Interactive Data Visualization

David Li

The goals of today

- The key ideas behind ggplot2
- The basic steps of data visualization
- Several important plots
- Learn the popular cross-language cross-platform plotting package plotly
- Gain insight and practical skills for creating interactive and dynamic web graphics for data analysis

Basic Plotting: ggplot2

- Advantages of ggplot2
  - -consistent underlying grammar of graphics (Wilkinson, 2005)
  - -plot specification at a high level of abstraction
  - -very flexible
  - -theme system for polishing plot appearance
  - -mature and complete graphics system
  - -many users, active mailing list

Basic Plotting: ggplot2

- Some things you cannot (or should not) do with ggplot2:
  - 3-dimensional graphics (see the rgl package)
  - Graph-theory type graphs (nodes/edges layout, Spark GraphX)
  - Interactive graphics (We will learn plotly today)

Grammar Of Graphics in ggplot2

- Building blocks of a graph include:
  - data
  - aesthetic mapping
  - geometric object
  - statistical transformations
  - scales
  - coordinate system
  - position adjustments
  - faceting

Setup: install the tidyverse package

- Why tidyverse? Because this package includes a popular collection of packages
  - ggplot2, for data visualisation.
  - dplyr, for data manipulation.
  - tidyr, for data tidying.
  - readr, for data import.
  - purrr, for functional programming.
  - tibble, for tibbles, a modern re-imagining of data frames.

```
install.packages("tidyverse")
library(tidyverse)
```

```
installing the source packages 'tinytex', 'modelr'


-- Attaching packages ------------------------------------- tidyverse 1.3.0 --

v ggplot2 3.2.1     v purrr   0.3.3
v tibble  2.1.3     v dplyr   0.8.4
v tidyr   1.0.2     v stringr 1.4.0
v readr   1.3.1     v forcats 0.4.0
```

The first example

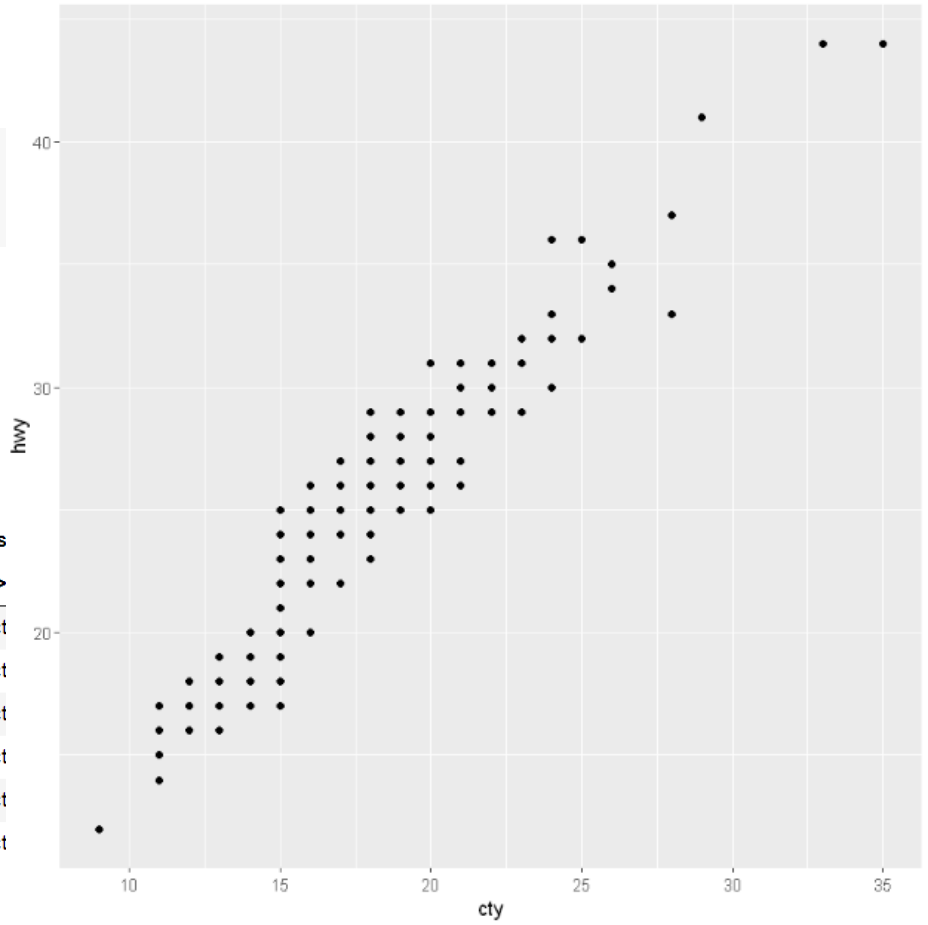
Three key components of a graph:
data, aesthetics, geometries

```
head(mpg)
ggplot(mpg, aes(cty, hwy)) + geom_point()
```

The full version is

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

manufacturer	model	displ	year	cyl	trans	drv	cty	hwy	fl	class
<chr>	<chr>	<dbl>	<int>	<int>	<chr>	<chr>	<int>	<int>	<chr>	<chr>
audi	a4	1.8	1999	4	auto(l5)	f	18	29	p	compact
audi	a4	1.8	1999	4	manual(m5)	f	21	29	p	compact
audi	a4	2.0	2008	4	manual(m6)	f	20	31	p	compact
audi	a4	2.0	2008	4	auto(av)	f	21	30	p	compact
audi	a4	2.8	1999	6	auto(l5)	f	16	26	p	compact
audi	a4	2.8	1999	6	manual(m5)	f	18	26	p	compact



Types of Statistical Data

Most data fall into one of two groups: numerical or categorical

- Numerical data
  - *Discrete data*
    - represent items that can be counted;
    - they take on possible values that can be listed out.
    - The list of possible values may be fixed (also called *finite*);
    - or it may go from 0, 1, 2, on to infinity (making it *countably infinite*).
  - *Continuous data*
    - represent measurements;
    - their possible values cannot be counted and can only be described using intervals on the real number line
- Categorical data
  - represent characteristics such as a person's gender, marital status, hometown
  - can take on numerical values (such as "1" indicating male and "2" indicating female), but those numbers don't have mathematical meaning

Most basic barplot

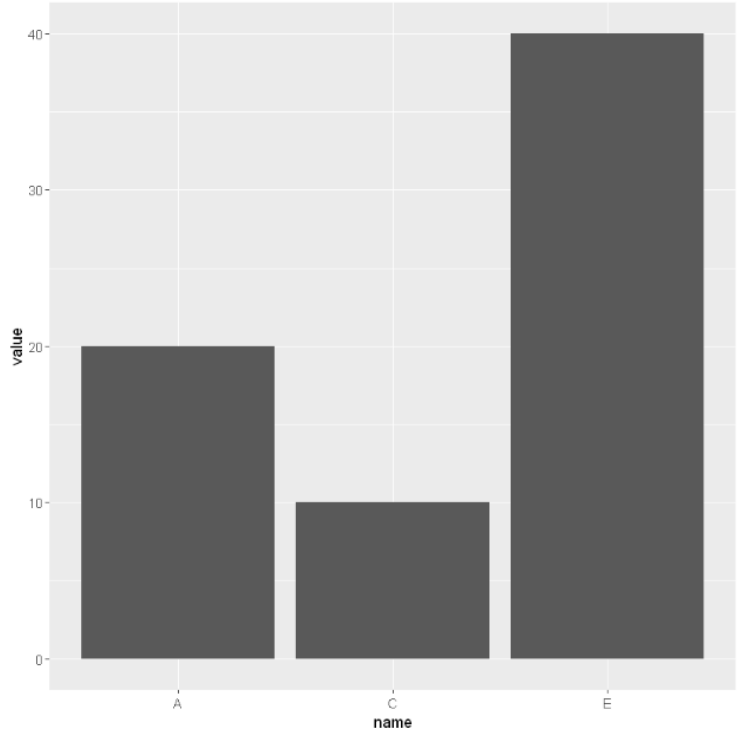
- Always start by calling the ggplot() function.
- Then specify the data object. It has to be a data frame. And it needs one numeric and one categorical variable.
- Then aesthetics, set in the aes() function: set the categorical variable for the X axis, use the numeric for the Y axis
- Finally call geom_bar(). You have to specify stat="identity" for this kind of dataset, which is sum of y for each category of x and is the height of bar.

```
data=data.frame(
  name=c("A","A","C","C","E") ,
  value=c(3,17,4,6,40)
  )

ggplot(data, aes(x=name, y=value)) + geom_bar(stat = "identity")
```

Most basic barplot

```
data=data.frame(
  name=c("A","A","C","C","E") ,
  value=c(3,17,4,6,40)
  )

ggplot(data, aes(x=name, y=value)) + geom_bar(stat = "identity")
```

name	value
<fct>	<dbl>
A	3
A	17
C	4
C	6
E	40



Basic barplot without y variable

- Start by calling the ggplot() function.
- Then specify the data object. It has to be a data frame. And it needs one categorical variable.
- Then aesthetics, set in the aes() function: set the categorical variable for the x axis
- Finally call geom_bar(). Because you don't have y, so you can't specify stat="identity". The default is stat="count", which is count of rows for each category of x and is the height of bar.

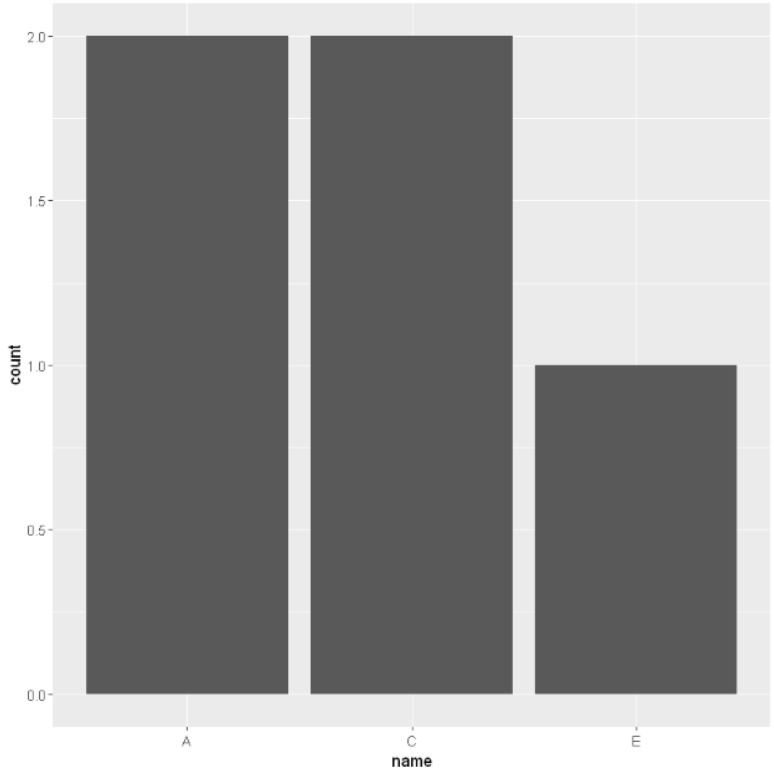
```
data=data.frame(name=c("A","A","C","C","E"))

ggplot(data, aes(x=name)) + geom_bar()
ggplot(data, aes(x=name)) + geom_bar(stat="count")
```

data aesthetics geometries statistical transformations

Basic barplot without y variable

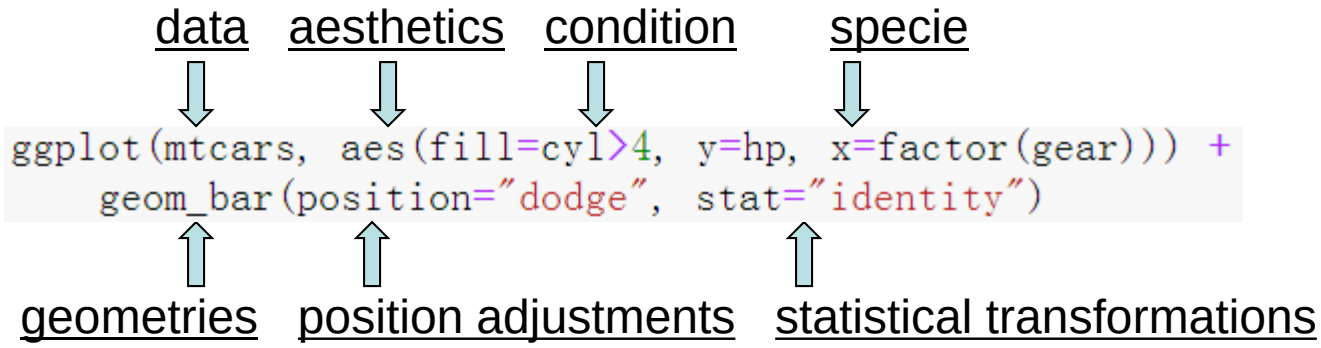
```
data=data.frame(name=c("A","A","C","C","E"))

ggplot(data, aes(x=name)) + geom_bar()
ggplot(data, aes(x=name)) + geom_bar(stat="count")
```

name
<fct>
A
A
C
C
E



Grouped barplot

• A grouped barplot display a numeric value for a set of entities split in groups and subgroups.
• Data must have *3 columns*: the numeric value (value), and 2 categorical variables for the group (specie) and the subgroup (condition) levels.
• In aes(), is the group (specie), and the subgroup (condition) is given to the fill argument.
• In geom_bar(), position="dodge" must be specified to have the bars one beside each other. Here we specify stat="identity" to use y values as bar heights.



