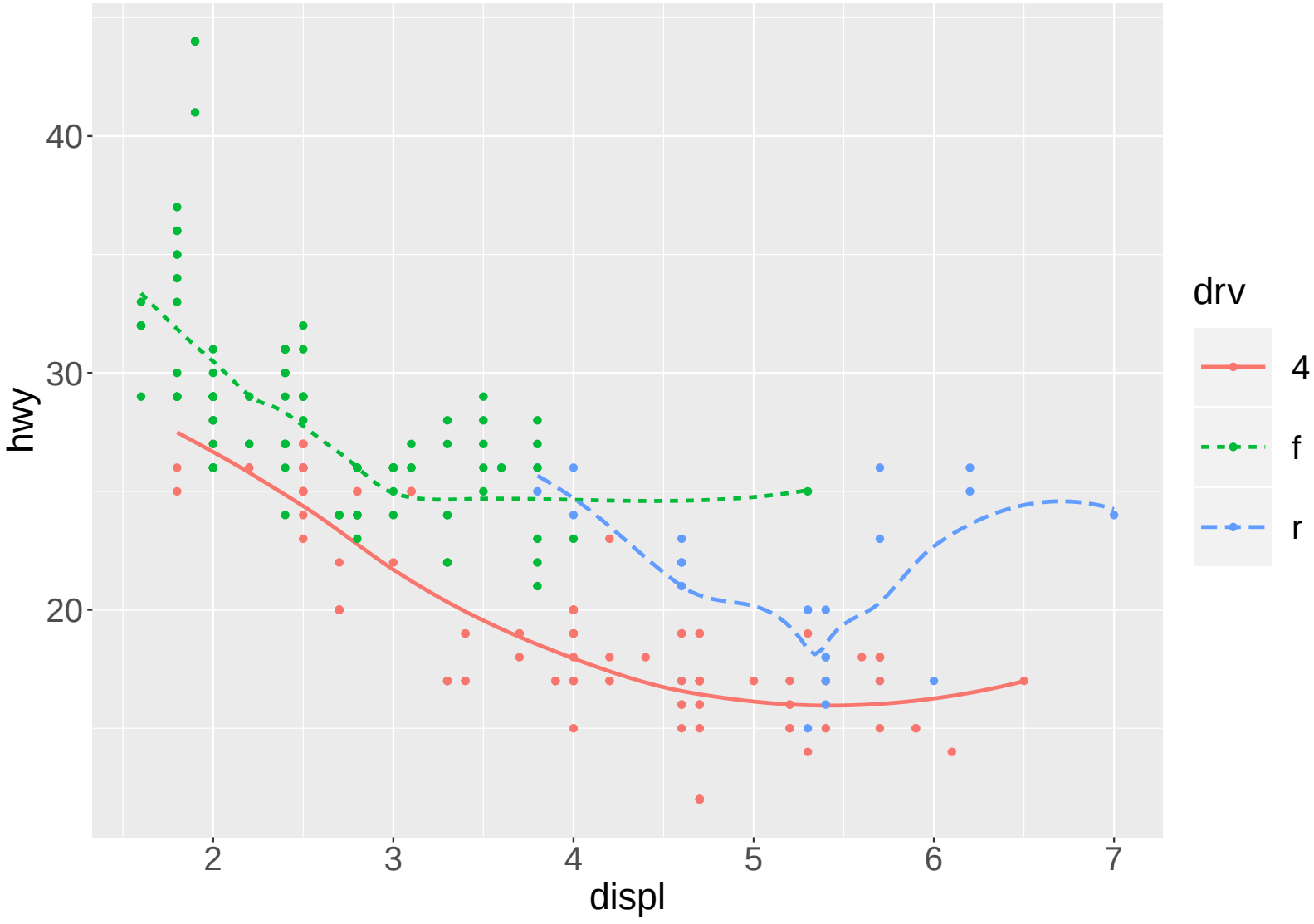
# Multiple geoms



# Multiple geoms

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

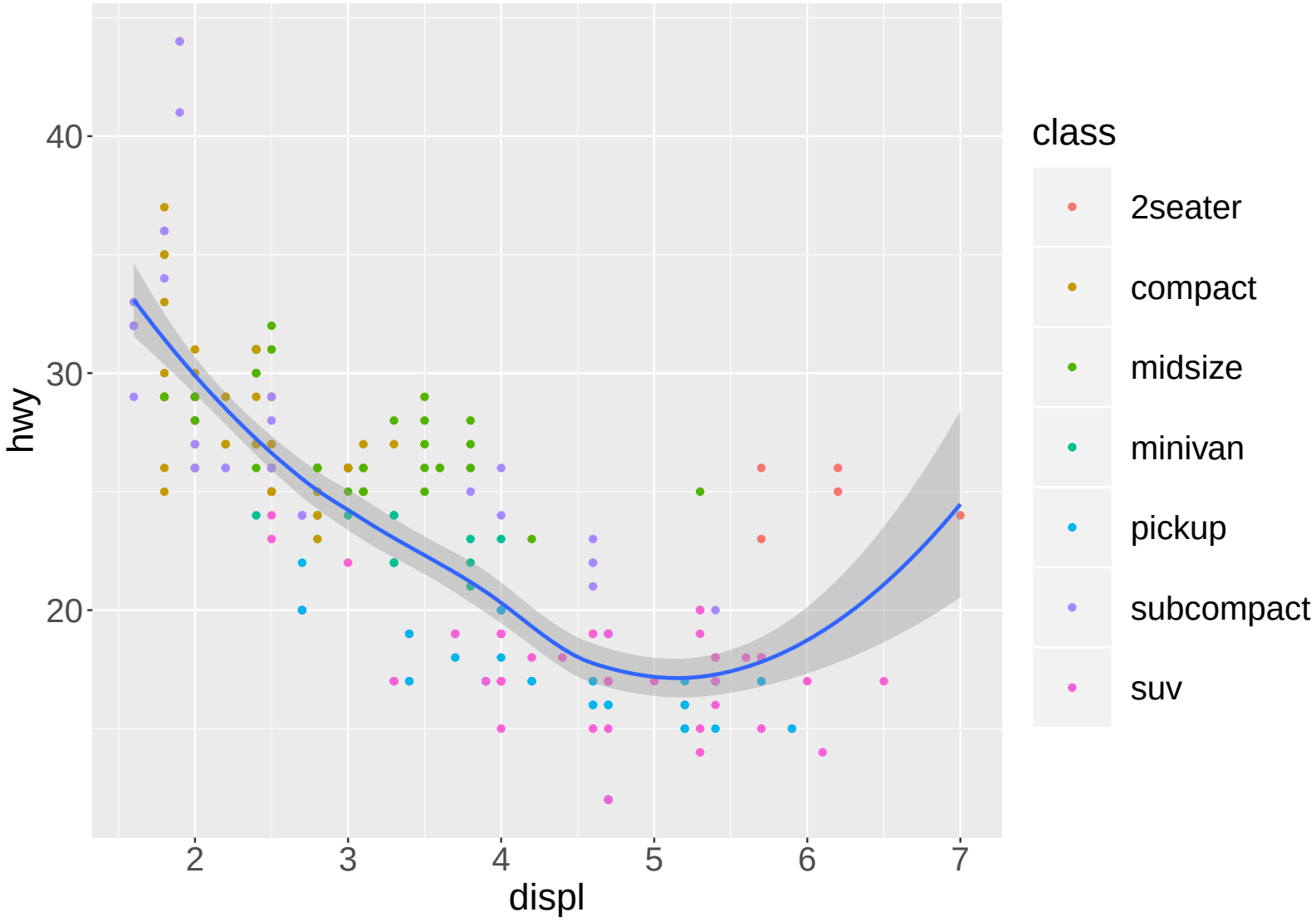
# Multiple geoms



# Multiple geoms

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

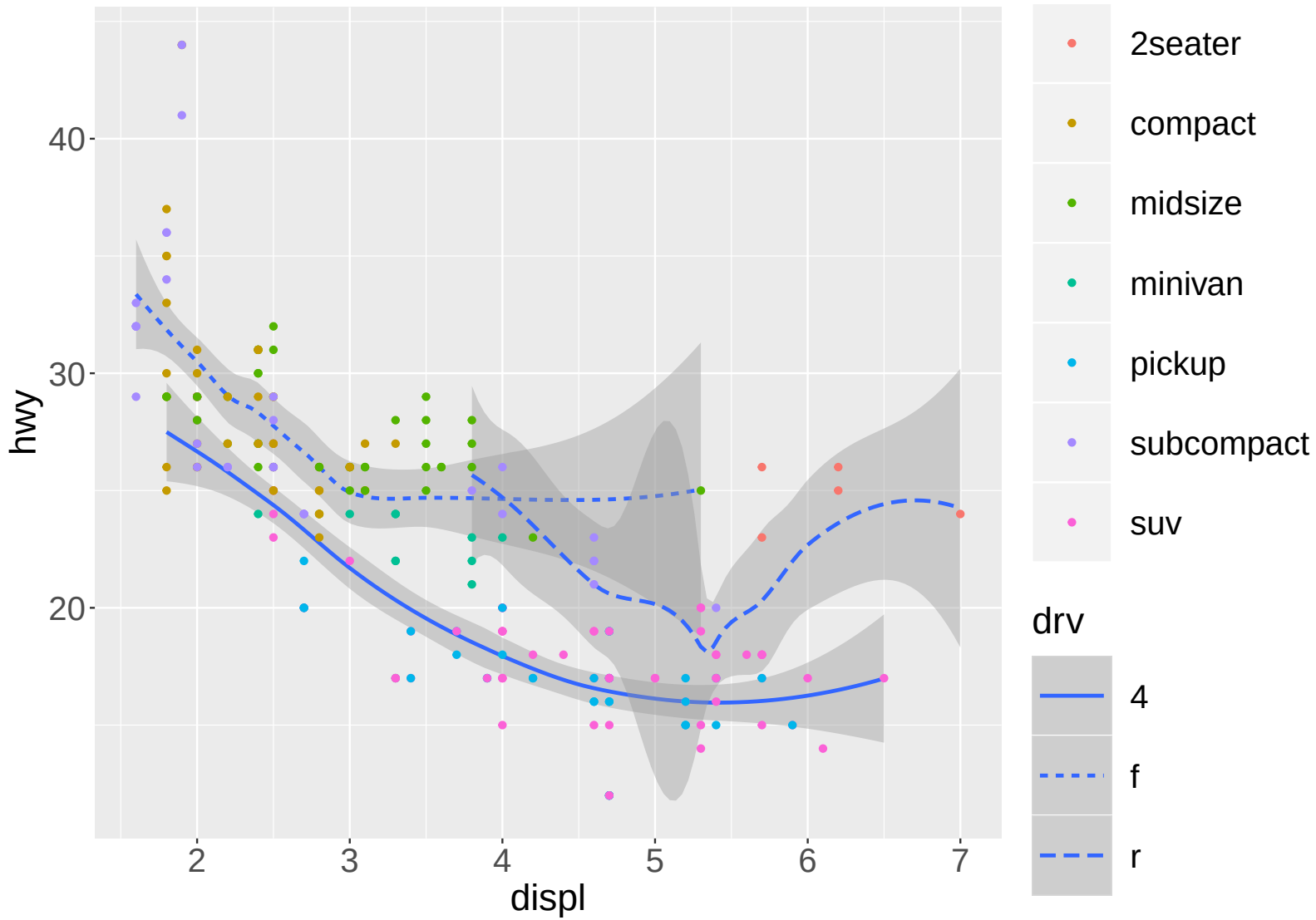
# Multiple geoms



# Multiple geoms

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

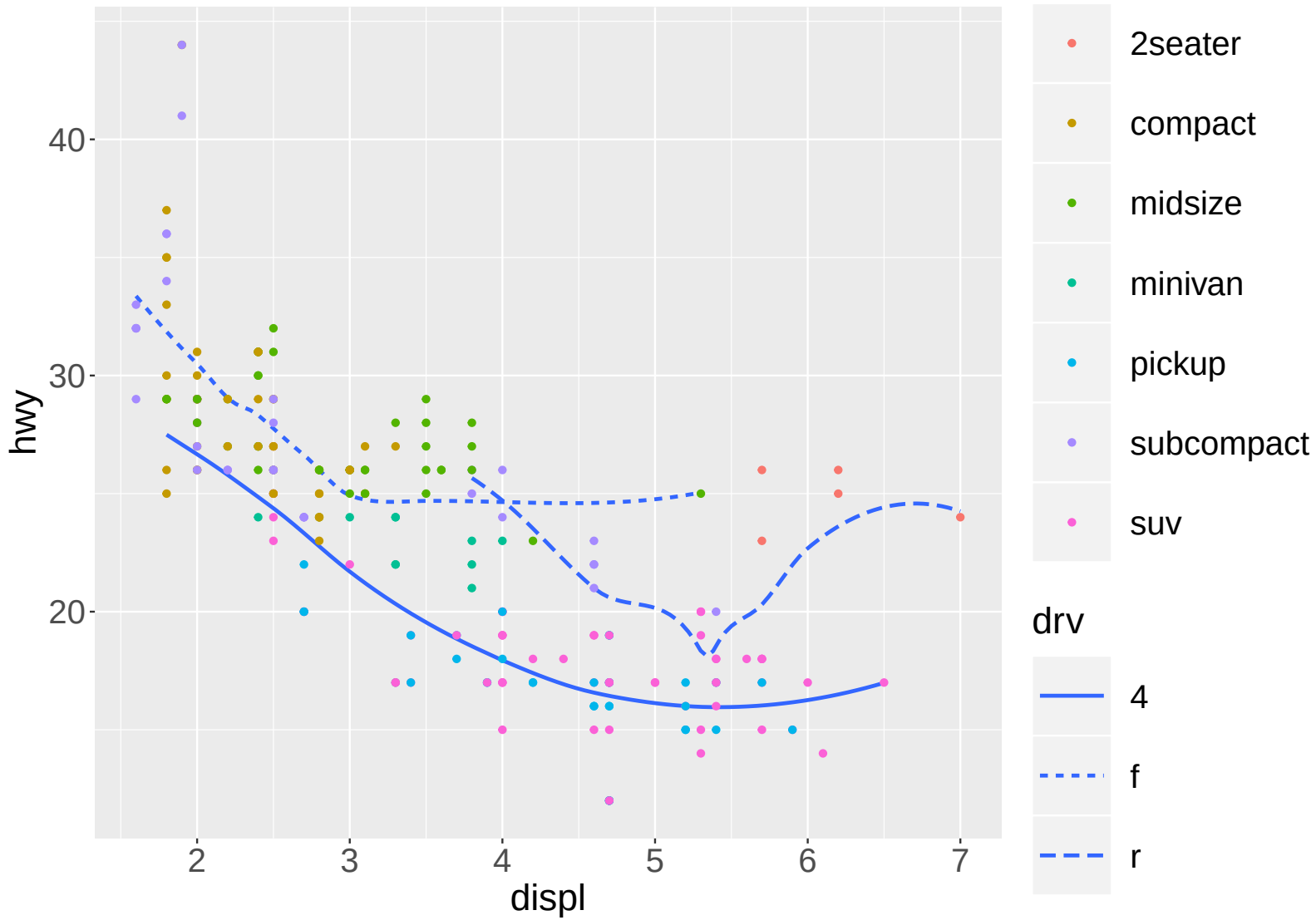
# Multiple geoms



# Multiple geoms

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

# Multiple geoms

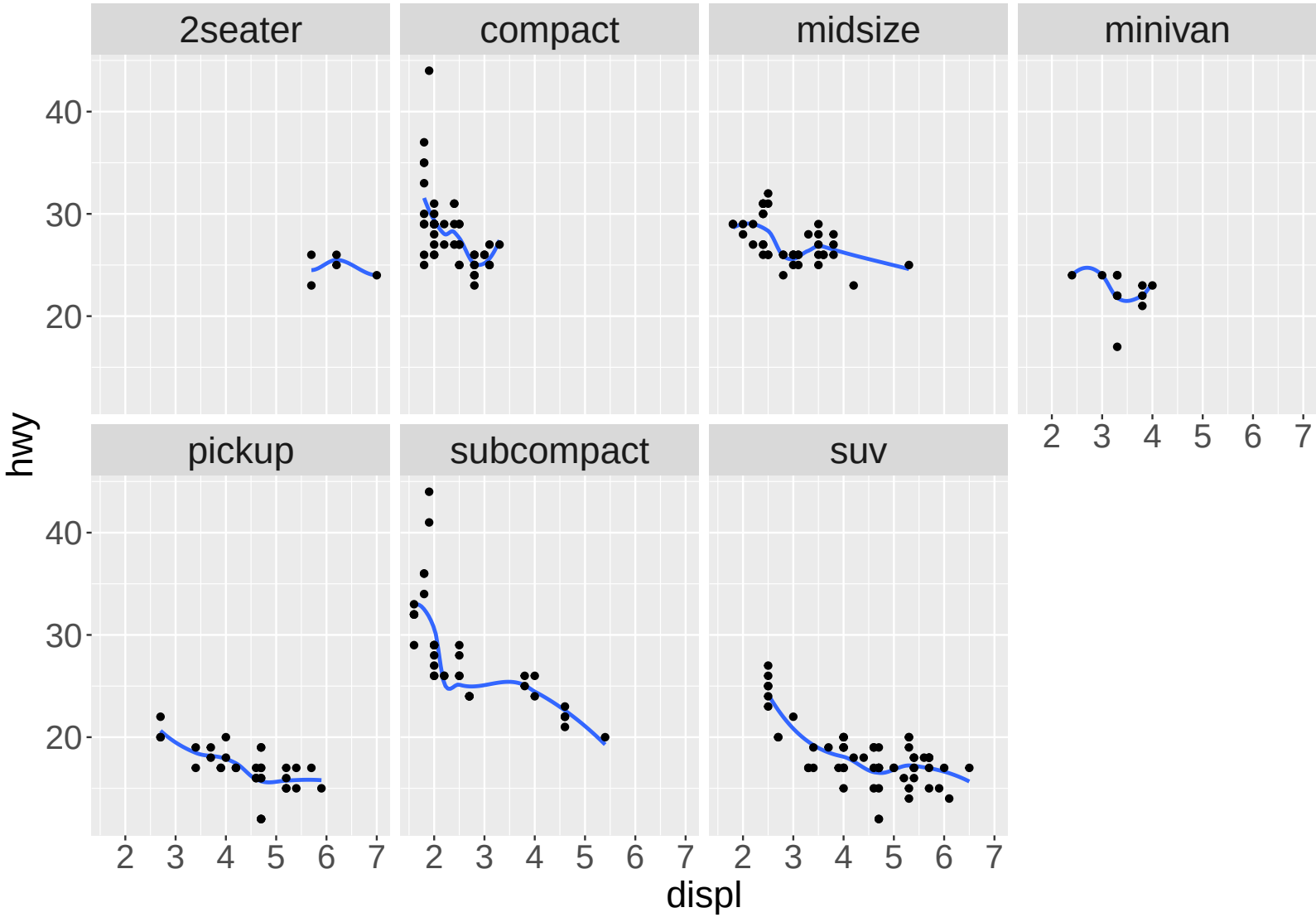


# Multiple geoms

We can also overlap geoms in grids:

```
ggplot(data = mpg, aes(x = displ, y = hwy)) +
  geom_smooth(se = FALSE) +
  geom_point() +
  facet_wrap(~class, nrow = 2)
```

