

# SML 201 – Week 5

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*Spring 2016*

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## A Grammar of Graphics

### Rationale

A grammar for communicating data visualization:

- Data: the data set we are plotting
- Aesthetics: the variation or relationships in the data we want to visualize
- Geometries: the geometric object by which we render the aesthetics
- Coordinates: the coordinate system used (not covered here)
- Facets: the layout of plots required to visualize the data
- Other Options: any other customizations we wish to make, such as changing the color scheme or labels

These are strung together like words in a sentence.

## Package `ggplot2`

The R package `ggplot2` implements a grammar of graphics along these lines. First, let's load `ggplot2`:

```
> library(ggplot2)
```

Now let's set a theme (more on this later):

```
> theme_set(theme_bw())
```

## Pieces of the Grammar

- `ggplot()`
- `aes()`
- `geom_*`()
- `facet_*`()
- `scale_*`()
- `theme()`
- `labs()`

The `*` is a placeholder for a variety of terms that we will consider.

## Geometries

Perhaps the most important aspect of `ggplot2` is to understand the “geoms”. We will cover the following:

- `geom_bar()`
- `geom_boxplot()`
- `geom_violin()`
- `geom_histogram()`
- `geom_density()`
- `geom_line()`
- `geom_point()`
- `geom_smooth()`
- `geom_hex()`

## Call Format

The most basic `ggplot2` plot is made with something like:

```
ggplot(data = <DATA FRAME>) +  
  geom_*(mapping = aes(x = <VAR X>, y = <VAR Y>))
```

where `<DATA FRAME>` is a data frame and `<VAR X>` and `<VAR Y>` are variables (i.e., columns) from this data frame. Recall `geom_*` is a placeholder for a geometry such as `geom_boxplot`.

## Layers

There's a complex "layers" construct occurring in the `ggplot2` package. However, for our purposes, it suffices to note that the different parts of the plots are layered together through the `+` operator:

```
> ggplot(data = mpg) +  
+   geom_point(mapping = aes(x = displ, y = hwy, color=drv)) +  
+   geom_smooth(mapping = aes(x = displ, y = hwy, color=drv)) +  
+   scale_color_brewer(palette = "Set1", name = "Drivetrain") +  
+   labs(title = "Highway MPG By Drivetrain and Displacement",  
+        x = "Displacement", y = "Highway MPG")
```

## Placement of the `aes()` Call

In the previous slide, we saw that the same `aes()` call was made for two `geom`'s. When this is the case, we may more simply call `aes()` from within `ggplot()`:

```
> ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color=drv)) +  
+   geom_point() +  
+   geom_smooth() +  
+   scale_color_brewer(palette = "Set1", name = "Drivetrain") +  
+   labs(title = "Highway MPG By Drivetrain and Displacement",  
+        x = "Displacement", y = "Highway MPG")
```

There may be cases where different `geom`'s are layered and require different `aes()` calls. This is something to keep in mind as we go through the specifics of the `ggplot2` package.

## Original Publications

Wickham, H. (2010) A Layered Grammar of Graphics. *Journal of Computational and Graphical Statistics*, 19 (1): 3–28.

This paper designs an implementation of *The Grammar of Graphics* by Leland Wilkinson (published in 2005).

## Documentation

- In R: `help(package="ggplot2")`
- <http://docs.ggplot2.org/current/>
- <http://www.cookbook-r.com/Graphs/>
- *ggplot2: Elegant Graphics for Data Analysis* (somewhat outdated, but gives clear rationale)

## Data Sets

### Data mpg

Load the `mpg` data set:

```
> library("dplyr") # why load dplyr?
> data("mpg", package="ggplot2")
> head(mpg)
Source: local data frame [6 x 11]

  manufacturer model displ year cyl trans drv cty
  (chr) (chr) (dbl) (int) (int) (chr) (chr) (int)
1 audi a4 1.8 1999 4 auto(f4) f 18
2 audi a4 1.8 1999 4 manual(m5) f 21
3 audi a4 2.0 2008 4 manual(m6) f 20
4 audi a4 2.0 2008 4 auto(av) f 21
5 audi a4 2.8 1999 6 auto(f6) f 16
6 audi a4 2.8 1999 6 manual(m5) f 18
Variables not shown: hwy (int), fl (chr), class (chr)
```

### Data diamonds

Load the `diamonds` data set:

```
> data("diamonds", package="ggplot2")
> head(diamonds)
Source: local data frame [6 x 10]

  carat cut color clarity depth table price x y
  (dbl) (fctr) (fctr) (fctr) (dbl) (dbl) (int) (dbl) (dbl)
1 0.23 Ideal E SI2 61.5 55 326 3.95 3.98
2 0.21 Premium E SI1 59.8 61 326 3.89 3.84
3 0.23 Good E VS1 56.9 65 327 4.05 4.07
4 0.29 Premium I VS2 62.4 58 334 4.20 4.23
```

```

5  0.31      Good      J      SI2  63.3    58   335  4.34  4.35
6  0.24 Very Good      J     VVS2  62.8    57   336  3.94  3.96
Variables not shown: z (dbl)

```

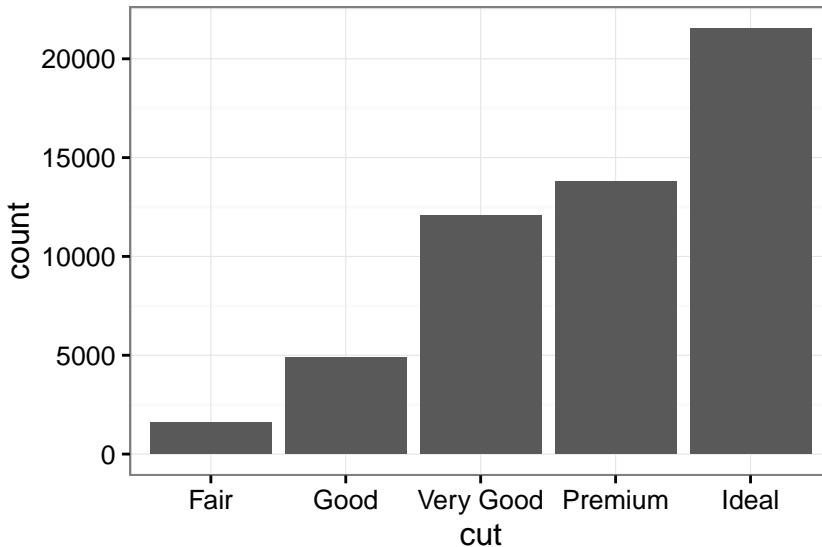
## Barplots

The `geom_bar()` layer forms a barplot and only requires an `x` assignment in the `aes()` call:

```

> ggplot(data = diamonds) +
+   geom_bar(mapping = aes(x = cut))

```

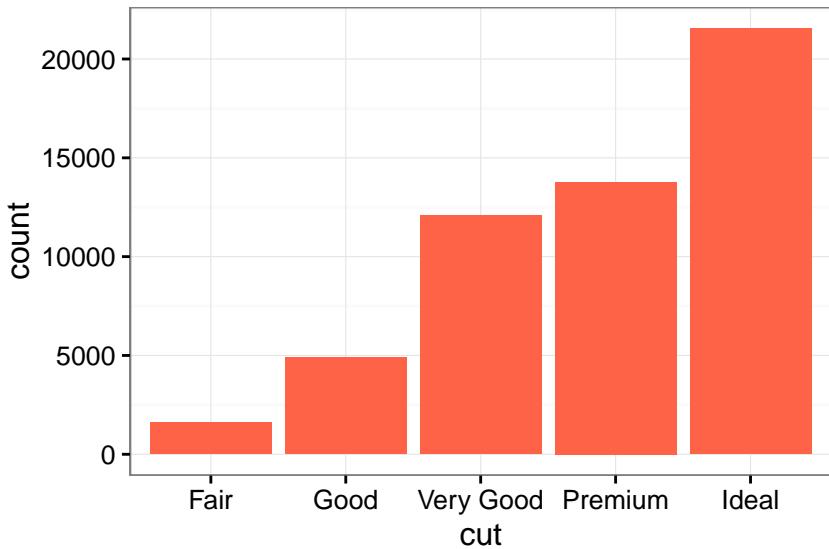


Color in the bars by assigning `fill` in `geom_bar()`, but outside of `aes()`:

```

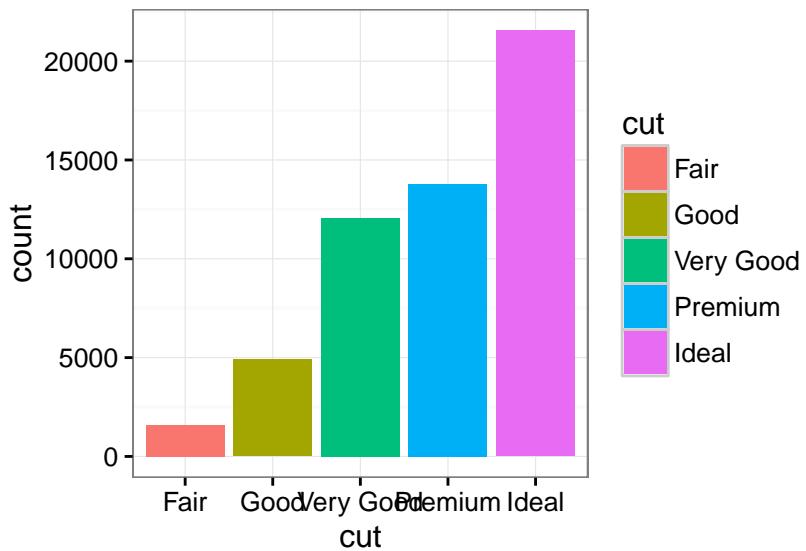
> ggplot(data = diamonds) +
+   geom_bar(mapping = aes(x = cut), fill = "tomato")

```



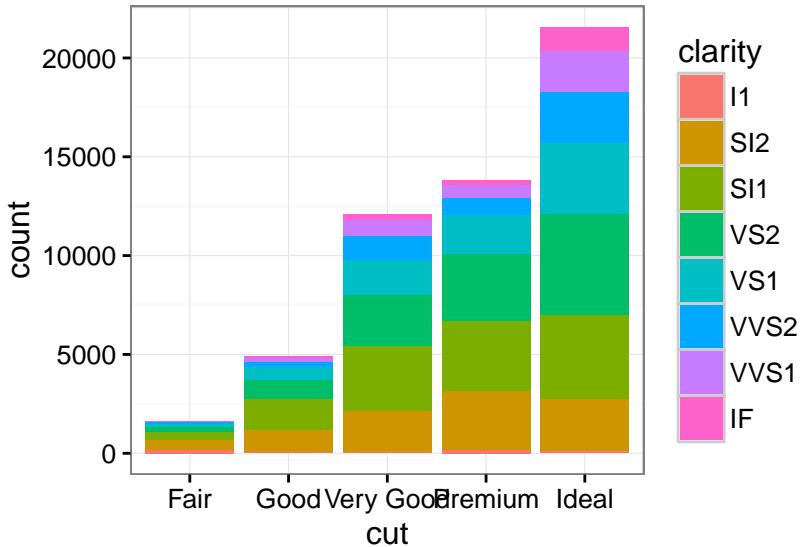
Color *within* the bars according to a variable by assigning `fill` in `geom_bar()` *inside* of `aes()`:

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



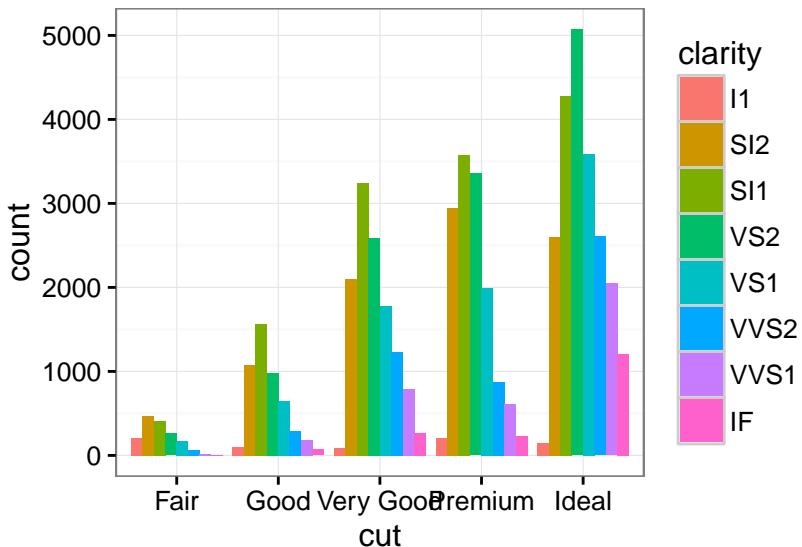
When we use `fill = clarity` within `aes()`, we see that it shows the proportion of each clarity value within each cut value:

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



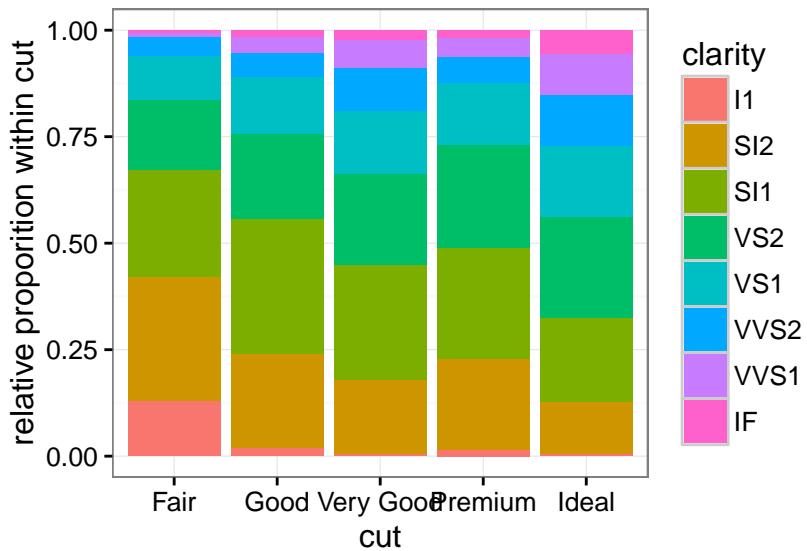
By setting `position = "dodge"` outside of `aes()`, it shows bar charts for the clarity values within each cut value:

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



By setting `position = "fill"`, it shows the proportion of `clarity` values within each `cut` value and no longer shows the `cut` values:

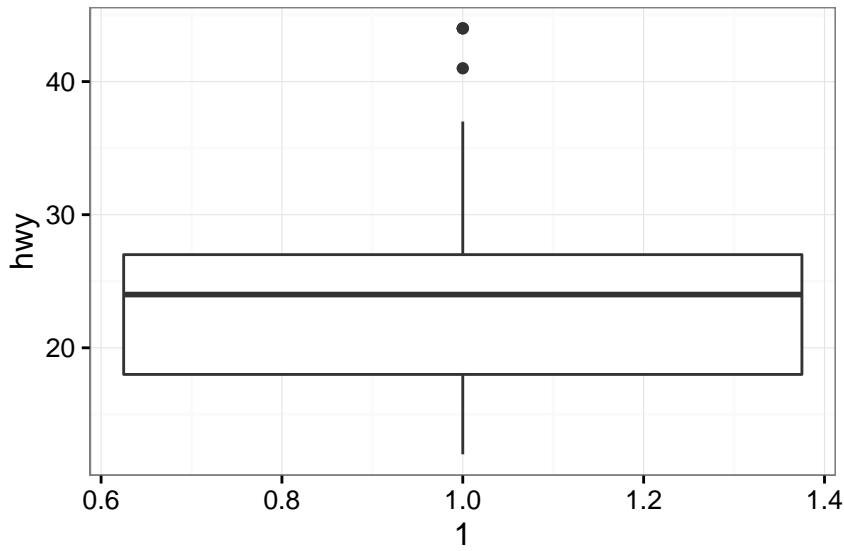
```
> ggplot(data = diamonds) +  
+   geom_bar(mapping=aes(x = cut, fill = clarity), position = "fill") +  
+   labs(x = "cut", y = "relative proportion within cut")
```



