NYC DATA SCIENCE ACADEMY

Data Science with R (Data Analytics)

Data Visualization with 'ggplot2'

Outline

- Why ggplot2?
- The “Grammar of Graphics”
- Constructing a ggplot2 plot
- Scatterplots
- Bar charts
- Histograms
- Visualizing big data
- Saving Graphs

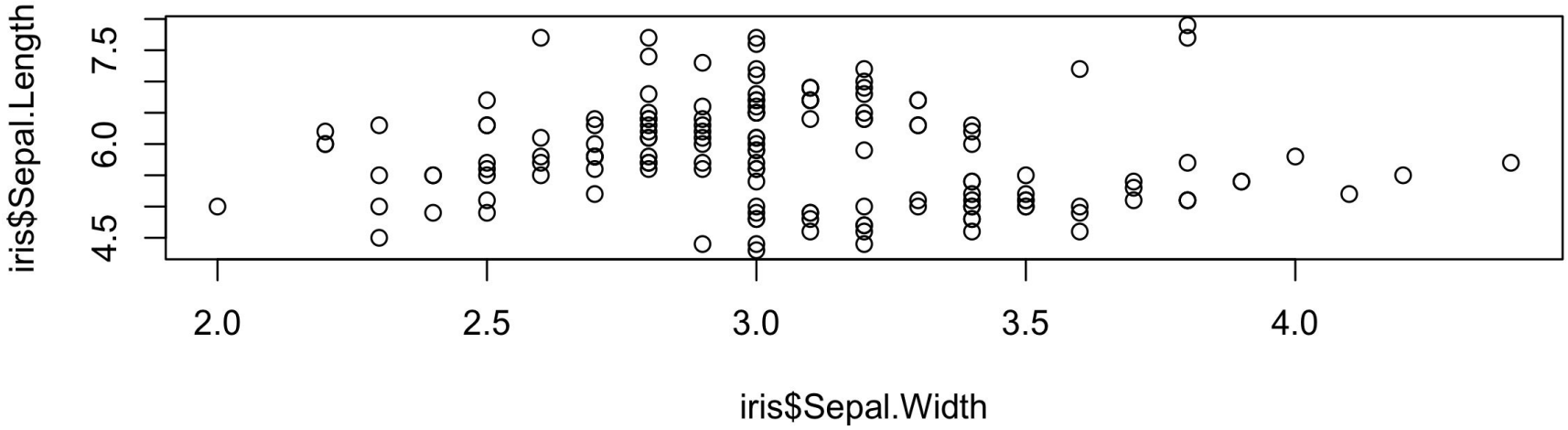
Why ggplot2?

- In the next few slides, we'll see some examples of plots you can make in ggplot2.

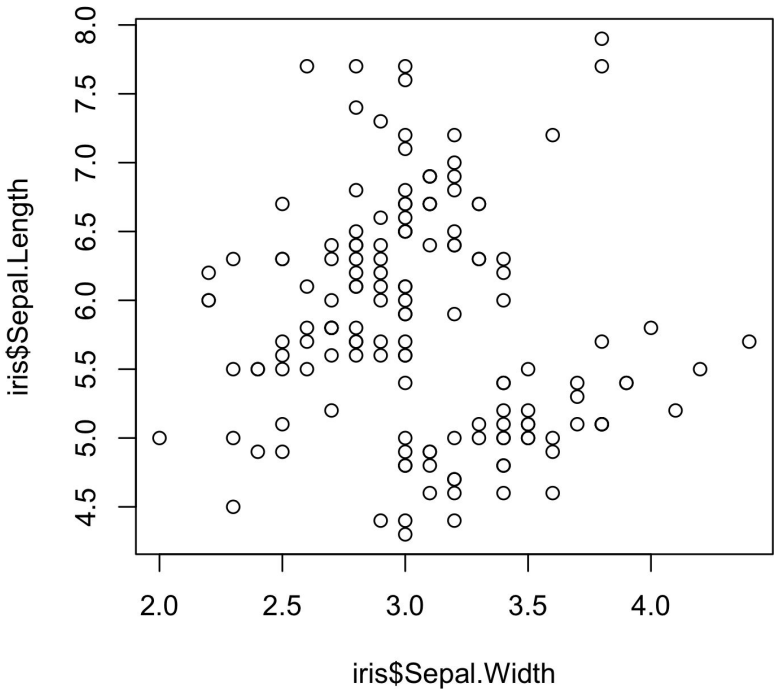
Why ggplot2?

- But first an example using base R's plot function:

```
plot(iris$Sepal.Width, iris$Sepal.Length)
```



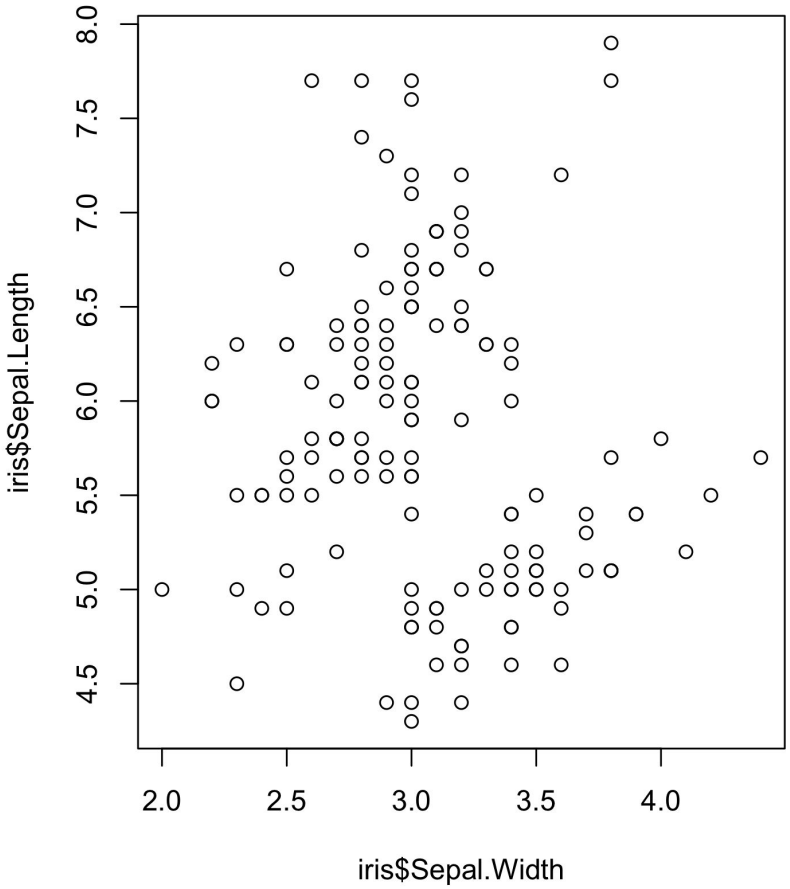
Why ggplot2?

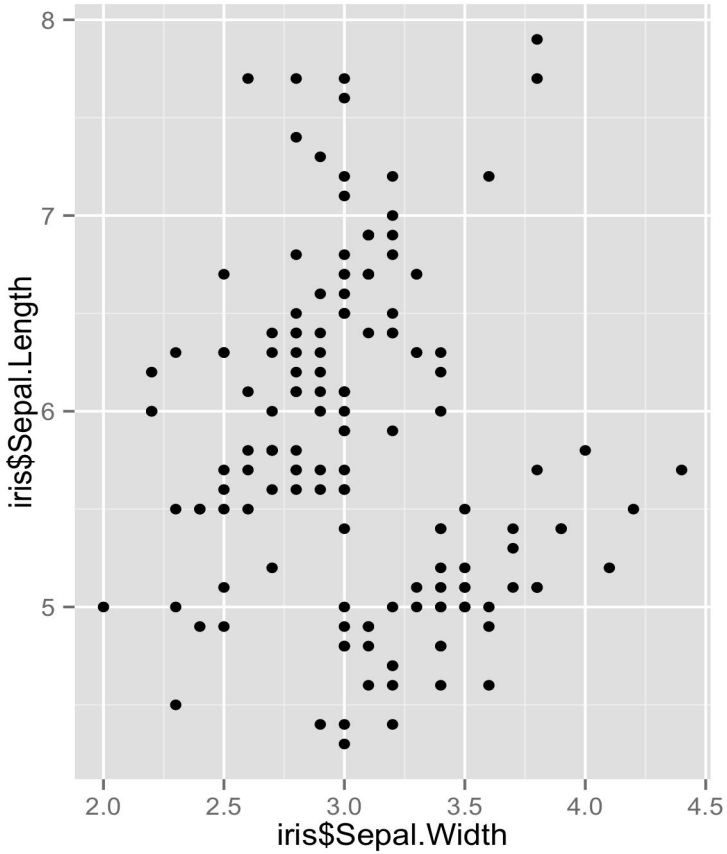



```
plot(iris$Sepal.Width,
     iris$Sepal.Length)
```

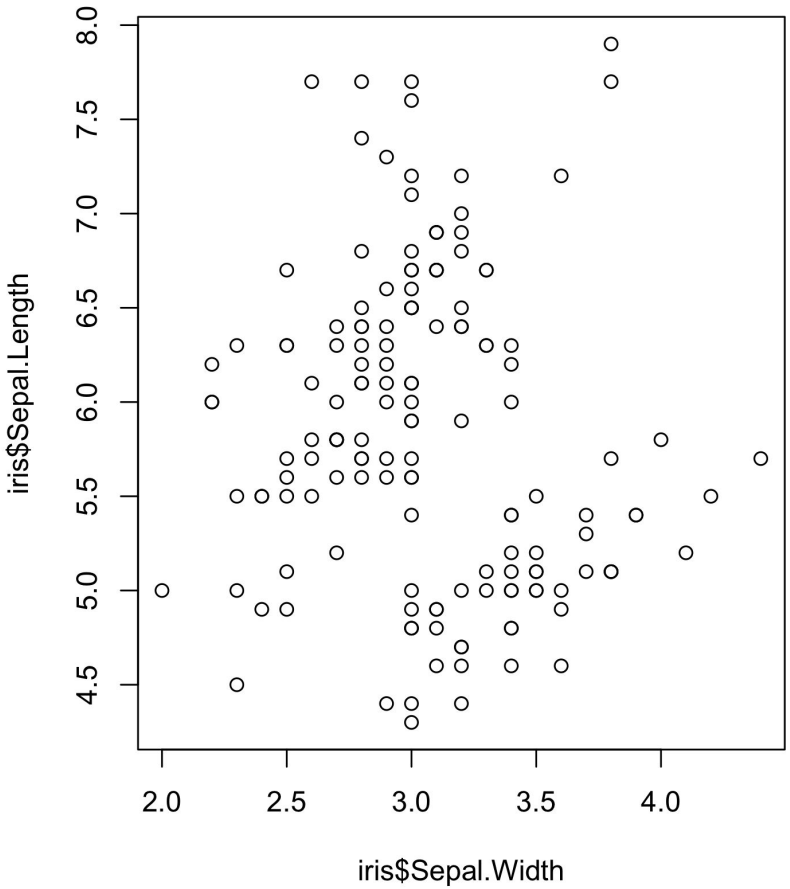
- R's basic plot method
- simple
- does different things in different contexts
- (usually in a helpful way)
- difficult to customize

Scatterplot

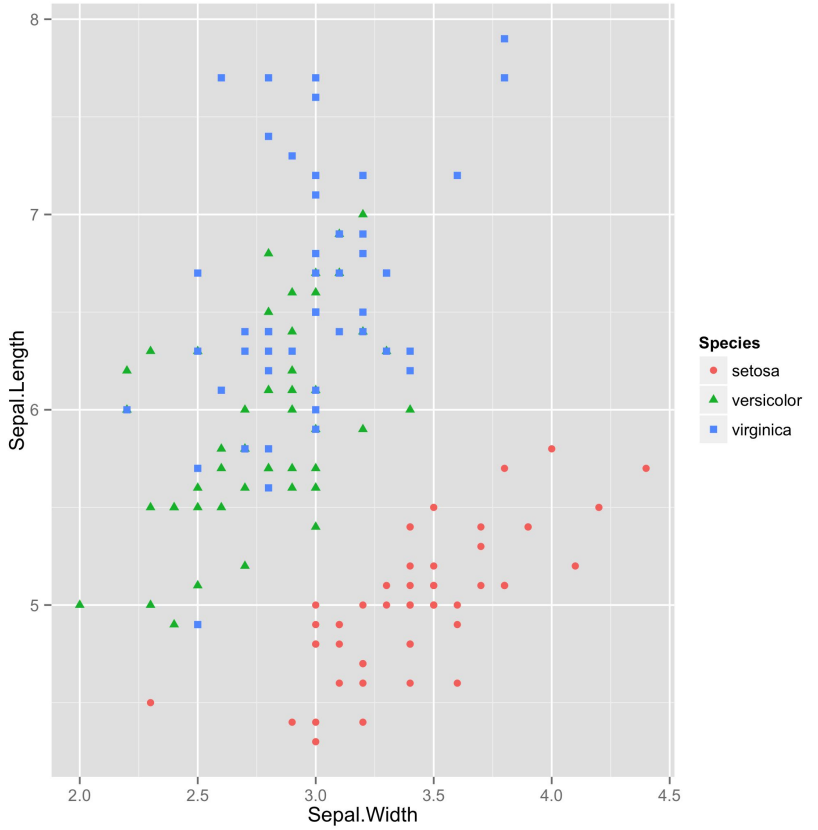




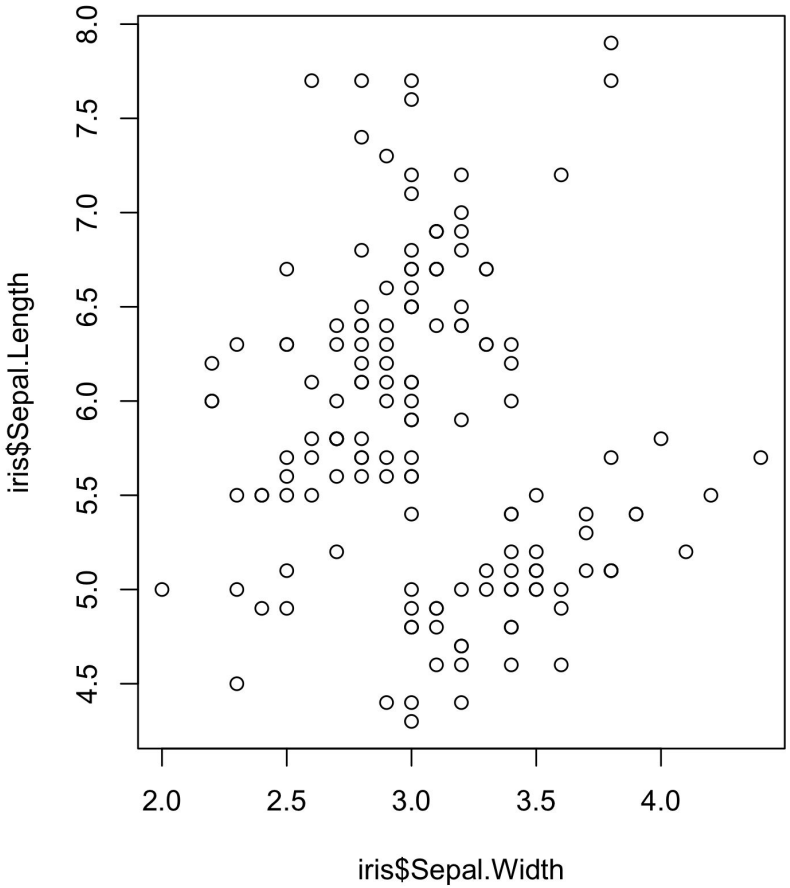
Scatterplot



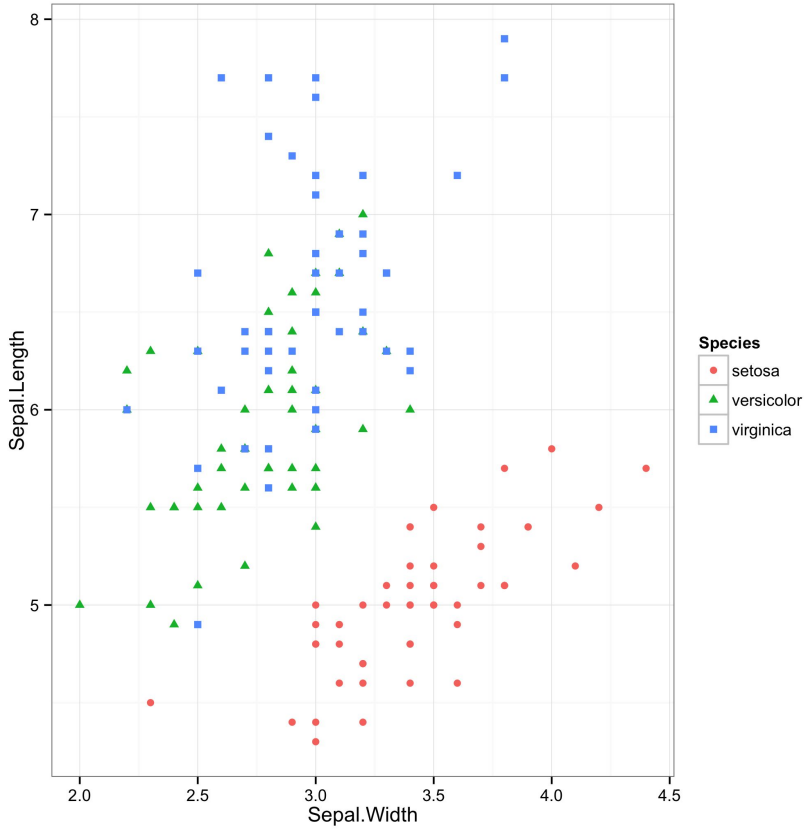
Same, but with species mapped to different colors and shapes.



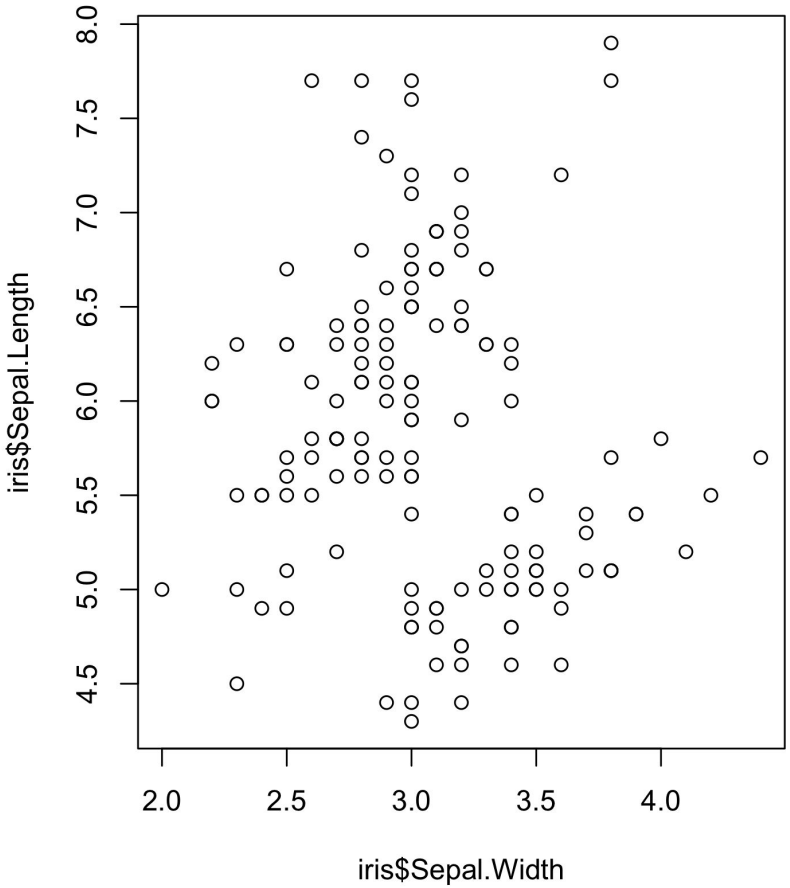
Scatterplot

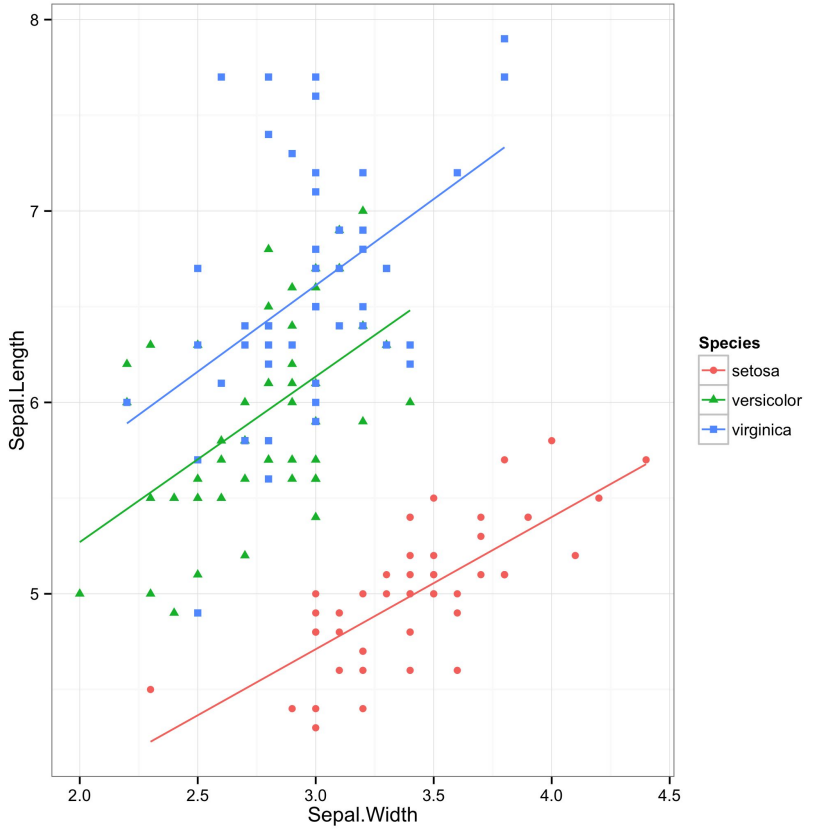


A different theme.

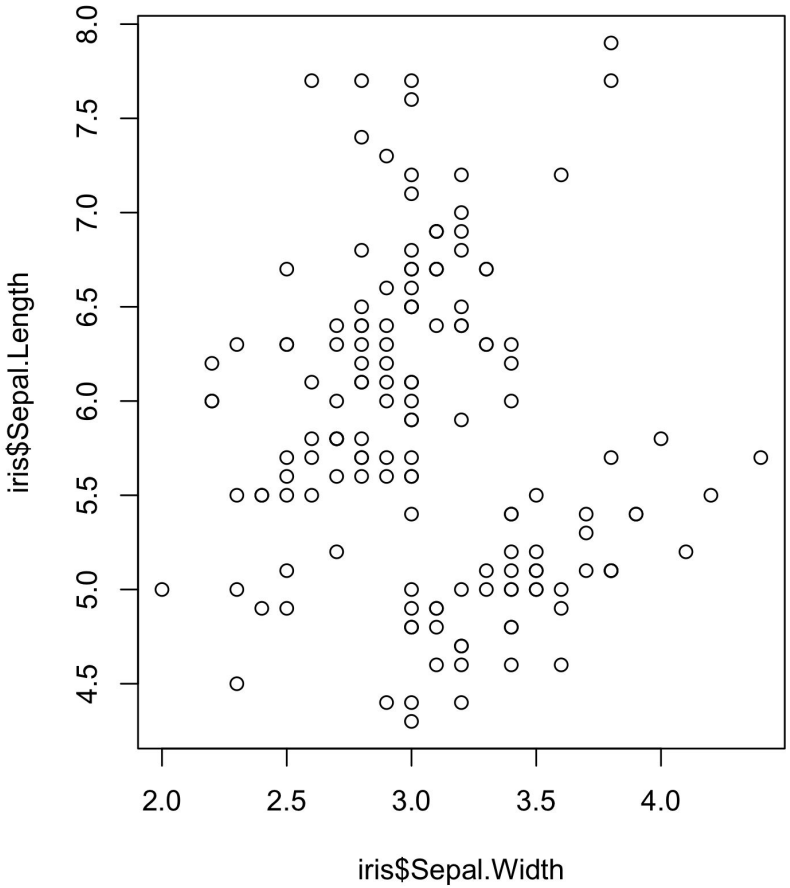


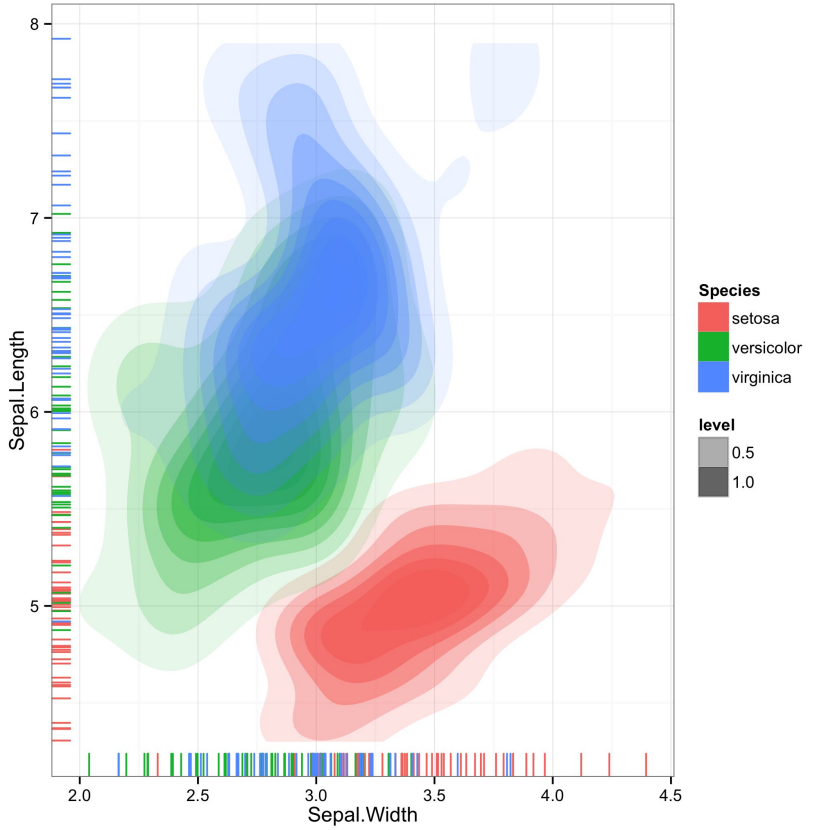
Scatterplot with Regression Line



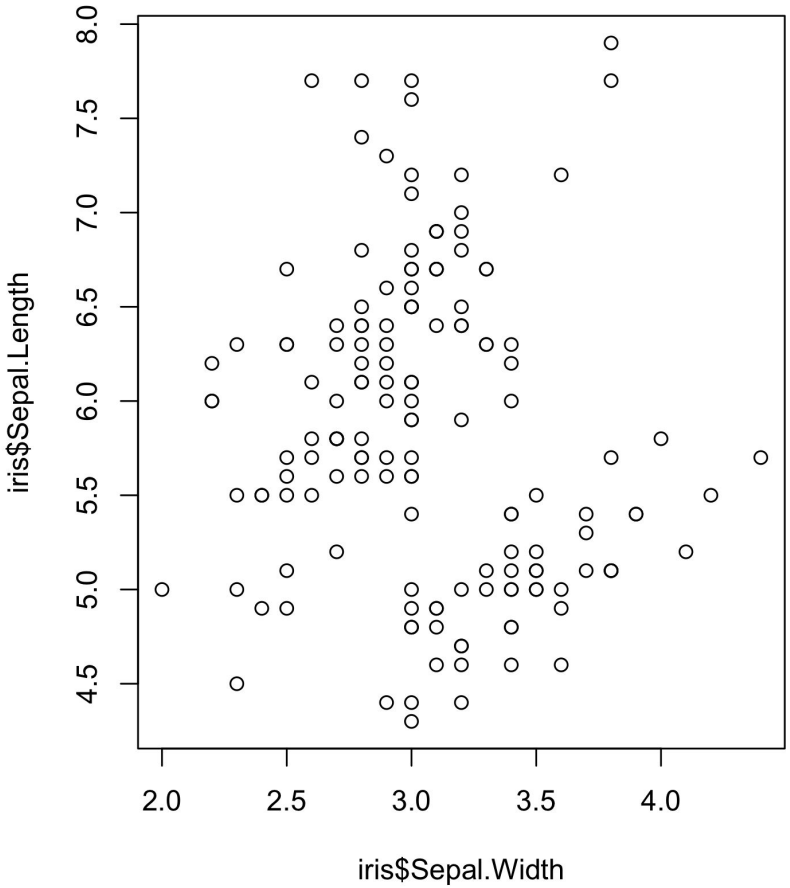


2D Density Plot with Rug Plot

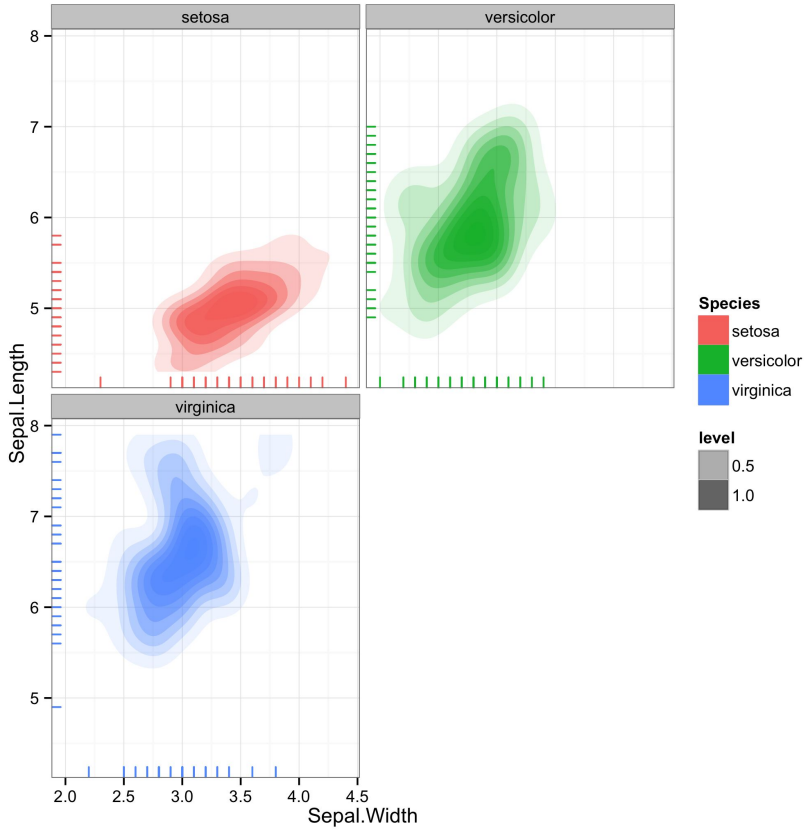




Grid of 2D Density Plots



Each species has its own plot.