Grouped barplot examples

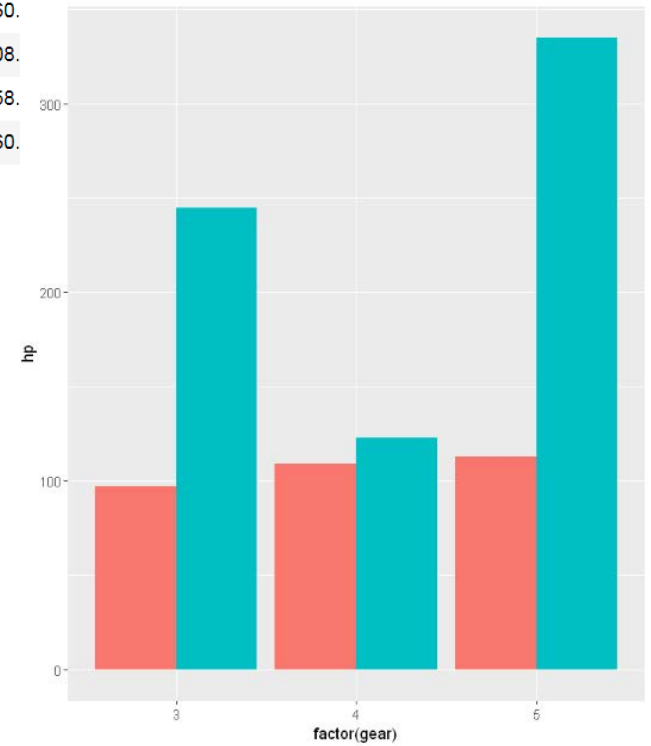
```
ggplot(mtcars, aes(fill=cyl>4, y=hp, x=factor(gear))) +
    geom_bar(position="dodge", stat="identity")
```

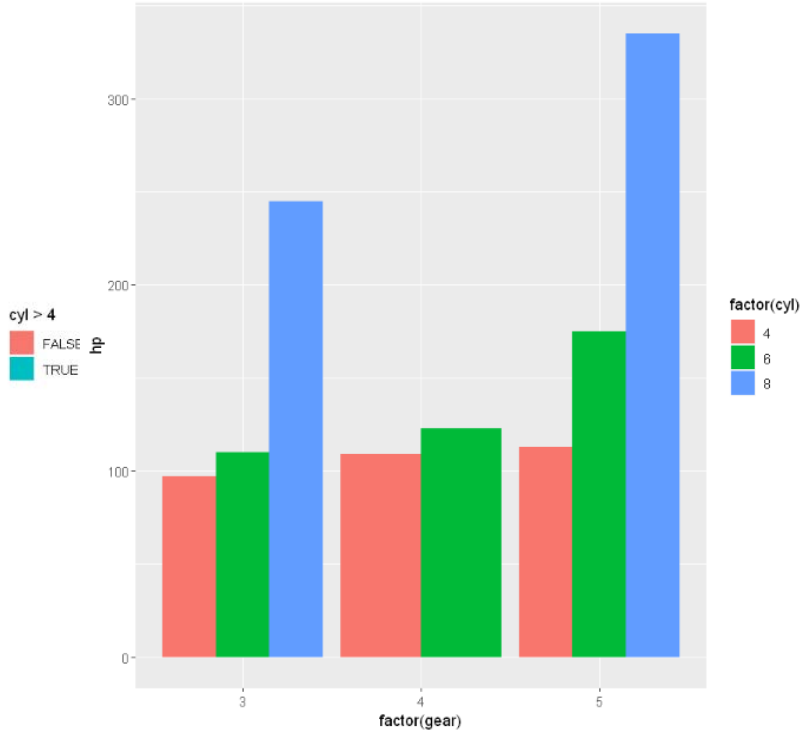
```
ggplot(mtcars, aes(fill=factor(cyl), y=hp, x=factor(gear))) +
    geom_bar(position="dodge", stat="identity")
```

factor() converts discrete to categorical

	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
Mazda RX4	21.0	6	160.0	110	3.90	2.620	16.46	0	1	4	4
Mazda RX4 Wag	21.0	6	160.								
Datsun 710	22.8	4	108.								
Hornet 4 Drive	21.4	6	258.								
Hornet Sportabout	18.7	8	360.								

Did you see any issues below?

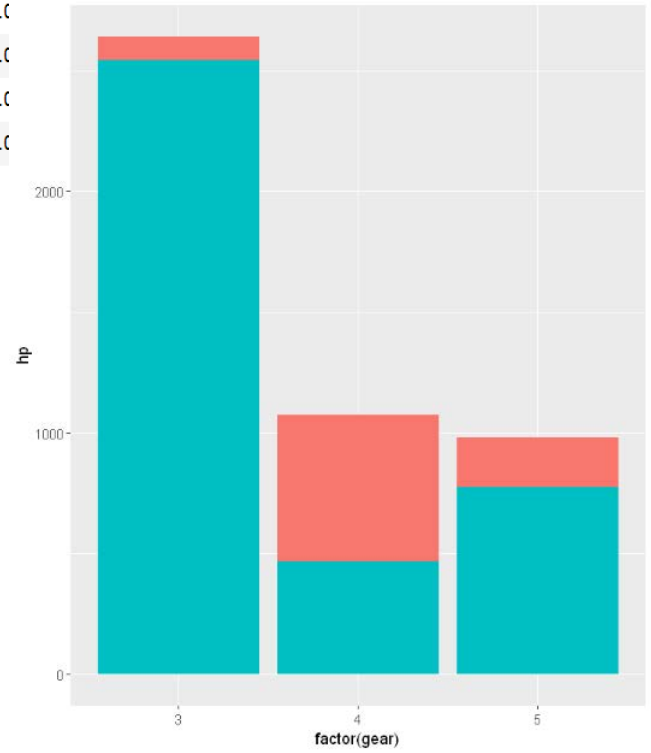


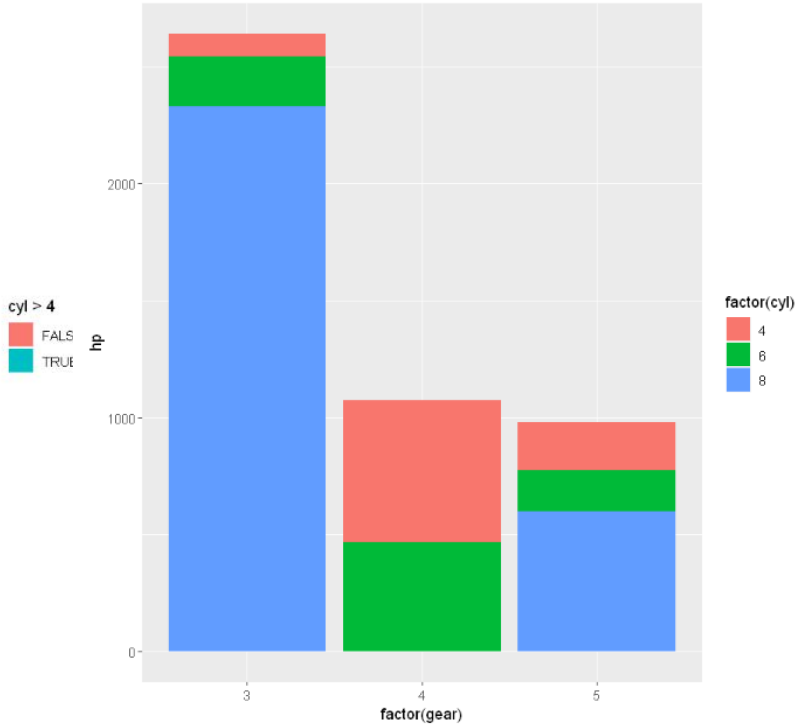


Stacked barplot examples

```
ggplot(mtcars, aes(fill=cyl>4, y=hp, x=factor(gear))) +
    geom_bar(position="stack", stat="identity")
ggplot(mtcars, aes(fill=factor(cyl), y=hp, x=factor(gear))) +
    geom_bar(position="stack", stat="identity")
```

	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
Mazda RX4	21.0	6	160.0	110	3.90	2.620	16.46	0	1	4	4
Mazda RX4 Wag	21.0	6	160.0								
Datsun 710	22.8	4	108.0								
Hornet 4 Drive	21.4	6	258.0								
Hornet Sportabout	18.7	8	360.0								

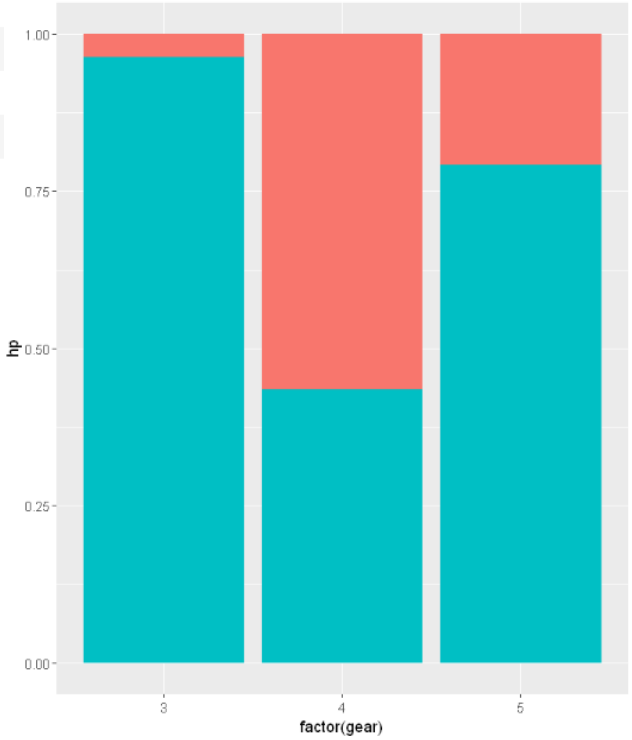


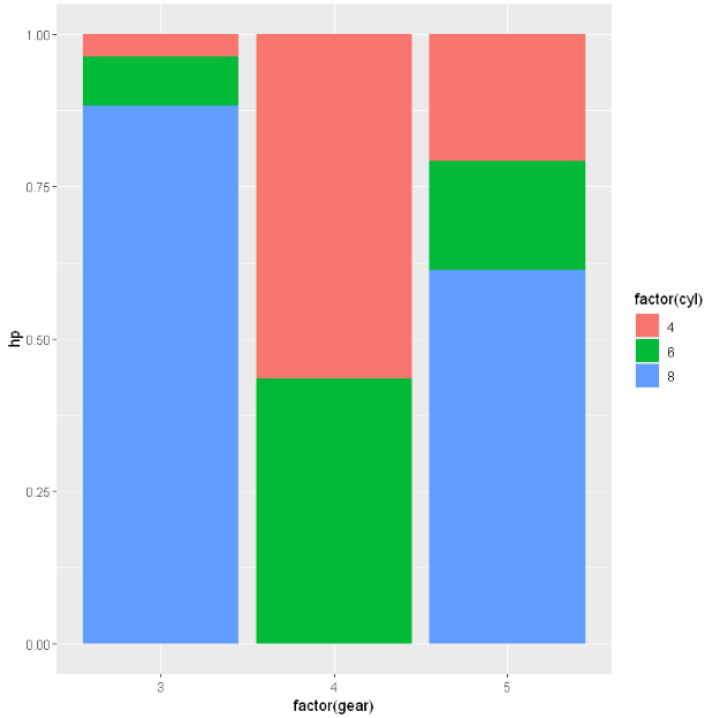


Percent Stacked barplot examples

```
ggplot(mtcars, aes(fill=cyl>4, y=hp, x=factor(gear))) +
    geom_bar(position="fill", stat="identity")
ggplot(mtcars, aes(fill=factor(cyl), y=hp, x=factor(gear))) +
    geom_bar(position="fill", stat="identity")
```