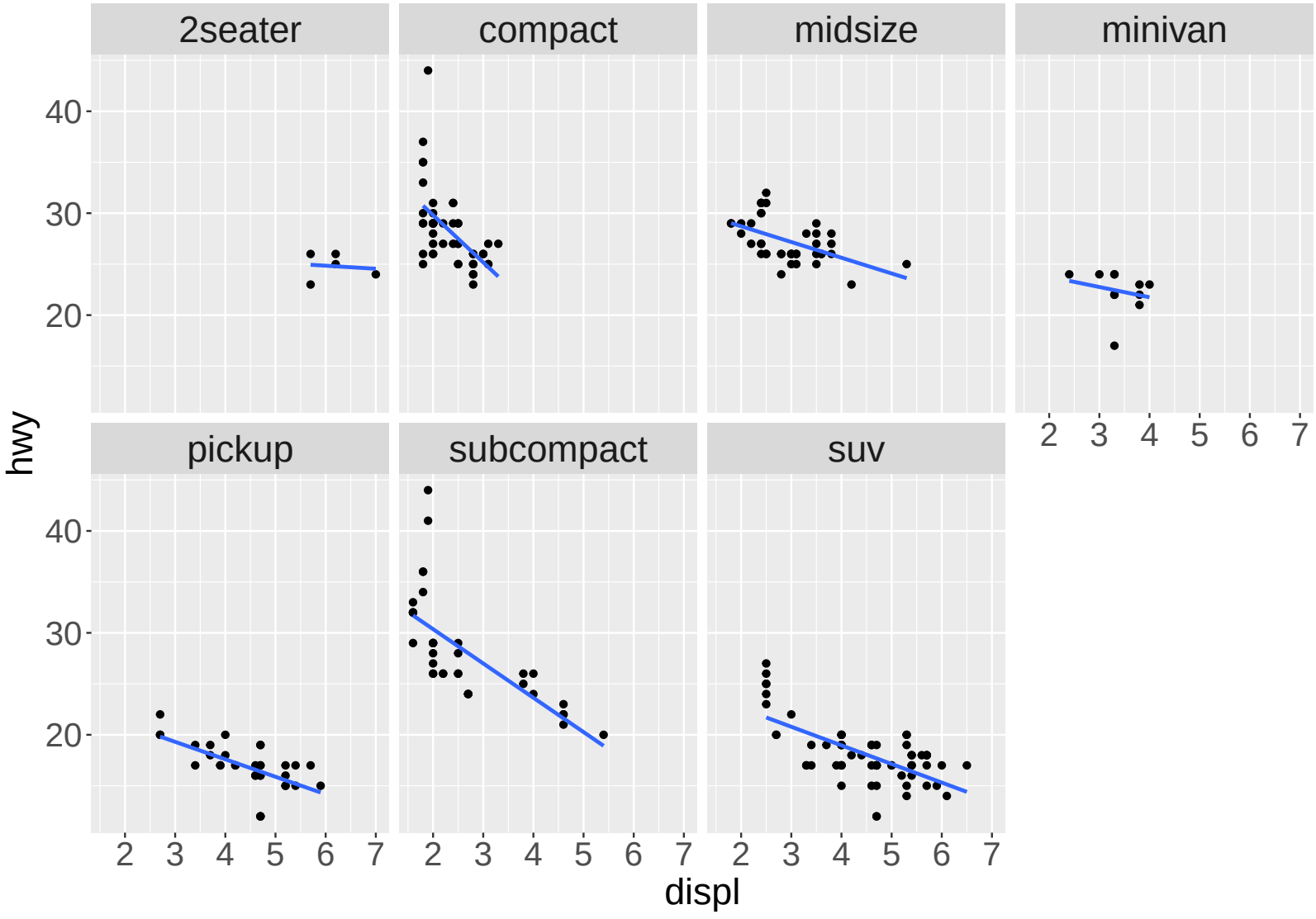
# Multiple geoms



# Multiple geoms

```
ggplot(data = mpg, aes(x = displ, y = hwy)) +
  geom_point() +
  geom_smooth(method = "lm", se = FALSE) +
  facet_wrap(~class, nrow = 2)
```

# Multiple geoms



# Multiple geoms

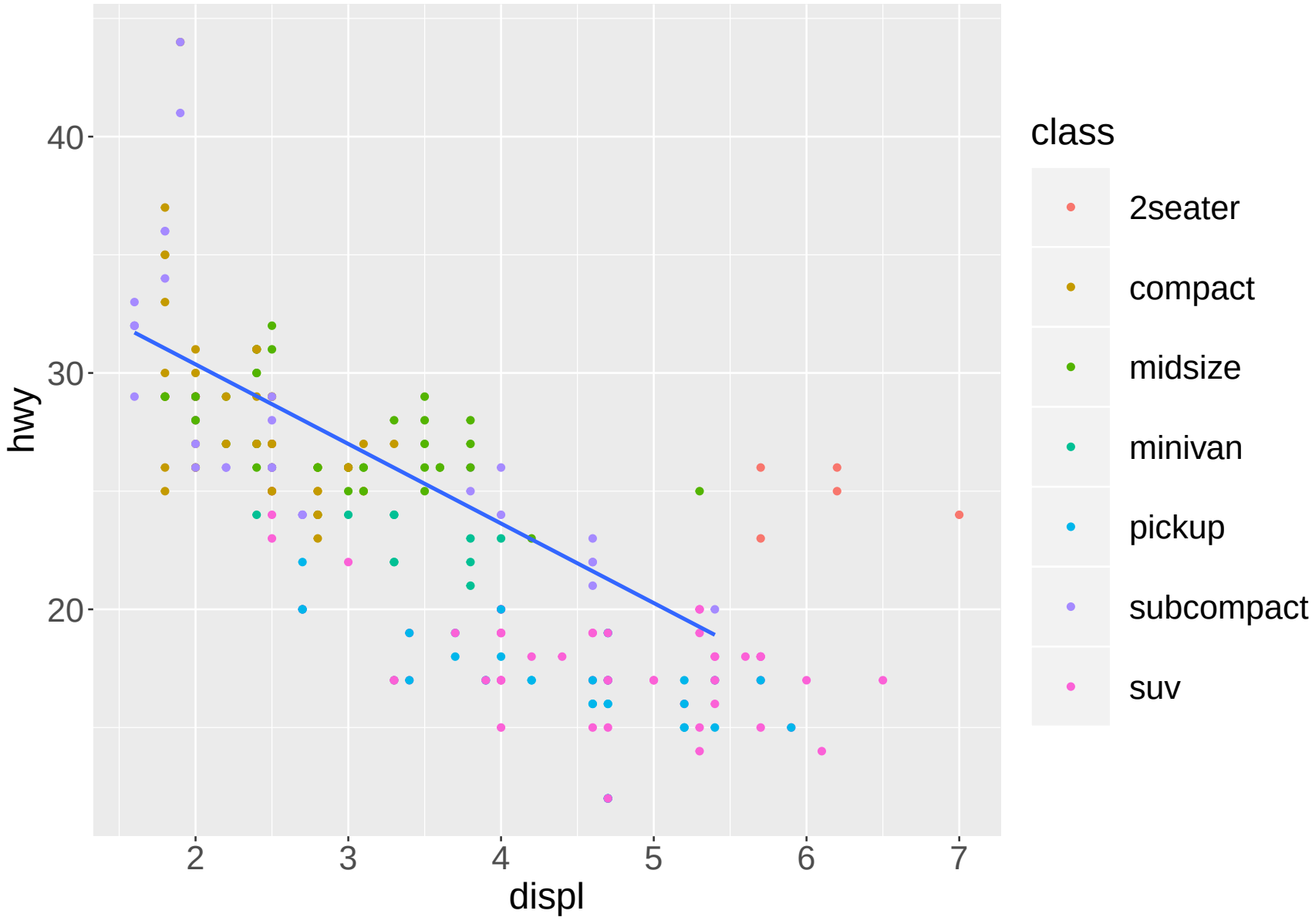
- We can use the same logic to specify a different dataset for each layer.

# Multiple geoms

```
subcompact <- subset(mpg, class == "subcompact")

ggplot(data = mpg, aes(x = displ, y = hwy)) +
  geom_point(aes(color = class)) +
  geom_smooth(data = subcompact, se = FALSE,
              method = "lm")
```

- The straight line displays just a subset of the mpg dataset, the subcompact cars.
- The local data argument in geom_smooth() overrides the global data argument in `ggplot()` for that layer only.

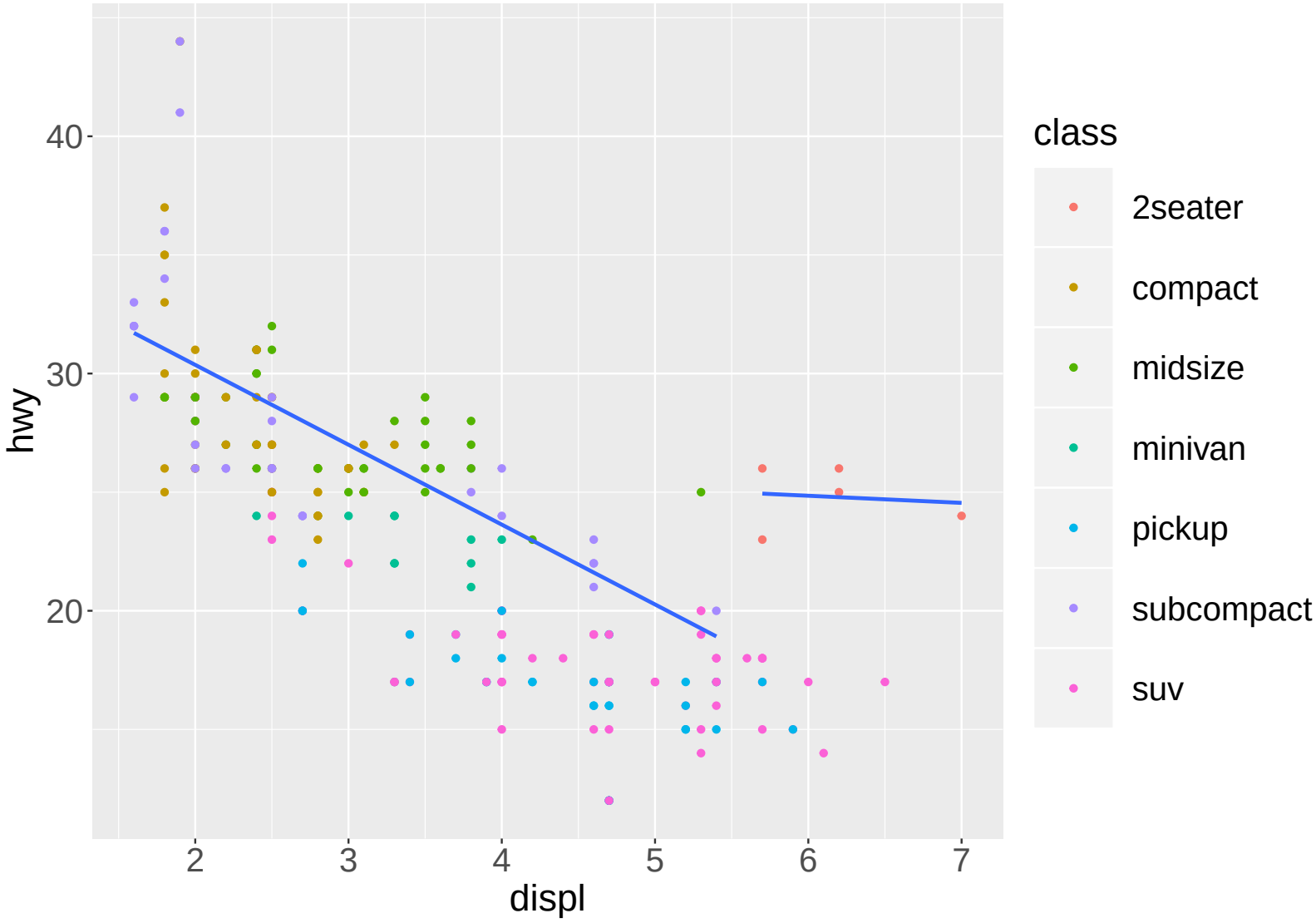
# Multiple geoms



# Multiple geoms

```
subcompact <- subset(mpg, class == "subcompact")
two_seater <- subset(mpg, class == "2seater")

ggplot(data = mpg, aes(x = displ, y = hwy)) +
  geom_point(aes(color = class)) +
  geom_smooth(data = subcompact, se = FALSE,
              method = "lm") +
  geom_smooth(data = two_seater, se = FALSE,
              method = "lm")
```

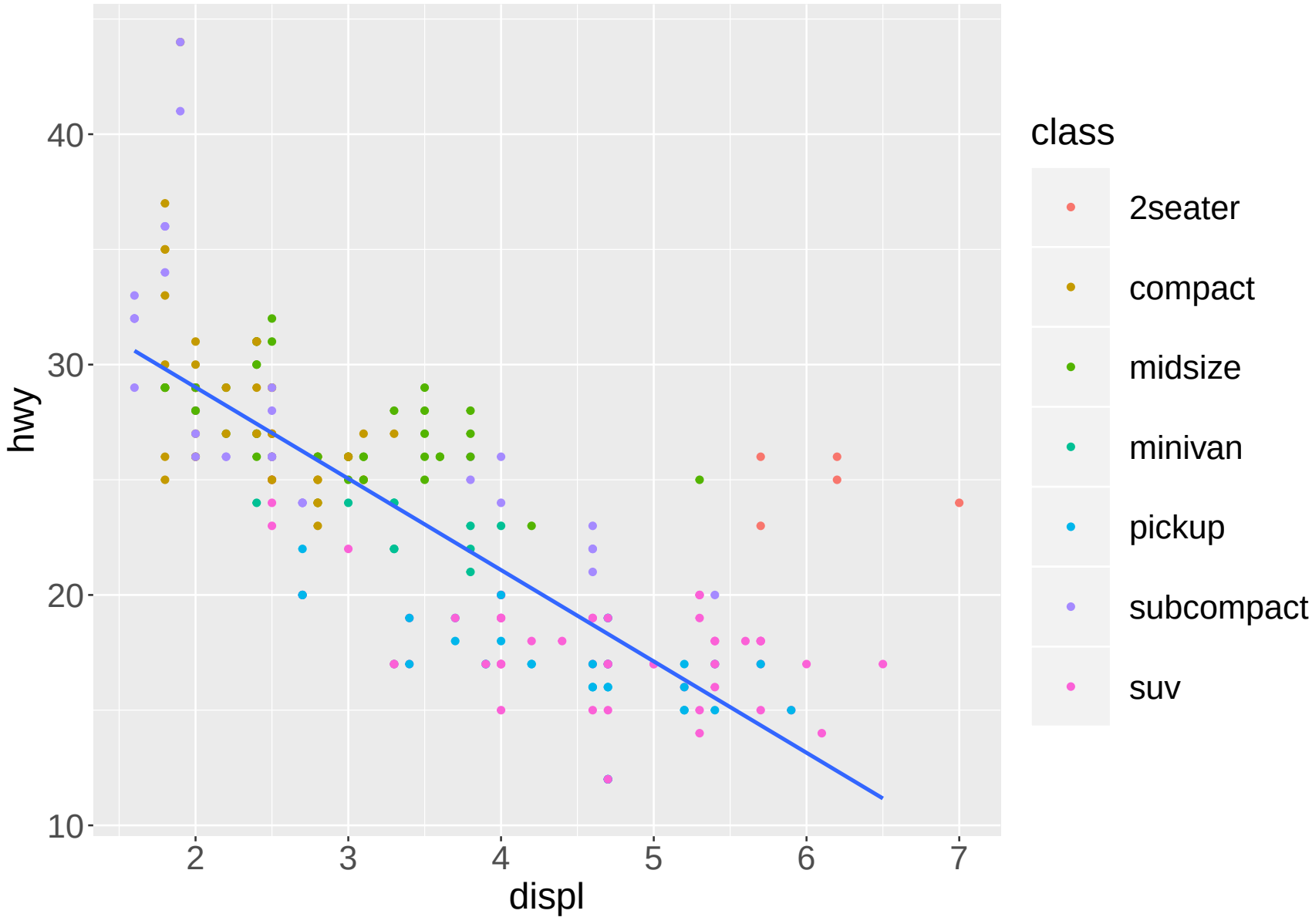
# Multiple geoms



# Multiple geoms

```
ggplot(data = mpg, aes(x = displ, y = hwy)) +
       geom_point(aes(color = class)) +
       geom_smooth(
         data = subset(mpg, class != "2seater"),
         se = FALSE,
         method = "lm")
```