Vector Field

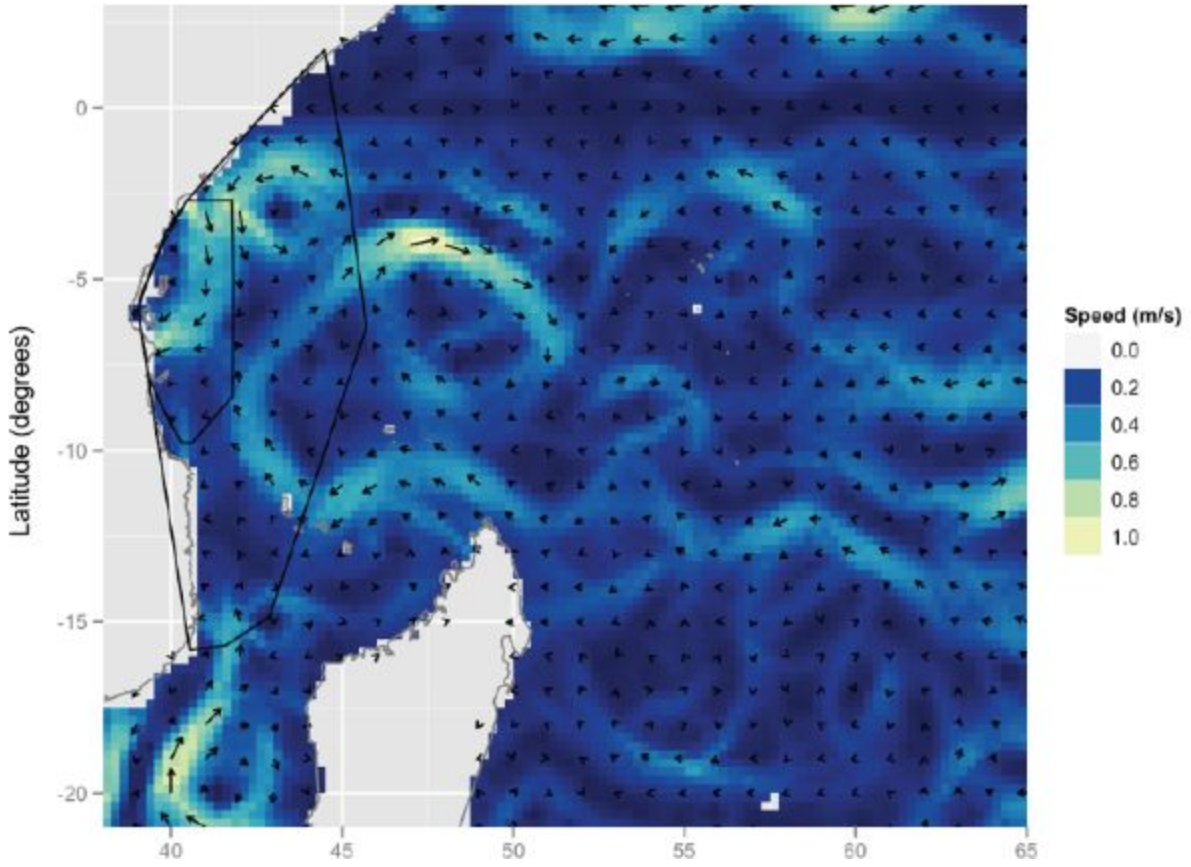
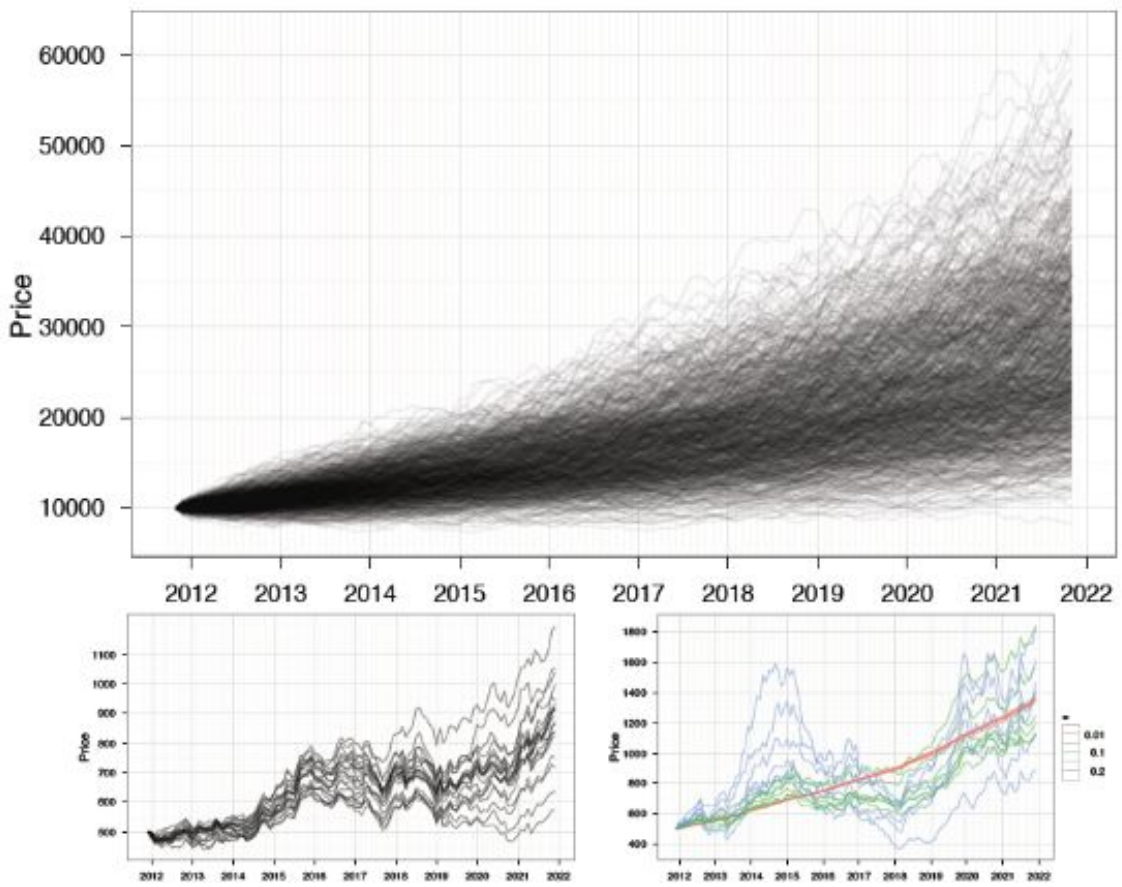


Figure: Charlotte Wickham, http://cwick.co.nz/

Time Series


Price
60000
50000
40000
30000
20000
10000
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

Coefficient Plot

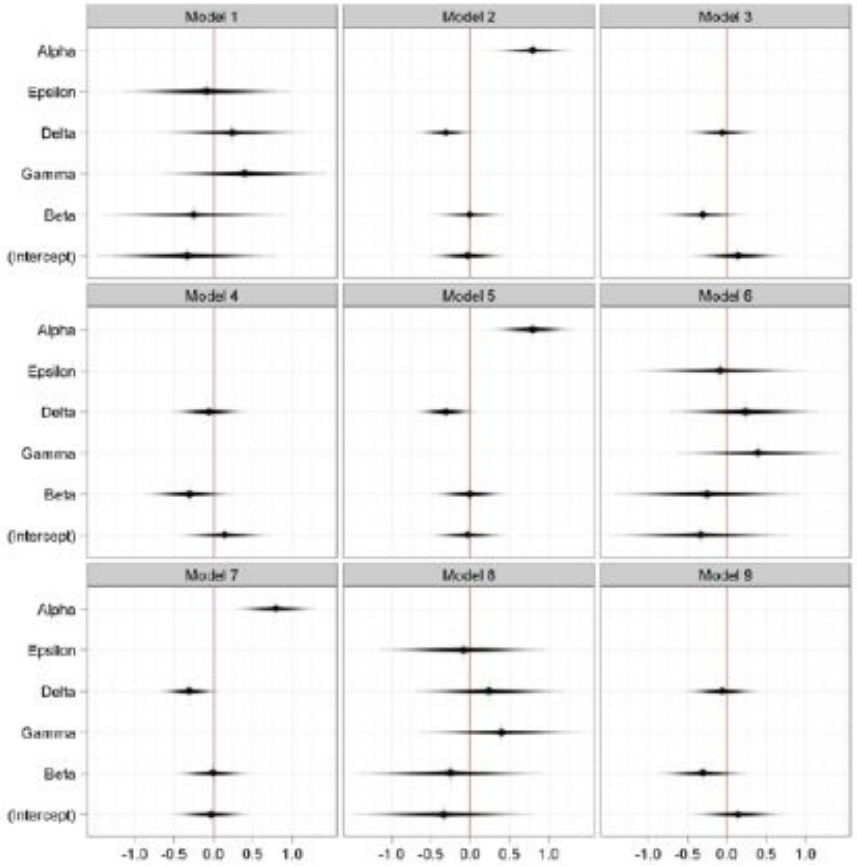


Figure: David B Sparks, http://bit.ly/hn54NW

Maps

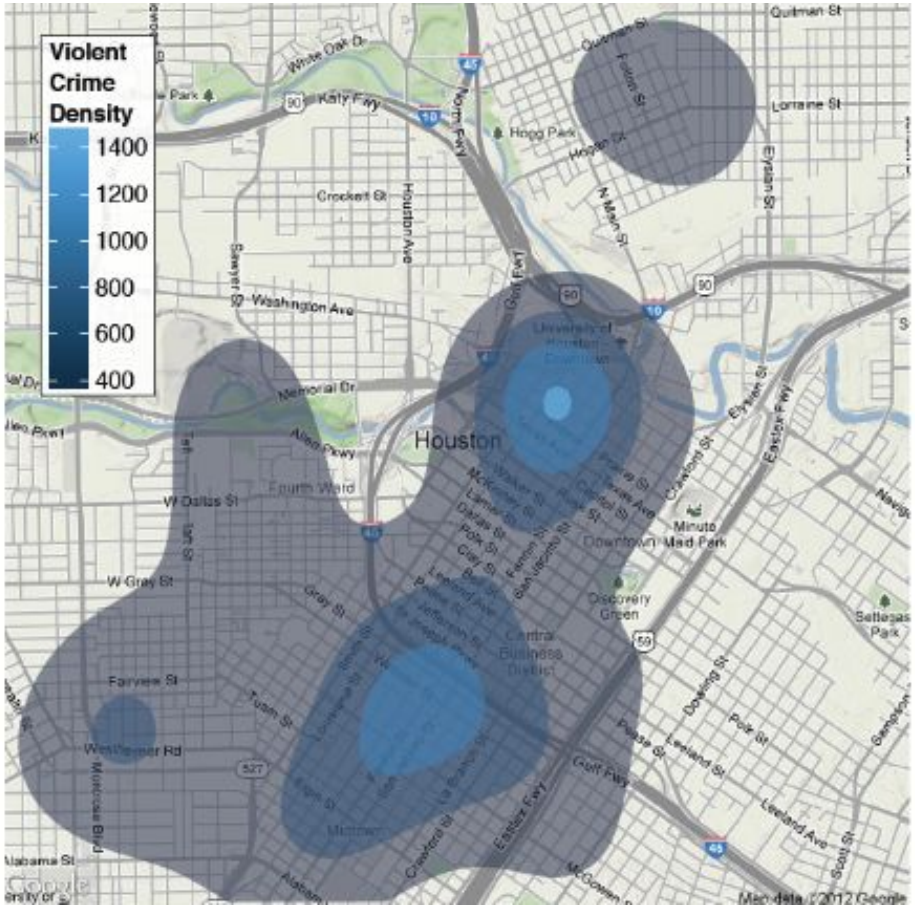


Figure: David Kahle, https://dl.dropbox.com/u/24648660/ggmap%20useR%202012.pdf

Maps

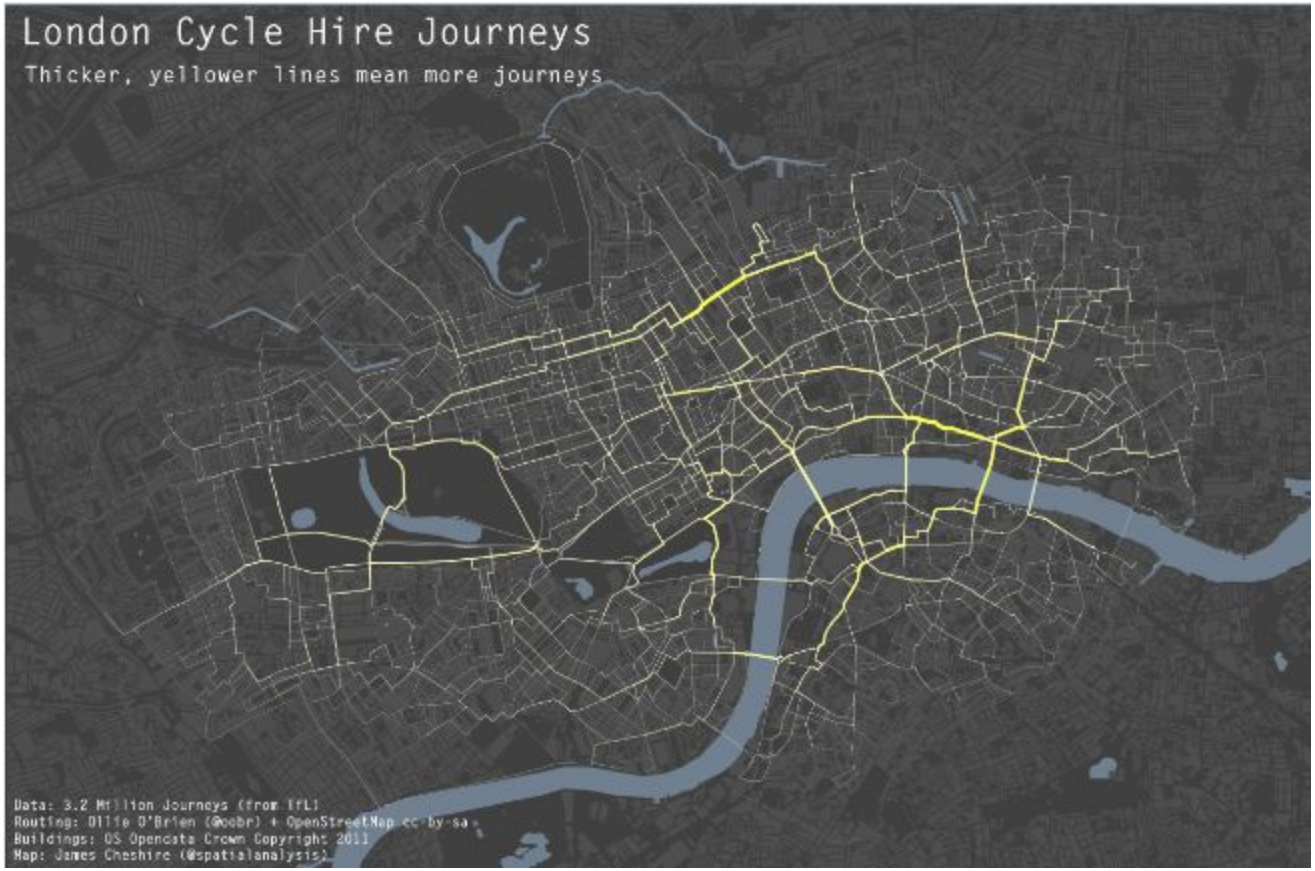


Figure: James Cheshire, http://bit.ly/xqHhAs

A picture is not merely worth a thousand words, it is much more likely to be scrutinized than words are to be read.

- John Tukey

Outline

- Why ggplot2?
- **The "Grammar of Graphics"**
- Constructing a ggplot2 plot
- Scatterplots
- Bar charts
- Histograms
- Visualizing big data
- Saving Graphs

The “Grammar of Graphics”

The “Grammar of Graphics”

- An abstraction which makes thinking about, reasoning about, and communicating graphics easier.
- Think “verb”, “noun”, “adjective” for graphics.
- Permits a “theory” of graphics on which to build new graphics and graphics objects.

The "Grammar of Graphics"

"In brief, the grammar tells us that a statistical graphic is a **mapping** from data to **aesthetic** attributes (color, shape, size) of **geometric** objects (points, lines, bars). The plot may also contain statistical transformations of the data and is drawn on a specific coordinate system."

-- *ggplot2: Elegant Graphics for Data Analysis*

The "Grammar of Graphics"

- A *ggplot2 graphic* consists of:
  - **data**: an R data frame
  - **aesthetics**: values that will be plotted, e.g. x and y values, plus color and shape of dots, for a scatter plot
  - **geoms**: the type of plot
  - **facets**: side-by-side plots distinguished by a categorical variable
  - **stats**: statistical transformations like binning or smoothing
  - **scales**: adjust sizes (and other attributes)
  - **coordinates**: what coordinate system to use
  - **themes**: the overall presentation of the graphic

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Constructing a ggplot2 Plot

Constructing a ggplot2 Plot

- A ggplot2 graphic is constructed by building up **layers**.
- The ggplot function is used to initialize the basic graph structure, and then we add to it:

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

g <- ggplot(data = <name of R data frame>,
            aes(x = <name of default x variable),
                y = <name of default y variable>, ...,
                <other aesthetic mappings>),
            <other plot defaults>)
```

- Note that this doesn't graph anything, because we haven't told it *how* to display these data!

Constructing a ggplot2 Plot

- Next, we add a **geom** layer to the base graph with the + operator.

```
p <- g + geom_<geom type>(aes(
                          <aesthetic mappings for this geom>),
                          <other arguments>)
```

- This is the minimum requirement to plot something.

Constructing a ggplot2 Plot

One can then add other layers as desired, e.g.,

- other **geoms**
- **facets** with facet_grid(...) or facet_wrap(...)
- **stats** with stat_<transformation>(...)
- **scales** with scale_<aesthetic>_<type>(...)
- **coordinate systems** with coord_<system>(...)
- **themes** with theme(...)
- **titles** and **labels** with ggtitle(...) or labs(...)

A complete list of the various features of ggplot2 plots can be found at http://docs.ggplot2.org/

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Scatterplots

Scatterplots

The mpg data set comes in the ggplot2 package. Always read the help page and take a quick look at the data.

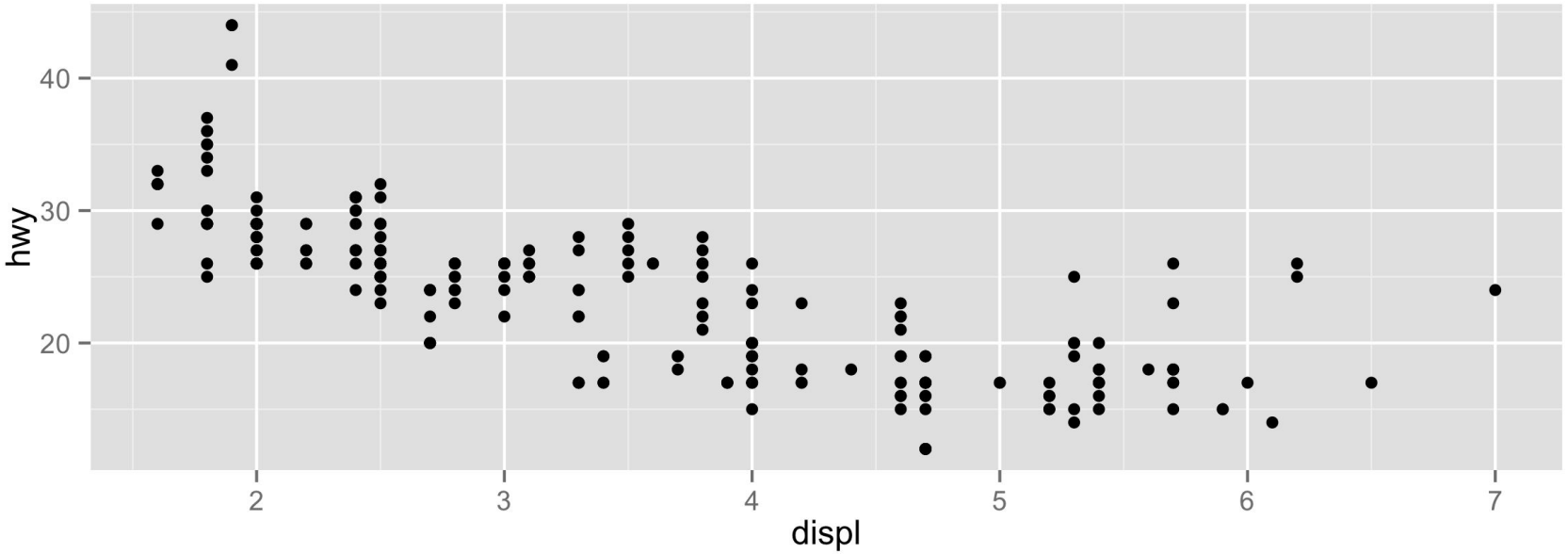
```
?mpg
head(mpg)
```

What relationship would you expect to see between:

- engine size (displ)
- highway mileage (hwy)

Scatterplots

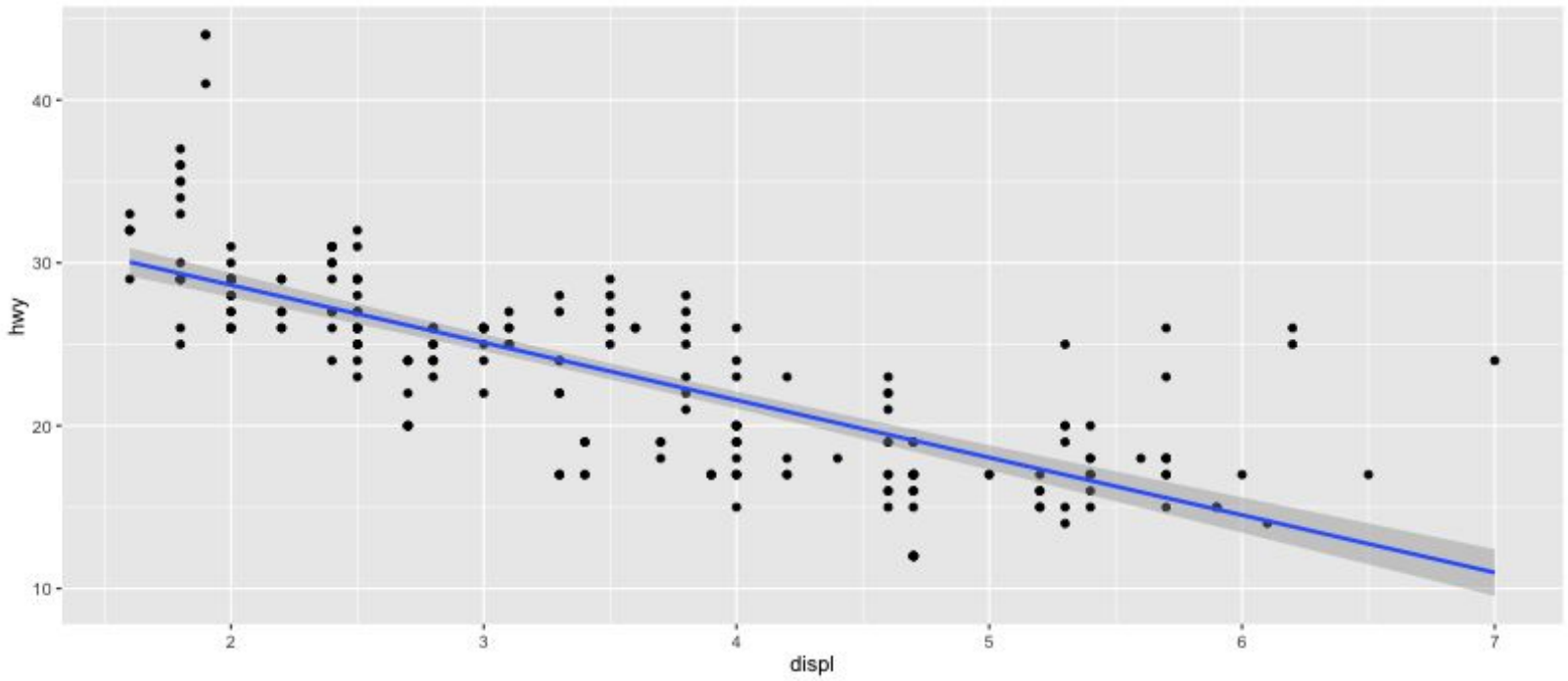
```
g <- ggplot(data = mpg, aes(x = displ, y = hwy))
g + geom_point()
```



Scatterplots

We can add a regression line to the existing plot to visualize this trend:

```
g + geom_point() + geom_smooth(method = "lm")
```



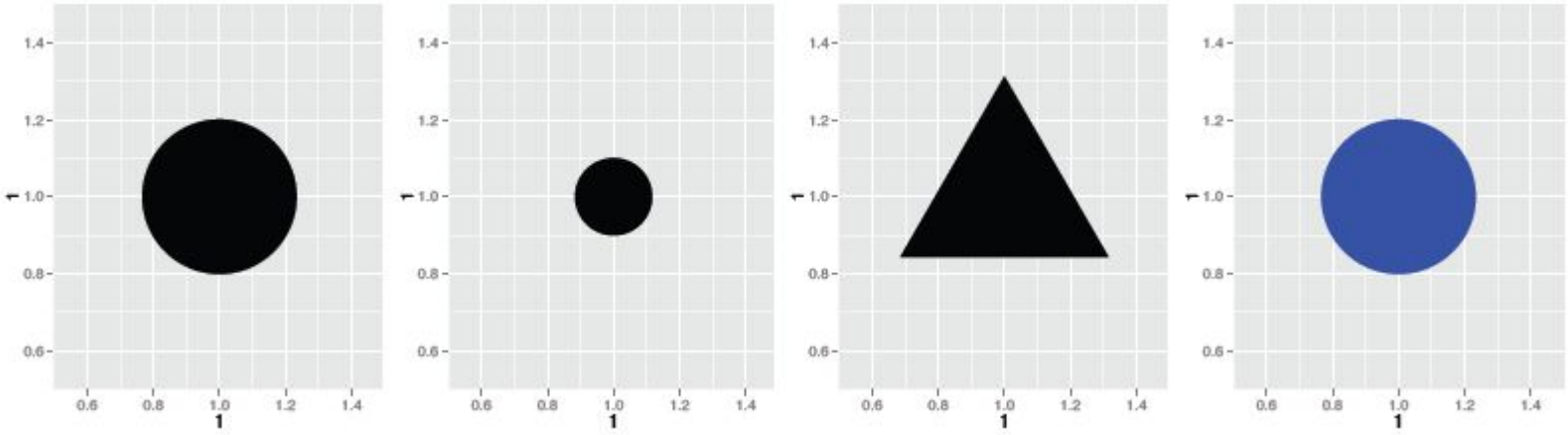
The greatest value of a picture is when it forces us to notice what we never expected to see.

- John Tukey

Aesthetics

Aesthetics

Visual characteristics that data are mapped to.



Aesthetics

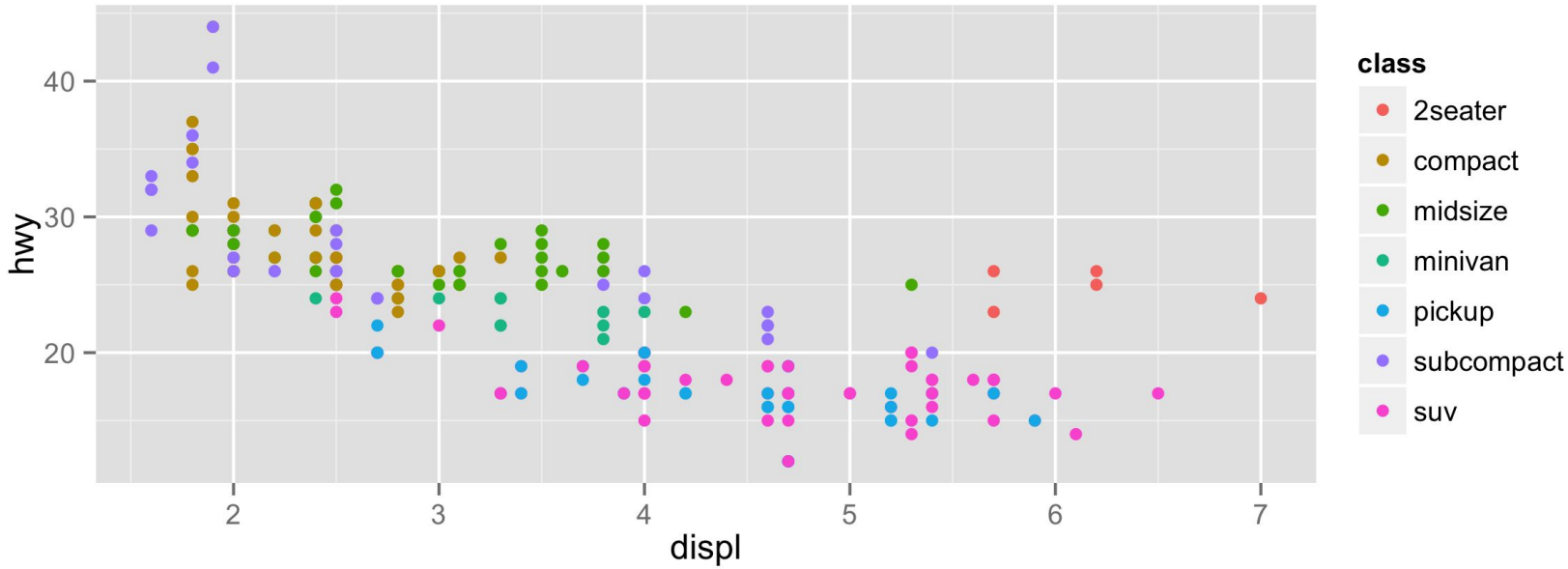
- color, size, shape, alpha
- Add color, size, and shape aesthetics to your graph. Experiment.
- Do different things happen for discrete and continuous variables?
- What happens when you use more than one aesthetic?
- What are the warning messages trying to tell us?

```
g + geom_point(aes(color = class))
g + geom_point(aes(size = class))
g + geom_point(aes(shape = class))
g + geom_point(aes(alpha = class))
```

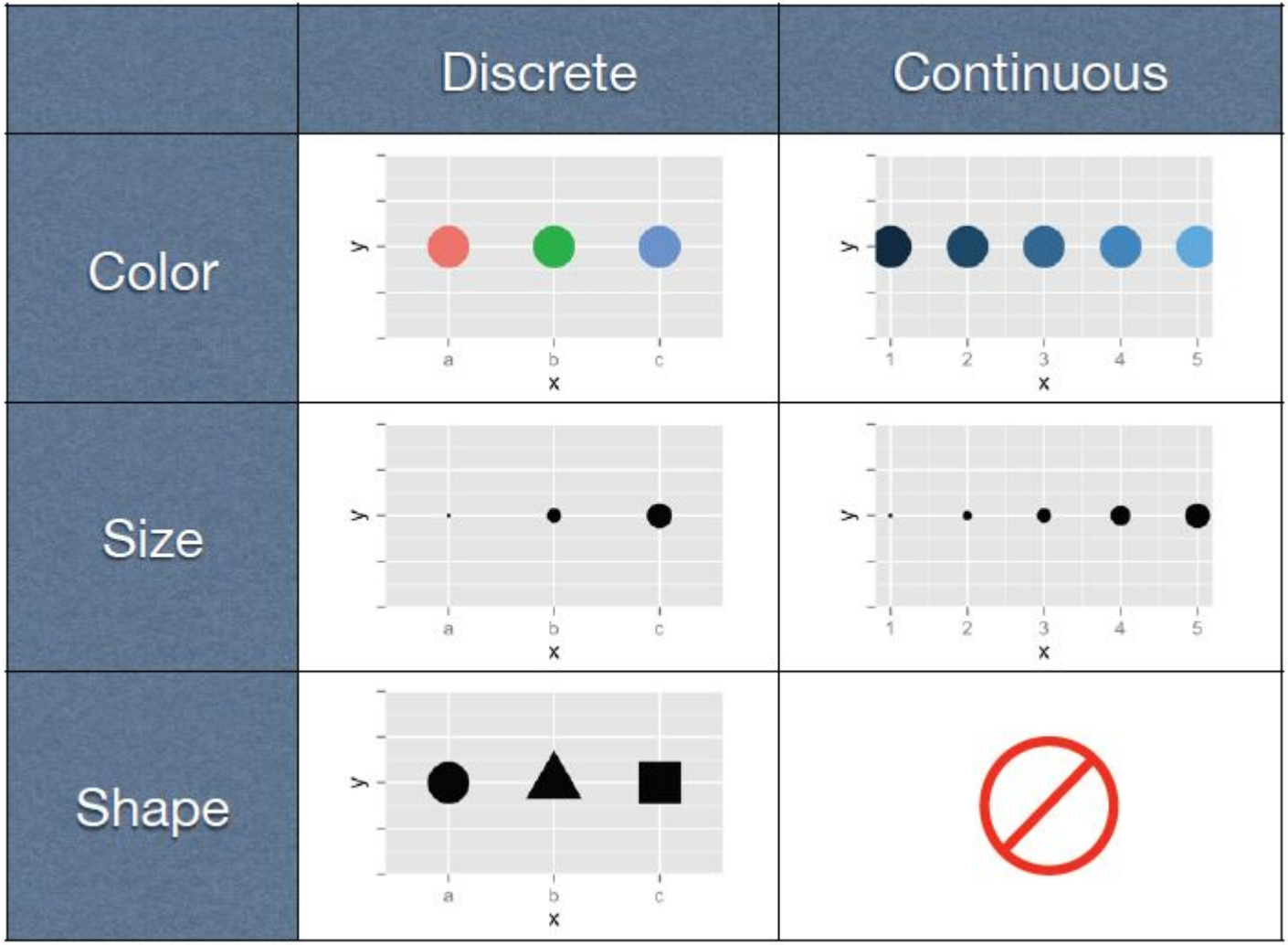
Aesthetics

Notice: The legend is chosen and displayed automatically.