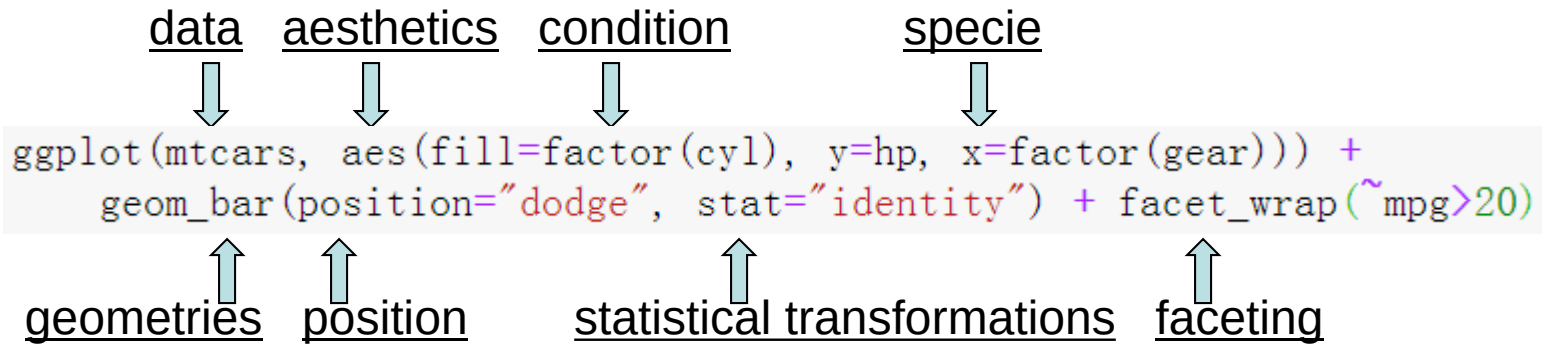
	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
Mazda RX4	21.0	6	160.0	110	3.90	2.620	16.46	0	1	4	4
Mazda RX4 Wag	21.0	6	160.0								
Datsun 710	22.8	4	108.0								
Hornet 4 Drive	21.4	6	258.0								
Hornet Sportabout	18.7	8	360.0								





Small multiple barplot

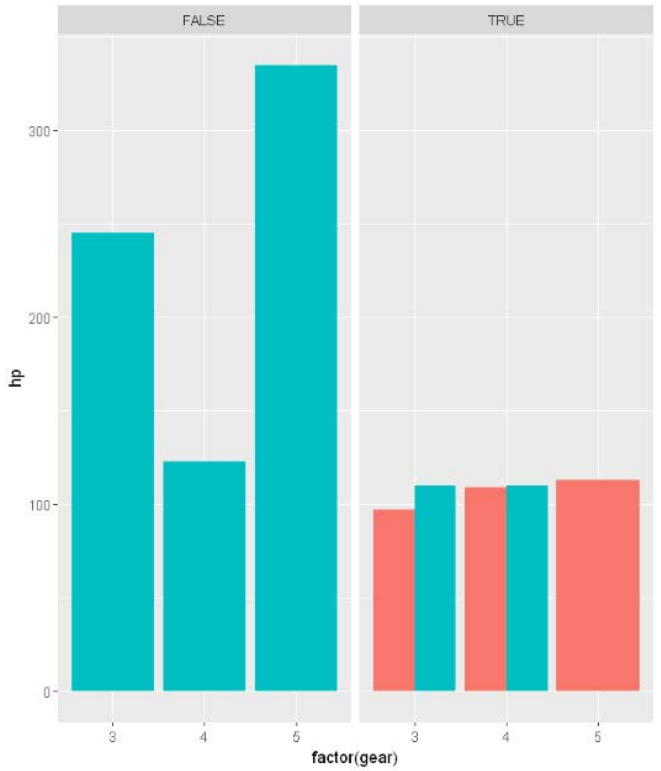
- Small multiple can be used as an alternative of stacking or grouping
- Use facet_wrap() to specify the first level grouping

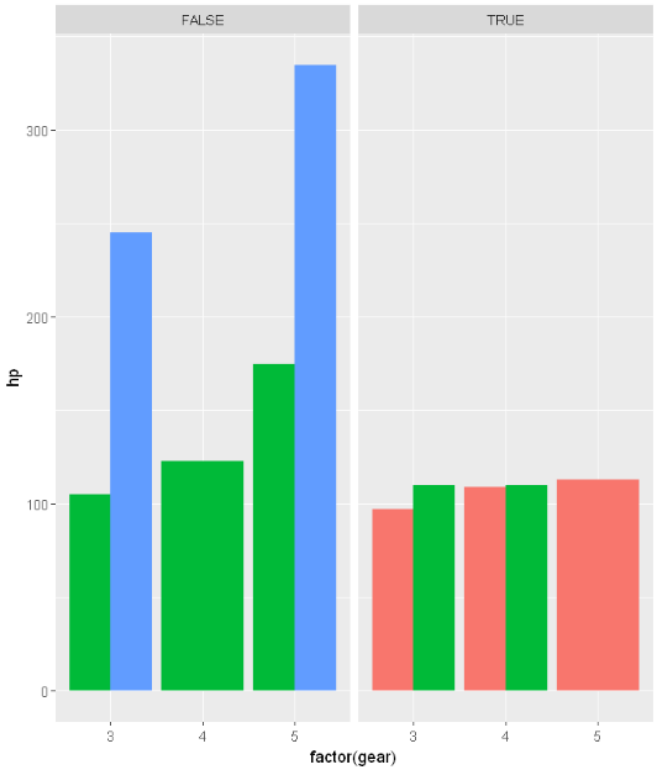


Small multiple barplot examples

```
ggplot(mtcars, aes(fill=cyl>4, y=hp, x=factor(gear))) +
    geom_bar(position="dodge", stat="identity") + facet_wrap(~mpg>20)
ggplot(mtcars, aes(fill=factor(cyl), y=hp, x=factor(gear))) +
    geom_bar(position="dodge", stat="identity") + facet_wrap(~mpg>20)
```

	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
Mazda RX4	21.0	6	160.0	110	3.90	2.620	16.46	0	1	4	4
Mazda RX4 Wag	21.0	6									
Datsun 710	22.8	4									
Hornet 4 Drive	21.4	6									
Hornet Sportabout	18.7	8									





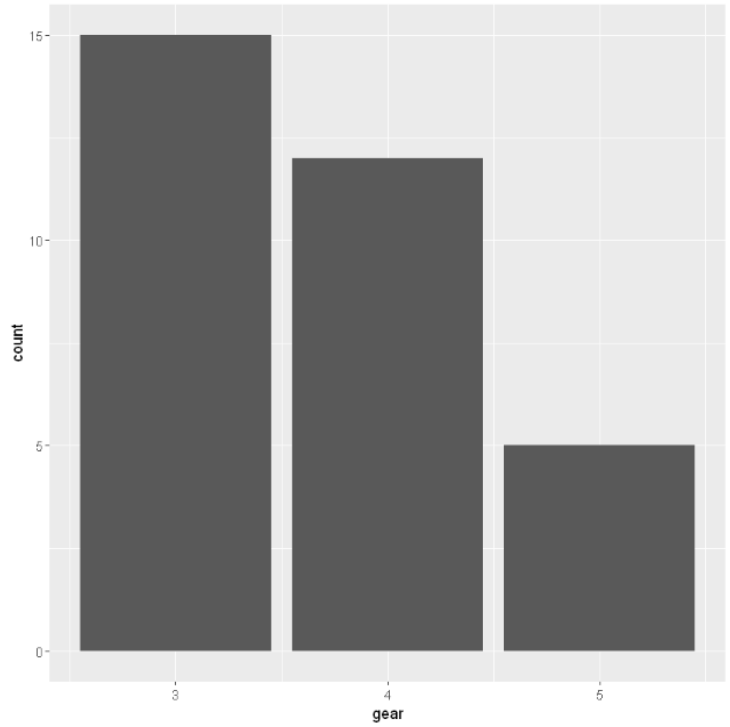
Difference between bar and histogram

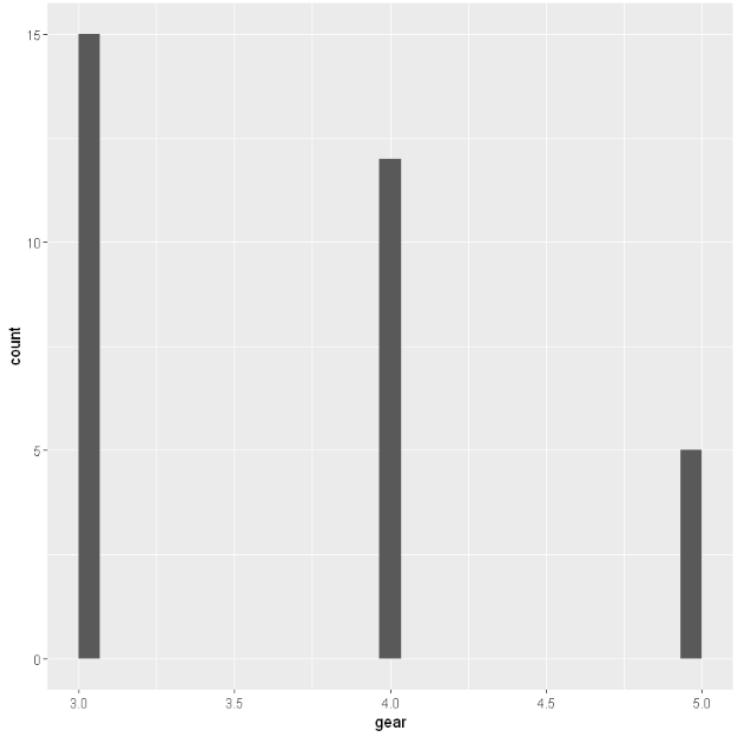
Count the rows for each value of “gear”

- To quickly see a distribution

```
ggplot(mtcars, aes(gear)) + geom_bar()
ggplot(mtcars, aes(gear)) + geom_histogram()
```

	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
Mazda RX4	21.0	6	160	110	3.90	2.620	16.46	0	1	4	4
Mazda RX4 Wag	21.0	6	160	110	3.90	2.875	17.02	0	1	4	4
Datsun 710	22.8	4	108	93	3.85	2.320	18.61	1	1	4	1
Hornet 4 Drive	21.4	6	258	110	3.08	3.215	19.44	1	0	3	1
Hornet Sportabout	18.7	8	360	175	3.15	3.440	17.02	0	0	3	2
Valiant	18.1	6	225	105	2.76	3.460	20.22	1	0	3	1





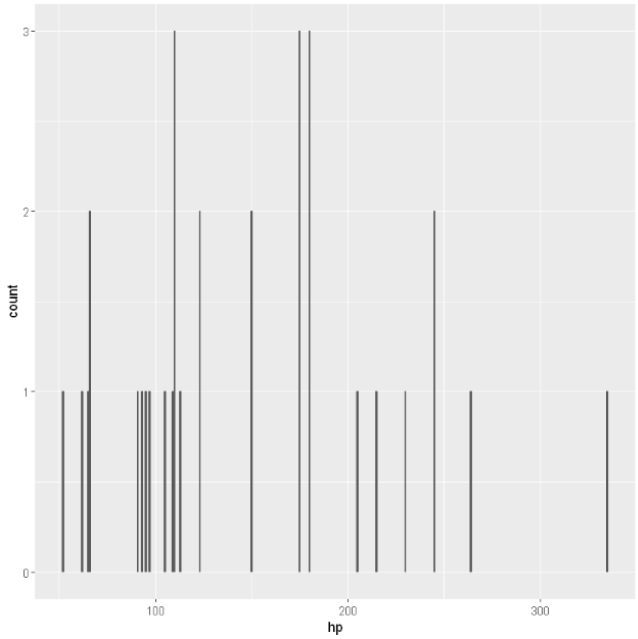
Difference between bar and histogram

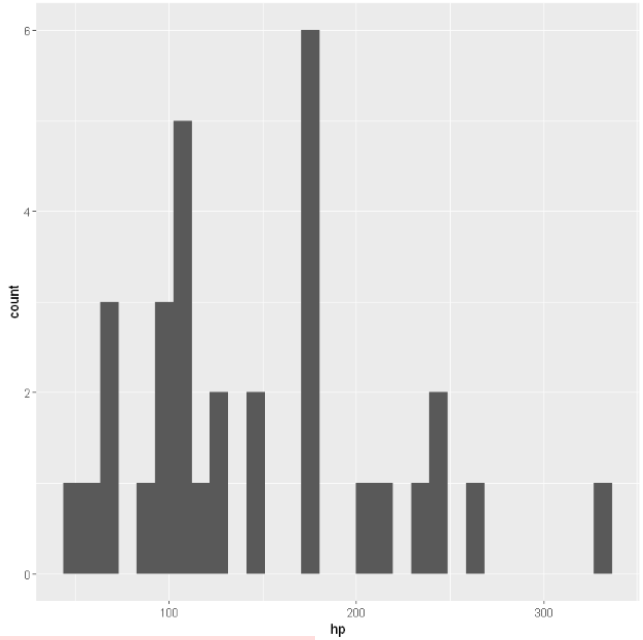
Difference between bar and histogram:

- Bar shows each individual x values
- Histogram splits the range of x values into bins

```
ggplot(mtcars, aes(hp)) + geom_bar()
ggplot(mtcars, aes(hp)) + geom_histogram()
```

	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
Mazda RX4	21.0	6	160	110	3.90	2.620	16.46	0	1	4	4
Mazda RX4 Wag	21.0	6	160	110	3.90	2.875	17.02	0	1	4	4
Datsun 710	22.8	4	108	93	3.85	2.320	18.61	1	1	4	1
Hornet 4 Drive	21.4	6	258	110	3.08	3.215	19.44	1	0	3	1
Hornet Sportabout	18.7	8	360	175	3.15	3.440	17.02	0	0	3	2
Valiant	18.1	6	225	105	2.76	3.460	20.22	1	0	3	1






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

Line Chart

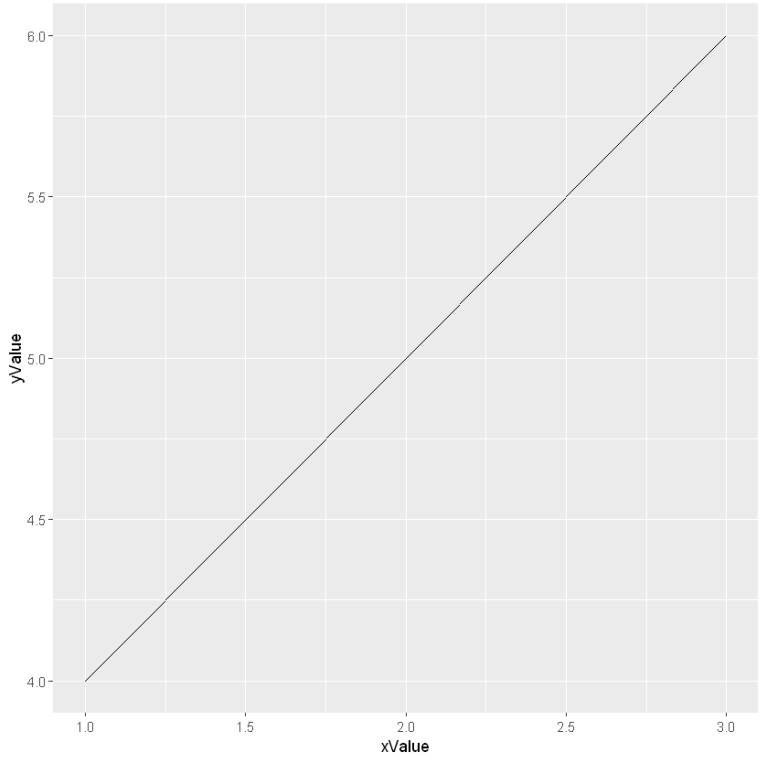
- A line chart or line graph displays the evolution of one or several numeric variables.
- Data points are usually connected by straight line segments.
- Start by calling the ggplot() function.
- Then specify the data object. The input data frame requires at least 2 columns:
  - An ***ordered*** numeric variable for the X axis
  - Another numeric variable for the Y axis
- Then aesthetics, set x and y in the aes() function
- Finally call geom_line().

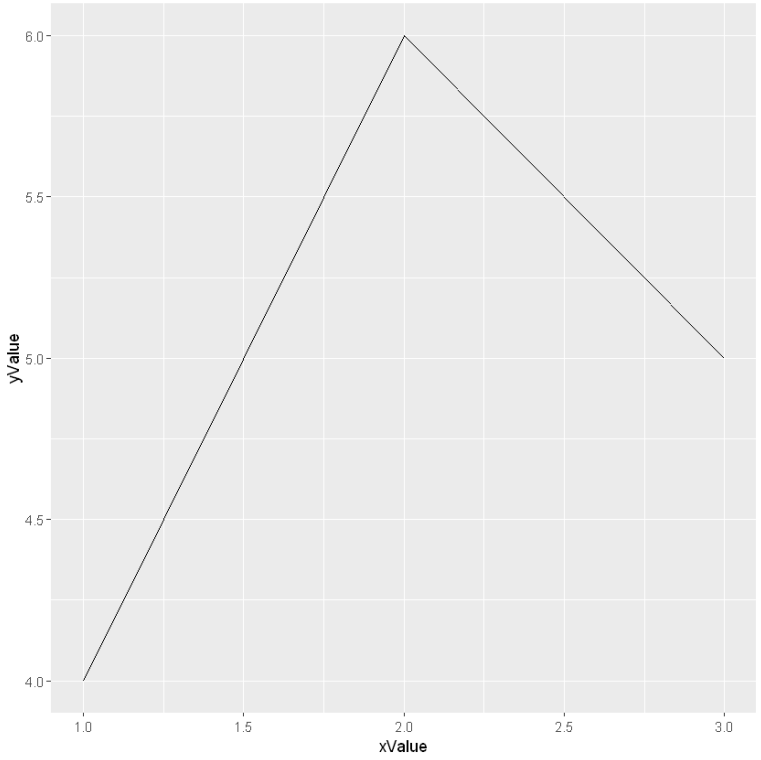
```
data=data.frame(xValue=1:3, yValue=4:6)
ggplot(data, aes(x=xValue, y=yValue)) + geom_line()
```

Line Chart examples

If x is not sorted, R will sort it before connecting points

```
data=data.frame(xValue=1:3, yValue=4:6)
ggplot(data, aes(x=xValue, y=yValue)) + geom_line()
data=data.frame(xValue=c(1,3,2), yValue=4:6)
ggplot(data, aes(x=xValue, y=yValue)) + geom_line()
```

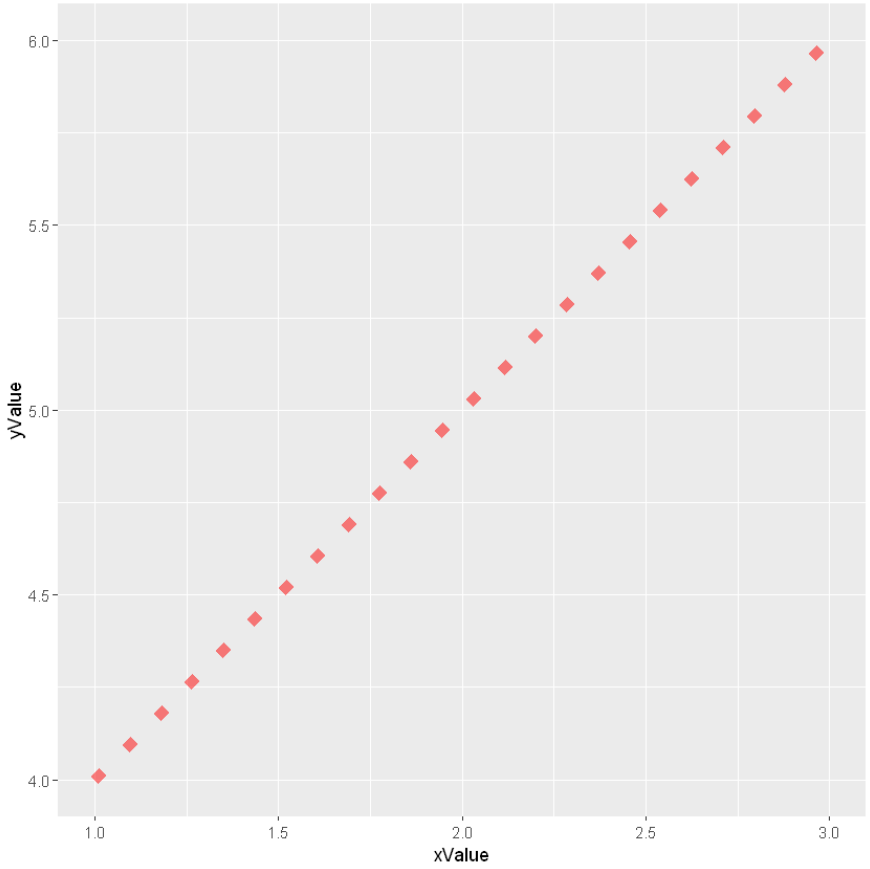




Line Chart examples

Line styles can be added in geom_line()

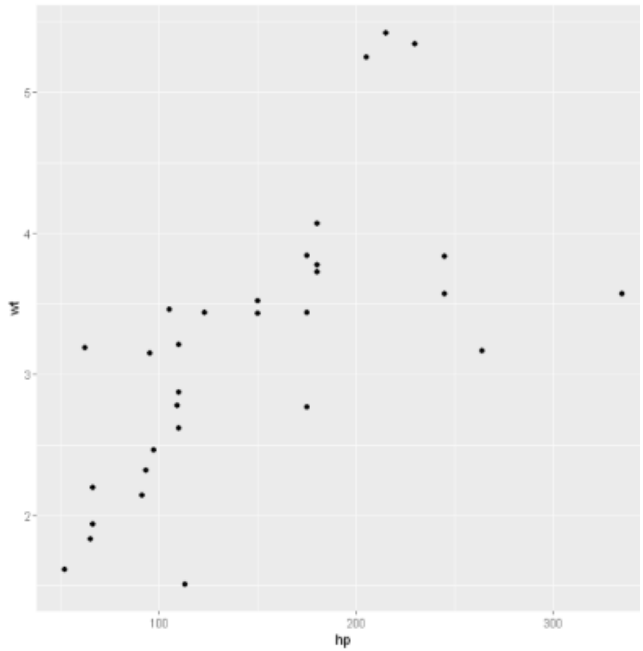
```
data=data.frame(xValue=1:3, yValue=4:6)
ggplot(data, aes(x=xValue, y=yValue)) + geom_line(color="red", size=3, alpha=0.5, linetype=3)
```

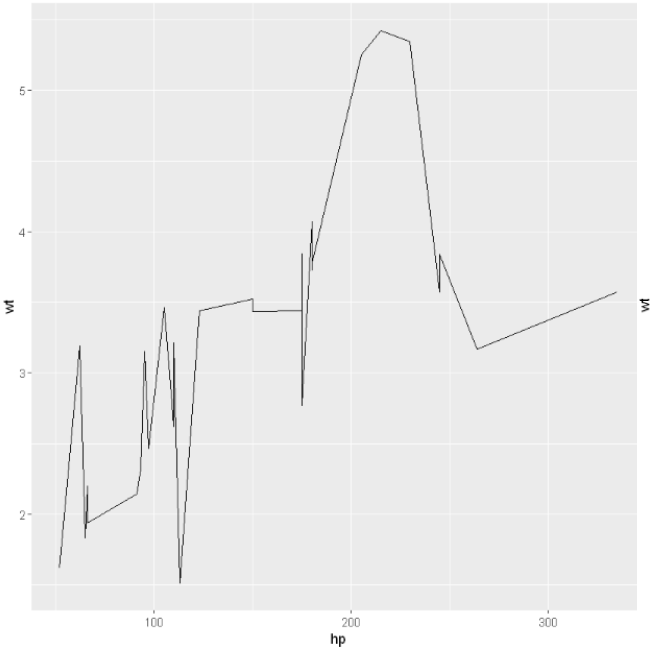


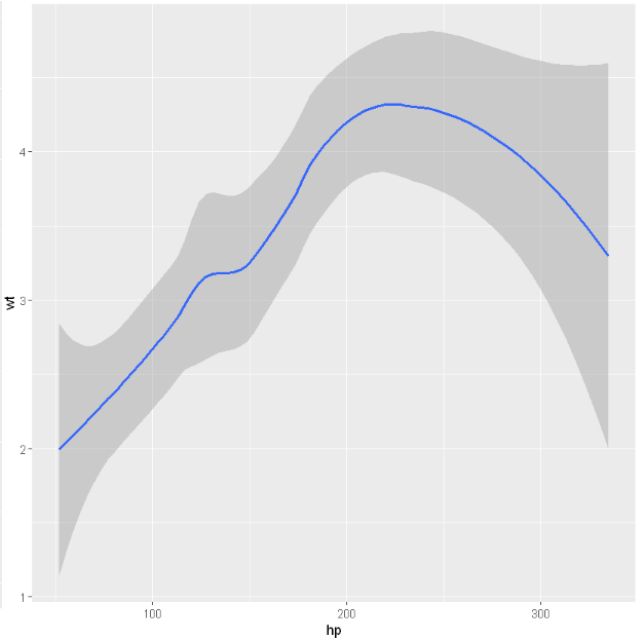
More examples of plotting (x, y)

```
ggplot(mtcars, aes(hp, wt)) + geom_point()
ggplot(mtcars, aes(hp, wt)) + geom_line()
ggplot(mtcars, aes(hp, wt)) + geom_smooth()
```