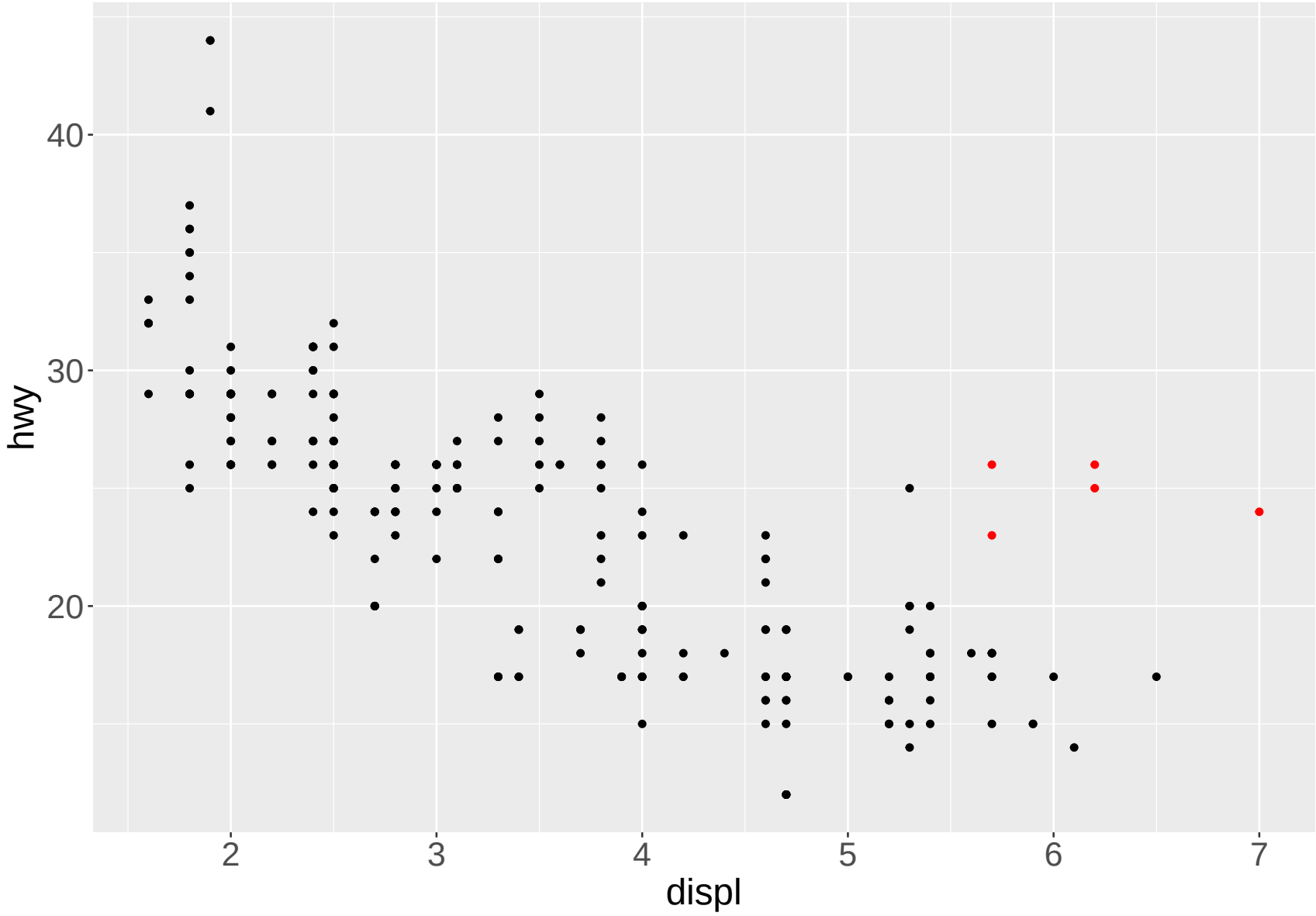
# Multiple geoms



# Multiple geoms

```
corvette <- subset(mpg, model == "corvette")
not_corvette <- subset(mpg, model != "corvette")

ggplot(mapping = aes(x = displ, y = hwy)) +
  geom_point(data = not_corvette) +
  geom_point(data = corvette,  color = "Red")
```

# Multiple geoms

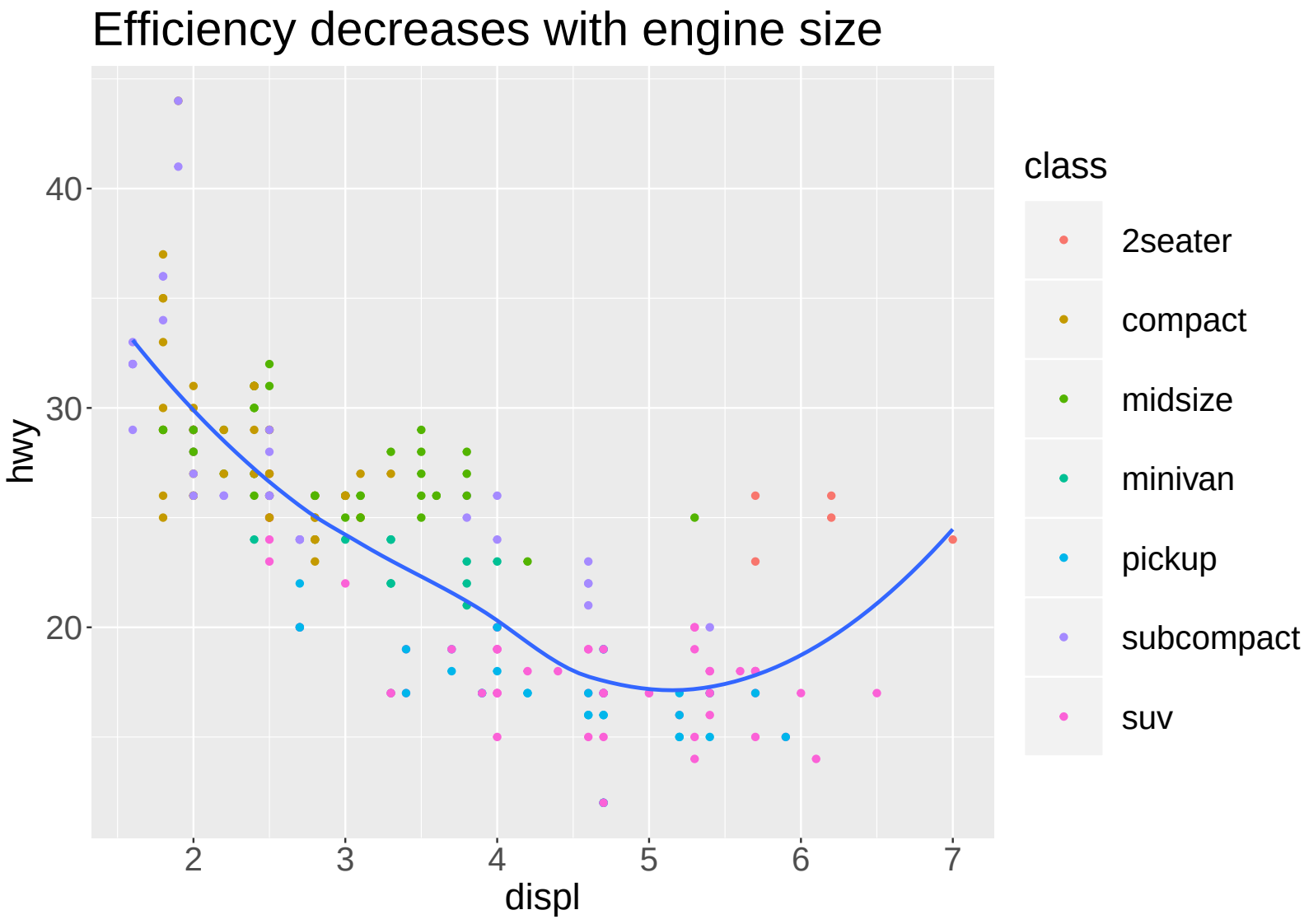


# Labels

We can add labels to a graph with the `labs()` function:

```
ggplot(mpg, aes(displ, hwy)) +
  geom_point(aes(color = class)) +
  geom_smooth(se = FALSE) +
  labs(
    title = "Efficiency decreases with engine size")
```

# Labels

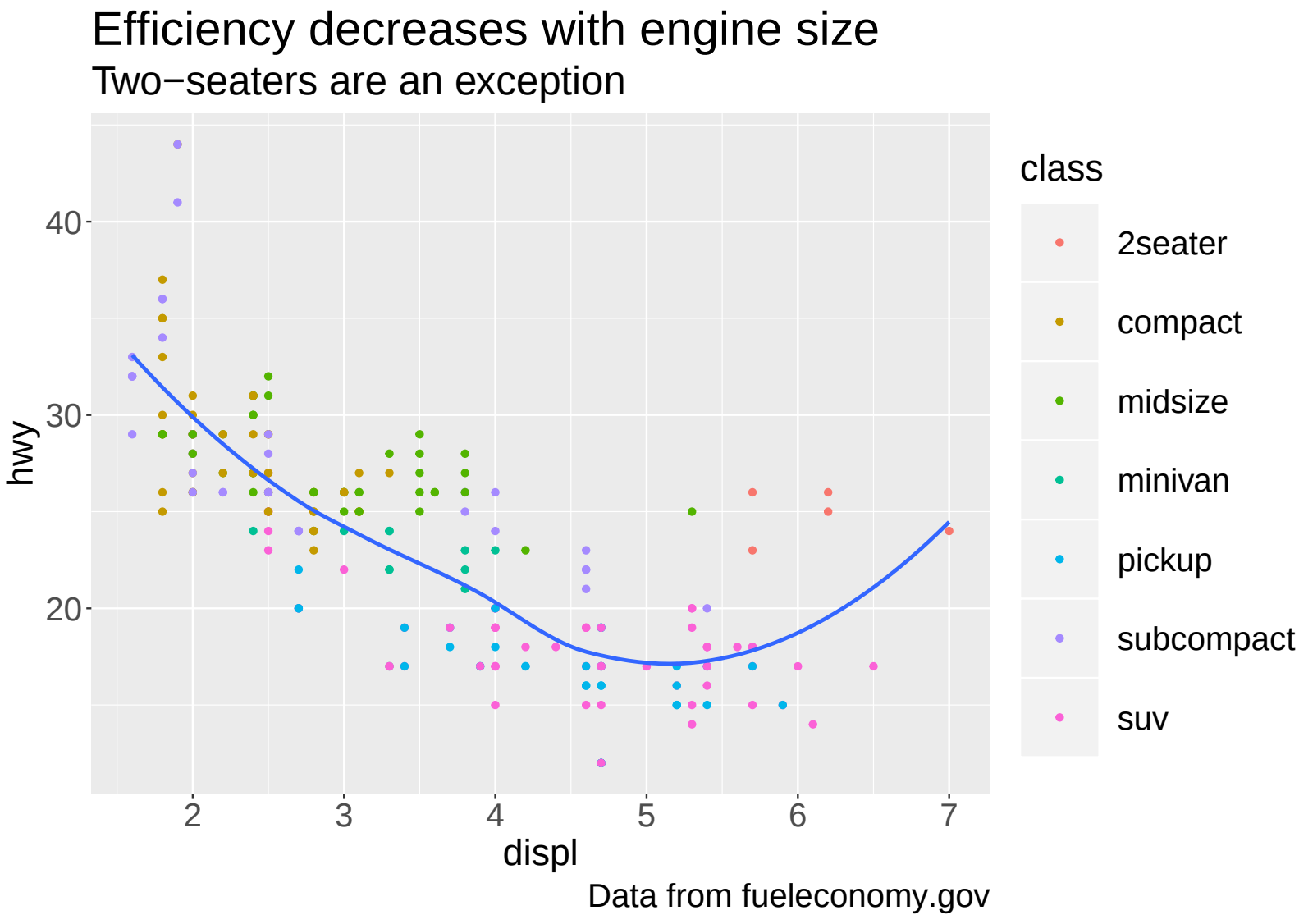

Efficiency decreases with engine size
hwy
40
30
20
2
3
4
5
6
7
displ
class
2seater
compact
midsize
minivan
pickup
subcompact
suv

# Labels

The `labs()` function can also be used to add a subtitle and/or a caption:

```
ggplot(mpg, aes(displ, hwy)) +
  geom_point(aes(color = class)) +
  geom_smooth(se = FALSE) +
  labs(
    title = "Efficiency decreases with engine size",
    subtitle = "Two-seaters are an exception",
    caption = "Data from fueleconomy.gov"
  )
```

# Labels


Efficiency decreases with engine size
Two−seaters are an exception
hwy
40
30
20
2
3
4
5
6
7
displ
Data from fueleconomy.gov
class
2seater
compact
midsize
minivan
pickup
subcompact
suv

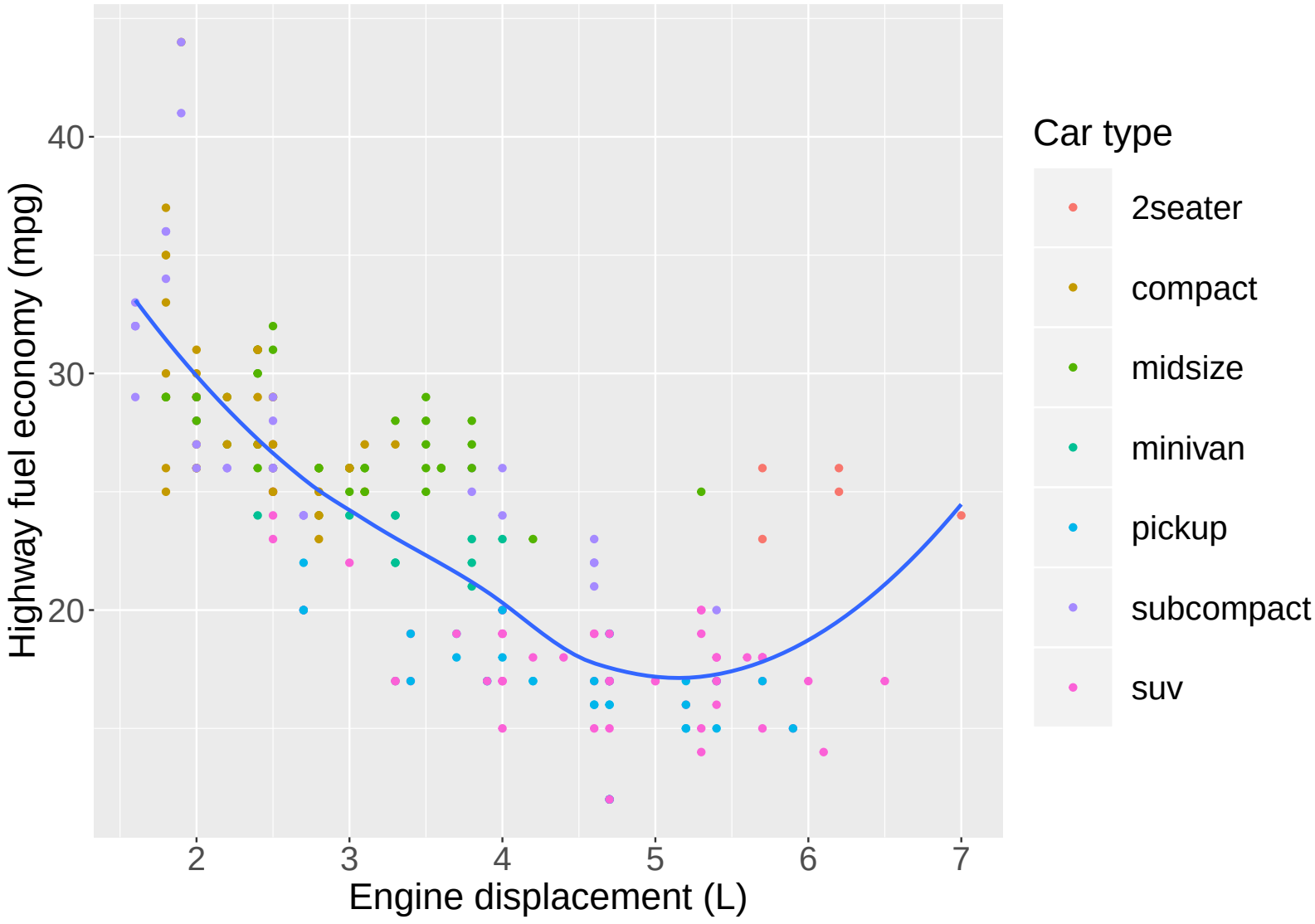
# Labels

- We can also use labs() to replace the axis and legend titles.
- It's usually a good idea to replace short variable names with more detailed descriptions, and to include the units.

# Labels

```
ggplot(mpg, aes(displ, hwy)) +
  geom_point(aes(color = class)) +
  geom_smooth(se = FALSE) +
  labs(
    x = "Engine displacement (L)",
    y = "Highway fuel economy (mpg)",
    color = "Car type"
```

# Labels

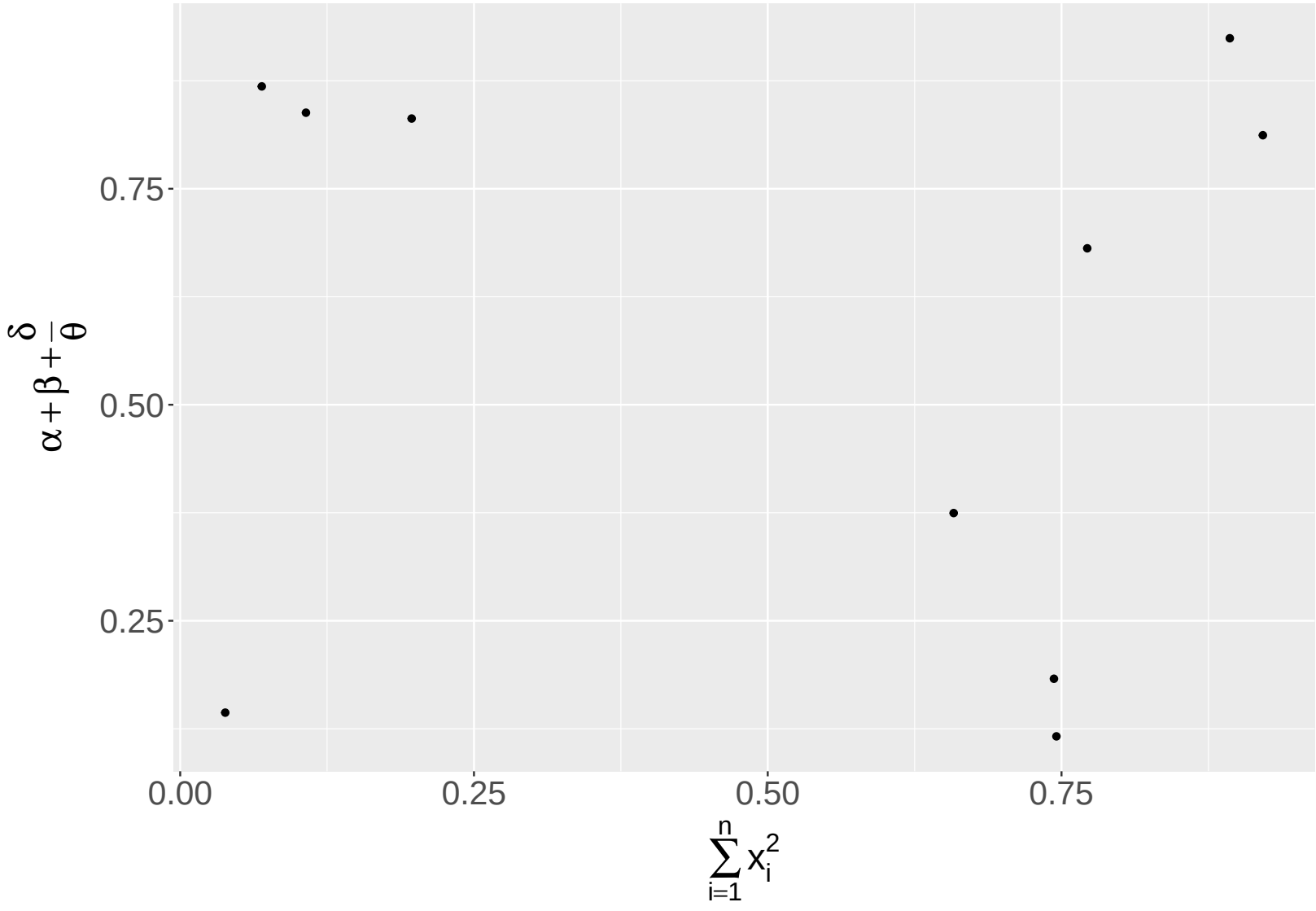

Highway fuel economy (mpg)
40
30
20
2
3
4
5
6
7
Engine displacement (L)
Car type
2seater
compact
midsize
minivan
pickup
subcompact
suv