## Boxplots and Violin Plots

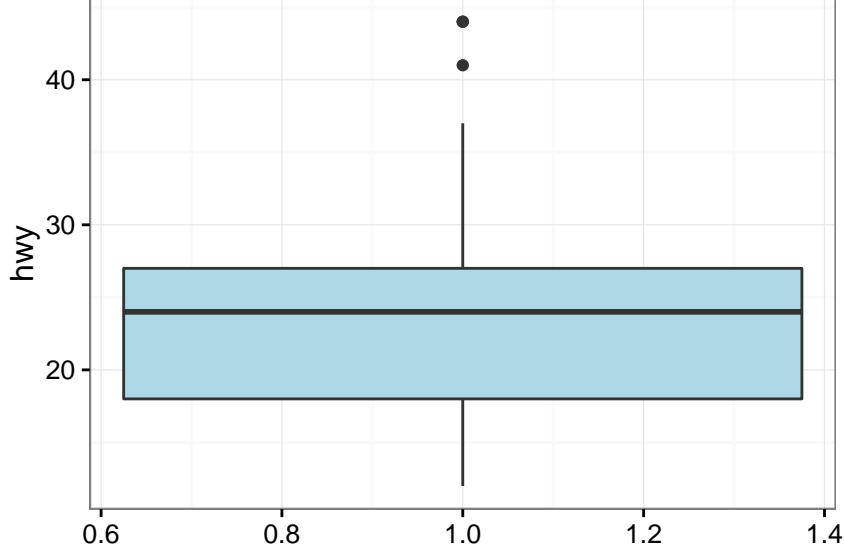
The `geom_boxplot()` layer forms a boxplot and requires both `x` and `y` assignments in the `aes()` call, even when plotting a single boxplot:

```
> ggplot(data = mpg) +  
+   geom_boxplot(mapping = aes(x = 1, y = hwy))
```



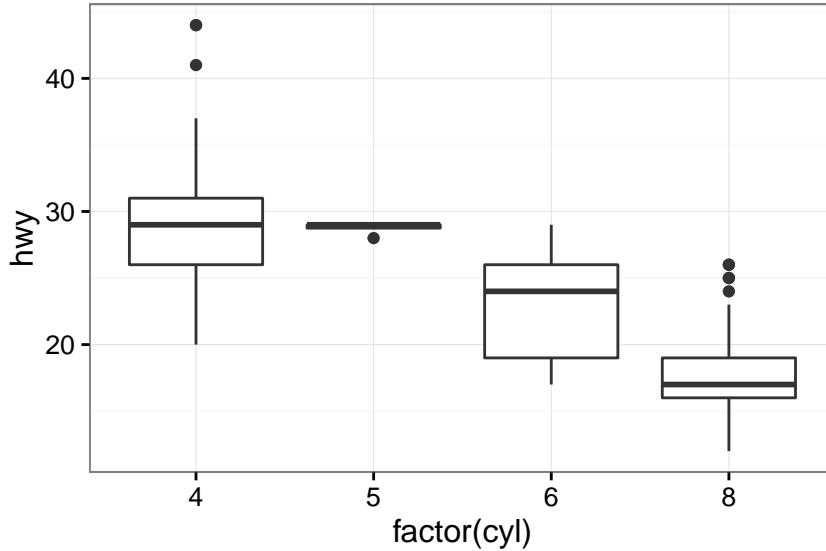
Color in the boxes by assigning `fill` in `geom_boxplot()`, but outside of `aes()`:

```
> ggplot(data = mpg) +
+   geom_boxplot(mapping = aes(x = 1, y = hwy), fill="lightblue") +
+   labs(x=NULL)
```



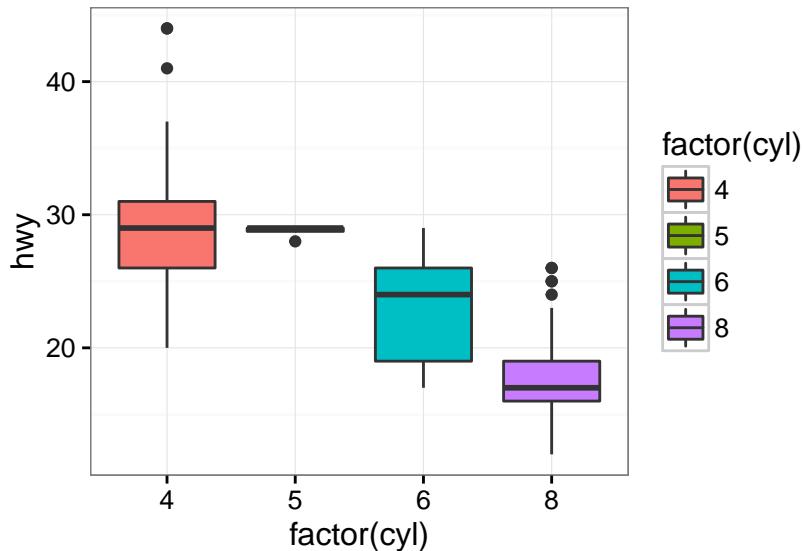
Show a boxplot for the y values occurring within each x factor level by making these assignments in `aes()`:

```
> ggplot(data = mpg) +
+   geom_boxplot(mapping = aes(x = factor(cyl), y = hwy))
```



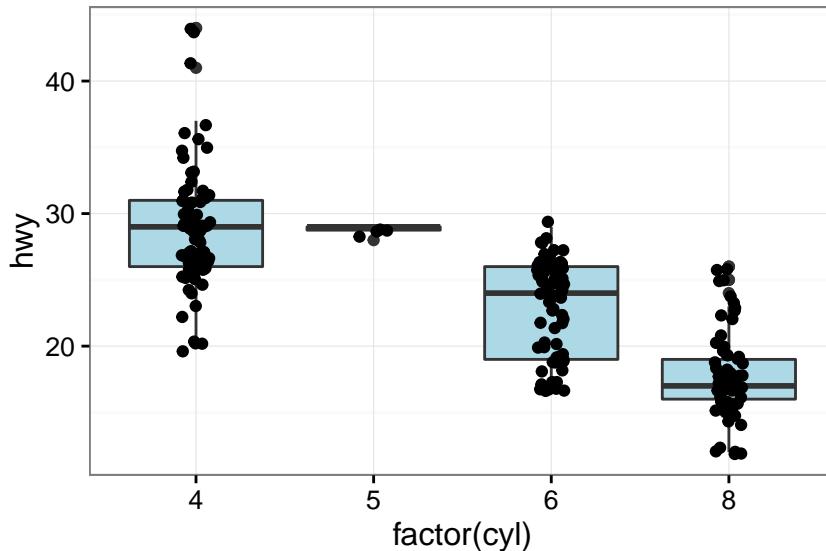
By assigning the `fill` argument *within* `aes()`, we can color each boxplot according to the x-axis factor variable:

```
> ggplot(data = mpg) +
+   geom_boxplot(mapping = aes(x = factor(cyl), y = hwy,
+                             fill = factor(cyl)))
```



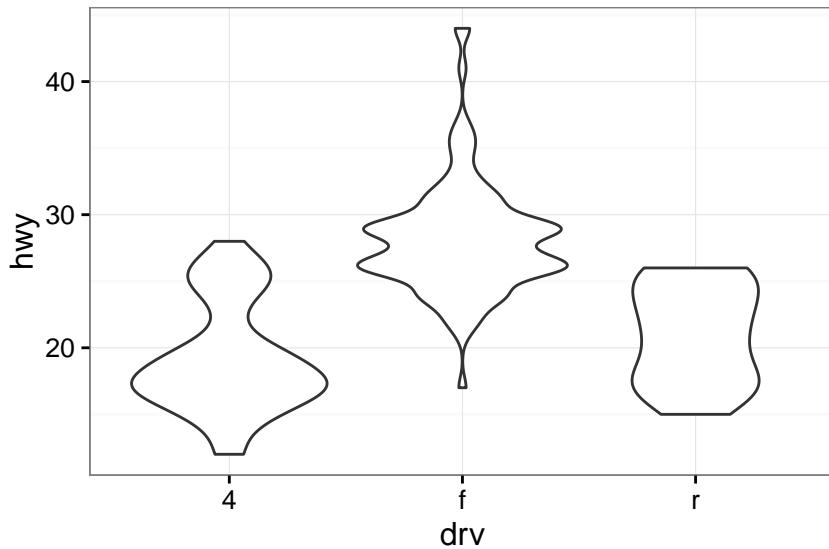
The `geom_jitter()` function plots the data points and randomly jitters them so we can better see all of the points:

```
> ggplot(data = mpg, mapping = aes(x=factor(cyl), y=hwy)) +  
+   geom_boxplot(fill = "lightblue") +  
+   geom_jitter(width = 0.2)
```



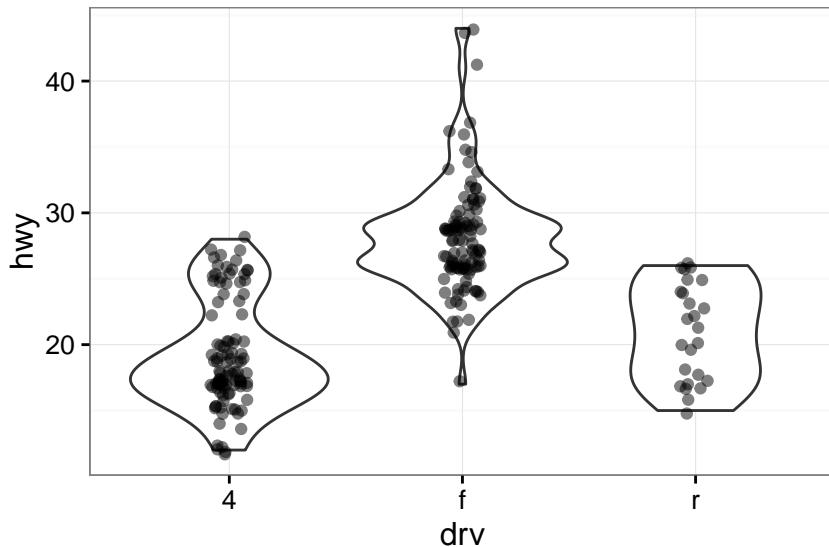
A violin plot, called via `geom_violin()`, is similar to a boxplot, except shows a density plot turned on its side and reflected across its vertical axis:

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



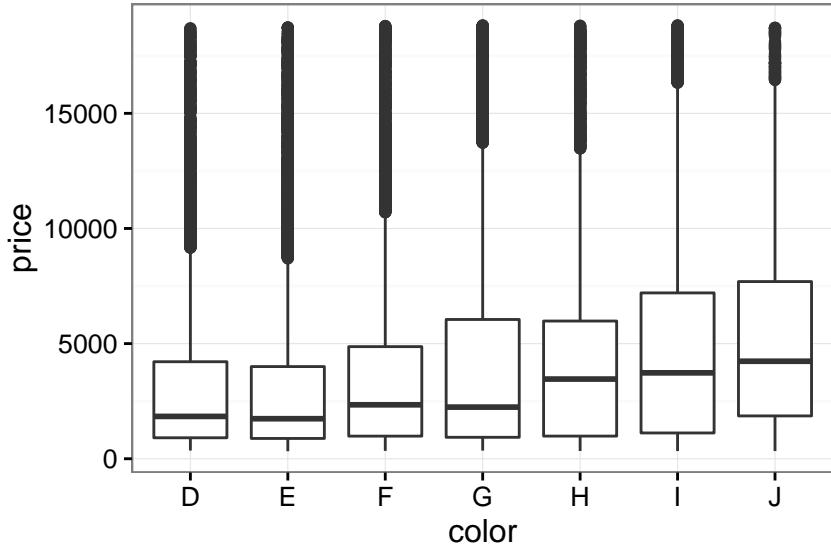
Add a `geom_jitter()` to see how the original data points relate to the violin plots:

```
> ggplot(data = mpg, mapping = aes(x = drv, y = hwy)) +
+   geom_violin(adjust=1.2) +
+   geom_jitter(width=0.2, alpha=0.5)
```



Boxplots made from the diamonds data:

```
> ggplot(diamonds) +  
+   geom_boxplot(mapping = aes(x=color, y=price))
```



The analogous violin plots made from the `diamonds` data:

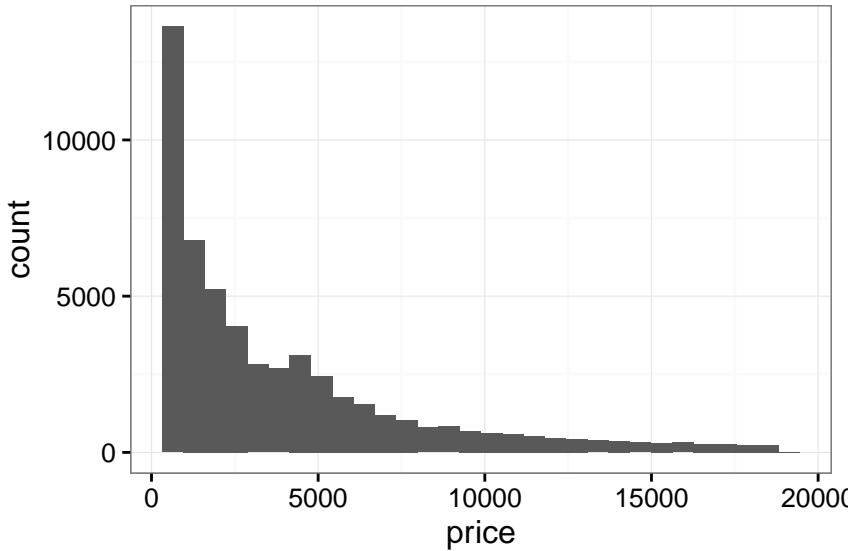
```
> ggplot(diamonds) +  
+   geom_violin(mapping = aes(x=color, y=price))
```



## Histograms and Density Plots

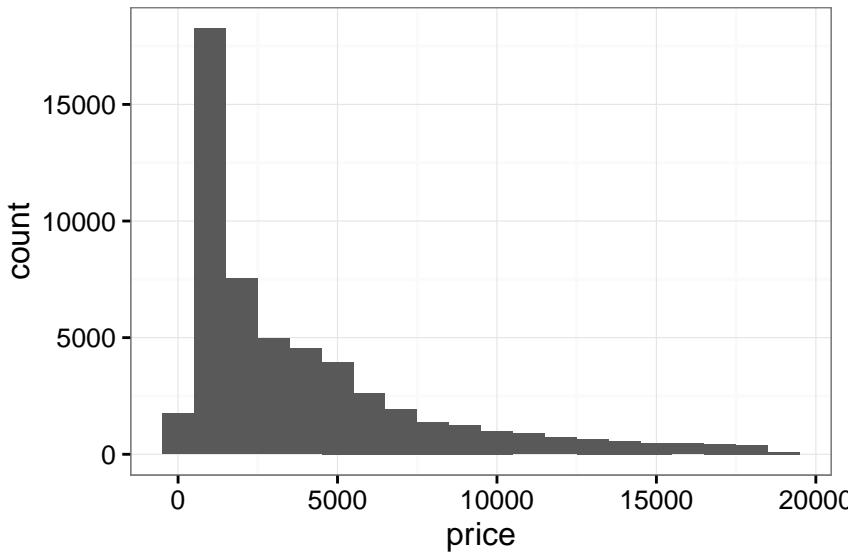
We can create a histogram using the `geom_histogram()` layer, which requires an `x` argument only in the `aes()` call:

```
> ggplot(diamonds) +  
+   geom_histogram(mapping = aes(x=price))
```



