



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

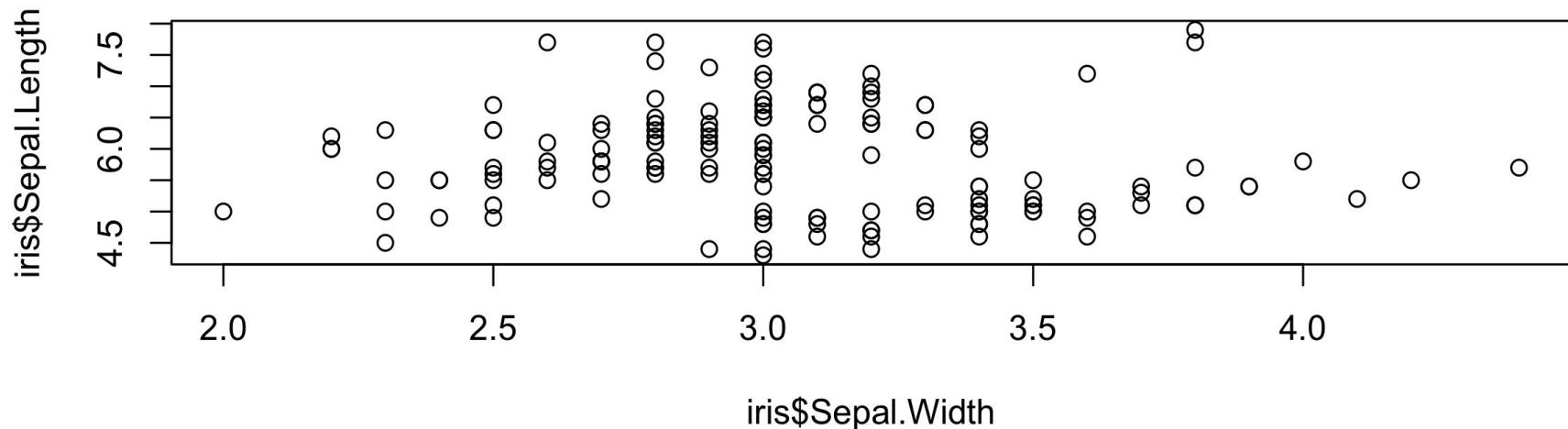
Why ggplot2?

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

Why ggplot2?

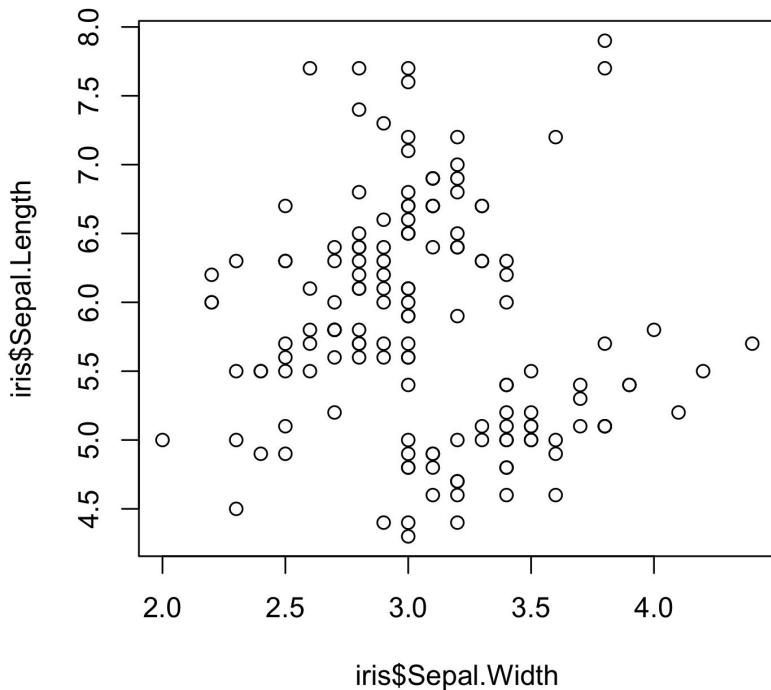
- ❖ But first an example using base R's plot function:

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



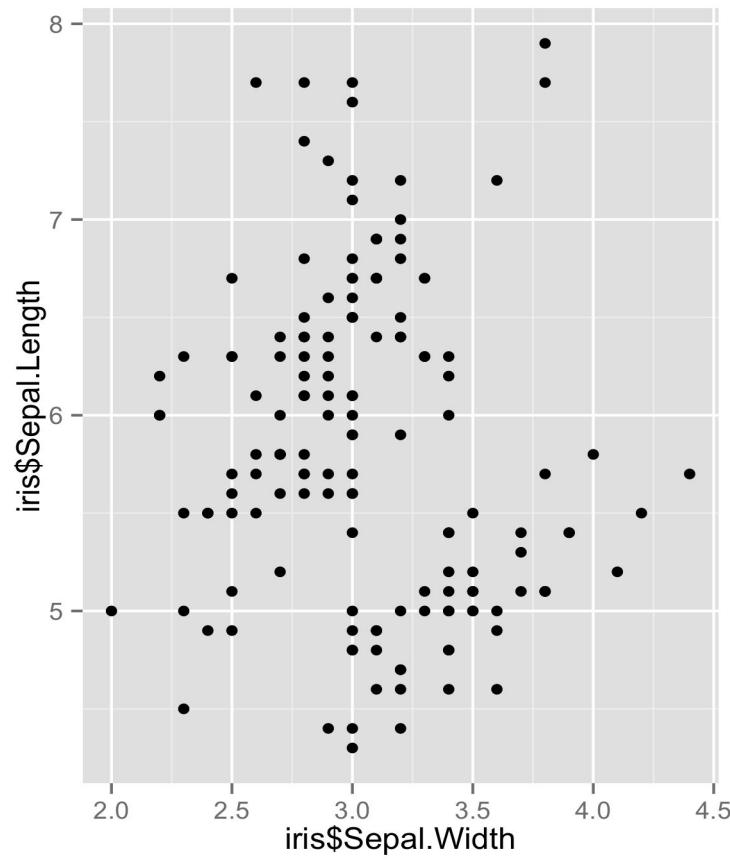
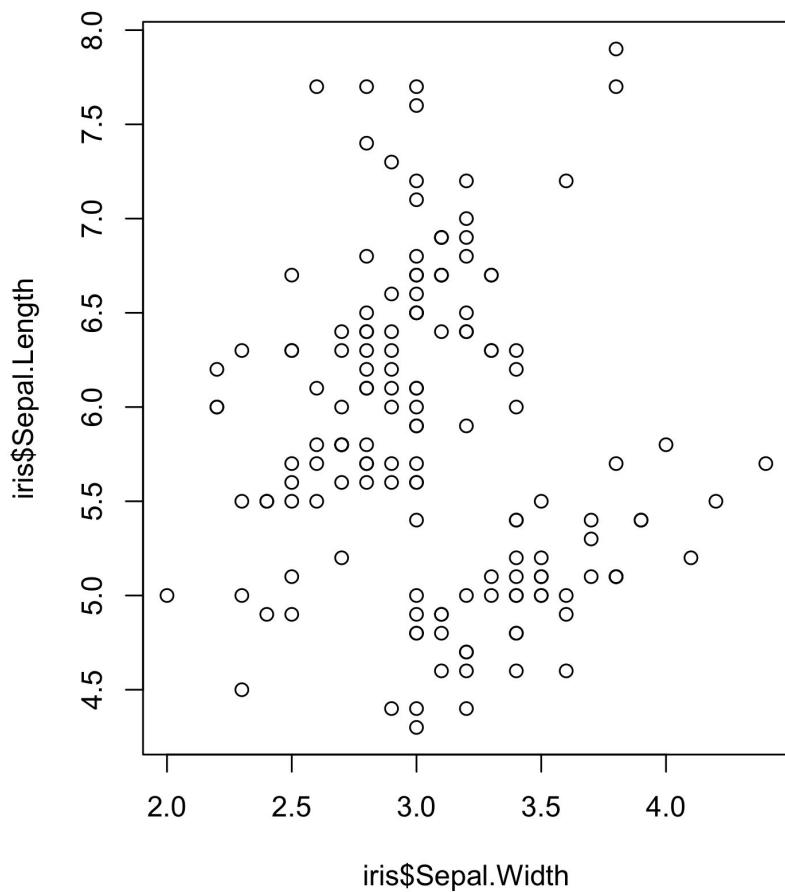
Why ggplot2?

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

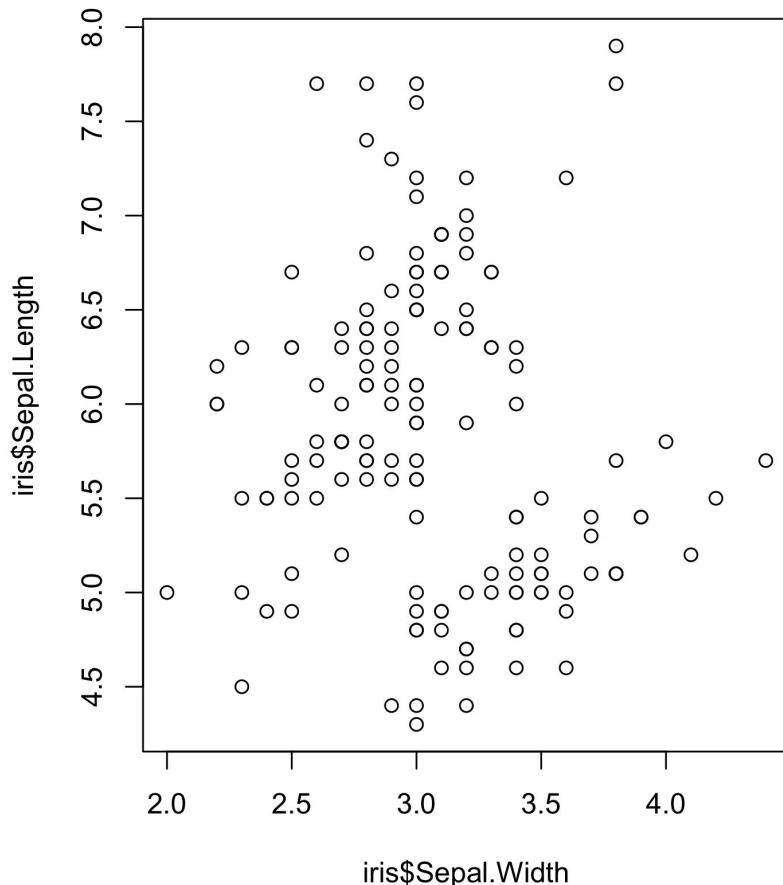


- ❖ R's basic plot method
- ❖ simple
- ❖ does different things in different contexts
- ❖ (usually in a helpful way)
- ❖ difficult to customize

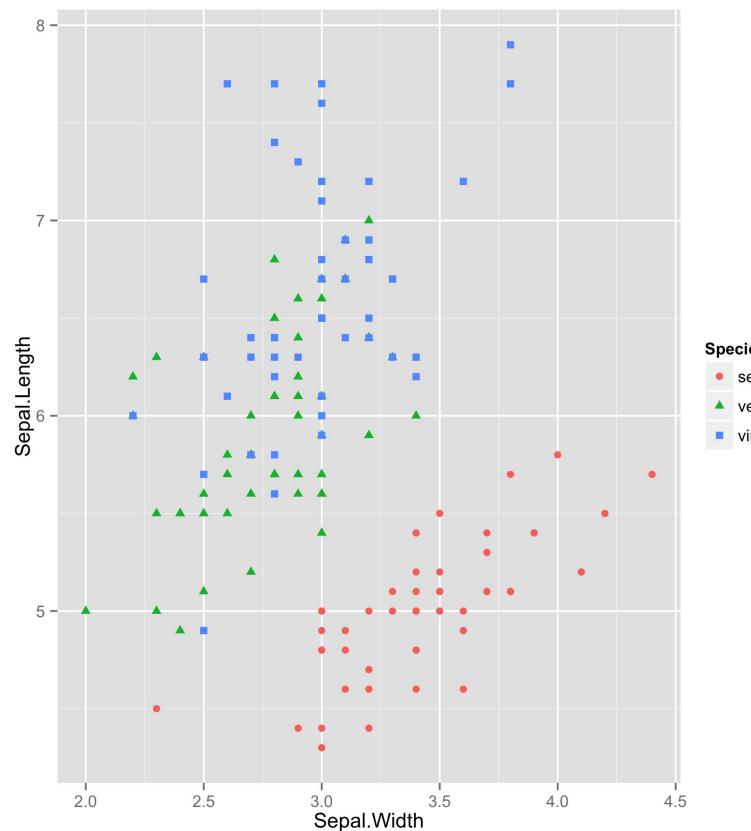
Scatterplot



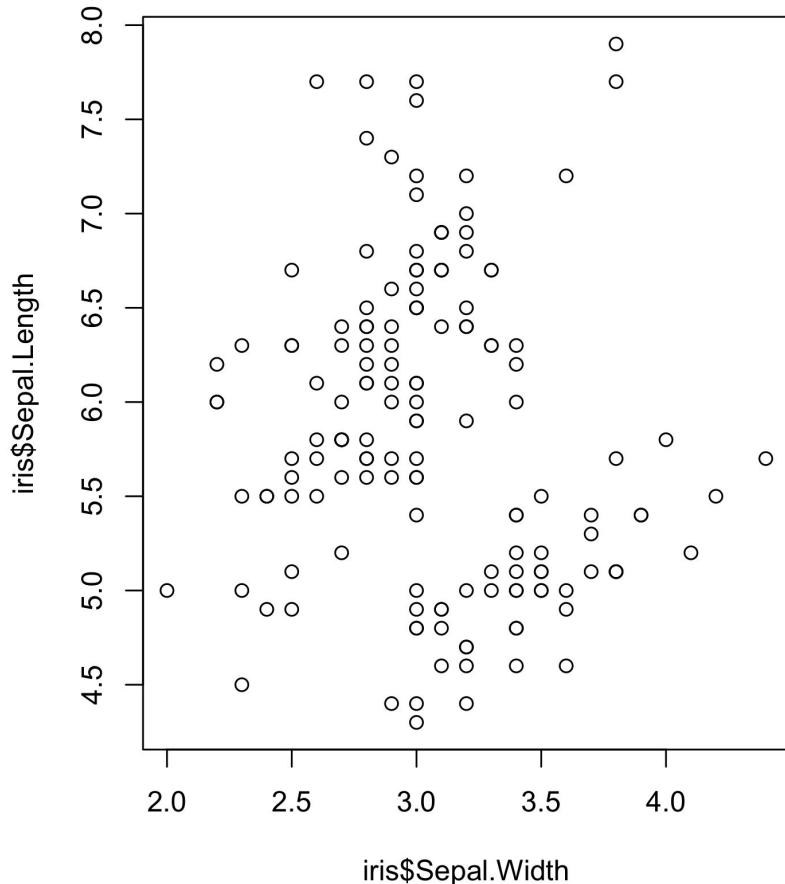
Scatterplot



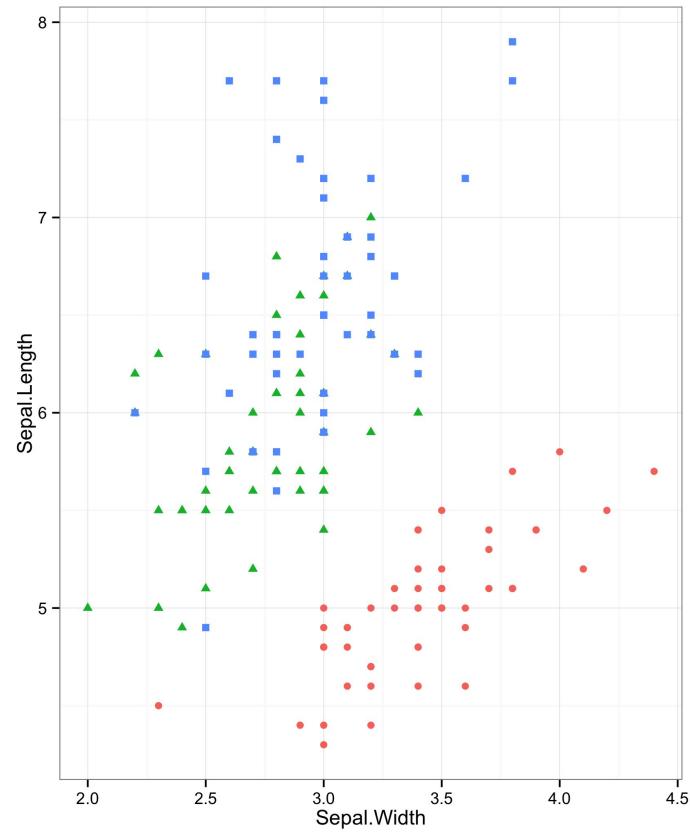
Same, but with species mapped to different colors and shapes.



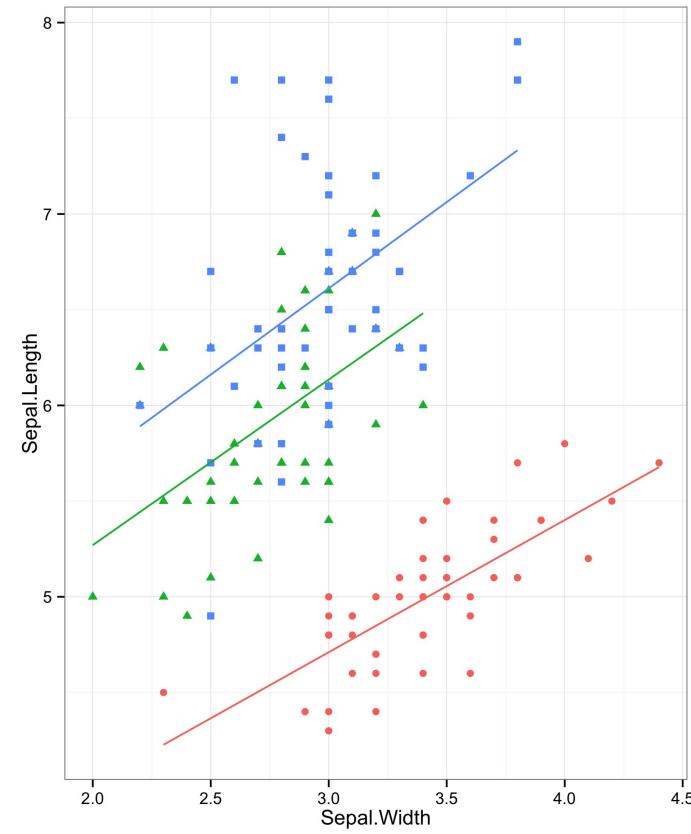
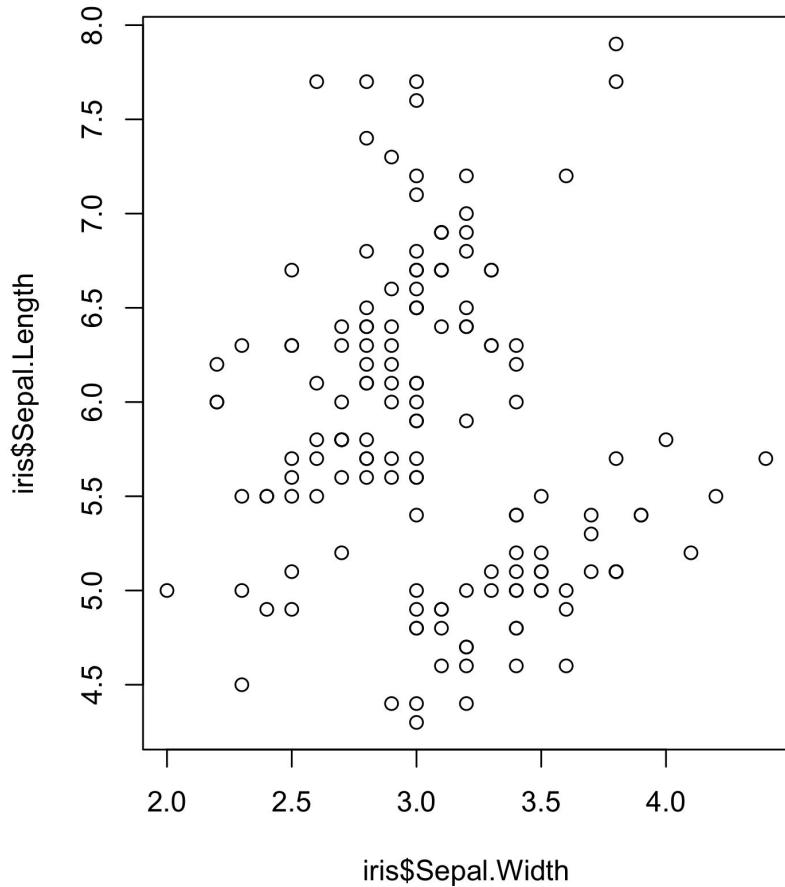
Scatterplot



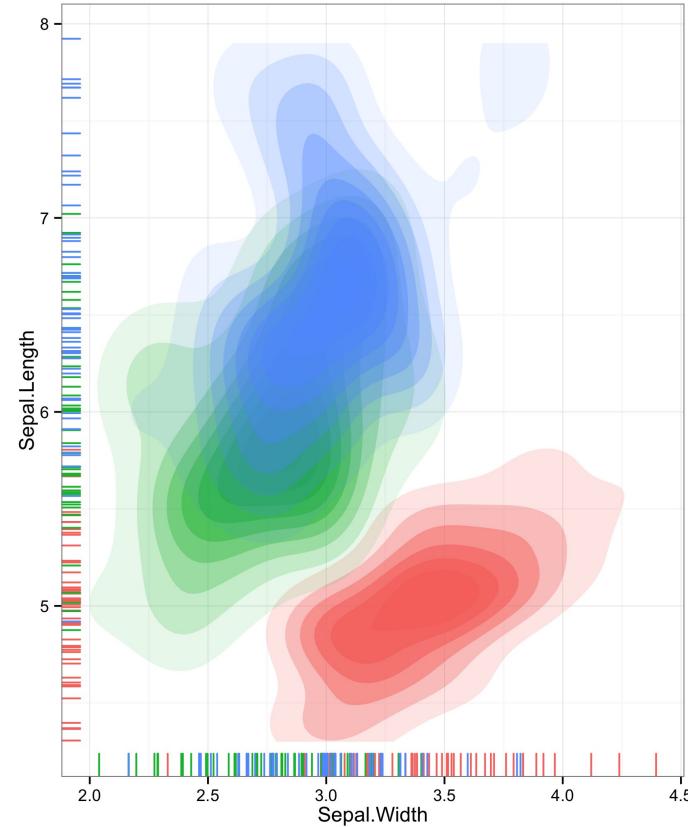
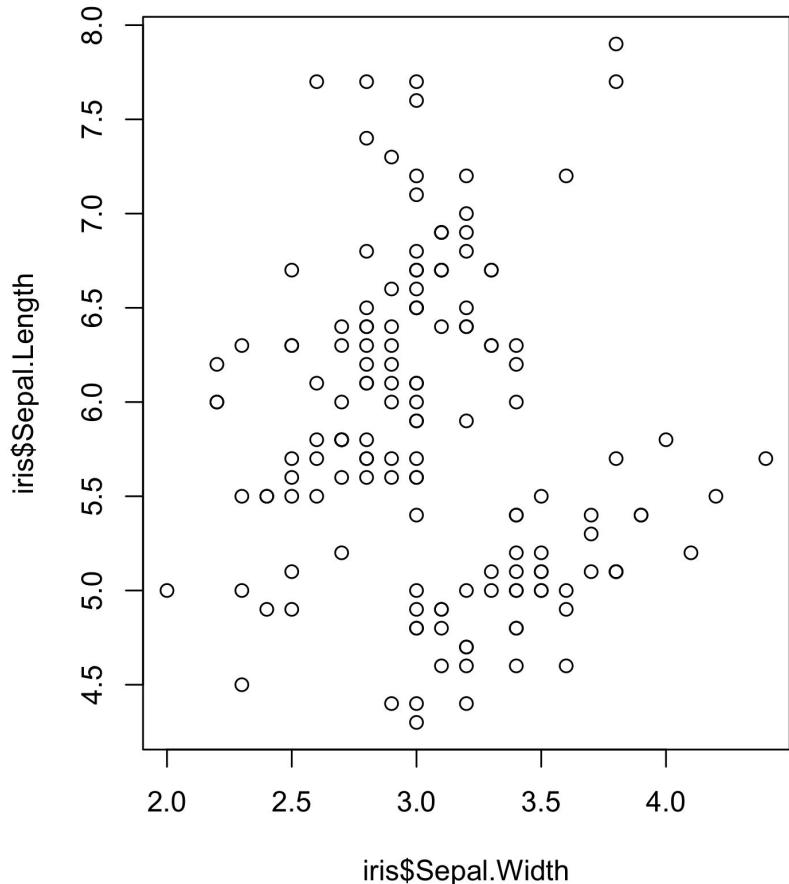
A different theme.



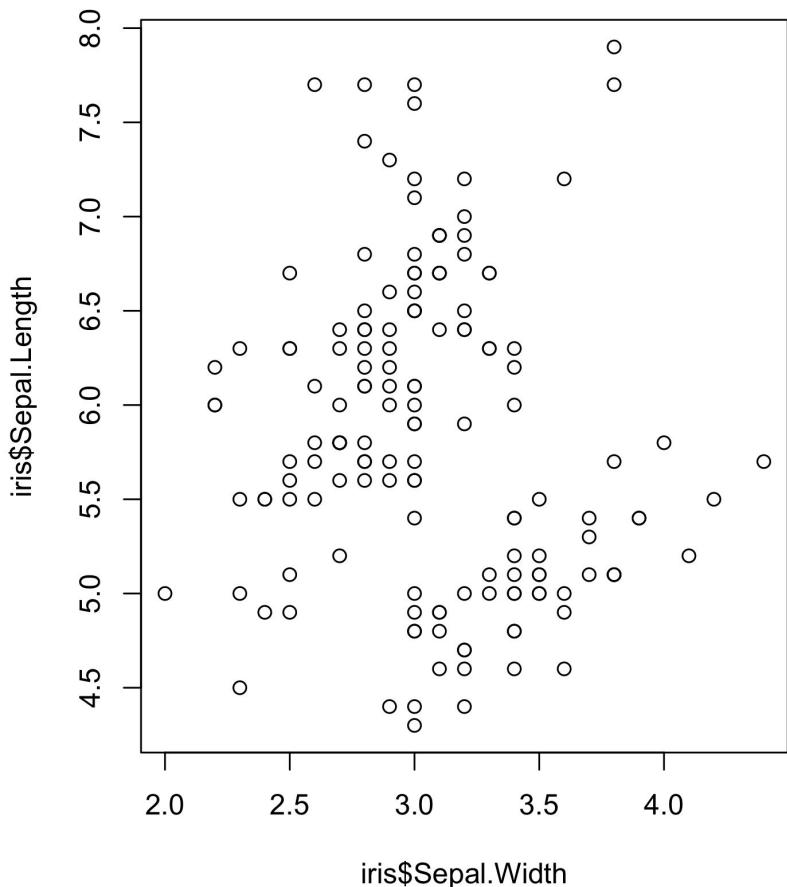
Scatterplot with Regression Line



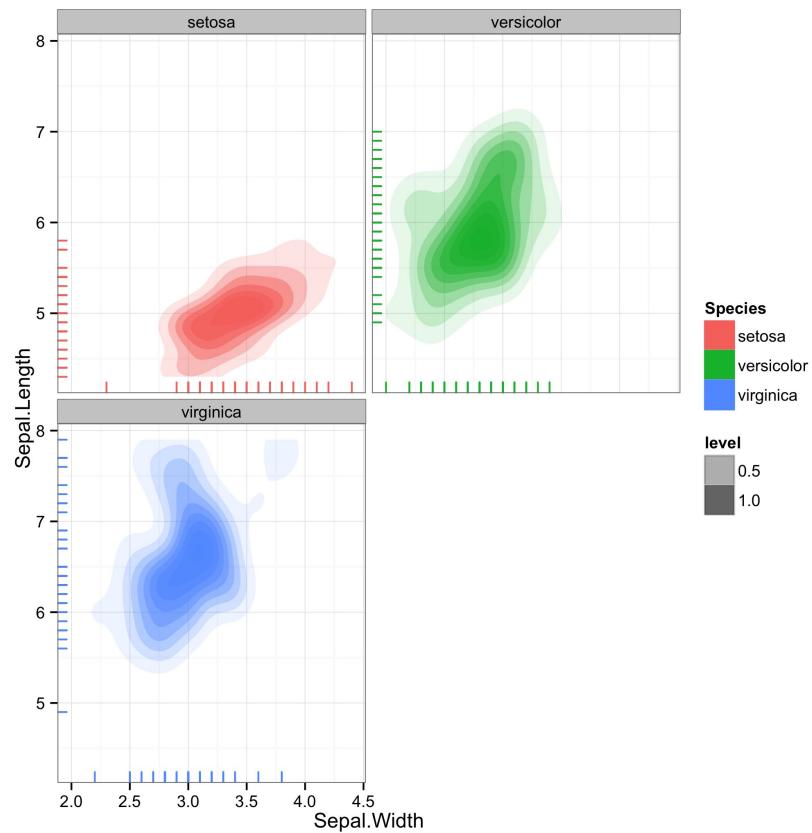
2D Density Plot with Rug Plot



Grid of 2D Density Plots



Each species has its own plot.