# Labels

It's possible to use mathematical equations instead of text strings:

```
df <- tibble(
  x = runif(10),
  y = runif(10))

ggplot(df, aes(x, y)) +
  geom_point() +
  labs(
    x = quote(sum(x[i] ^ 2, i == 1, n)),
    y = quote(alpha + beta + frac(delta, theta))
  )
```

# Labels


0.75
0.50
0.25
$\alpha+\beta+\frac{\delta}{\theta}$
0.00
0.25
0.50
0.75
$\sum_{i=1}^{n} x_i^2$

# Labels

To learn more about the mathematical syntax available see:

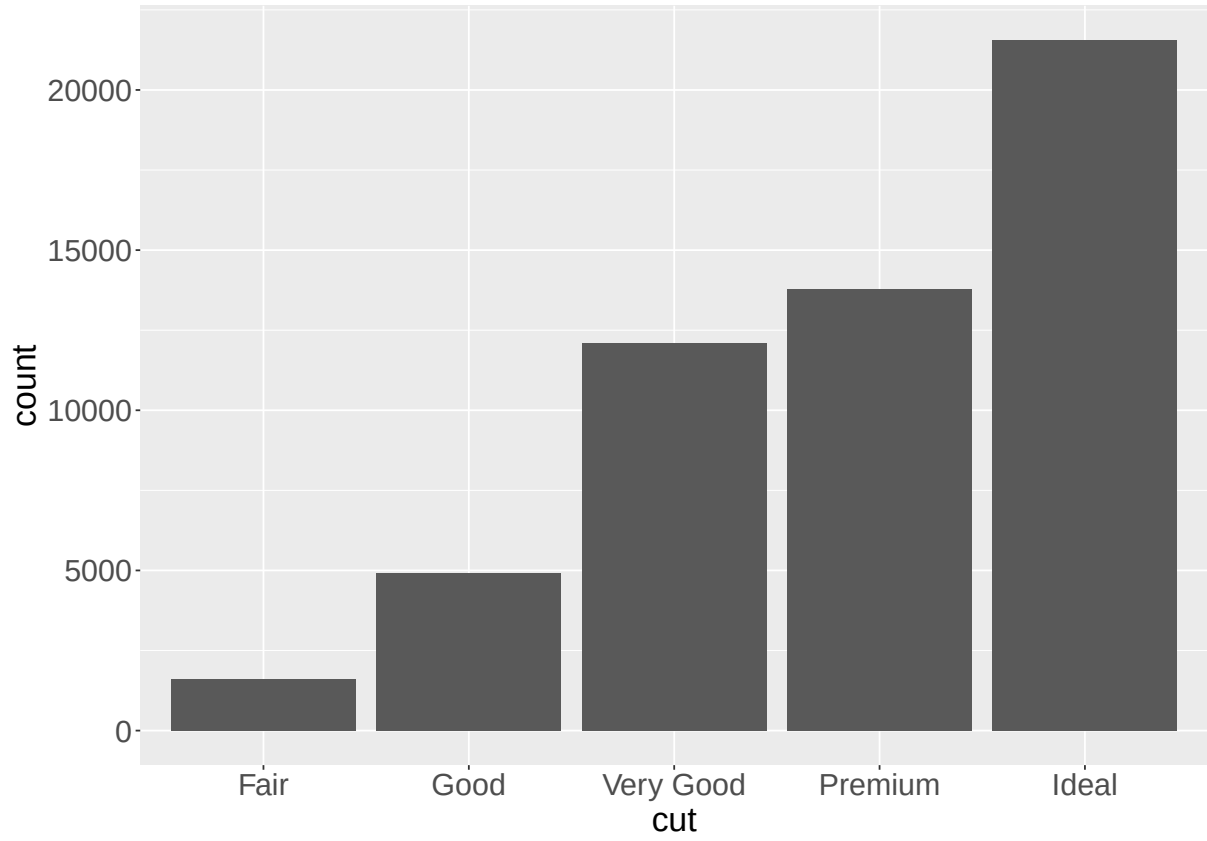
```
?plotmath
```

# The `diamonds` dataset

- Diamonds is a dataset included in the ggplot2 package.
- Contains attributes of almost 54000 diamonds.
- The variables include price, carat, quality of the cut, color and clarity

# Bar charts

```
ggplot(data = diamonds) +
  geom_bar(aes(x = cut))
```



# Statistical transformations

- On the y-axis, bar charts displays counts.
- But counts are not a variable in diamonds dataset!
- Many graphs, like scatterplots, plot the raw values the dataset.
- Other graphs, like bar charts, calculate new values to plot.
- The algorithm used to calculate new values for a graph is called a **stat**, short for statistical transformation.

# Statistical transformations

- Bar charts, histograms, and frequency polygons bin the data and then plot bin counts.
- Smoothers fit a model to the data and then plot predictions from the model.
- Boxplots compute summary statistics and then display them on specially formatted box.

# Statistical transformations

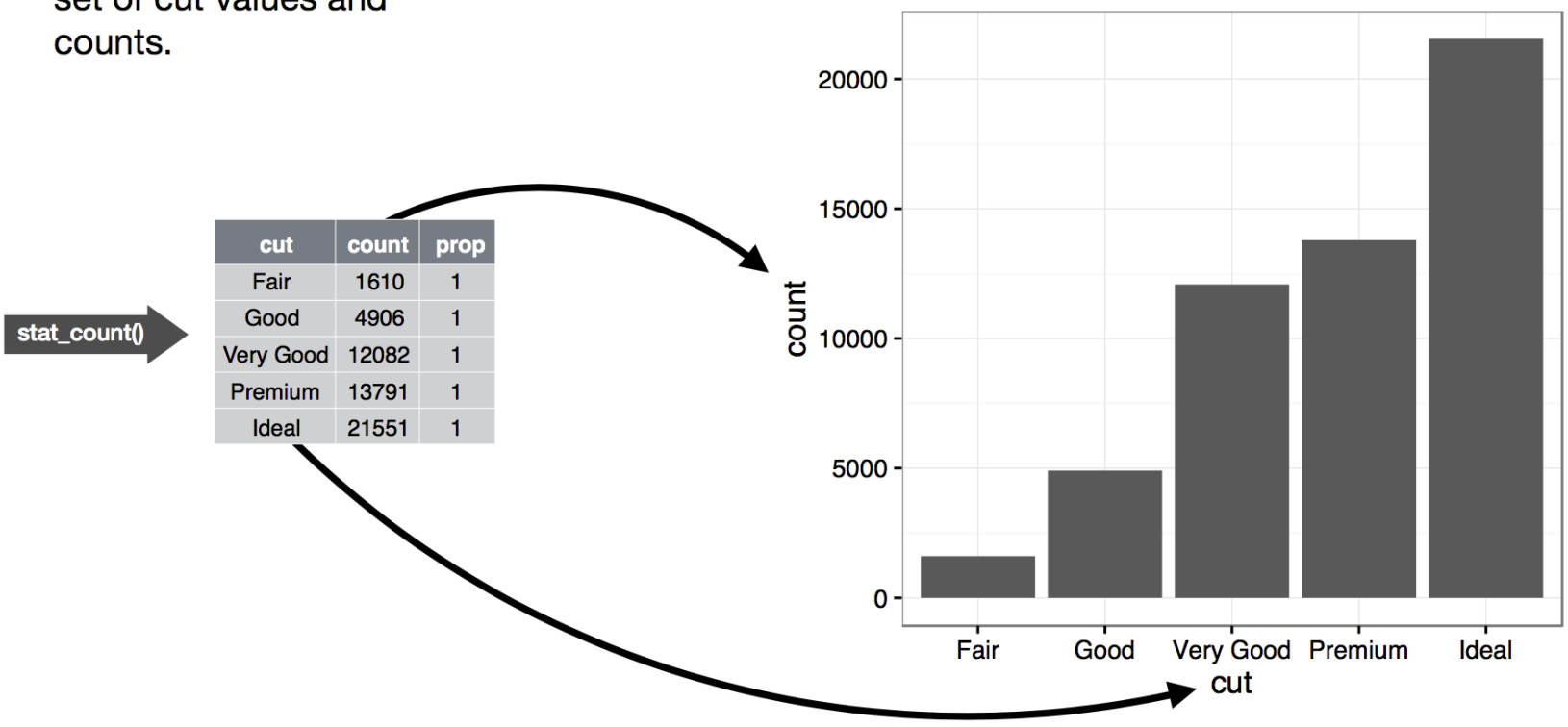
1. **`geom_bar()`** begins with the **`diamonds`** data set

| carat | cut | color | clarity | depth | table | price | x | y | z |
|---|---|---|---|---|---|---|---|---|---|
| 0.23 | Ideal | E | SI2 | 61.5 | 55 | 326 | 3.95 | 3.98 | 2.43 |
| 0.21 | Premium | E | SI1 | 59.8 | 61 | 326 | 3.89 | 3.84 | 2.31 |
| 0.23 | Good | E | VS1 | 56.9 | 65 | 327 | 4.05 | 4.07 | 2.31 |
| 0.29 | Premium | I | VS2 | 62.4 | 58 | 334 | 4.20 | 4.23 | 2.63 |
| 0.31 | Good | J | SI2 | 63.3 | 58 | 335 | 4.34 | 4.35 | 2.75 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

# Statistical transformations

2. **`geom_bar()`** transforms the data with the "count" stat, which returns a data set of cut values and counts.

3. **`geom_bar()`** uses the transformed data to build the plot. cut is mapped to the x axis, count is mapped to the y axis.

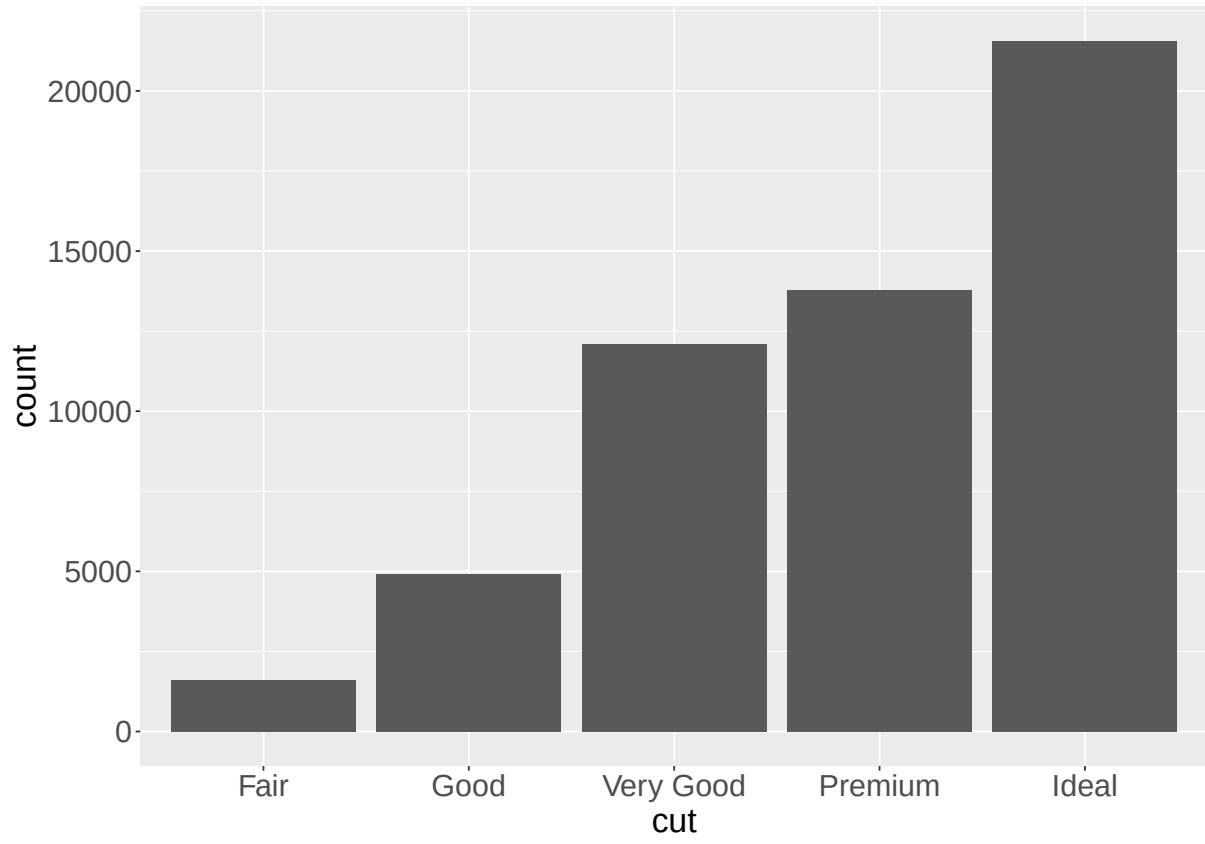


# Statistical transformations

- We can learn which stat a geom function uses by inspecting the default value of the `stat` argument.
- For example, with `?geom_bar` we learn that the default `stat` of `geom_bar()` is `count`.
- This means that `geom_bar()` uses `stat_count()` as the default statistical transformation.
- We can generally use geoms and stats interchangeably.
- For example, we can recreate the previous plot using `stat_count()` instead of `geom_bar()`.

# Statistical transformations

```
ggplot(data = diamonds) +
  stat_count(aes(x = cut))
```



# Statistical transformations

This works because:

- Every geom has a default stat, and every stat has a default geom.
- The default `stat` of `geom_bar()` is `count`.
- The default `geom` of `stat_count()` is `bar`.

# Overwriting the default stat

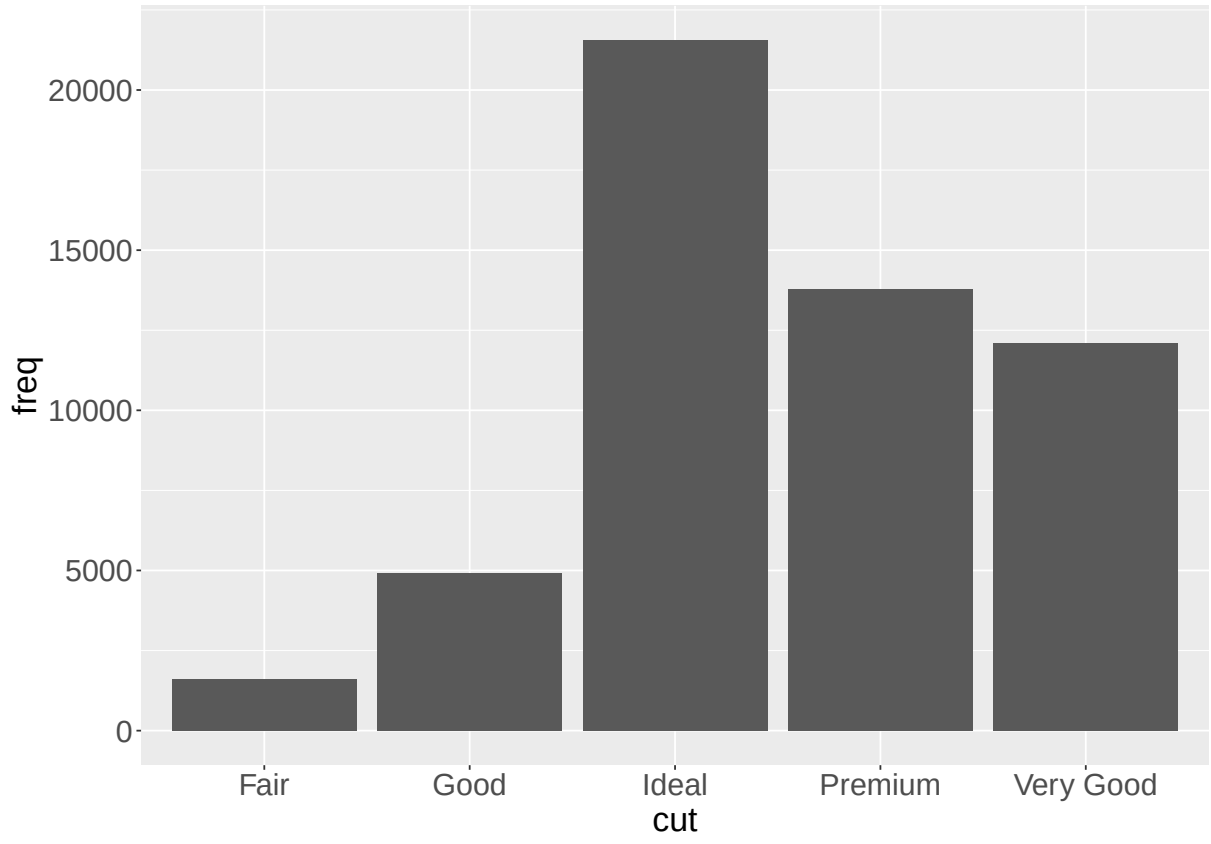
What if we want a bar chart that plot data as is?