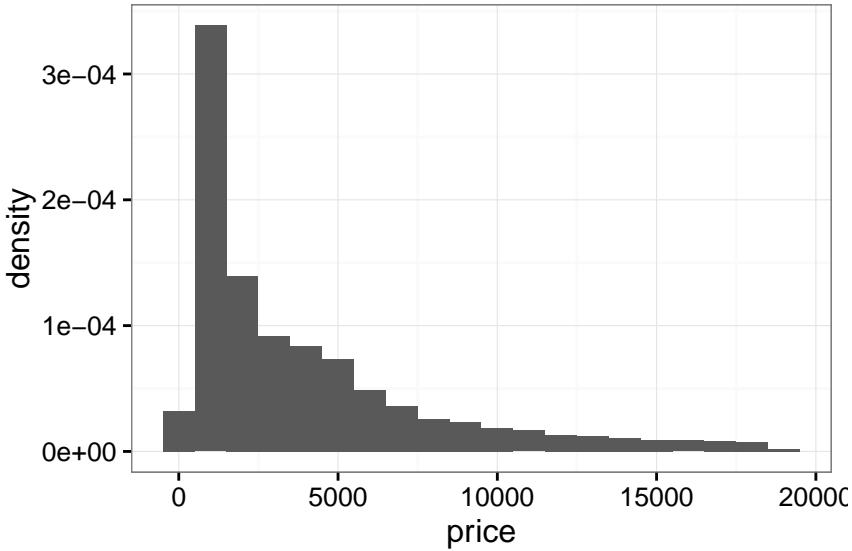
We can change the bin width directly in the histogram, which is an intuitive parameter to change based on visual inspection:

```
> ggplot(diamonds) +  
+   geom_histogram(mapping = aes(x=price), binwidth = 1000)
```



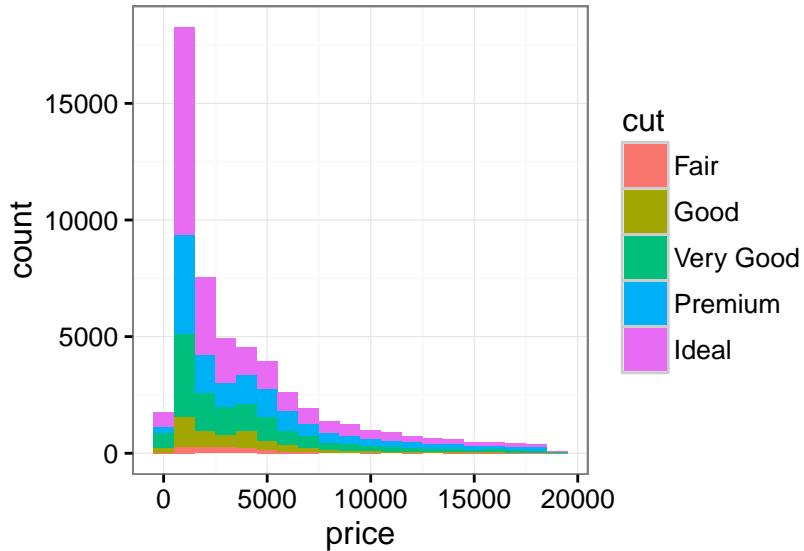
Instead of counts on the y-axis, we may instead want the area of the bars to sum to 1, like a probability density:

```
> ggplot(diamonds) +
+   geom_histogram(mapping = aes(x=price, y=..density..), binwidth=1000)
```



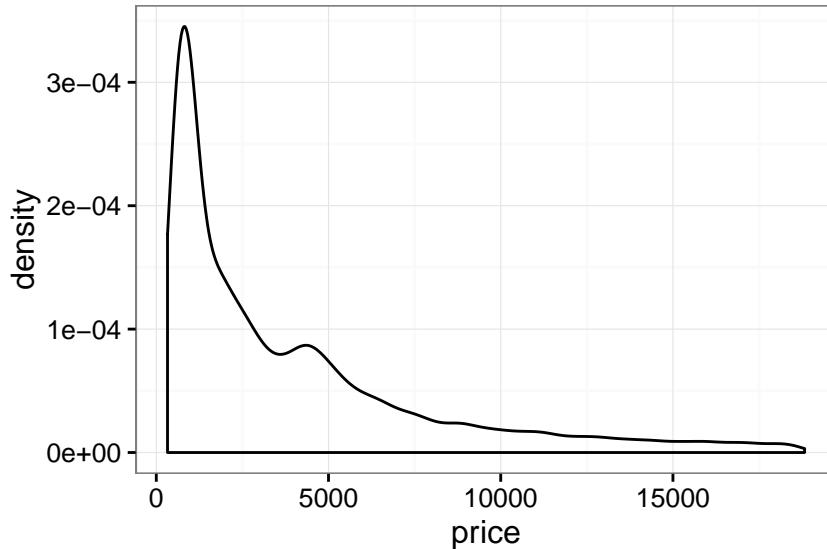
When we use `fill = cut` within `aes()`, we see that it shows the counts of each `cut` value within each `price` bin:

```
> ggplot(diamonds) +  
+   geom_histogram(mapping = aes(x=price, fill = cut), binwidth = 1000)
```



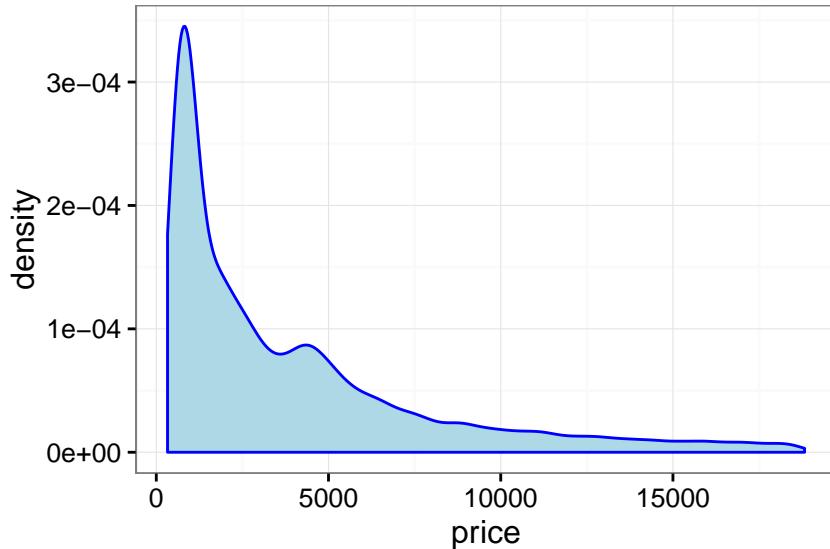
Display a density plot using the `geom_density()` layer:

```
> ggplot(diamonds) +  
+   geom_density(mapping = aes(x=price))
```



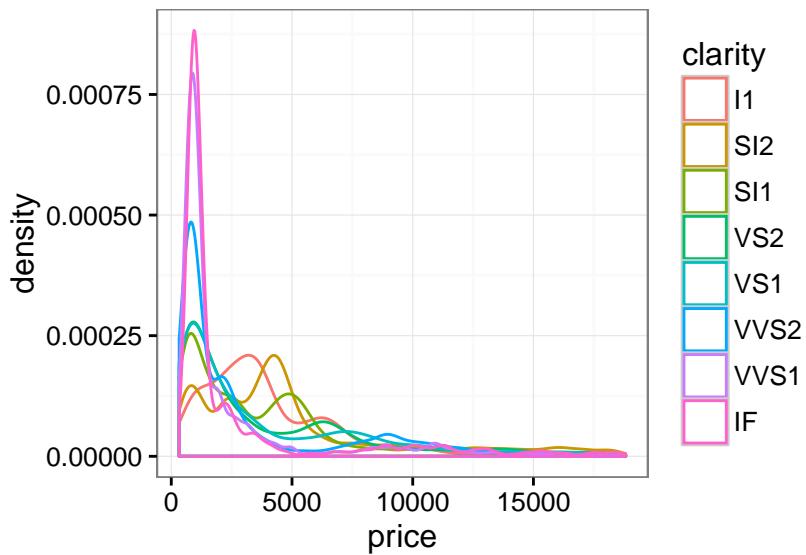
Employ the arguments `color="blue"` and `fill="lightblue"` outside of the `aes()` call to include some colors:

```
> ggplot(diamonds) +  
+   geom_density(mapping = aes(x=price), color="blue", fill="lightblue")
```



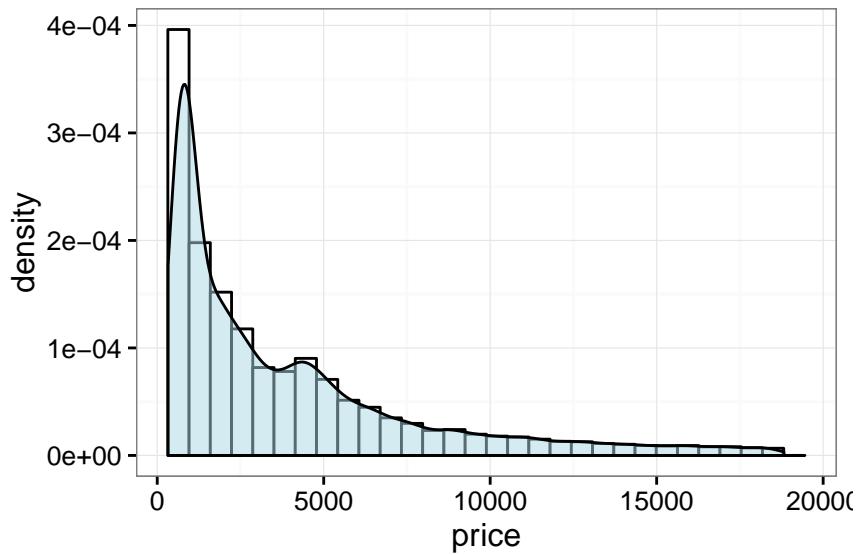
By utilizing `color=clarity` we plot a density of `price` stratified by each `clarity` value:

```
> ggplot(diamonds) +  
+   geom_density(mapping = aes(x=price, color=clarity))
```



Overlay a density plot and a histogram together:

```
> ggplot(diamonds, mapping = aes(x=price)) +
+   geom_histogram(aes(y=..density..), color="black", fill="white") +
+   geom_density(fill="lightblue", alpha=.5)
```



## Line Plots

`babynames` Revisited

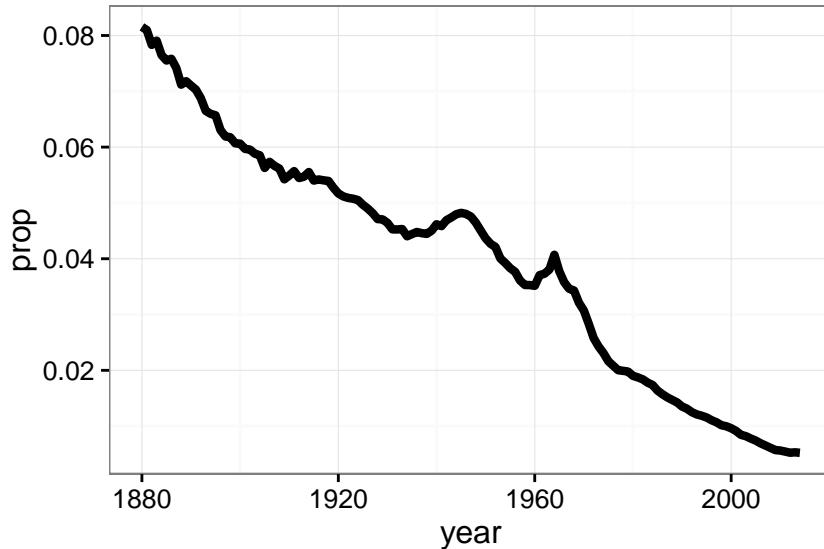
Let's first create a data frame that captures the number of times "John" is registered in males per year:

```
> library("babynames")
> john <- babynames %>% filter(sex=="M", name=="John")
> head(john)
Source: local data frame [6 x 5]

  year   sex  name    n      prop
  (dbl) (chr) (chr) (int)     (dbl)
1 1880     M  John  9655 0.08154561
2 1881     M  John  8769 0.08098149
3 1882     M  John  9557 0.07831488
4 1883     M  John  8894 0.07907183
5 1884     M  John  9388 0.07648626
6 1885     M  John  8756 0.07551726
```

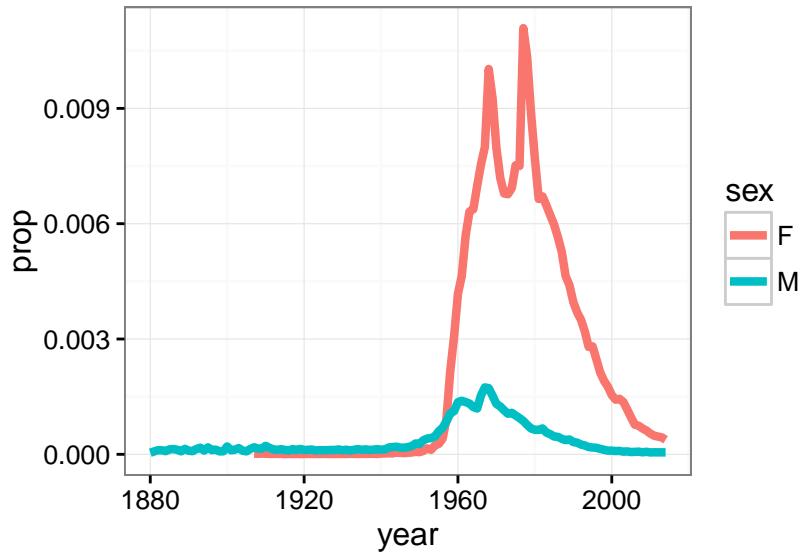
We can `geom_lines()` to plot a line showing the popularity of "John" over time:

```
> ggplot(data = john) +
+   geom_line(mapping = aes(x=year, y=prop), size=1.5)
```



Now let's look at a name that occurs nontrivially in males and females:

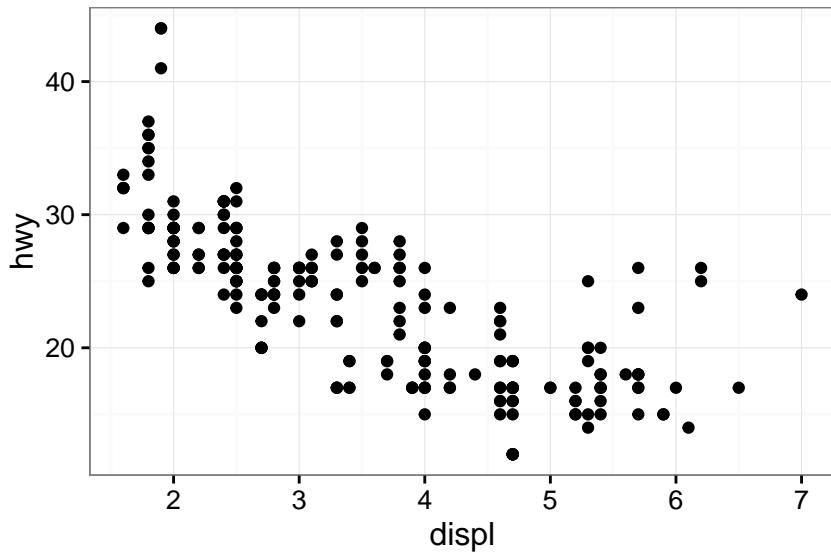
```
> kelly <- babynames %>% filter(name=="Kelly")
> ggplot(data = kelly) +
+   geom_line(mapping = aes(x=year, y=prop, color=sex), size=1.5)
```



## Scatterplots

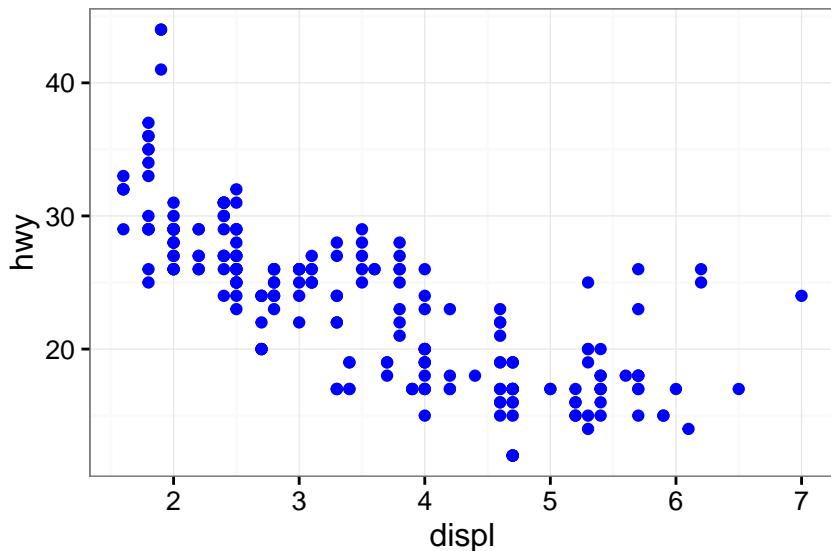
The layer `geom_point()` produces a scatterplot, and the `aes()` call requires `x` and `y` assignment:

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



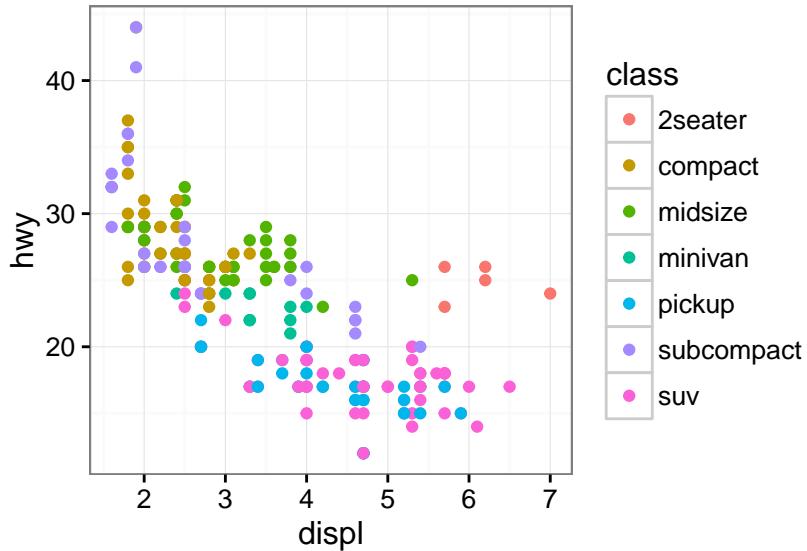
Give the points a color:

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



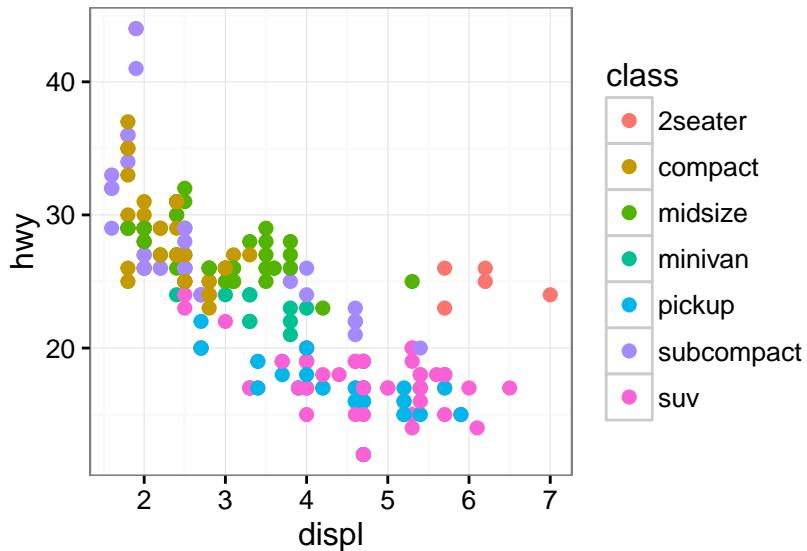
Color the points according to a factor variable by including `color = class` within the `aes()` call:

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



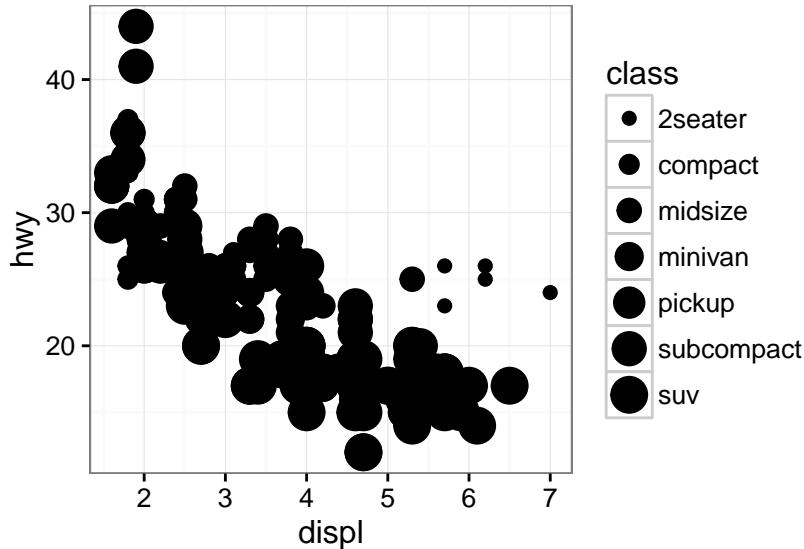
Increase the size of points with `size=2` outside of the `aes()` call:

```
> ggplot(data = mpg) +
+   geom_point(mapping = aes(x = displ, y = hwy, color = class), size=2)
```



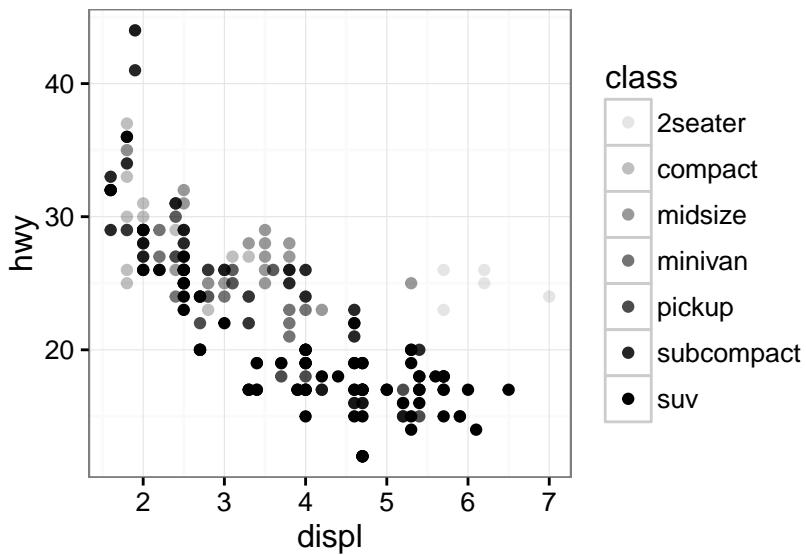
Vary the size of the points according to the `class` factor variable:

```
> ggplot(data = mpg) +  
+   geom_point(mapping = aes(x = displ, y = hwy, size = class))  
Warning: Using size for a discrete variable is not advised.
```



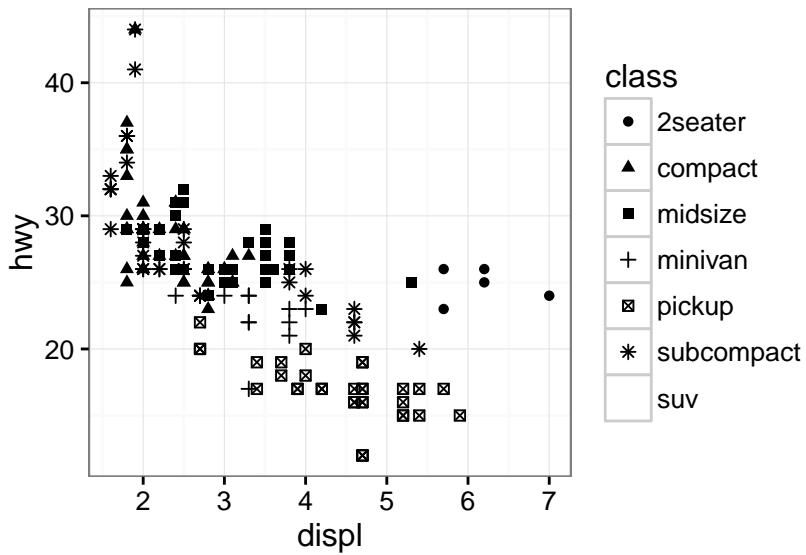
Vary the transparency of the points according to the `class` factor variable by setting `alpha=class` within the `aes()` call:

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



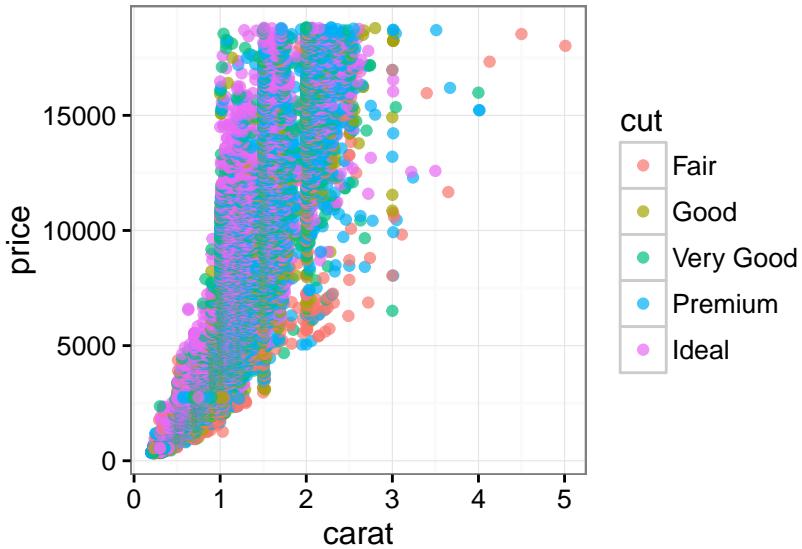
Vary the shape of the points according to the `class` factor variable by setting `alpha=class` within the `aes()` call (maximum 6 possible shapes – oops!):

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



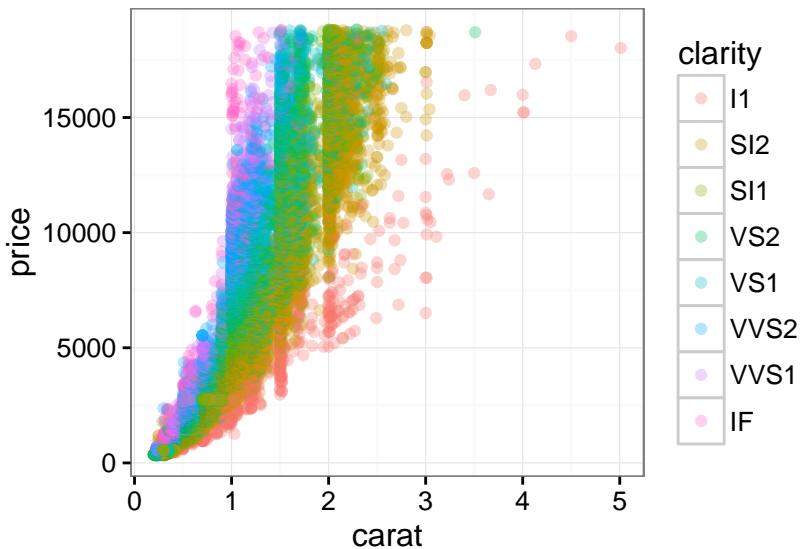
Color the points according to the `cut` variable by setting `color=cut` within the `aes()` call:

```
> ggplot(data = diamonds) +
+   geom_point(mapping = aes(x=carat, y=price, color=cut), alpha=0.7)
```



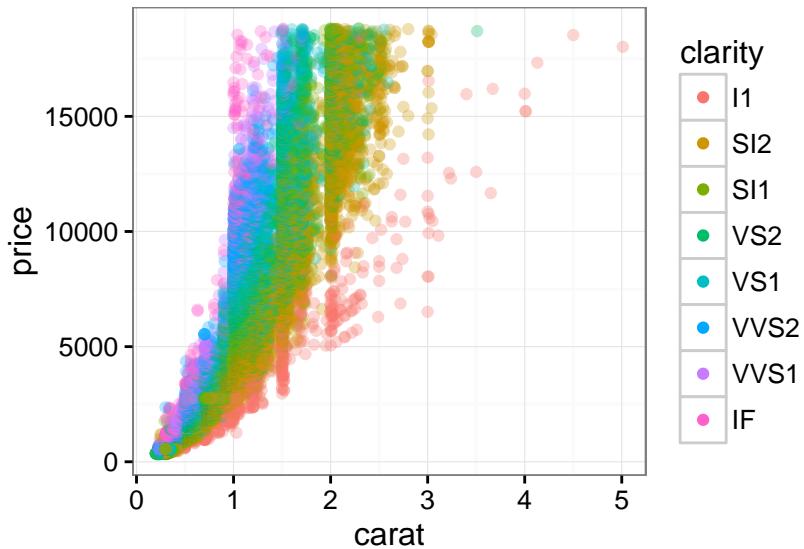
Color the points according to the clarity variable by setting `color=clarity` within the `aes()` call:

```
> ggplot(data = diamonds) +
+   geom_point(mapping=aes(x=carat, y=price, color=clarity), alpha=0.3)
```



Override the `alpha=0.3` in the legend:

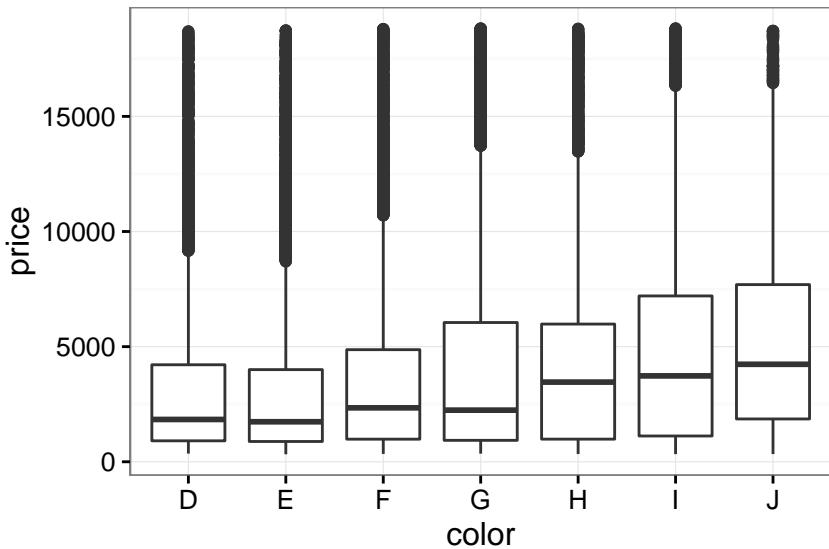
```
> ggplot(data = diamonds) +  
+   geom_point(mapping=aes(x=carat, y=price, color=clarity), alpha=0.3) +  
+   guides(color = guide_legend(override.aes = list(alpha = 1)))
```



## Axis Scales

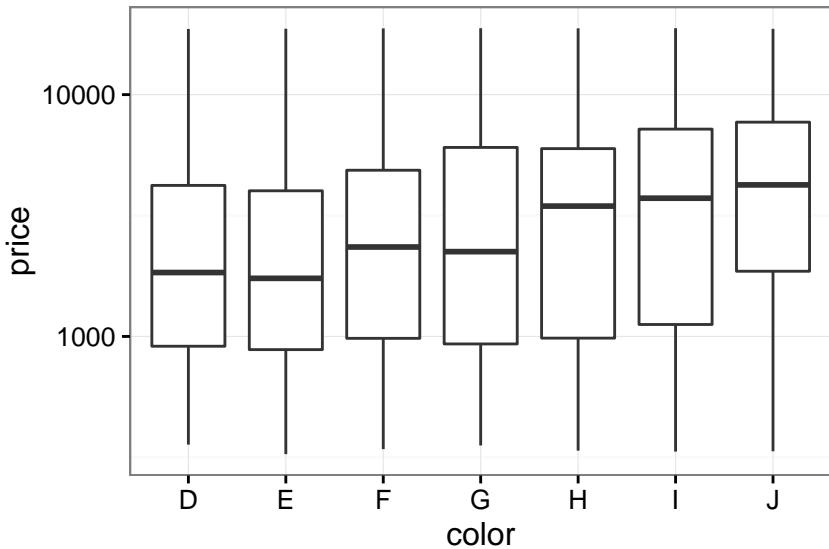
The `price` variable seems to be significantly right-skewed:

```
> ggplot(diamonds) +  
+   geom_boxplot(aes(x=color, y=price))
```