Vector Field

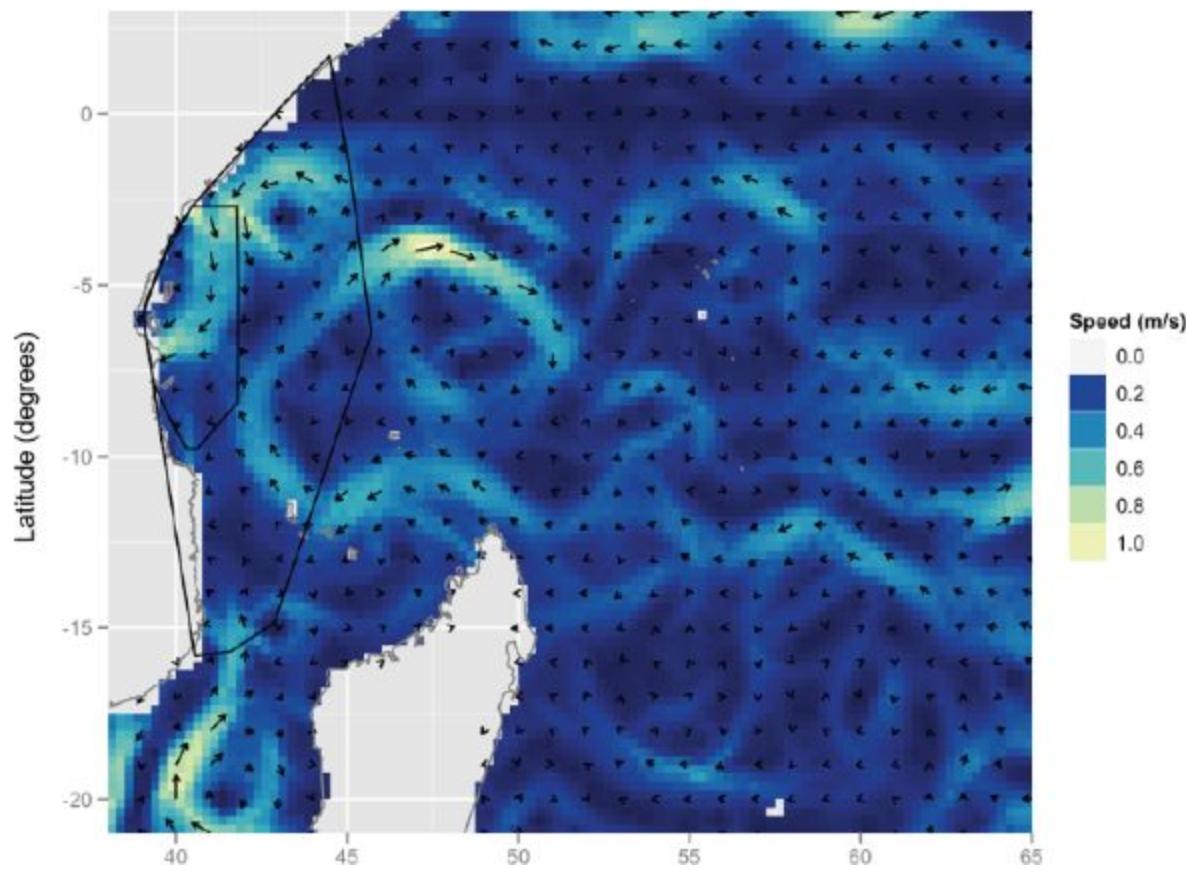
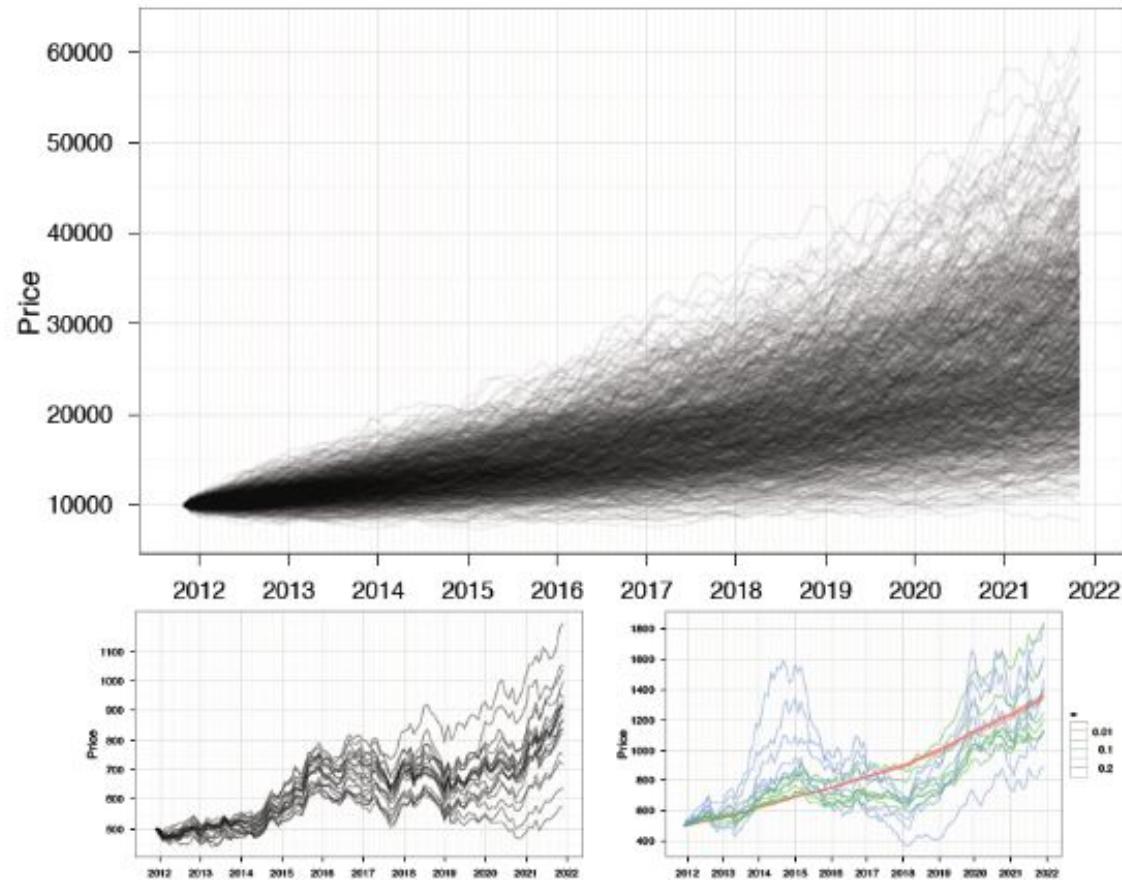


Figure: Charlotte Wickham, <http://cwick.co.nz/>

Time Series



Coefficient Plot

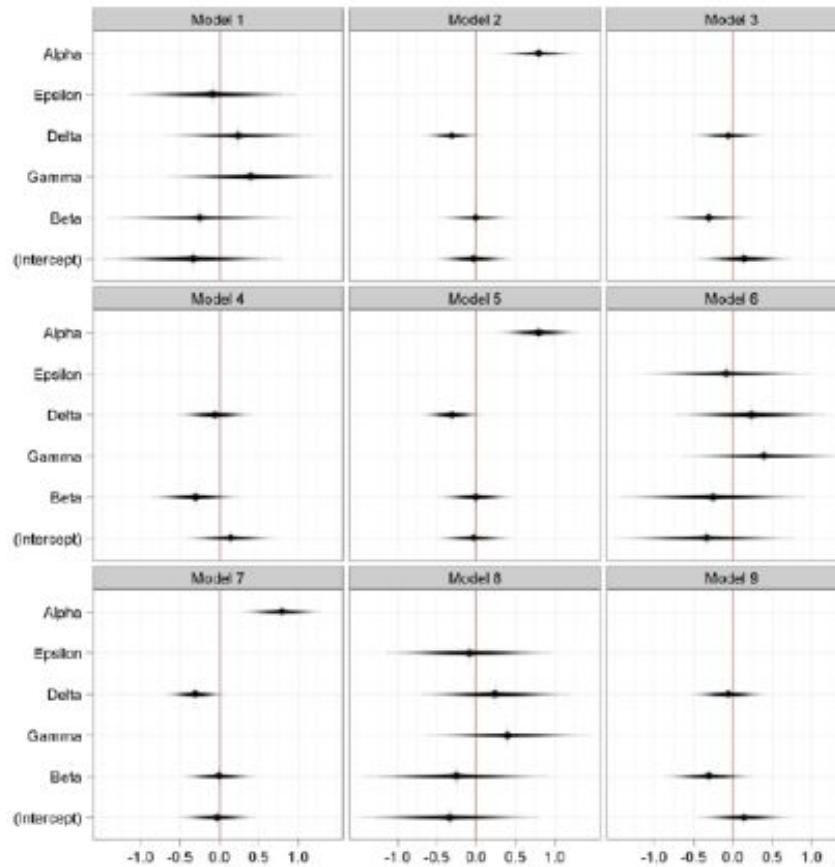


Figure: David B Sparks, <http://bit.ly/hn54NW>

Maps

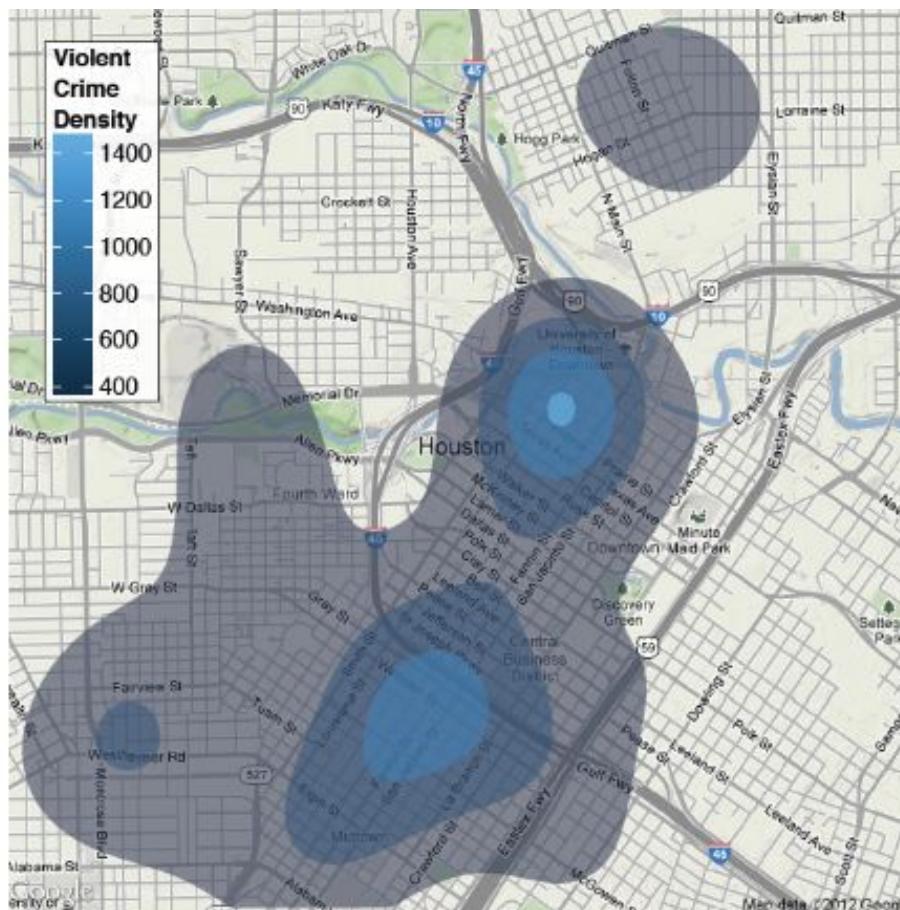


Figure: David Kahle, <https://dl.dropbox.com/u/24648660/ggmap%20useR%202012.pdf>

Maps

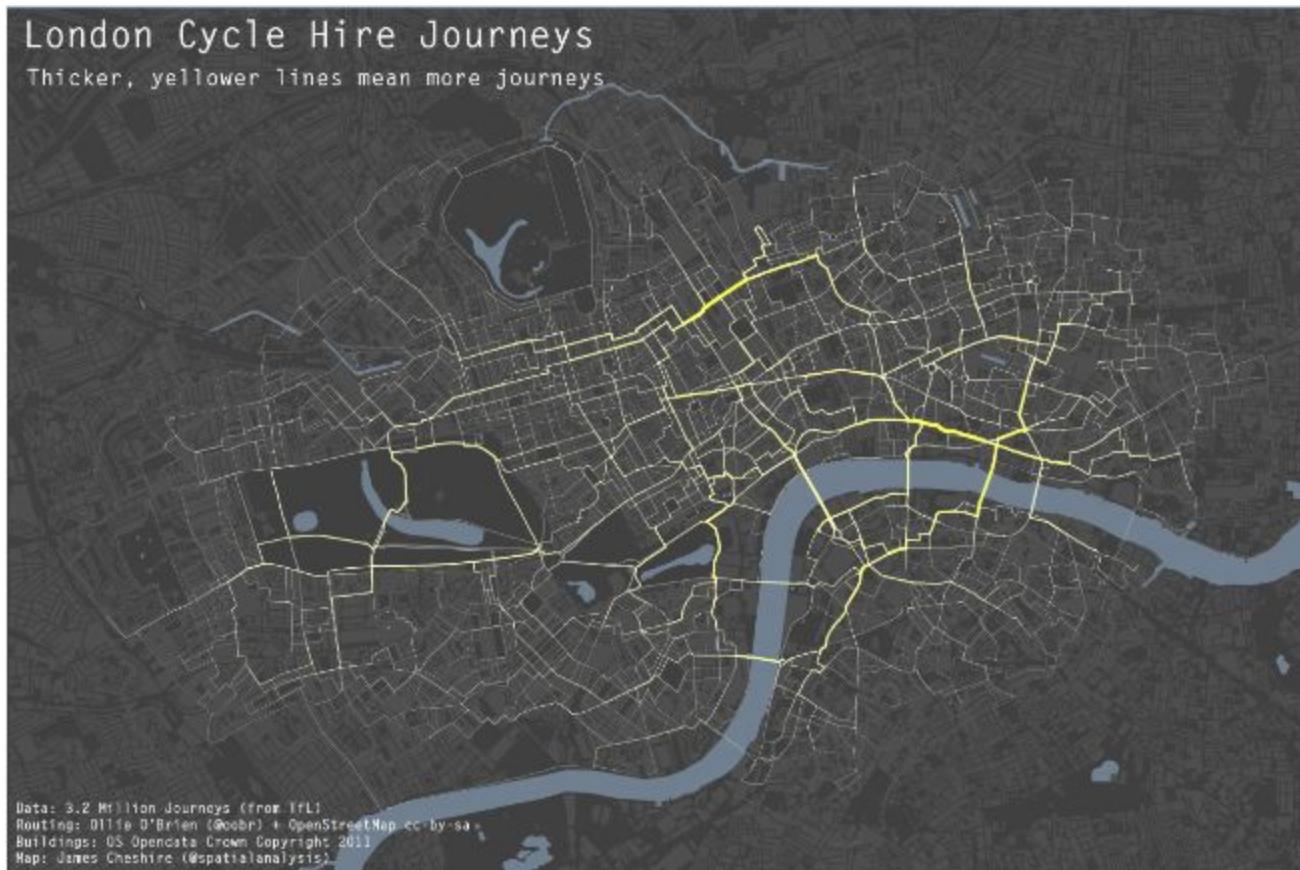


Figure: James Cheshire, <http://bit.ly/xqHhAs>

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

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- ❖ 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.

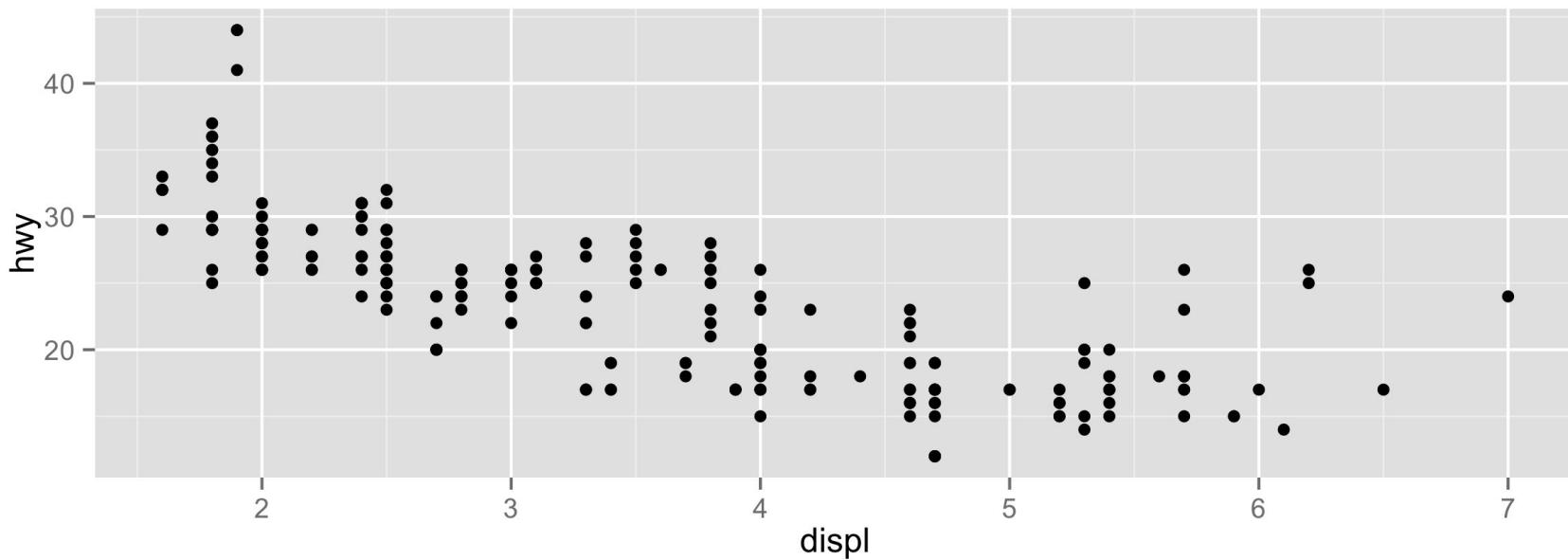
```
?mpg  
head(mpg)
```

What relationship would you expect to see between:

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

Scatterplots

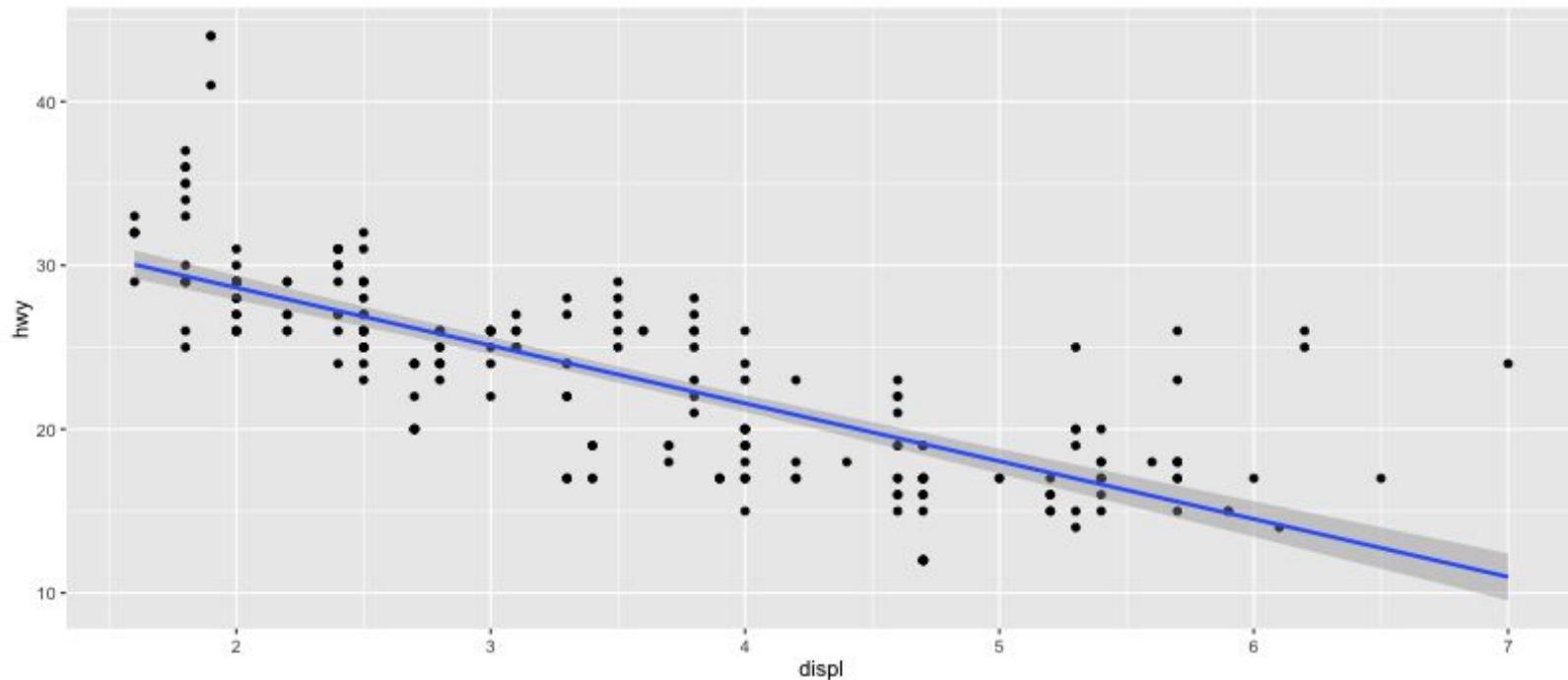
```
g <- ggplot(data = mpg, aes(x = displ, y = hwy))  
g + geom_point()
```



Scatterplots

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

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



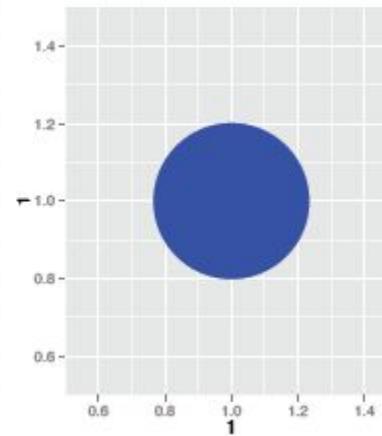
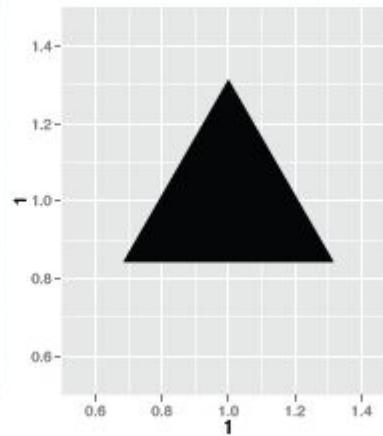
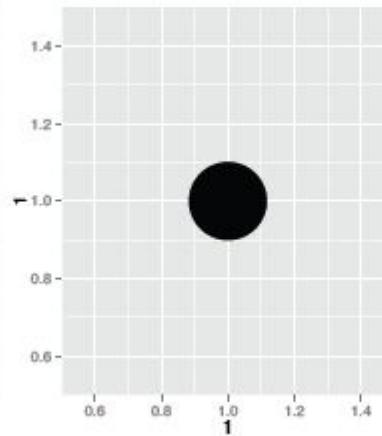
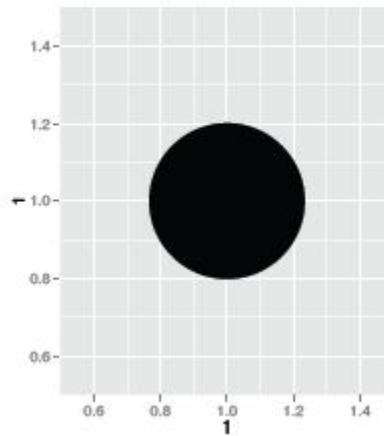
The greatest value of a picture is when it
forces us to notice what we never expected
to see.

- John Tukey

Aesthetics

Aesthetics

Visual characteristics that data are mapped to.



Aesthetics

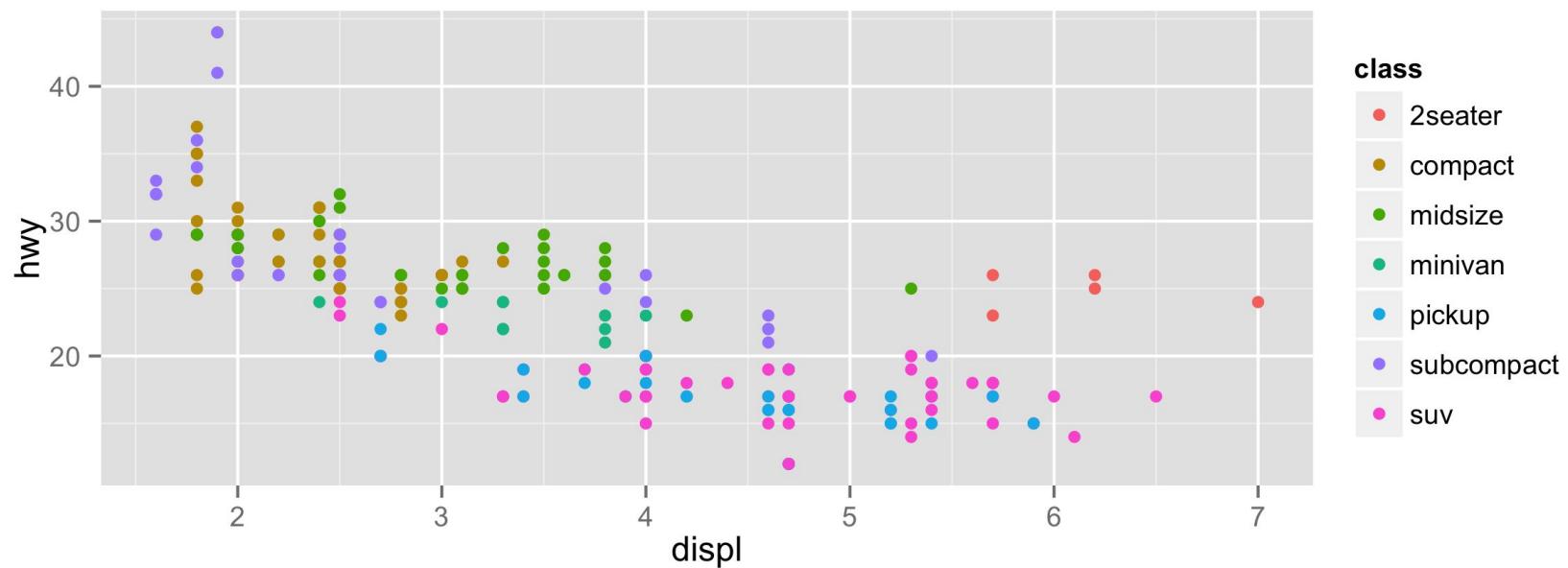
- ❖ color, size, shape, alpha
- ❖ Add color, size, and shape aesthetics to your graph. Experiment.
- ❖ Do different things happen for discrete and continuous variables?
- ❖ What happens when you use more than one aesthetic?
- ❖ What are the warning messages trying to tell us?