	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
Mazda RX4	21.0	6	160	110	3.90	2.620	16.46	0	1	4	4
Mazda RX4 Wag	21.0	6	160	110	3.90	2.875	17.02	0	1	4	4
Datsun 710	22.8	4	108	93	3.85	2.320	18.61	1	1	4	1
Hornet 4 Drive	21.4	6	258	110	3.08	3.215	19.44	1	0	3	1
Hornet Sportabout	18.7	8	360	175	3.15	3.440	17.02	0	0	3	2
Valiant	18.1	6	225	105	2.76	3.460	20.22	1	0	3	1







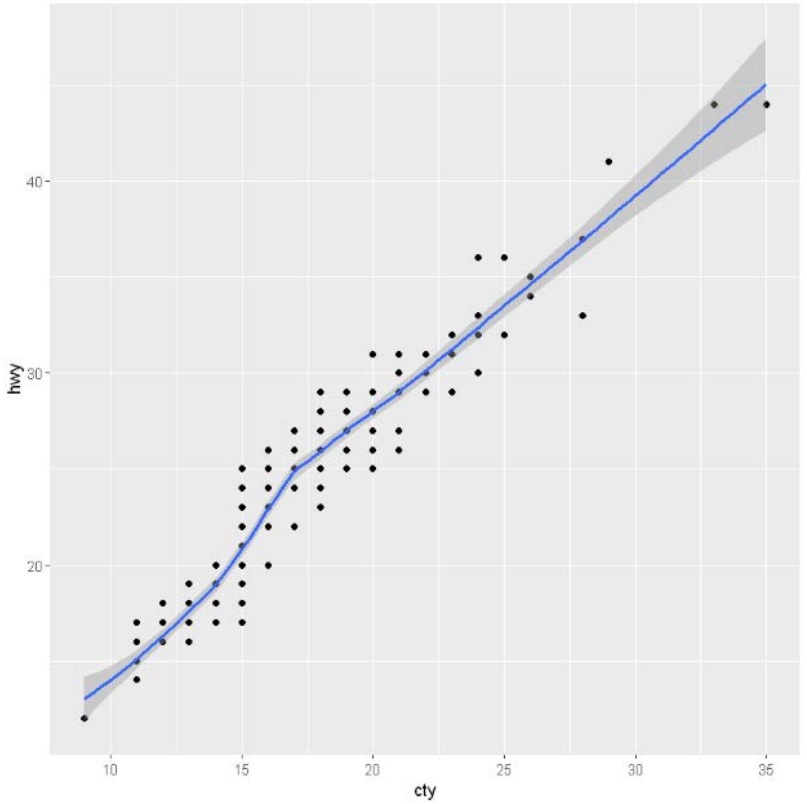
Overlap plotting

We can add more geometries so that the plots will be on one graph

```
ggplot(DATAFRAME, aes(X_COLUMN, Y_COLUMN)) + GEOM_TYPE1 + GEOM_TYPE2
```

Example,

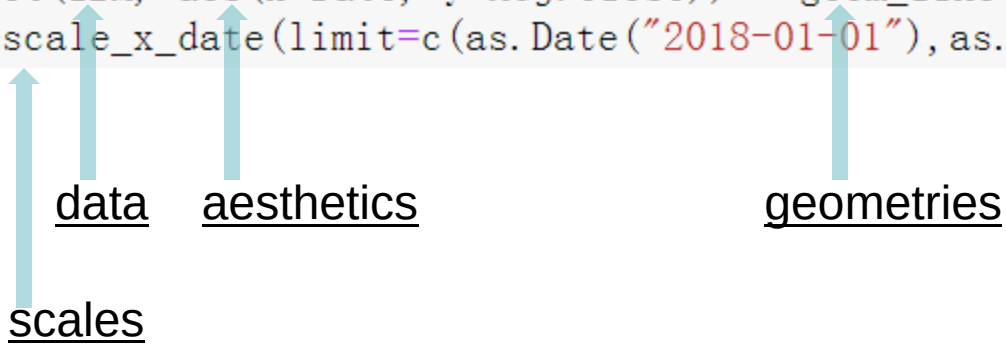
```
ggplot(mpg, aes(cty, hwy))
+ geom_point()
+ geom_smooth()
```



Line Chart for Time Series

- The ggplot2 package recognizes the date format and automatically uses a specific type of X axis.
  - If the time variable isn't at the date format, this won't work.
  - Check with str(data) how variables are understood by R.
  - If not read as a date, use lubridate or anytime to convert it
- Then the rest is the same as line chart

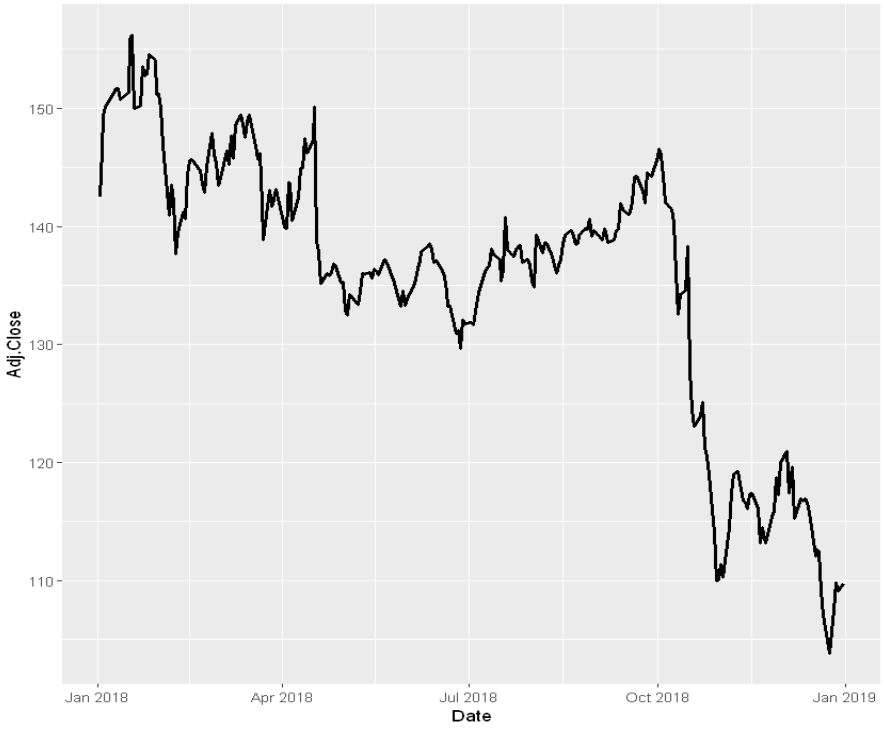
```
library(anytime)
IBM=read.csv('IBM.csv')
IBM$Date = anydate(IBM$Date)
ggplot(IBM, aes(x=Date, y=Adj.Close)) + geom_line() +
    scale_x_date(limit=c(as.Date("2018-01-01"),as.Date("2018-02-11")))
```

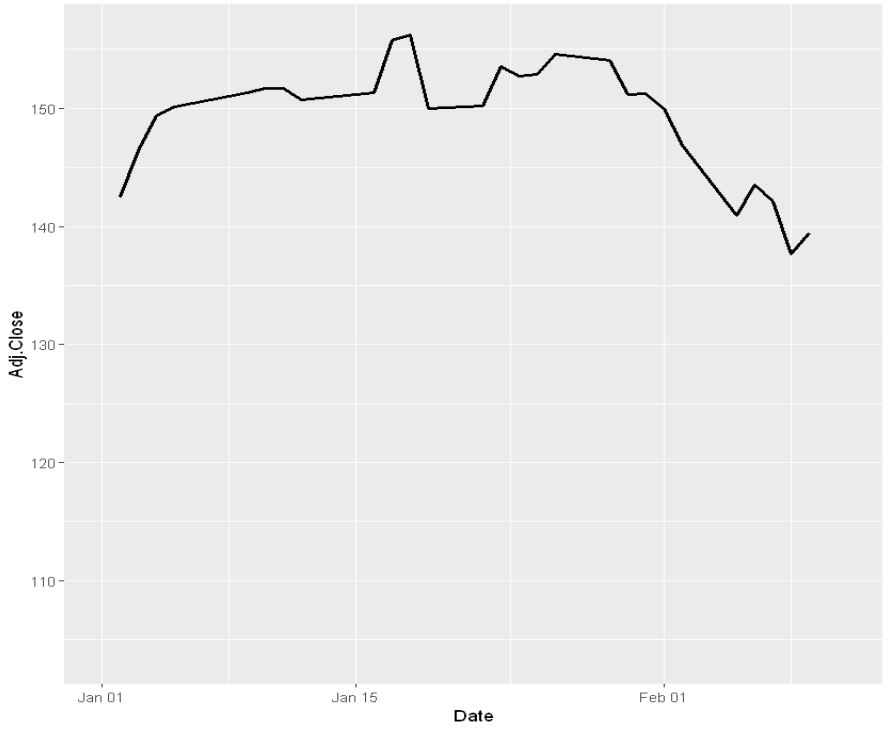


Time Series examples

Assume time series has sorted date column

```
library(anytime)
IBM=read.csv('IBM.csv')
IBM$Date = anydate(IBM$Date)
ggplot(IBM, aes(x=Date, y=Adj.Close)) + geom_line(size=1)
ggplot(IBM, aes(x=Date, y=Adj.Close)) + geom_line(size=1) +
    scale_x_date(limit=c(as.Date("2018-01-01"),as.Date("2018-02-11")))
```

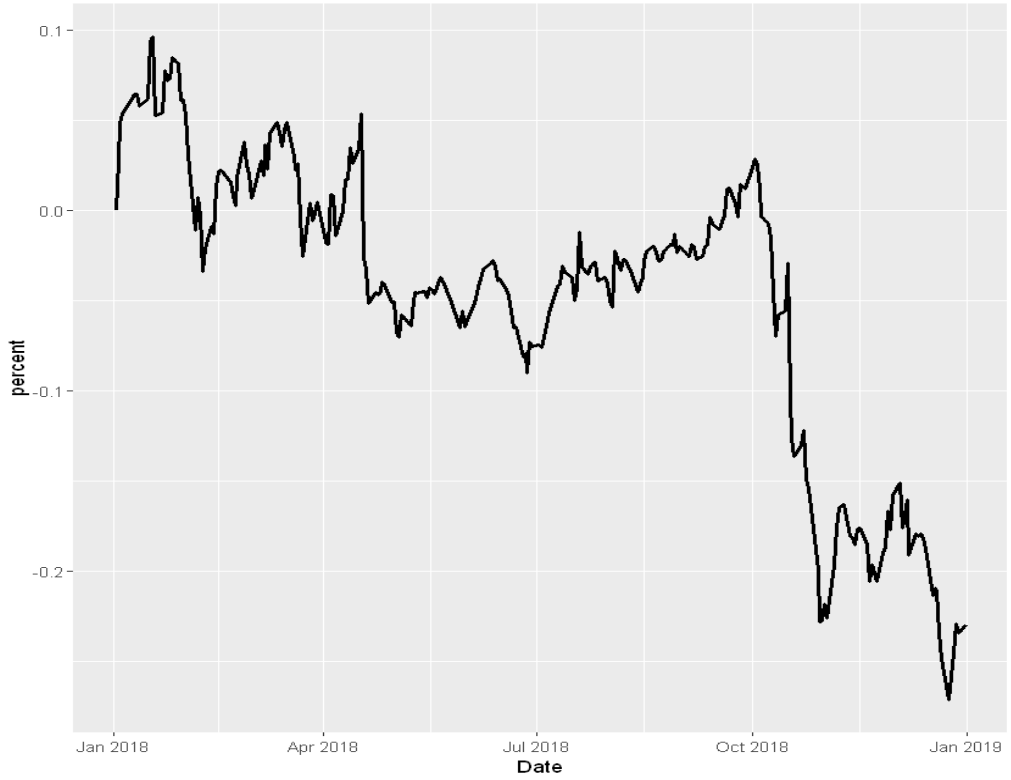




Time Series examples

Convert y to the percent change from the first day

```
startprice=IBM[1, 6]
IBM %>%
mutate(percent=(Adj.Close-startprice)/startprice) %>%
ggplot(aes(x=Date, y=percent)) + geom_line(size=1)
```