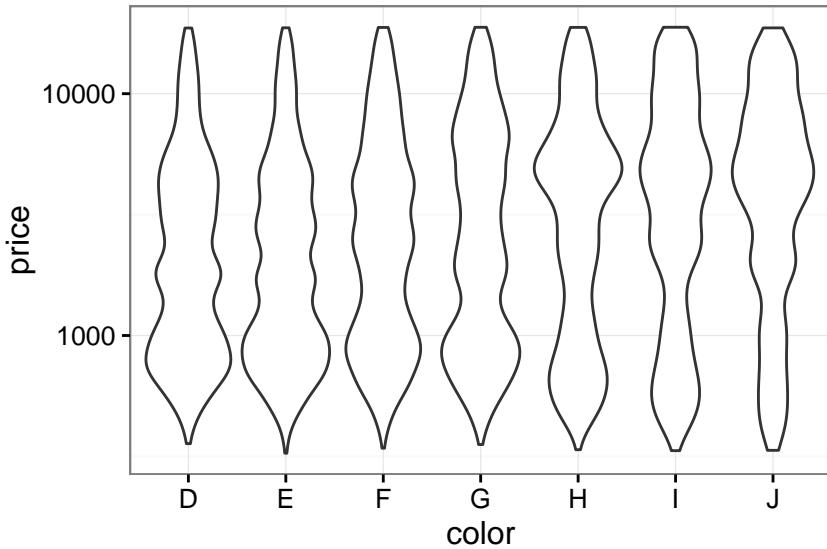
We can try to reduce this skewness by rescaling the variables. We first try to take the `log(base=10)` of the `price` variable via `scale_y_log10()`:

```
> ggplot(diamonds) +
+   geom_boxplot(aes(x=color, y=price)) +
+   scale_y_log10()
```



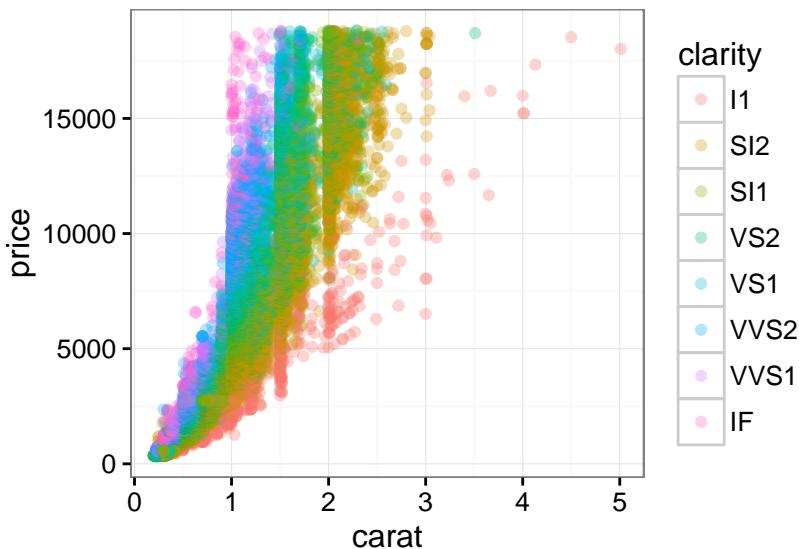
Let's repeat this on the analogous violin plots:

```
> ggplot(diamonds) +
+   geom_violin(aes(x=color, y=price)) +
+   scale_y_log10()
```



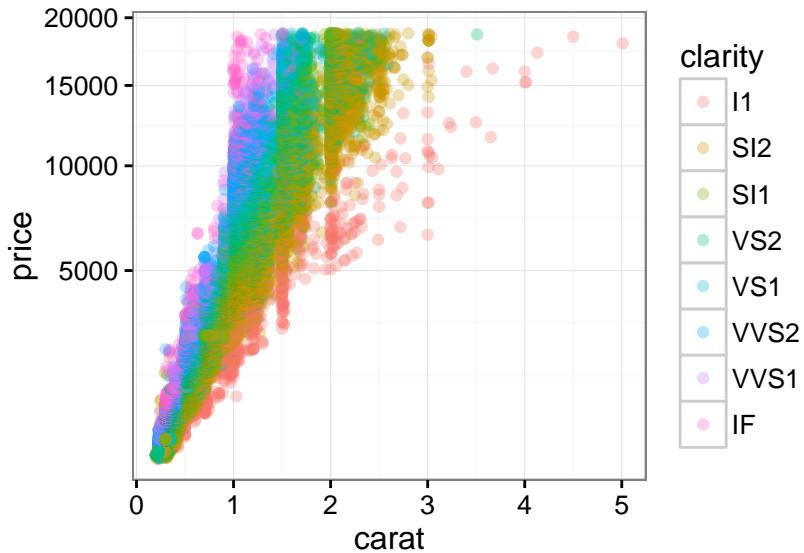
The relationship between `carat` and `price` is very nonlinear. Let's explore different transformations to see if we can find an approximately linear relationship.

```
> ggplot(data = diamonds) +
+   geom_point(mapping=aes(x=carat, y=price, color=clarity), alpha=0.3)
```



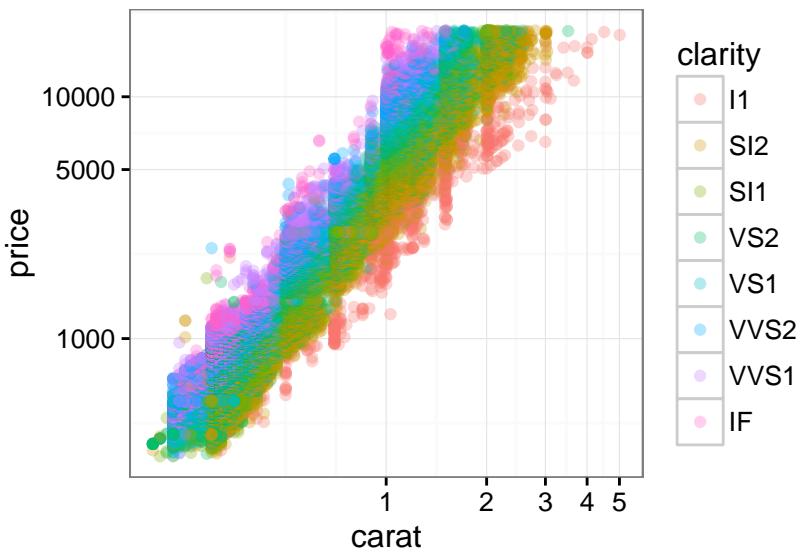
First try to take the squareroot of the the `price` variable:

```
> ggplot(data = diamonds) +  
+   geom_point(aes(x=carat, y=price, color=clarity), alpha=0.3) +  
+   scale_y_sqrt()
```



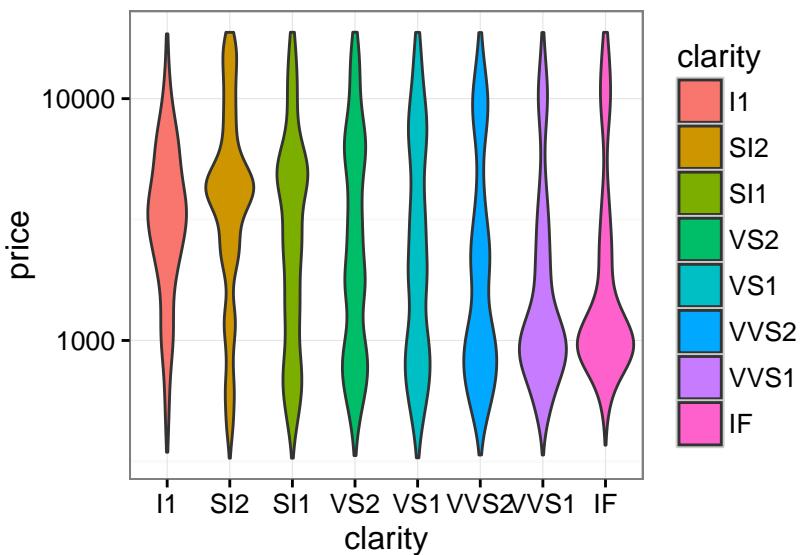
Now let's try to take `log(base=10)` on both the `carat` and `price` variables:

```
> ggplot(data = diamonds) +  
+   geom_point(aes(x=carat, y=price, color=clarity), alpha=0.3) +  
+   scale_y_log10(breaks=c(1000,5000,10000)) +  
+   scale_x_log10(breaks=1:5)
```



Forming a violin plot of `price` stratified by `clarity` and transforming the `price` variable yields an interesting relationship in this data set:

```
> ggplot(diamonds) +
+   geom_violin(aes(x=clarity, y=price, fill=clarity), adjust=1.5) +
+   scale_y_log10()
```



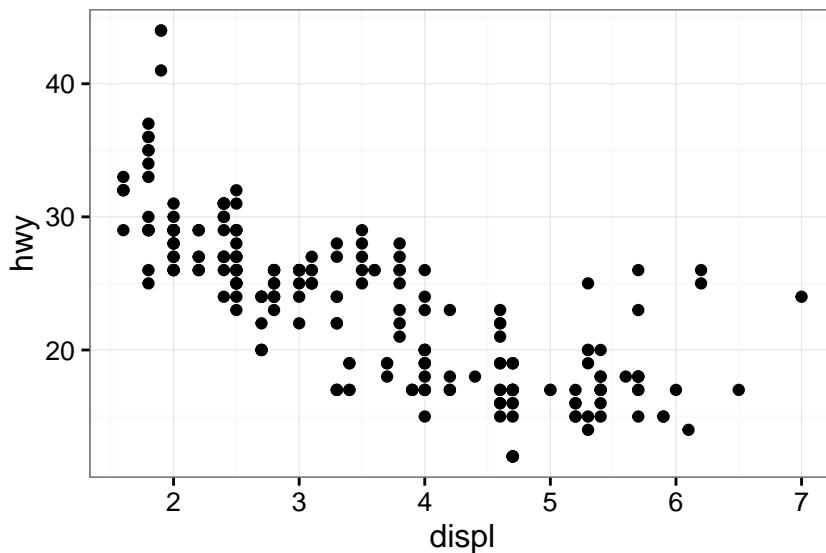
## Scatterplot Smoothers

Fitting “Smoothers” and Other Models to Scatterplots

- Later this semester, we will spend several weeks learning how to explain or predict an outcome variable in terms of predictor variables
- We will briefly show here how to plot some simple model fits to scatterplots
- You may want to return to these slides later in the semester once we cover modeling in more detail

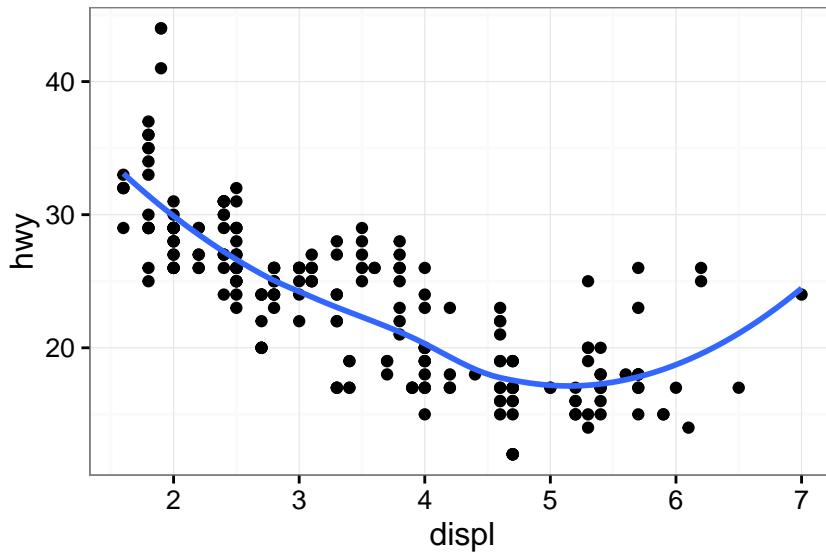
Recall the scatterplot showing the relationship between highway mpg and displacement. How can we plot a smoothed relationship between these two variables?

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



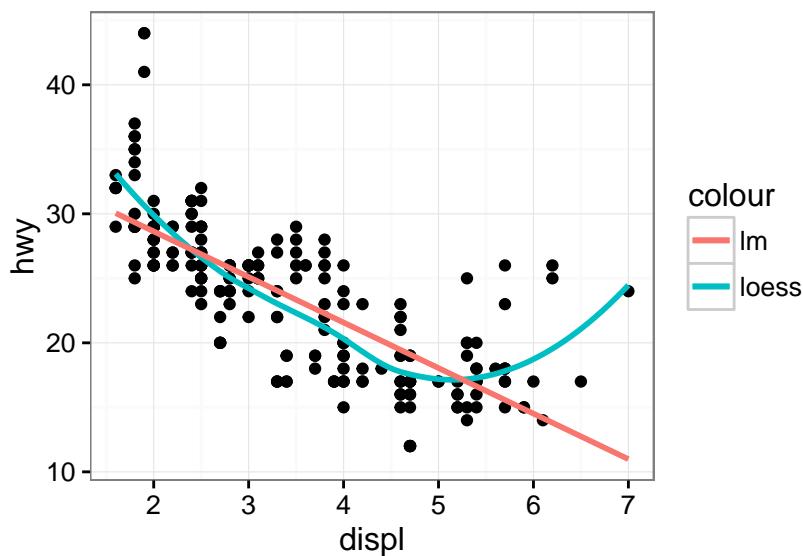
Plot a smoother with `geom_smooth()` using the default settings (other than removing the error bands):

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



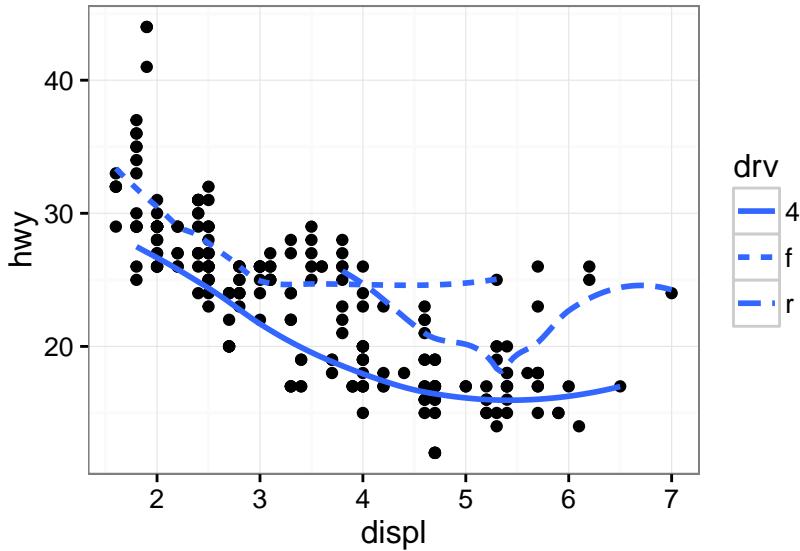
The default smoother here is a “loess” smoother. Let’s compare that to the least squares regression line:

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



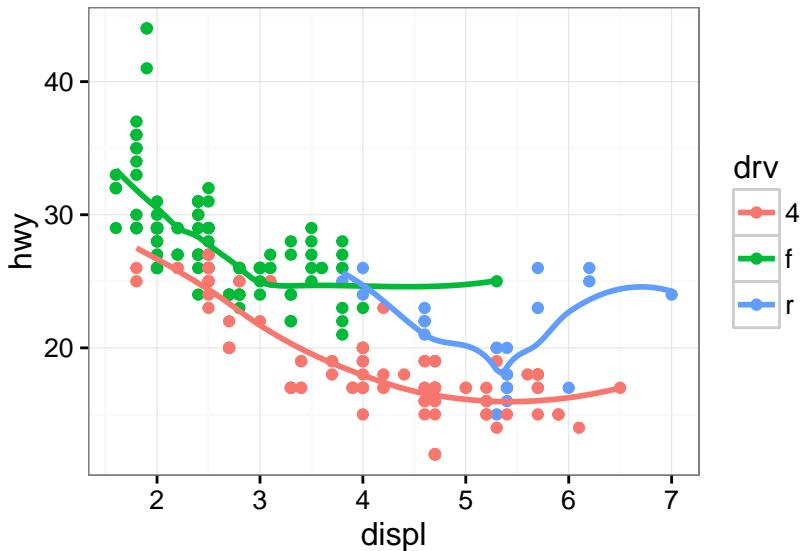
Now let’s plot a smoother to the points stratified by the `drv` variable:

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



Instead of different line types, let's instead differentiate them by line color:

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



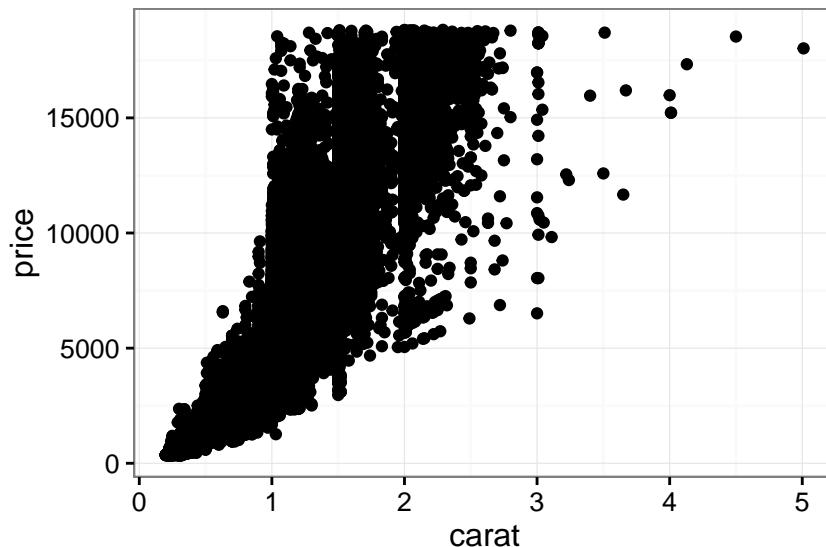
## Overplotting

Definition

- Overplotting occurs when there are many observations, resulting in many objects being plotted on top of each other
- For example, the `diamonds` data set has 53940 observations per variable
- Let's explore some ways to deal with overplotting

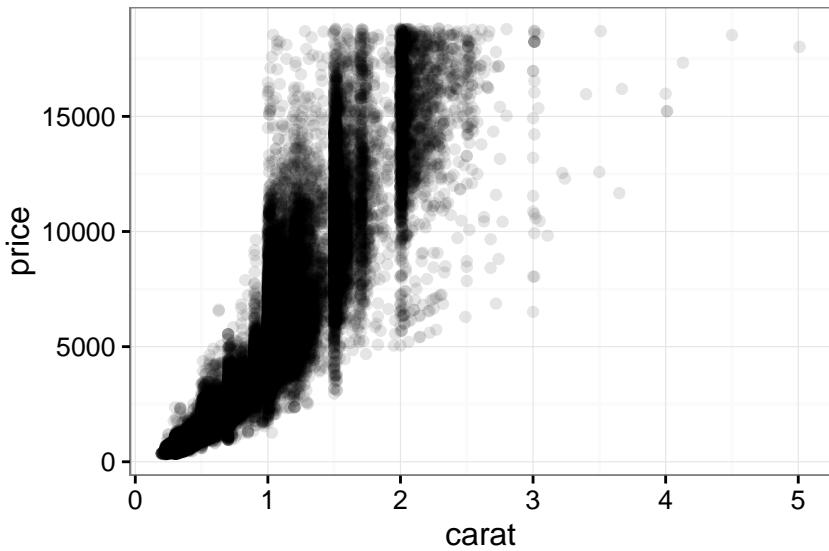
Here is an example of an overplotted scatterplot:

```
> ggplot(data = diamonds, mapping = aes(x=carat, y=price)) +  
+   geom_point()
```



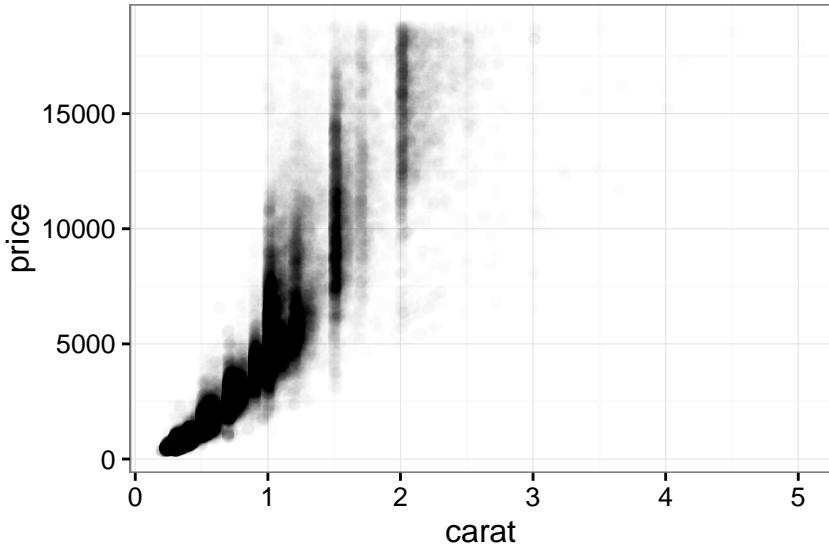
Let's reduce the alpha of the points:

```
> ggplot(data = diamonds, mapping = aes(x=carat, y=price)) +  
+   geom_point(alpha=0.1)
```



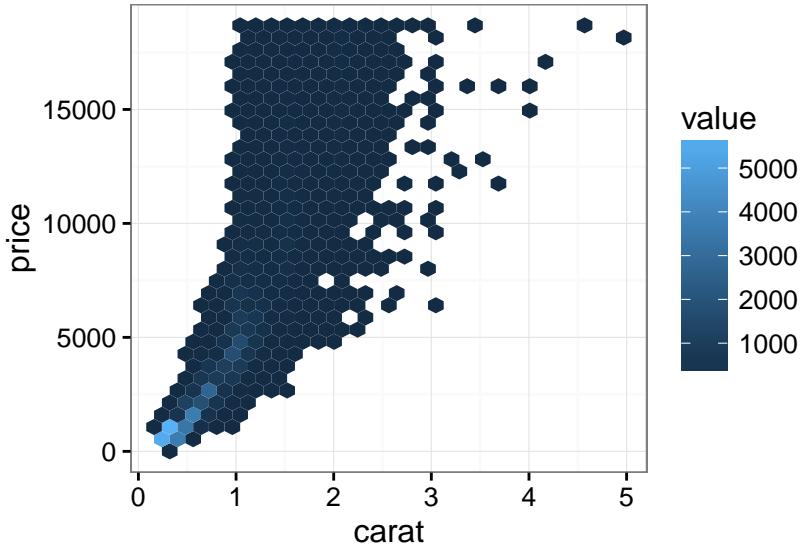
Let's further reduce the alpha:

```
> ggplot(data = diamonds, mapping = aes(x=carat, y=price)) +
+   geom_point(alpha=0.01)
```



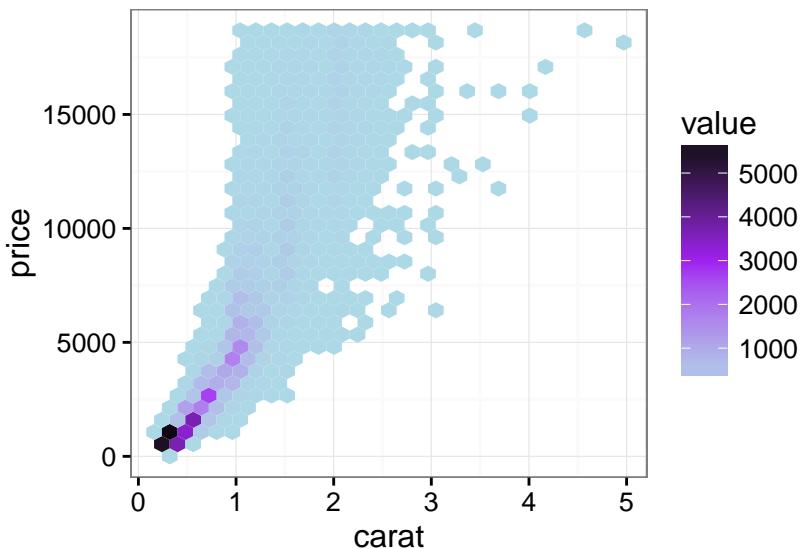
We can bin the points into hexagons, and report how many points fall within each bin. We use the `geom_hex()` layer to do this:

```
> ggplot(data = diamonds, mapping = aes(x=carat, y=price)) +  
+   geom_hex()
```



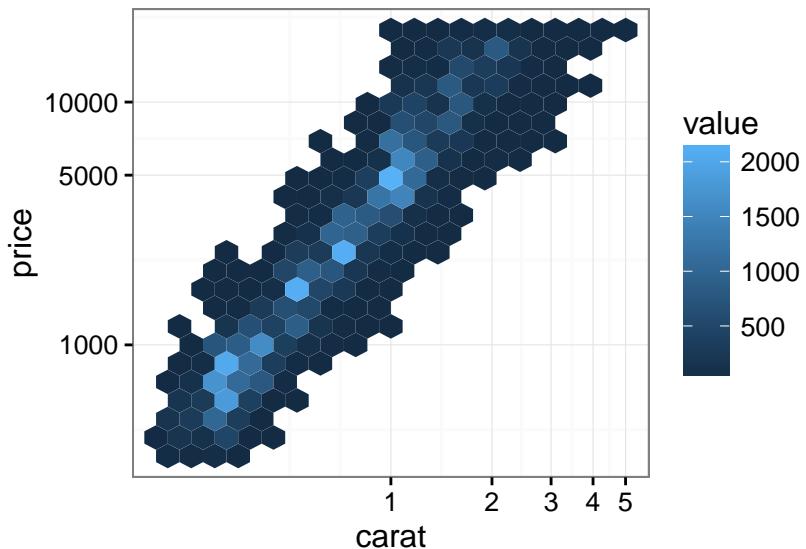
Let's try to improve the color scheme:

```
> ggplot(data = diamonds, mapping = aes(x=carat, y=price)) +  
+   geom_hex() +  
+   scale_fill_gradient2(low="lightblue", mid="purple", high="black",  
+                         midpoint=3000)
```



We can combine the scale transformation used earlier with the “hexbin” plotting method:

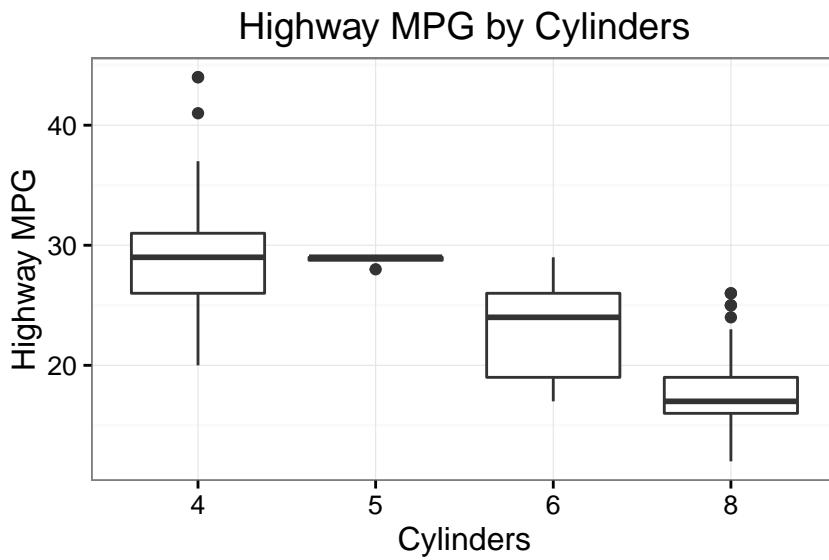
```
> ggplot(data = diamonds, mapping = aes(x=carat, y=price)) +  
+   geom_hex(bins=20) +  
+   scale_x_log10(breaks=1:5) + scale_y_log10(breaks=c(1000,5000,10000))
```



## Labels and Legends

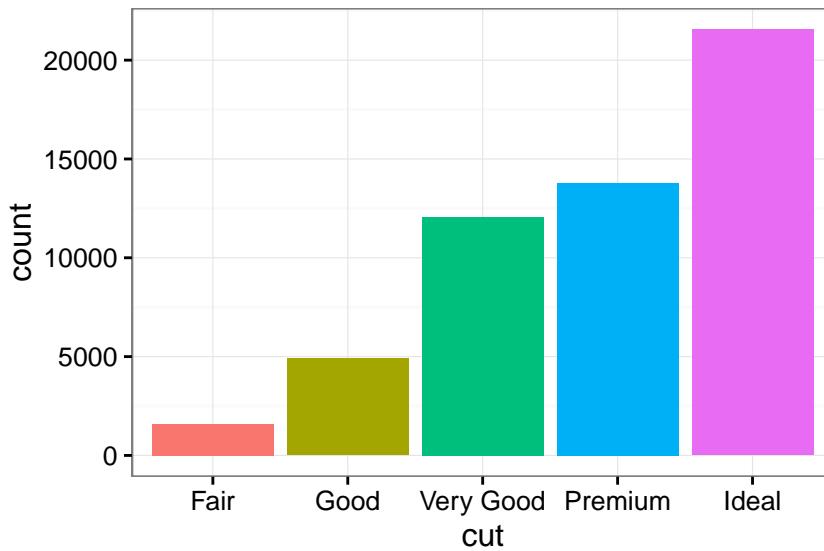
Here's how you can change the axis labels and give the plot a title:

```
> ggplot(data = mpg) +  
+   geom_boxplot(mapping = aes(x = factor(cyl), y = hwy)) +  
+   labs(title="Highway MPG by Cylinders",x="Cylinders",y="Highway MPG")
```



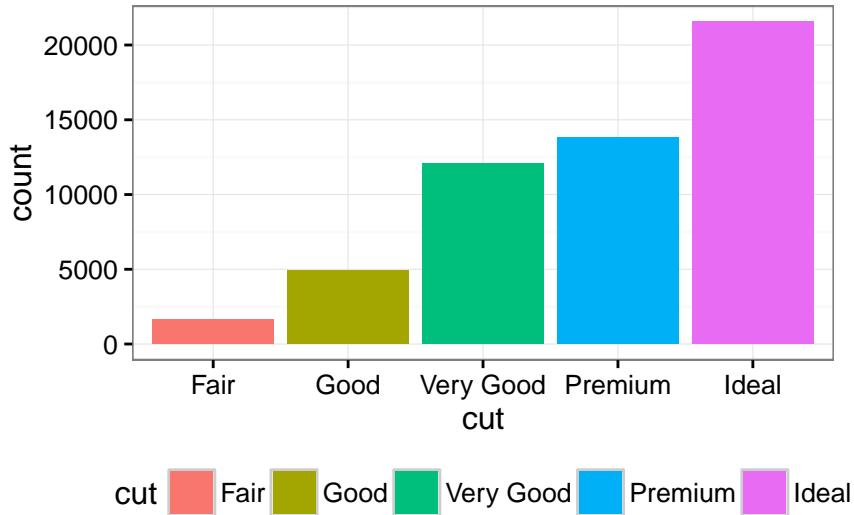
You can remove the legend to a plot by the following:

```
> ggplot(data = diamonds) +
+   geom_bar(mapping = aes(x = cut, fill = cut)) +
+   theme(legend.position="none")
```