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

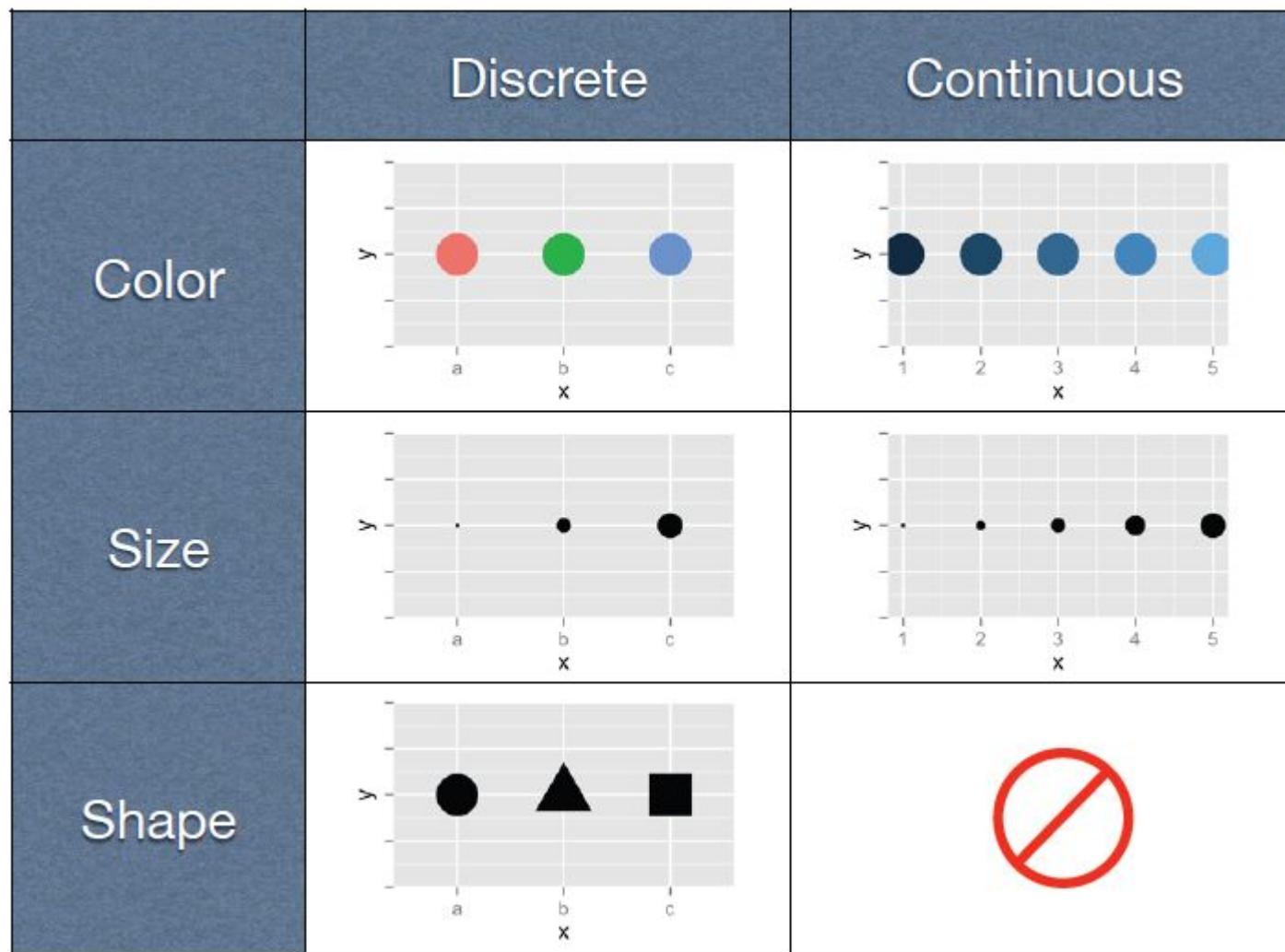
Aesthetics

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 ~ .)
```

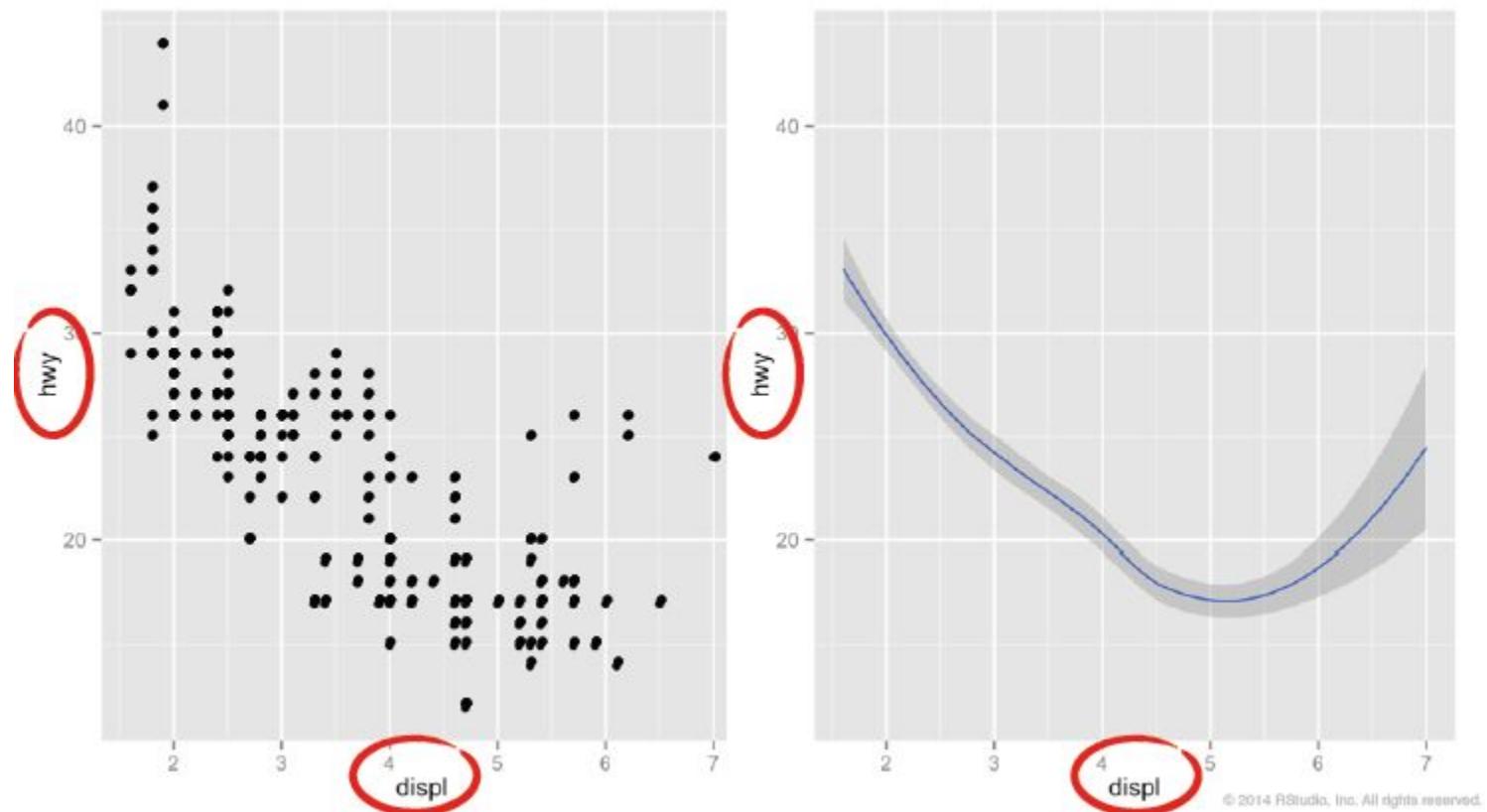
```
g + geom_point() + facet_grid(drv ~ cyl)
```

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

Geoms

Geoms

How are these plots similar?

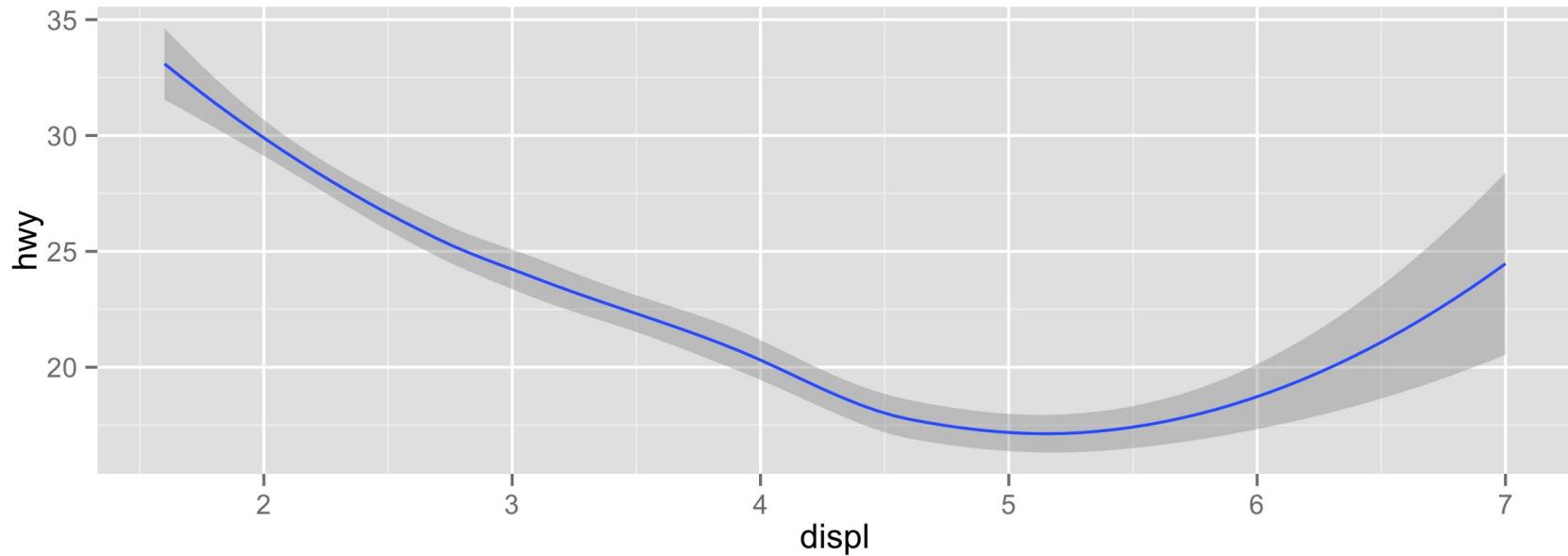


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Geoms

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

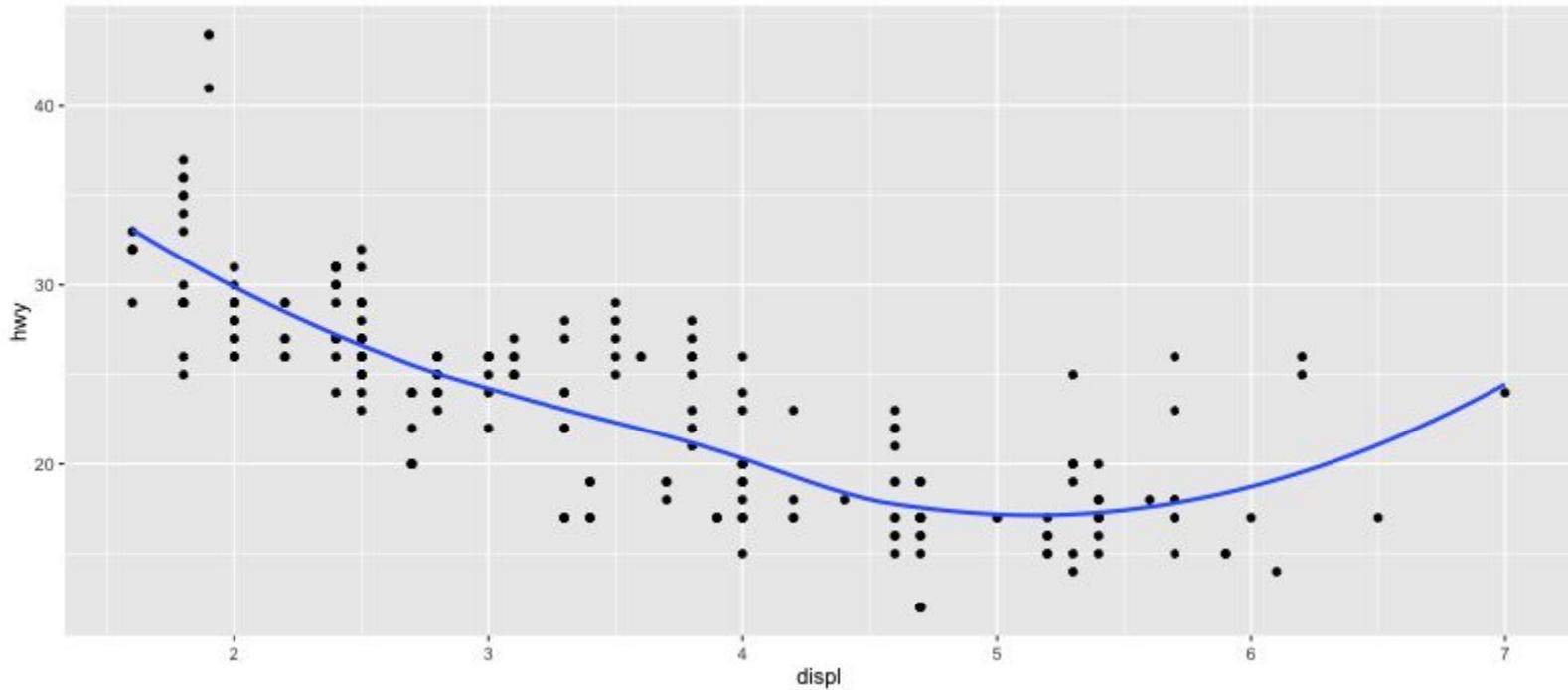
```
g + geom_smooth() # method = "auto" is the default
```



Geoms

As we saw earlier, we can layer multiple geoms.

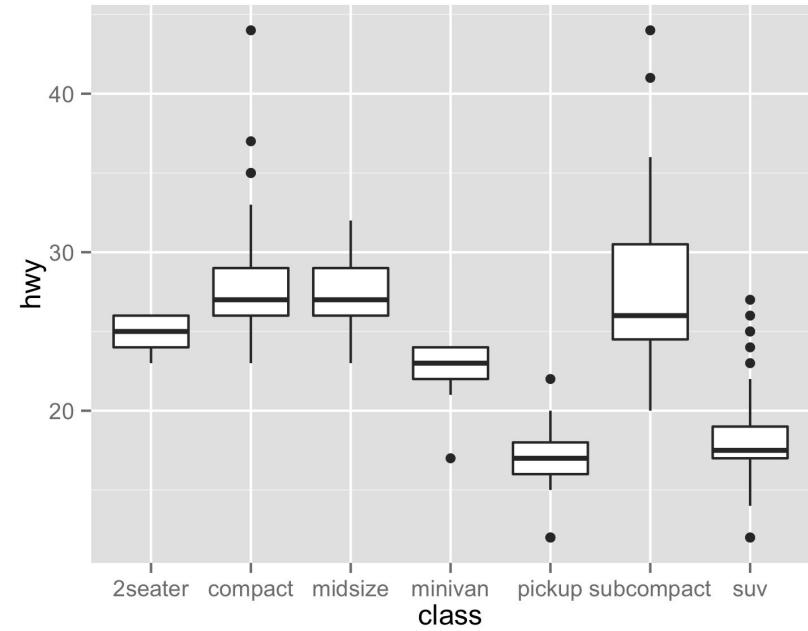
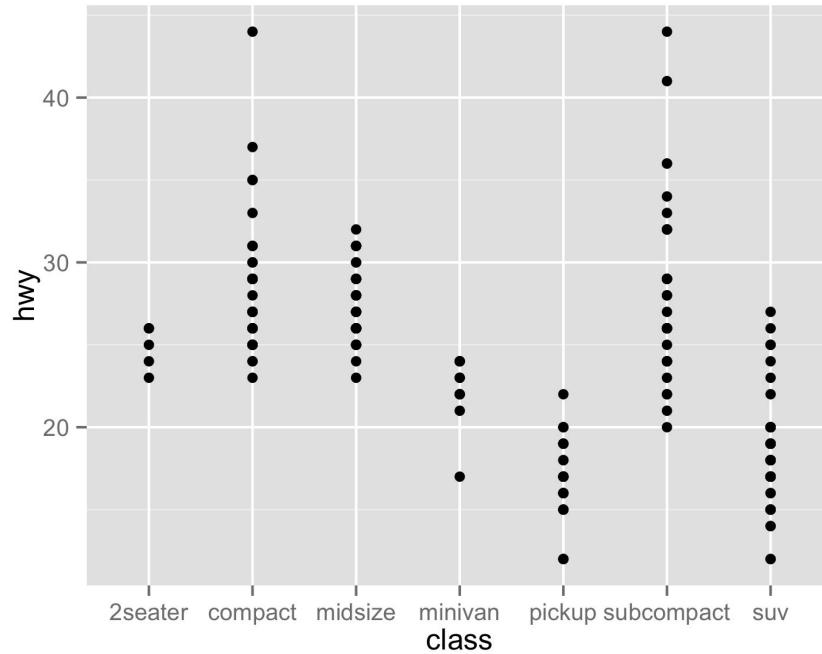
```
g + geom_point() + geom_smooth(se = FALSE) # Turn off  
confidence band
```



Geoms

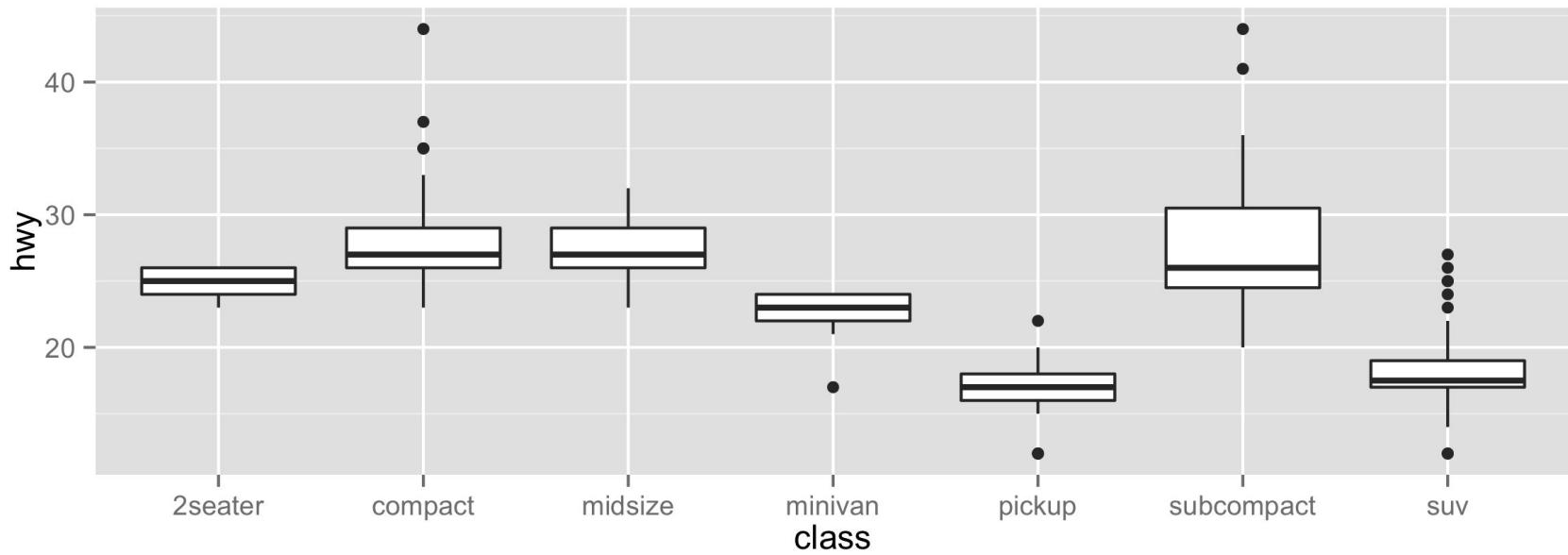
How would you replace this scatterplot with one that draws boxplots?

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

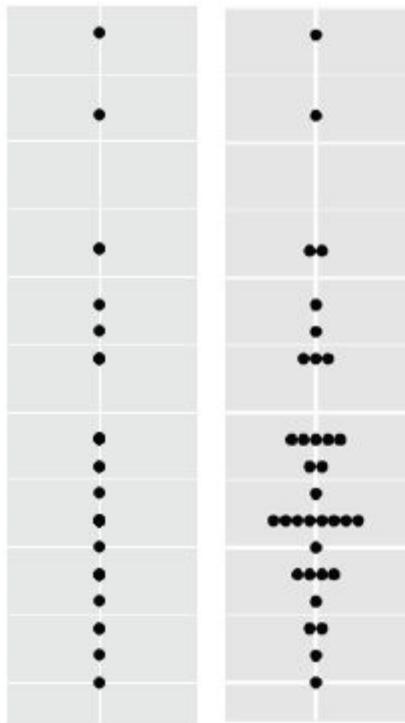


Geoms

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

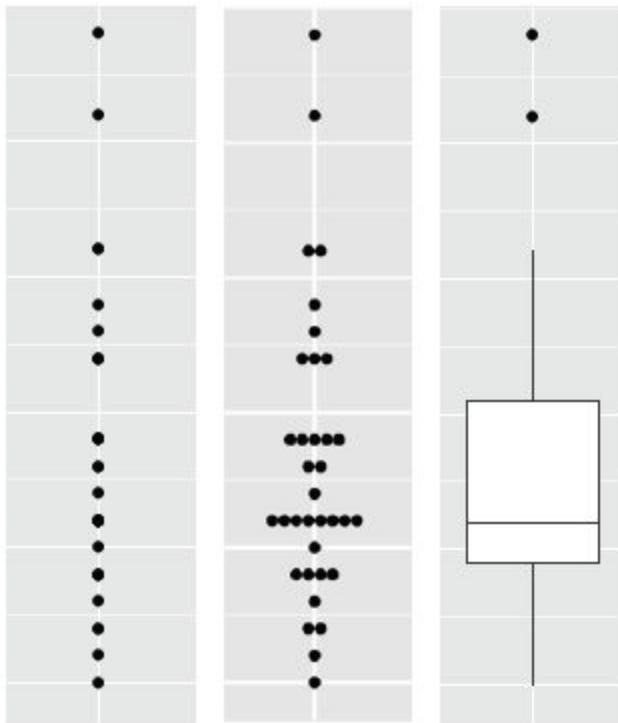


boxplots



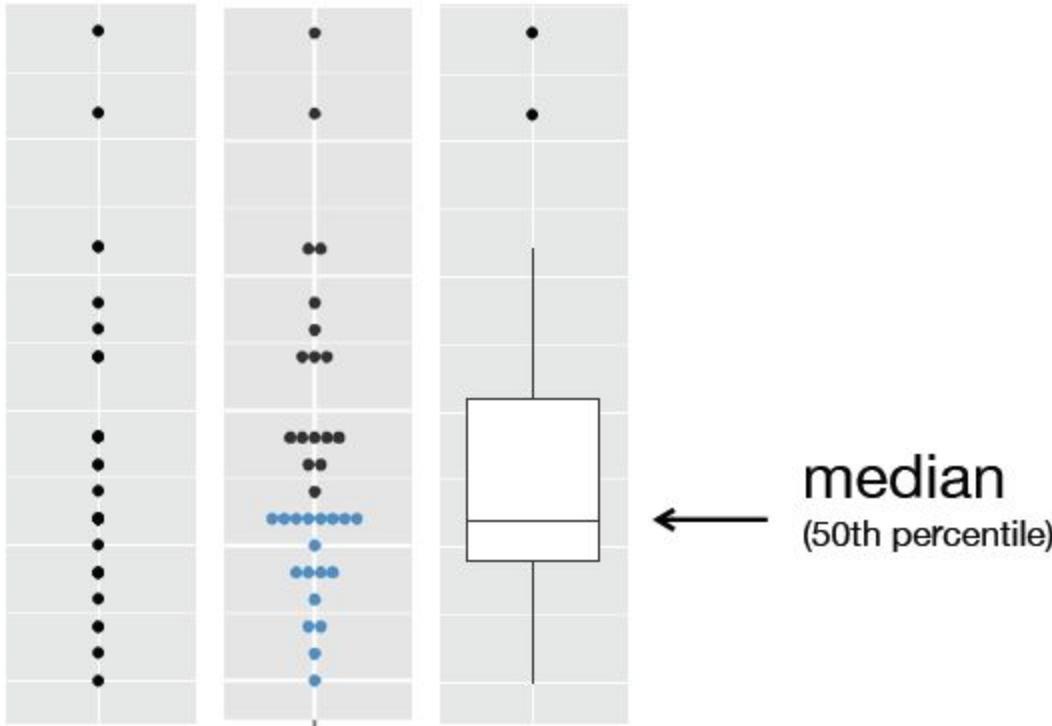
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boxplots



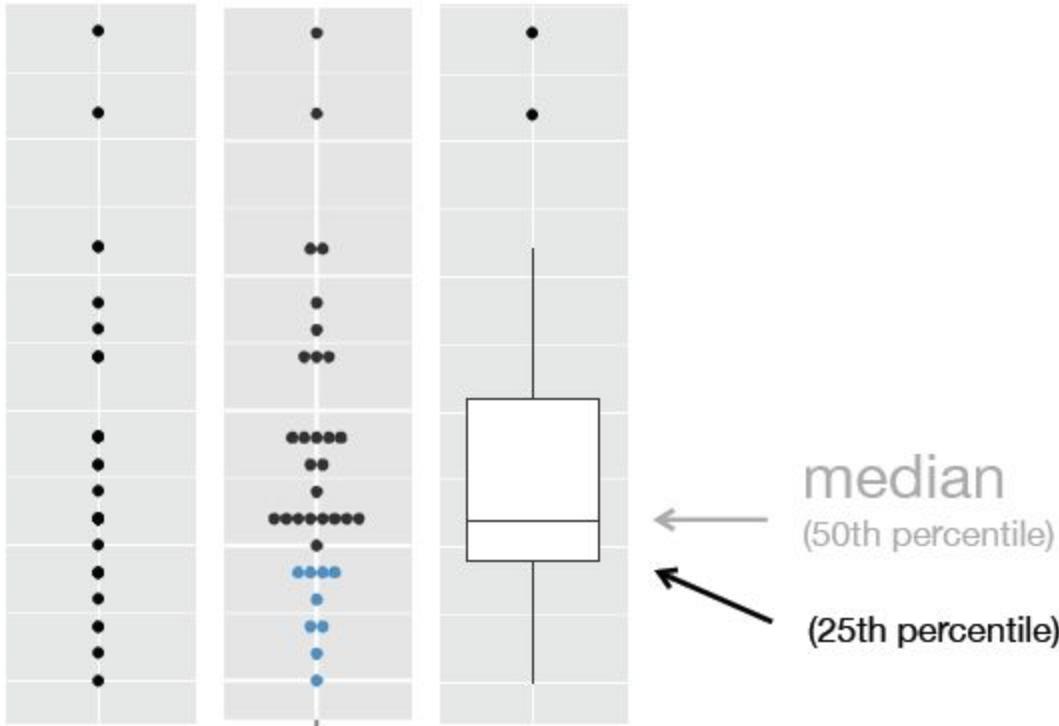
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boxplots



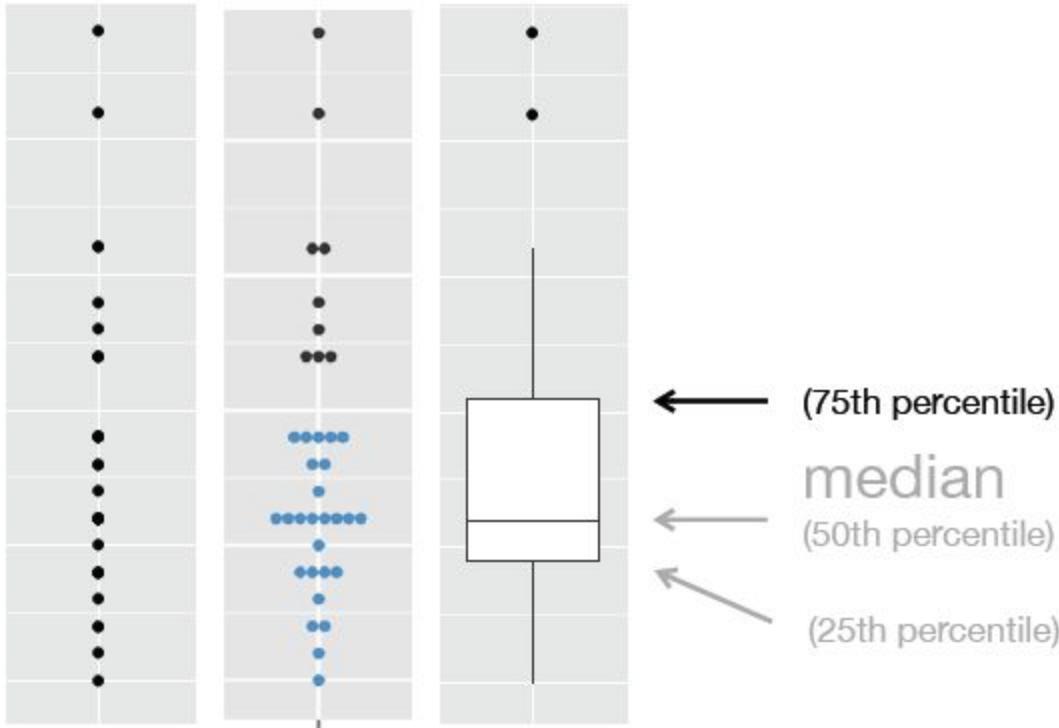
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boxplots



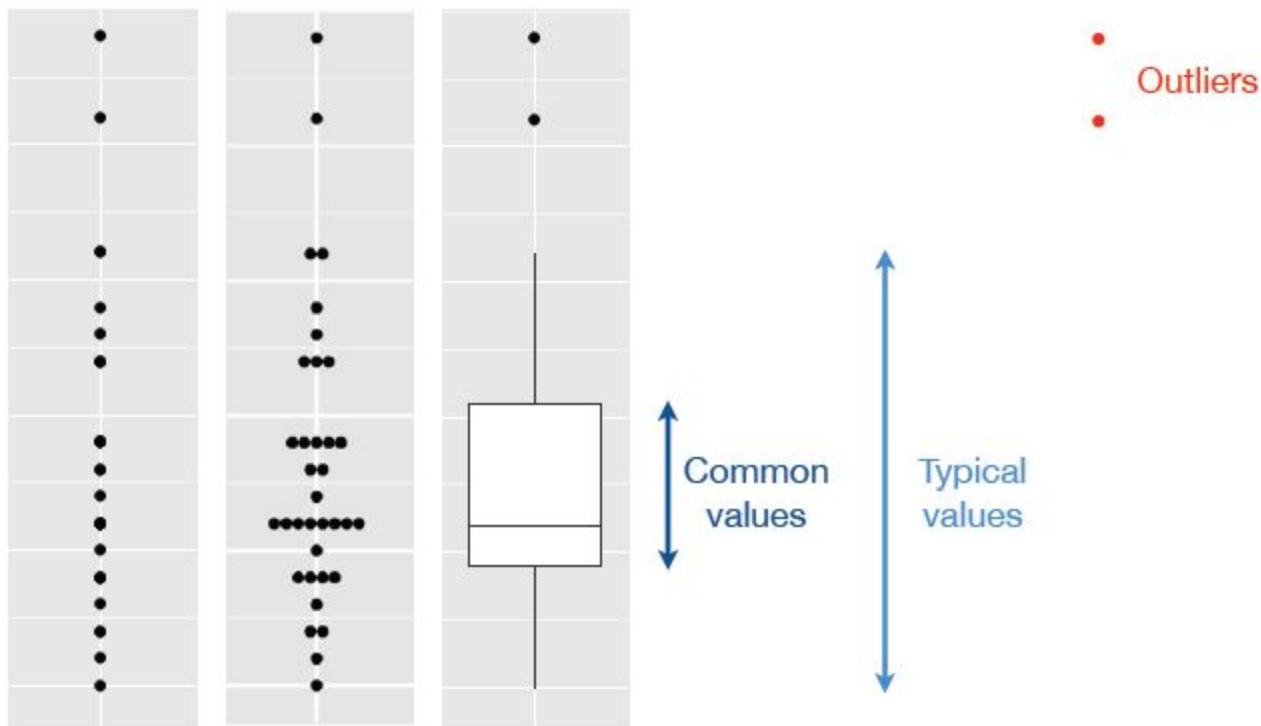
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boxplots



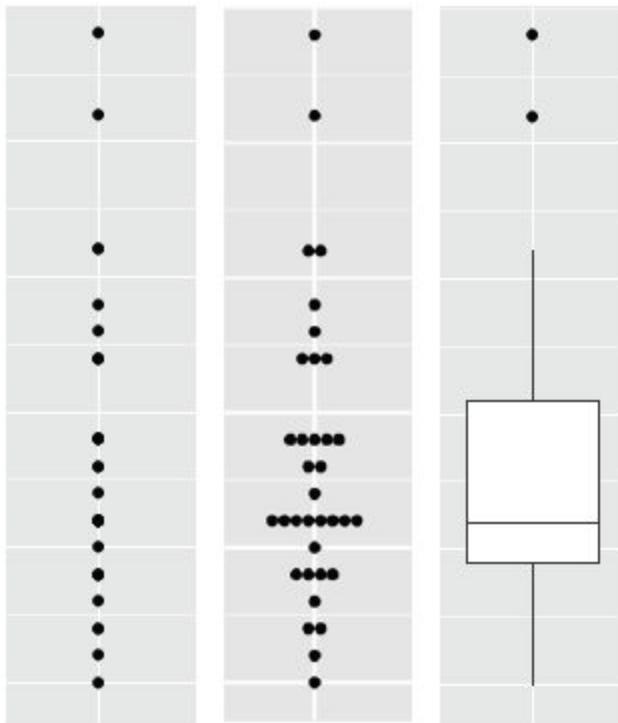
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boxplots



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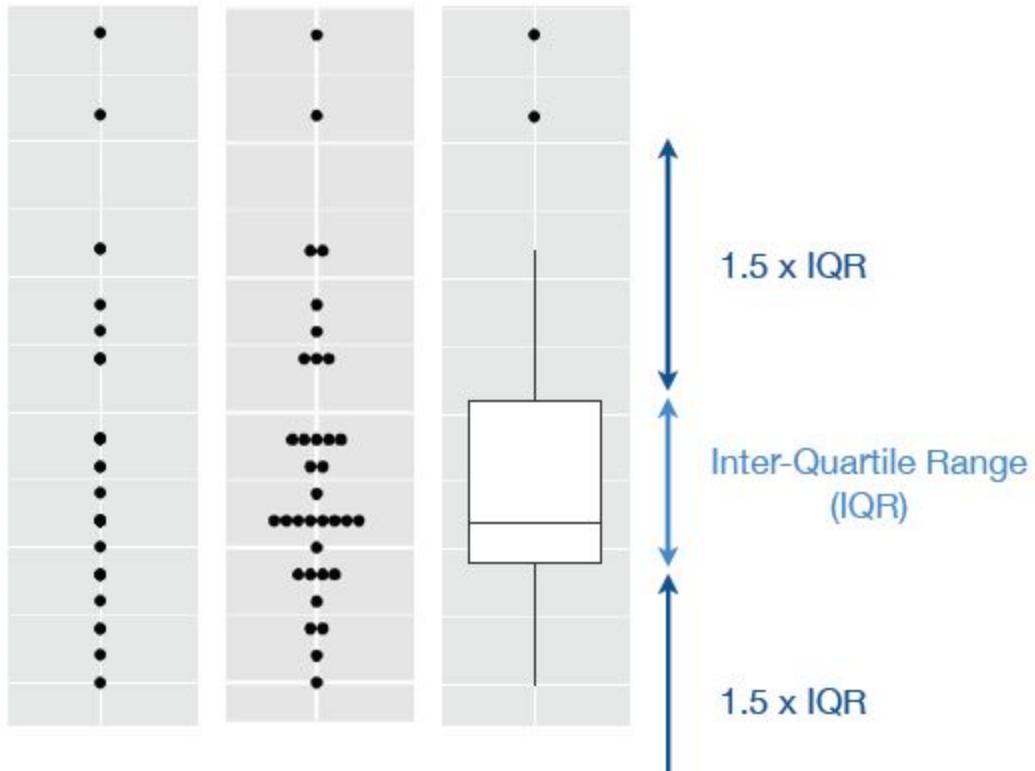
boxplots



Inter-Quartile Range
(IQR)

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boxplots

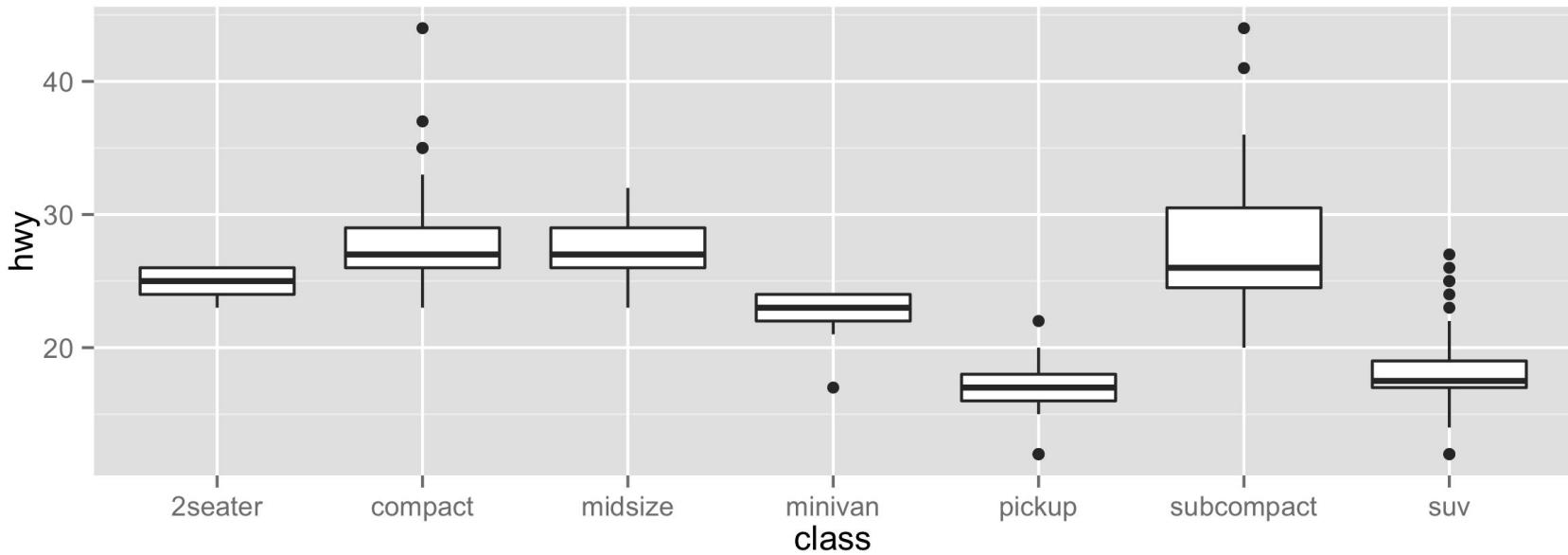


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Geoms

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

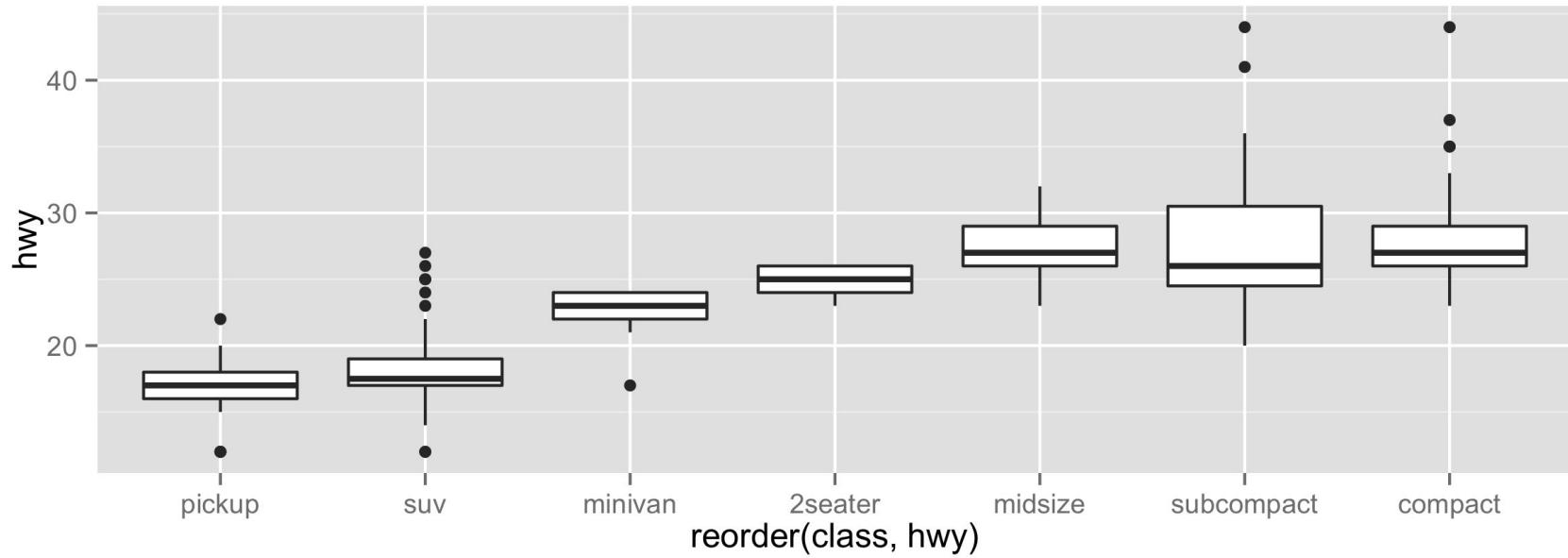
```
g + geom_boxplot()
```



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

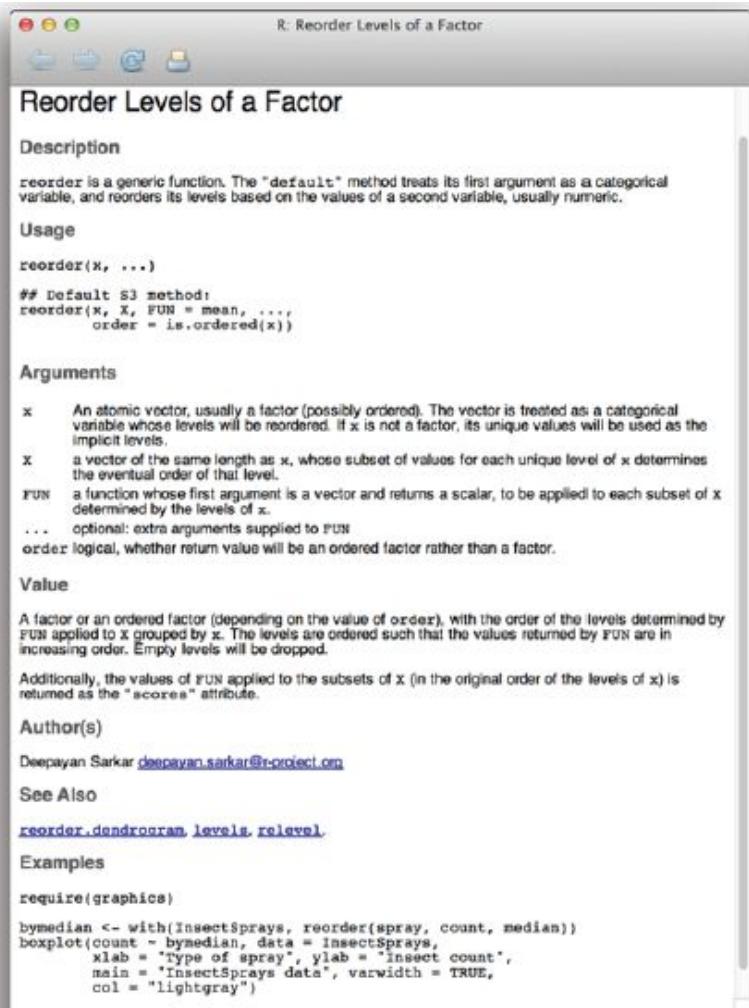
explanation of each argument

Value

what the function returns

Examples

Most helpful section!



The screenshot shows the R help documentation for the 'reorder' function. The title is 'R: Reorder Levels of a Factor'. The 'Description' section states that 'reorder' is a generic function that reorders levels based on a numeric variable. The 'Usage' section shows the function signature: 'reorder(x, ...)' and its default S3 method: '# Default S3 method: reorder(x, X, FUN = mean, ..., order = is.ordered(x))'. The 'Arguments' section details the parameters: 'x' (atomic vector, factor), 'X' (vector of the same length as x), 'FUN' (function applying to subsets), '...' (optional extra arguments to FUN), and 'order' (logical for ordered factor). The 'Value' section describes the output as a factor or ordered factor with levels ordered by FUN. The 'Author(s)' section credits Deepayan Sarkar. The 'See Also' section links to 'reorder.dendrogram', 'levels', and 'relevel'. The 'Examples' section provides R code to reorder 'InsectSprays' data by 'spray' and 'count'.