- We may have a column with column heights.
- In that case, we need to change the default statistical transformation.

```
tib <- tribble(
  ~cut,          ~freq,
  "Fair",        1610,
  "Good",        4906,
  "Very Good",   12082,
  "Premium",     13791,
  "Ideal",       21551
)
```

# Overriding the default stat

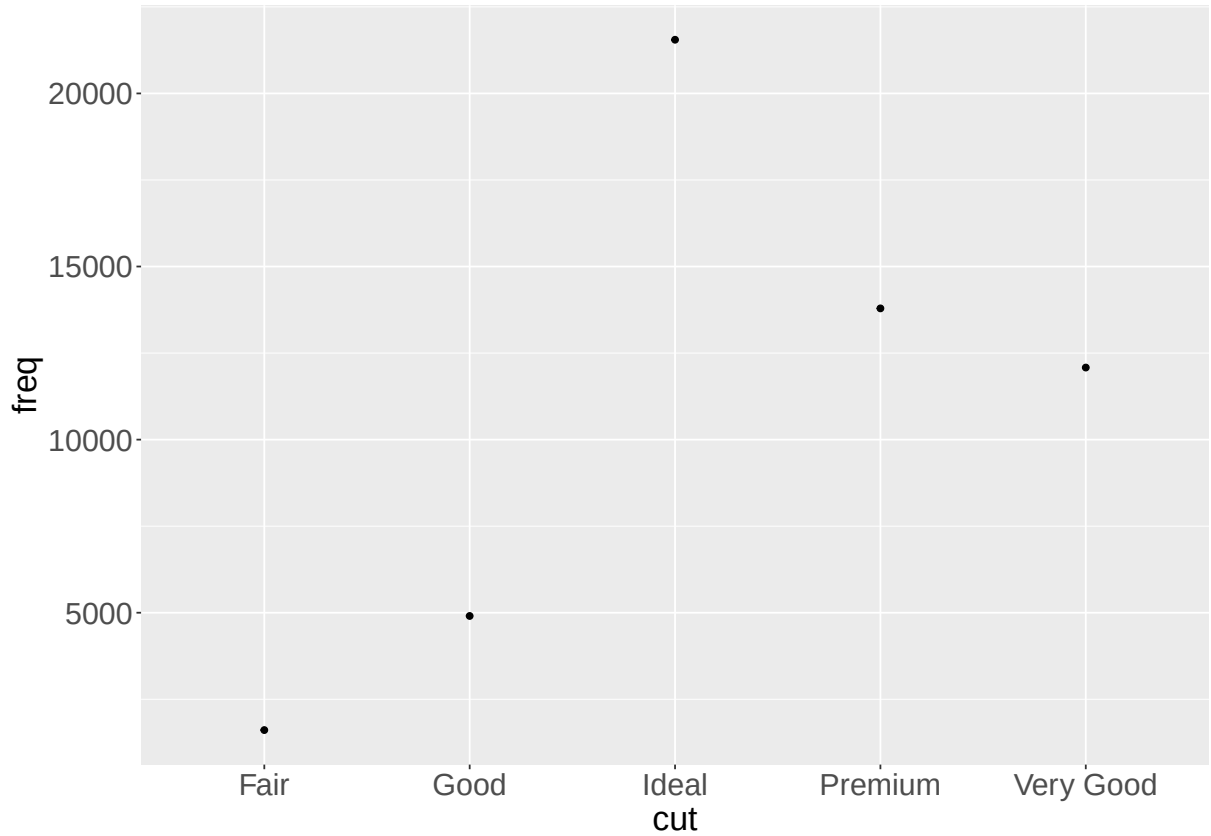
```
ggplot(data = tib) +
  geom_bar(aes(x = cut, y = freq),
    stat = "identity")
```



# Overriding the default stat

The default stat of `stat_identity()` is `point`, not `bar`:

```
ggplot(data = tib) +
  stat_identity(aes(x = cut, y = freq))
```

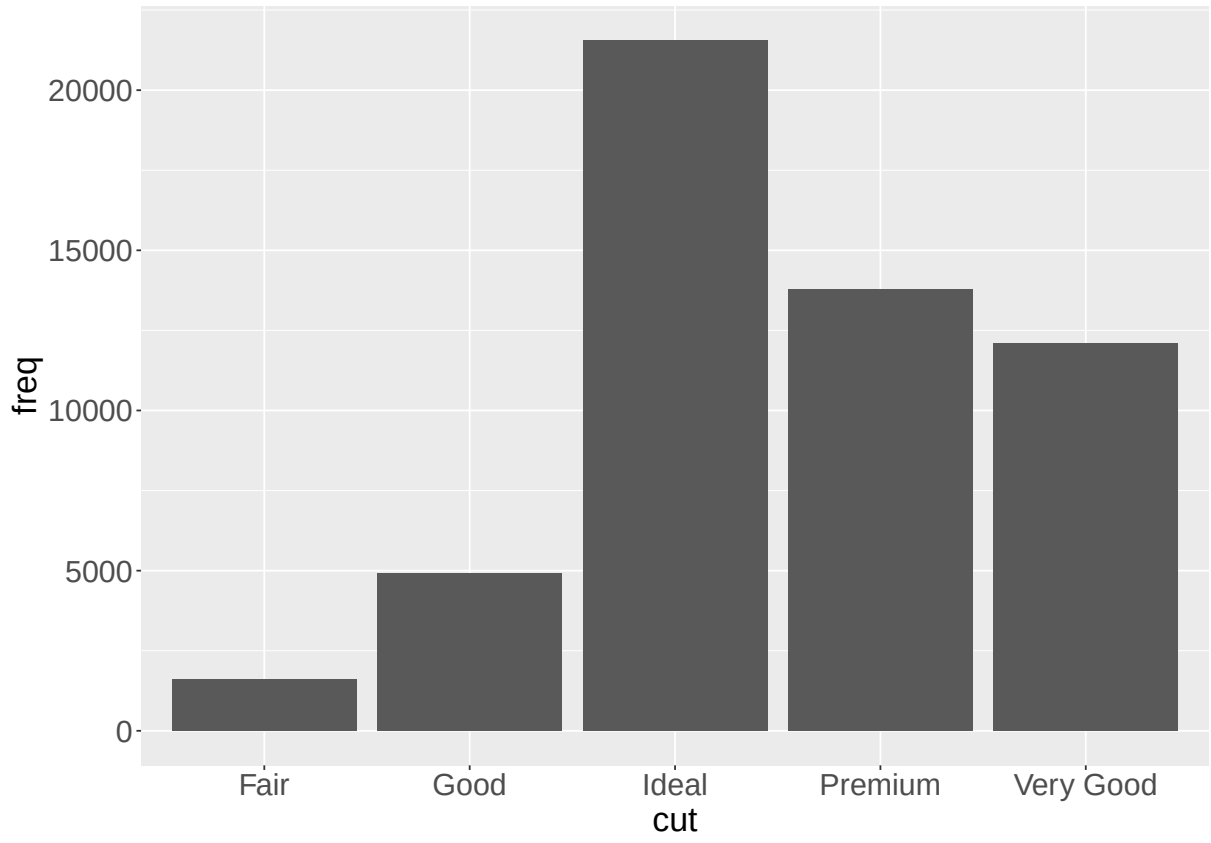


# geom_col()

- To plot data as is, we can use `geom_col()`.
- The default stat of `geom_col()` is `stat_identity()`.
- `geom_col()` expects a column of y values with bar heights.

# geom_col()

```
ggplot(data = tib) +
  geom_col(aes(x = cut, y = freq))
```



# Statistical transformations

- Stat functions calculate more variables than the ones that end up being displayed.
- To find the variables computed by a stat, look for the help section titled "computed variables".
- From `?stat_count` we learn that the computed variables are counts and proportions.
- `ggplot_build()` let's us see every value that is calculated in the process of building a graph.

# Statistical transformations

```
plt_1 <- ggplot(data = diamonds) +
  geom_bar(aes(x = cut))

plt_1 <- ggplot_build(plt_1)
plt_1$data[[1]][, 1:8]
```

```
##       y count prop x PANEL group ymin  ymax
## 1  1610  1610    1 1     1     1    0  1610
## 2  4906  4906    1 2     1     2    0  4906
## 3 12082 12082    1 3     1     3    0 12082
## 4 13791 13791    1 4     1     4    0 13791
## 5 21551 21551    1 5     1     5    0 21551
```

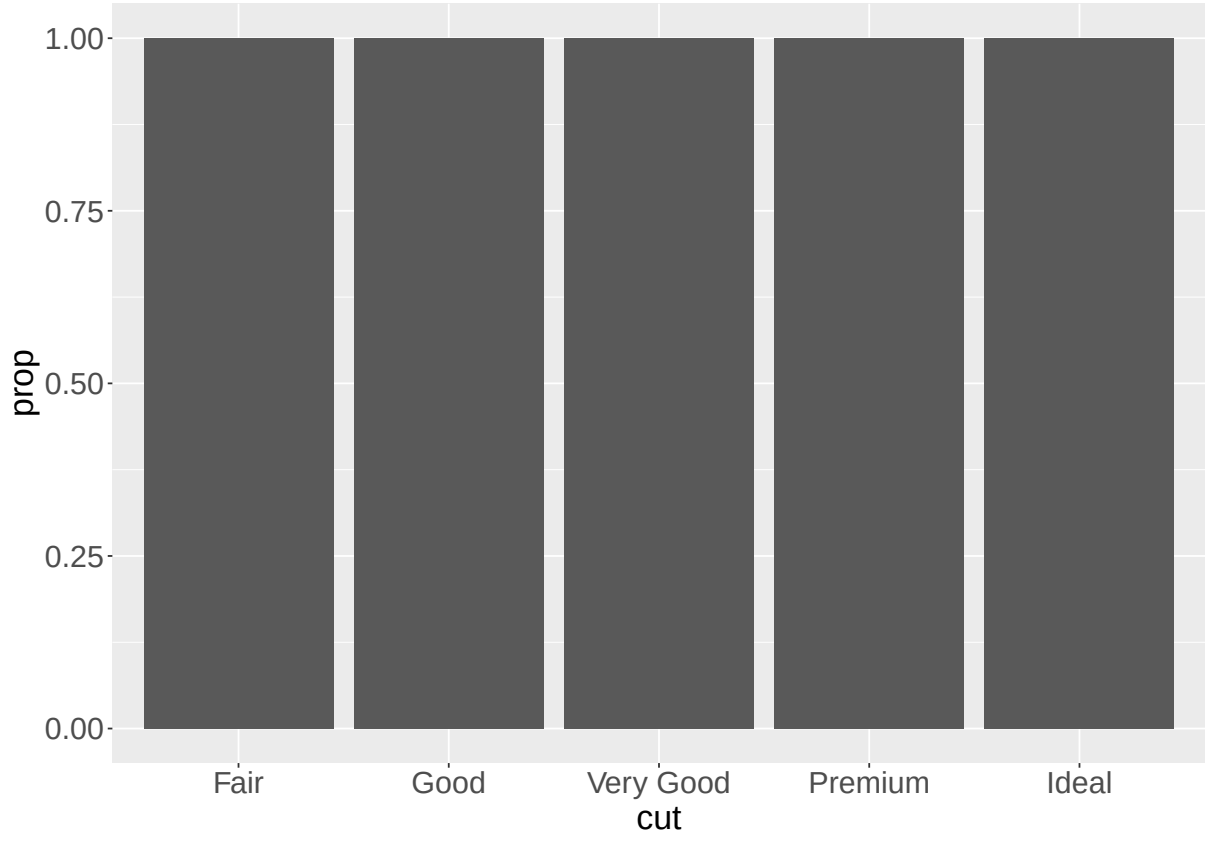
# Mapping from transformed variables to aesthetics

- We can override the default mapping from transformed variables to aesthetics.
- For example, we might want to display a bar chart of proportions rather than counts.

# Mapping from transformed variables to aesthetics

Let´s map proportions, instead of counts, to the y axis:

```
ggplot(data = diamonds) +
  geom_bar(aes(x = cut, y = stat(prop)))
```




What went wrong?

# Mapping from transformed variables to aesthetics

Lets see the computed values:

```
plt_2 <- ggplot(data = diamonds) +
  geom_bar(aes(x = cut, y = stat(prop)))

plt_2 <- ggplot_build(plt_2)
plt_2$data[[1]][, 1:8]
```

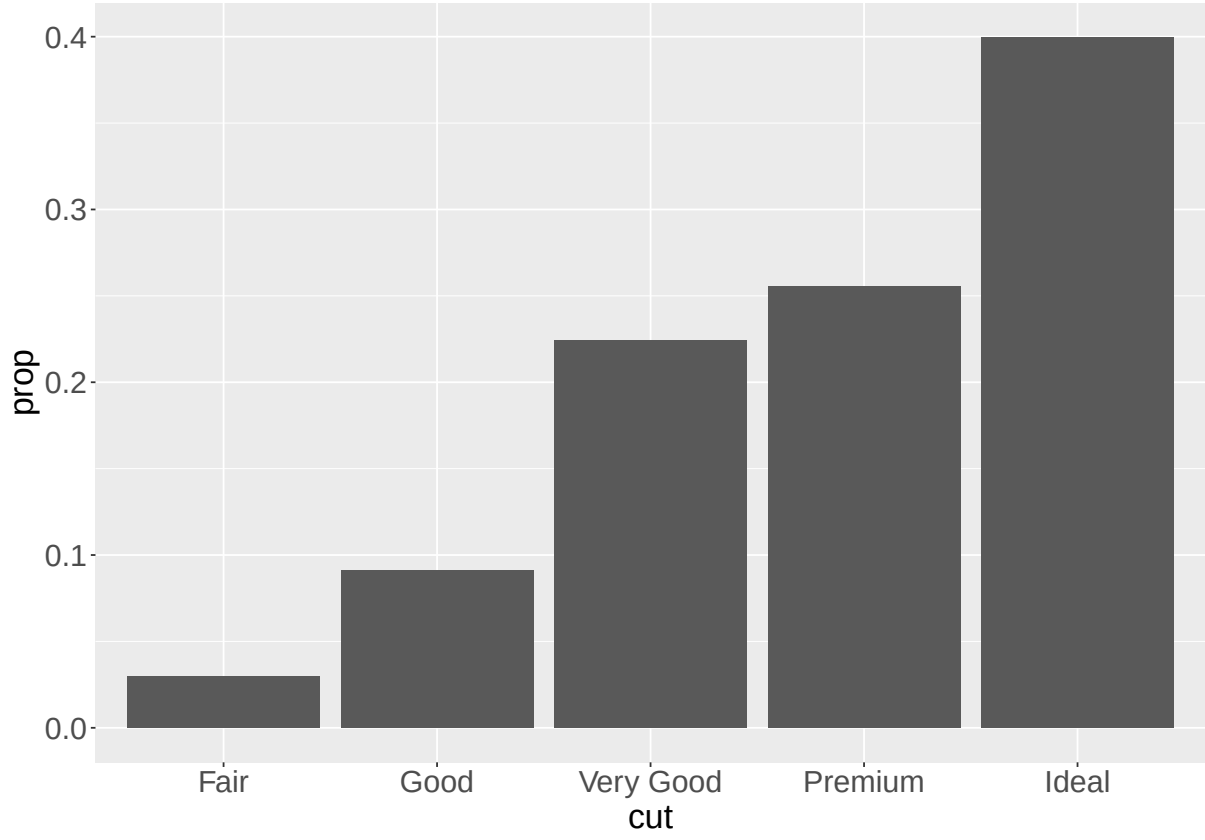
```
##   y count prop x PANEL group ymin ymax
## 1 1  1610    1 1     1     1    0    1
## 2 1  4906    1 2     1     2    0    1
## 3 1 12082    1 3     1     3    0    1
## 4 1 13791    1 4     1     4    0    1
## 5 1 21551    1 5     1     5    0    1
```

# Mapping from transformed variables to aesthetics

- The `prop` column is created as `count` divided by the sum of all of the counts that belong to the same group.
- By default, ggplot2 created one group for each level of `x`, so:
  - Each proportion is calculated by dividing the count of each group by itself.
  - All the proportions are set to 1.
- To display proportions instead of counts we have to tell ggplot2 that there is only one group so that it divides the counts by the total number of observations.

# Mapping from transformed variables to aesthetics

```
ggplot(data = diamonds) +
  geom_bar(aes(x = cut, y = stat(prop), group = 1))
```



# Mapping from transformed variables to aesthetics

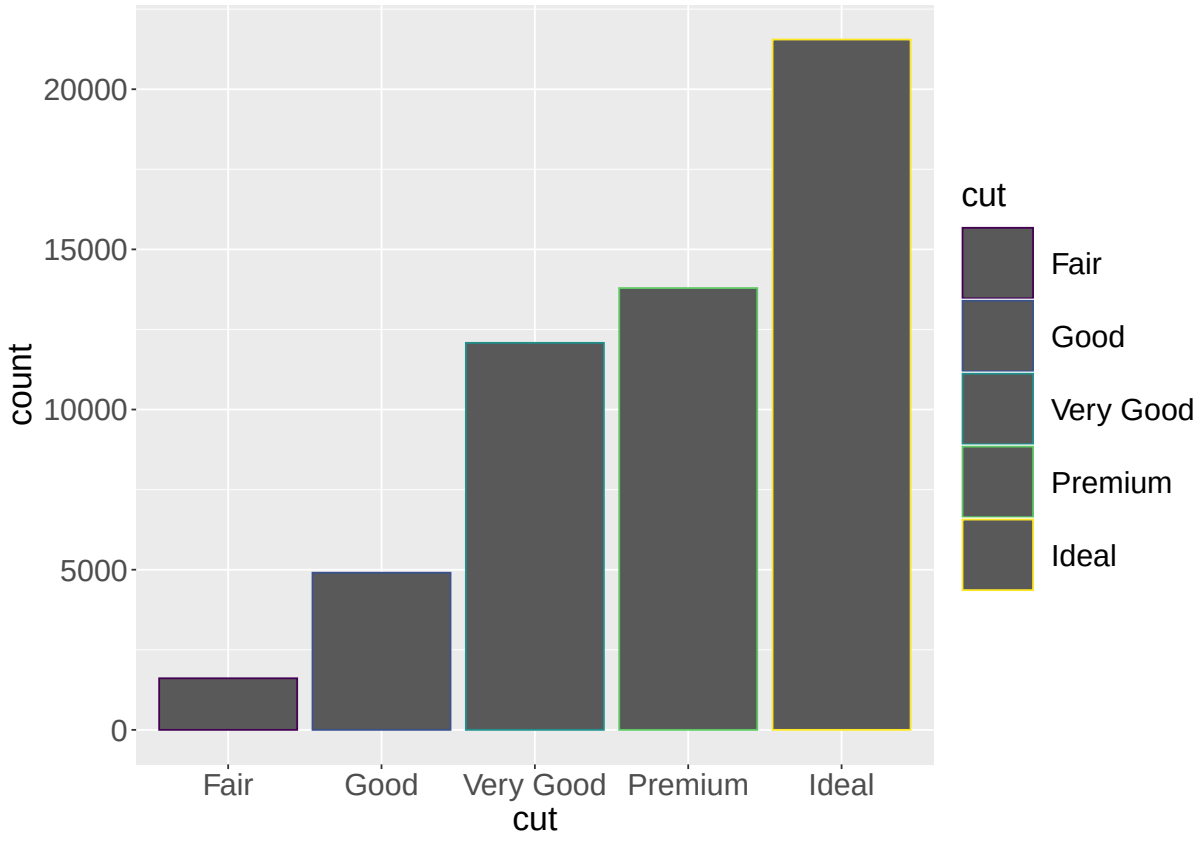
```
plt_3 <- ggplot(data = diamonds) +
  geom_bar(aes(x = cut, y = stat(prop), group = 1))
plt_3 <- ggplot_build(plt_3)

plt_3$data[[1]][, 1:5]
```

```
##             y count       prop x group
## 1 0.02984798  1610 0.02984798 1     1
## 2 0.09095291  4906 0.09095291 2     1
## 3 0.22398962 12082 0.22398962 3     1
## 4 0.25567297 13791 0.25567297 4     1
## 5 0.39953652 21551 0.39953652 5     1
```