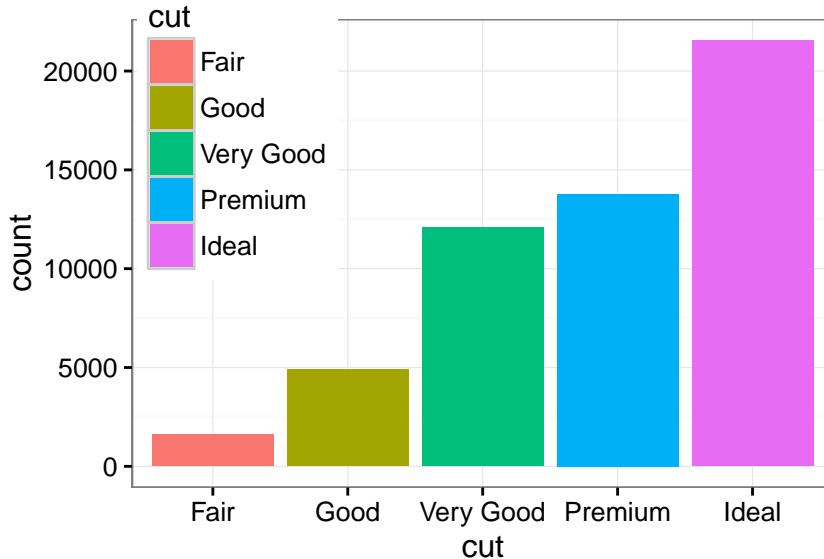
The legend can be placed on the “top”, “bottom”, “left”, or “right”:

```
> ggplot(data = diamonds) +
+   geom_bar(mapping = aes(x = cut, fill = cut)) +
+   theme(legend.position="bottom")
```



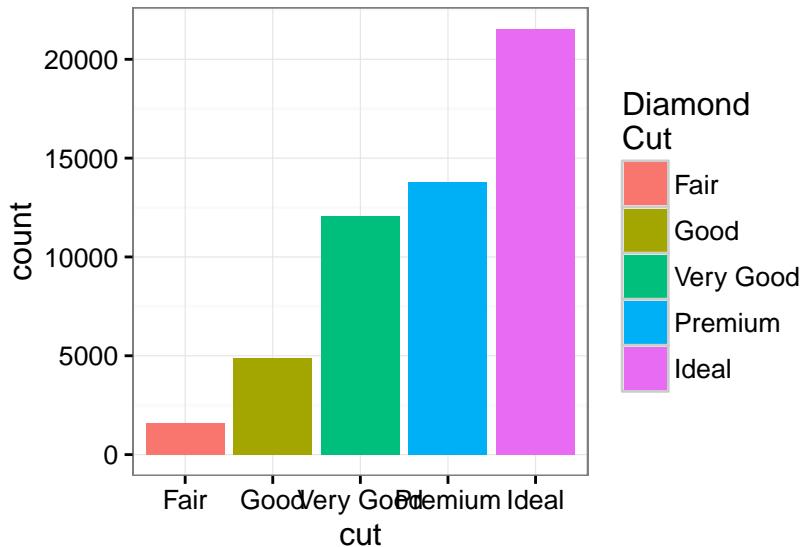
The legend can be moved inside the plot itself:

```
> ggplot(data = diamonds) +
+   geom_bar(mapping = aes(x = cut, fill = cut)) +
+   theme(legend.position=c(0.15,0.75))
```



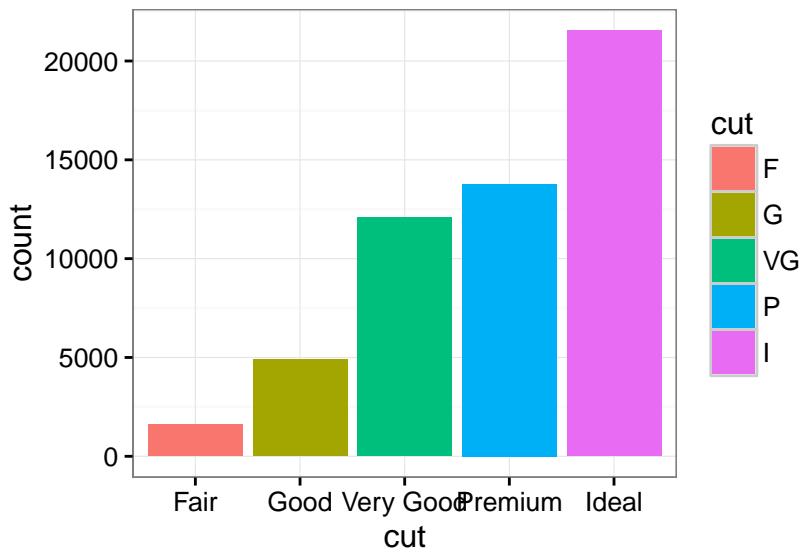
Change the name of the legend:

```
> ggplot(data = diamonds) +  
+   geom_bar(mapping = aes(x = cut, fill = cut)) +  
+   scale_fill_discrete(name="Diamond\\nCut")
```



Change the labels within the legend:

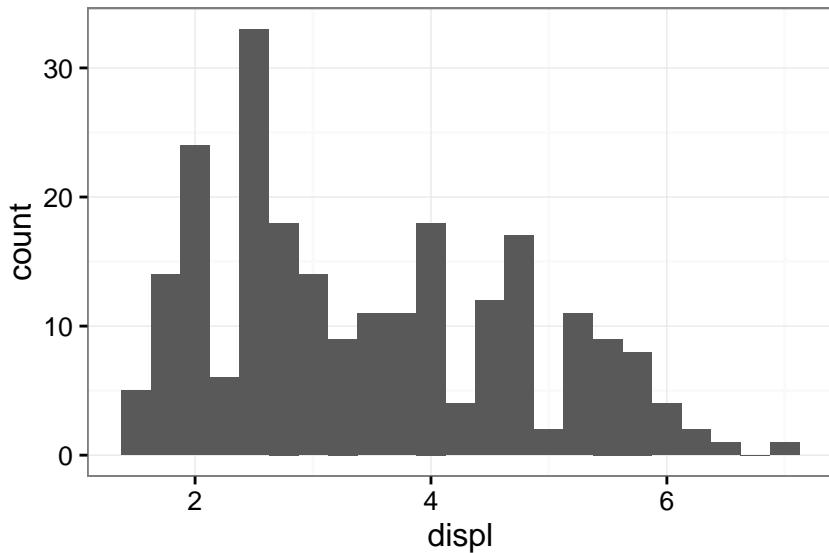
```
> ggplot(data = diamonds) +  
+   geom_bar(mapping = aes(x = cut, fill = cut)) +  
+   scale_fill_discrete(labels=c("F", "G", "VG", "P", "I"))
```



## Facets

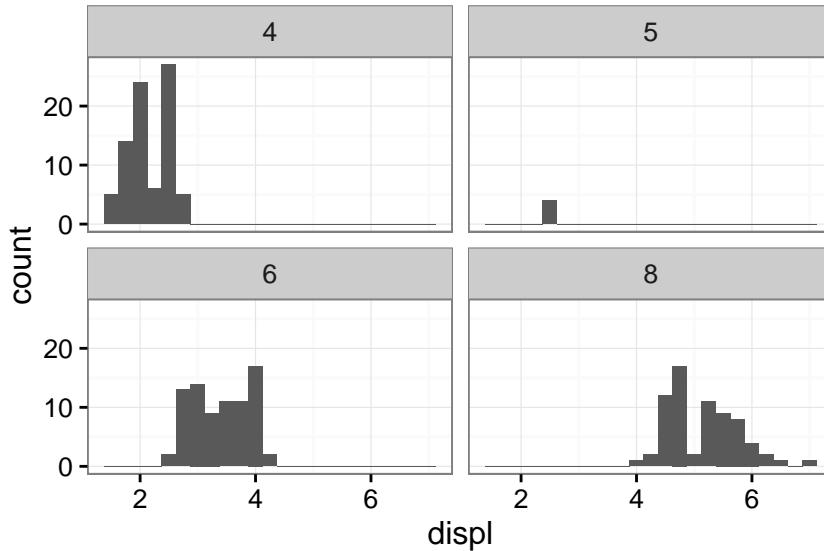
Here is the histogram of the `displ` variable from the `mpg` data set:

```
> ggplot(mpg) + geom_histogram(mapping=aes(x=displ), binwidth=0.25)
```



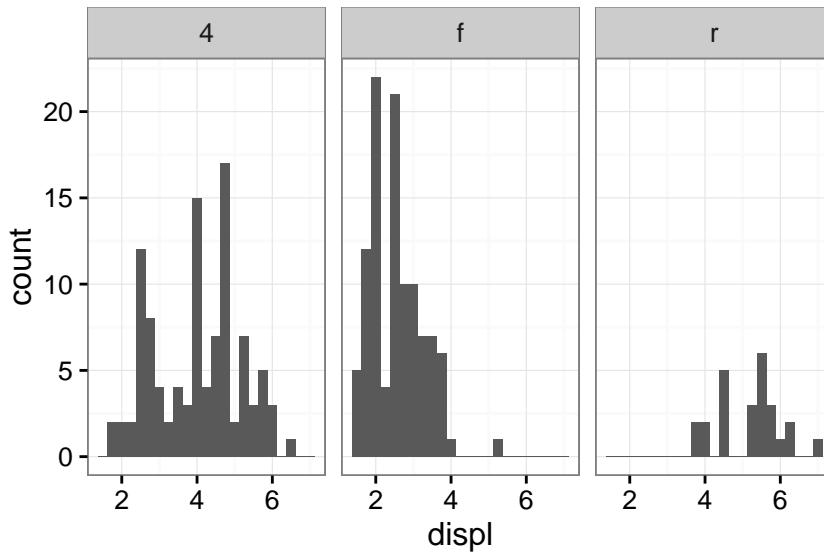
The `facet_wrap()` layer allows us to stratify the `displ` variable according to `cyl`, and show the histograms for the strata in an organized fashion:

```
> ggplot(mpg) +
+   geom_histogram(mapping=aes(x=displ), binwidth=0.25) +
+   facet_wrap(~ cyl)
```



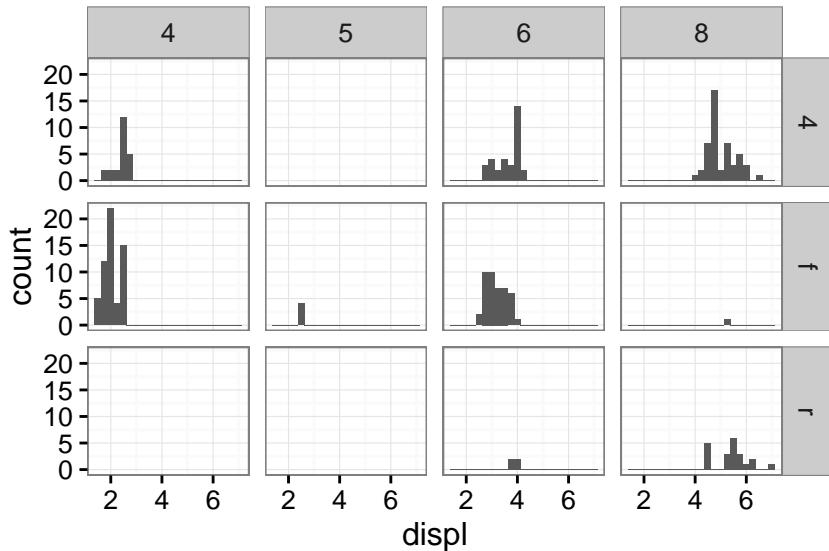
Here is `facet_wrap()` applied to `displ` stratified by the `drv` variable:

```
> ggplot(mpg) +
+   geom_histogram(mapping=aes(x=displ), binwidth=0.25) +
+   facet_wrap(~ drv)
```



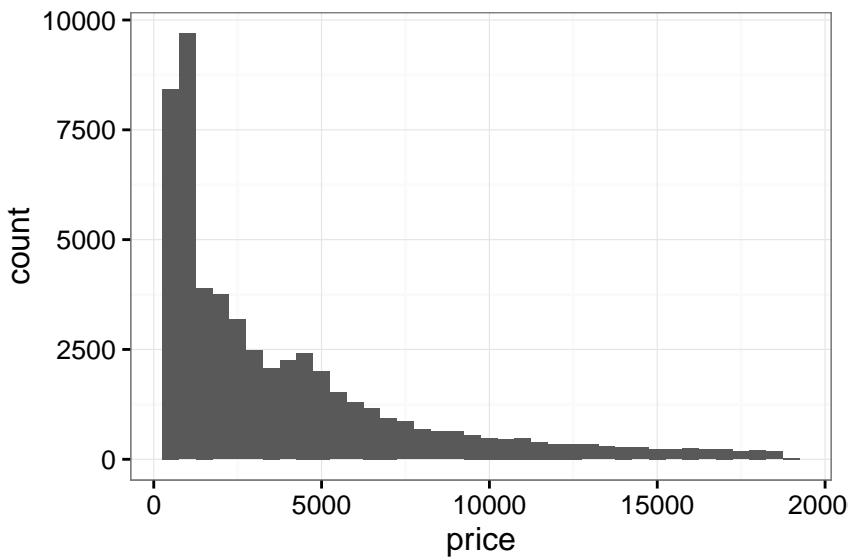
We can stratify by two variable simultaneously by using the `facet_grid()` layer:

```
> ggplot(mpg) +  
+   geom_histogram(mapping=aes(x=displ), binwidth=0.25) +  
+   facet_grid(drv ~ cyl)
```



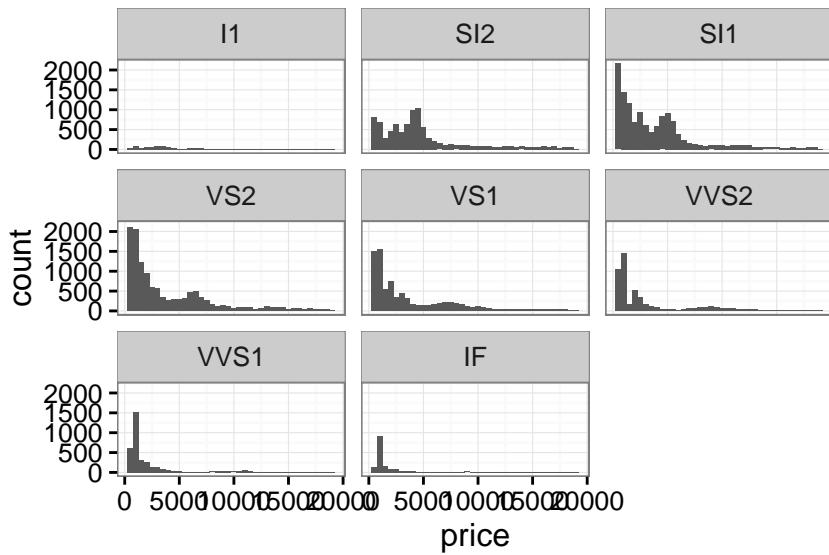
Let's carry out a similar faceting on the `diamonds` data over the next four plots:

```
> ggplot(diamonds) +  
+   geom_histogram(mapping=aes(x=price), binwidth=500)
```



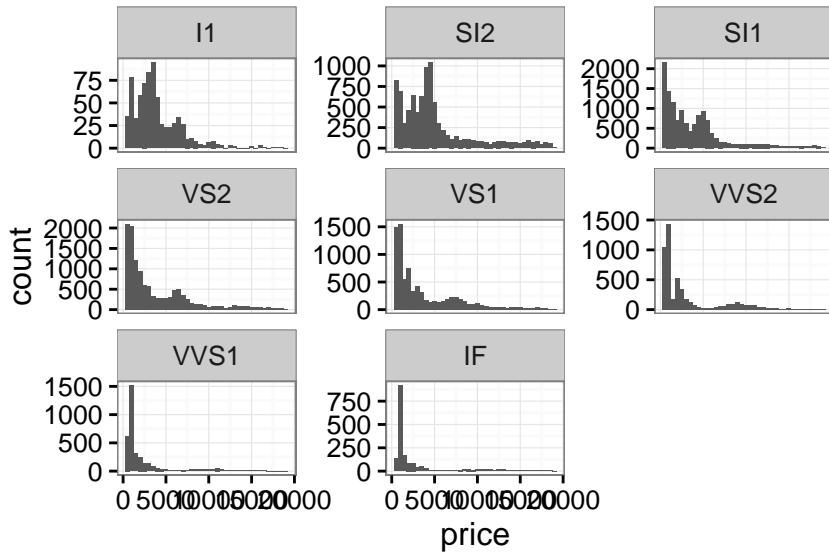
Stratify price by clarity:

```
> ggplot(diamonds) +
+   geom_histogram(mapping=aes(x=price), binwidth=500) +
+   facet_wrap(~ clarity)
```