```
reorder(x, ...)

# Default S3 method:
reorder(x, X, FUN = mean, ...,
       order = is.ordered(x))

x      An atomic vector, usually a factor (possibly ordered). The vector is treated as a categorical variable whose levels will be reordered. If x is not a factor, its unique values will be used as the implicit levels.
X      a vector of the same length as x, whose subset of values for each unique level of x determines the eventual order of that level.
FUN    a function whose first argument is a vector and returns a scalar, to be applied to each subset of x determined by the levels of x.
...    optional: extra arguments supplied to FUN
order  logical, whether return value will be an ordered factor rather than a factor.

A factor or an ordered factor (depending on the value of order), with the order of the levels determined by FUN applied to x grouped by x. The levels are ordered such that the values returned by FUN are in increasing order. Empty levels will be dropped.

Additionally, the values of FUN applied to the subsets of x (in the original order of the levels of x) is returned as the "scores" attribute.

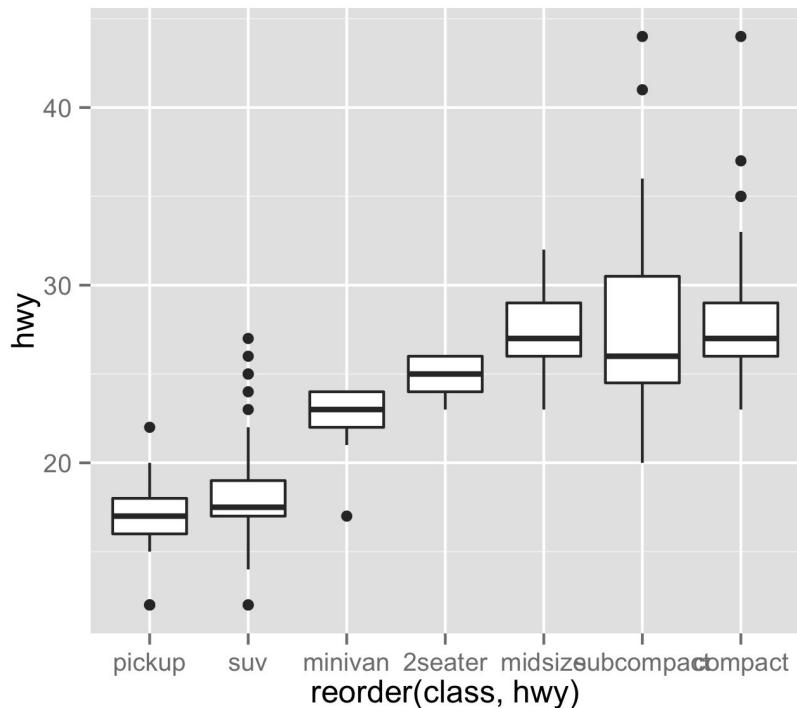
Deepayan Sarkar deepayan.sarkar@r-project.org

reorder.dendrogram, levels, relevel

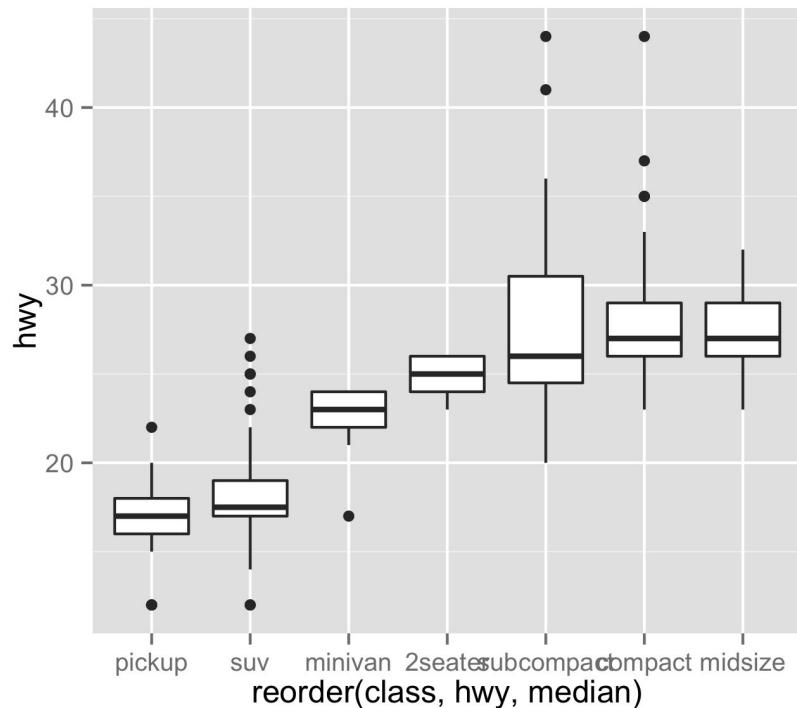
require(graphics)
bymedian <- with(InsectSprays, reorder(spray, count, median))
boxplot(count ~ bymedian, data = InsectSprays,
        xlab = "Type of spray", ylab = "Insect count",
        main = "InsectSprays data", varwidth = TRUE,
        col = "lightgray")
```

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/>

ggplot2 0.9.3.1 [Index](#)

Help topics

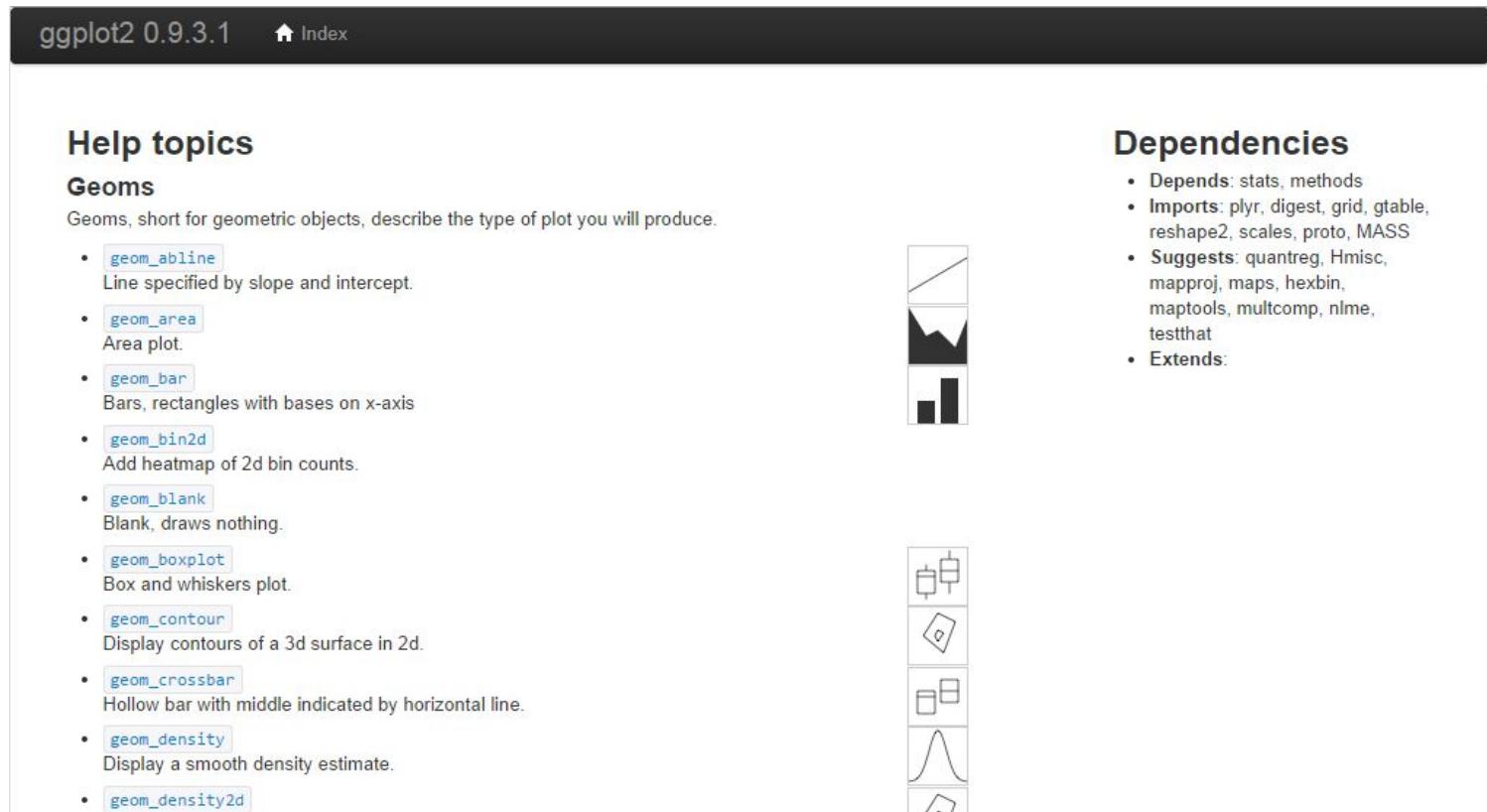
Geoms

Geoms, short for geometric objects, describe the type of plot you will produce.

- [geom_abline](#)
Line specified by slope and intercept.
- [geom_area](#)
Area plot.
- [geom_bar](#)
Bars, rectangles with bases on x-axis
- [geom_bin2d](#)
Add heatmap of 2d bin counts.
- [geom_blank](#)
Blank, draws nothing.
- [geom_boxplot](#)
Box and whiskers plot.
- [geom_contour](#)
Display contours of a 3d surface in 2d.
- [geom_crossbar](#)
Hollow bar with middle indicated by horizontal line.
- [geom_density](#)
Display a smooth density estimate.
- [geom_density2d](#)

Dependencies

- Depends: stats, methods
- Imports: plyr, digest, grid, gtable, reshape2, scales, proto, MASS
- Suggests: quantreg, Hmisc, mapproj, maps, hexbin, maptools, multcomp, nlme, testthat
- Extends:



Diamonds Data Set

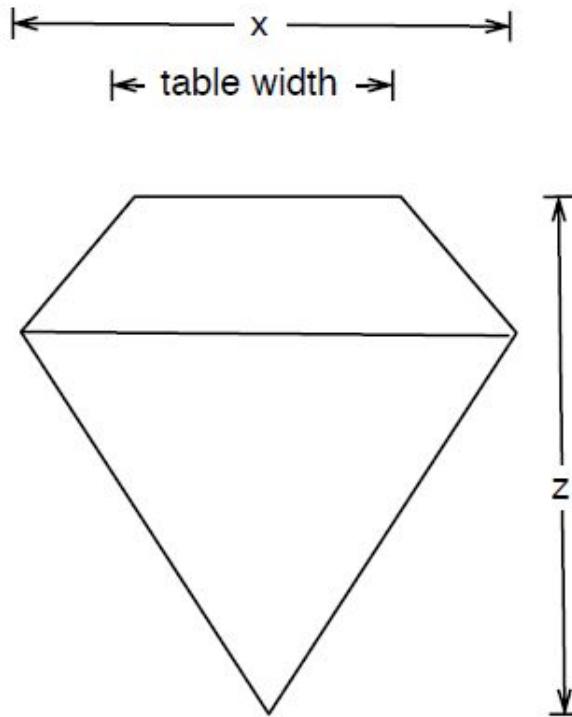
Diamonds Data Set

- ❖ 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



$\text{depth} = z / \text{diameter}$
 $\text{table} = \text{table width} / x * 100$

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Diamonds Data Set



Figure: <http://www.mlcl.com/colour.aspx>

Diamonds Data Set

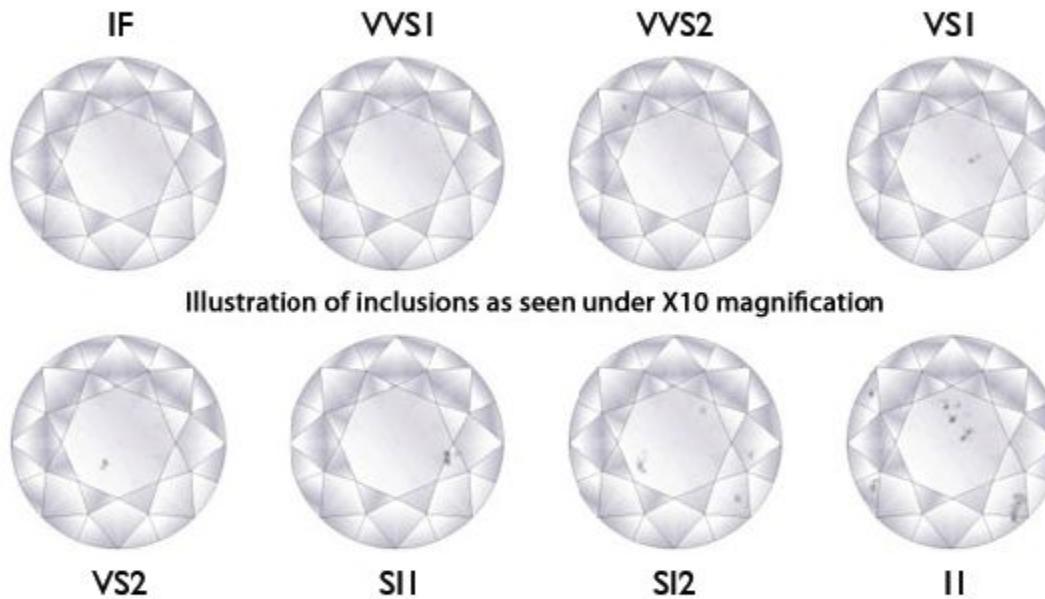


Figure: <http://www.thediamondsexperts.com/diamonds-guide>

Outline

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

Bar Charts

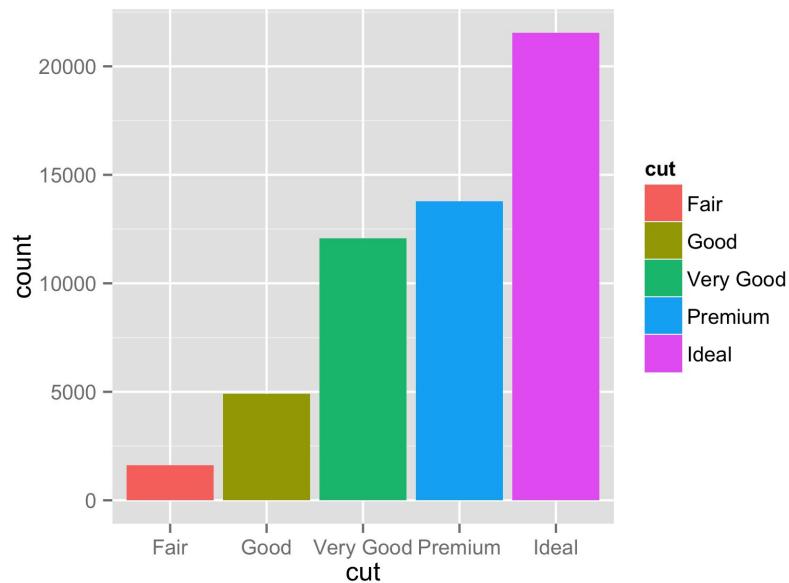
Bar Charts

What would be a sensible way to display:

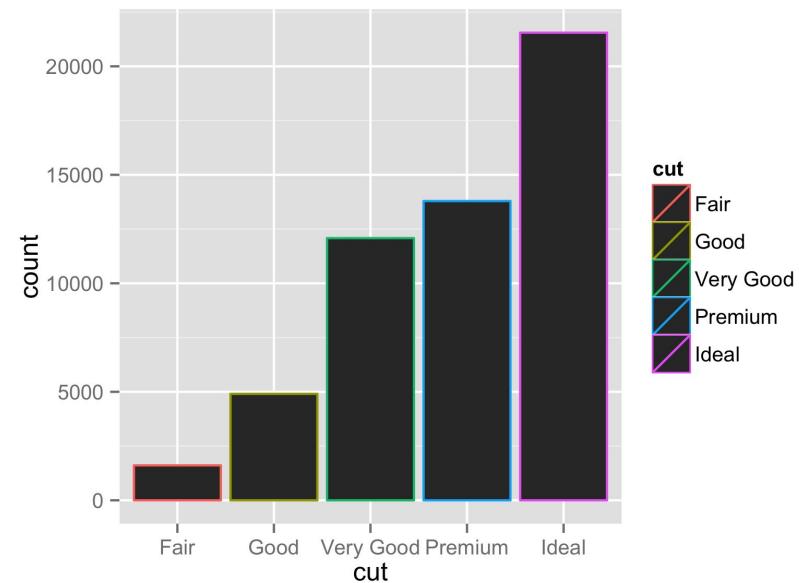
- ❖ The relationship between the x and z variables (two continuous variables)?
- ❖ Just the cut variable (a categorical variable)?
- ❖ Just the x variable (a continuous variable)?

Bar Charts

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



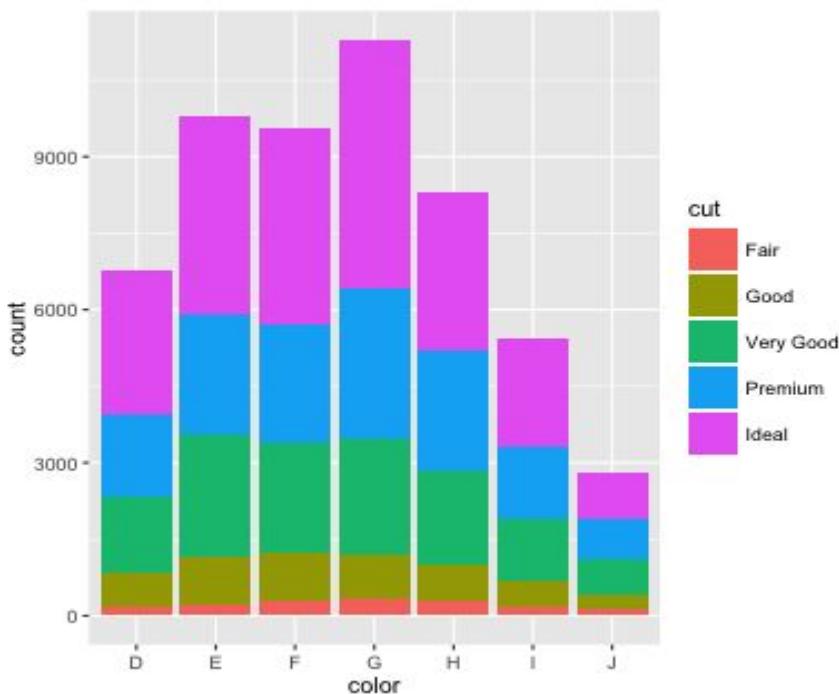
```
ggplot(data = diamonds, aes(x = cut)) + geom_bar(aes(color = cut))
```



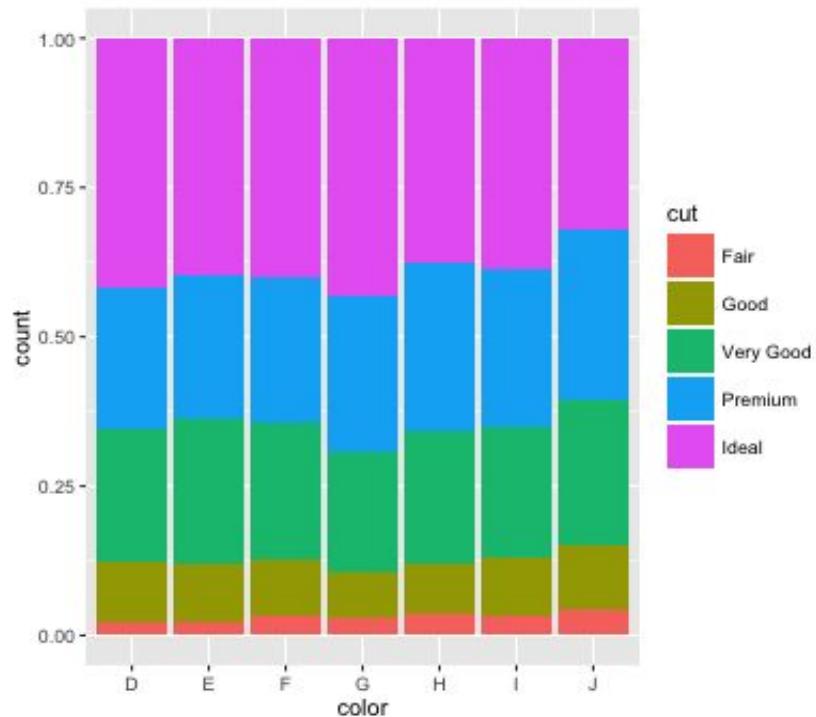
Position Adjustments

Position Adjustments

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

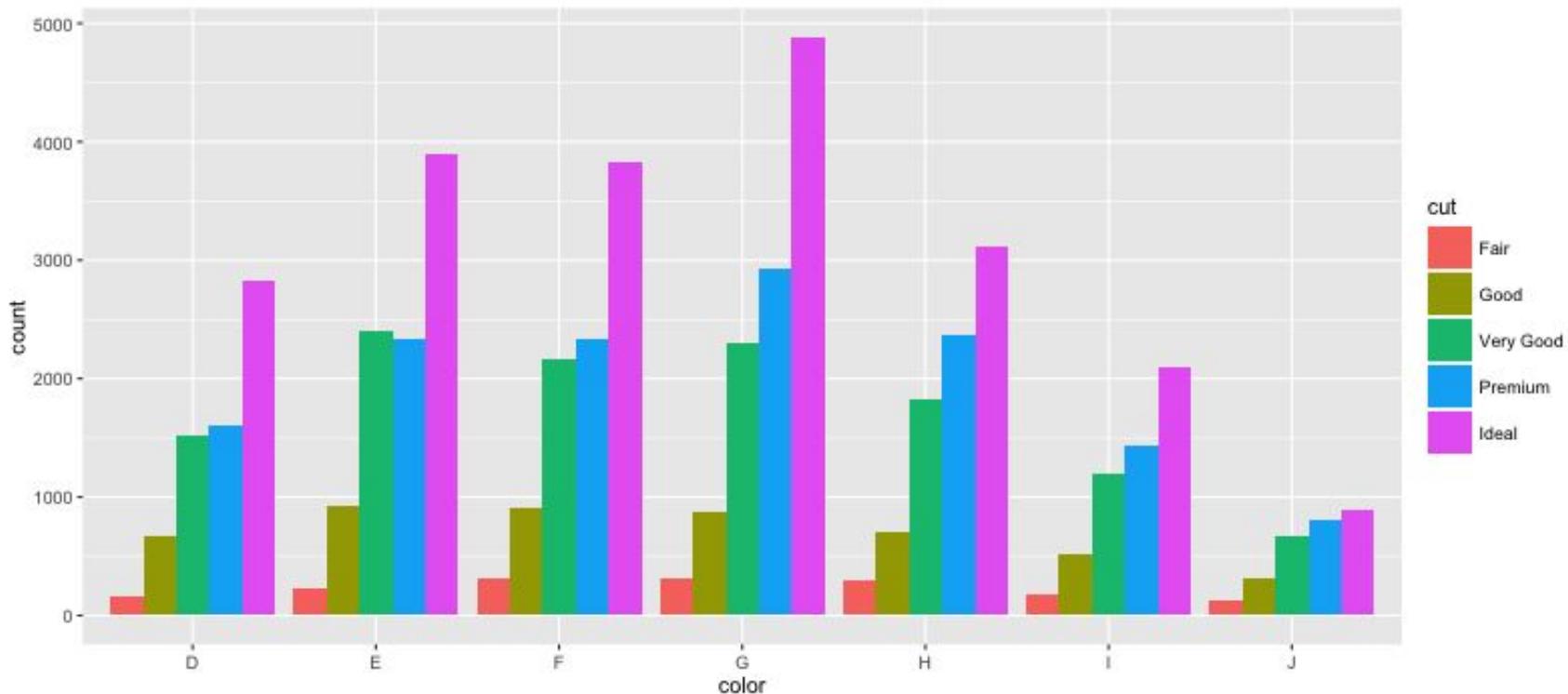