# Aesthetics of bar charts

We can map the color aesthetic to a grouping variable:

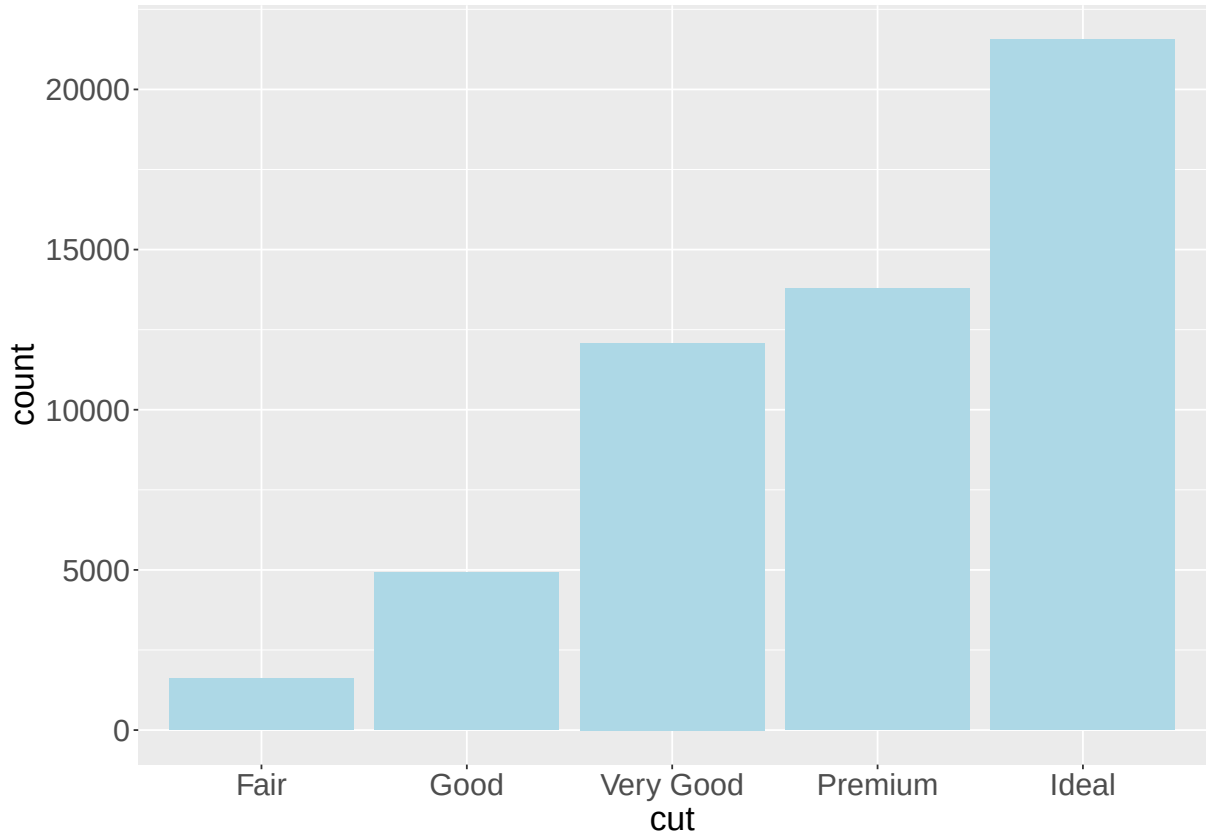
```
ggplot(data = diamonds) +
  geom_bar(aes(x = cut, color = cut))
```



# Aesthetics of bar charts

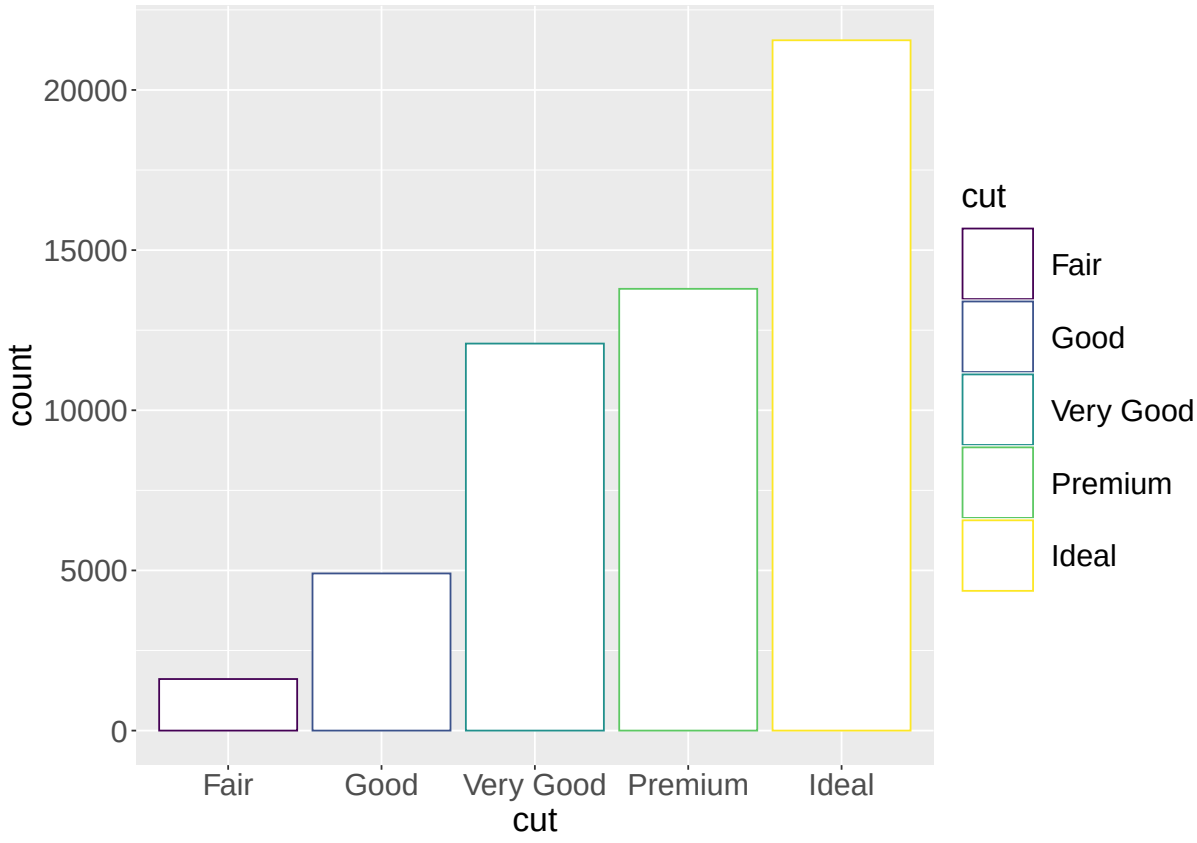
We can also change the default `fill` color of `geom_bar()`:

```
ggplot(data = diamonds) +
  geom_bar(aes(x = cut), fill = "lightblue")
```



# Aesthetics of bar charts

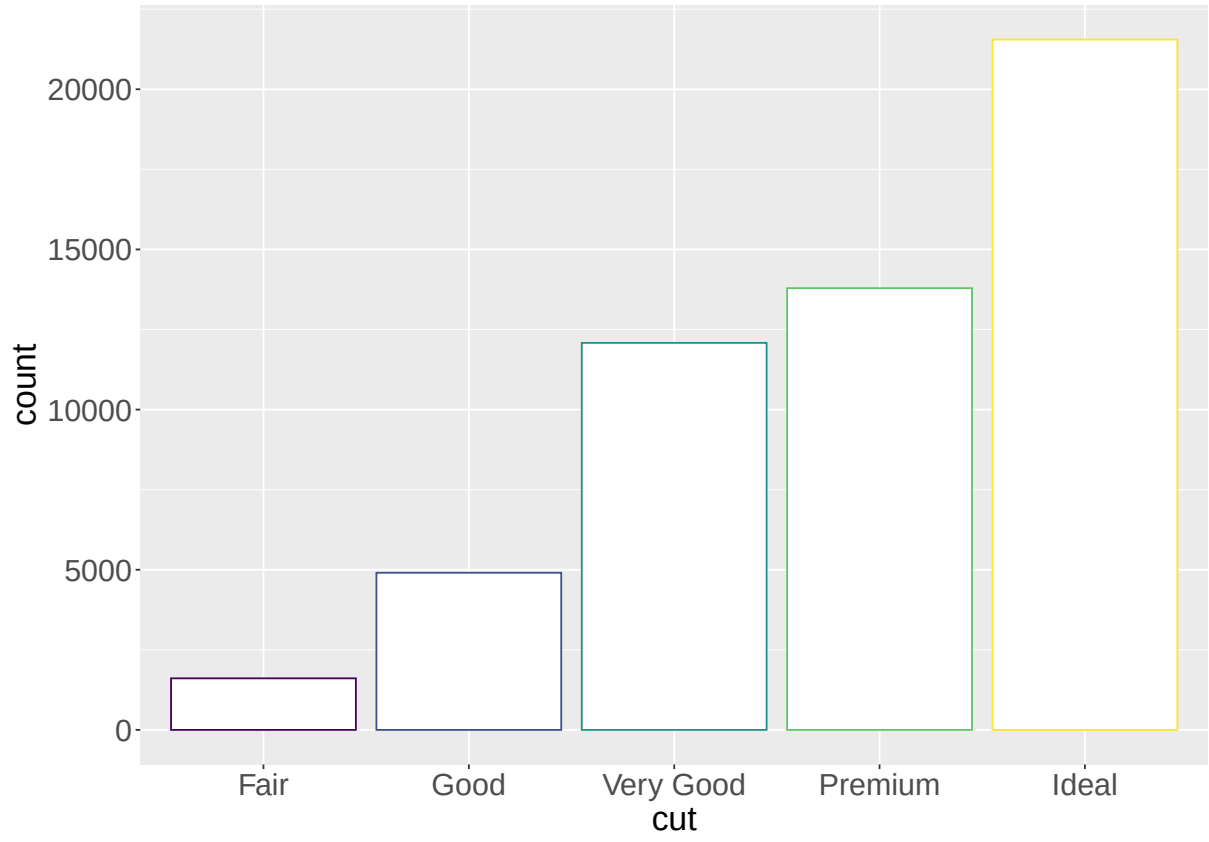
```
ggplot(data = diamonds) +
  geom_bar(aes(x = cut, color = cut), fill = "white")
```



# Aesthetics of bar charts

And disable the legend:

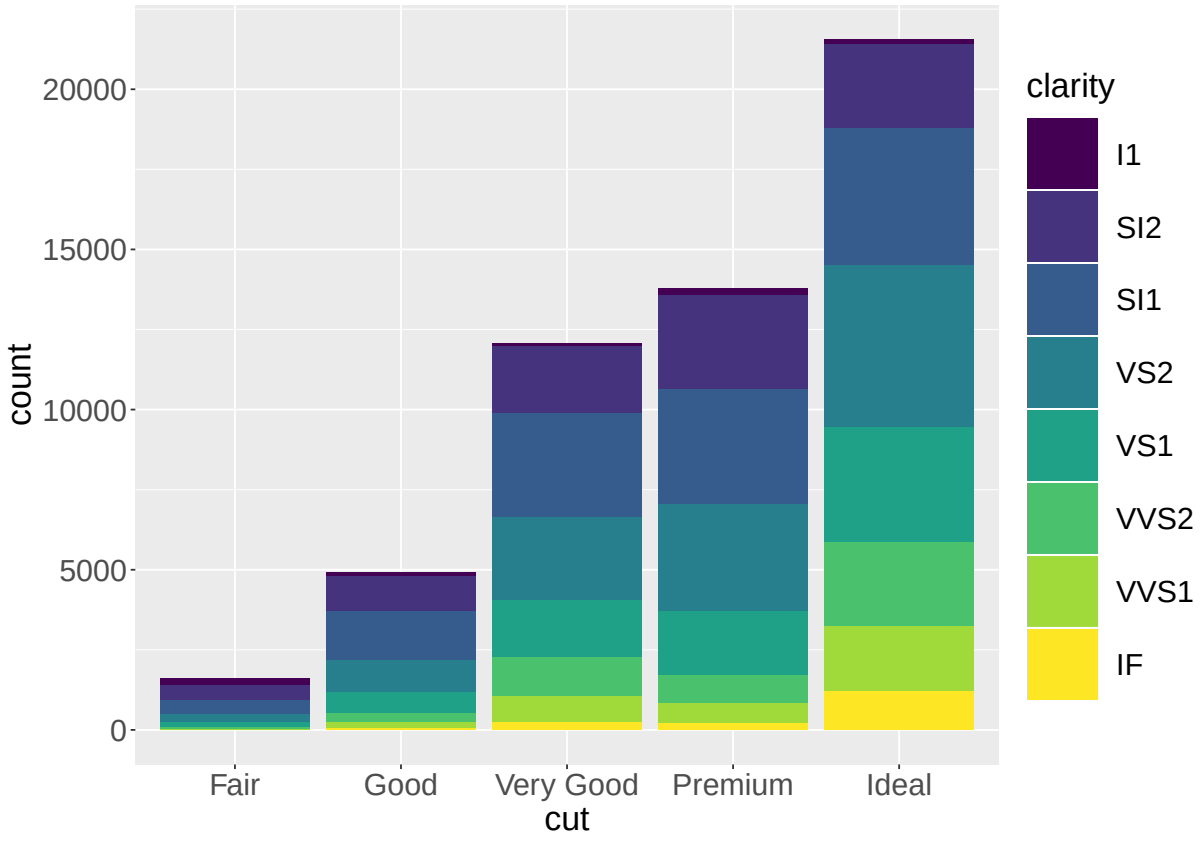
```
ggplot(data = diamonds) +
  geom_bar(aes(x = cut, color = cut),
           fill = "white", show.legend = FALSE)
```



# Stacked bar charts

The fill aesthetic can be mapped to variables other than x to add a dimension to the plot:

```
ggplot(data = diamonds) +
  geom_bar(aes(x = cut, fill = clarity))
```



# Position adjustments

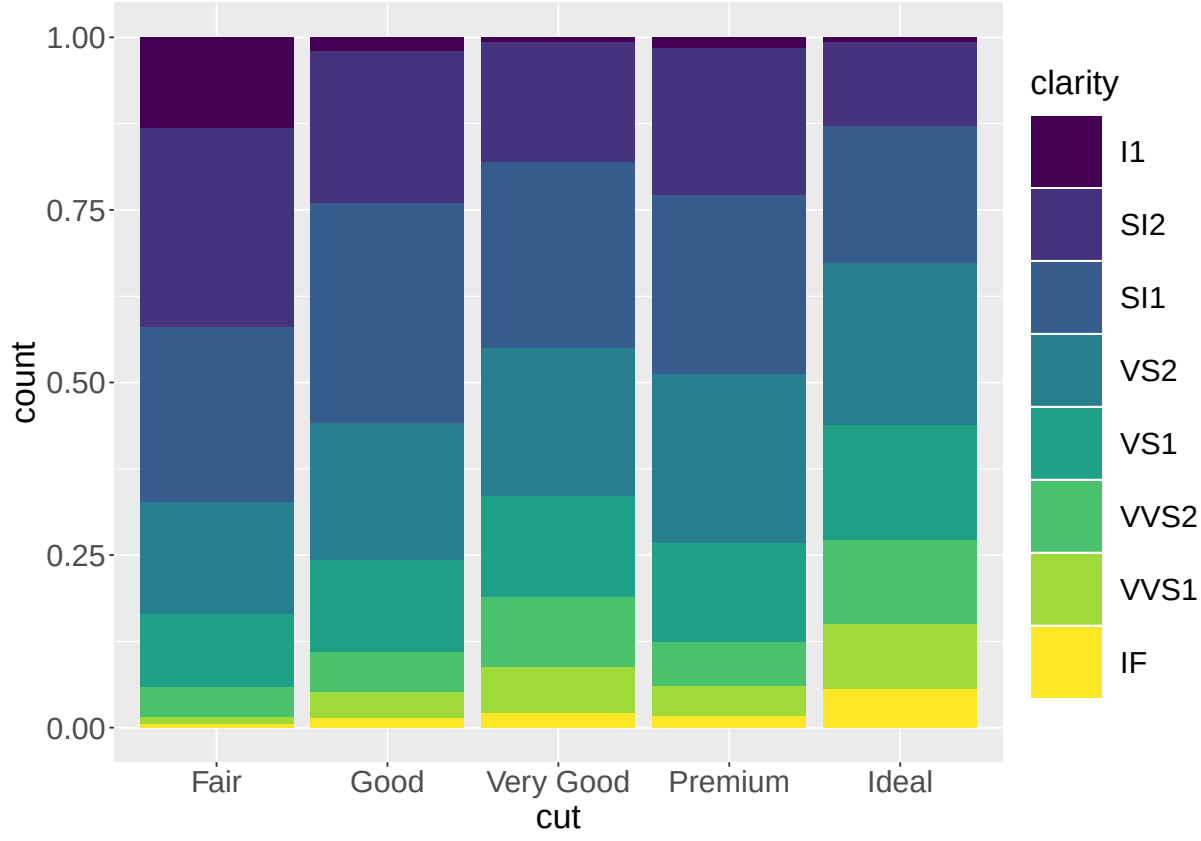
- Each colored rectangle represents a combination of cut and clarity.
- The stacking is performed automatically by the position adjustment specified in the `position` argument of the geom function.
- The default value is `stack`.

# Position adjustments

- `position = "fill"` works like stacking but makes each set of stacked bars the same height.
- This makes it easier to compare proportions across groups.