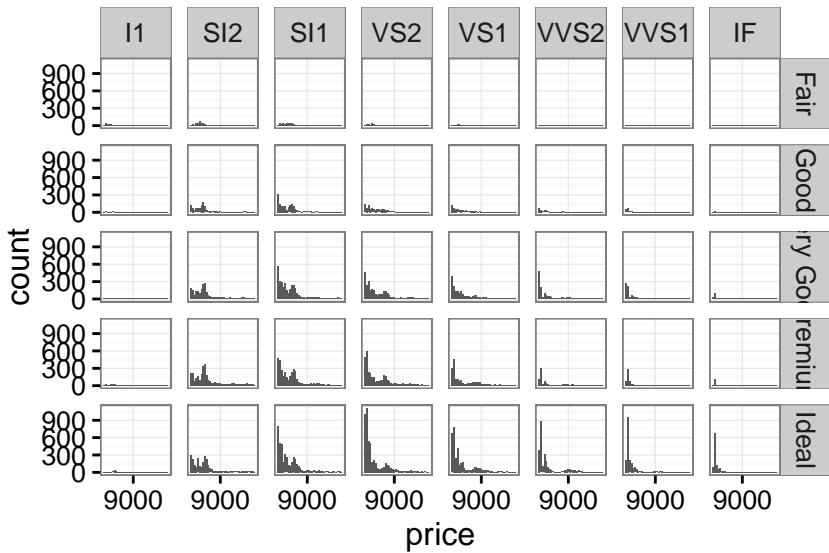
Stratify price by clarity, but allow each y-axis range to be different by including the `scale="free_y"` argument:

```
> ggplot(diamonds) +
+   geom_histogram(mapping=aes(x=price), binwidth=500) +
+   facet_wrap(~ clarity, scale="free_y")
```



Jointly stratify price by cut and clarity:

```
> ggplot(diamonds) +
+   geom_histogram(mapping=aes(x=price), binwidth=500) +
+   facet_grid(cut ~ clarity) +
+   scale_x_continuous(breaks=9000)
```



## Colors

### Finding Colors

- A list of named colors in R (e.g., “lightblue”)
- RColorBrewer package
- The Crayola crayon colors from the `broman` package – use `brocolors(set="crayons")`
- Color blind palette:

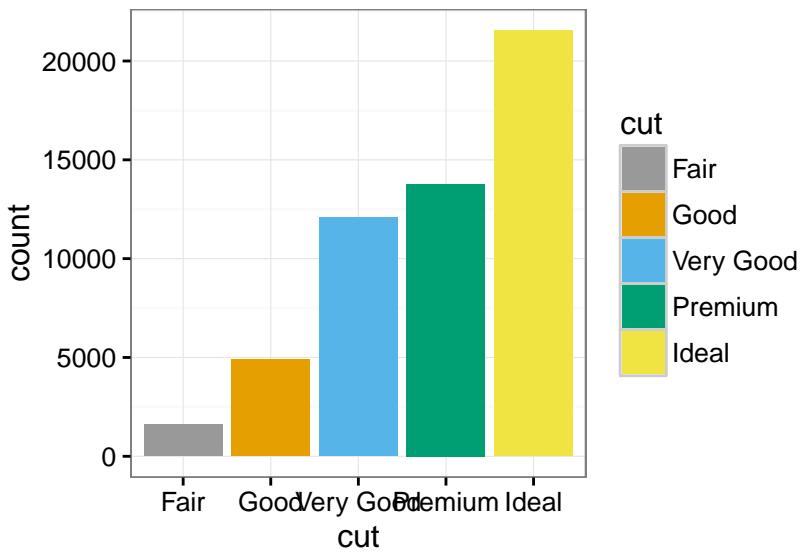
```
> cbPalette <- c("#999999", "#E69F00", "#56B4E9", "#009E73", "#F0E442", "#0072B2",
+                  "#D55E00", "#CC79A7")
```

### Some Useful Layers

- `scale_fill_manual()`
- `scale_color_manual()`
- `scale_fill_gradient()`
- `scale_color_gradient()`

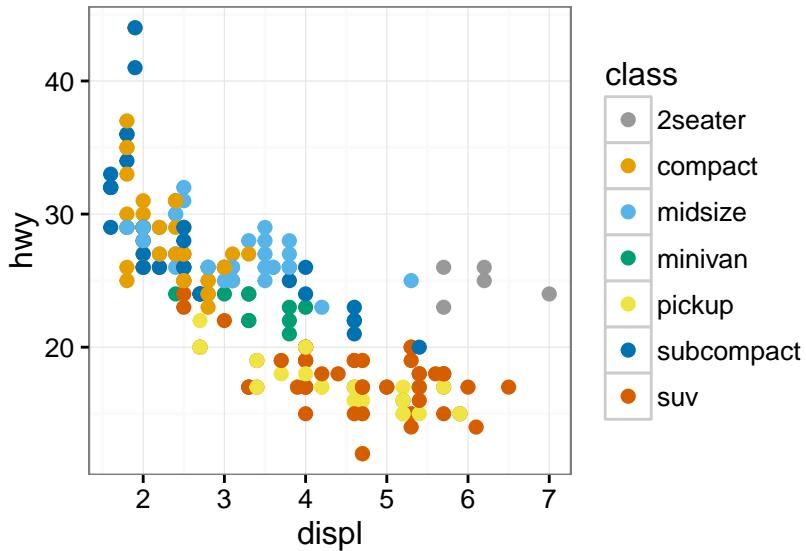
Manually determine colors to fill the barplot using the color blind palette defined above, `cbPalette`:

```
> ggplot(data = diamonds) +
+   geom_bar(mapping = aes(x = cut, fill = cut)) +
+   scale_fill_manual(values=cbPalette)
```



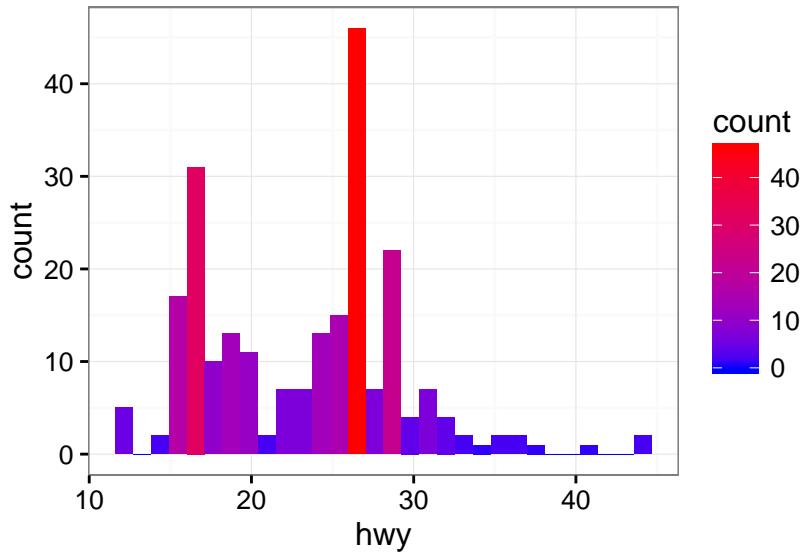
Manually determine point colors using the color blind palette defined above, cbPalette:

```
> ggplot(data = mpg) +
+   geom_point(mapping = aes(x = displ, y = hwy, color = class), size=2) +
+   scale_color_manual(values=cbPalette)
```



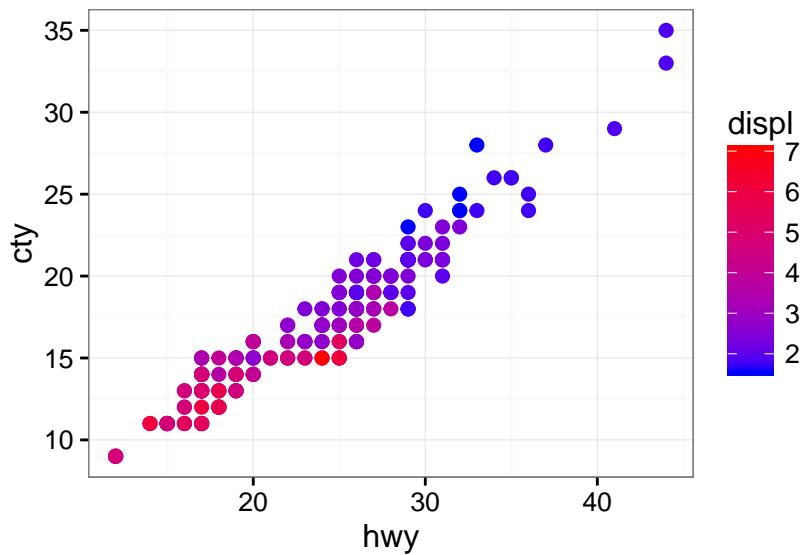
Fill the histogram bars using a color gradient by their counts, where we determine the endpoint colors:

```
> ggplot(data = mpg) +  
+   geom_histogram(aes(x=hwy, fill=..count..)) +  
+   scale_fill_gradient(low="blue", high="red")
```



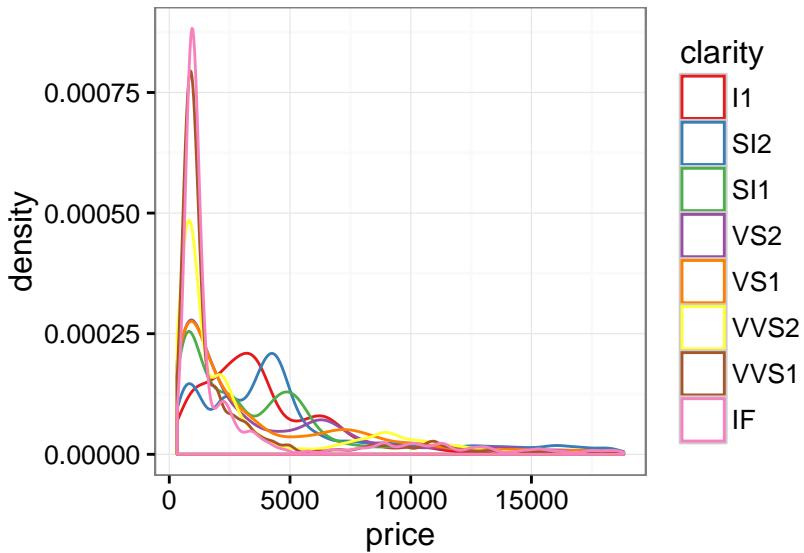
Color the points based on a gradient formed from the quantitative variable, `displ`, where we determine the endpoint colors:

```
> ggplot(data = mpg) +  
+   geom_point(aes(x=hwy, y=cty, color=displ), size=2) +  
+   scale_color_gradient(low="blue", high="red")
```



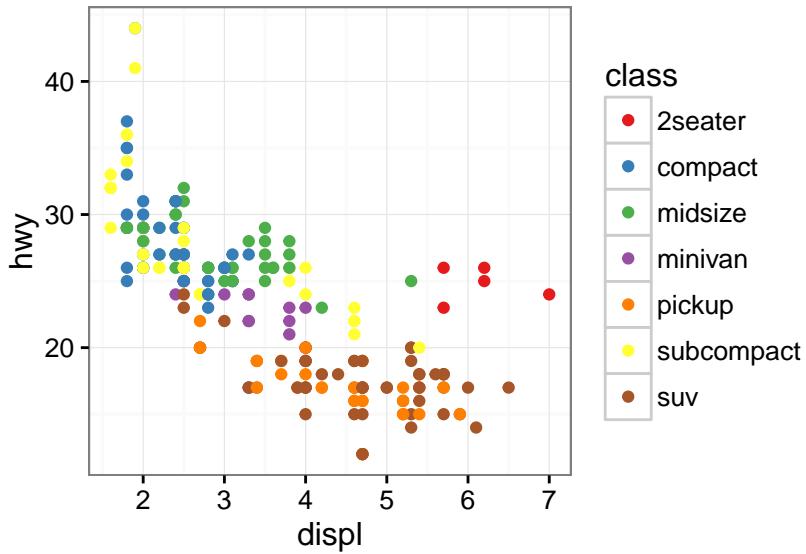
An example of using the palette “Set1” from the RColorBrewer package, included in ggplot2:

```
> ggplot(diamonds) +
+   geom_density(mapping = aes(x=price, color=clarity)) +
+   scale_color_brewer(palette = "Set1")
```



Another example of using the palette “Set1” from the RColorBrewer package, included in ggplot2:

```
> ggplot(data = mpg) +
+   geom_point(mapping = aes(x = displ, y = hwy, color = class)) +
+   scale_color_brewer(palette = "Set1")
```



## Saving Plots

### Saving Plots as Variables

Pieces of the plots can be saved as variables, which is particularly useful to exploratory data analysis. These all produce the same plot:

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

> p <- ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color=drv)) +
+   geom_point()
> p + geom_smooth(se=FALSE)

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

Try it yourself!

## Saving Plots to Files

Plots can be saved to many formats using the `ggsave()` function. Here are some examples:

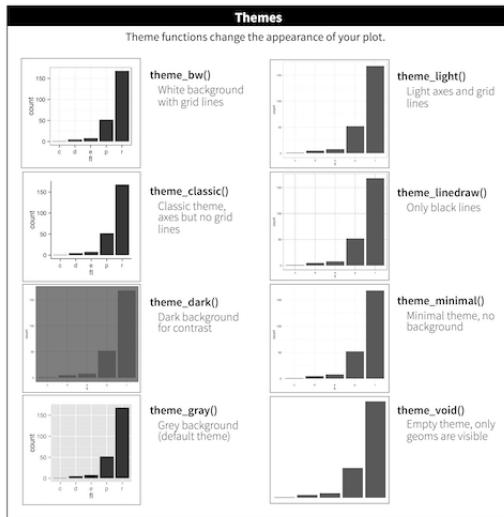
```
> p <- ggplot(data = mpg, mapping = aes(x = displ, y = hwy, color=drv)) +  
+   geom_point() +  
+   geom_smooth(se=FALSE)  
> ggsave(filename="my_plot.pdf", plot=p) # saves PDF file  
> ggsave(filename="my_plot.png", plot=p) # saves PNG file
```

Here are the arguments that `ggsave()` takes:

```
> str(ggsave)  
function (filename, plot = last_plot(), device = NULL,  
        path = NULL, scale = 1, width = NA, height = NA, units = c("in",  
        "cm", "mm"), dpi = 300, limitsize = TRUE, ...)
```

## Themes

### Available Themes



From <http://r4ds.had.co.nz/visualize.html>. See also `ggthemes` package.

### Setting a Theme

Globally:

```
> theme_set(theme_minimal())
```

Locally:

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

## Extras

### License

<https://github.com/SML201/lectures/blob/master/LICENSE.md>

### Source Code

<https://github.com/SML201/lectures/tree/master/week5>

### Session Information

```
> sessionInfo()  
R version 3.2.3 (2015-12-10)  
Platform: x86_64-apple-darwin13.4.0 (64-bit)  
Running under: OS X 10.11.3 (El Capitan)  
  
locale:  
[1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8  
  
attached base packages:  
[1] stats      graphics    grDevices utils      datasets   methods  
[7] base  
  
other attached packages:  
[1] hexbin_1.27.1   babynames_0.2.1 dplyr_0.4.3  
[4] ggplot2_2.1.0   knitr_1.12.3   magrittr_1.5  
[7] devtools_1.10.0  
  
loaded via a namespace (and not attached):  
[1] Rcpp_0.12.3       munsell_0.4.3      lattice_0.20-33  
[4] colorspace_1.2-6   R6_2.1.2         highr_0.5.1
```

```
[7] stringr_1.0.0      plyr_1.8.3       tools_3.2.3  
[10] parallel_3.2.3    grid_3.2.3       gtable_0.2.0  
[13] DBI_0.3.1        htmltools_0.3    lazyeval_0.1.10  
[16] yaml_2.1.13       digest_0.6.9     assertthat_0.1  
[19] RColorBrewer_1.1-2 reshape2_1.4.1   formatR_1.2.1  
[22] codetools_0.2-14 memoise_1.0.0    evaluate_0.8  
[25] rmarkdown_0.9.5    labeling_0.3    stringi_1.0-1  
[28] scales_0.4.0
```