```
ggplot(data = diamonds, aes(x = color)) +  
  geom_bar(aes(fill = cut),  
           position = "fill")
```



Position Adjustments

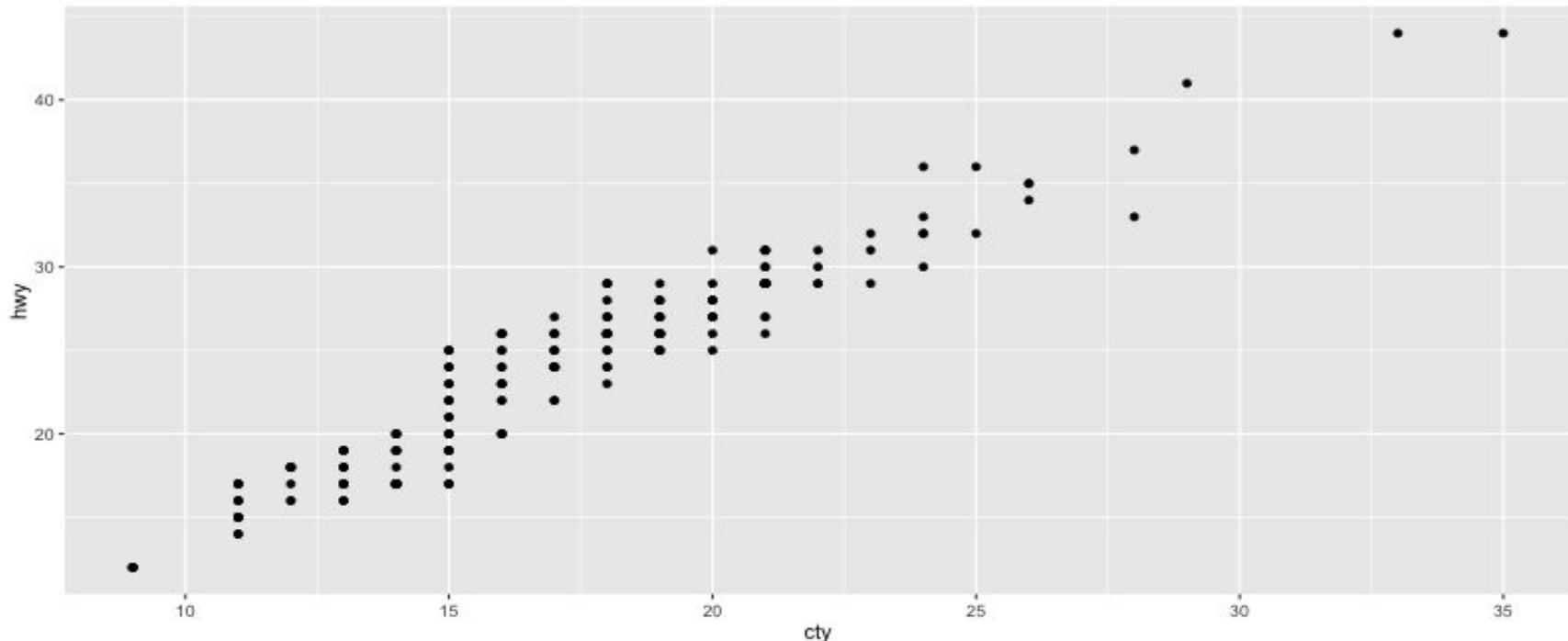
```
ggplot(data = diamonds, aes(x = color)) +  
  geom_bar(aes(fill = cut), position = "dodge")
```



Position Adjustments

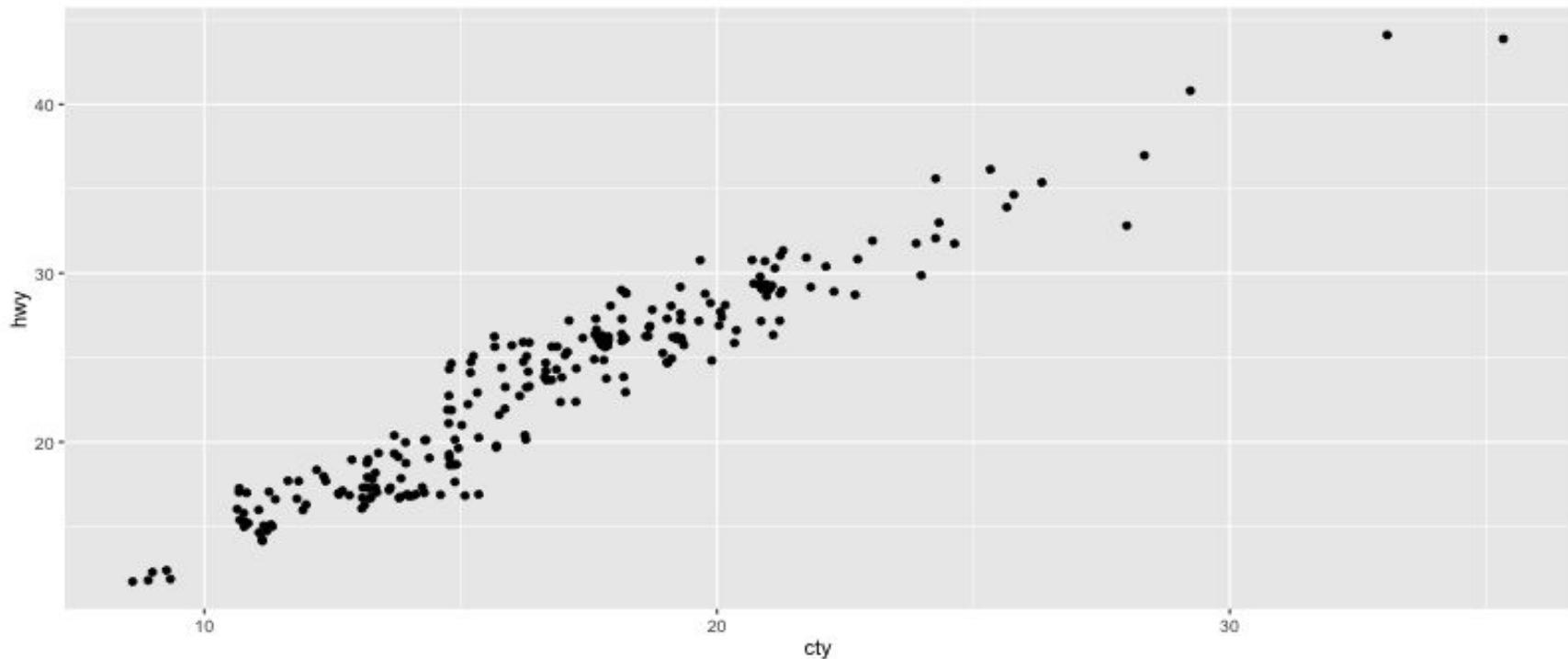
What is strange about this graph?

```
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")
```

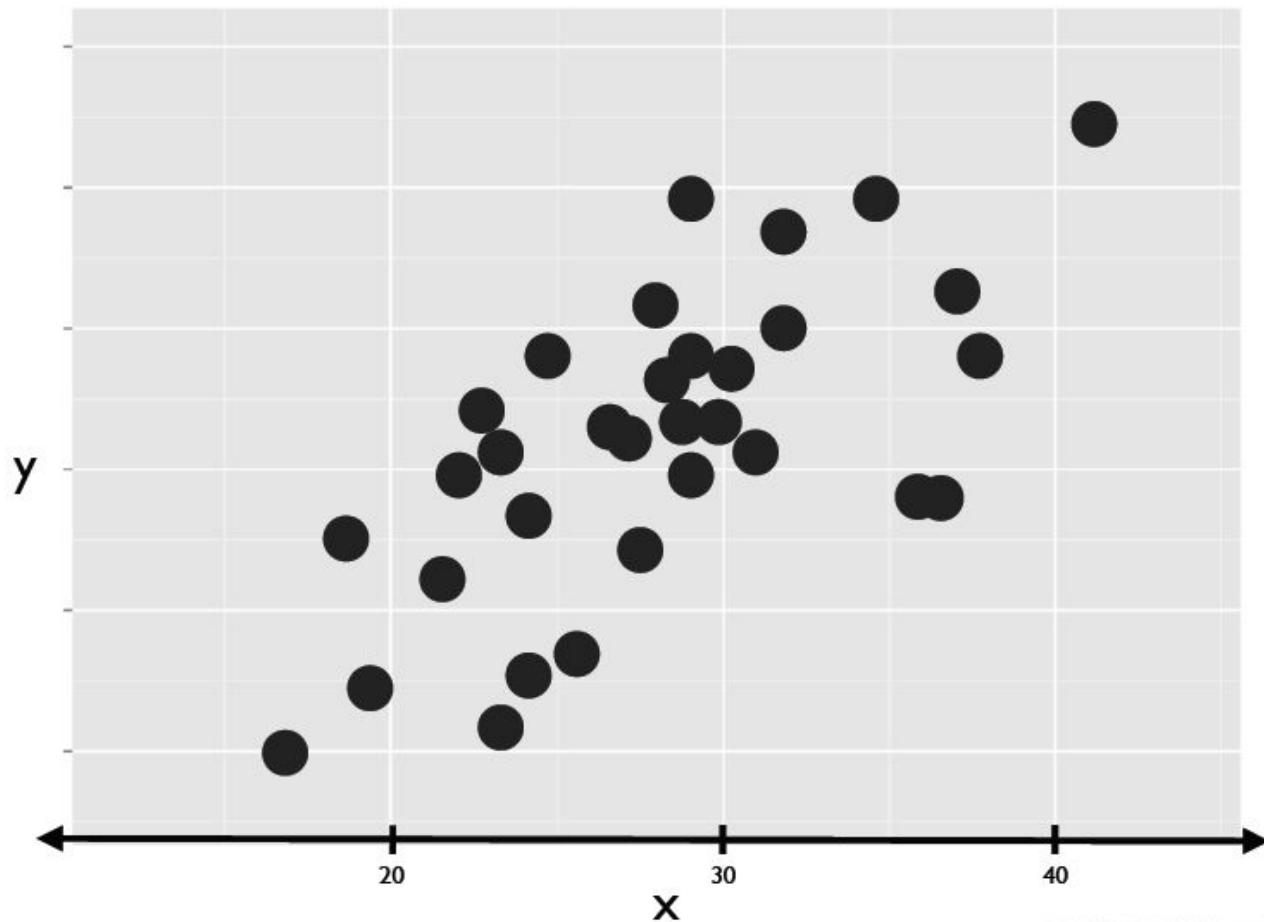
```
ggplot(data = mpg, aes(x = cty, y = hwy)) + geom_jitter()
```

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- ❖ Visualizing big data
- ❖ Saving Graphs

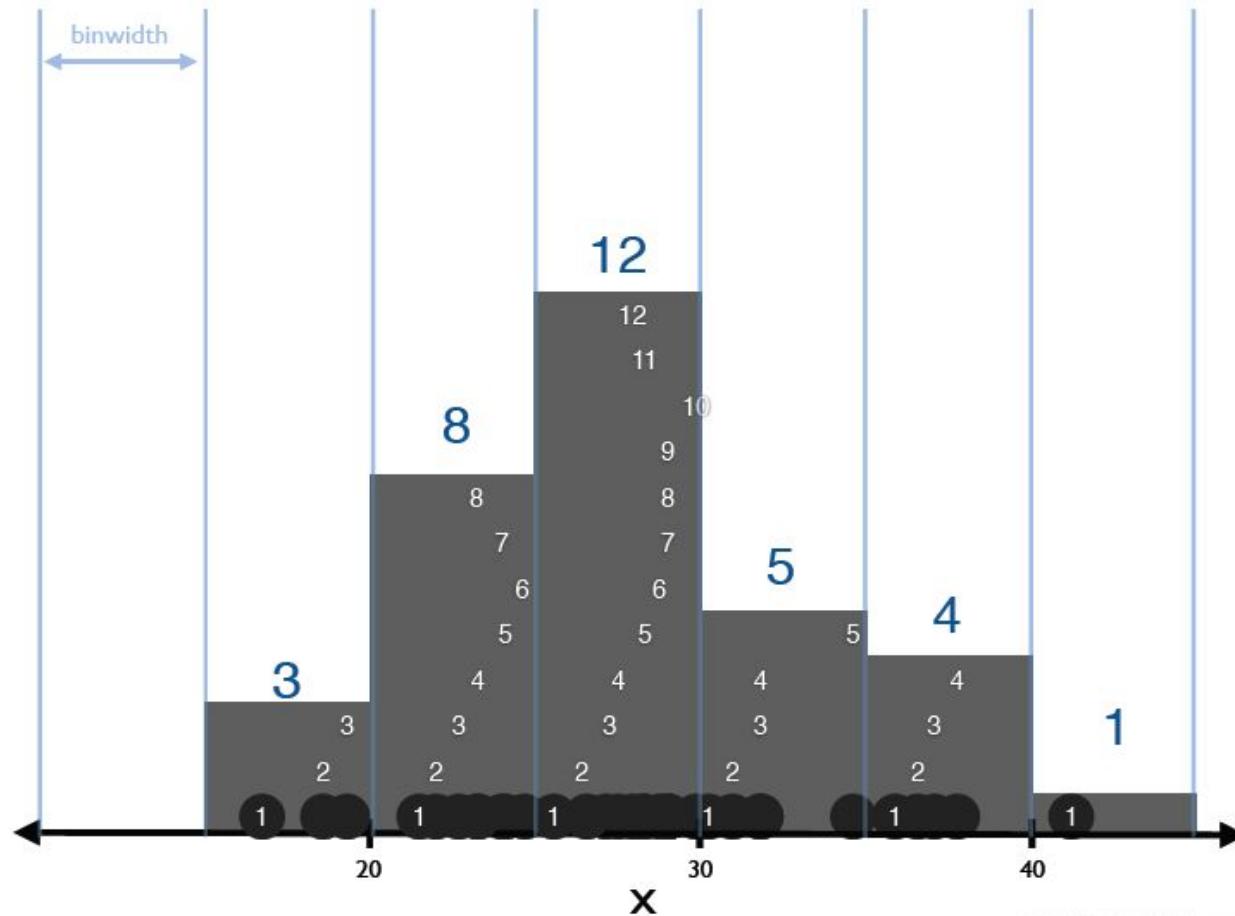
Histograms

Histograms



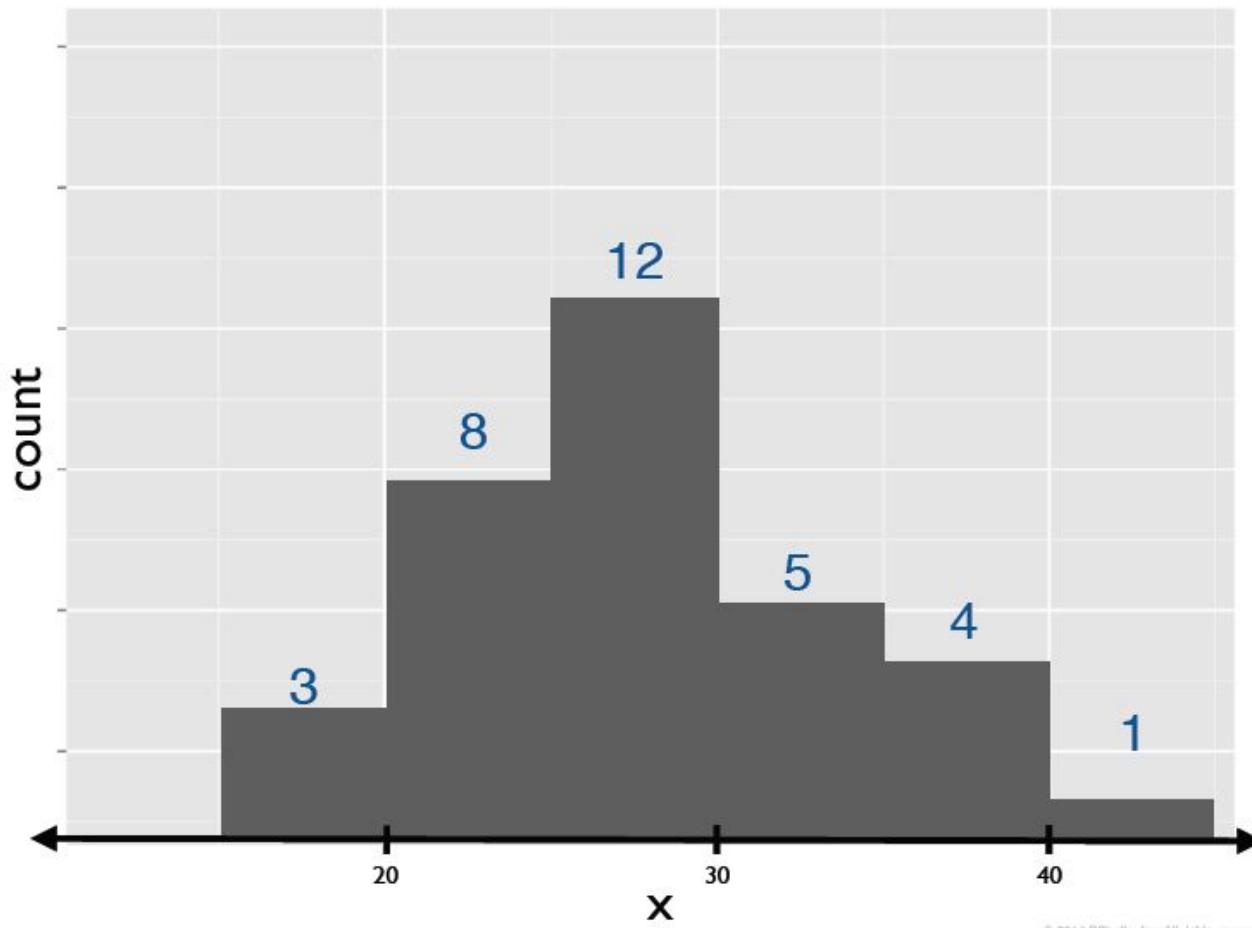
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Histograms



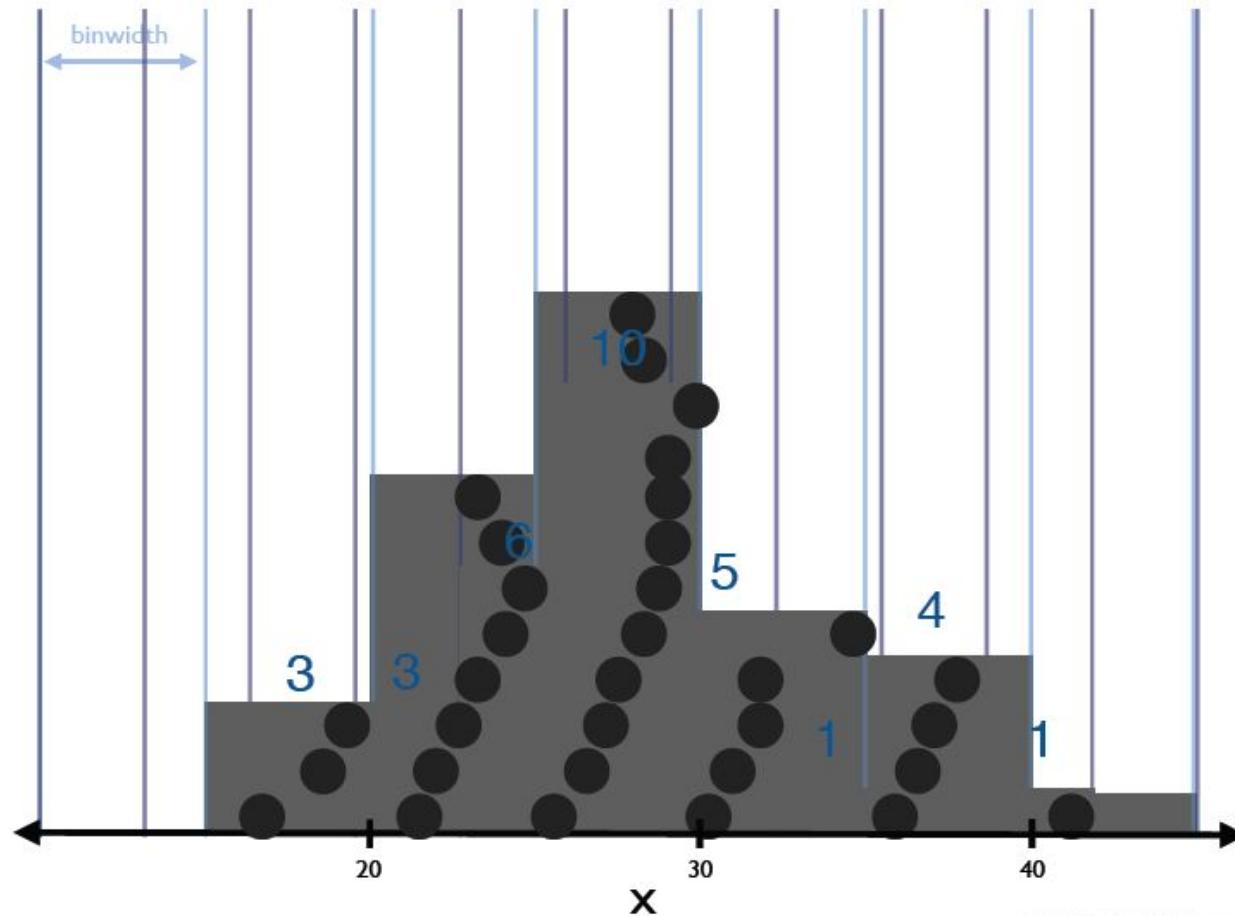
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Histograms



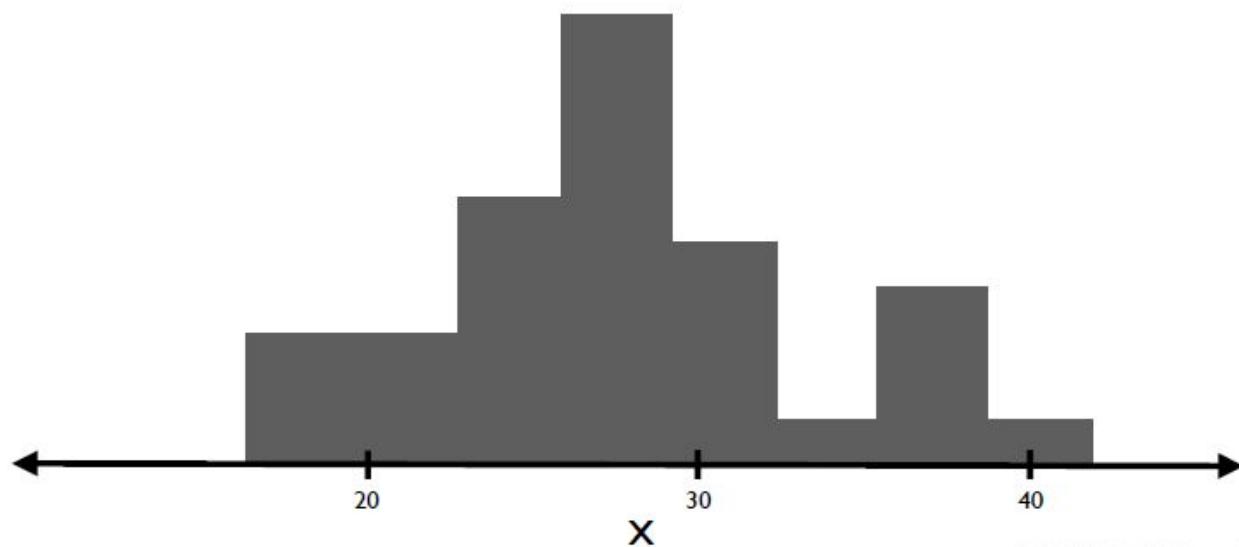
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Histograms



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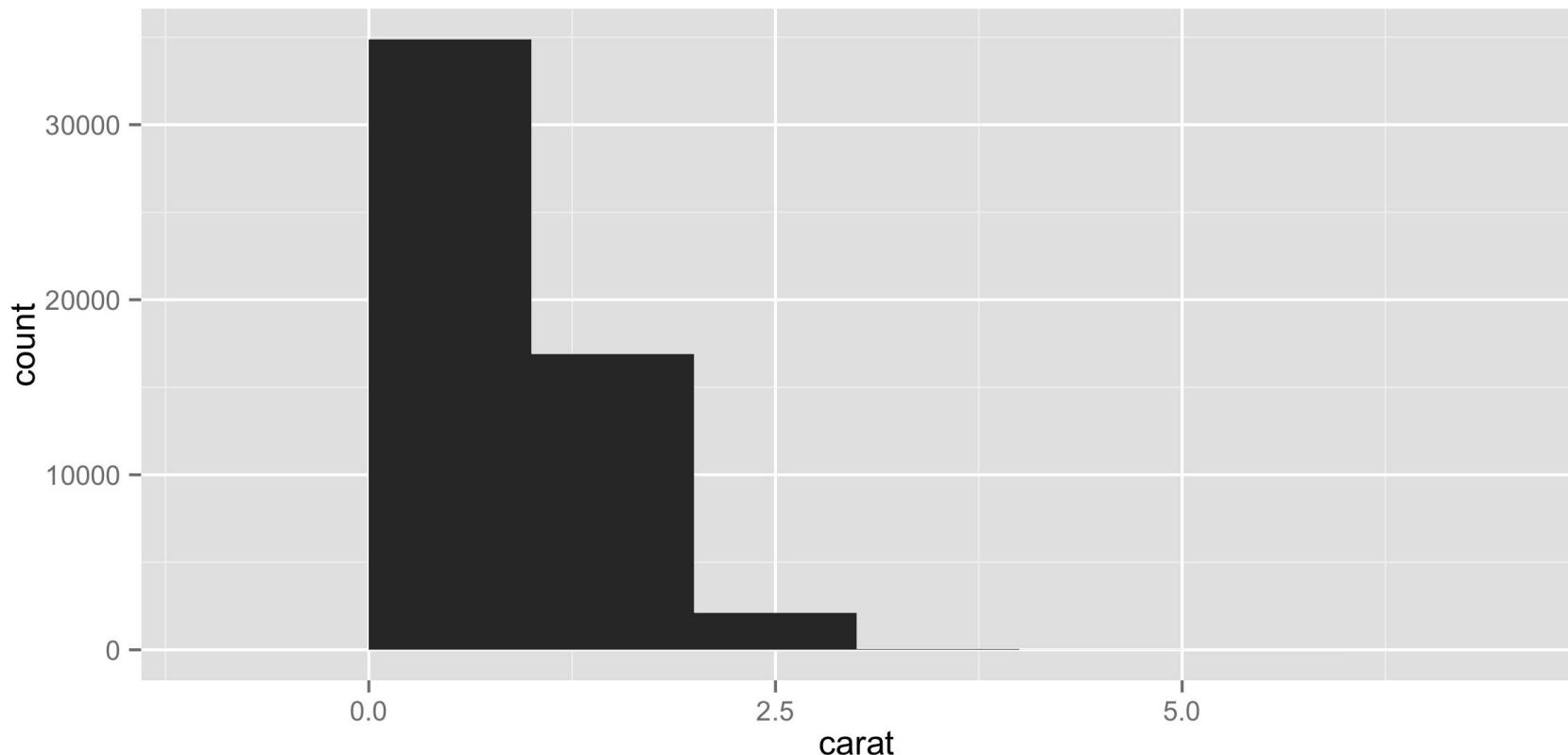
Histograms



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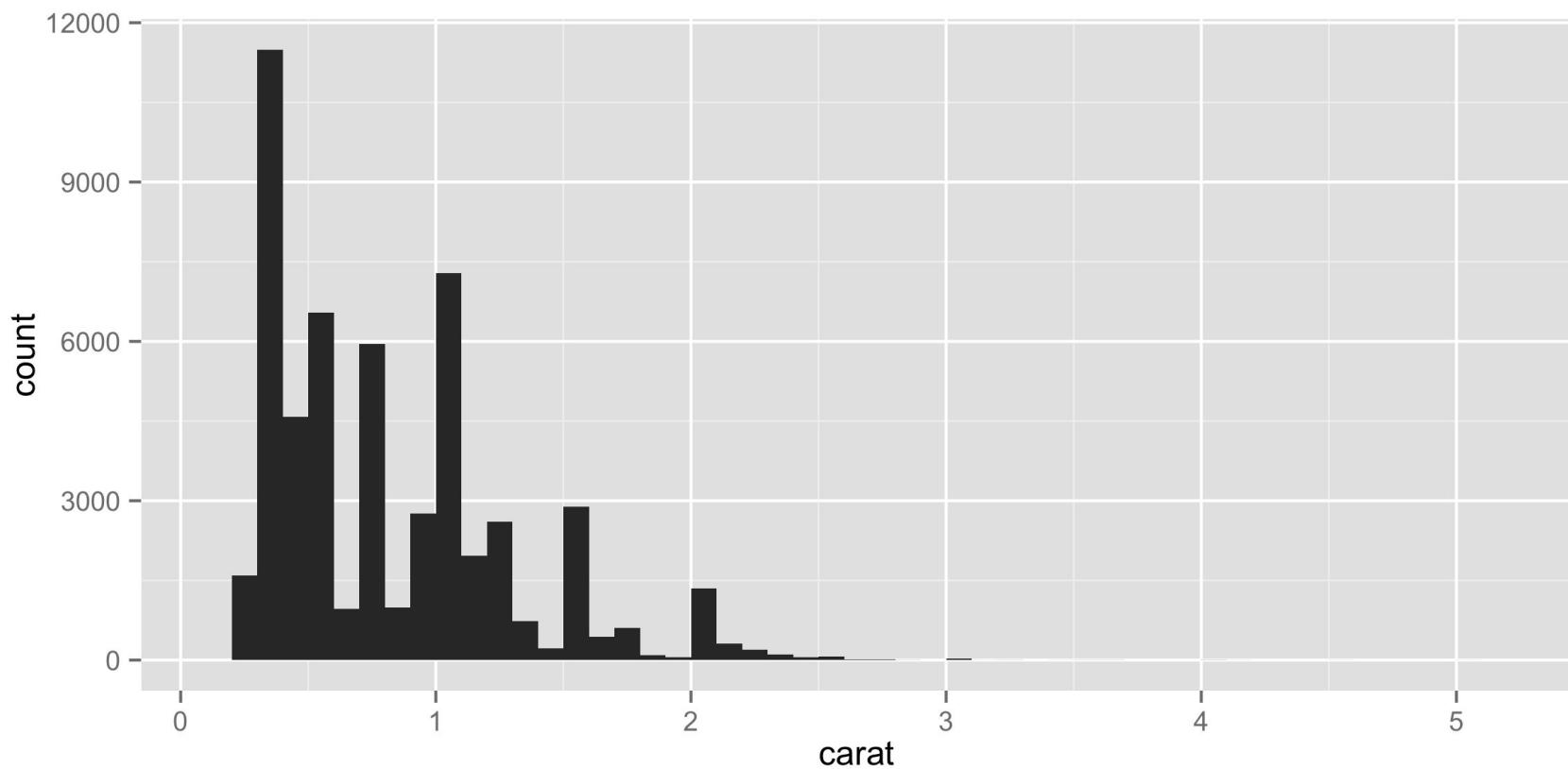
Histograms

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



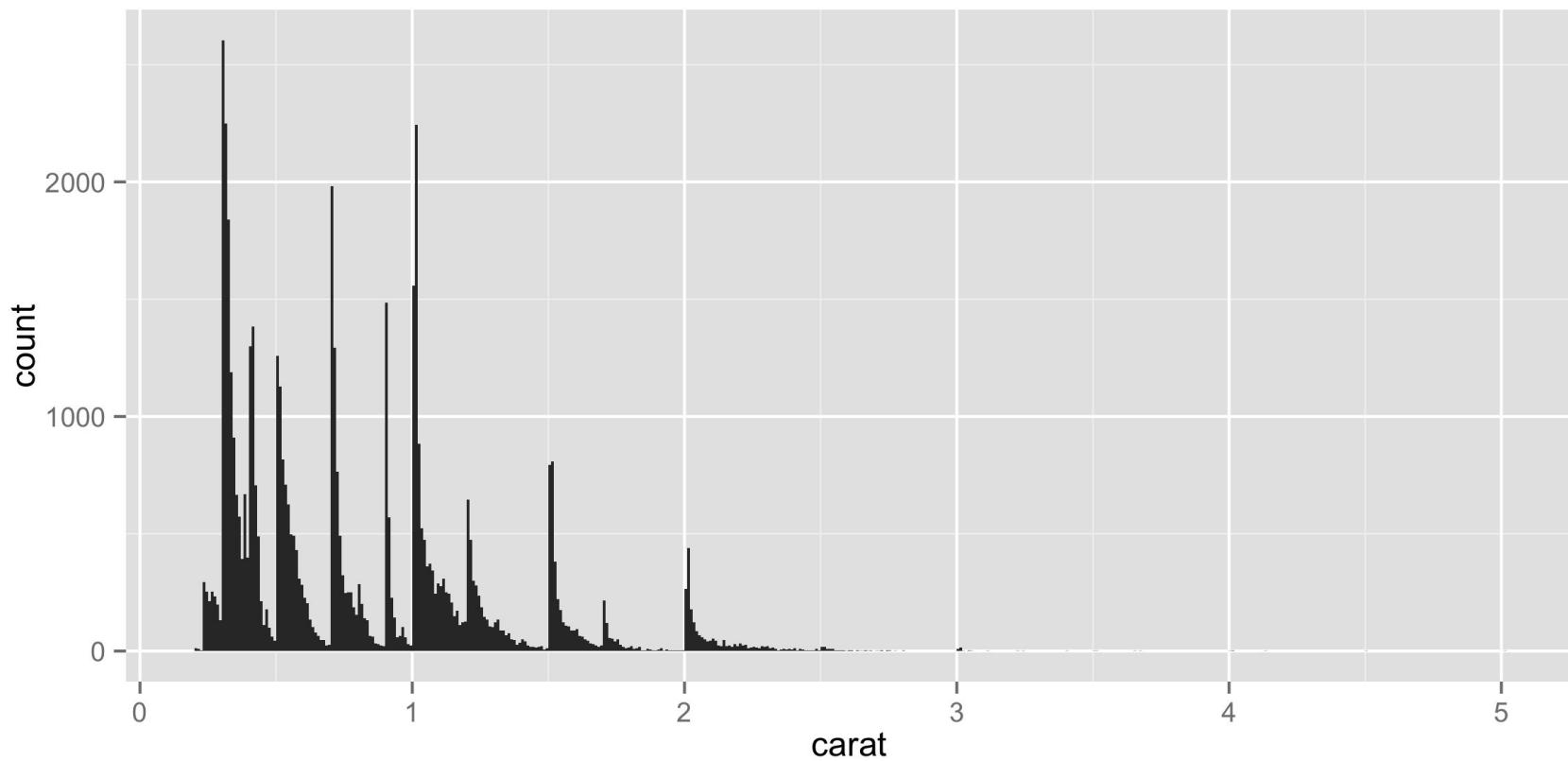
Histograms

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



Histograms

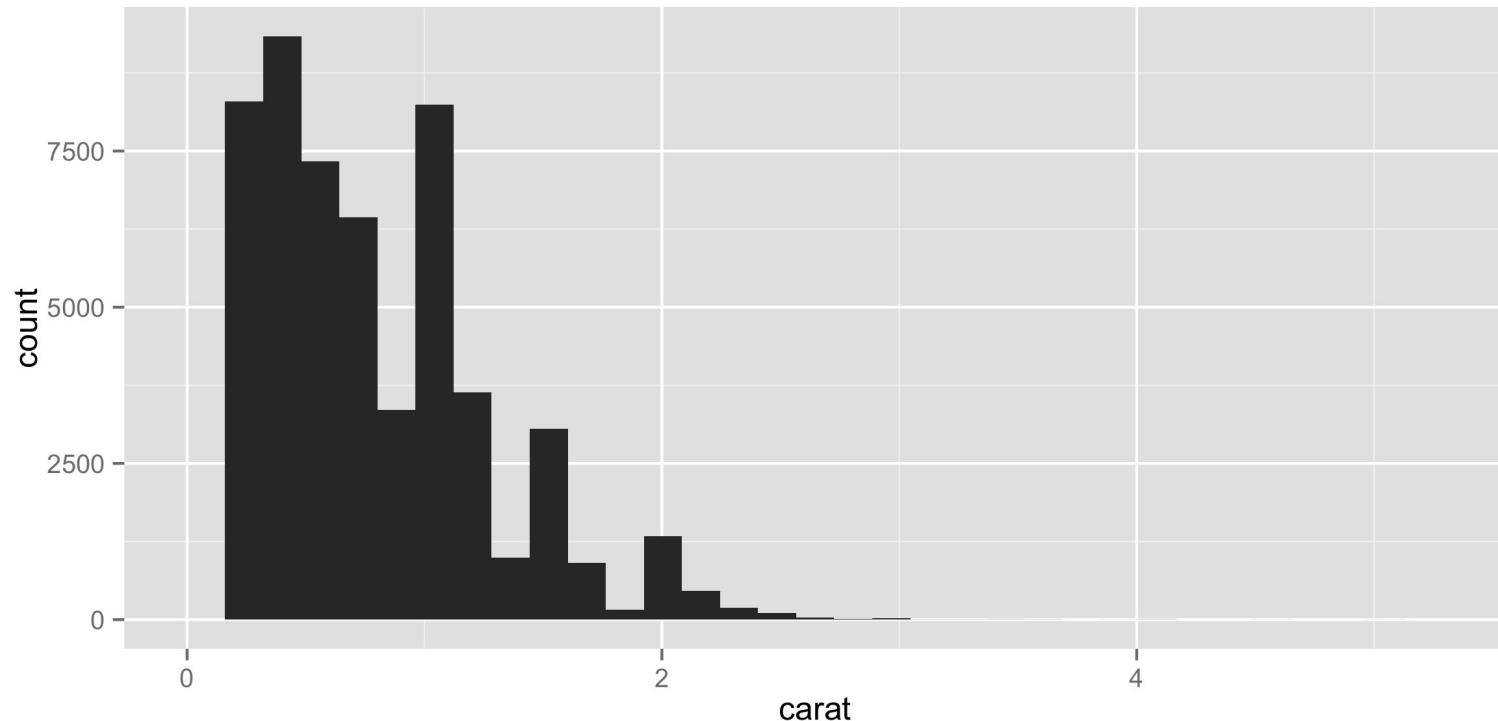
```
g + geom_histogram(binwidth = 0.01)
```



Histograms

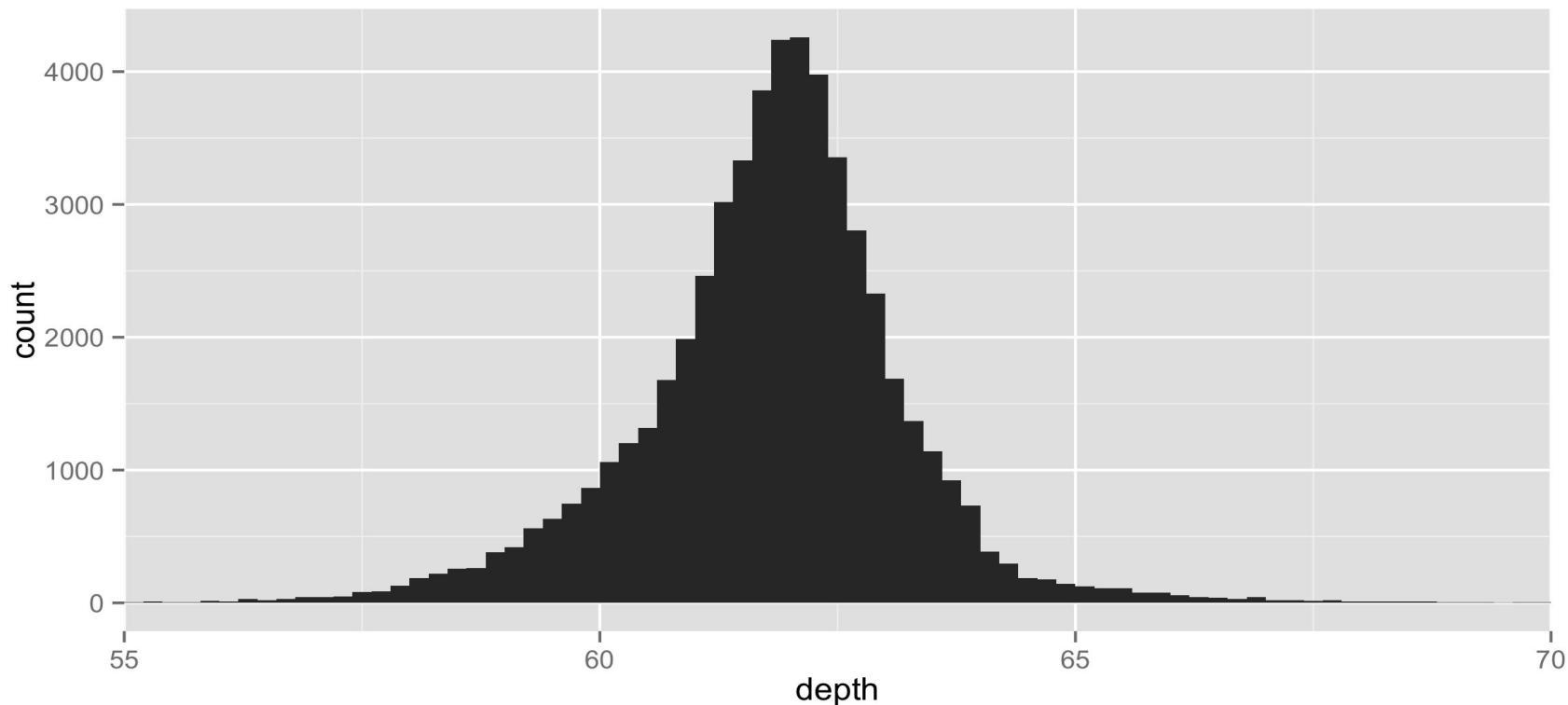
Most parameters come with a preset [default value](#).

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



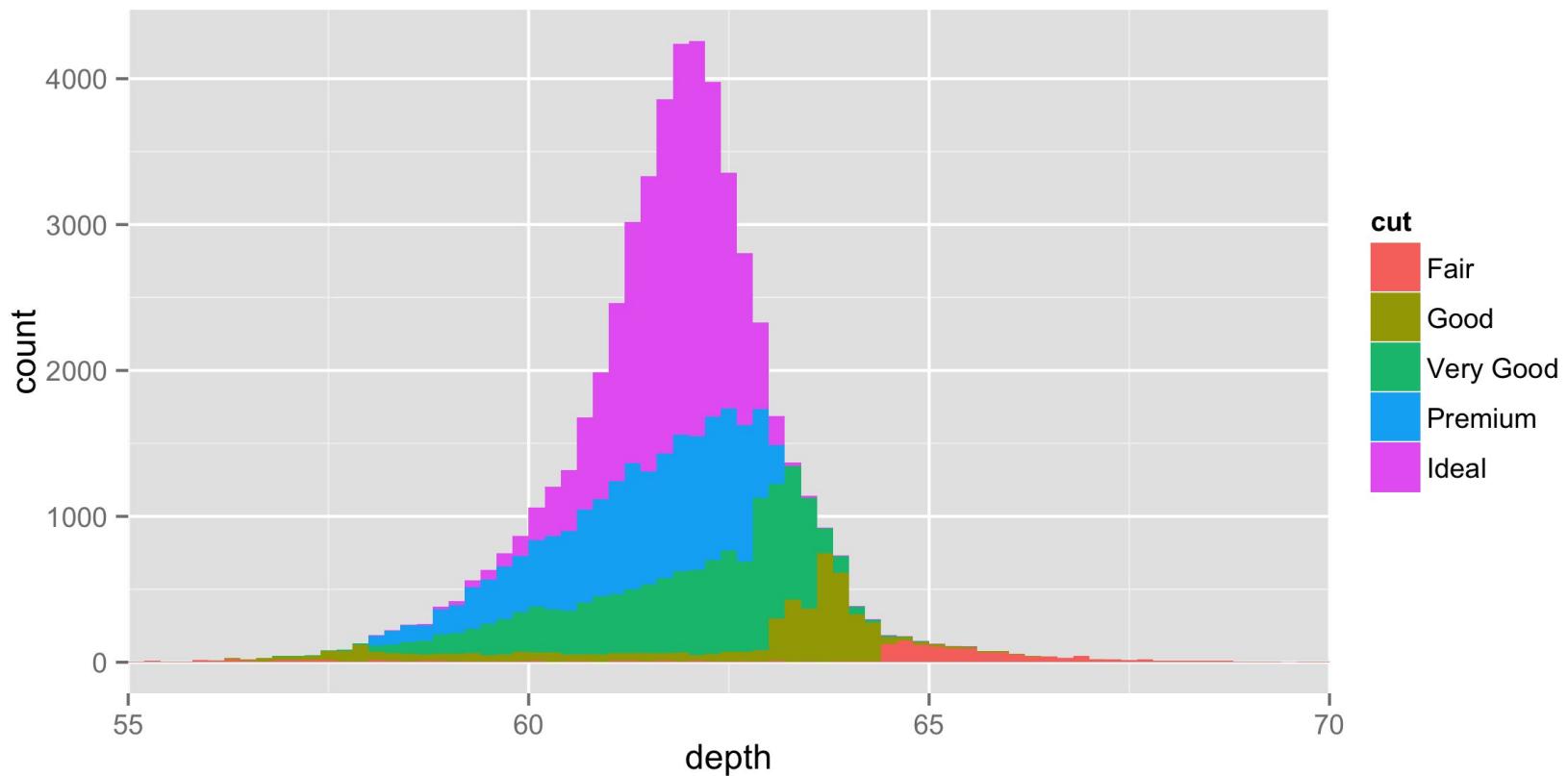
Histograms