# Position adjustments

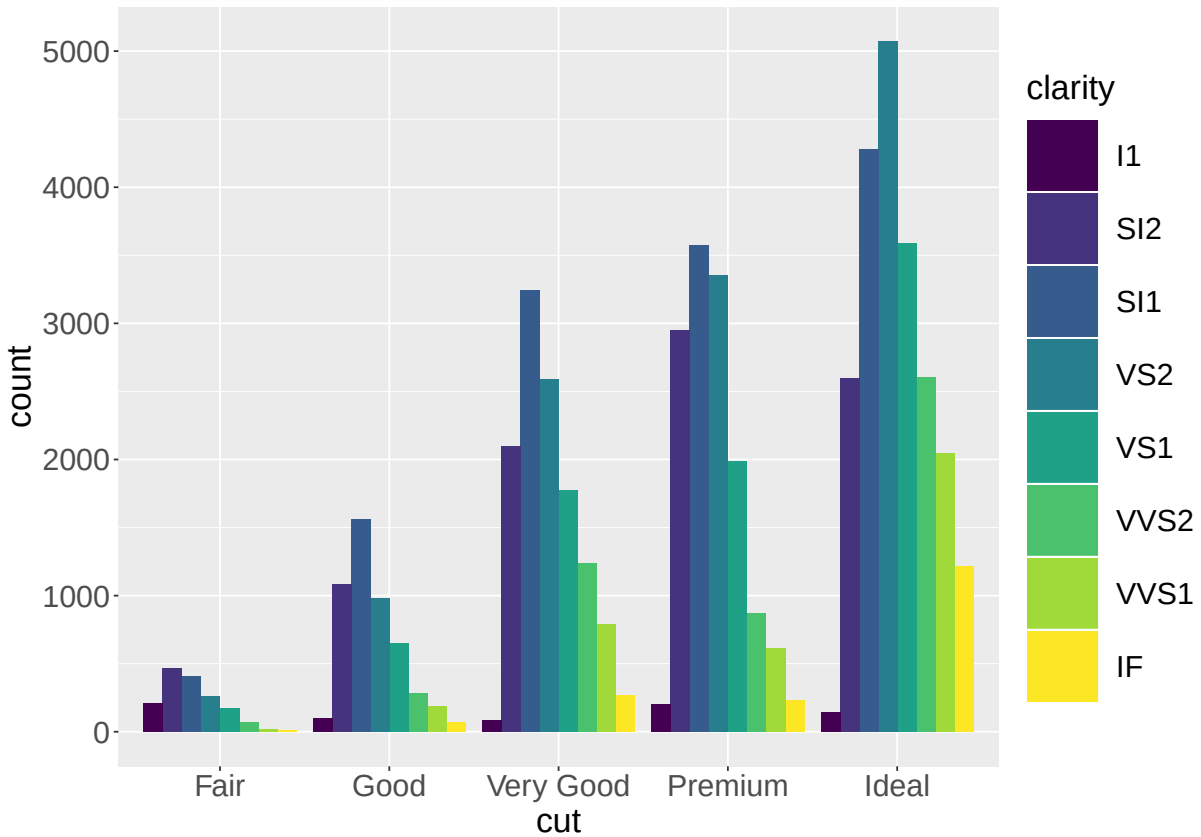
```
ggplot(data = diamonds) +
  geom_bar(aes(x = cut, fill = clarity),
           position = "fill")
```



# Position adjustments

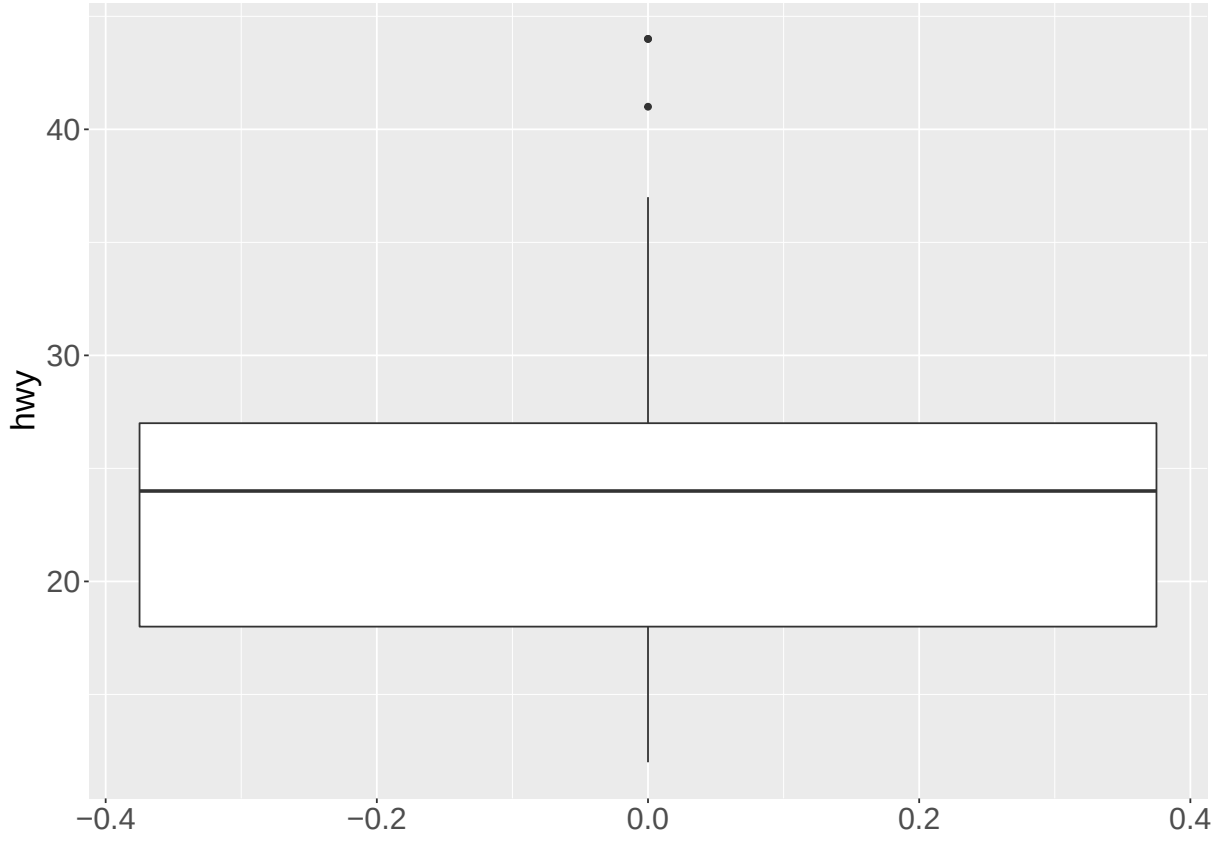
Setting `position = "dodge"` places overlapping objects directly beside one another:

```
ggplot(data = diamonds) +
  geom_bar(aes(x = cut, fill = clarity),
           position = "dodge")
```