```
g + geom_point(aes(color = class))
```



Aesthetics



Faceting

Faceting

- Smaller plots that display different subsets of the data.
- Also useful for exploring conditional relationships.
- Useful for large data.
- facet_grid function.
- facet_wrap function.

Faceting

- facet_grid(): 2d grid, rows ~ cols, . is a placeholder that can be used if you don't want a split.
- facet_wrap(): 1d ribbon wrapped into 2d.

Faceting

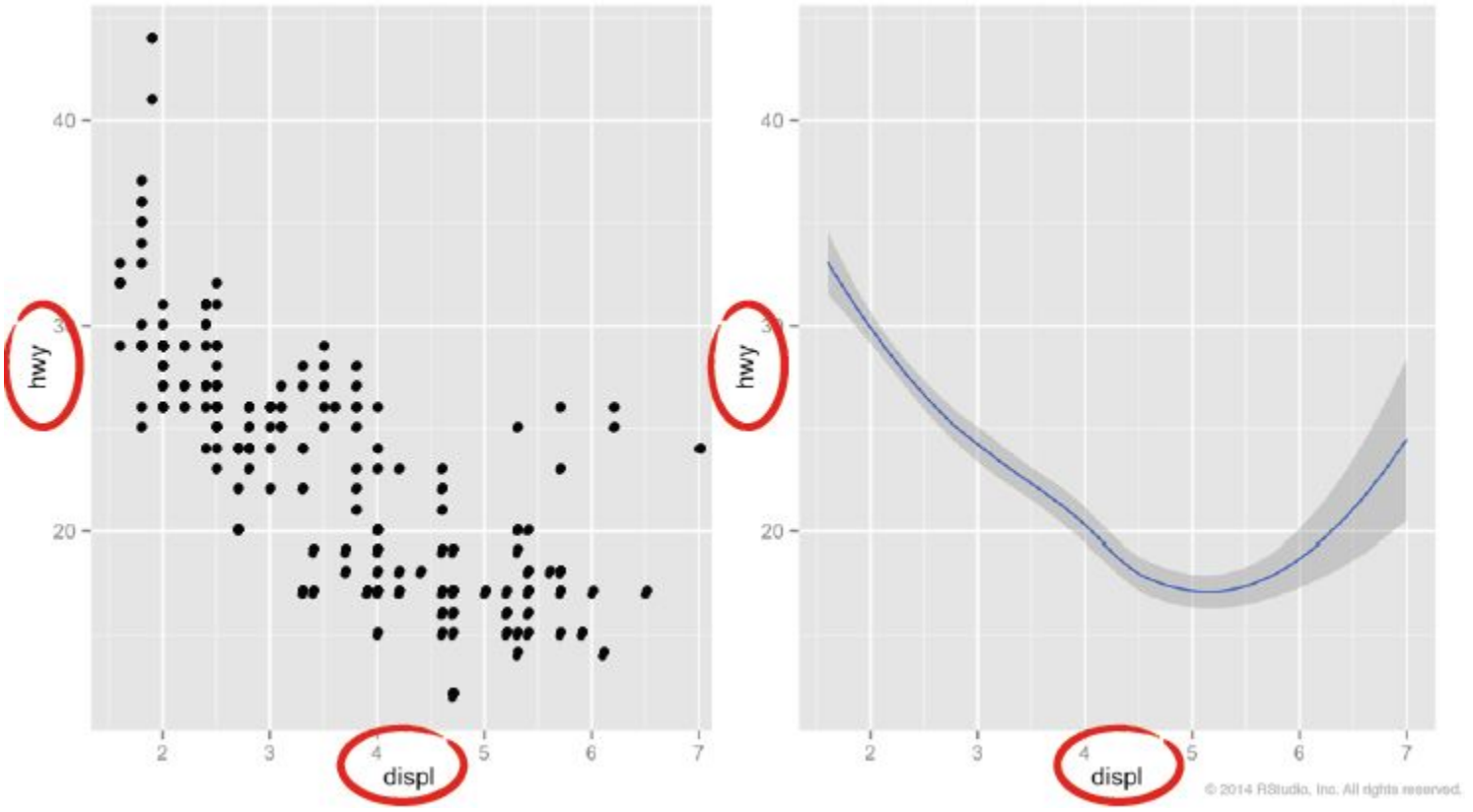
Your turn

```
g + geom_point() + facet_grid(. ~ cyl)

g + geom_point() + facet_grid(drv ~ .)

g + geom_point() + facet_grid(drv ~ cyl)

g + geom_point() + facet_wrap( ~ class)
```

Geoms

Geoms

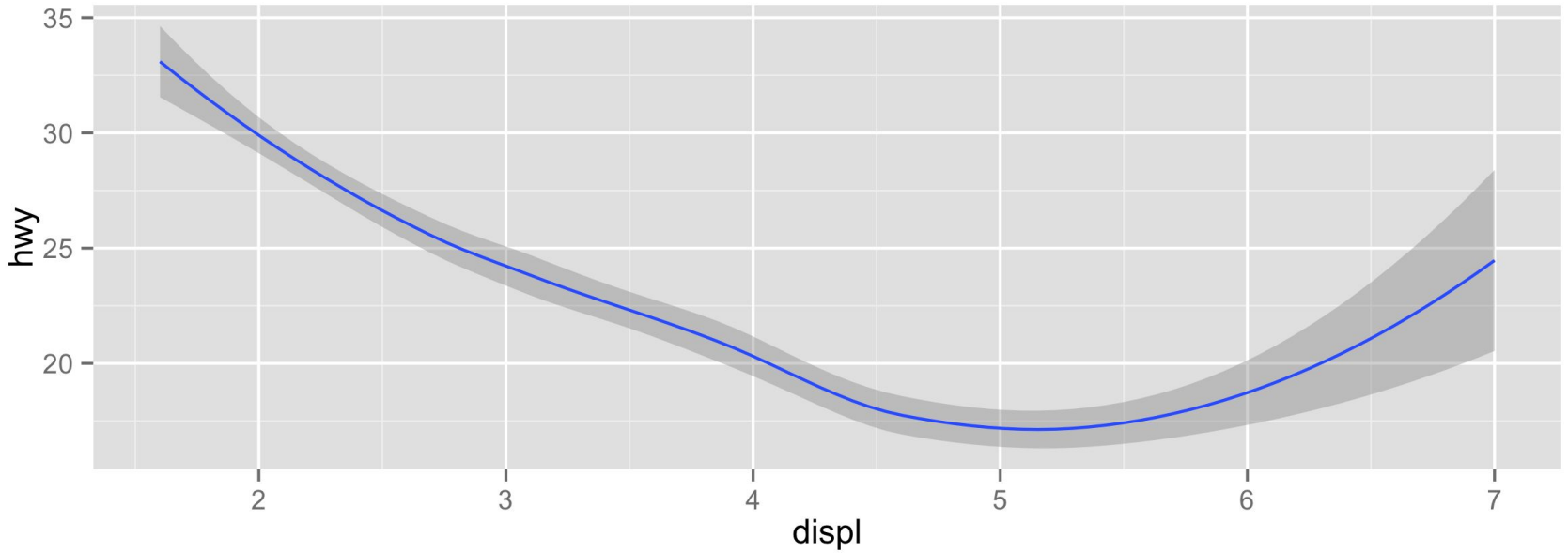
How are these plots similar?



Geoms

The geom_<type>(...) function determines the "type" of graph.

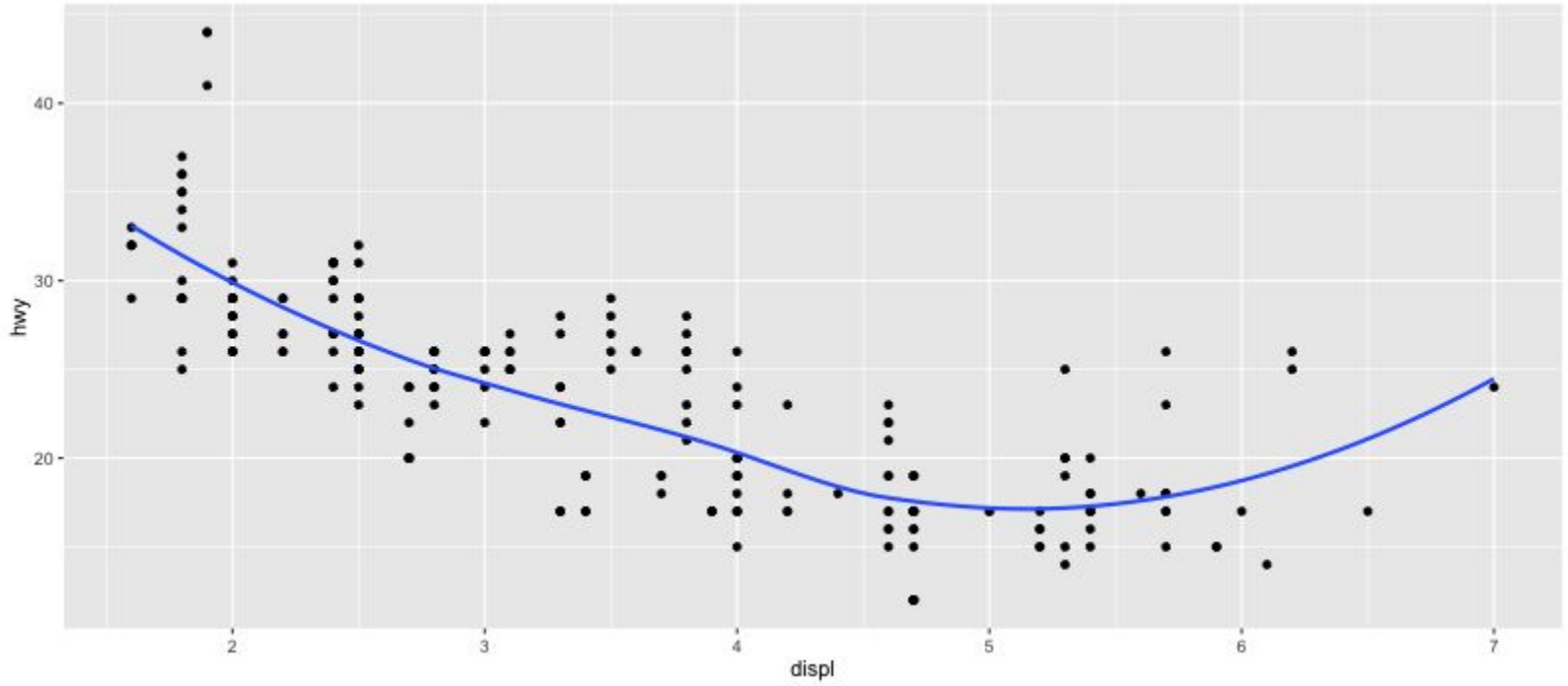
```
g + geom_smooth() # method = "auto" is the default
```



Geoms

As we saw earlier, we can layer multiple geoms.

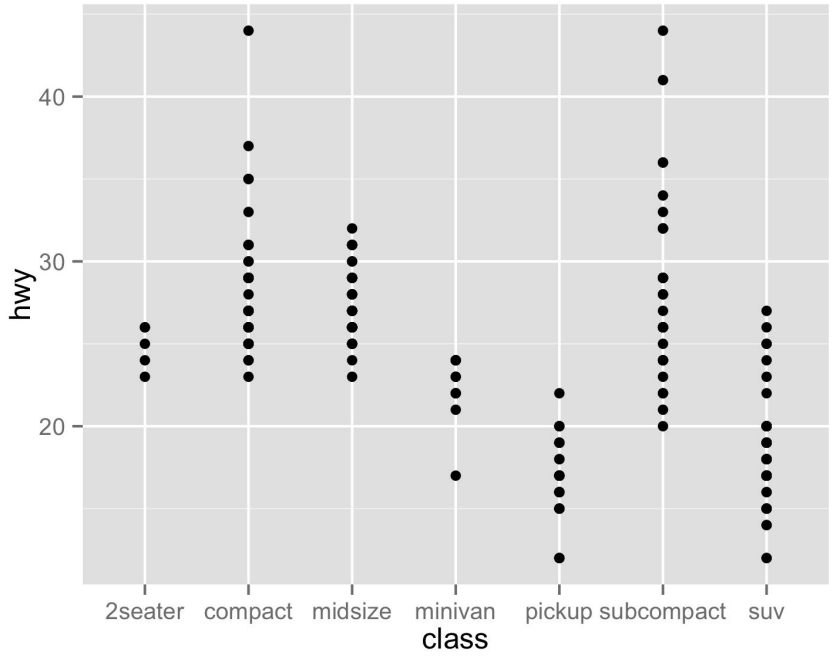
```
g + geom_point() + geom_smooth(se = FALSE)  # Turn off
confidence band
```

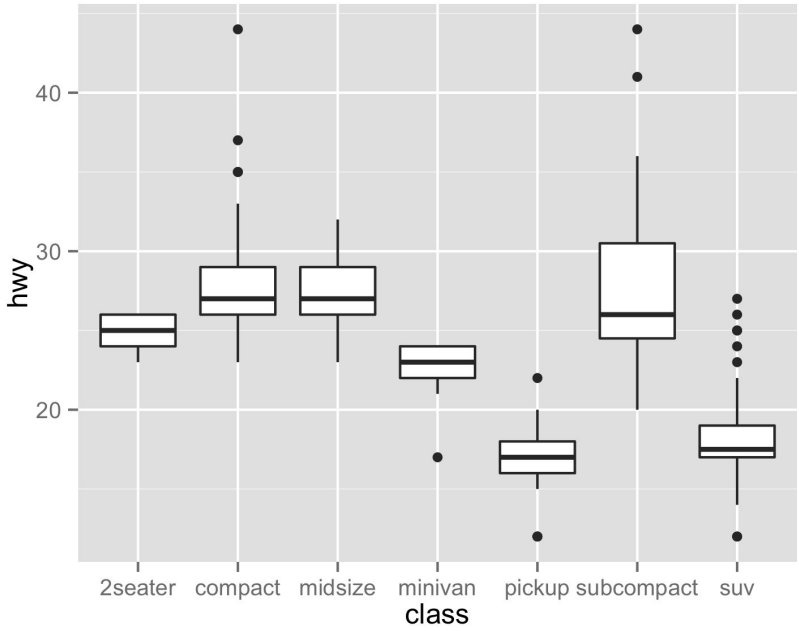


Geoms

How would you replace this scatterplot with one that draws boxplots?

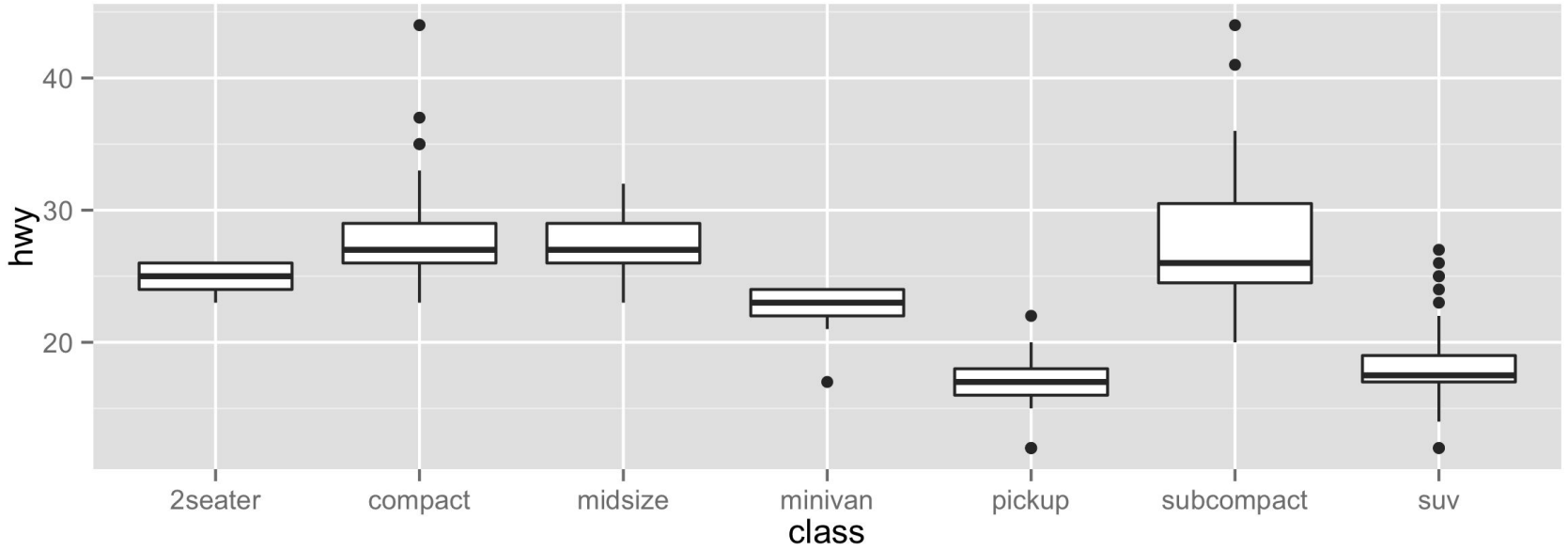
```
ggplot(data = mpg, aes(x = class, y = hwy)) + geom_point()
```





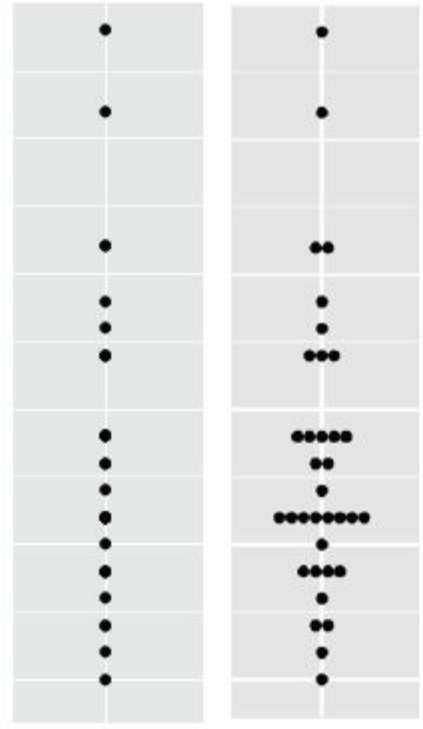
Geoms

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



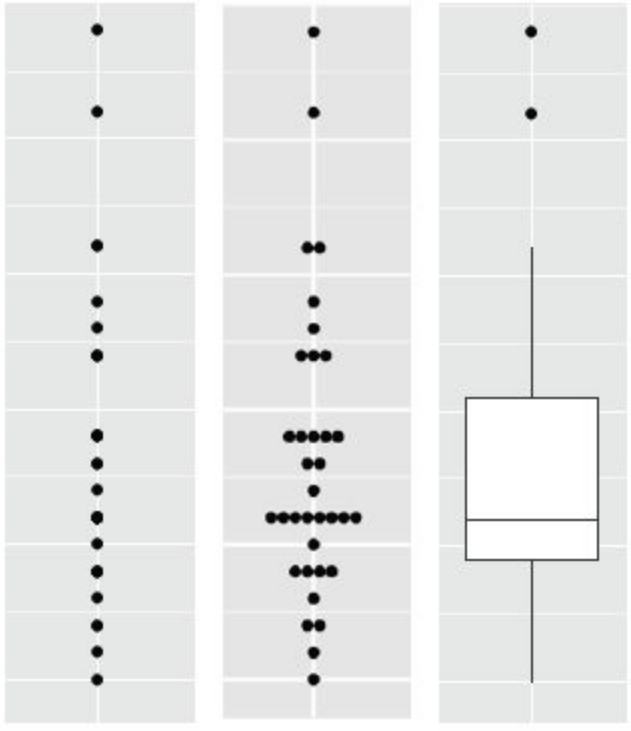
Geoms

boxplots



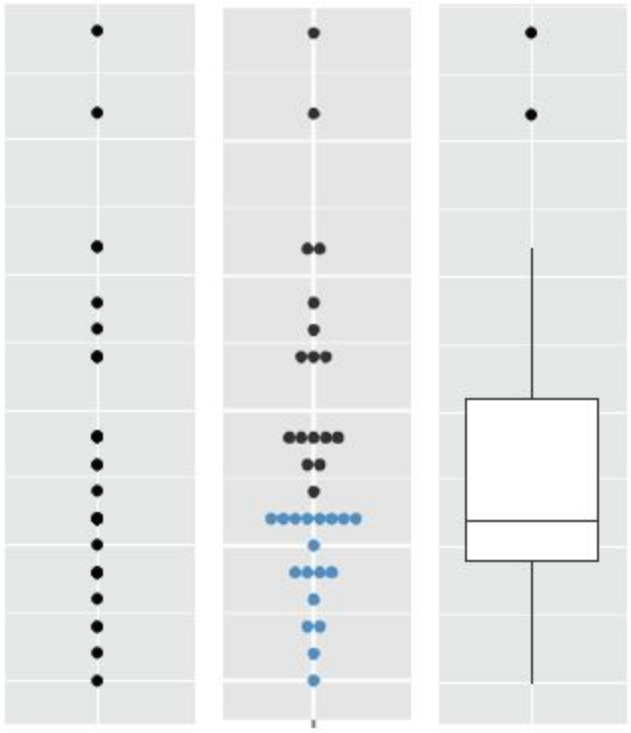
Geoms

boxplots



Geoms

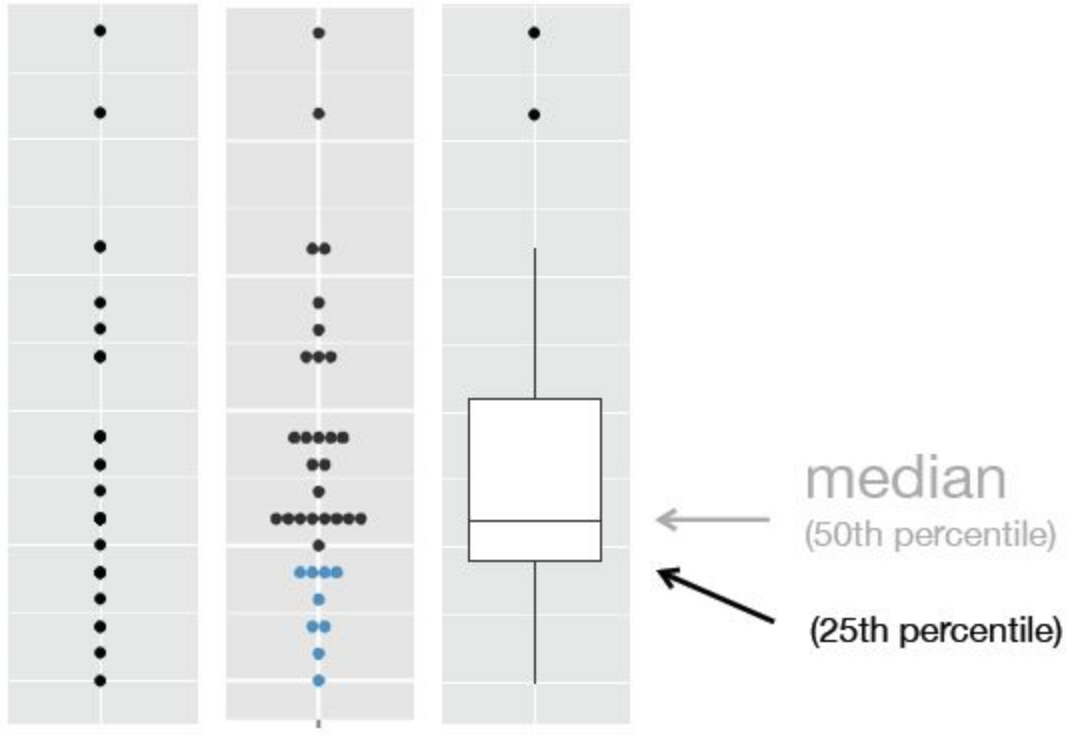
boxplots



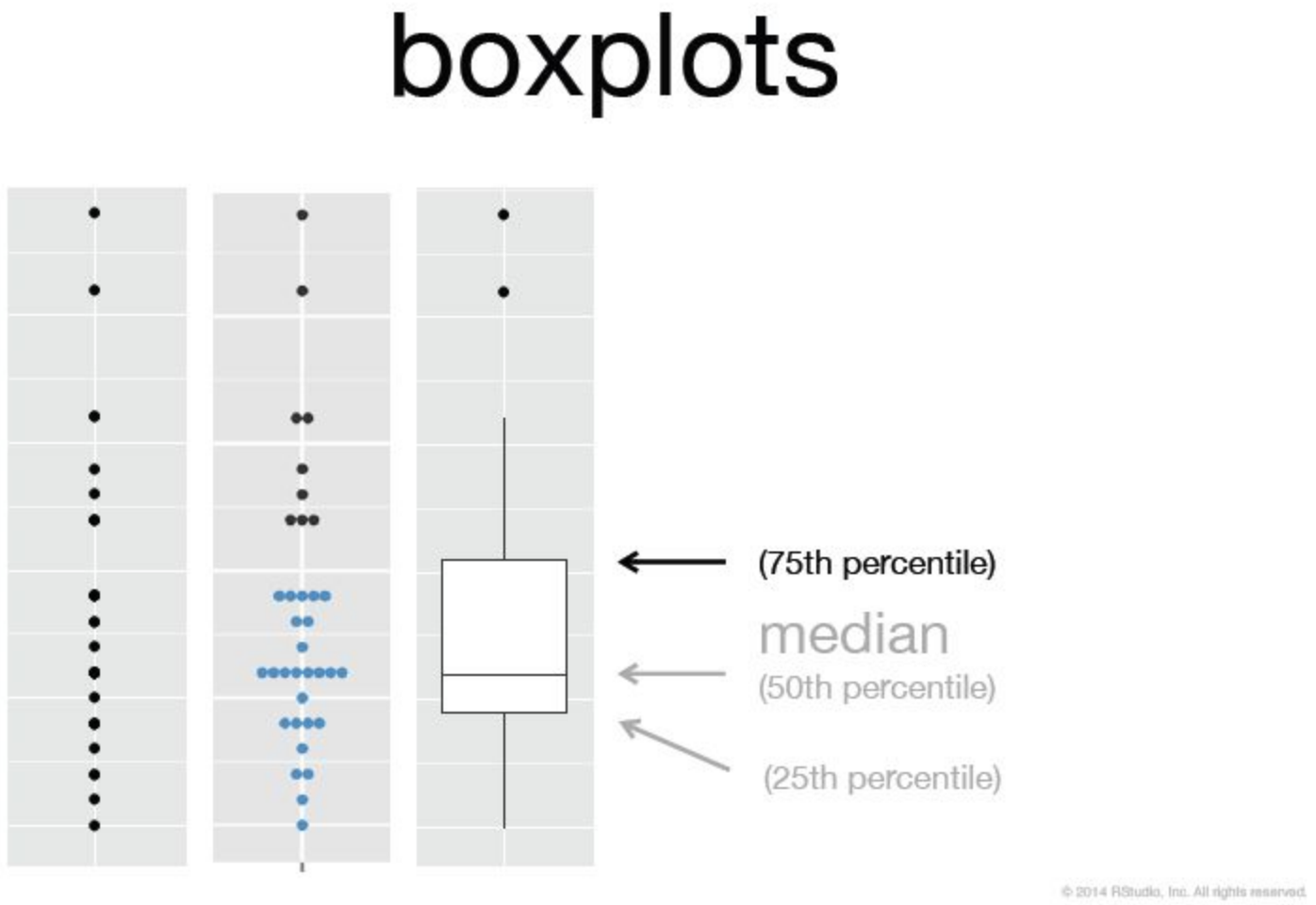
median
(50th percentile)

Geoms

boxplots



Geoms


boxplots
(75th percentile)
median
(50th percentile)
(25th percentile)
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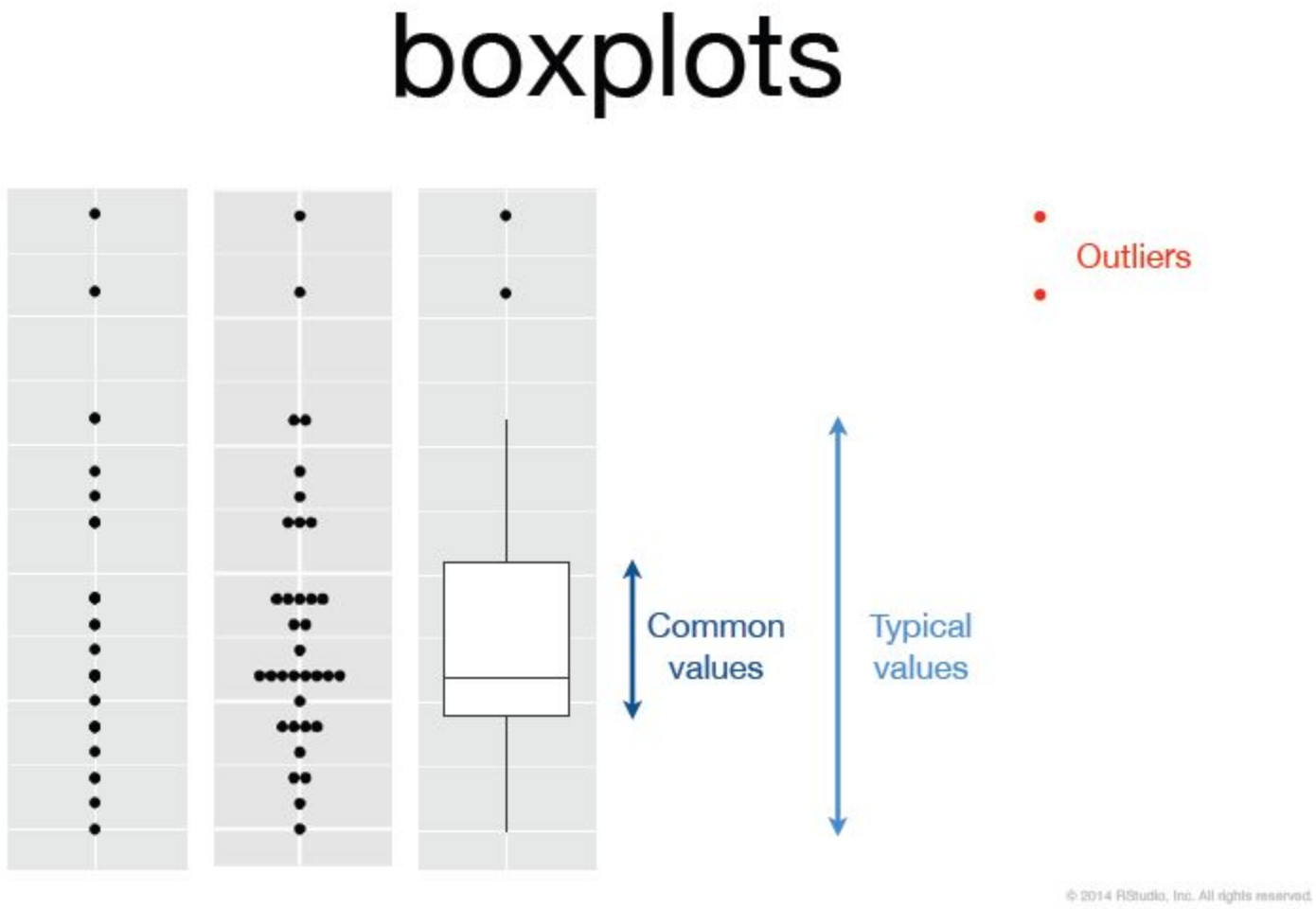
Geoms


boxplots
Outliers
Common values
Typical values
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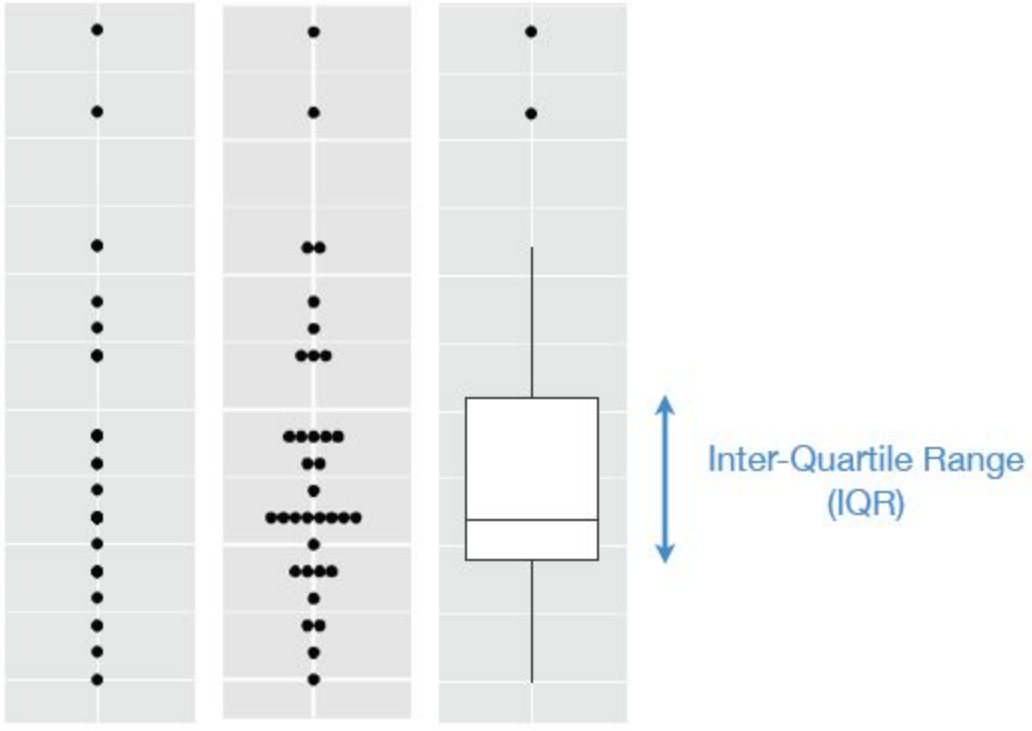
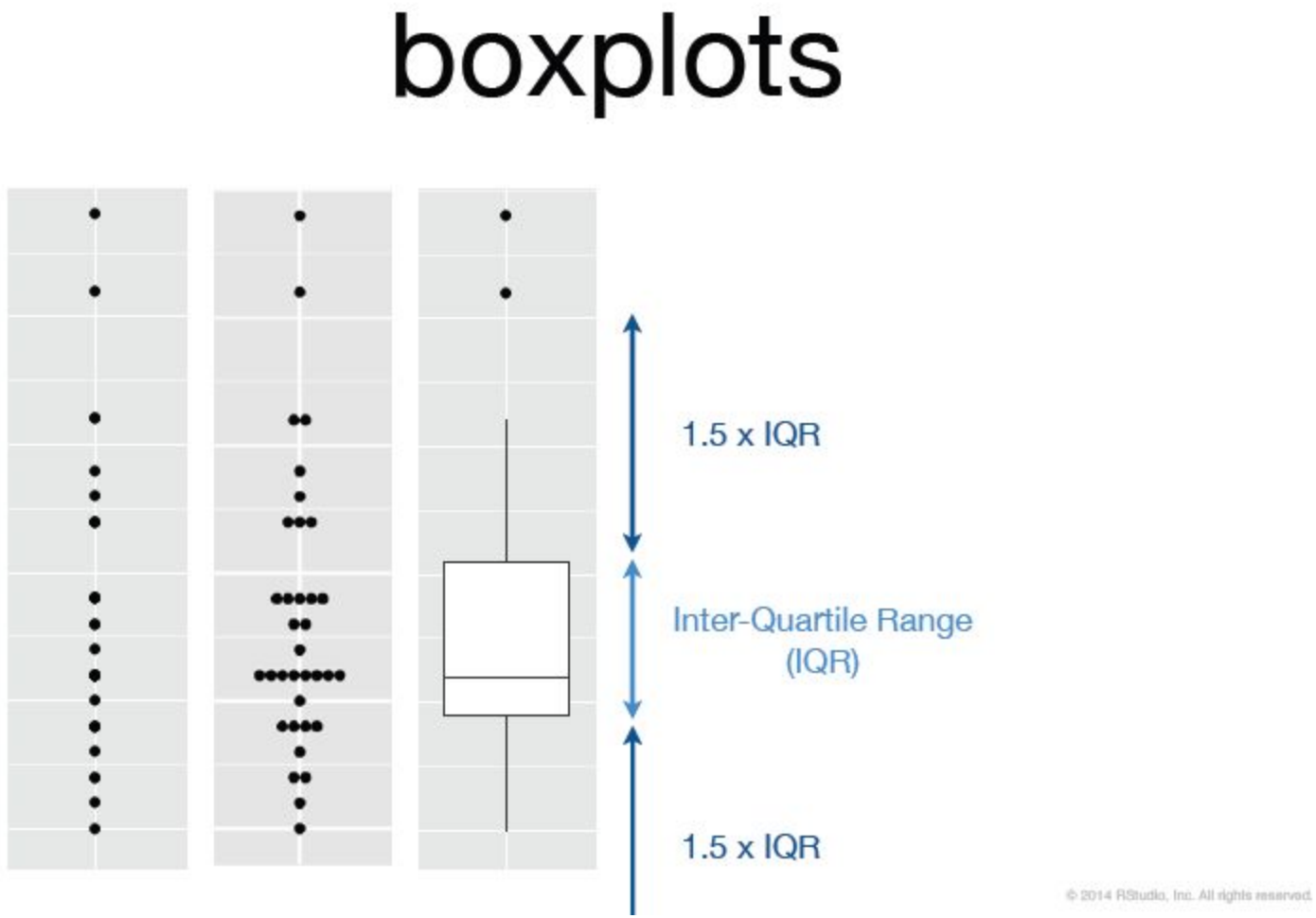
Geoms

boxplots



Geoms


boxplots
1.5 x IQR
Inter-Quartile Range
(IQR)
1.5 x IQR
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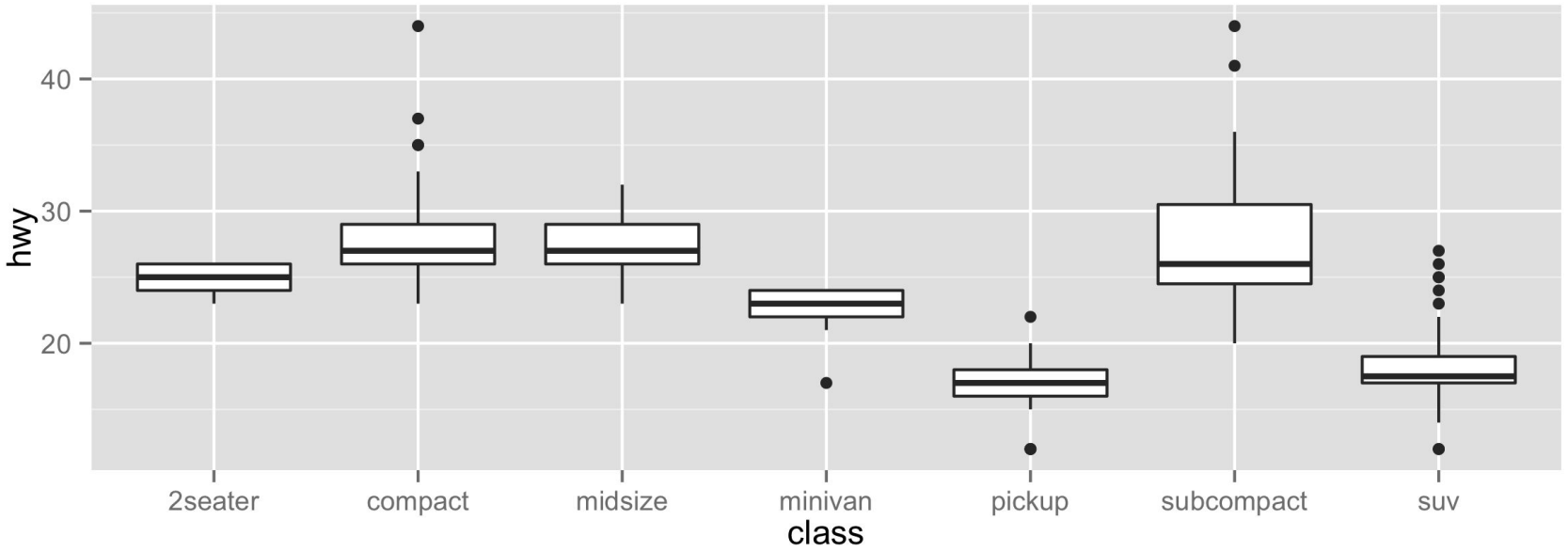
Geoms

How could we make the relationship between class and hwy easier to read?

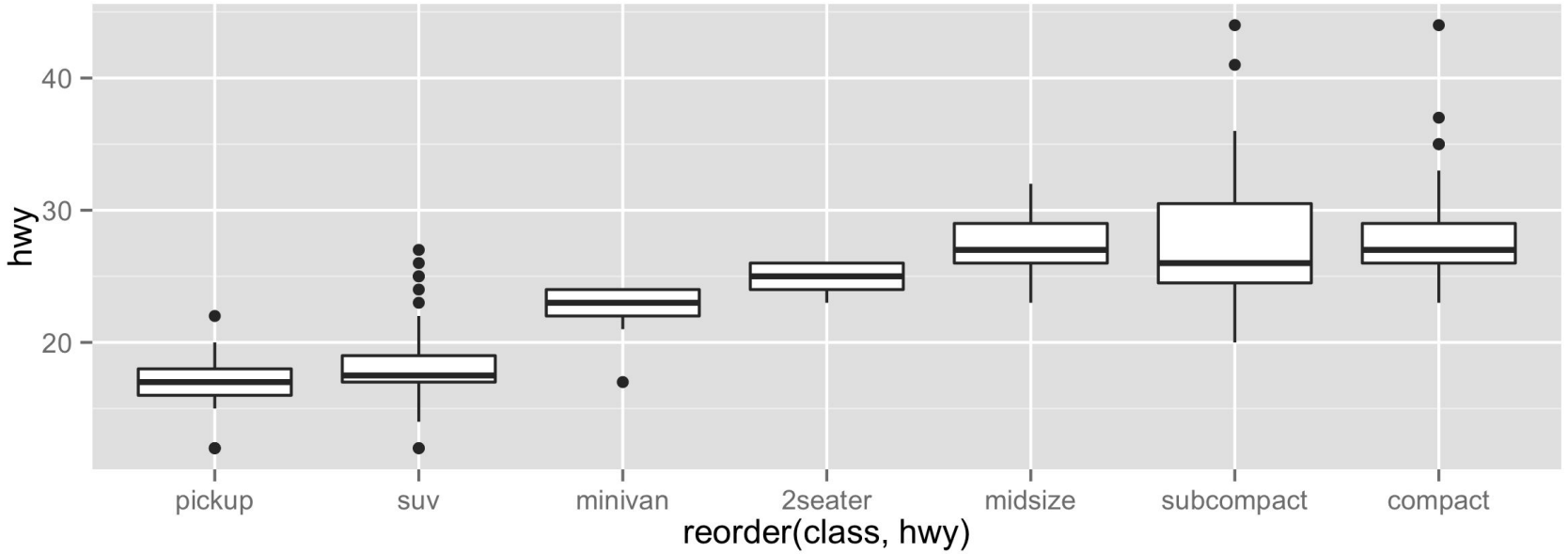
```
g + geom_boxplot()
```



Geoms

Use the reorder function to make it easier to compare classes.