```
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

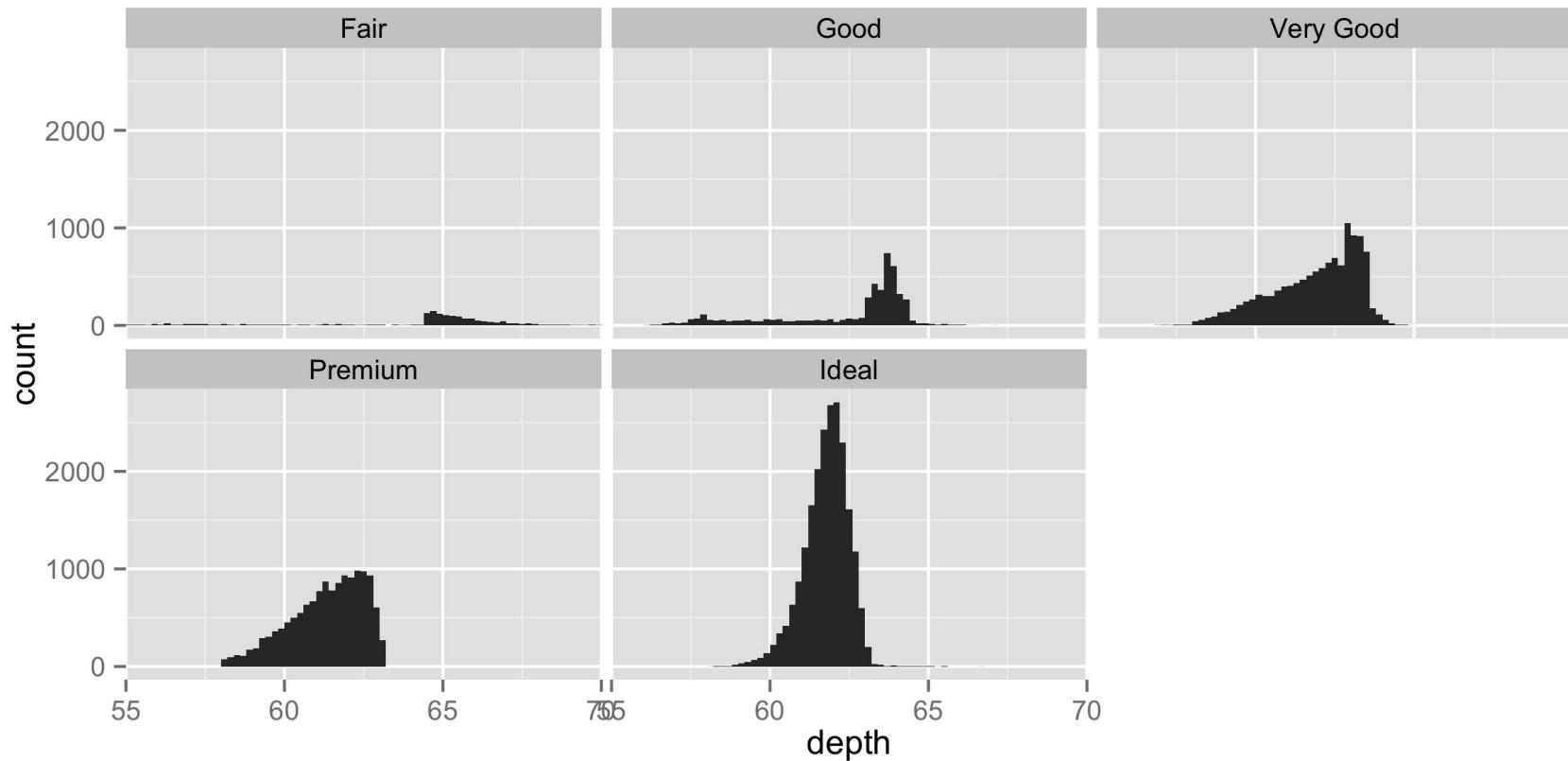
Comparing Variables

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

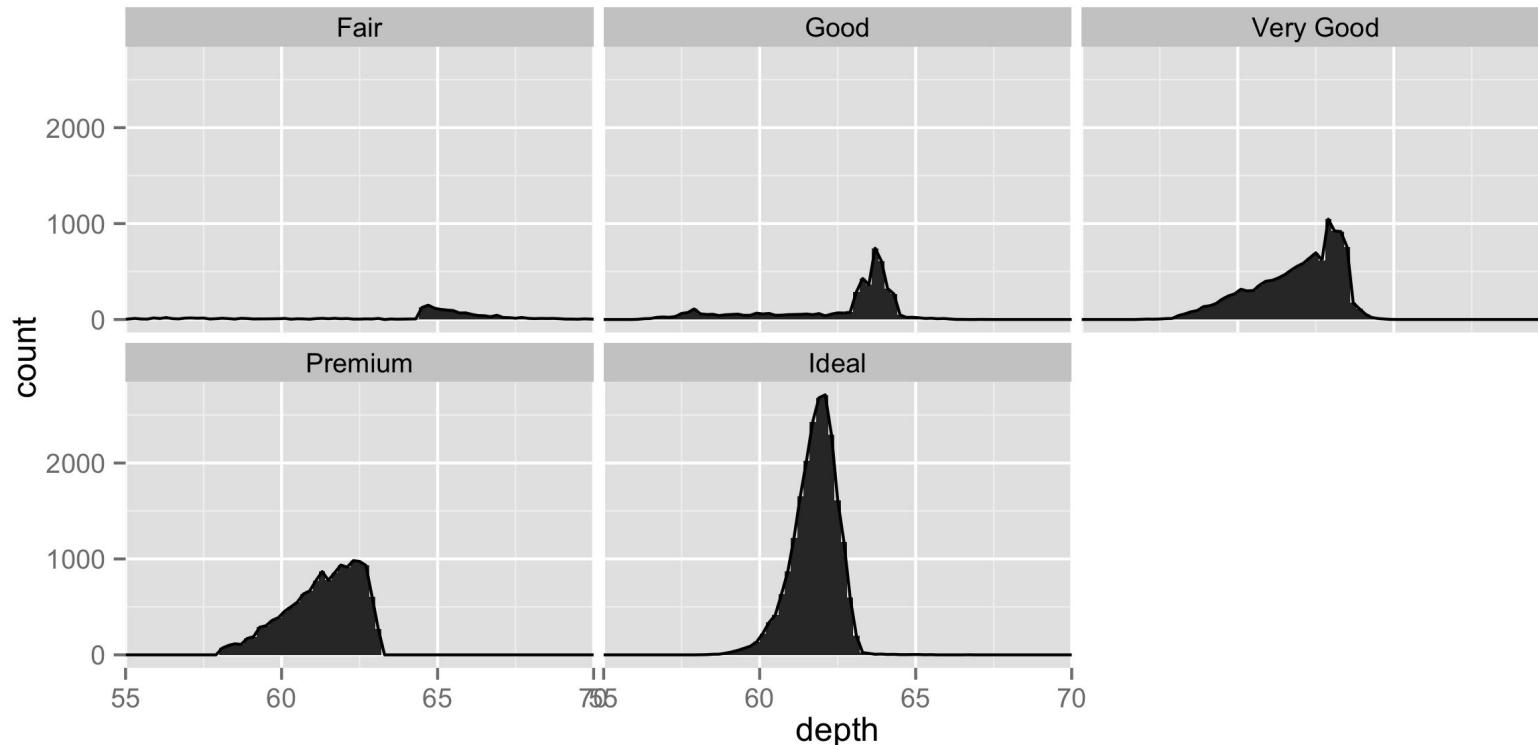
```
g + geom_histogram(binwidth = 0.2) + facet_wrap(~ cut) + zoom
```



Comparing Variables

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

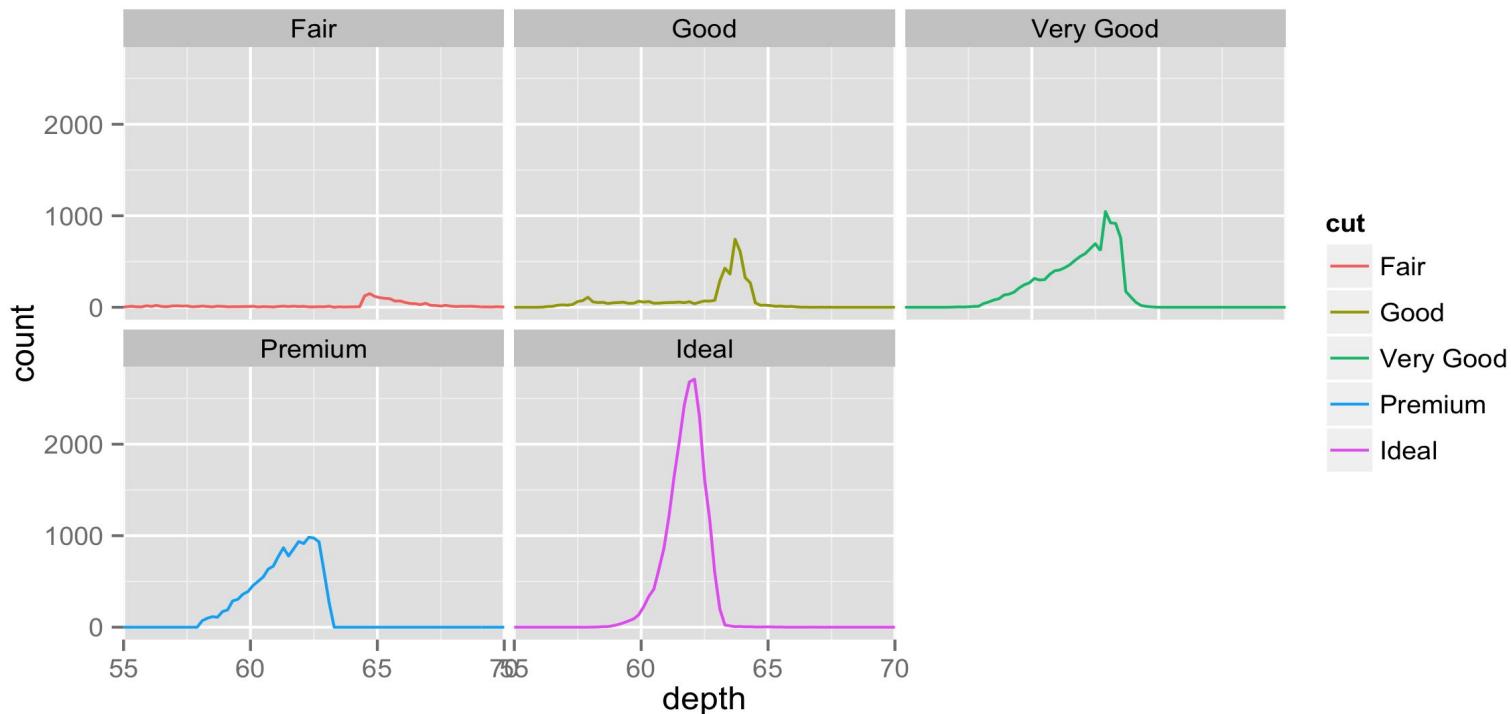
```
g + geom_histogram(binwidth = 0.2) + geom_freqpoly(binwidth=0.2)  
+ facet_wrap( ~ cut) + zoom
```



Comparing Variables

What if we threw away the bars?

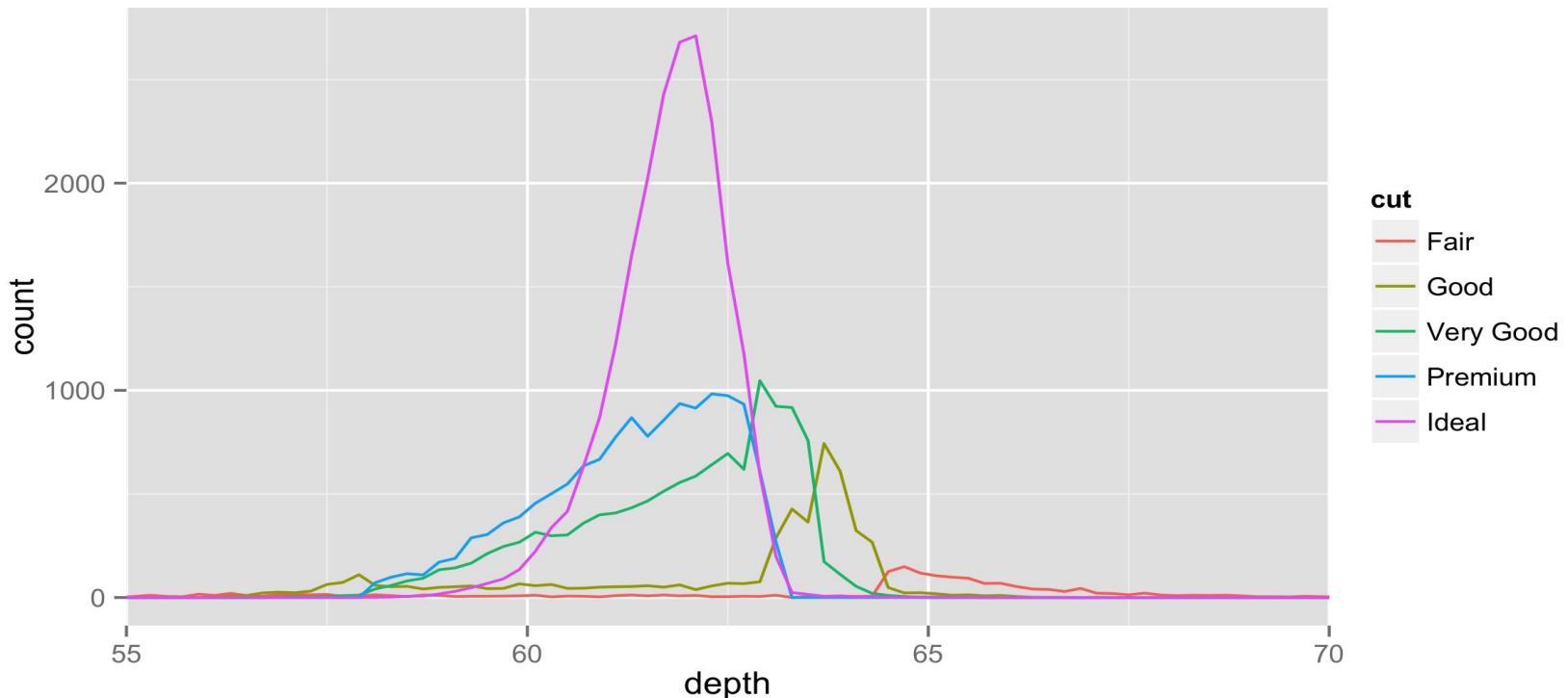
```
g + geom_freqpoly(aes(color = cut), binwidth = 0.2) +  
  facet_wrap( ~ cut) + zoom
```



Comparing Variables

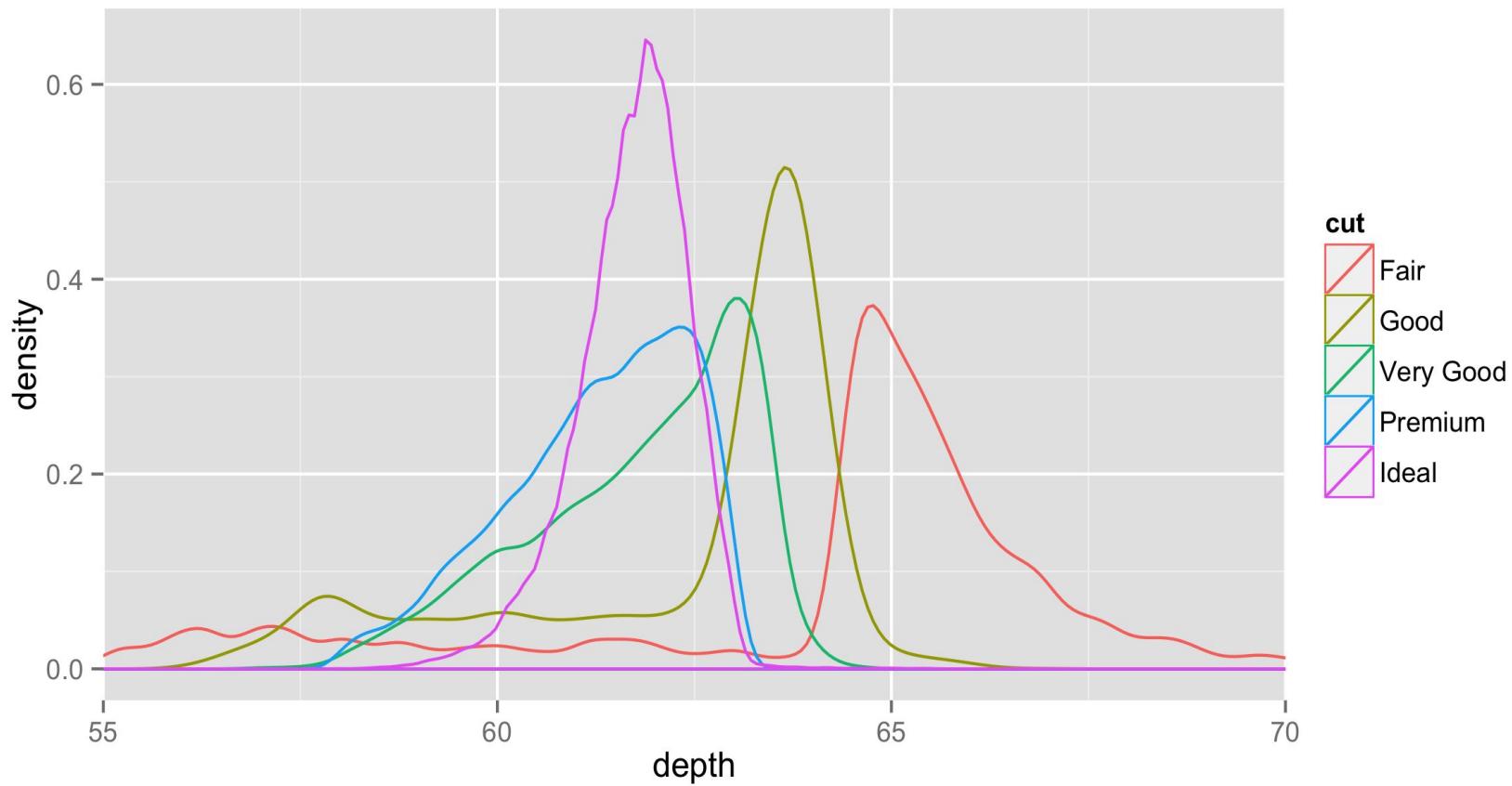
What if we just drew each on the same plot?