Multi groups line chart for Time Series

- The input data frame is composed by 3 columns:
  - An ***ordered*** numeric variable for the X axis. For time series, it is the Date column.
  - Another numeric variable for the Y axis
  - A categorical variable that specify the group of the observation
- The idea is to draw one line per group

```
data.frame(Date=IBM$Date, IBM=IBM$Adj.Close, GOOG=GOOG$Adj.Close) %>%
reshape2::melt(id.vars="Date") %>%
ggplot(aes(x=Date, y=value, group=variable, color=variable)) + geom_line(size=1)
```

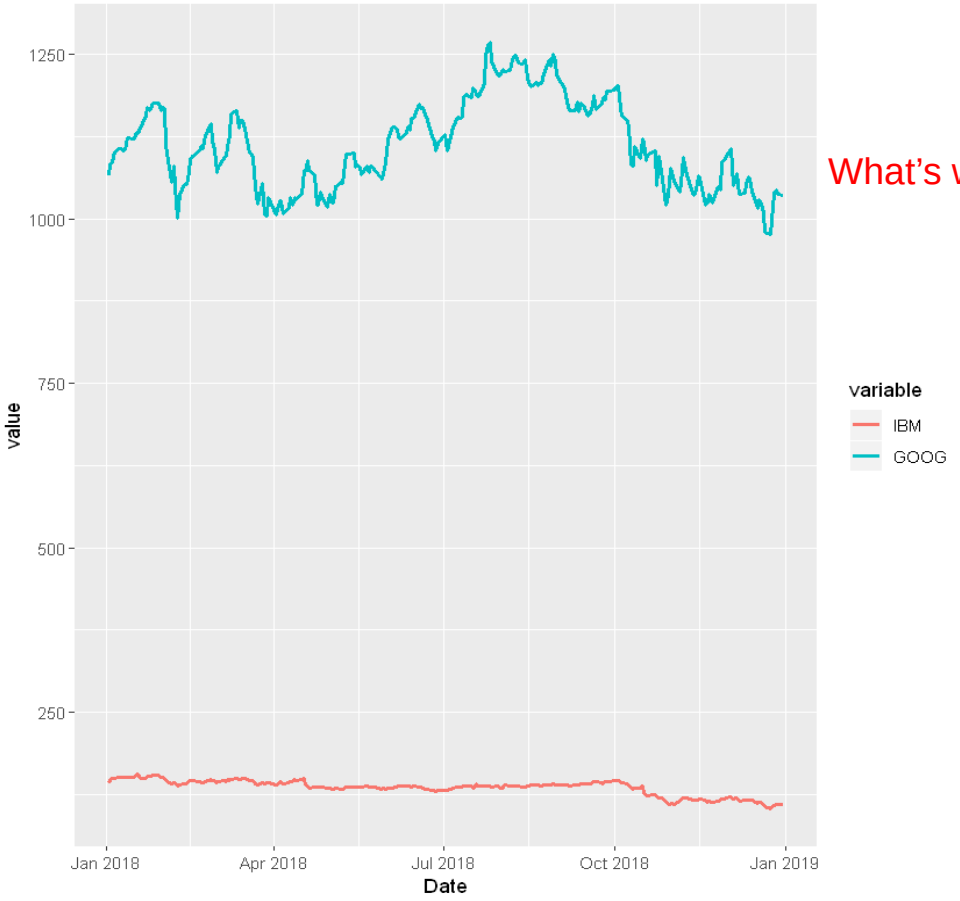
data aesthetics geometries

Multiple Time Series examples

```
data.frame(Date=IBM$Date, IBM=IBM$Adj.Close, GOOG=GOOG$Adj.Close) %>%
reshape2::melt(id.vars="Date") %>%
ggplot(aes(x=Date, y=value, group=variable, color=variable)) + geom_line(size=1)
```

	Date	IBM	GOOG
	<date>	<dbl>	<dbl>
1	2018-01-02	142.4840	1065.00
2	2018-01-03	146.4006	1082.48
3	2018-01-04	149.3657	1086.40
4	2018-01-05	150.0954	1102.23
5	2018-01-08	151.0007	1106.94
6	2018-01-09	151.3332	1106.26

Date	variable	value
<date>	<fct>	<dbl>
2018-01-02	IBM	142.4840
2018-01-03	IBM	146.4006
...	...	...
2018-11-15	GOOG	1064.71
2018-11-16	GOOG	1061.49



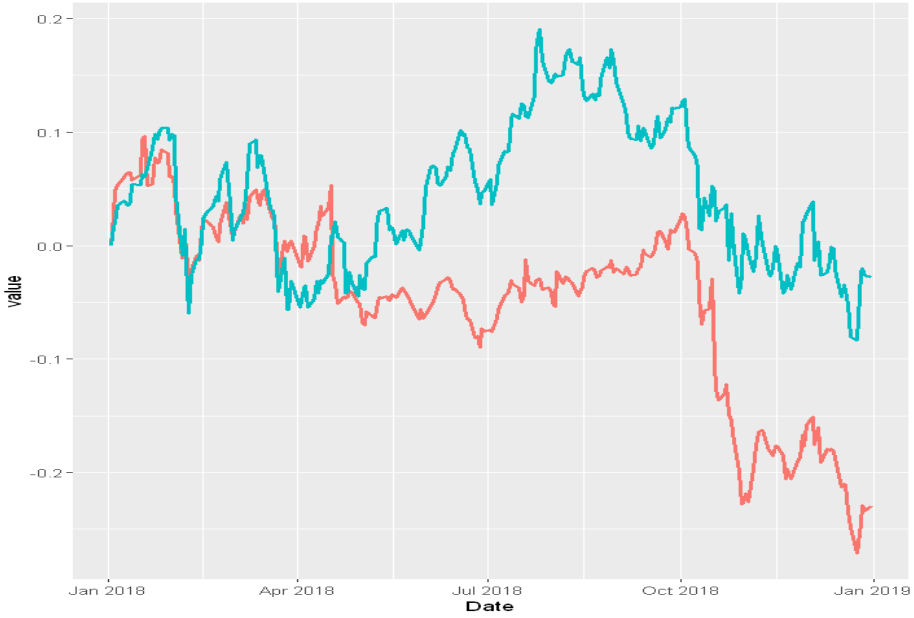
What's wrong with it?

Multiple Time Series examples

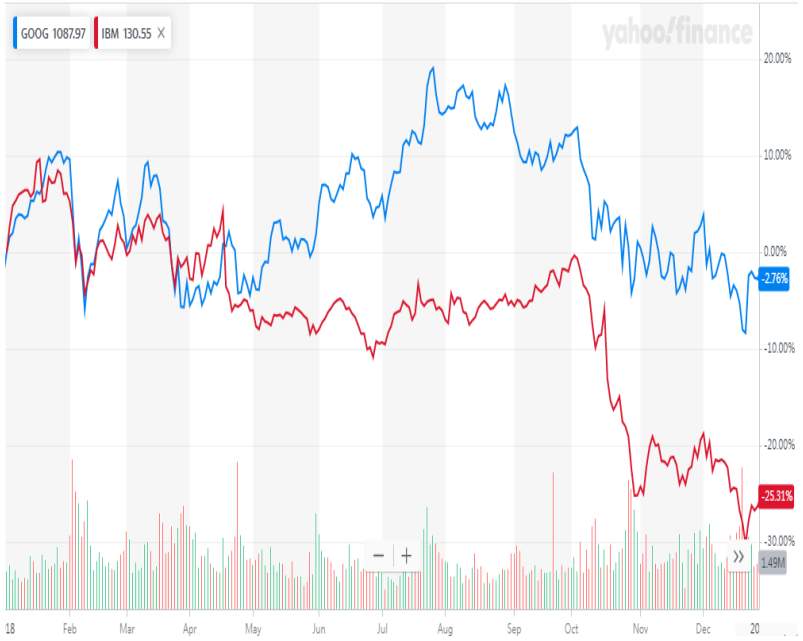
Use percent change when plotting multiple stocks

```
ibm_startprice=IBM[1, 6]
goog_startprice=GOOG[1, 6]
data.frame(Date=IBM$Date,
           IBM=transmute(IBM, IBM=(Adj.Close-ibm_startprice)/ibm_startprice),
           GOOG=transmute(GOOG, GOOG=(Adj.Close-goog_startprice)/goog_startprice)) %>%
reshape2::melt(id.vars="Date") %>%
ggplot(aes(x=Date, y=value, group=variable, color=variable)) + geom_line(size=1)
```

From R code



From Yahoo finance



Interactive data visualization: plotly

- Plotly is helping to close the gap between data science and the business.
- Plotly provides online graphing, analytics, and statistics tools for individuals and collaboration, as well as scientific graphing libraries for Python, R, MATLAB, Perl, Julia, Arduino, and REST.
- Create interactive and dynamic web graphics for data analysis
- No need web technology (e.g., JavaScript, HTML, CSS)

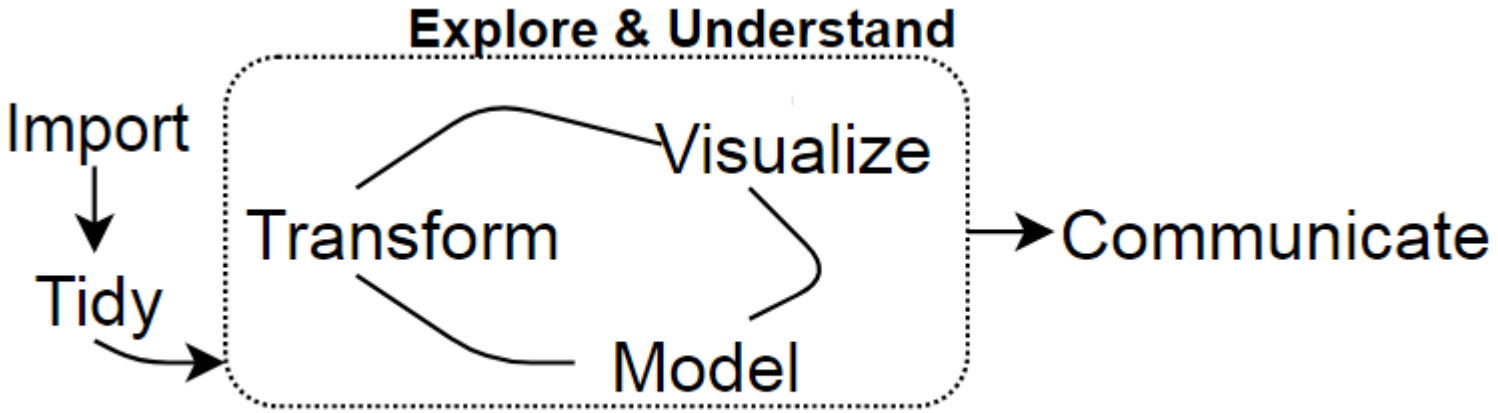
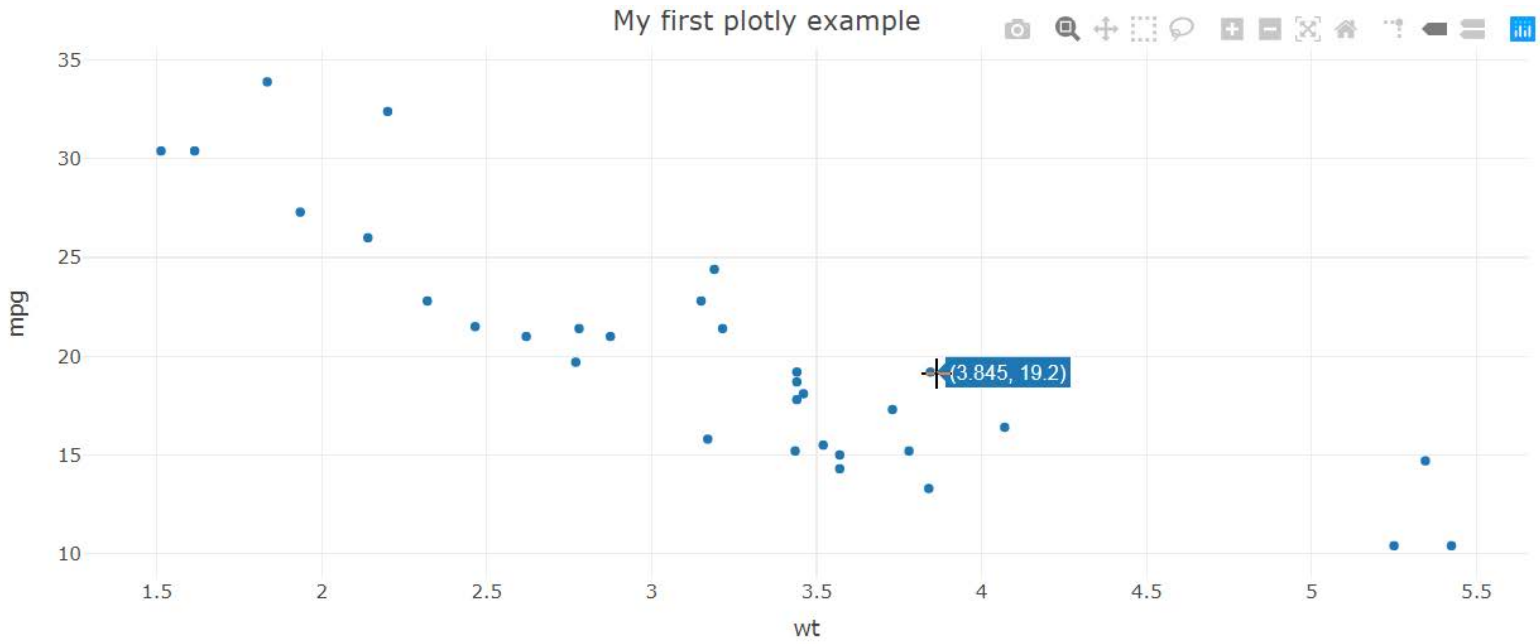