```
g <- ggplot(data = mpg, aes(x = reorder(class, hwy), y = hwy))
g + geom_boxplot()
```



Geoms

- Read the help for the reorder function.
- Redraw the previous plots with the classes ordered by the median.

Geoms

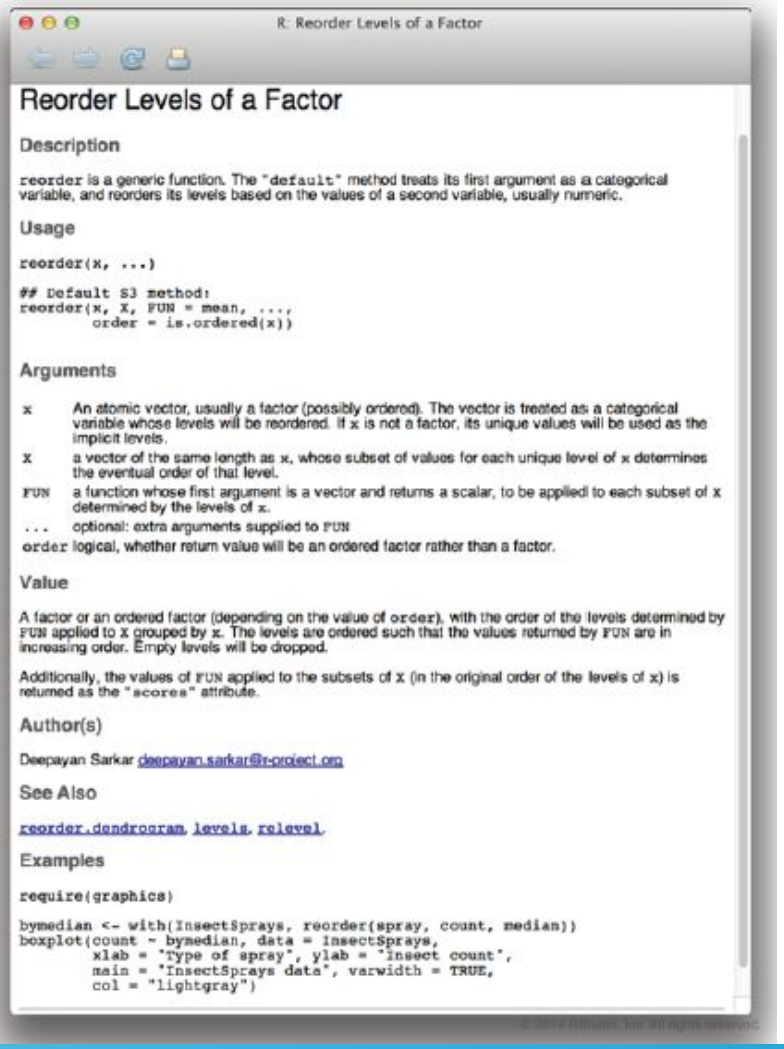
Description
Useful overview

Usage
Good place to spot default values

Arguments
explanation of each argument

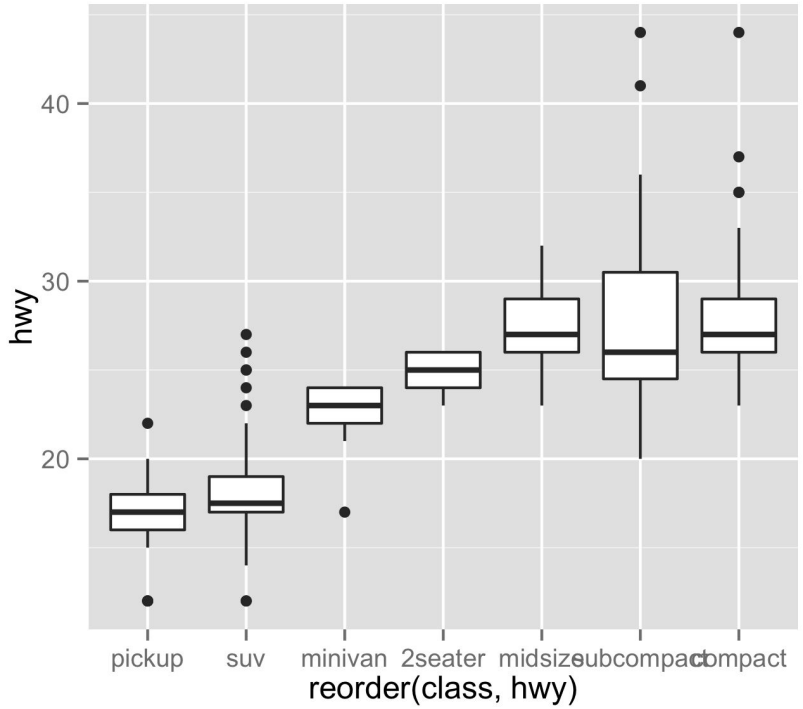
Value
what the function returns

Examples
Most helpful section!

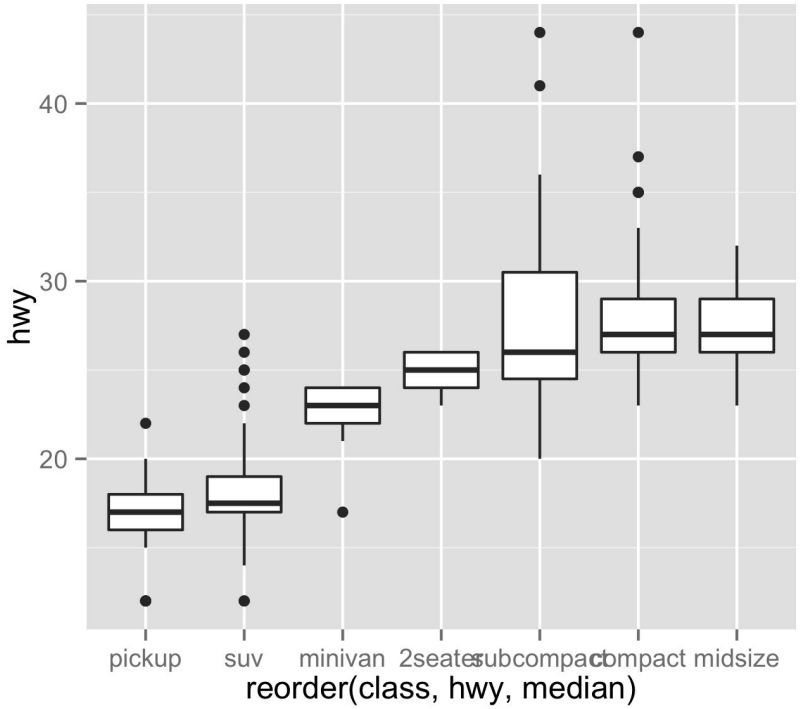


Geoms

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



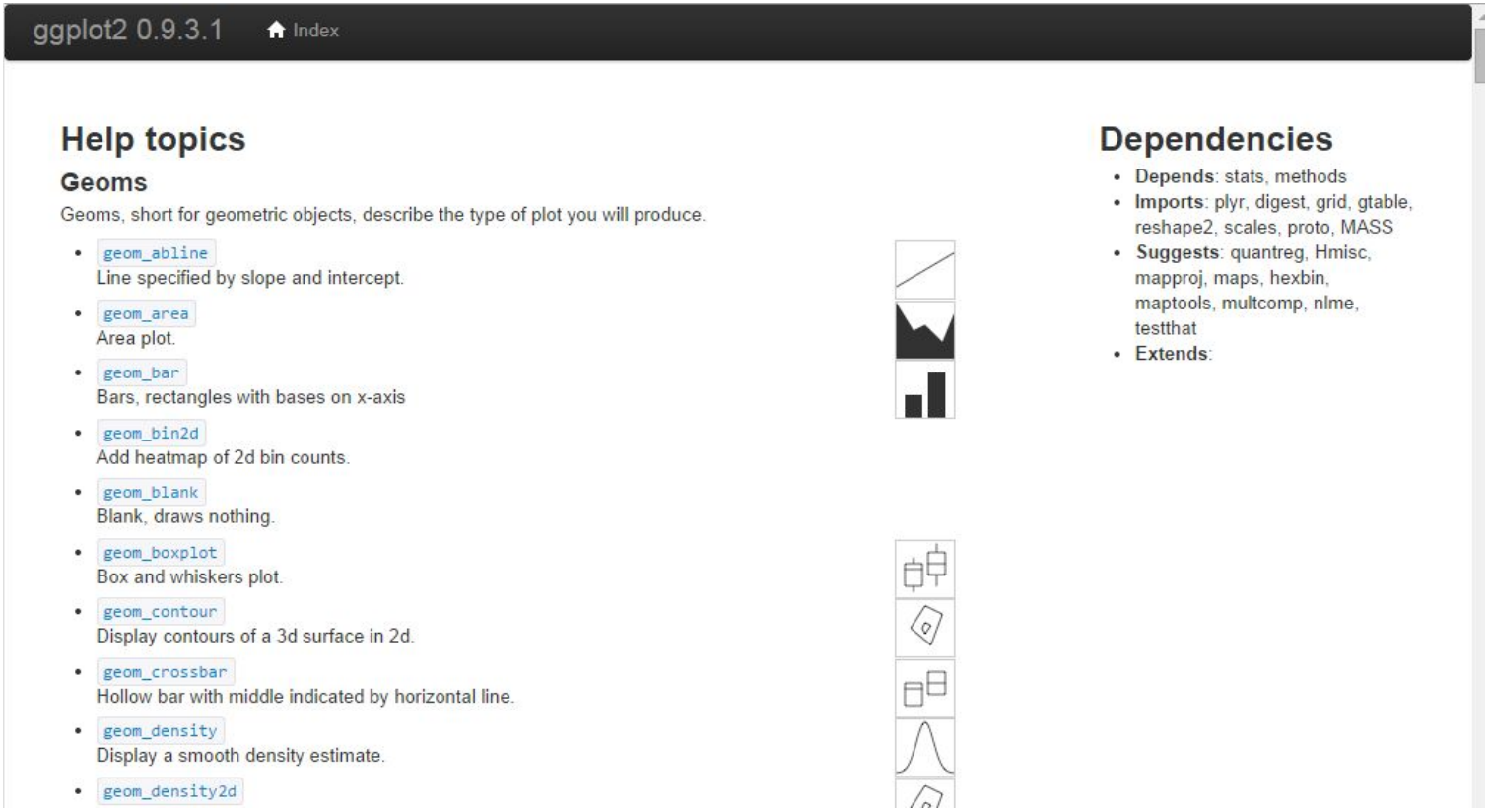

```
ggplot(data = mpg, aes(x = reorder(class, hwy, median), y = hwy)) + geom_boxplot()
```



Geoms

As a reminder, there are always the help pages:

- http://docs.ggplot2.org/



Diamonds Data Set

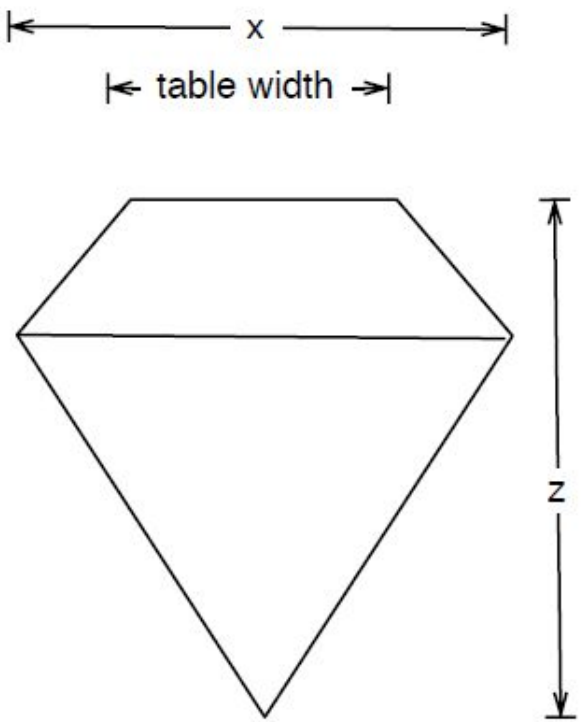
Diamonds Data Set

- Approx. 54,000 round diamonds from http://www.diamondse.info/
- comes in the ggplot2 package

```
names(diamonds)
```

```
[1]    "carat"   "cut"     "color"   "clarity" "depth"
"table"   "price"   "x"       "y"
[10]   "z"
```

Diamonds Data Set



depth = z / diameter
table = table width / x * 100

Diamonds Data Set

Figure: http://www.mlcld.com/colour.aspx

Diamonds Data Set

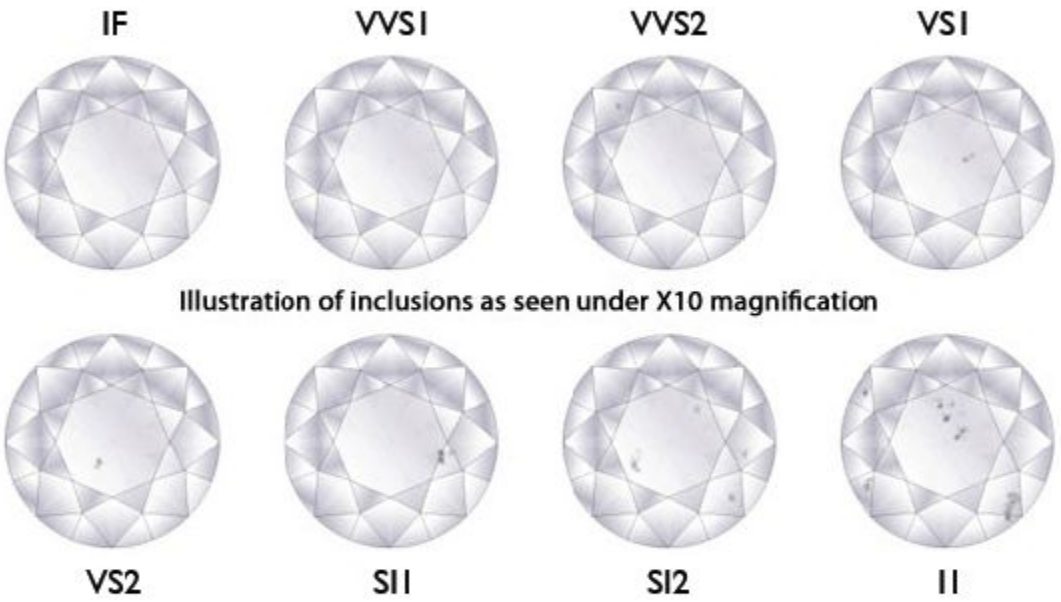


Figure: http://www.thediamondsexperts.com/diamonds-guide

Outline

- Why ggplot2?
- The “Grammar of Graphics”
- Constructing a ggplot2 plot
- Scatterplots
- **Bar charts**
- Histograms
- Visualizing big data
- Saving Graphs

Bar Charts

Bar Charts

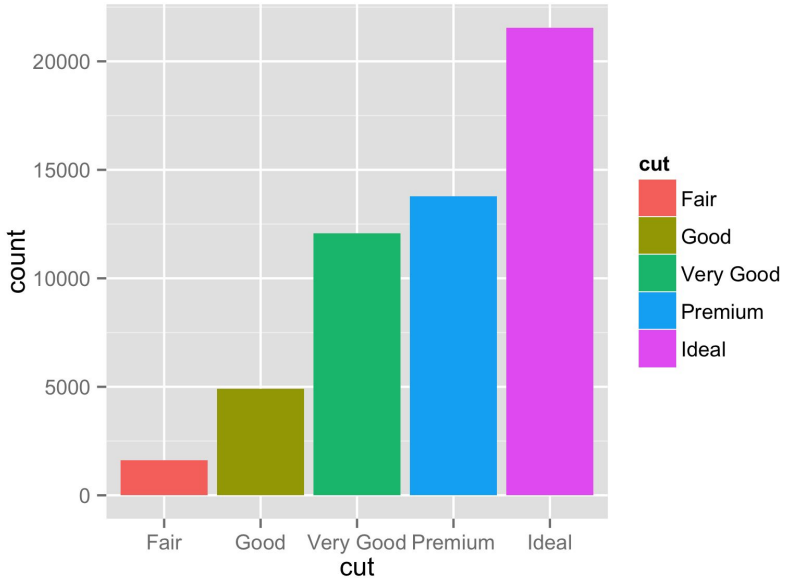
What would be a sensible way to display:

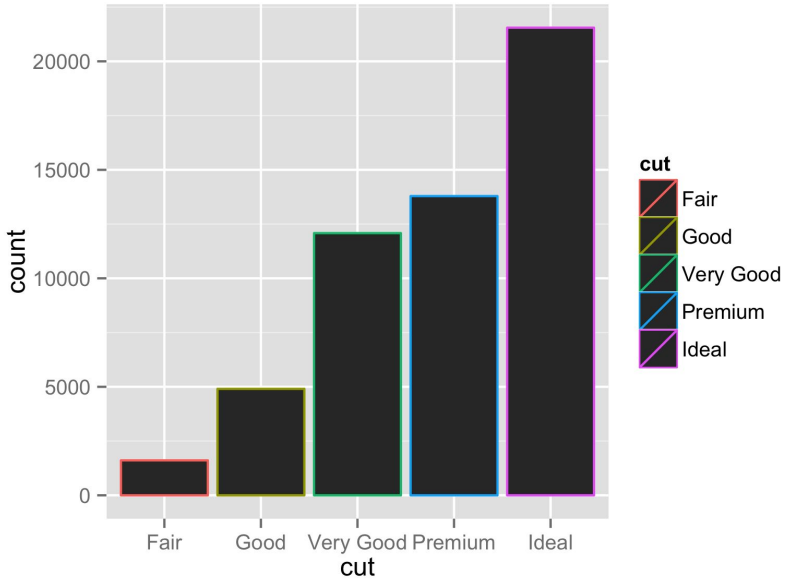
- The relationship between the x and z variables (two continuous variables)?
- Just the cut variable (a categorical variable)?
- Just the x variable (a continuous variable)?

Bar Charts

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

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



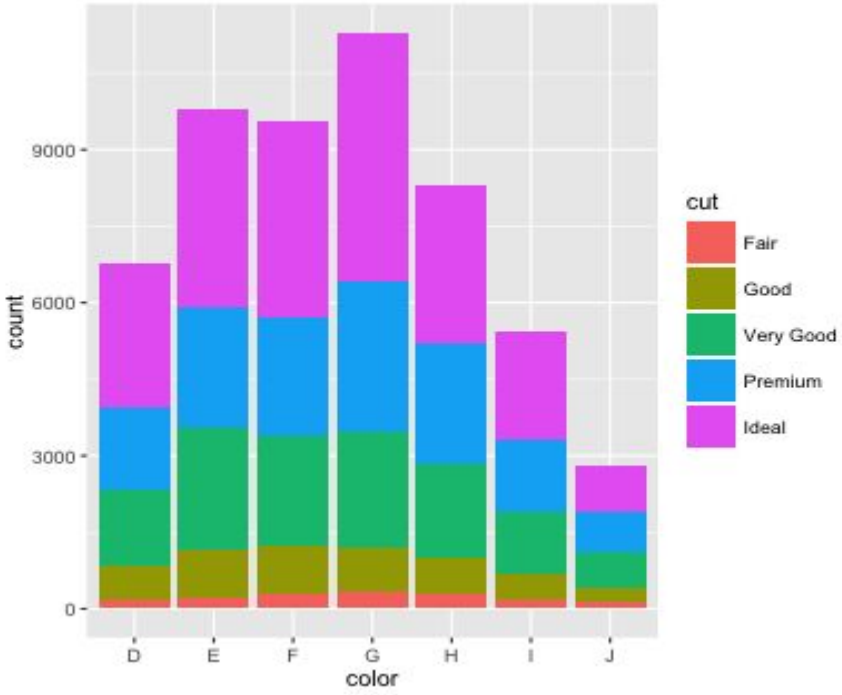


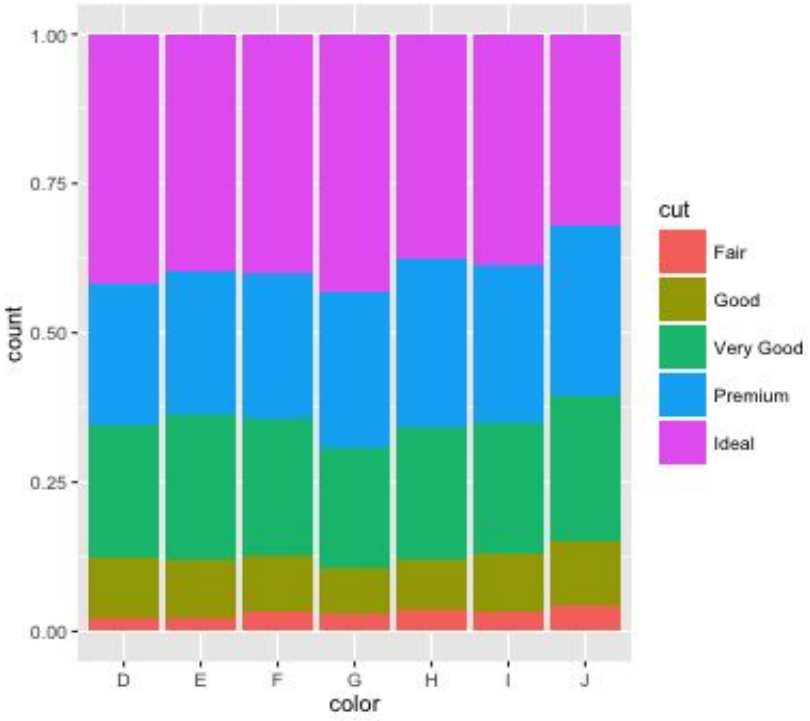
Position Adjustments

Position Adjustments

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

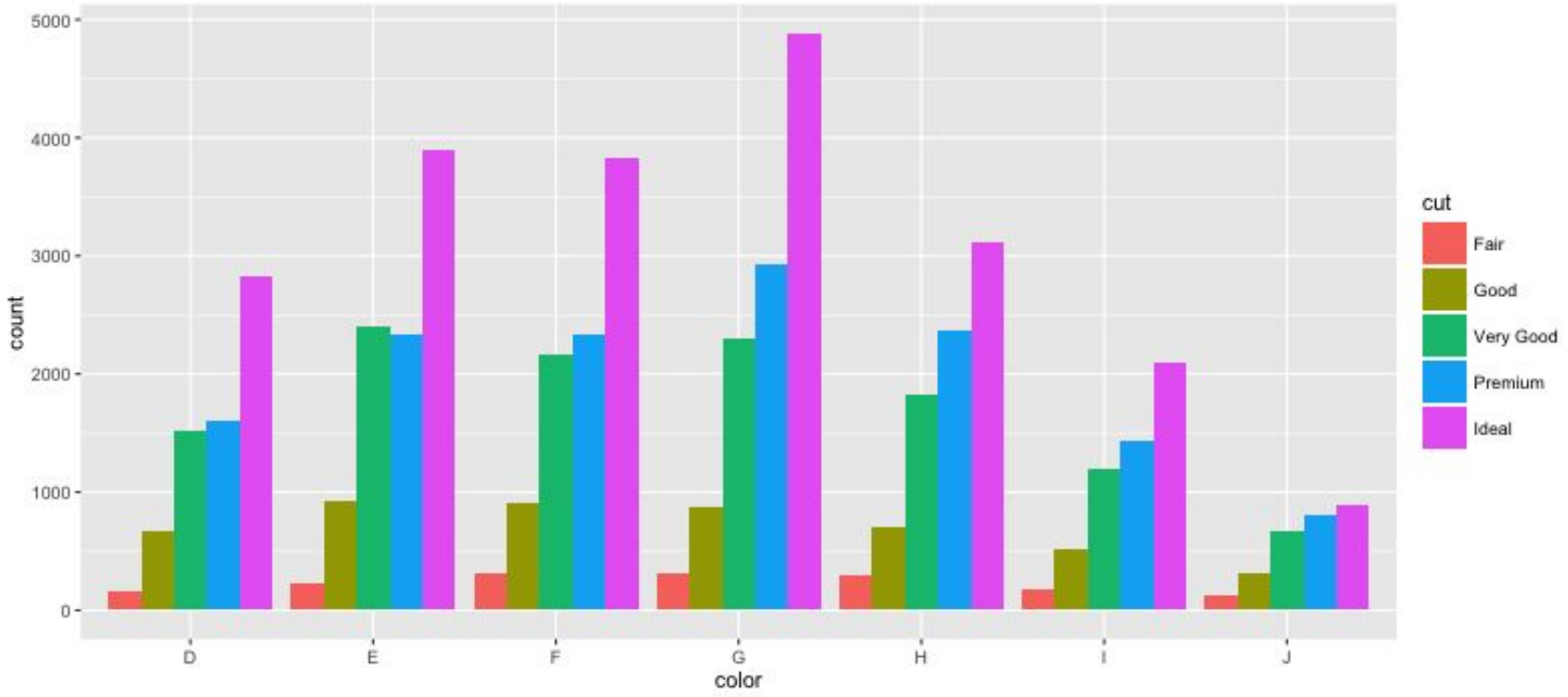
```
ggplot(data = diamonds, aes(x
  = color)) + geom_bar(aes
  (fill = cut), position =
  "fill")
```





Position Adjustments

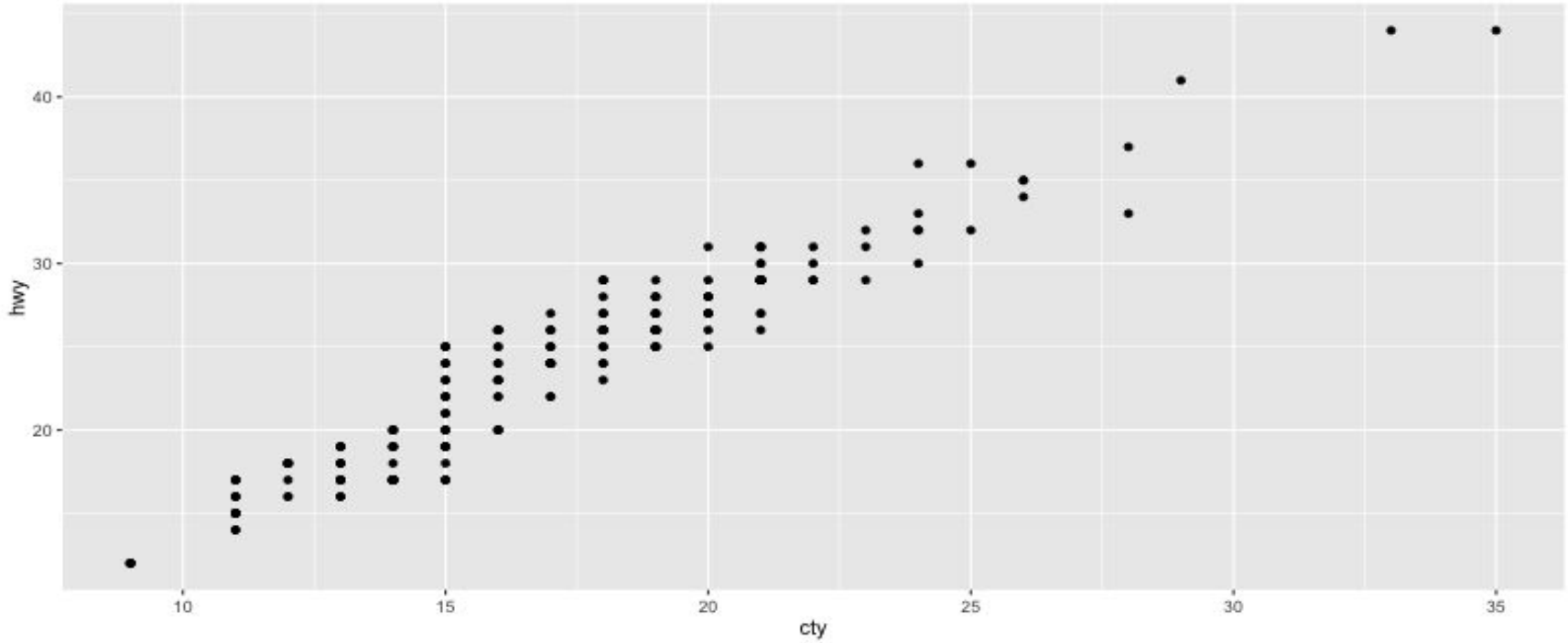
```
ggplot(data = diamonds, aes(x = color)) +
       geom_bar(aes(fill = cut), position = "dodge")
```



Position Adjustments

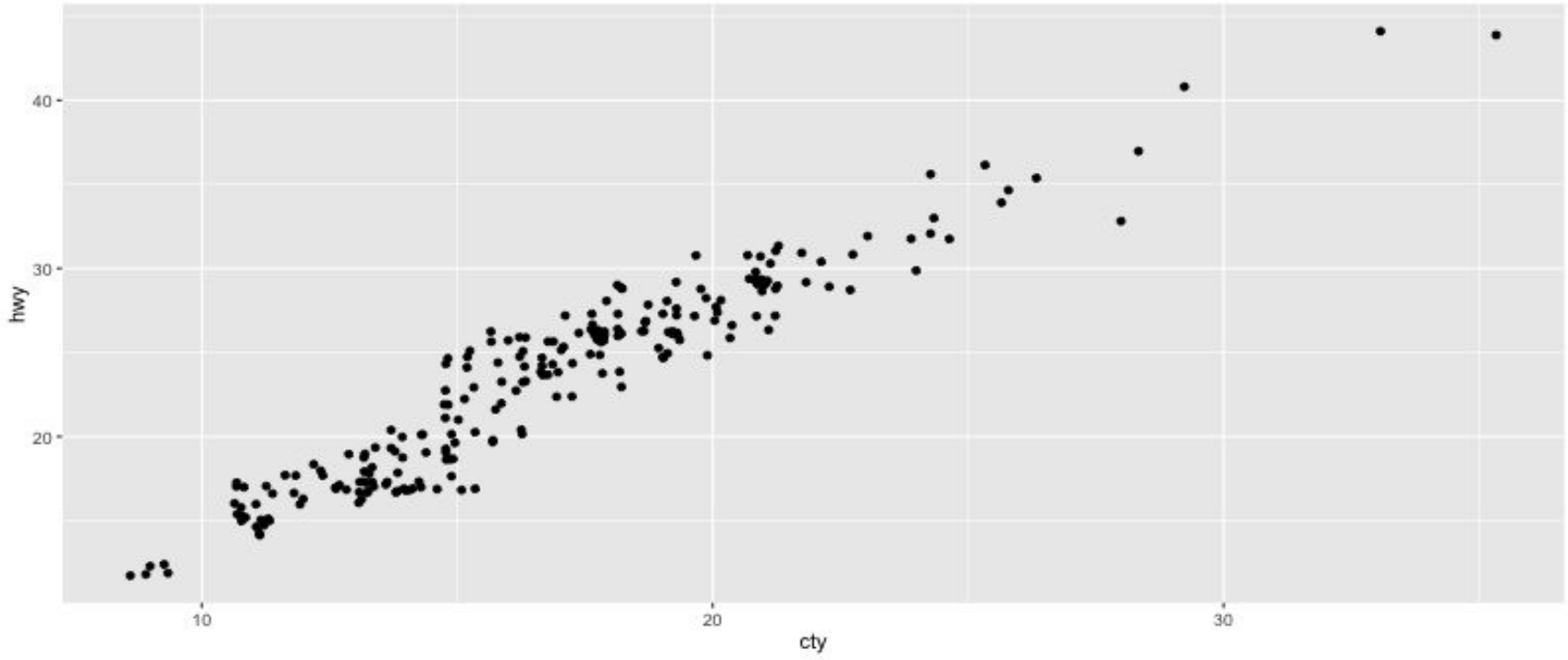
What is strange about this graph?

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



Position Adjustments