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



Comparing Variables

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



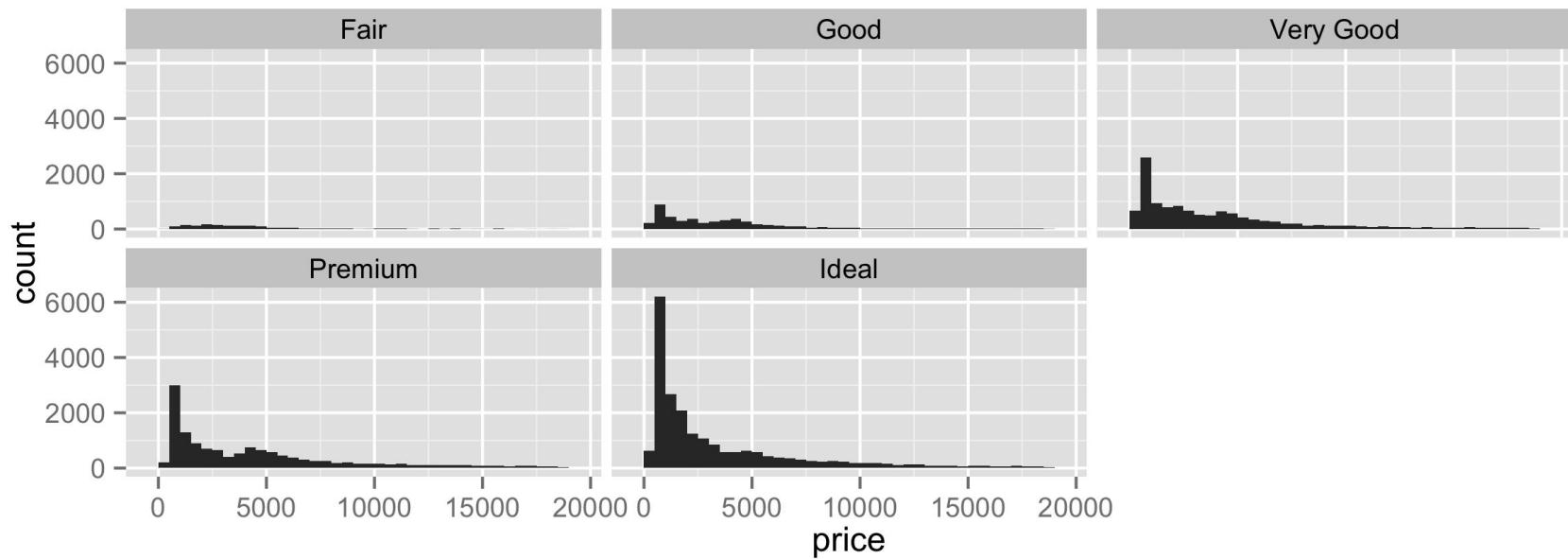
Comparing Variables

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

Comparing Variables

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

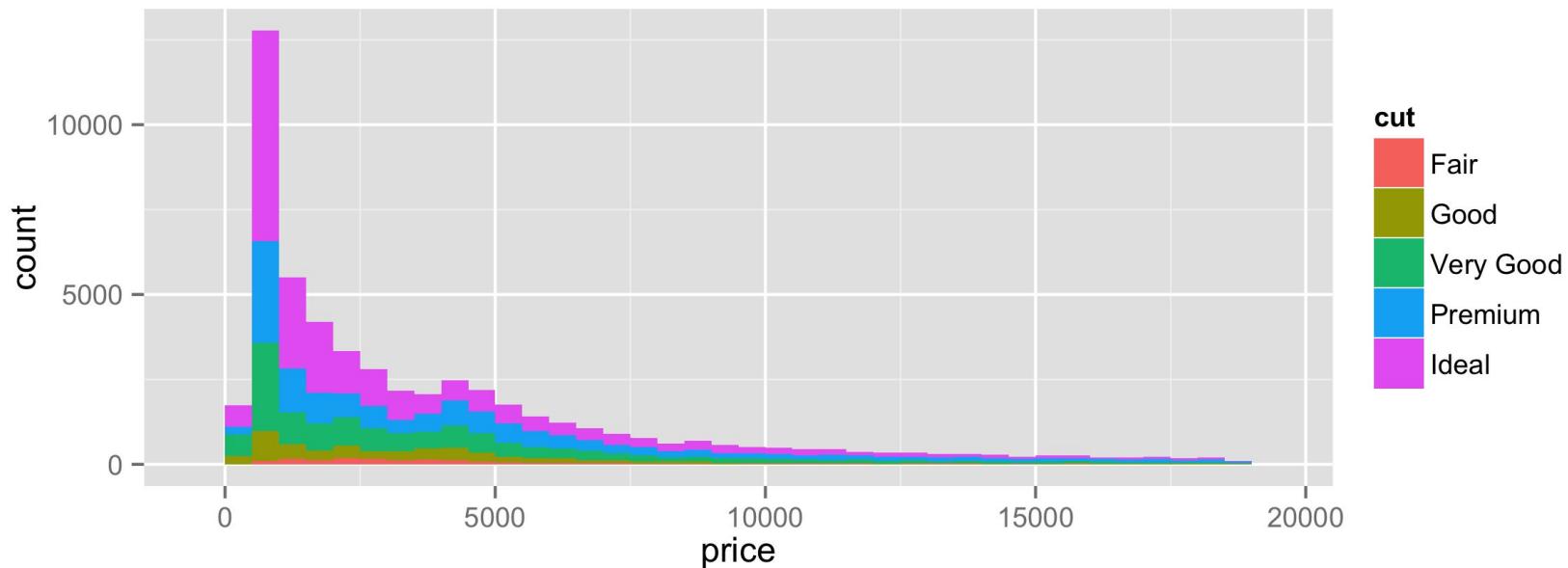
```
ggplot(data = diamonds, aes(x = price)) +  
  geom_histogram(binwidth = 500) + facet_wrap(~ cut)
```



Comparing Variables

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

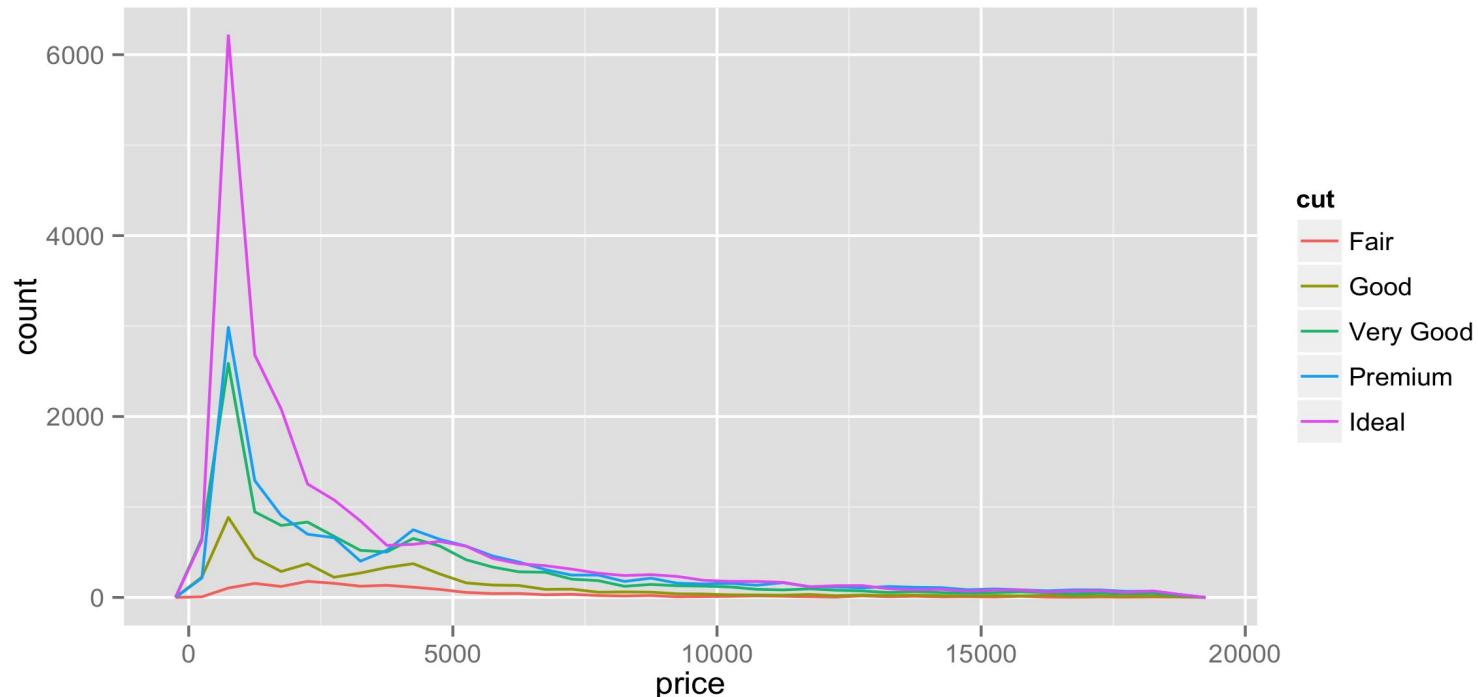
```
ggplot(data = diamonds, aes(x = price)) +  
  geom_histogram(aes(fill = cut))
```