Diagram from: *R for Data Science* (Grolemund & Wickham 2016)

Install plotly and your first example

The graph is interactive when view on a webpage such as jupyter notebook. Tooltips appear when your mouse hovers over each point.

```
install.packages("plotly")
library(plotly)
plot_ly(mtcars, x=~wt, y=~mpg) %>% layout(title = "My first plotly example")
```



Key components in plotly

- In plotly terminology, a *figure* has two key components

- data (aka, traces)
  - Defines a mapping from data and visuals
  - Every trace has a *type* (e.g., histogram, pie, scatter, etc)
  - The trace type determines what other attributes (i.e., visual and/or interactive properties, like x, hoverinfo, name) are available to control the trace mapping
- layout
  - layout() function anticipates a **plotly** object in it's first argument
  - Other arguments add and/or modify various layout components of that object (e.g., the title)

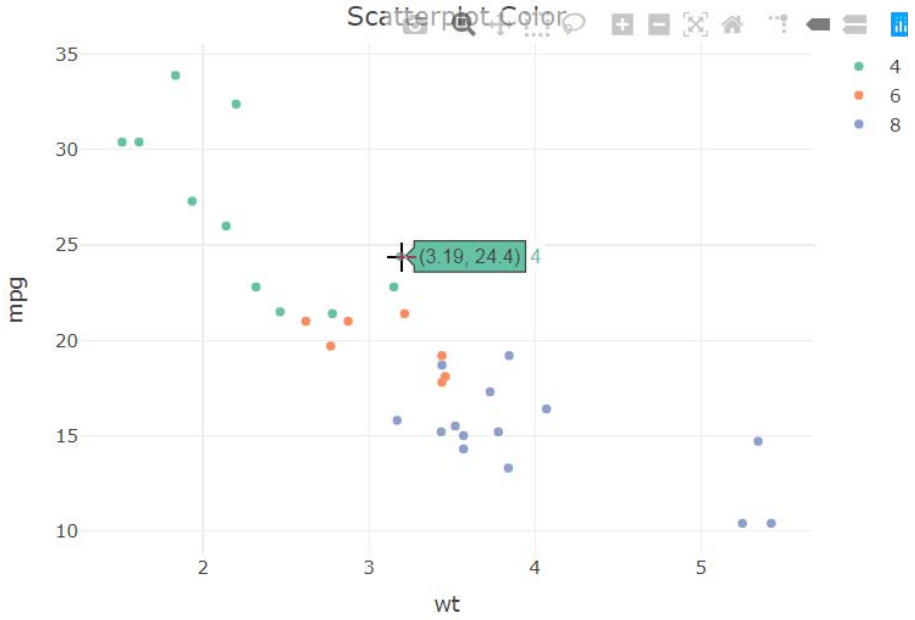
```
plot_ly(mtcars, x=~wt, y=~mpg) %>% layout(title = "My first plotly example")
```

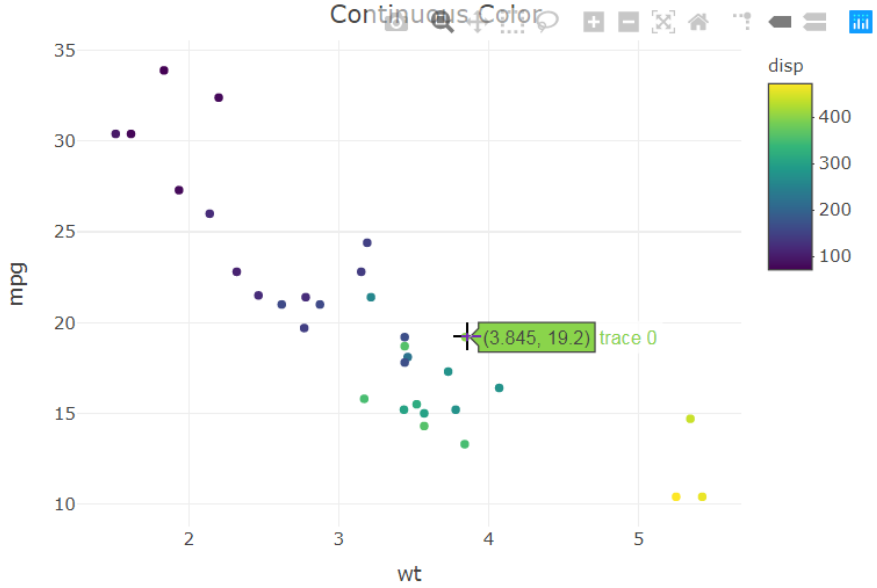
Trace

Layout

Add the 3rd dimension to scatterplot

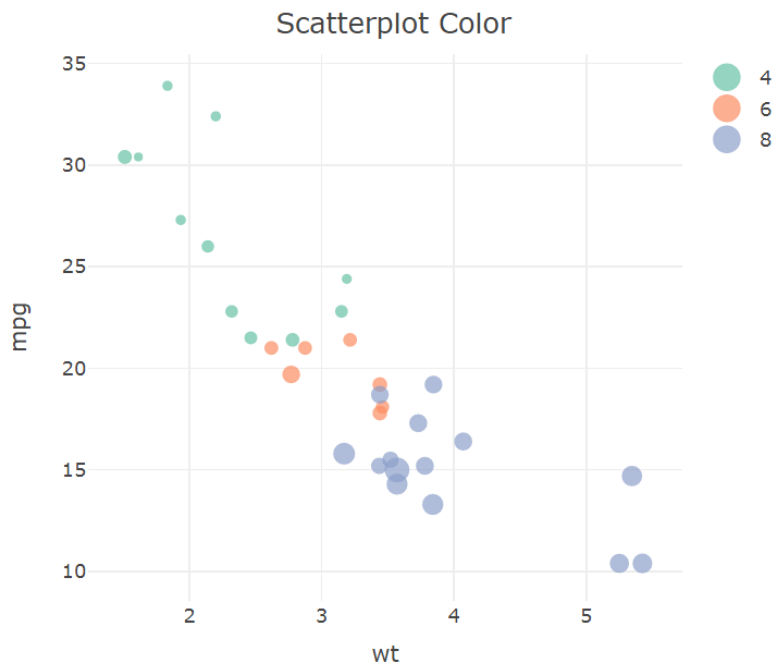
```
plot_ly(mtcars, x=~wt, y=~mpg, mode="markers", type="scatter",
        color=~factor(cyl)) %>% layout(title = "Scatterplot Color")
plot_ly(mtcars, x=~wt, y=~mpg, mode="markers", type="scatter",
        color=~disp) %>% layout(title = "Continuous Color")
```

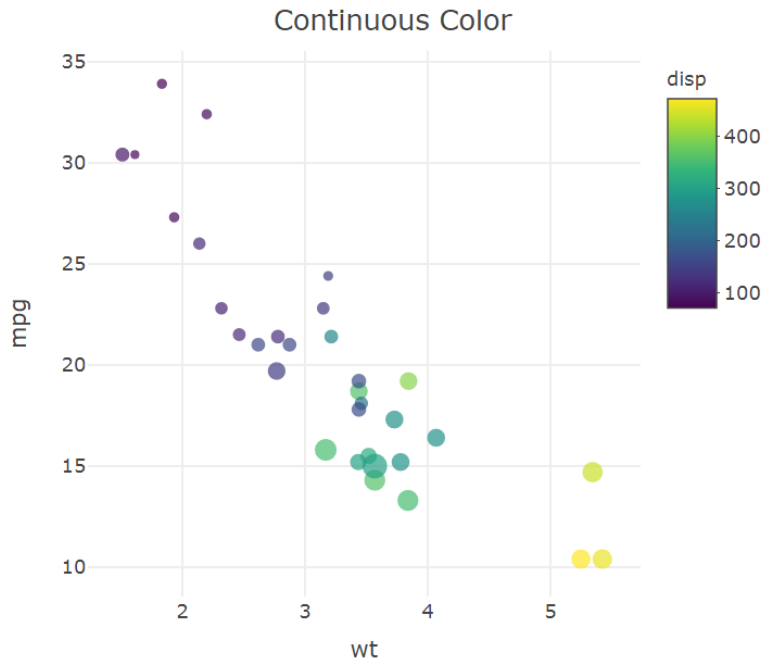




Add the 4th dimension to scatterplot

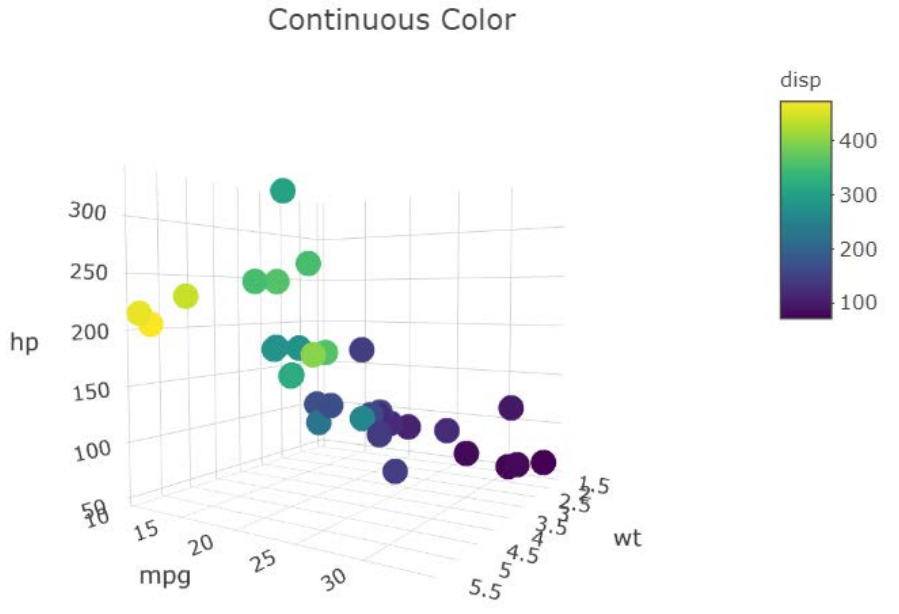
```
plot_ly(mtcars, x=~wt, y=~mpg, mode="markers", type="scatter",
        color=~factor(cyl), size=~hp) %>% layout(title = "Scatterplot Color")
plot_ly(mtcars, x=~wt, y=~mpg, mode="markers", type="scatter",
        color=~disp, size=~hp) %>% layout(title = "Continuous Color")
```