```
ggplot(data = mpg, aes(x = cty, y = hwy)) +
       geom_point(position = "jitter")
```



Position Adjustments

Jittering

- The jittering adjustment adds random noise to each point.
- As a result they are unlikely to overlap.
- Jittering is so common that ggplot2 comes with a jitter geom.
- It's just a short cut for a point geom with a jitter position adjustment.
- For example, these do the same thing:

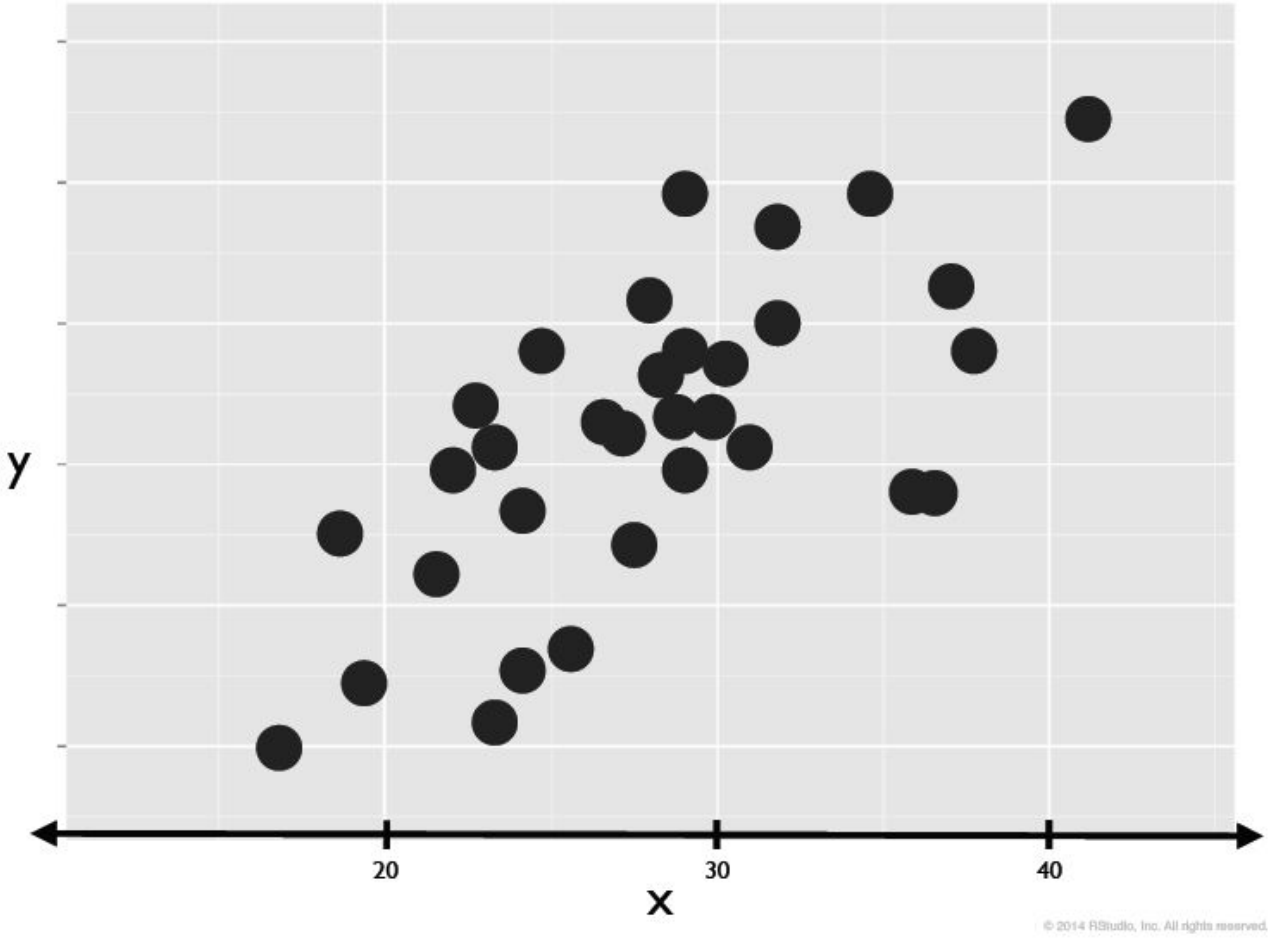
```
ggplot(data = mpg, aes(x = cty, y = hwy)) +
       geom_point(position = "jitter")

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

Outline

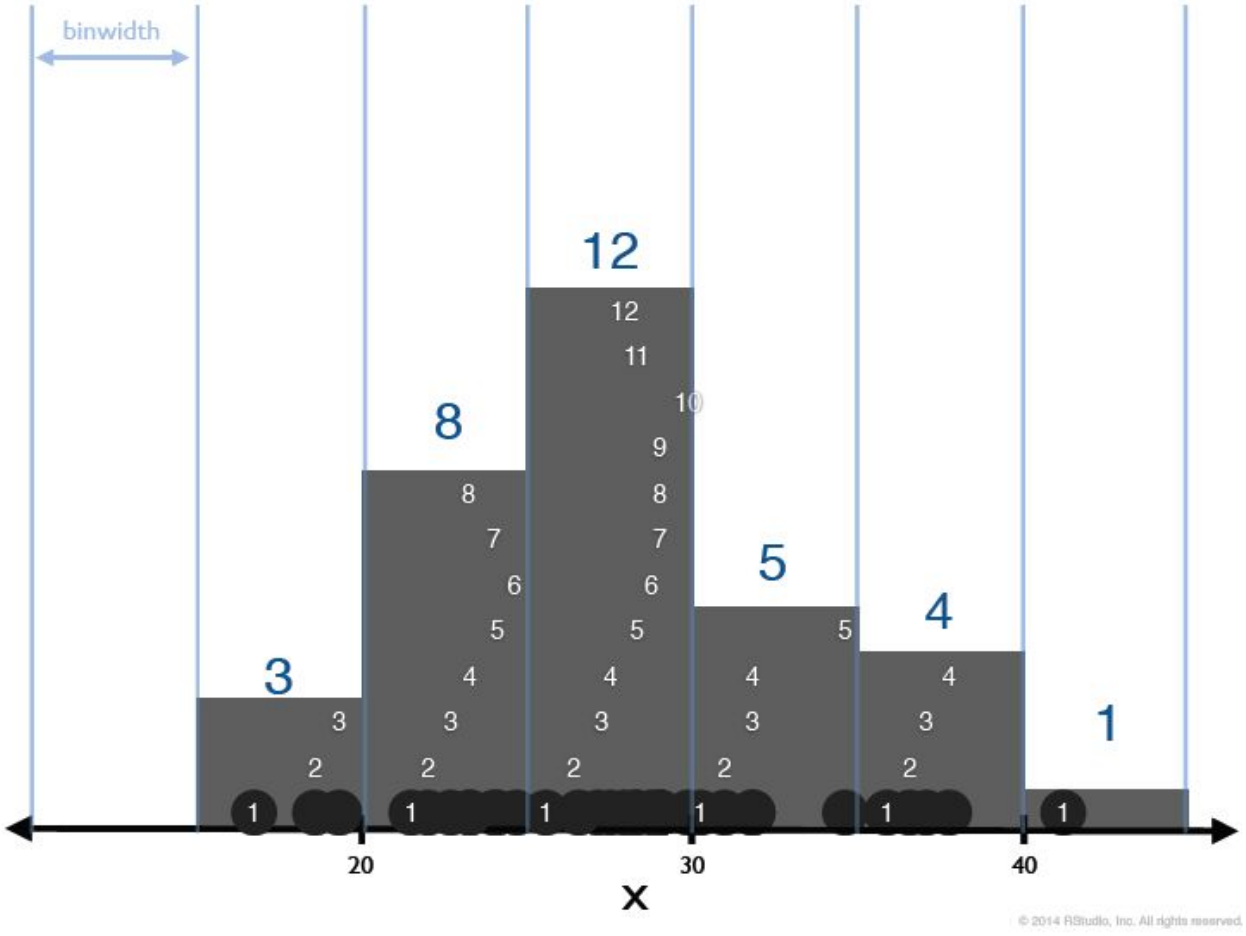
- Why ggplot2?
- The “Grammar of Graphics”
- Constructing a ggplot2 plot
- Scatterplots
- Bar charts
- **Histograms**
- Visualizing big data
- Saving Graphs

Histograms

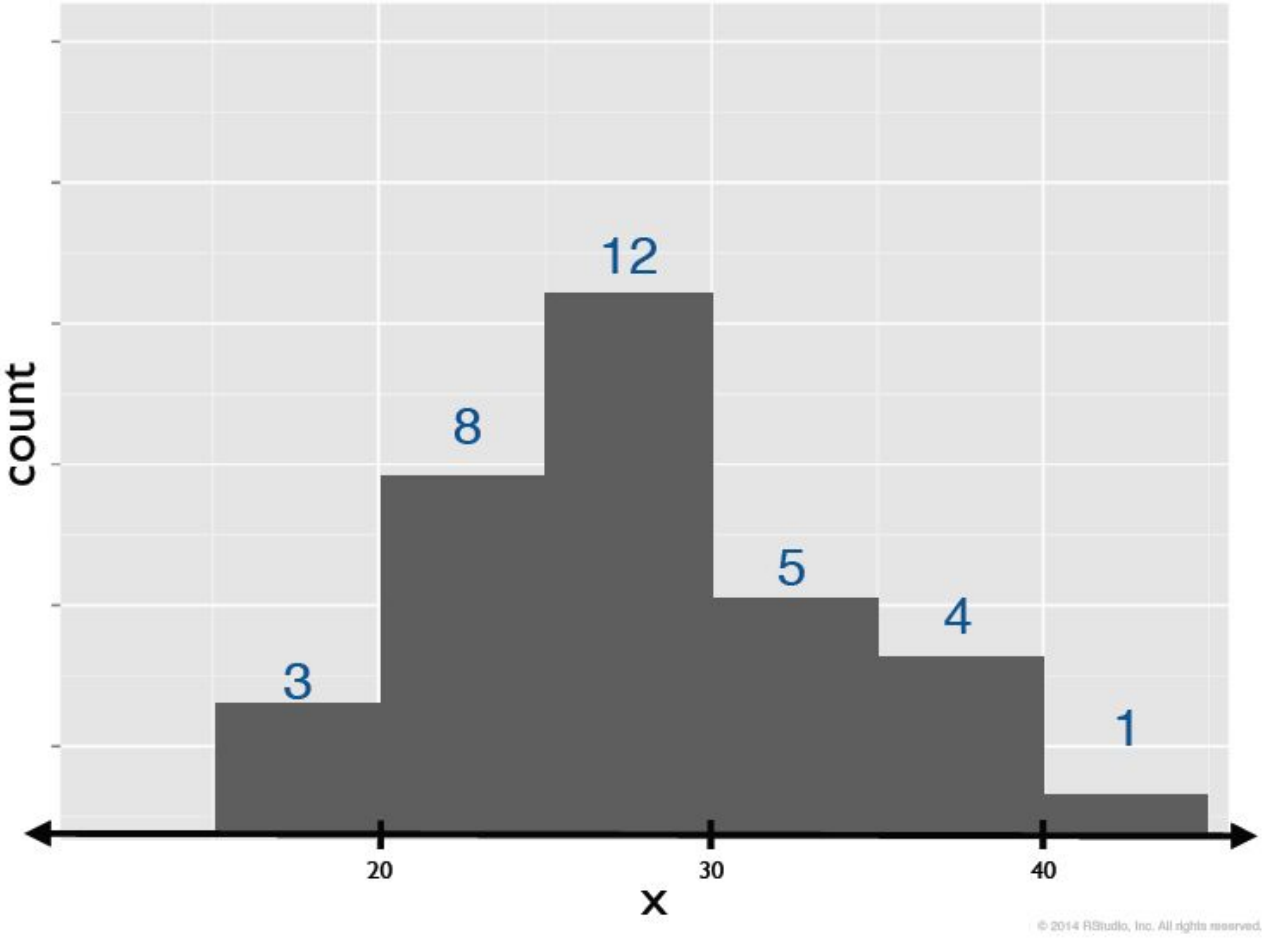
Histograms



Histograms



Histograms


count
12
8
5
4
3
1
20
30
40
x
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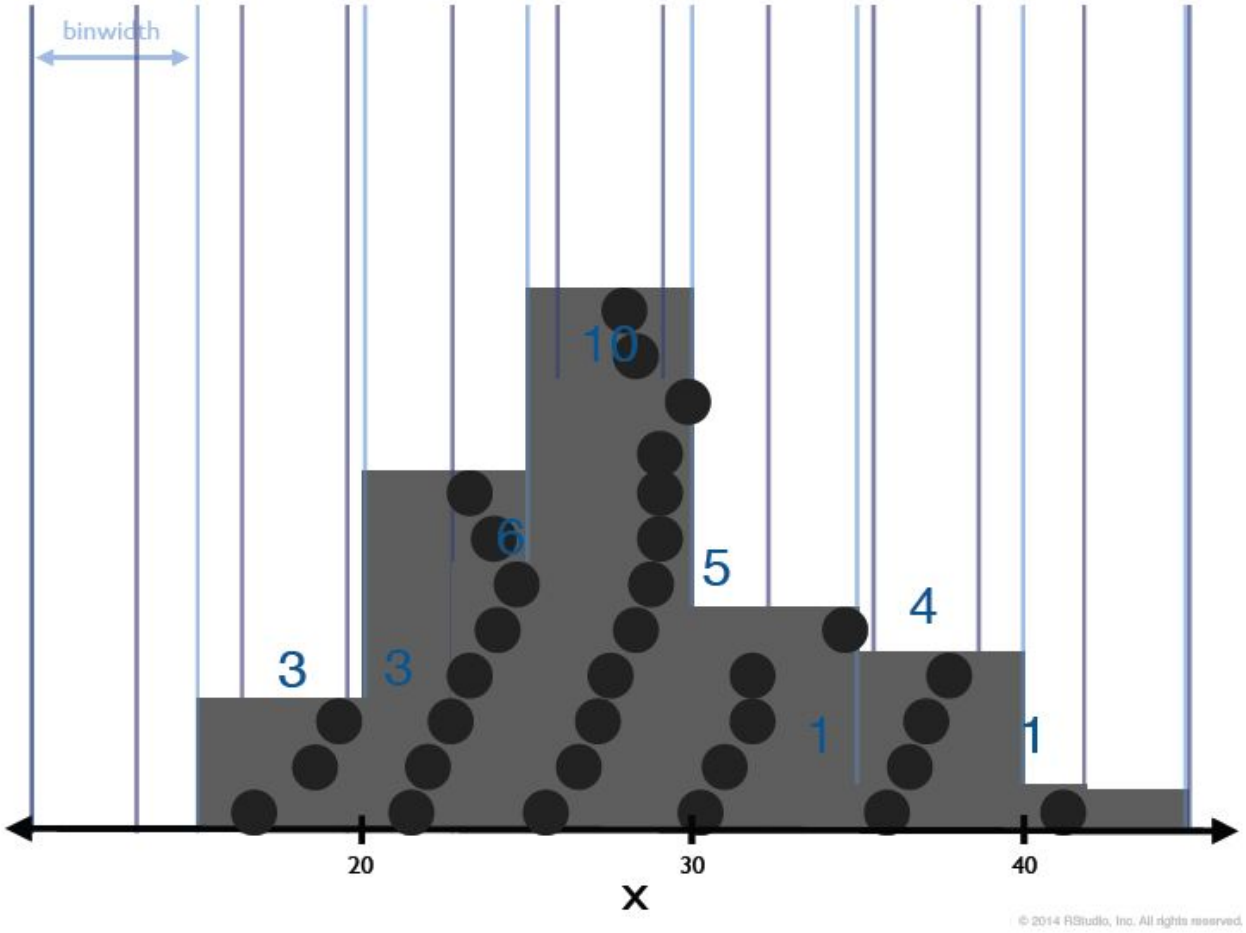
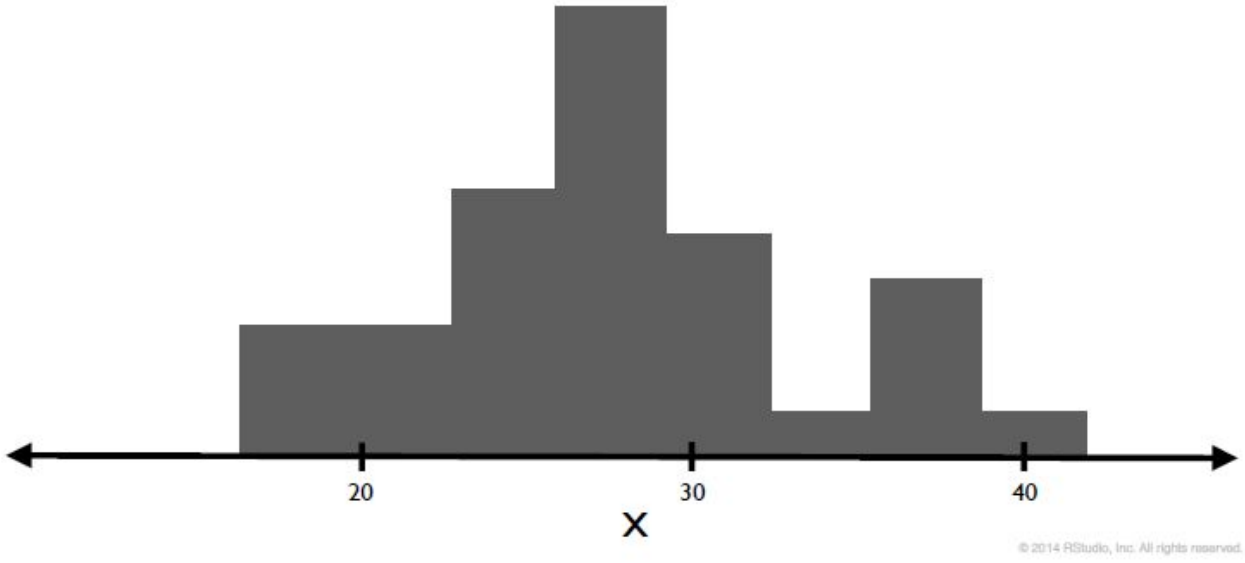
Histograms

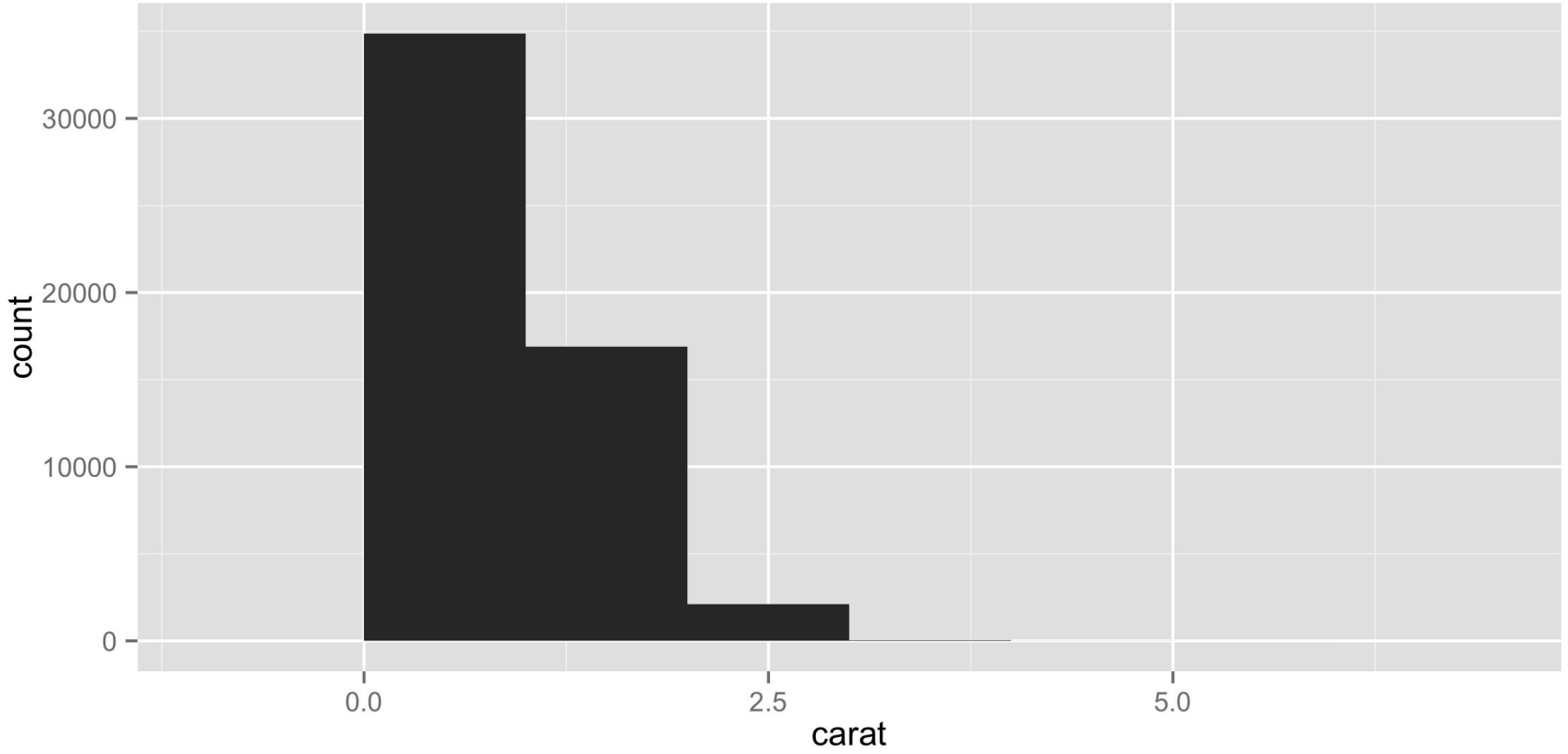


Histograms



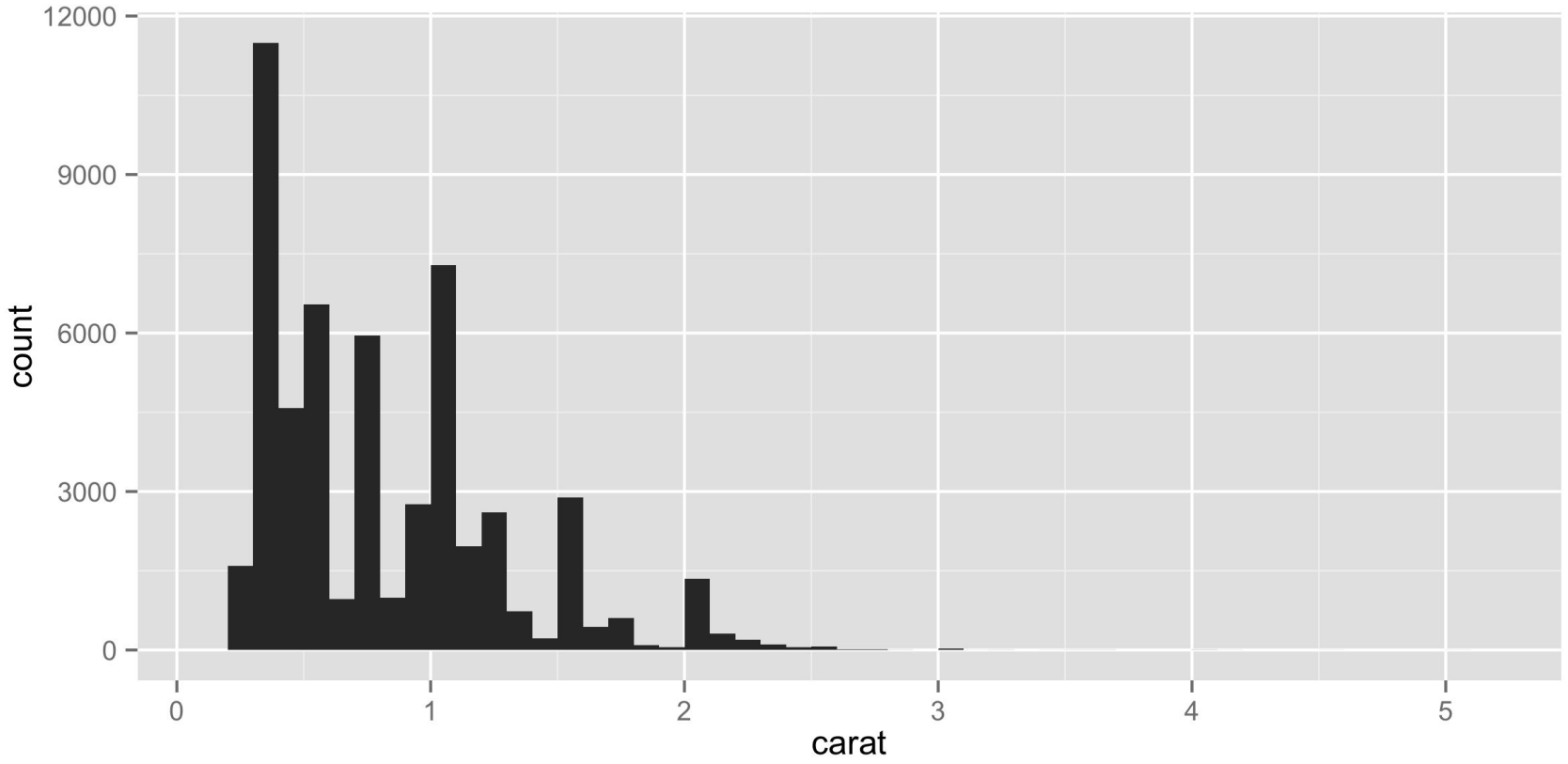
Histograms

```
g <- ggplot(data = diamonds, aes(x = carat))
g + geom_histogram(binwidth = 1)
```