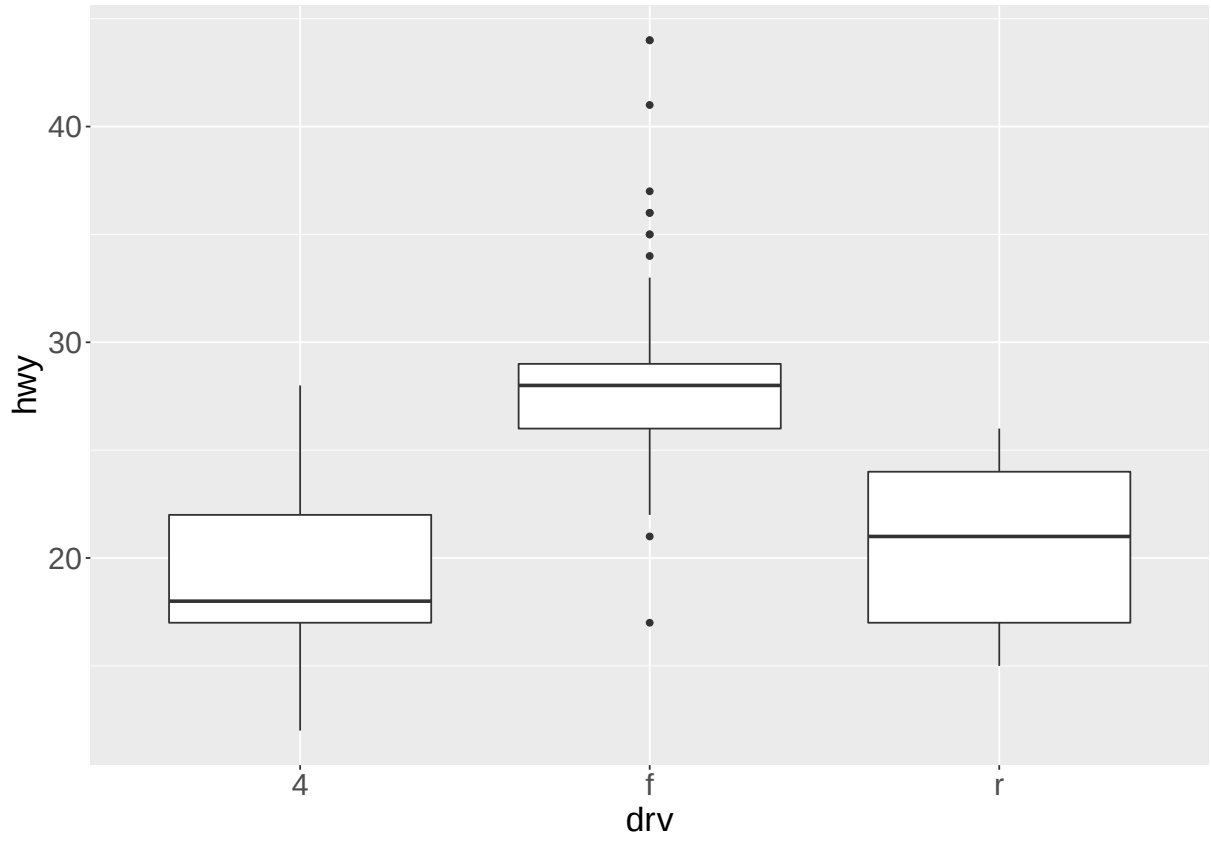
# Boxplots

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



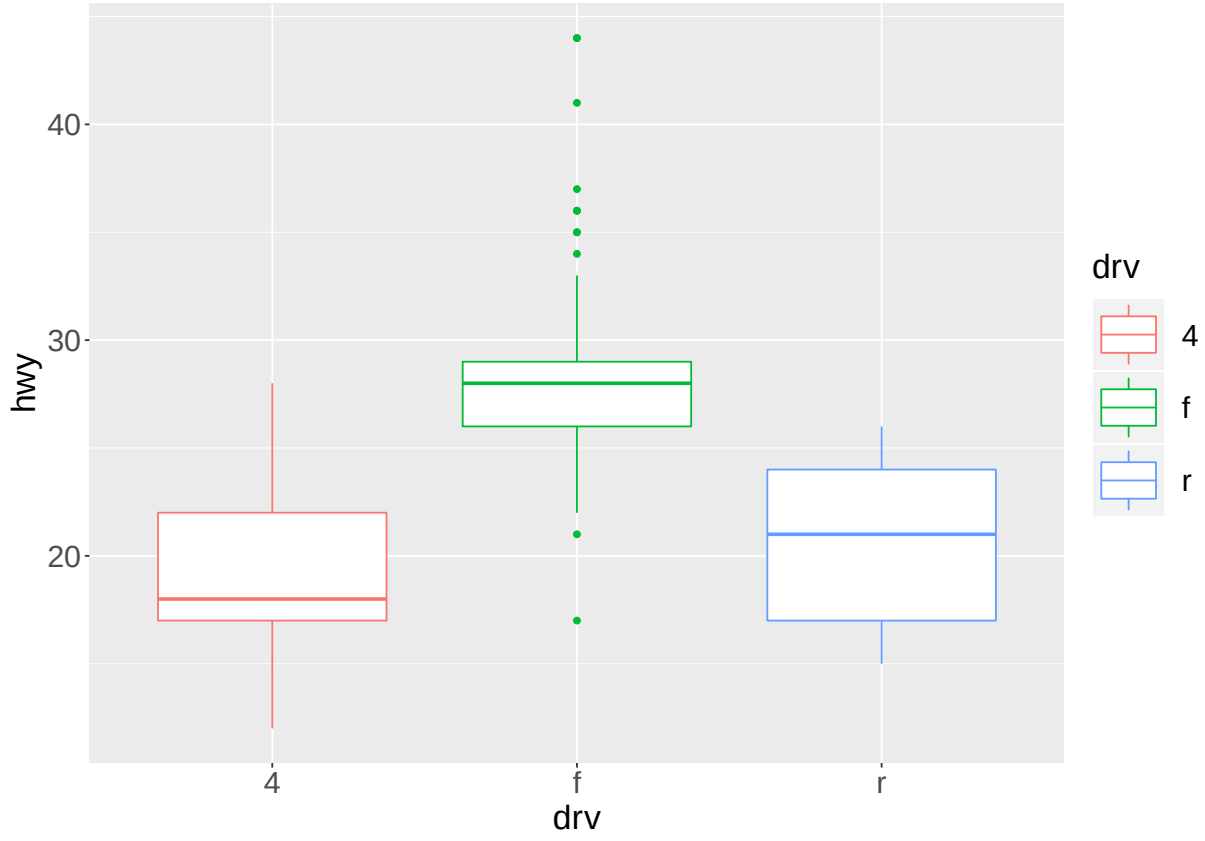
# Boxplots

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



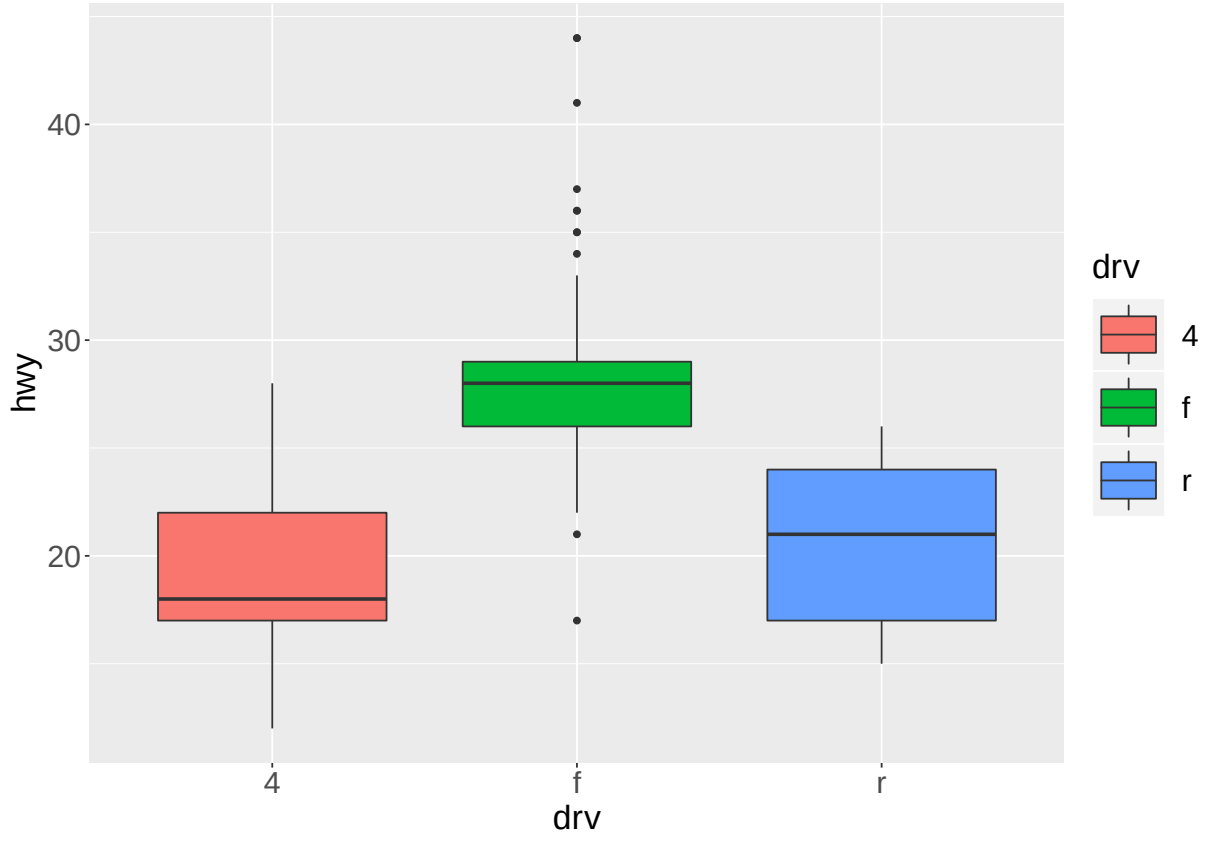
# Boxplots

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



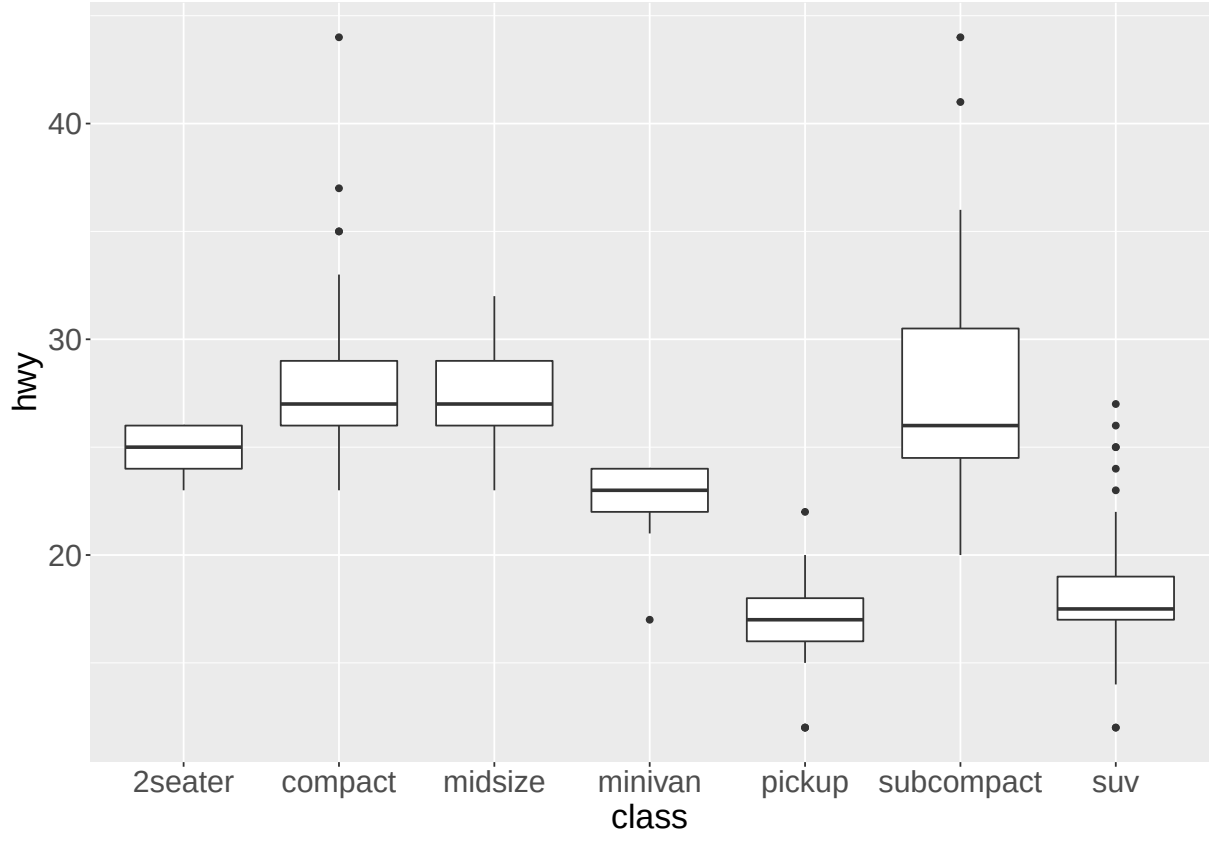
# Boxplots

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



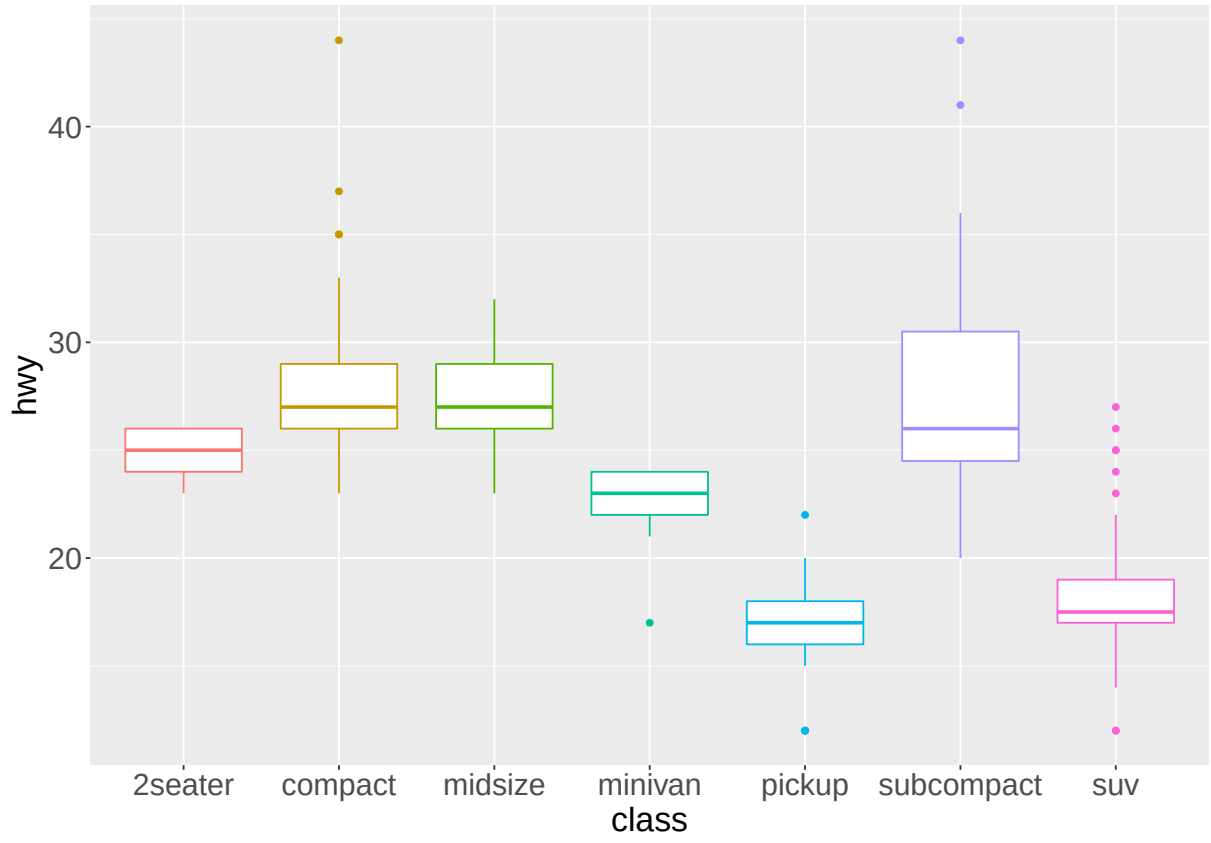
# Boxplots

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



# Boxplots

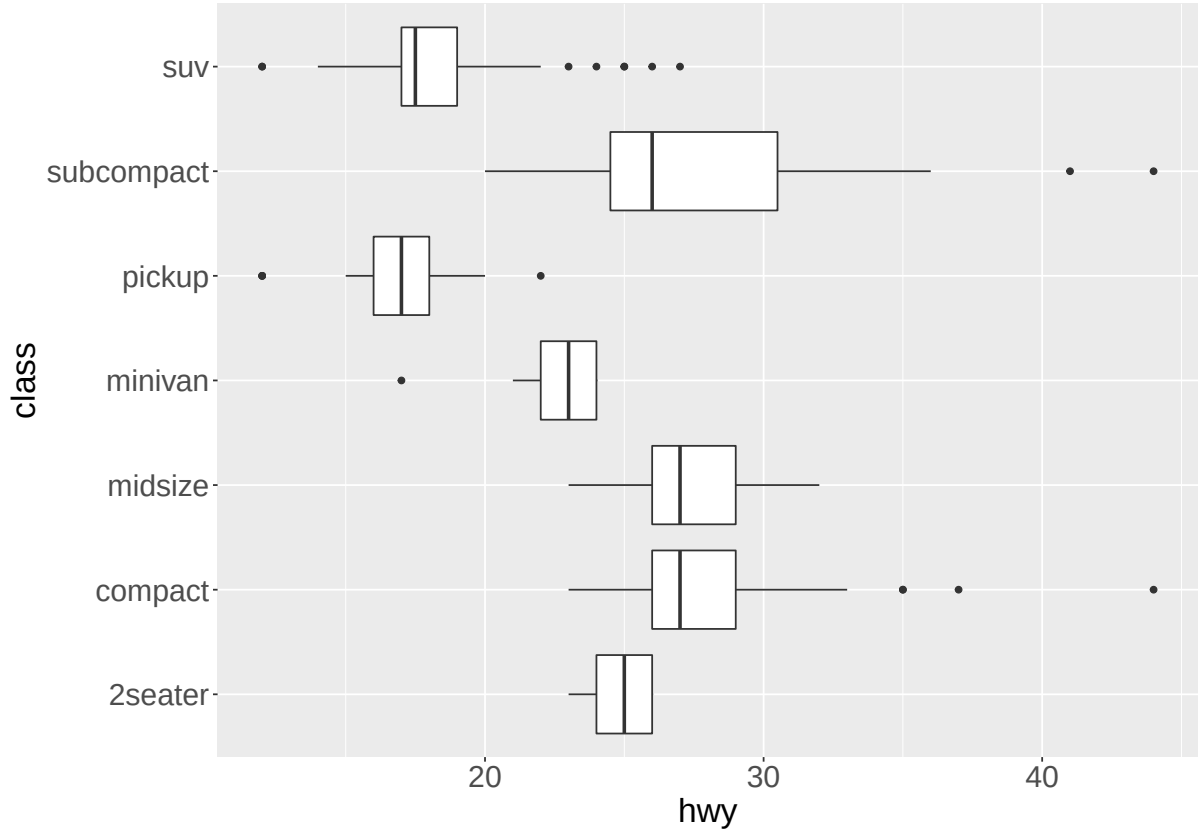
```
ggplot(data = mpg,
       aes(x = class, y = hwy, color = class)) +
  geom_boxplot(show.legend = FALSE)
```



# Coordinate systems

`coord_flip()` flips the coordinate system:

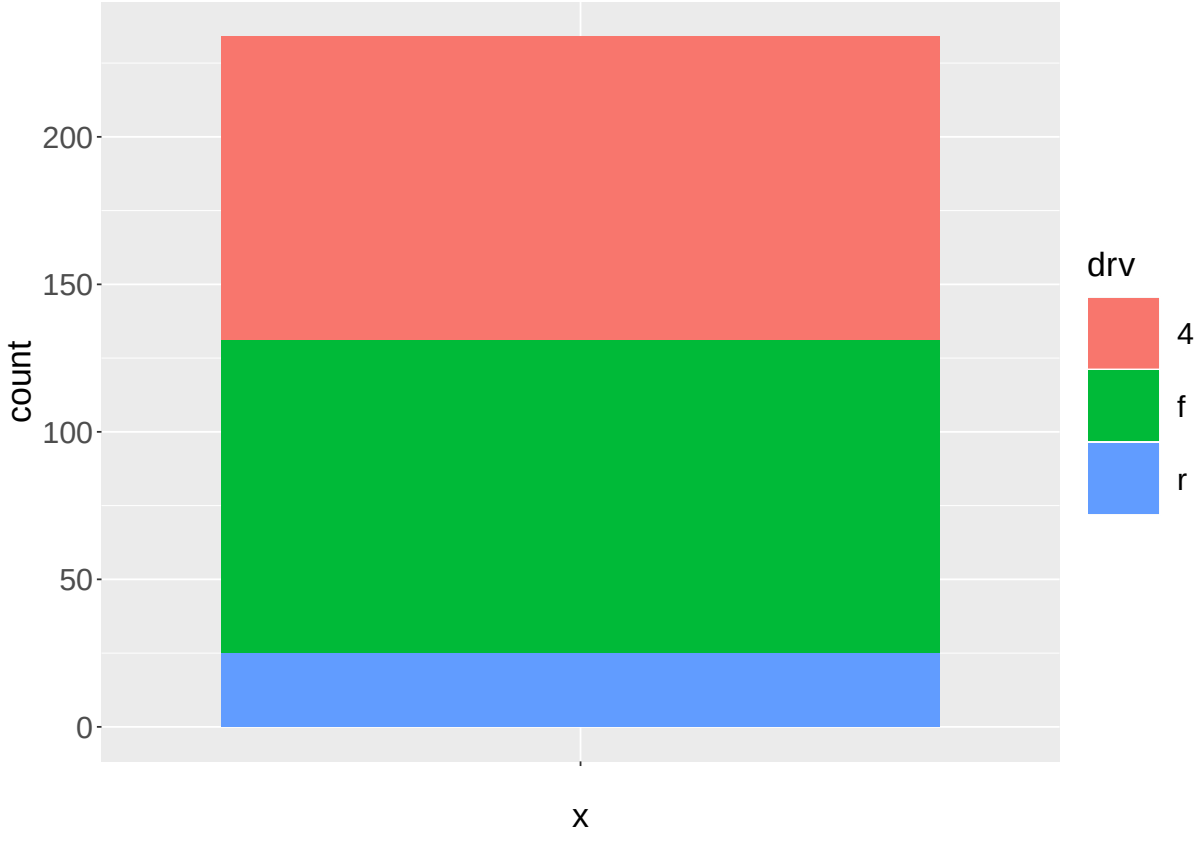
```
ggplot(data = mpg, aes(x = class, y = hwy)) +
  geom_boxplot() +
  coord_flip()
```



# Coordinate systems

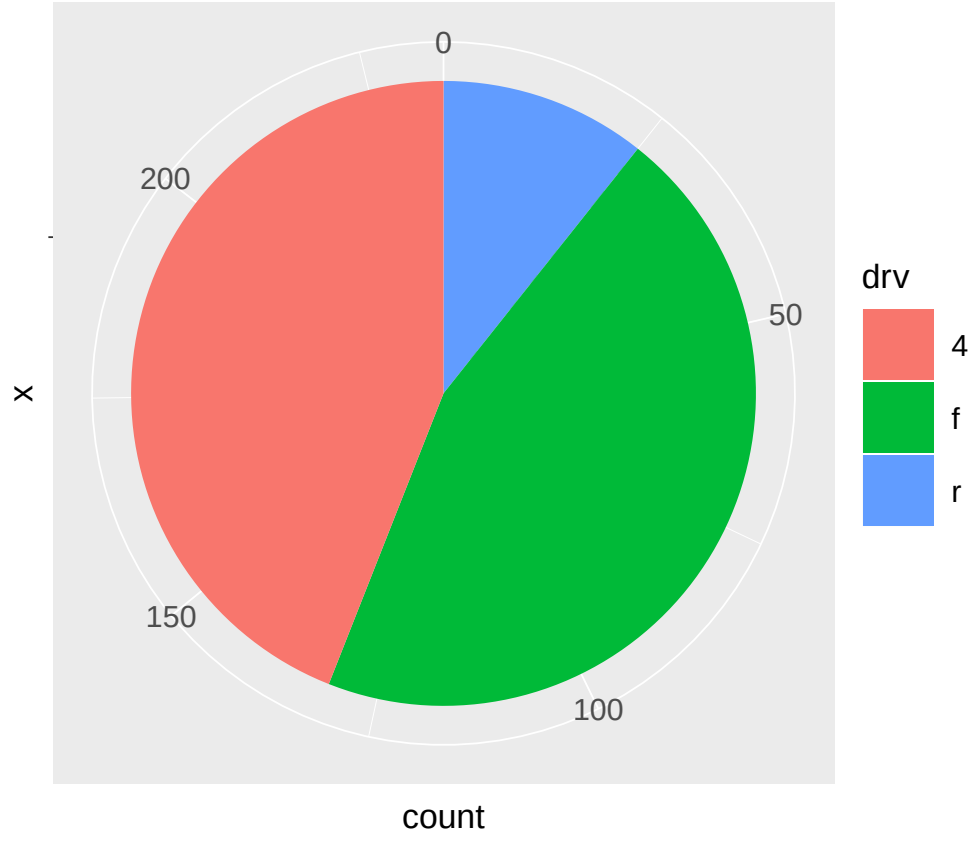
A pie chart is a stacked bar chart with polar coordinates:

```
ggplot(mpg, aes(x = "", fill = drv)) +
  geom_bar()
```



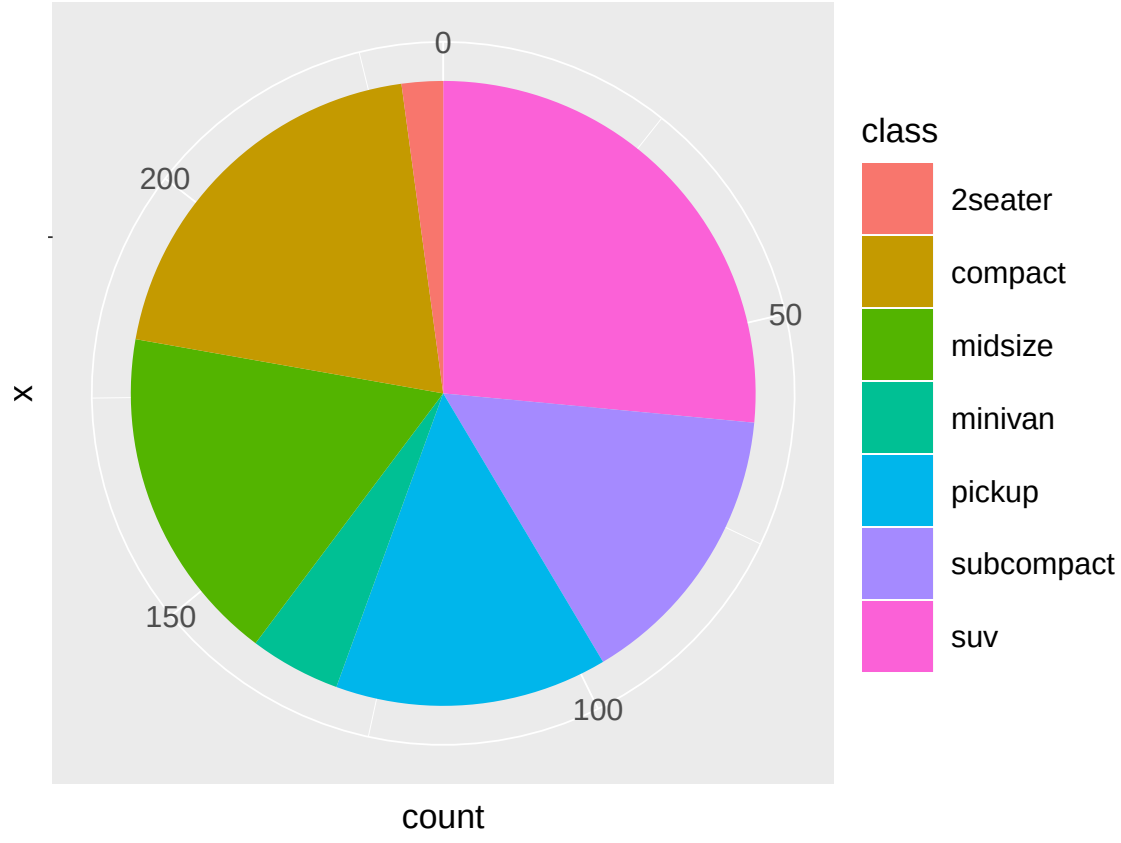
# Coordinate systems

```
ggplot(mpg, aes(x = "", fill = drv)) +
  geom_bar() +
  coord_polar("y")
```



# Coordinate systems

```
ggplot(mpg, aes(x = "", fill = class)) +
  geom_bar() +
  coord_polar("y")
```



# The ggplot template

```
ggplot(data = <DATA>) +
  <GEOM_FUNCTION>(
     mapping = aes(<MAPPINGS>),
     stat = <STAT>,
     position = <POSITION>
  ) +
  <COORDINATE_FUNCTION> +
  <FACET_FUNCTION>
```

# Saving plots

Let's build a scatterplot and save it on the working directory:

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

ggsave("my-plot.pdf")
```

# Saving plots

We can save graphs in other locations by providing the path to `ggsave()`:

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

ggsave("outputs/my-plot.pdf")
```

# Saving plots

We can use the `plot` argument of `ggsave()` to save any graph that is assigned to an objects:

```
my_plot <- ggplot(mpg, aes(displ, hwy)) +
  geom_point()

ggsave("outputs/my-plot-v2.pdf", plot = my_plot)
```

The default value of the `plot` argument is `last_plot()`.

# Bibliography

Wichkam, Hadley, and Garrett Grolemund. 2016. "R for Data Science." *O'Reilly*.

Wickham, Hadley. 2010. "A Layered Grammar of Graphics." *Journal of Computational and Graphical Statistics* 19 (1). Taylor & Francis: 3–28.