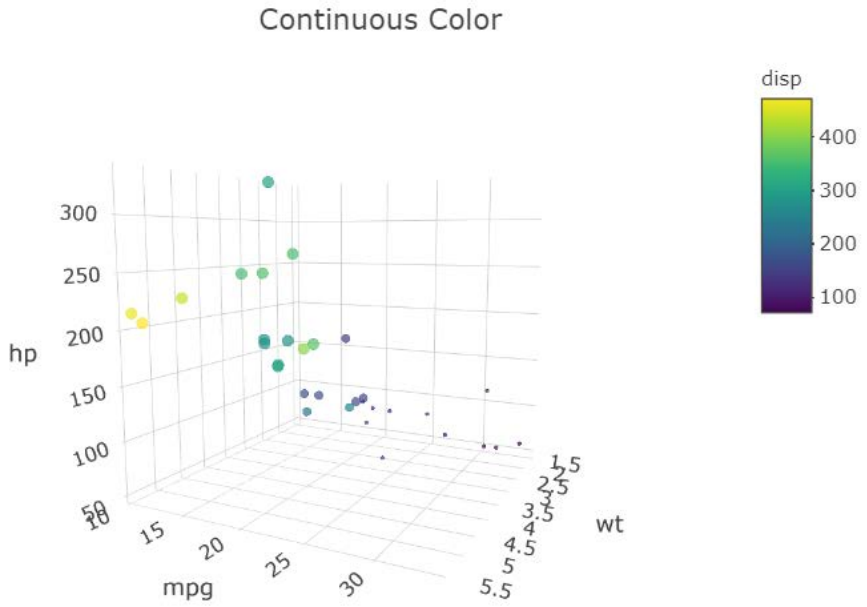




Plot 4 and 5 dimensions in 3d scatterplot

```
plot_ly(mtcars, x=~wt, y=~mpg, z=~hp, mode="markers", type="scatter3d",
        color=~disp) %>% layout(title = "Continuous Color")
plot_ly(mtcars, x=~wt, y=~mpg, z=~hp, mode="markers", type="scatter3d",
        color=~disp, size=~cyl) %>% layout(title = "Continuous Color")
```



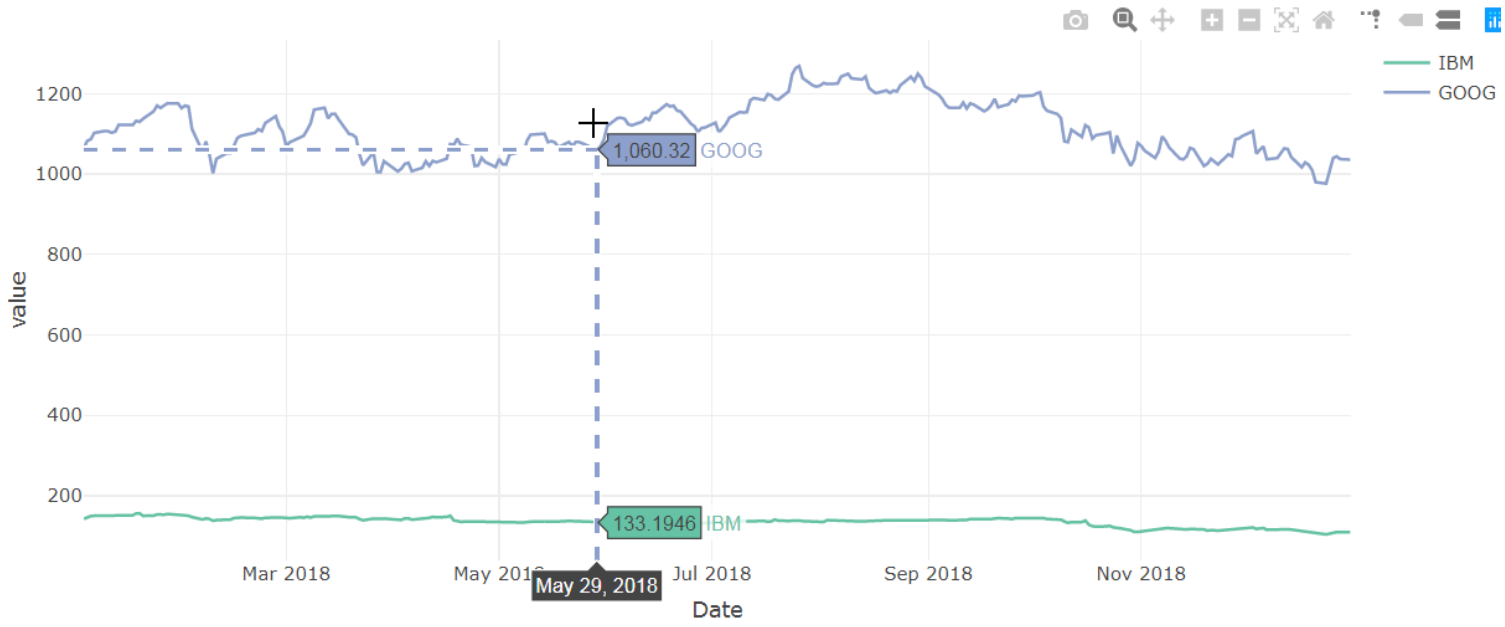


Lineplot in plotly: time series

```
plot_ly(x=IBM$Date, y=IBM$Adj.Close) %>% add_lines

or

IBM %>% plot_ly(x=~Date, y=~Adj.Close) %>% add_lines
```

Plot multiple time series

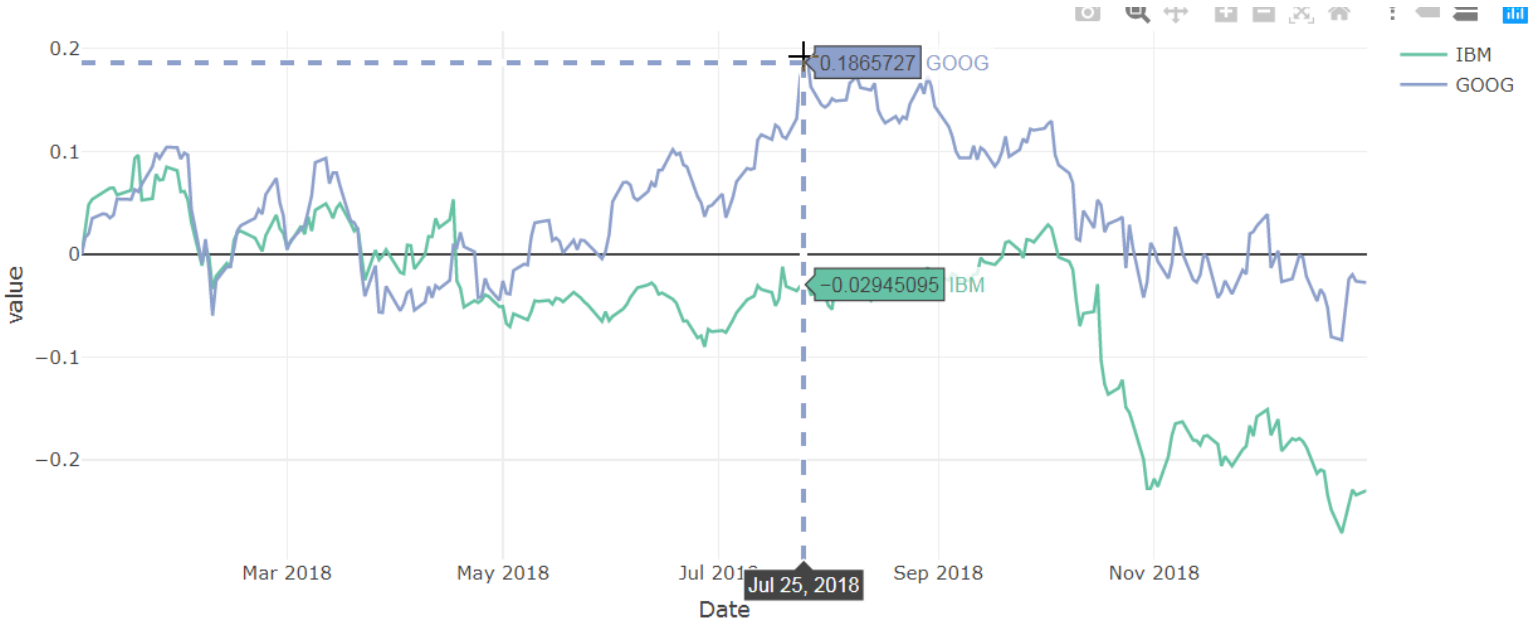
```
data.frame(Date=IBM$Date, IBM=IBM$Adj.Close, GOOG=GOOG$Adj.Close) %>%
reshape2::melt(id.vars="Date") %>%
plot_ly(x=~Date, y=~value, color=~variable) %>% add_lines
```



Same problem. We need to plot the percent change to compare two stocks

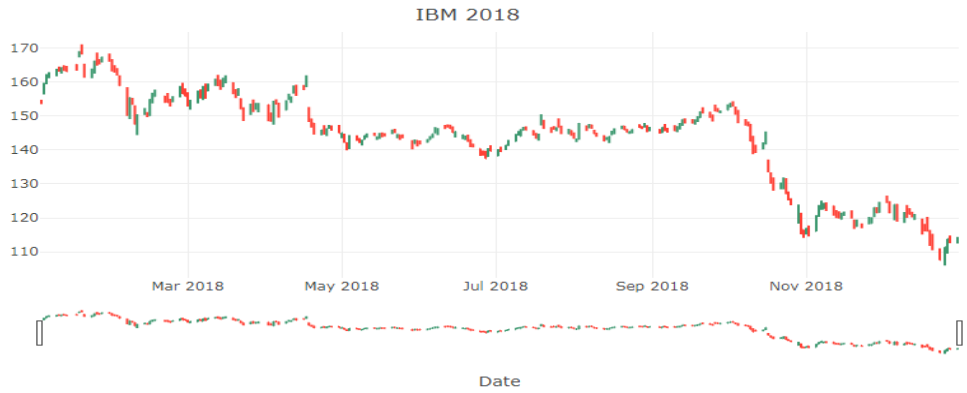
Plot multiple time series with percent change

```
ibm_startprice=IBM[1, 6]
goog_startprice=GOOG[1, 6]
data.frame(Date=IBM$Date,
           IBM=transmute(IBM, IBM=(Adj.Close-ibm_startprice)/ibm_startprice),
           GOOG=transmute(GOOG, GOOG=(Adj.Close-goog_startprice)/goog_startprice)) %>%
reshape2::melt(id.vars="Date") %>%
plot_ly(x=~Date, y=~value, color=~variable) %>% add_lines
```

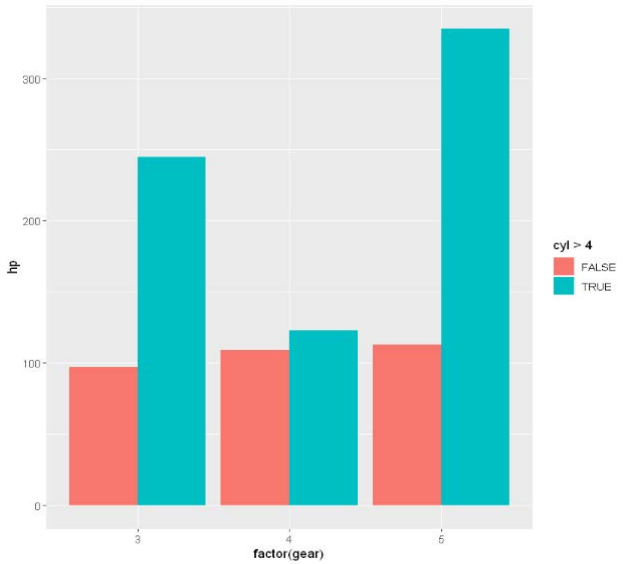


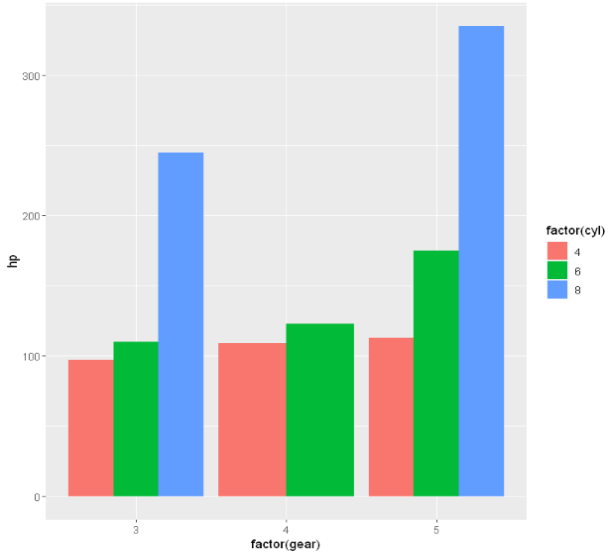
Lab exercise of today

1. Using plotly, figure out how to plot stock OHLC chart and plot IBM as below



2. Using plotly, write R code to generate grouped barplots similar to ggplot2 as below





Read more

- https://tutorials.iq.harvard.edu/R/Rgraphics/Rgraphics.html
- http://r-statistics.co/ggplot2-Tutorial-With-R.html
- https://www.r-graph-gallery.com/index.html
- https://plotly-r.com/

•Issue with ggplot2, geom_bar, and position="dodge": stacked has correct y values, dodged does not

https://stackoverflow.com/questions/11604070/issue-with-ggplot2-geom-bar-and-position-dodge-stacked-has-correct-y-values