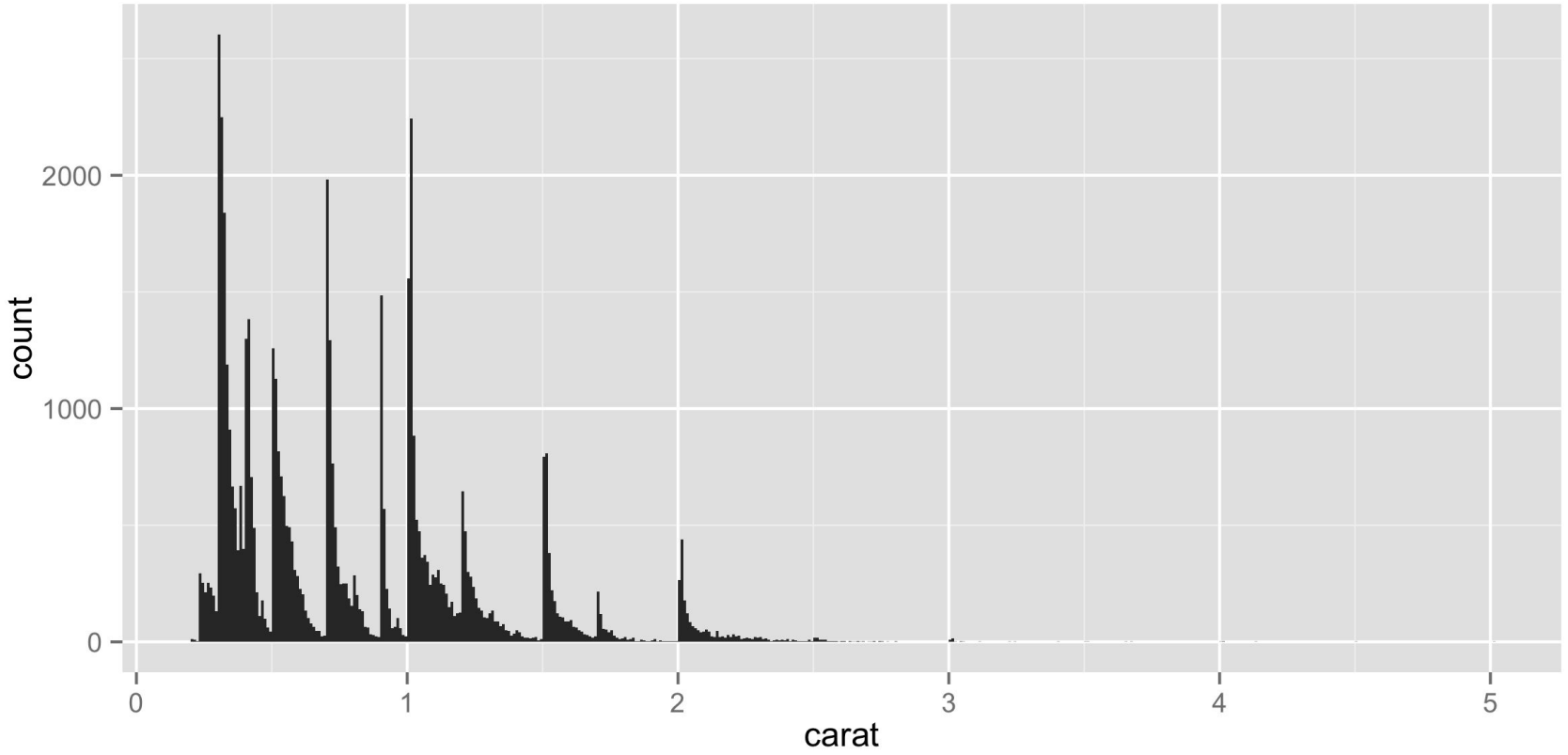
Histograms

```
g + geom_histogram(binwidth = 0.1)
```



Histograms

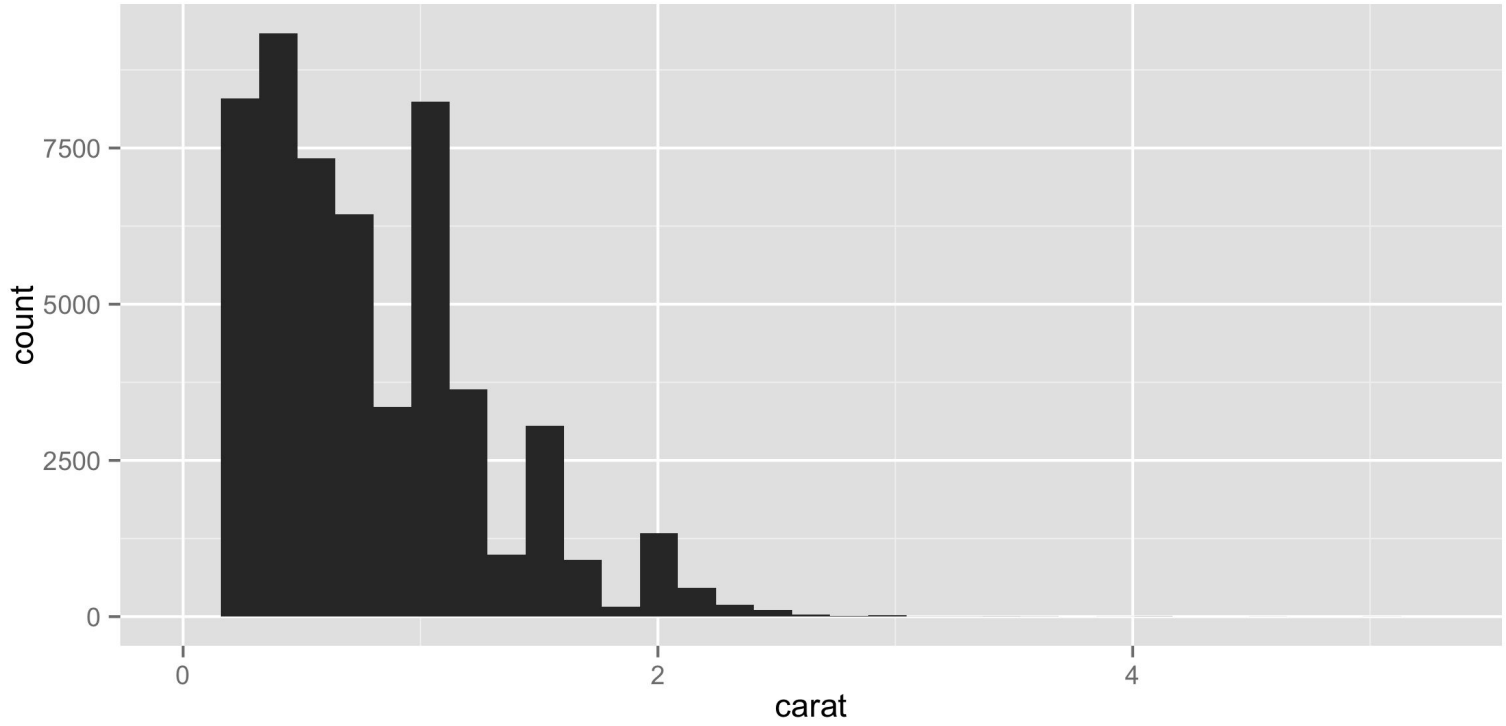
```
g + geom_histogram(binwidth = 0.01)
```



Histograms

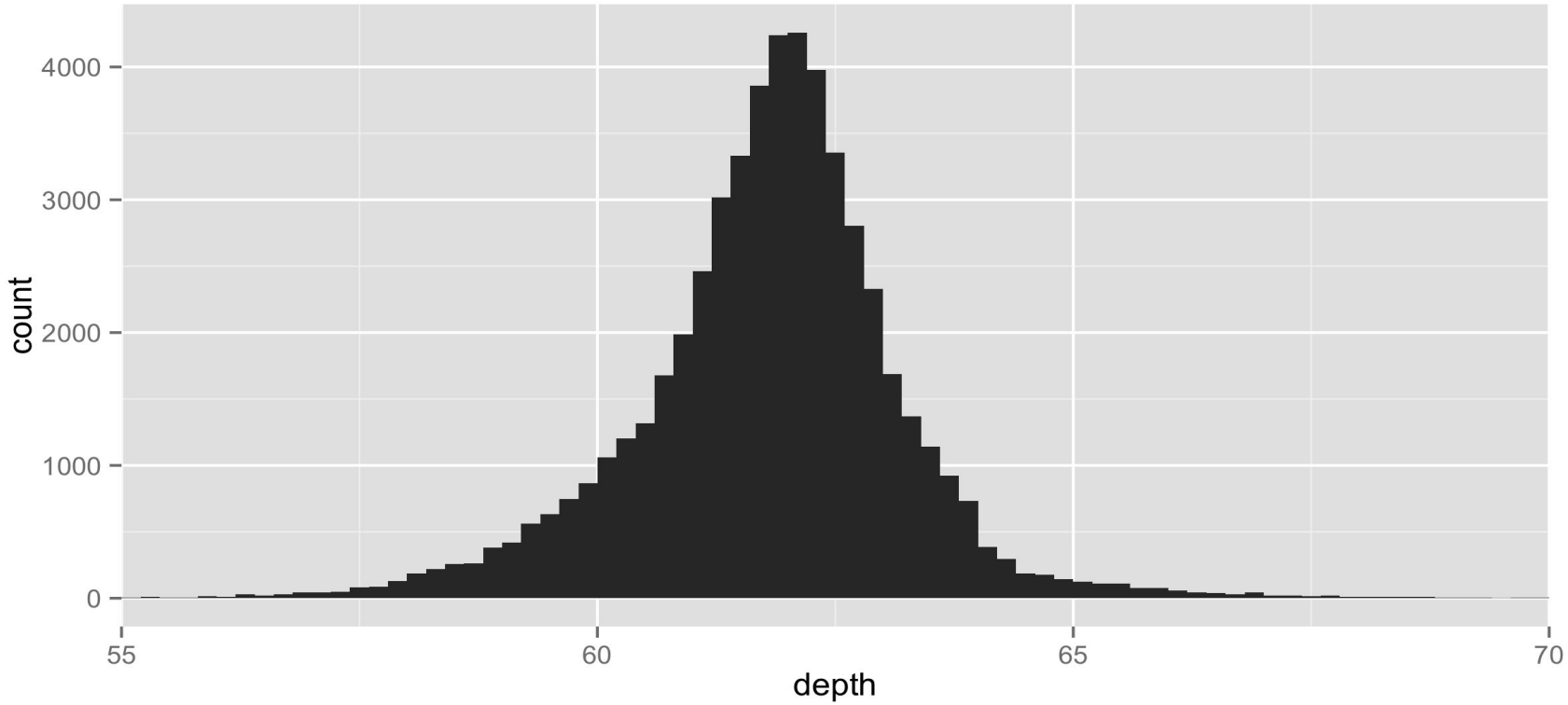
Most parameters come with a preset default value.

```
#stat_bin: binwidth defaulted to range/30.
g + geom_histogram()
```



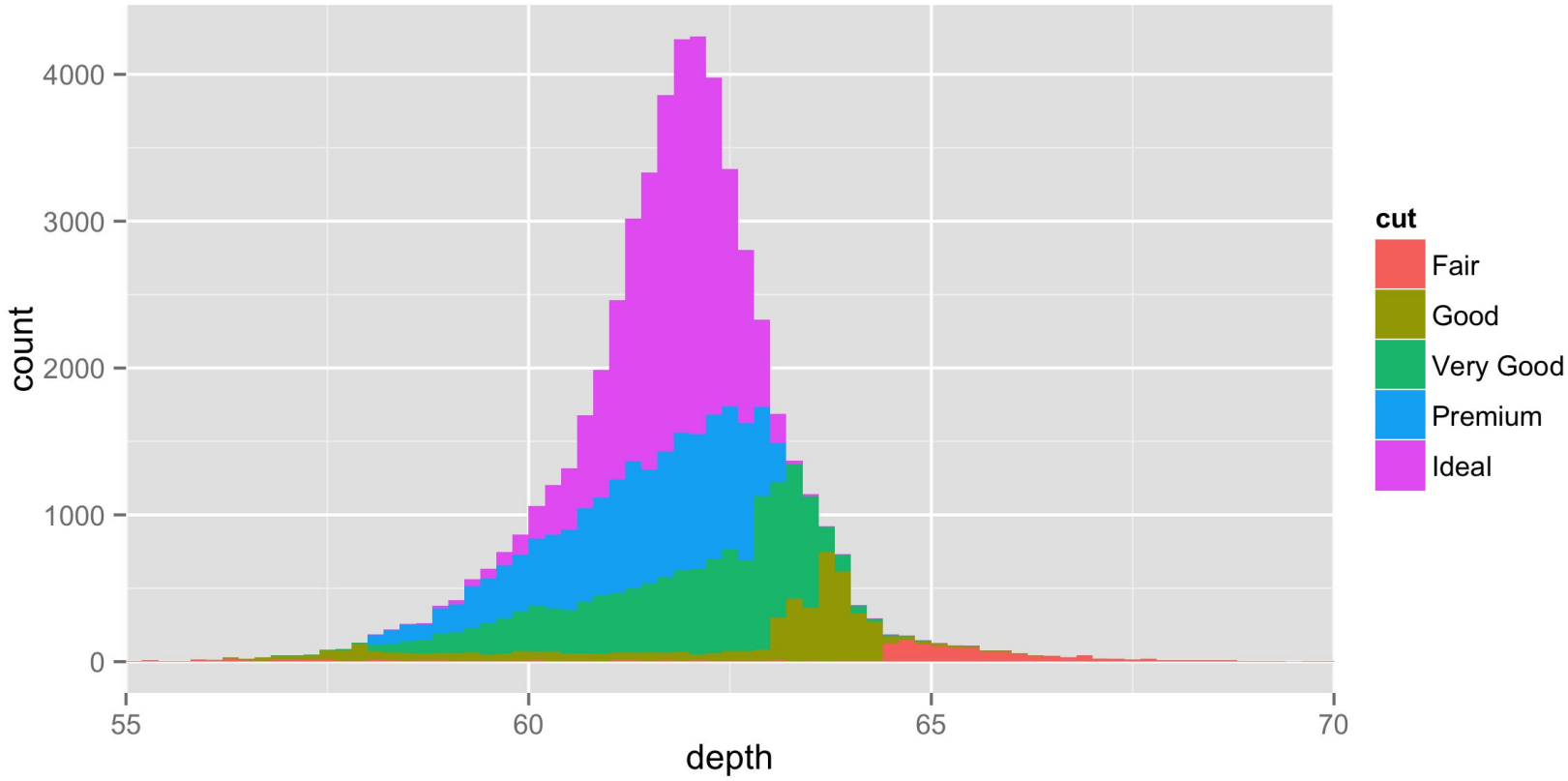
Histograms

```
g <- ggplot(data = diamonds, aes(x = depth))
zoom <- coord_cartesian(xlim = c(55, 70))
g + geom_histogram(binwidth = 0.2) + zoom
```



Histograms

```
g + geom_histogram(aes(fill = cut), binwidth = 0.2) + zoom
```



Comparing Variables

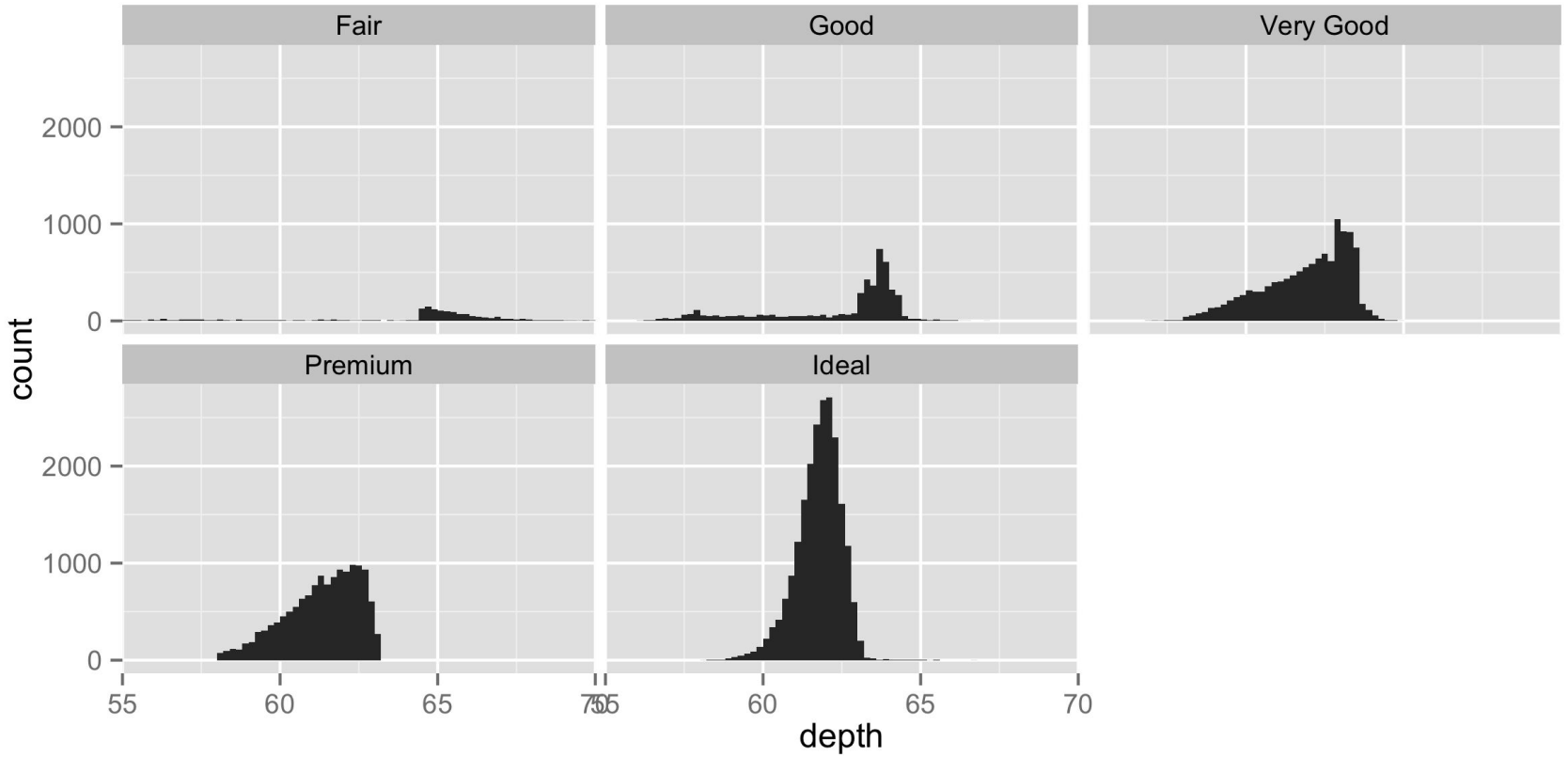
Comparing Variables

Additional variables are sometimes hard to compare if they are separated into facets because the shape for smaller groups can be diminished or overshadowed by larger groups.

```
g <- ggplot( data = diamonds, aes(x = depth))
zoom <- coord_cartesian(xlim = c(55, 70))
g + geom_histogram(binwidth = 0.2) + facet_wrap( ~ cut) + zoom
```

Comparing Variables

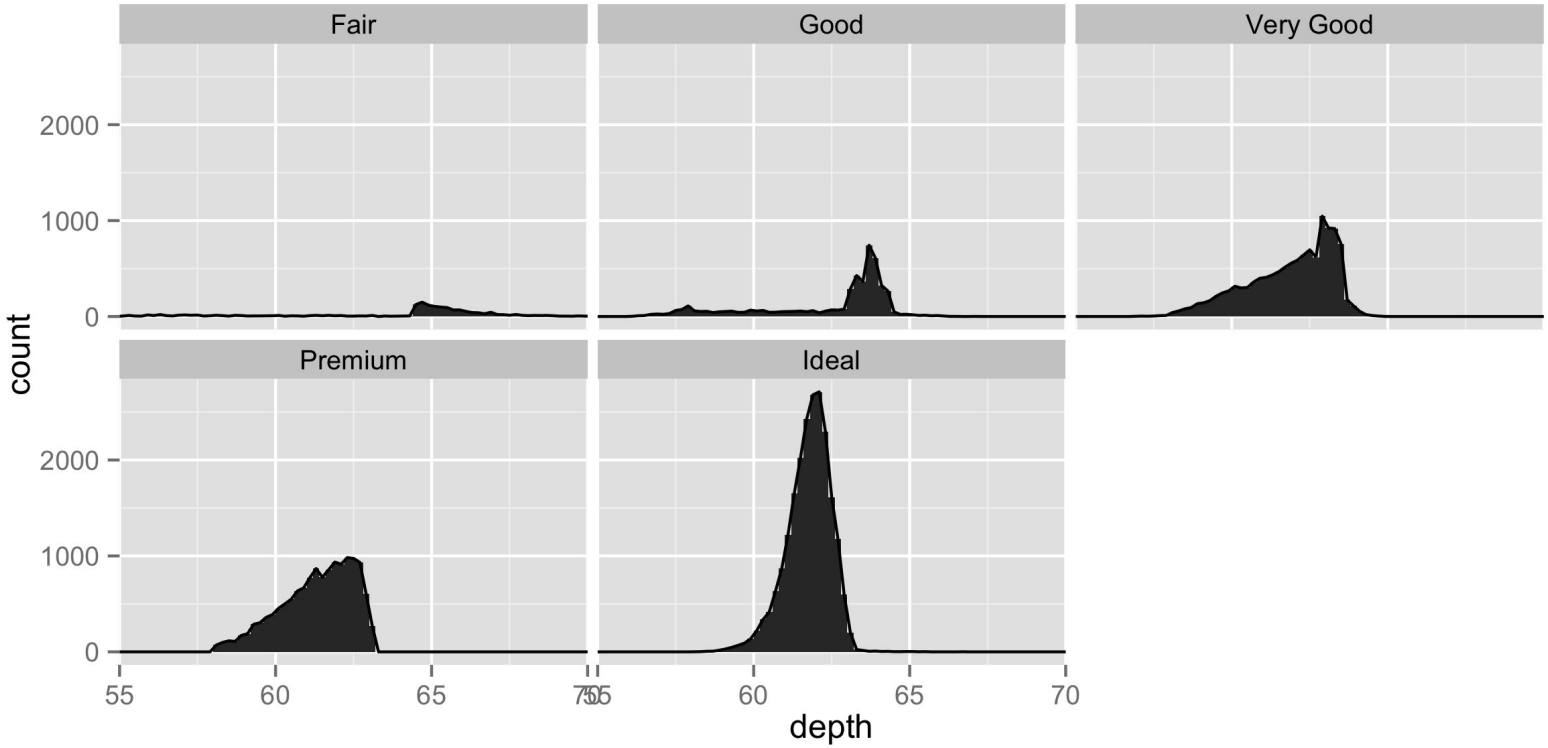
```
g + geom_histogram(binwidth = 0.2) + facet_wrap( ~ cut) + zoom
```



Comparing Variables

What if we just drew a line along the tops of the histograms?

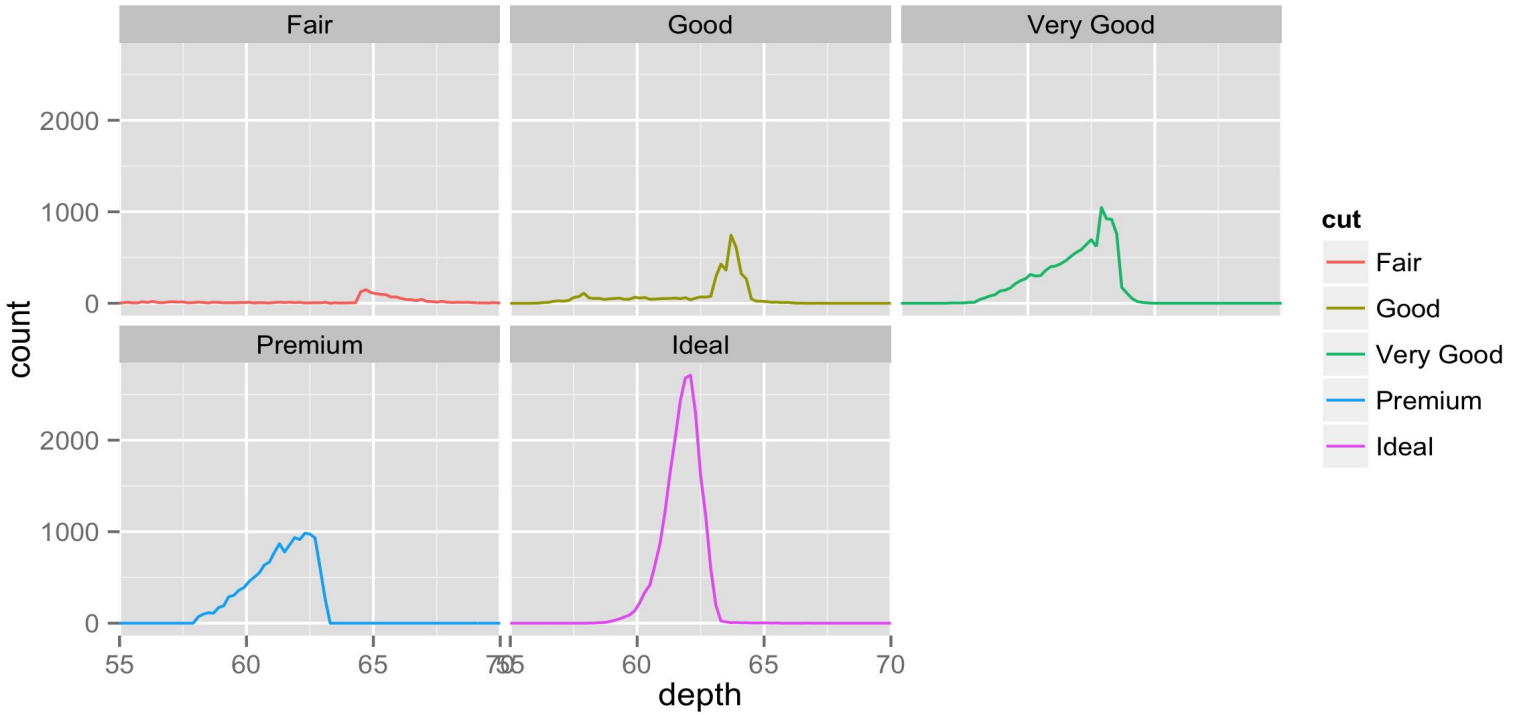
```
g + geom_histogram(binwidth = 0.2) + geom_freqpoly(binwidth=0.2)
+ facet_wrap( ~ cut) + zoom
```



Comparing Variables

What if we threw away the bars?