Comparing Variables

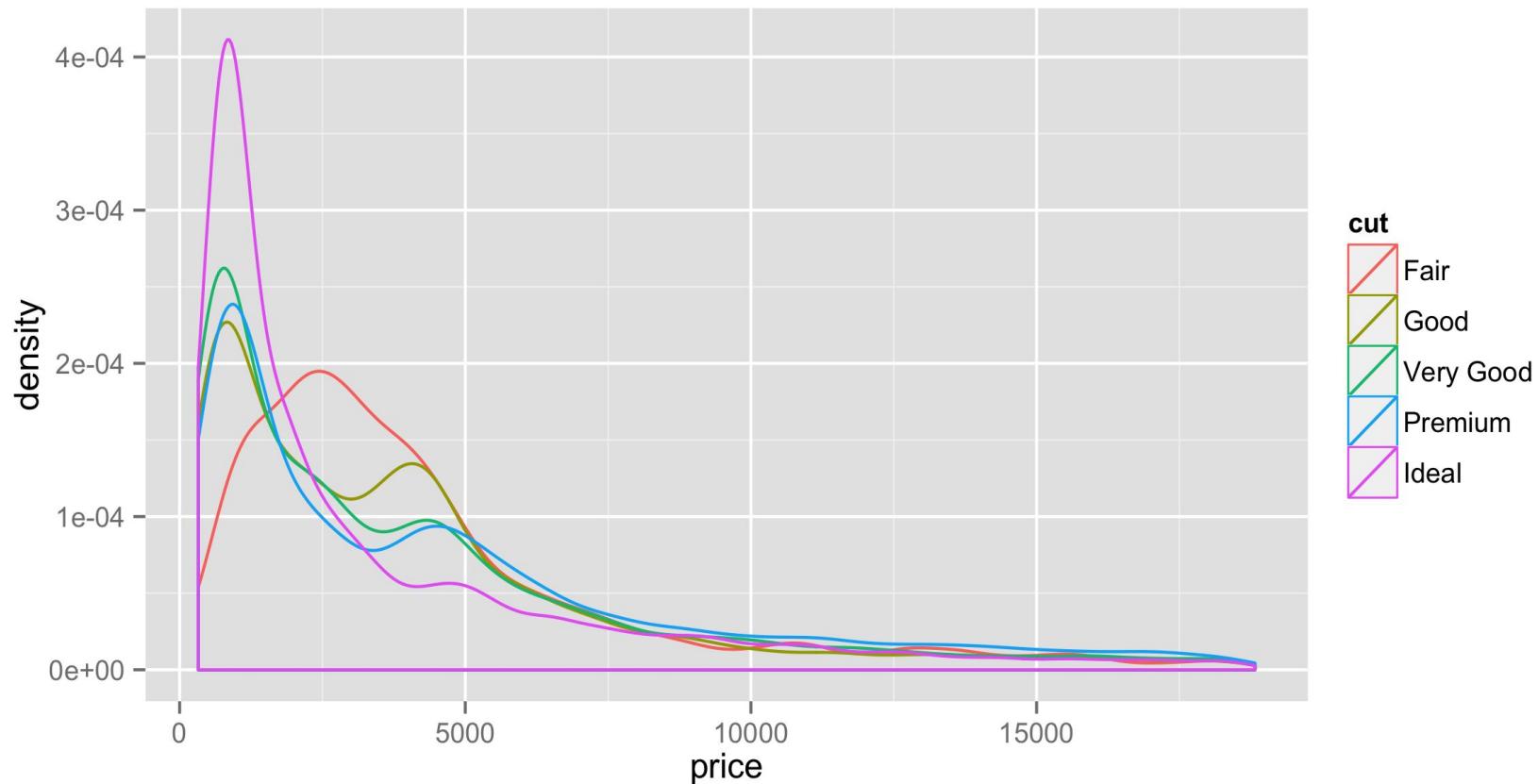
Attempt #3: Better, but categories still have differing relative frequencies.

```
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

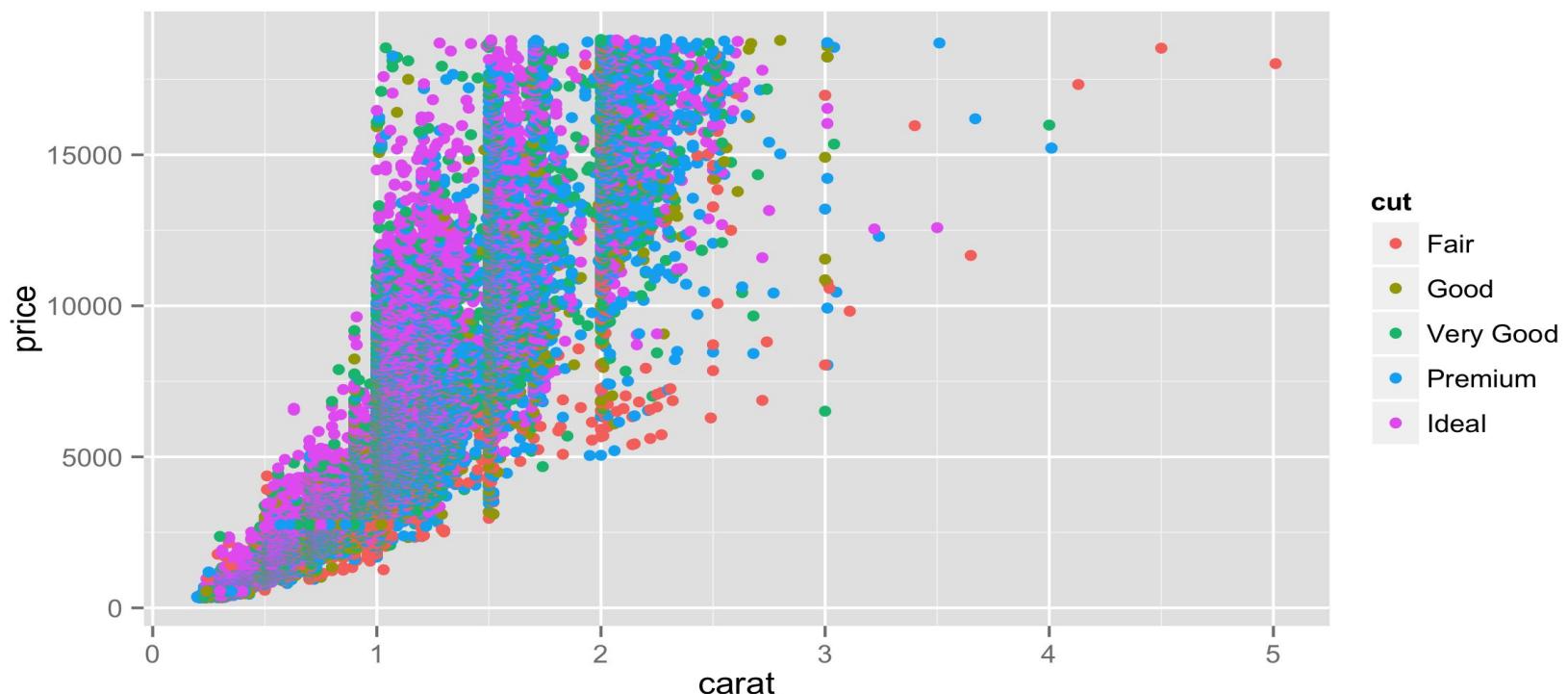
- ❖ Why ggplot2?
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Visualizing Big Data

Geoms for Big Data

Is this helpful at all?

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



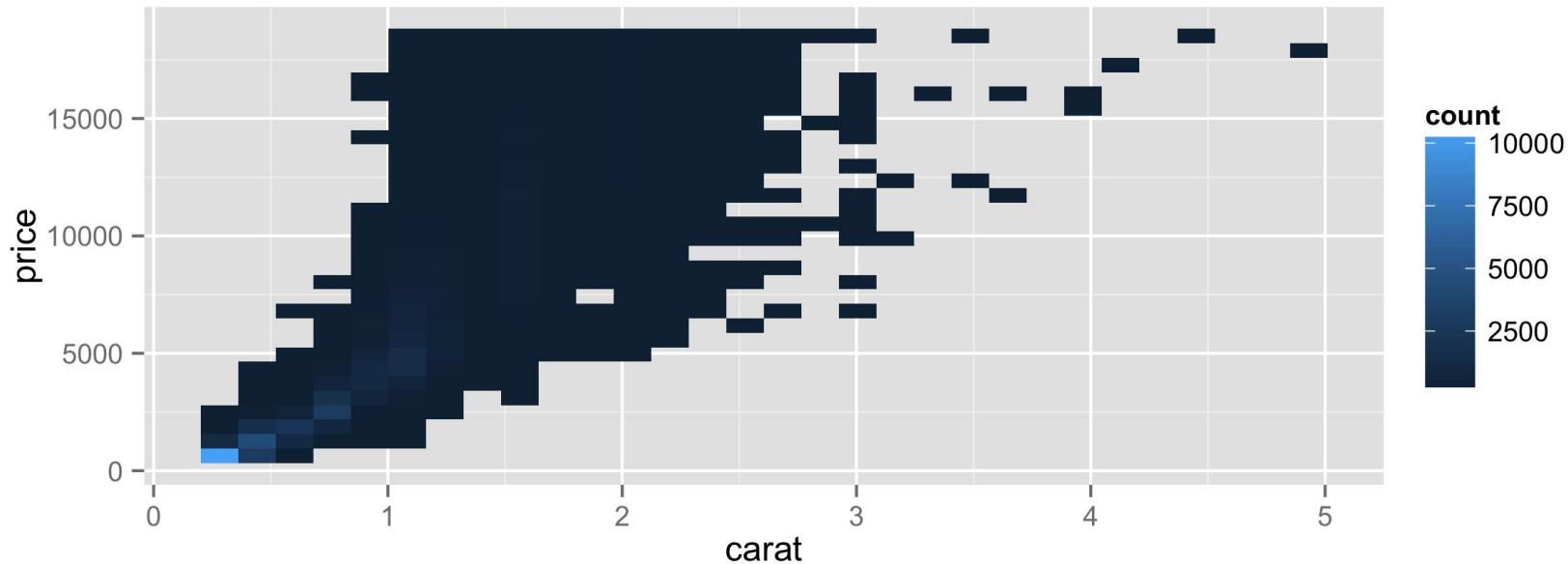
Geoms for Big Data

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

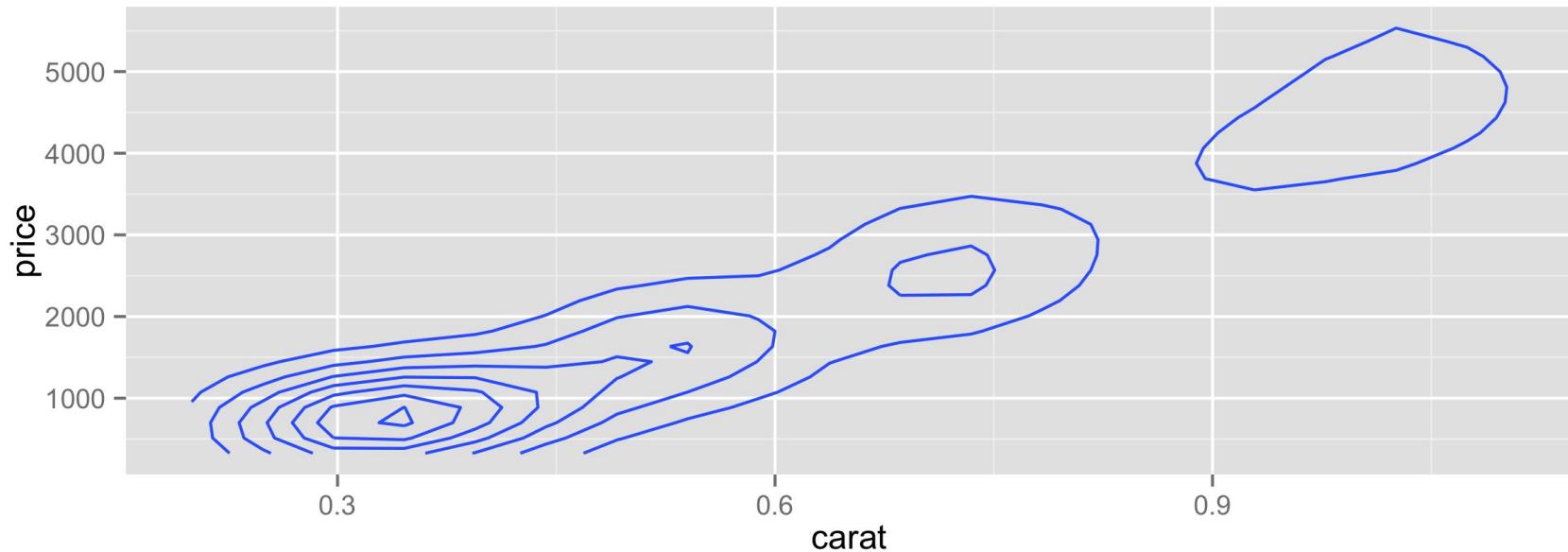
```
g + geom_bin2d()
```



Geoms for Big Data

2d density plot

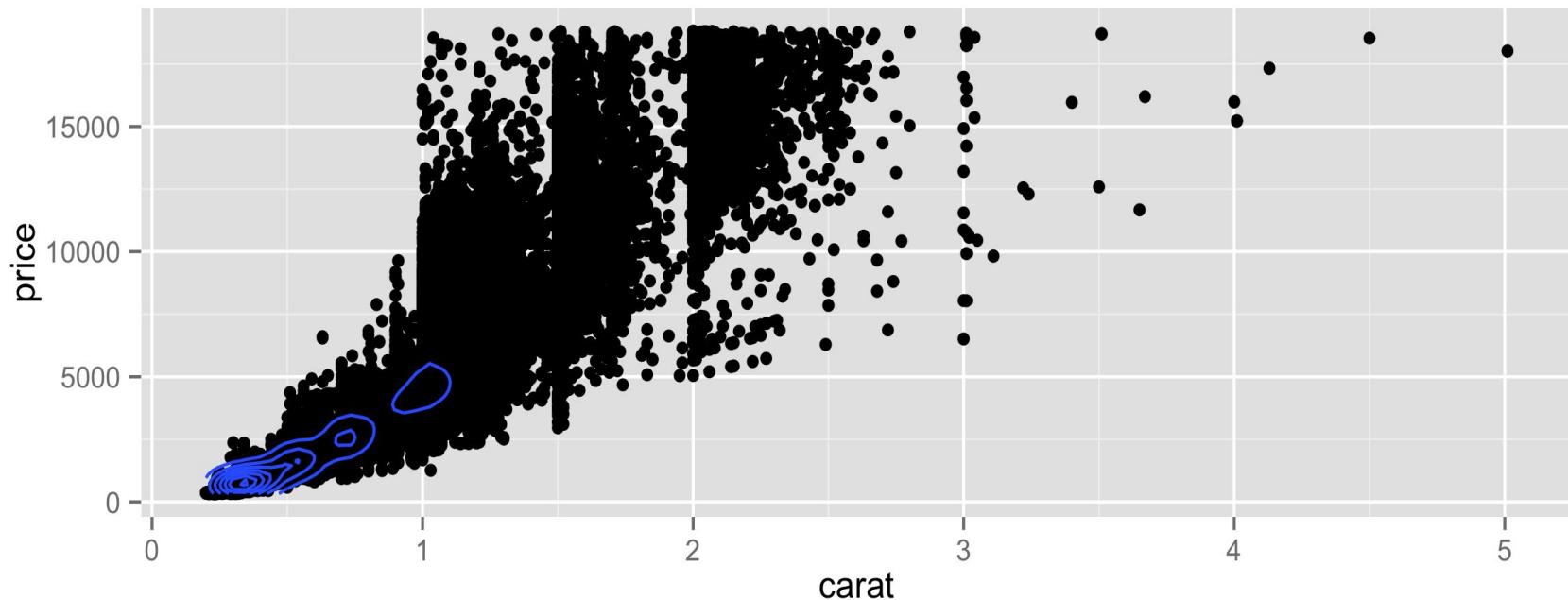
```
g + geom_density2d()
```



Geoms for Big Data

2d density on top of a scatter plot

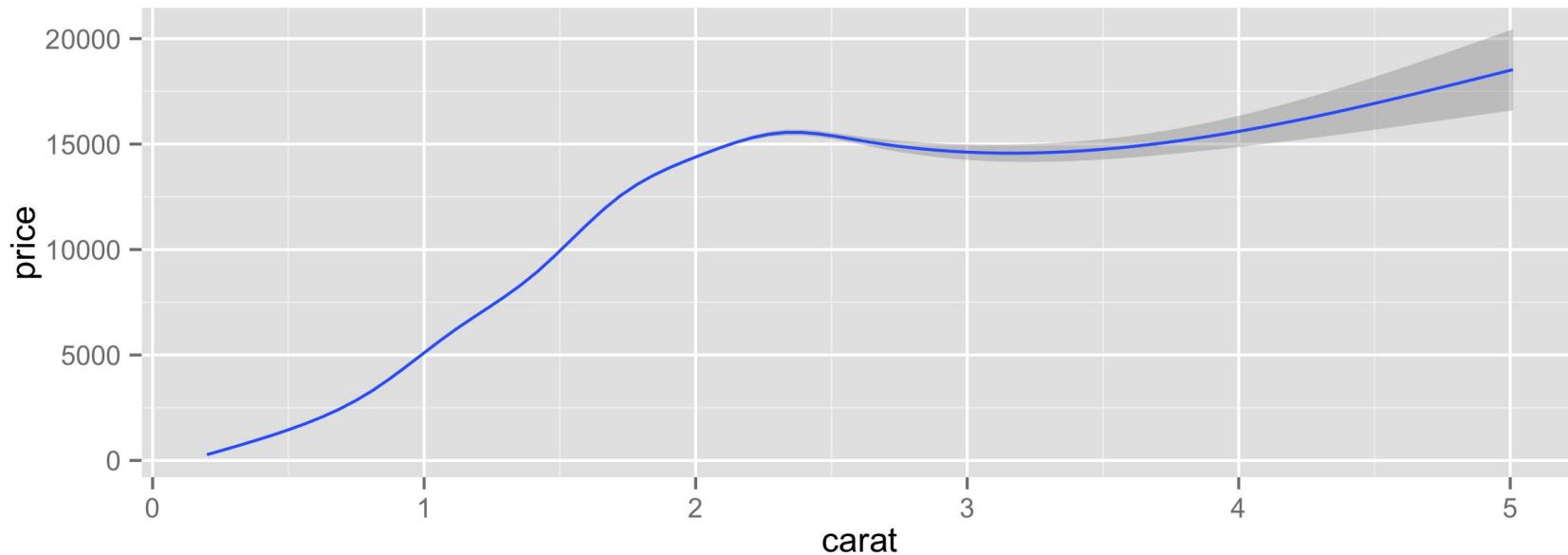
```
g + geom_point() + geom_density2d()
```



Geoms for Big Data

Smoothed conditional mean

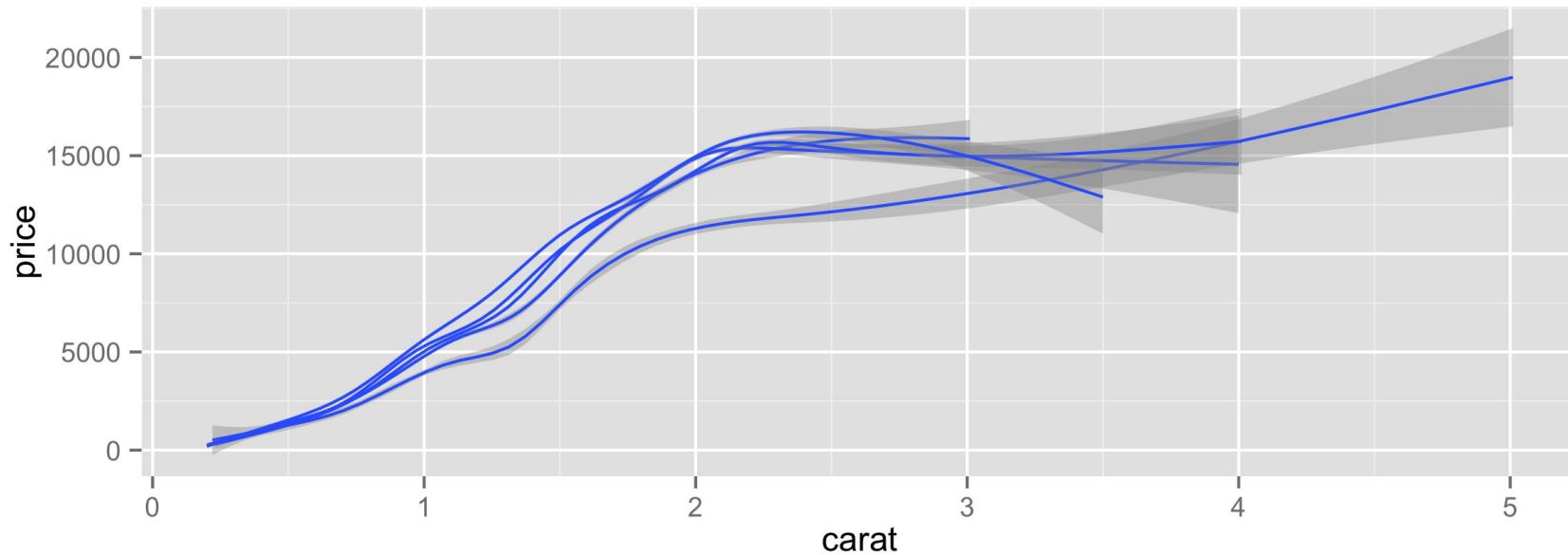
```
g + geom_smooth()
```



Geoms for Big Data

Same, but for each level of cut

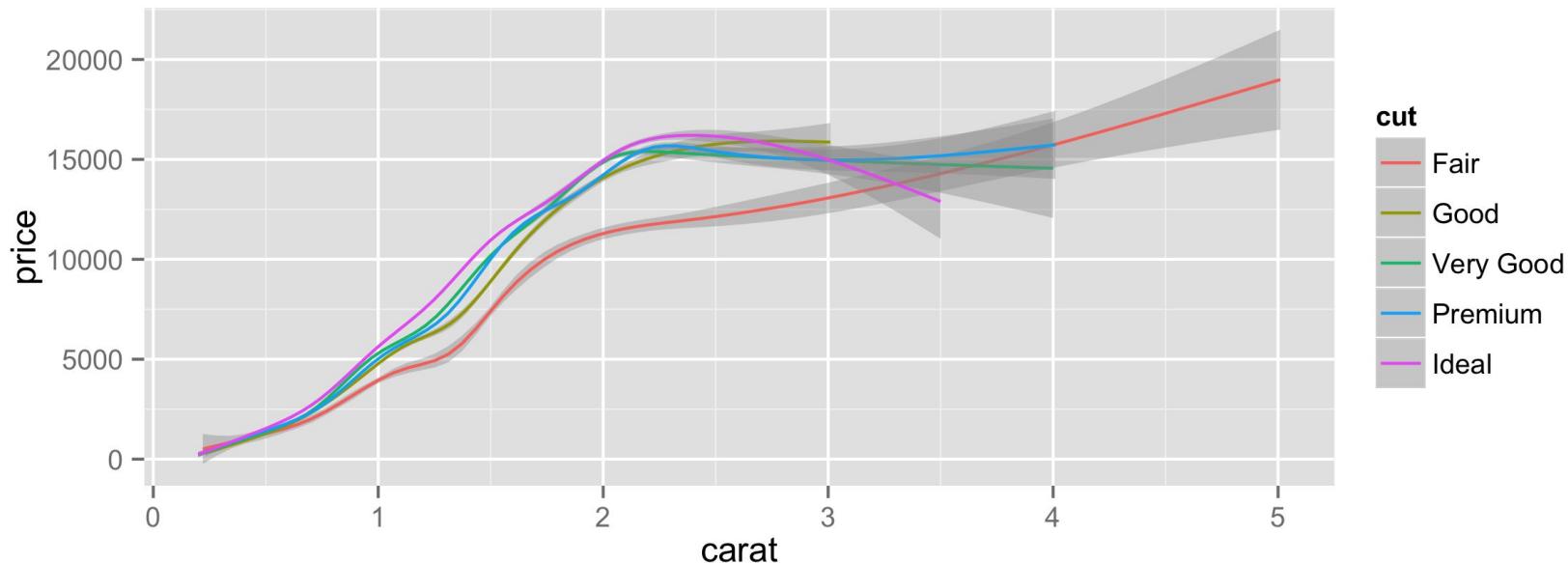
```
g + geom_smooth(aes(group = cut))
```



Geoms for Big Data

Same, but each cut receives a different color

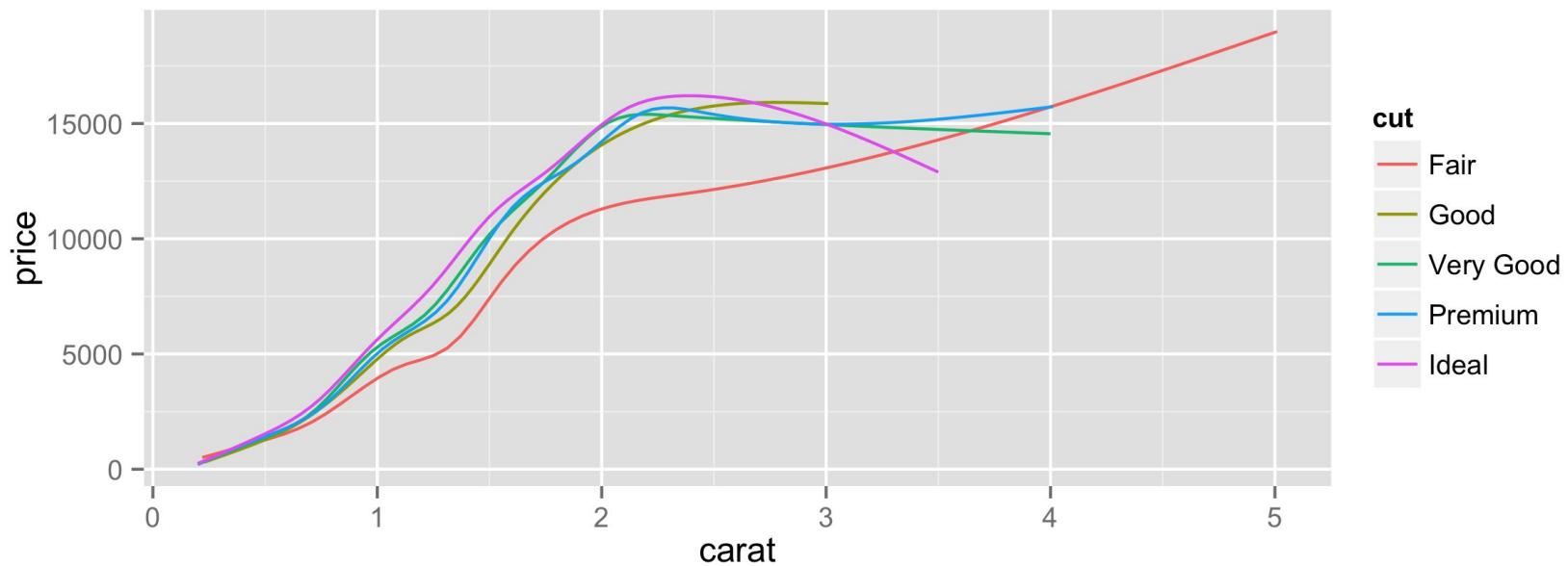
```
g + geom_smooth(aes(color = cut))
```



Geoms for Big Data

Same, but without confidence bands

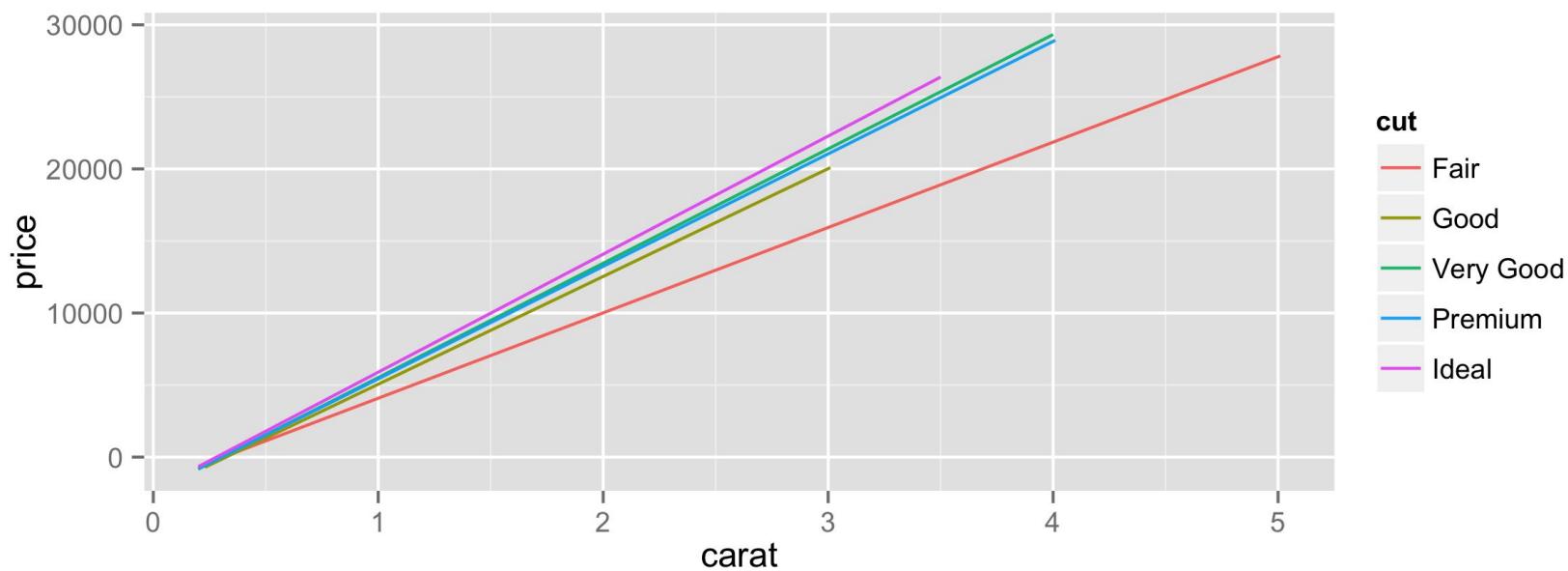
```
g + geom_smooth(aes(color = cut), se = FALSE)
```



Geoms for Big Data

Regression lines

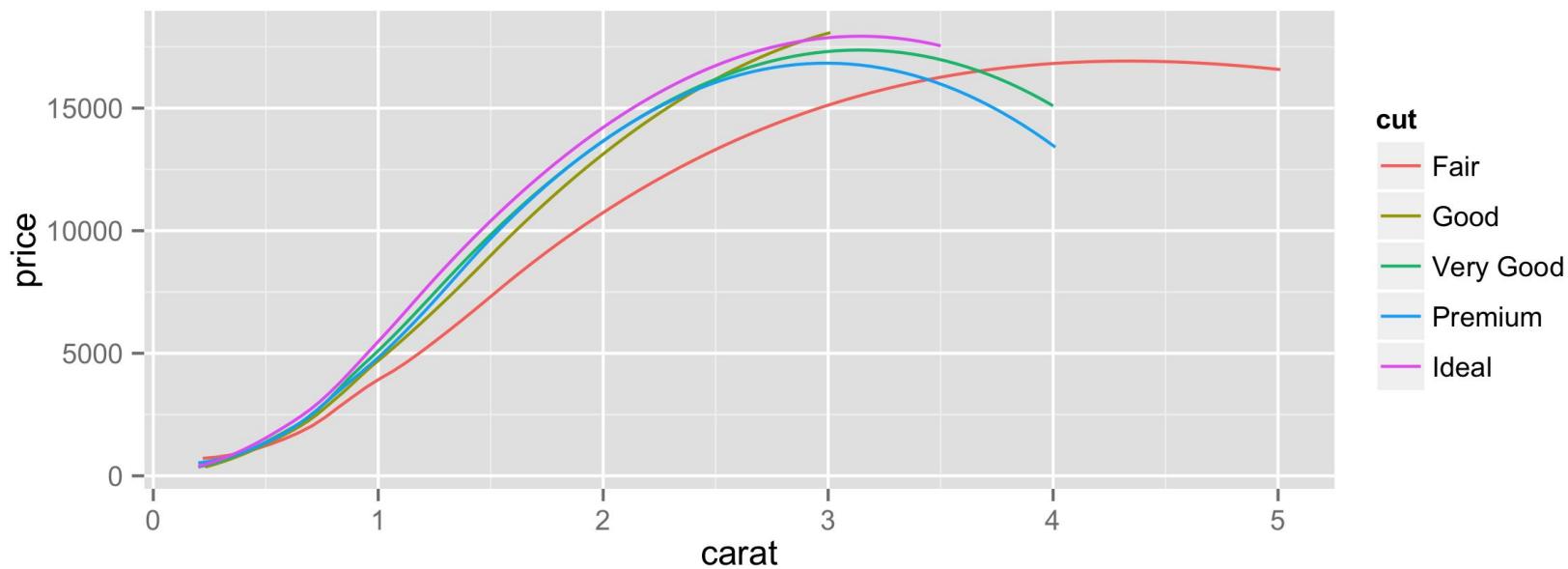
```
g + geom_smooth(aes(color = cut), method = "lm", se = FALSE)
```



Geoms for Big Data

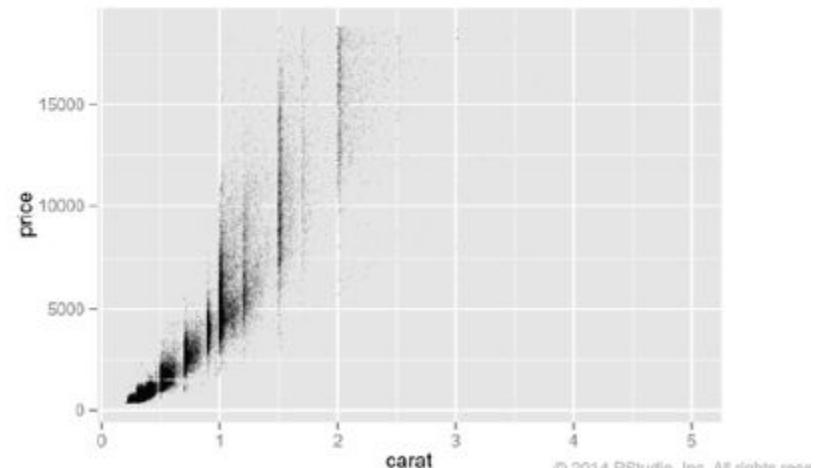
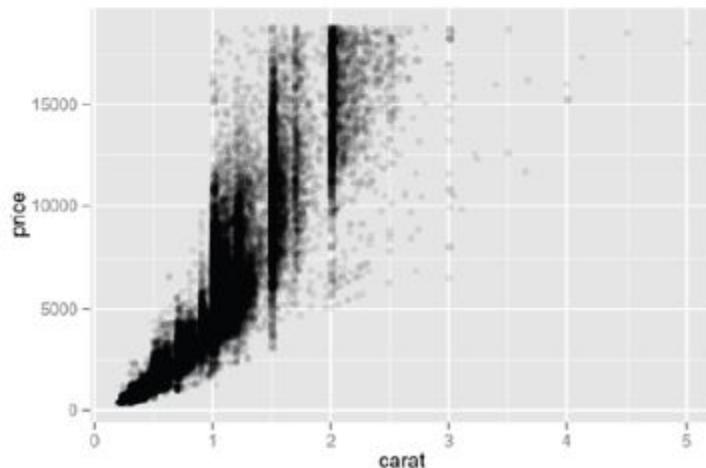
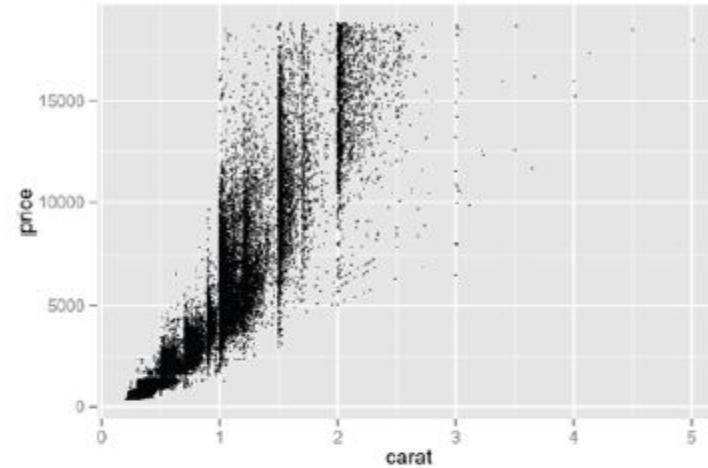
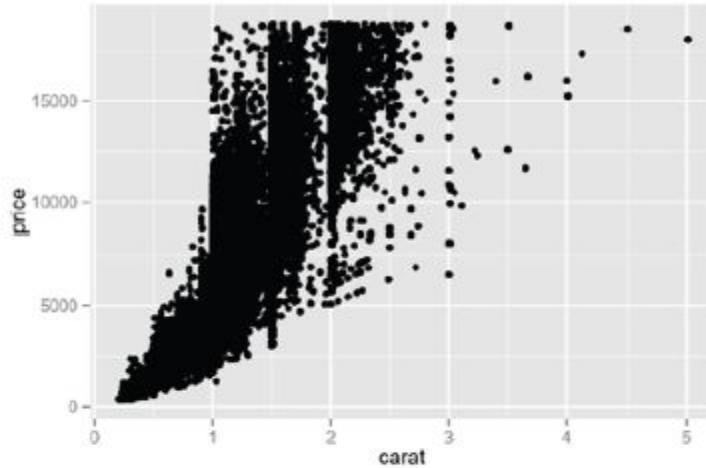
LOESS smoother

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



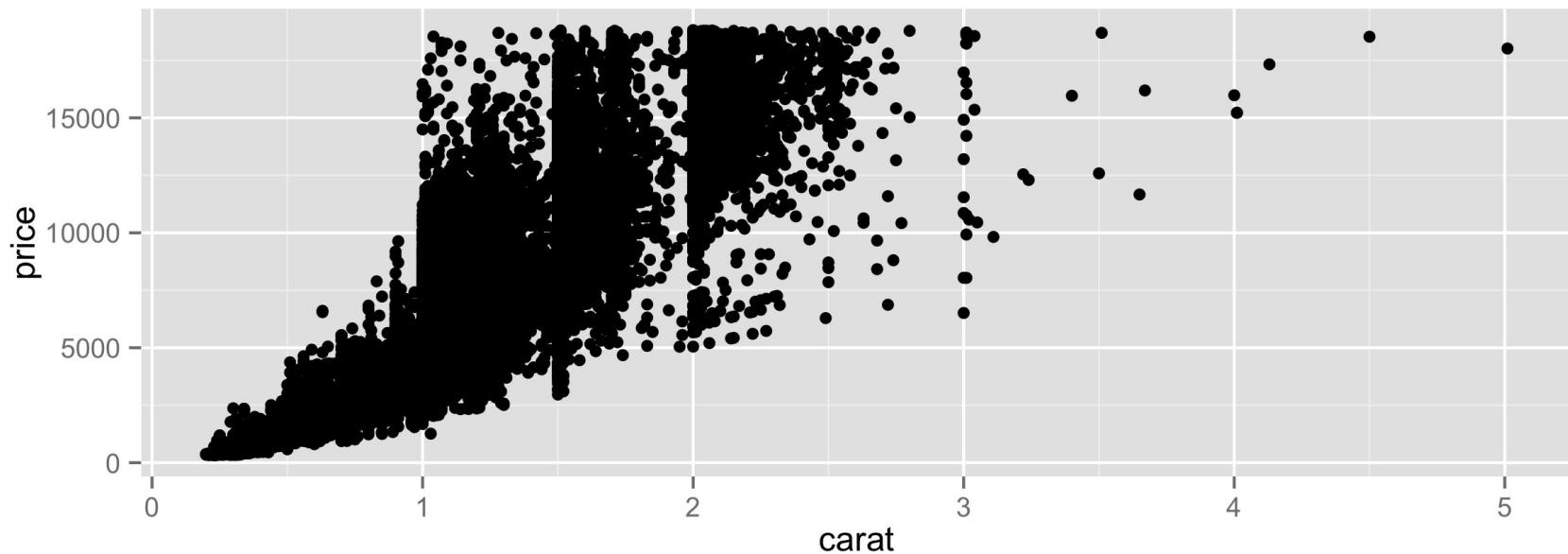
Geoms for Big Data

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



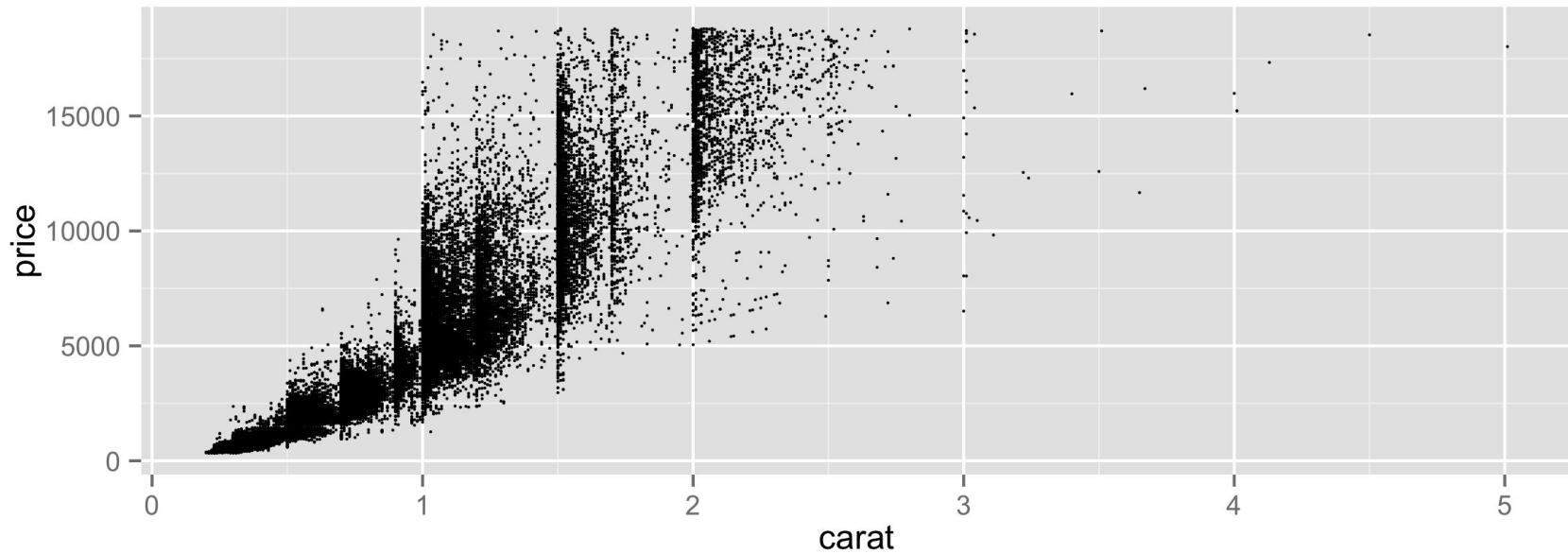
Geoms for Big Data

```
g + geom_point()
```



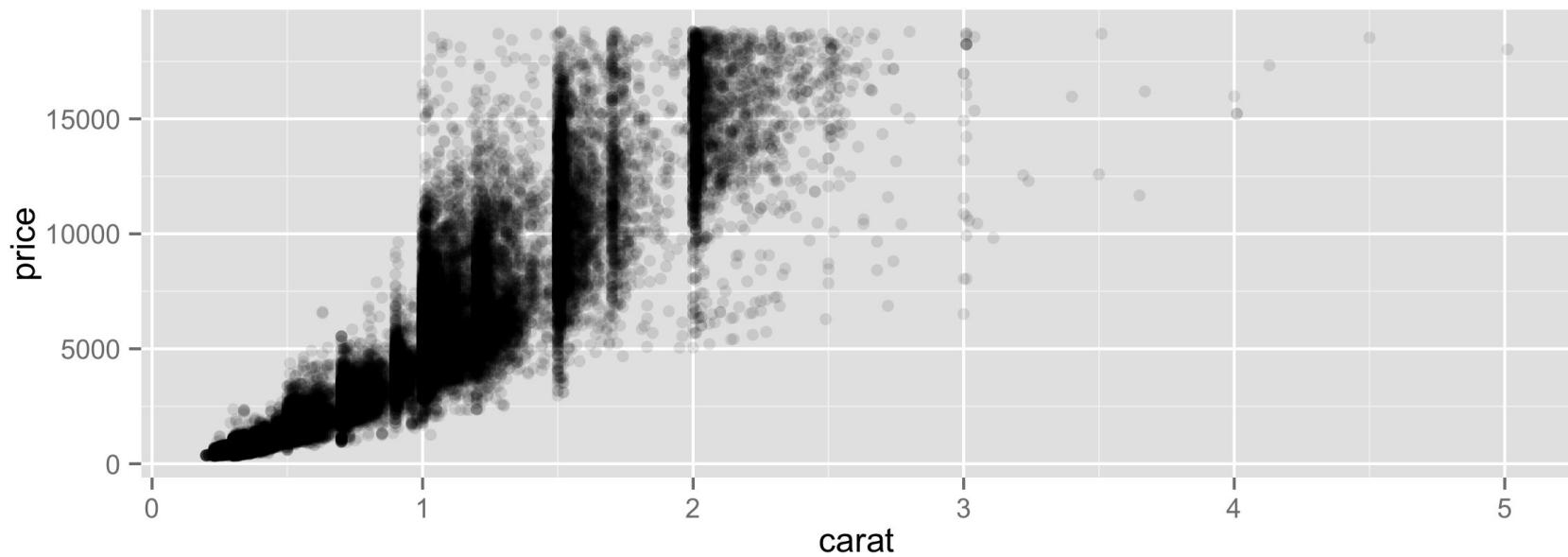
Geoms for Big Data

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



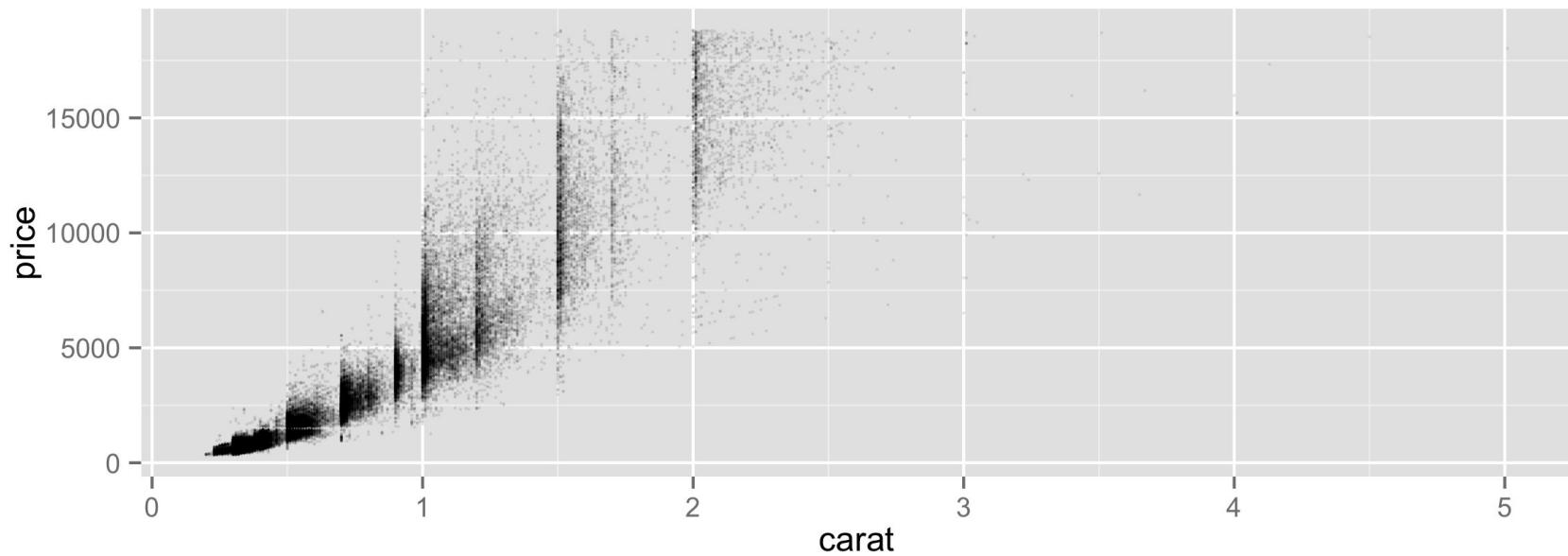
Geoms for Big Data

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



Geoms for Big Data

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



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Saving Graphs

Saving Plots

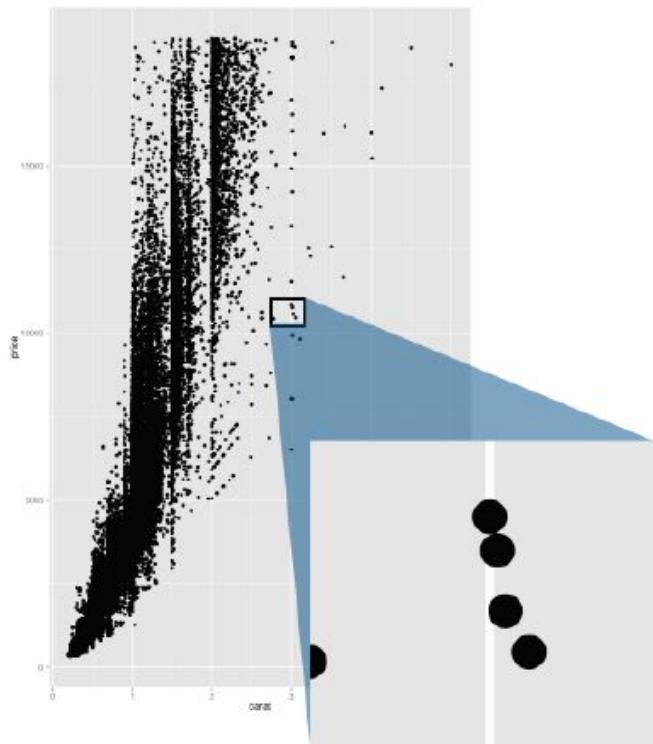
Uses size on screen:

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

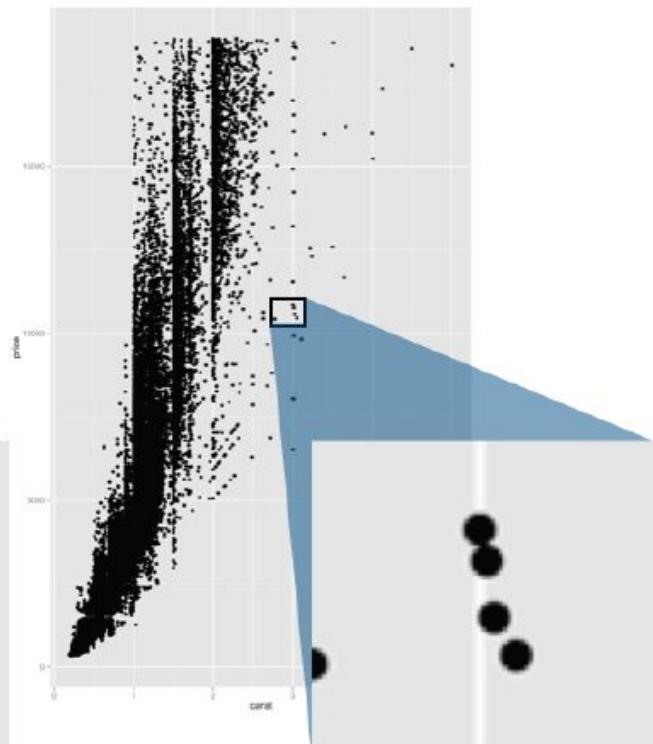
Uses specified size:

```
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