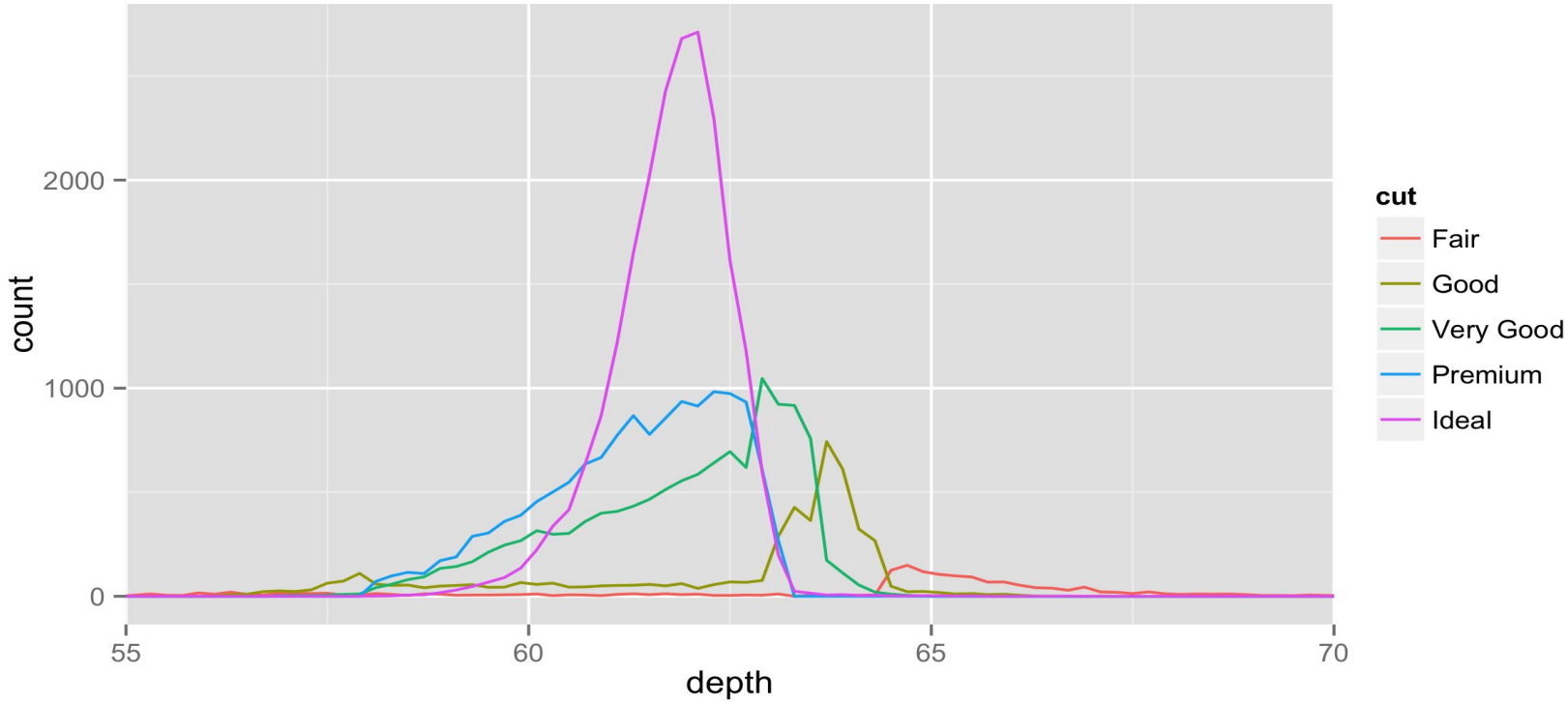
```
g + geom_freqpoly(aes(color = cut), binwidth = 0.2) +
    facet_wrap( ~ cut) + zoom
```



Comparing Variables

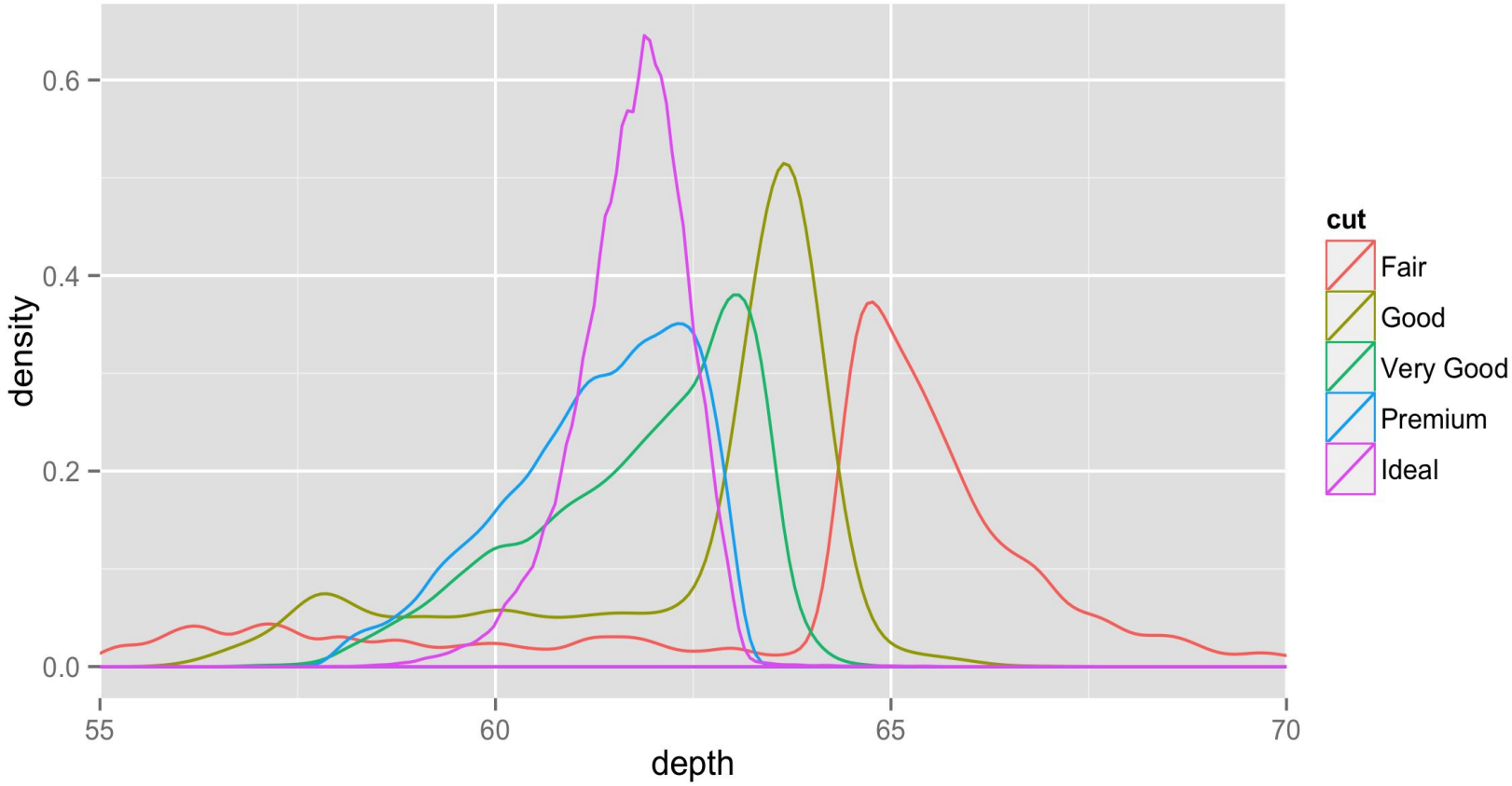
What if we just drew each on the same plot?

```
g + geom_freqpoly(aes(color = cut), binwidth = 0.2) + zoom
```



Comparing Variables

```
g + geom_density(aes(color = cut)) + zoom
```



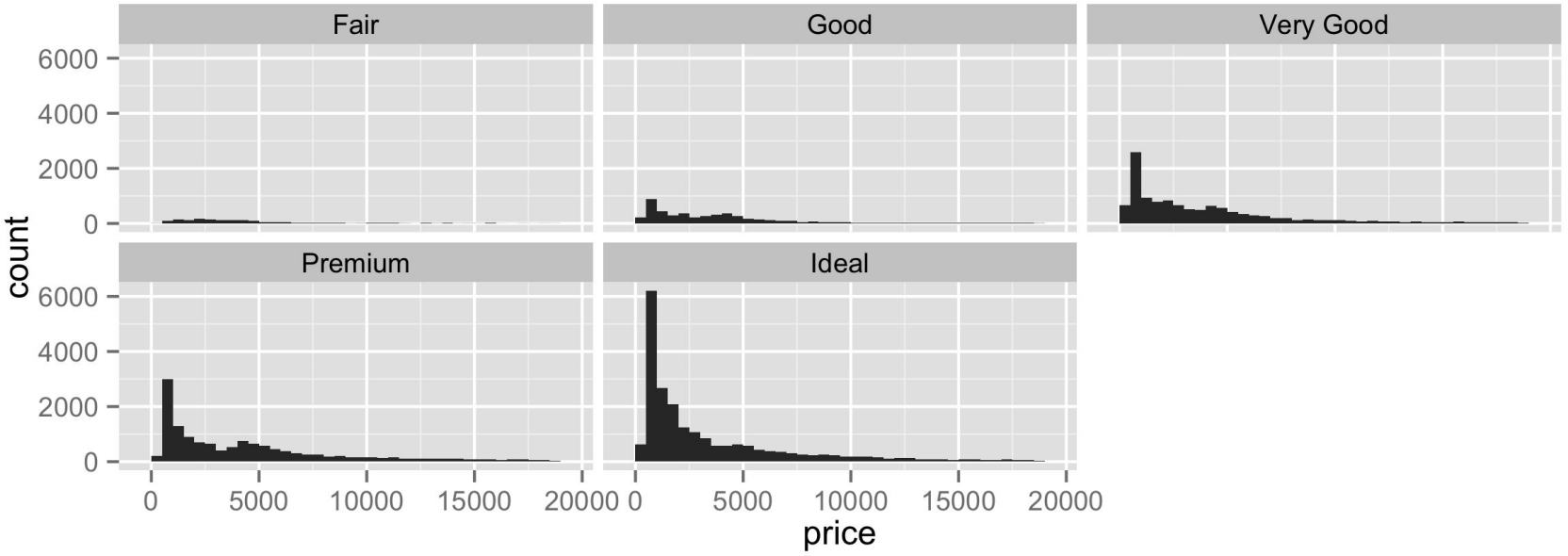
Comparing Variables

- Compare the distribution of prices for different cuts.
- Does anything seem unusual?

Comparing Variables

Attempt #1: Faceting makes comparison hard in this case.

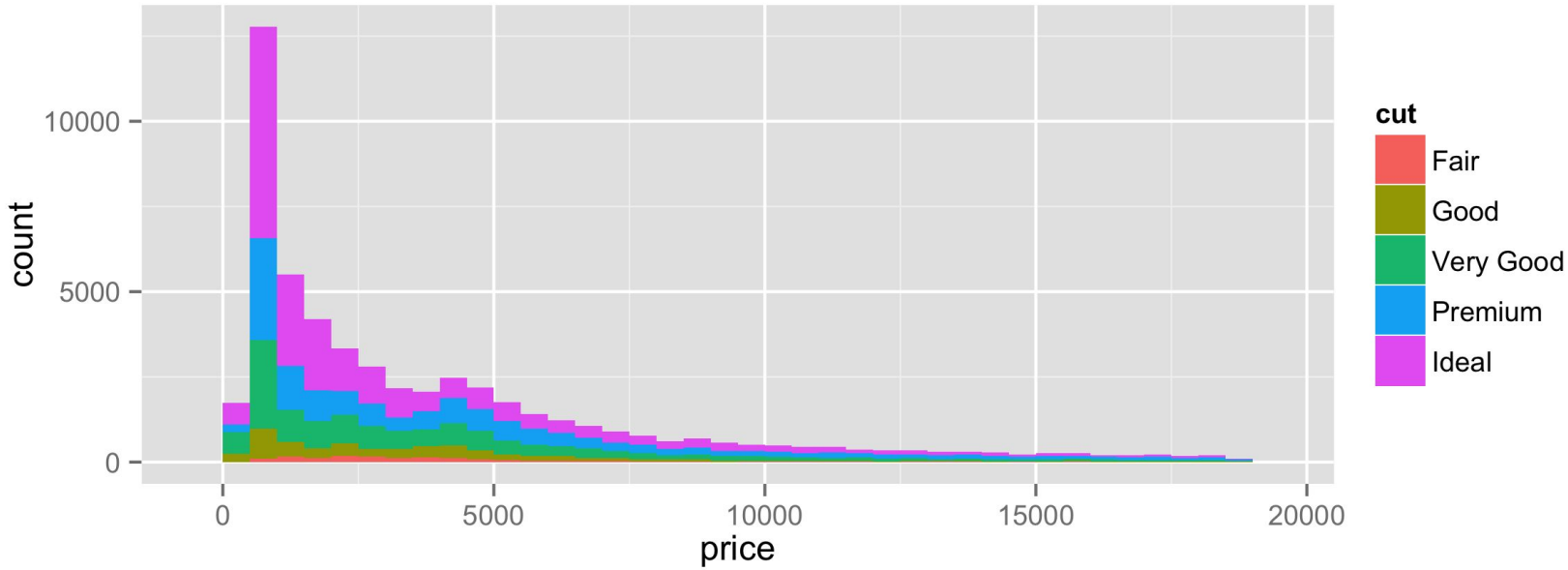
```
ggplot(data = diamonds, aes(x = price)) + geom_histogram
(binwidth = 500) + facet_wrap(~ cut)
```



Comparing Variables

Attempt #2: Stacked heights are also hard to compare.

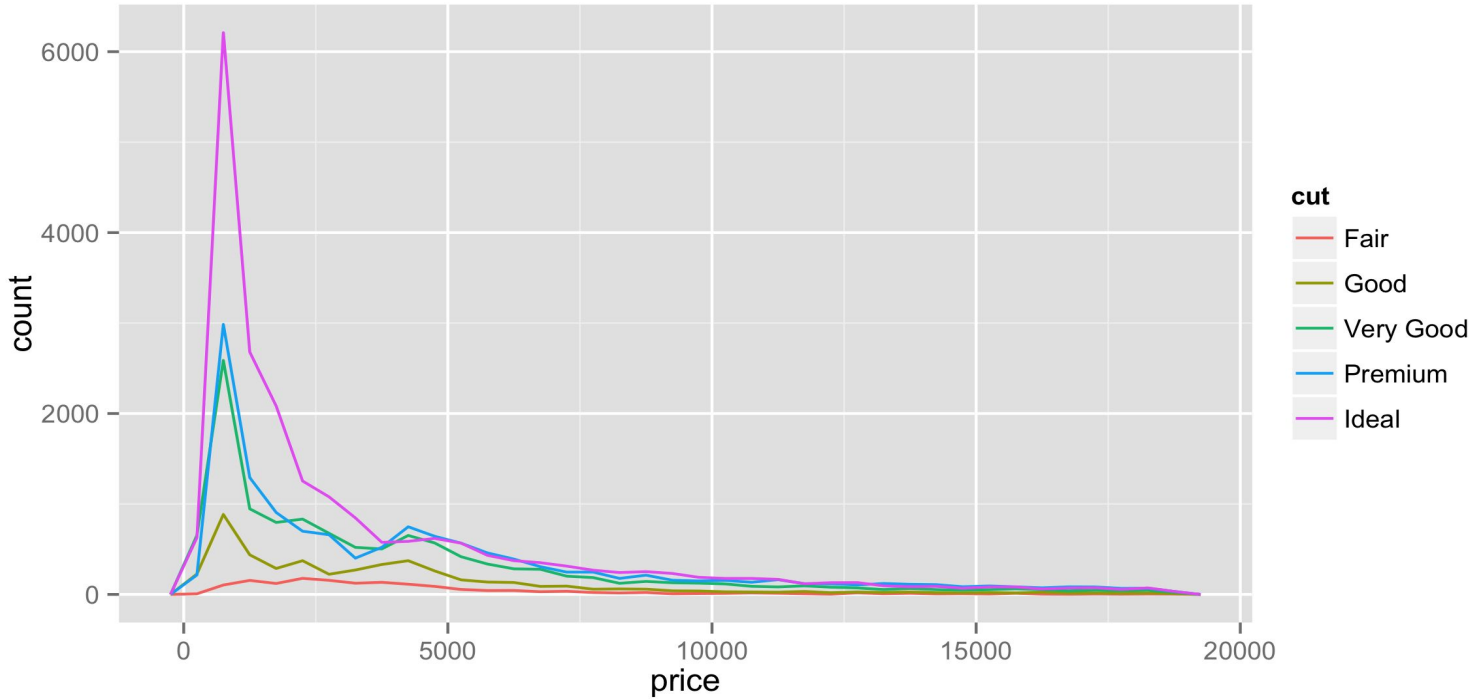
```
ggplot(data = diamonds, aes(x = price)) + geom_histogram(aes
(fill = cut))
```



Comparing Variables

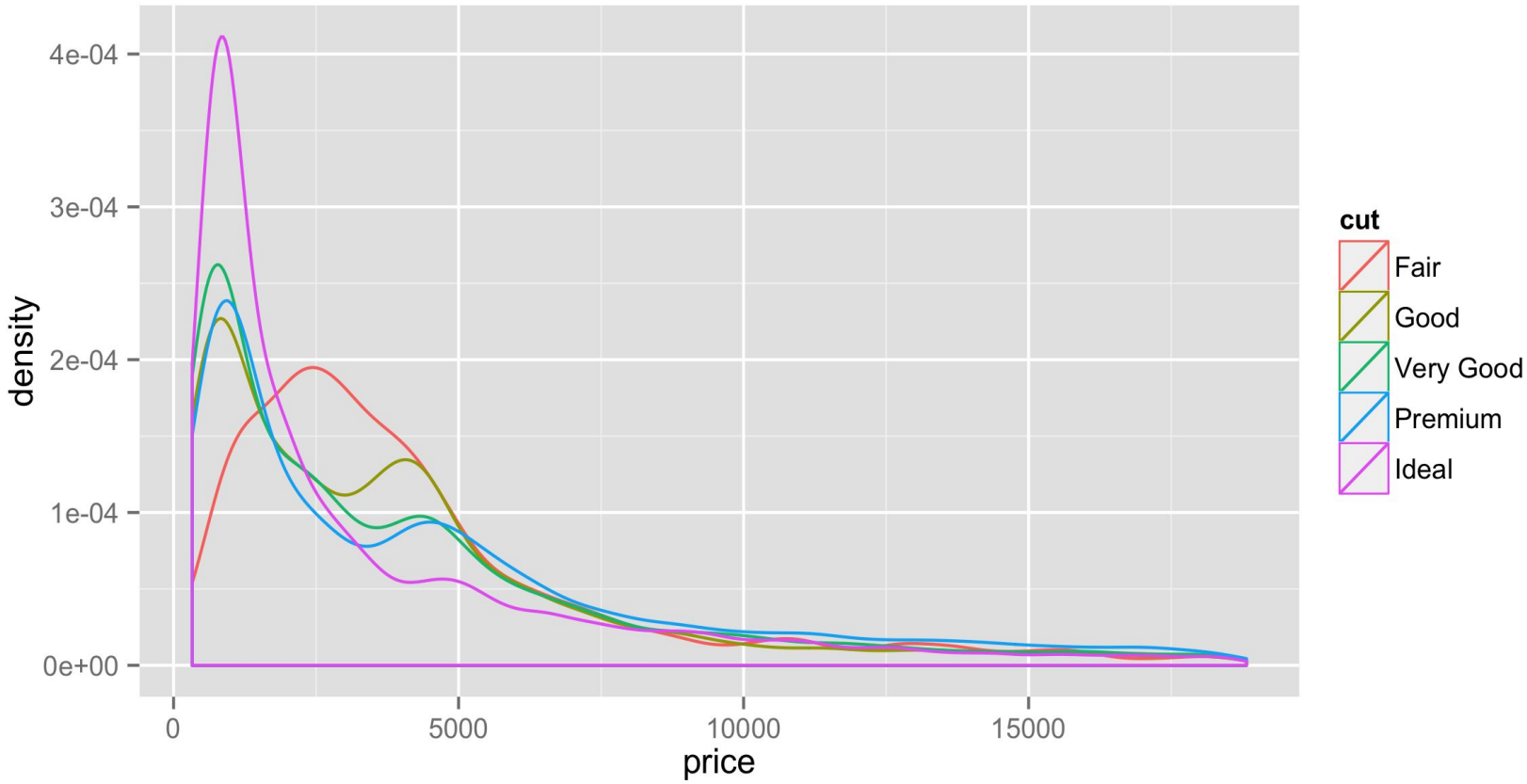
Attempt #3: Better, but categories still have differing relative frequencies.

```
ggplot(data = diamonds, aes(x = price)) + geom_freqpoly(aes
(color = cut), binwidth = 500)
```



Comparing Variables

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



Outline

- Why ggplot2?
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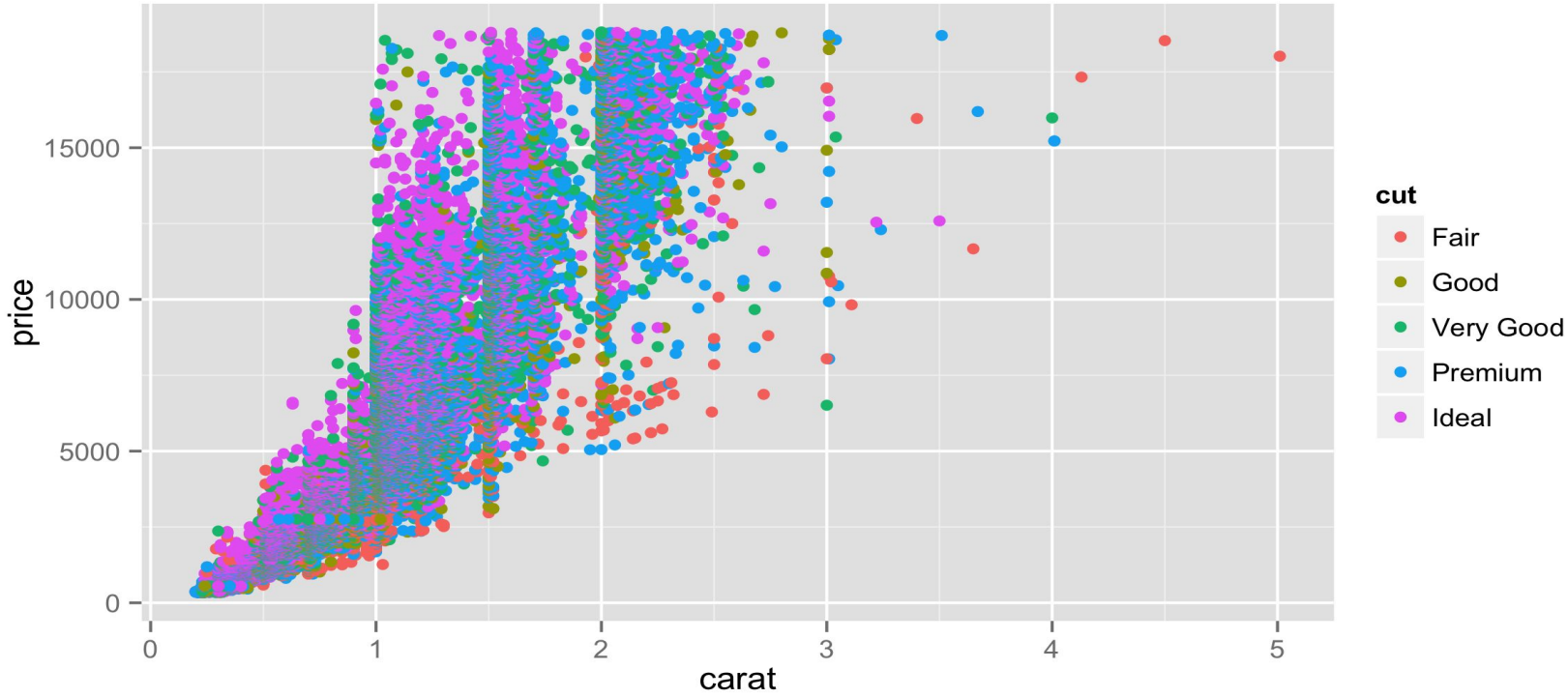
Visualizing Big Data

Geoms for Big Data

Is this helpful at all?

```
g <- ggplot(data = diamonds, aes(x = carat, y = price))
g + geom_point(aes(color = cut))
```



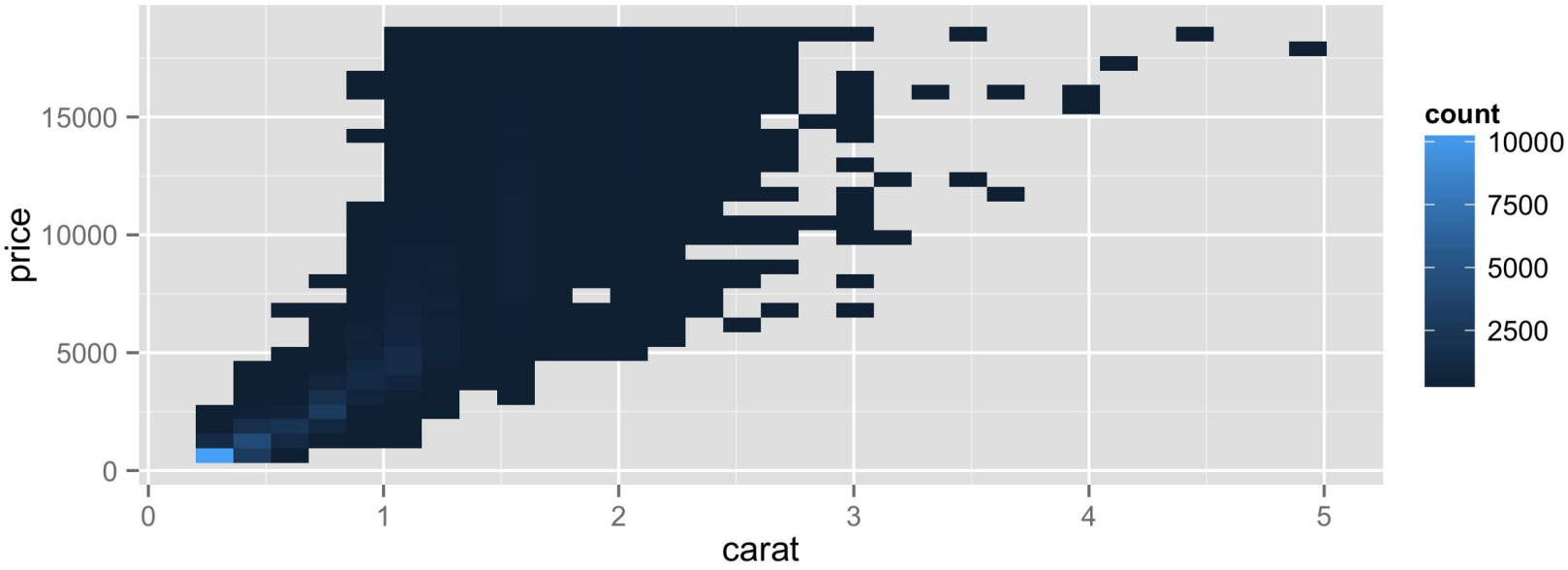
Geoms for Big Data

How do we work with visualizations when they become overwhelming due to the amount of data?

Geoms for Big Data

Heat map of 2d bin counts

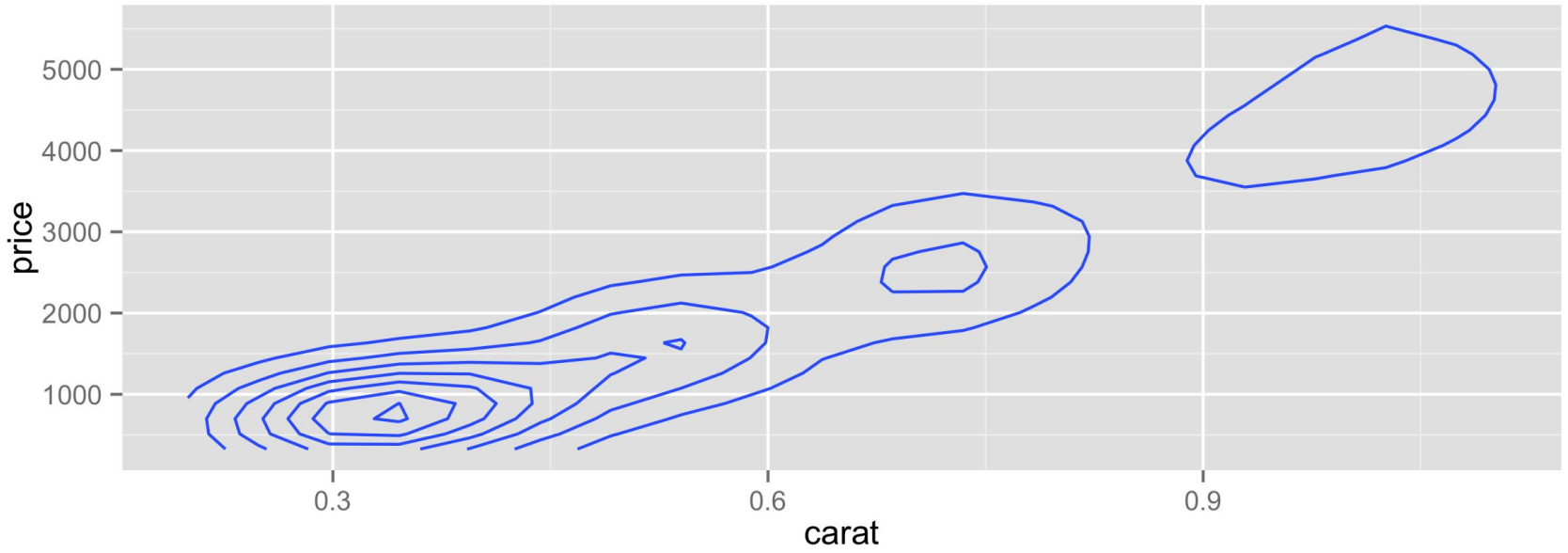
```
g + geom_bin2d()
```



Geoms for Big Data

2d density plot

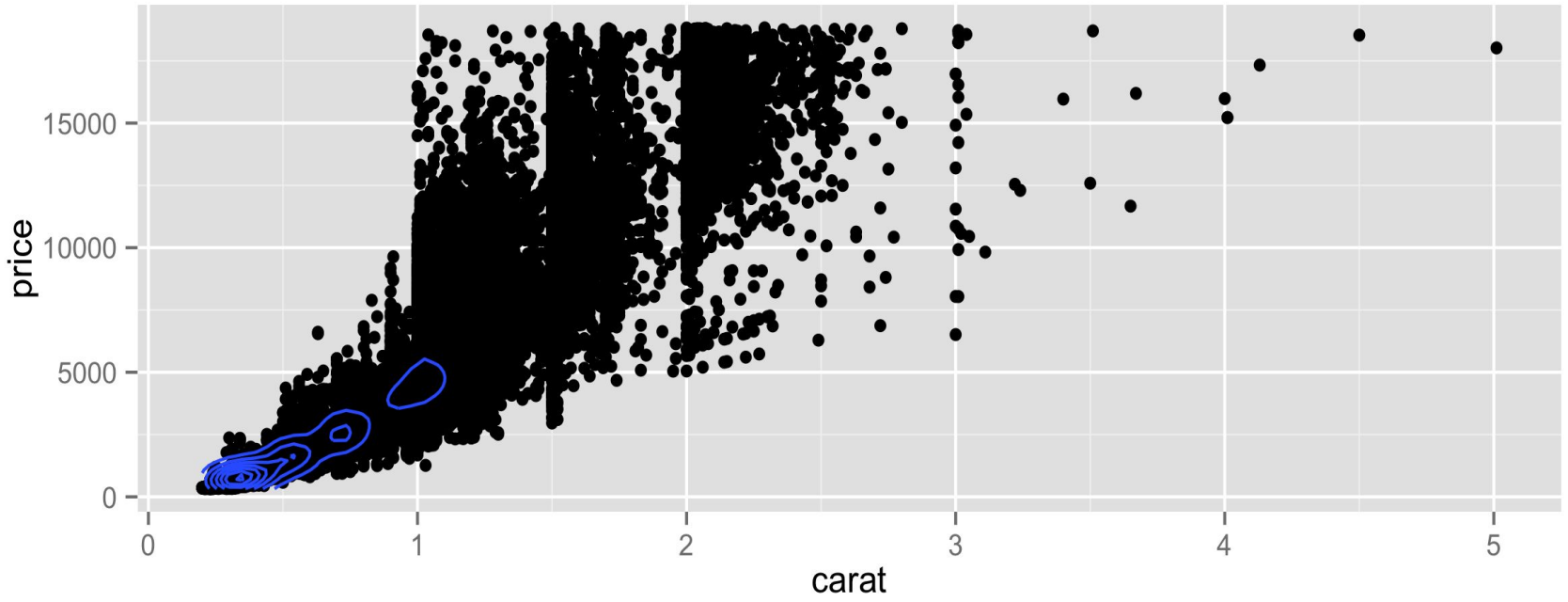
```
g + geom_density2d()
```



Geoms for Big Data

2d density on top of a scatter plot

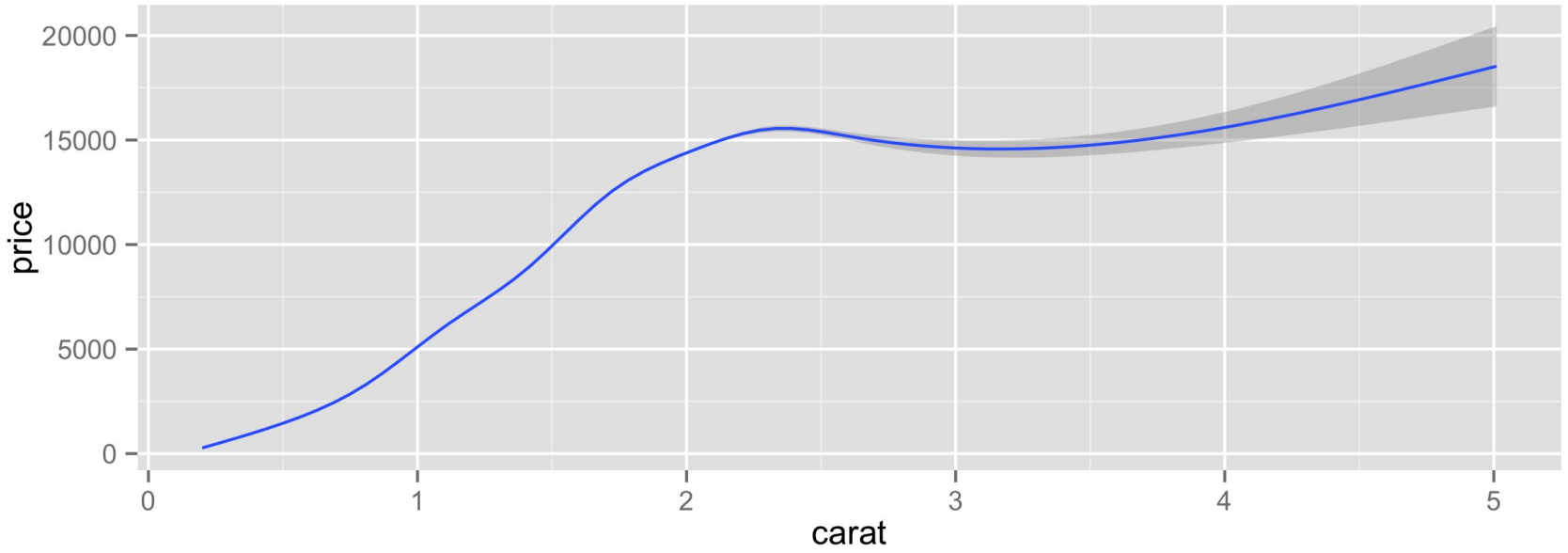
```
g + geom_point() + geom_density2d()
```



Geoms for Big Data

Smoothed conditional mean

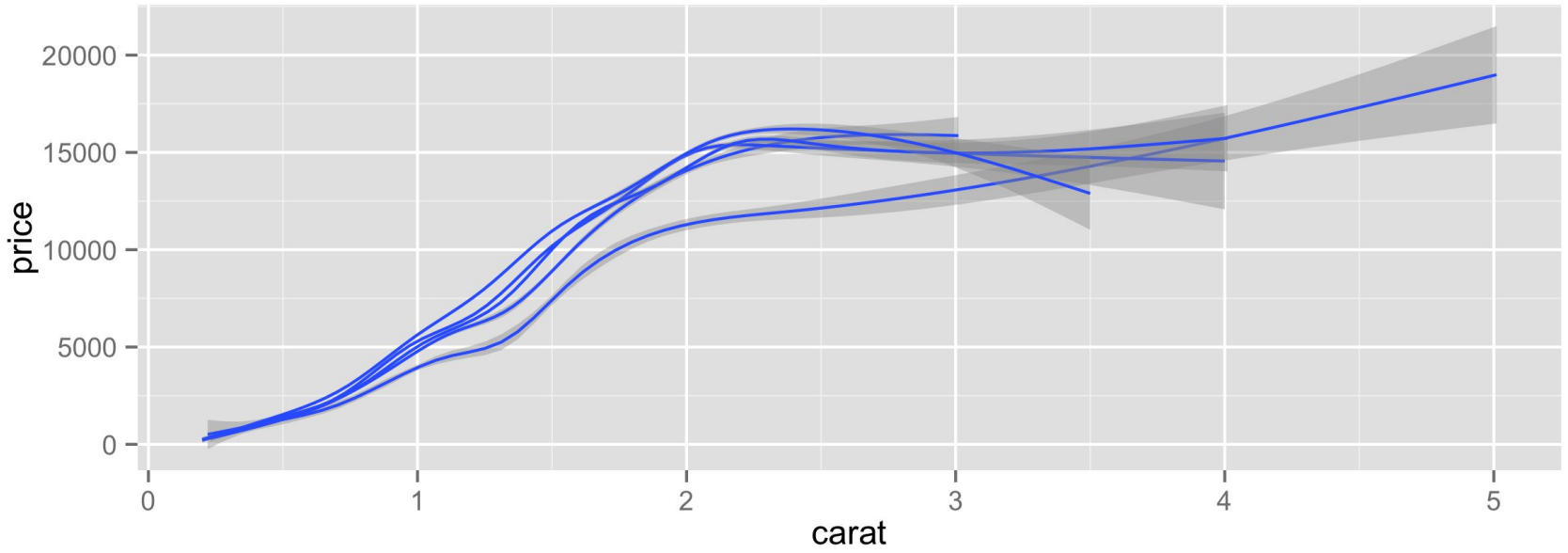
```
g + geom_smooth()
```



Geoms for Big Data

Same, but for each level of cut

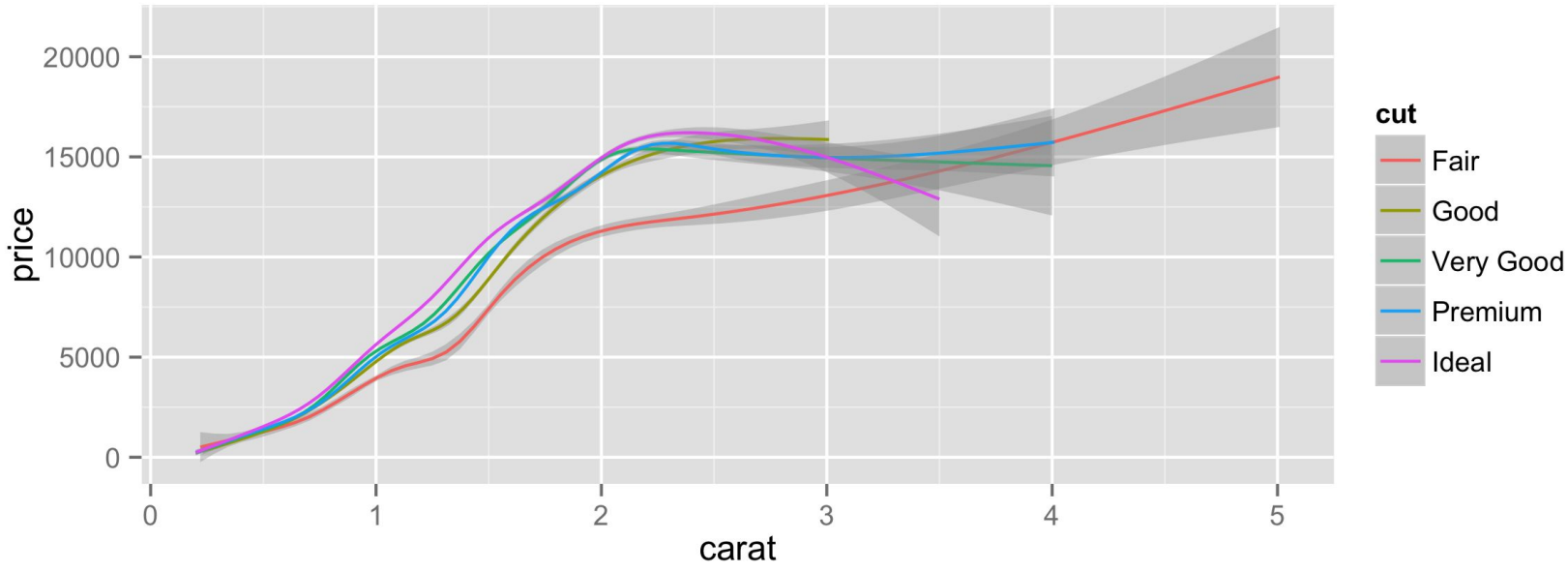
```
g + geom_smooth(aes(group = cut))
```



Geoms for Big Data

Same, but each cut receives a different color

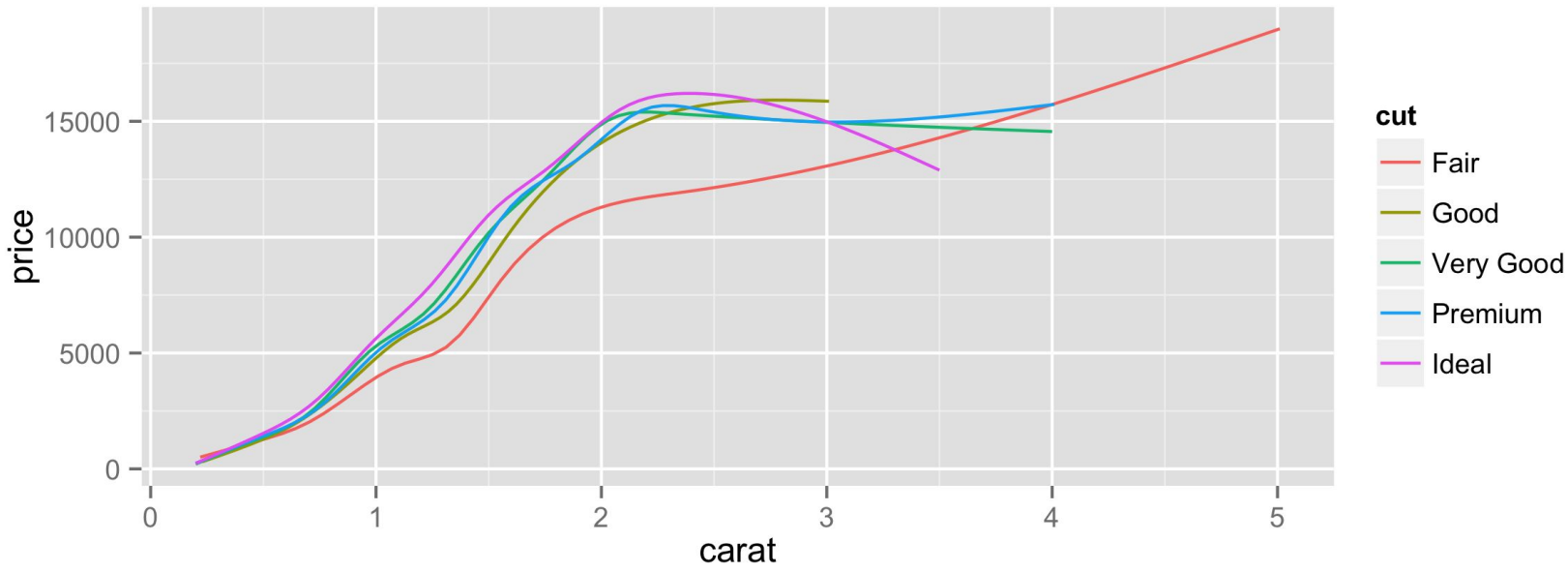
```
g + geom_smooth(aes(color = cut))
```



Geoms for Big Data

Same, but without confidence bands

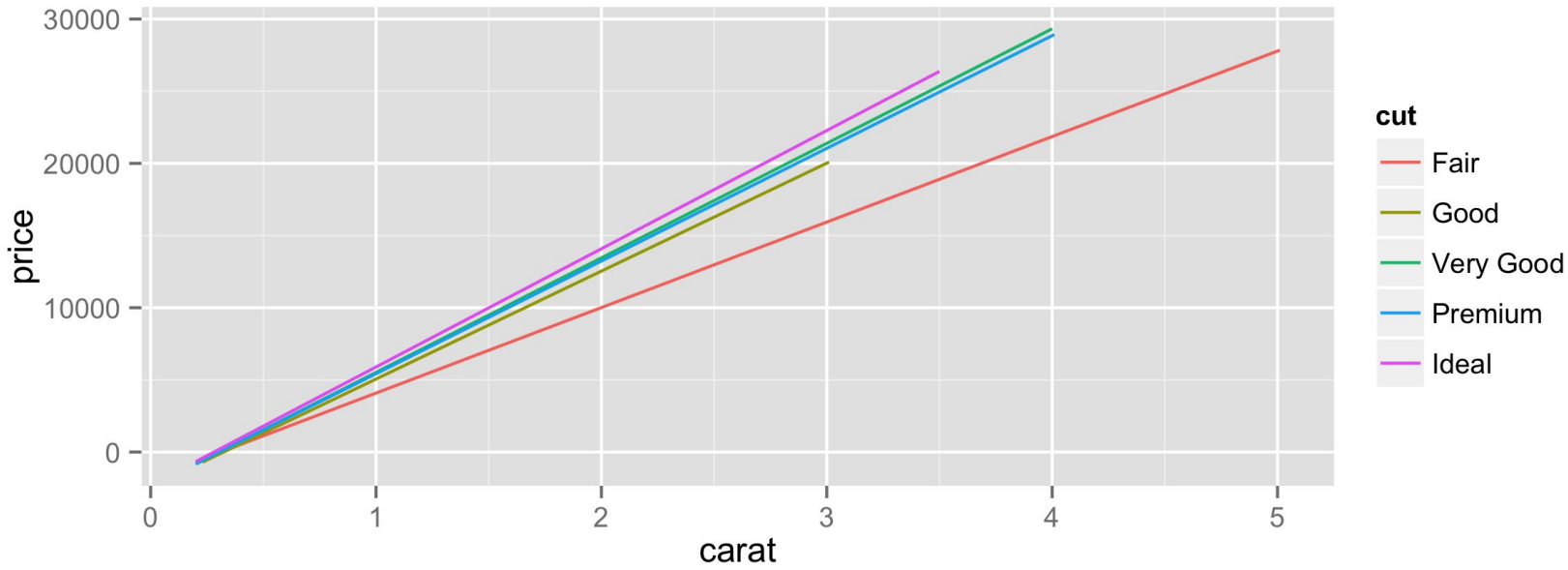
```
g + geom_smooth(aes(color = cut), se = FALSE)
```



Geoms for Big Data

Regression lines

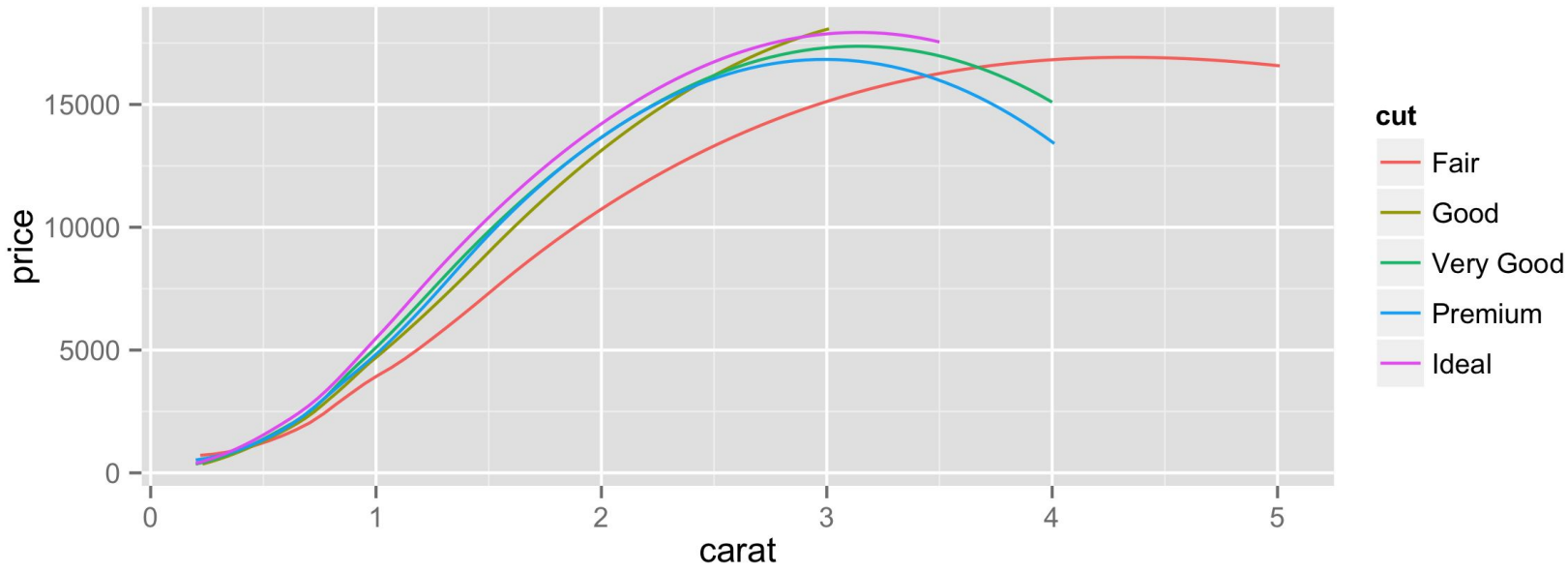
```
g + geom_smooth(aes(color = cut), method = "lm", se = FALSE)
```



Geoms for Big Data

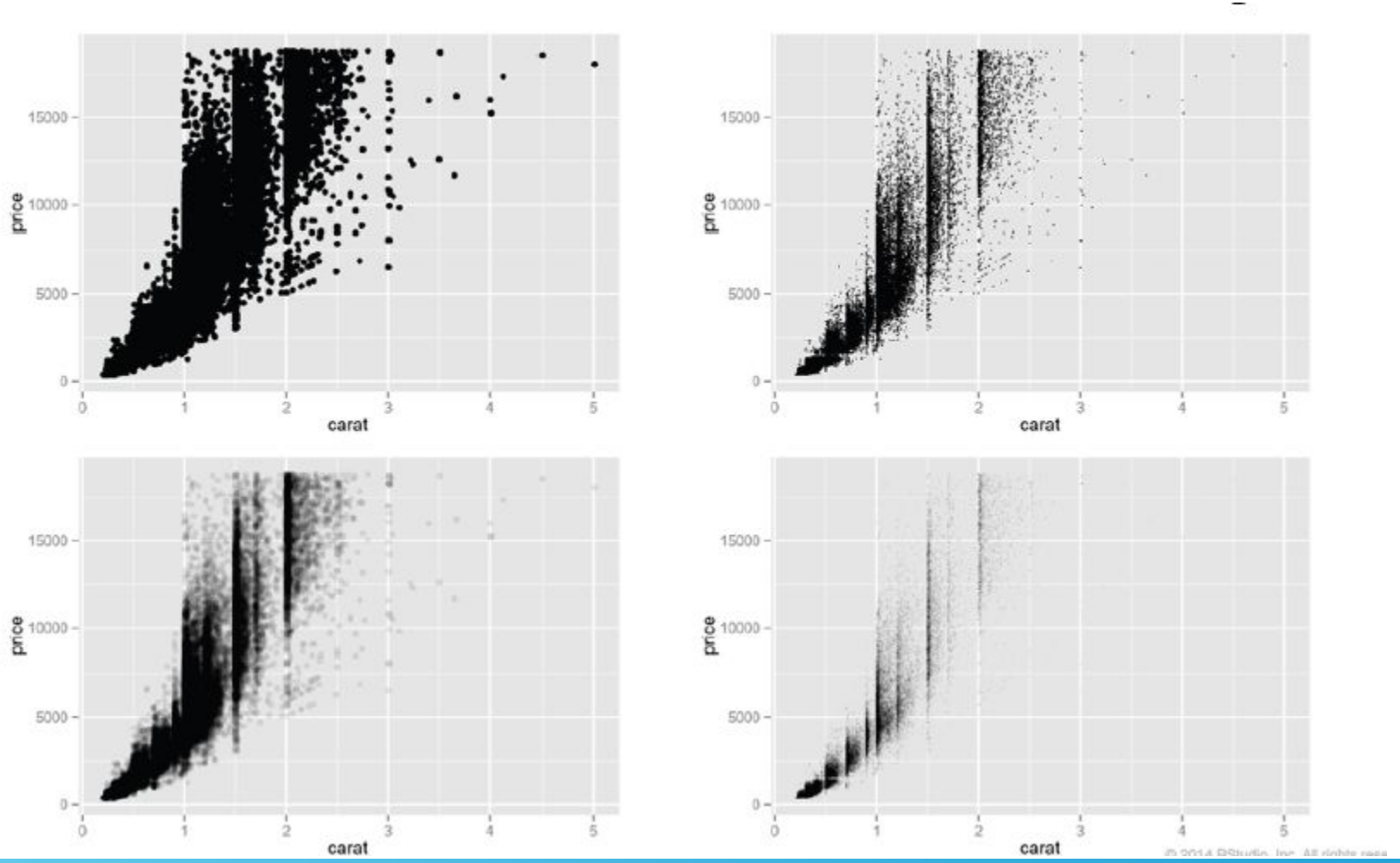
LOESS smoother

```
g + geom_smooth(aes(color = cut), method = "loess", se = FALSE)
```



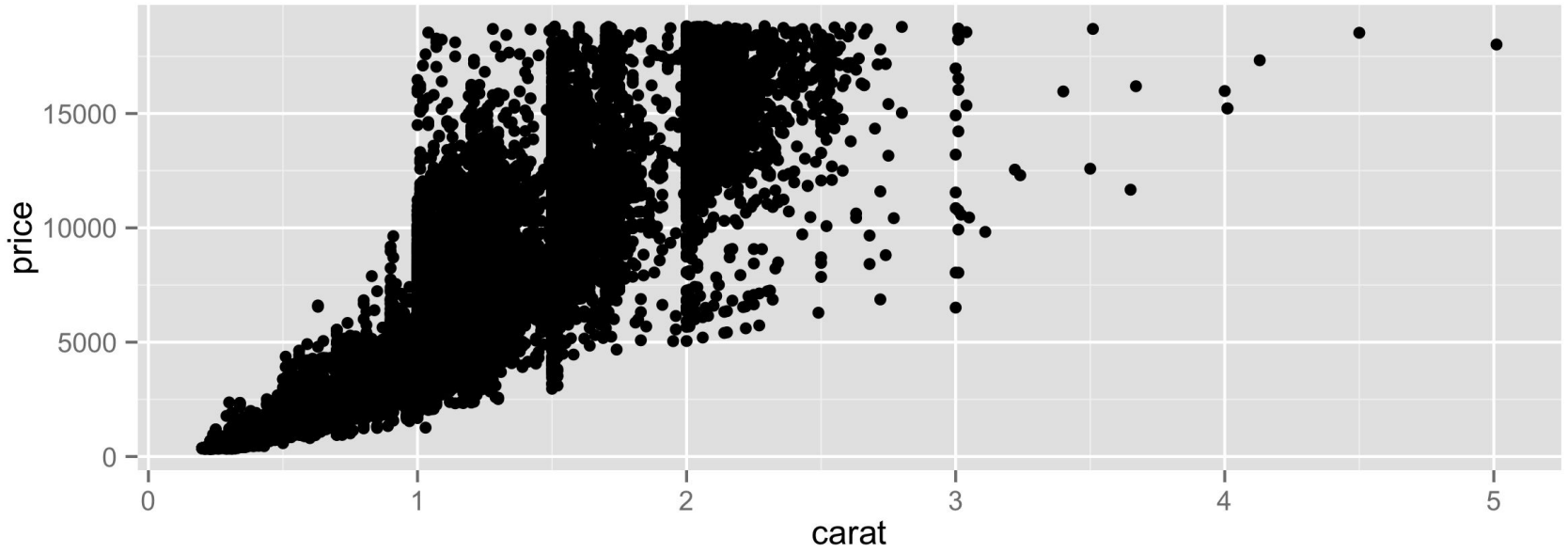
Geoms for Big Data

We can also adjust the size and/or transparency of points.



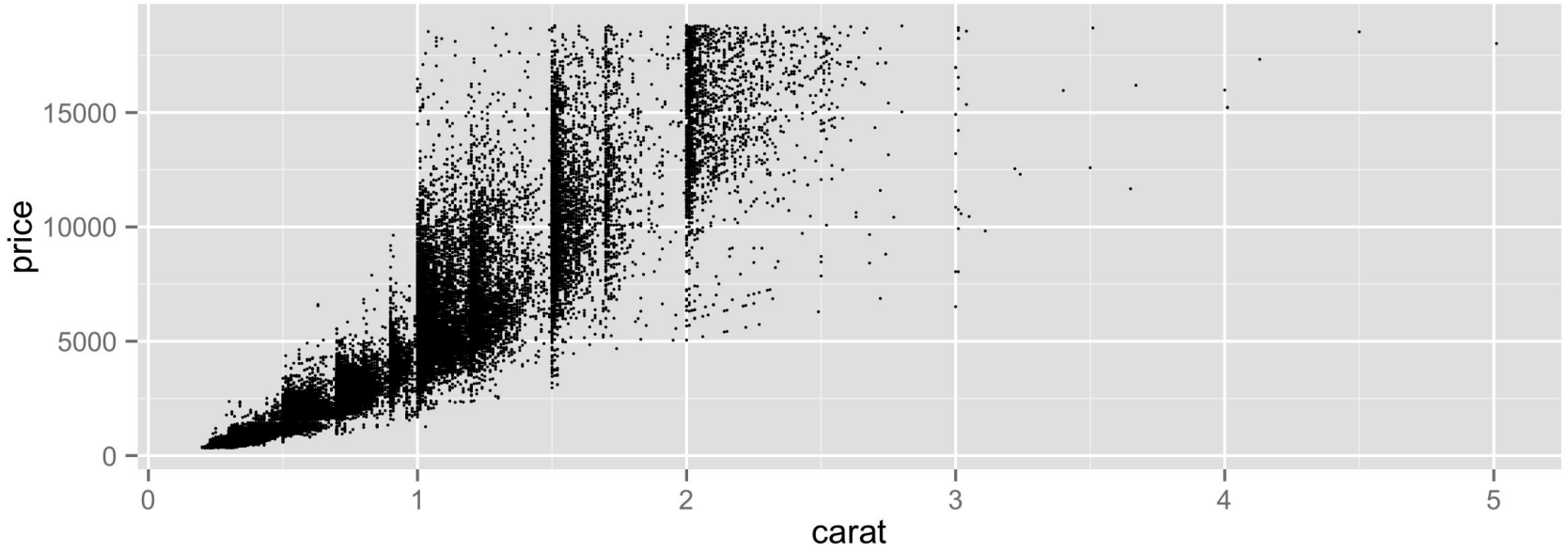
Geoms for Big Data

```
g + geom_point()
```



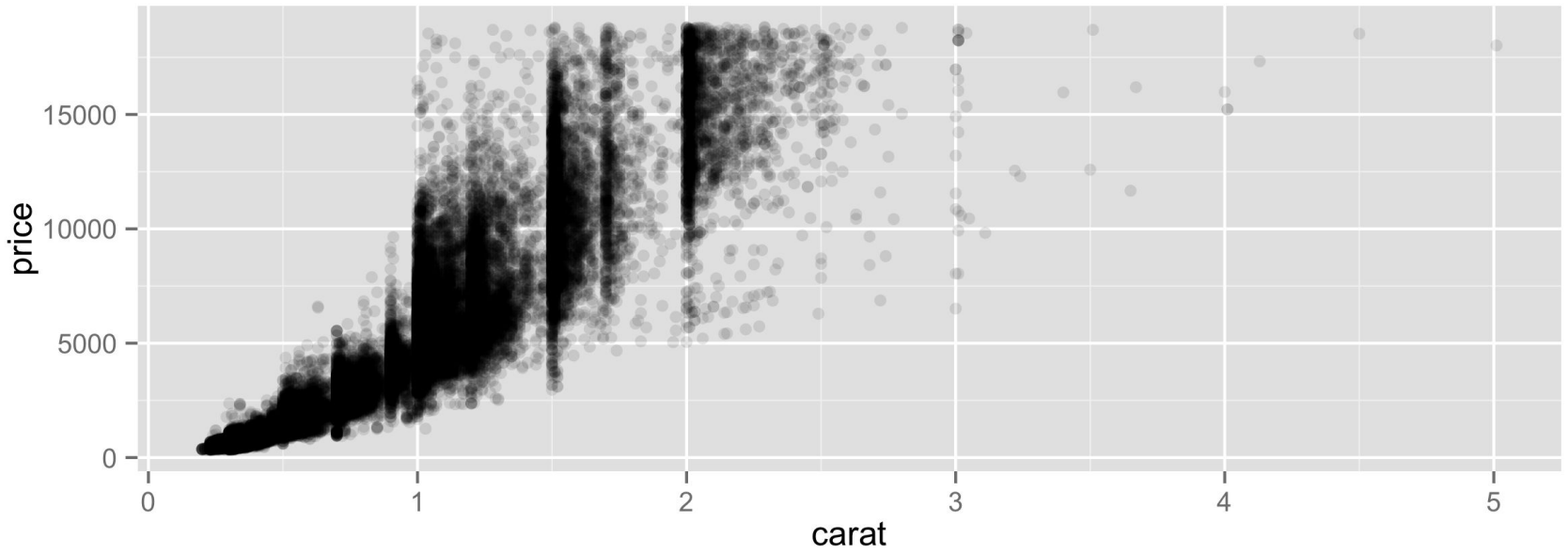
Geoms for Big Data

```
g + geom_point(size = 0.5)
```



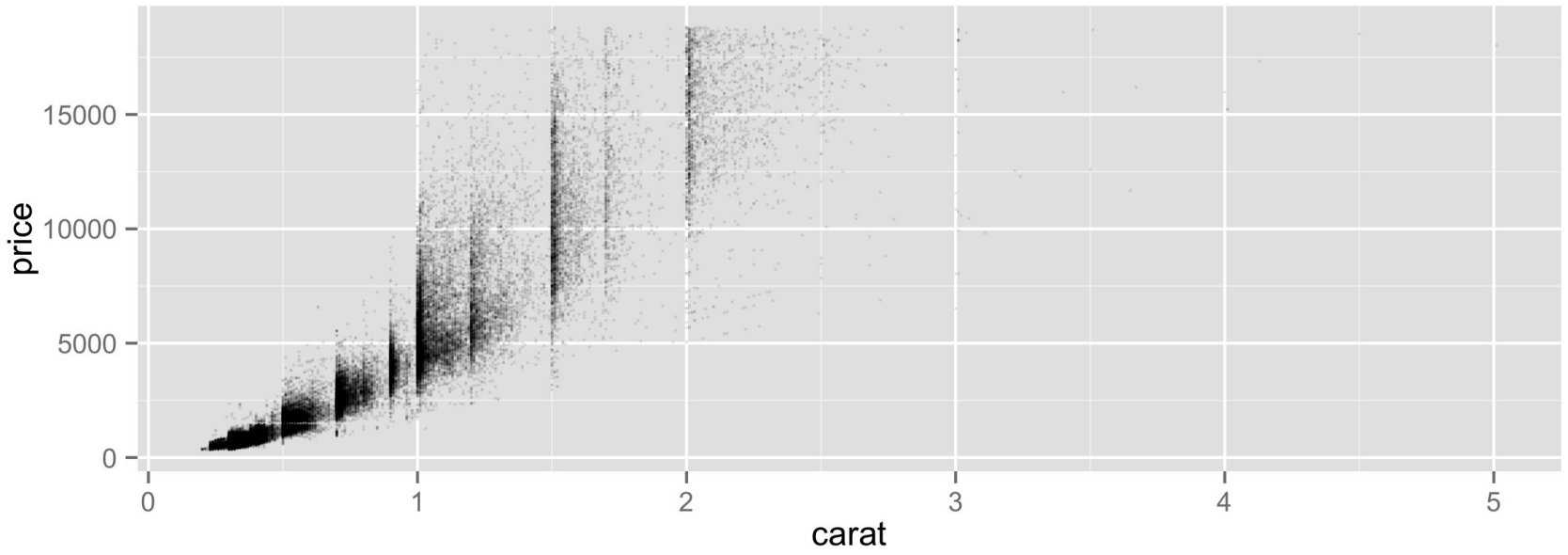
Geoms for Big Data

```
g + geom_point(alpha = 0.1)
```



Geoms for Big Data

```
g + geom_point(size = 0.5, alpha = 0.1)
```



Outline

- Why ggplot2?
- The “Grammar of Graphics”
- Constructing a ggplot2 plot
- Scatterplots
- Bar charts
- Histograms
- Visualizing big data
- **Saving Graphs**

Saving Graphs

Saving Plots

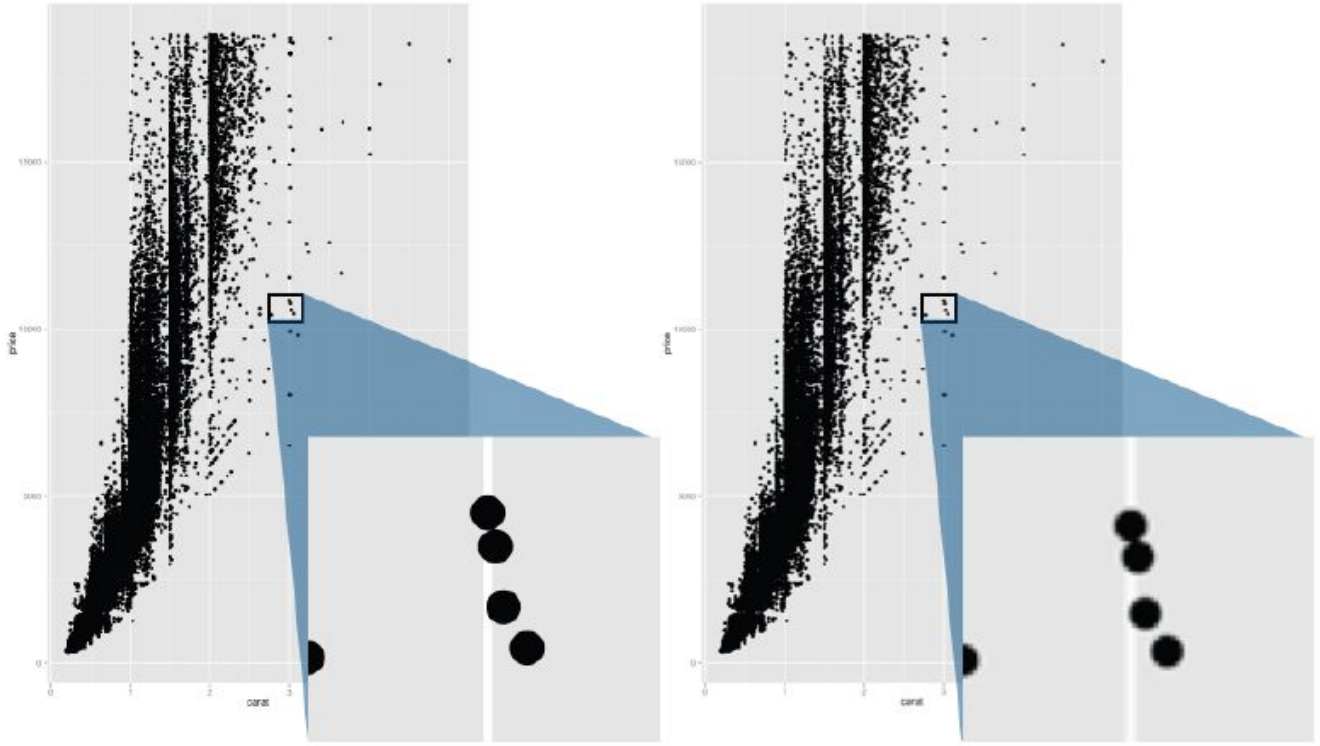
Uses size on screen:

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

Uses specified size:

```
ggsave("my-plot.pdf", width = 6, height = 6)
ggsave("my-plot.png", width = 6, height = 6)
```

Saving Plots



pdf

png

Summary

- ggplot + aesthetics = hundreds of plots (e.g., color, size, shape, alpha, etc.)
- ggplot + geoms = hundreds of plots (e.g., point, boxplots, smooth, bar, etc.)
- ggplot + geoms + aesthetics = thousands of plots
- ggplot + geoms + aesthetics + parameters = hundreds of thousands of plots