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R graphics with ggplot2 workshop notes

Materials and setup

Laptop users: You should have R installed; if not:

1. Open a web browser and go to <http://cran.r-project.org> (<http://cran.r-project.org>) and download and install it
2. Also helpful to install RStudio (download from <http://rstudio.com> (<http://rstudio.com>))
3. In R, type `install.packages("tidyverse")` to install a suite of useful packages including `ggplot2`

Everyone: Download workshop materials:

1. Download materials from <http://tutorials.iq.harvard.edu/R/Rgraphics.zip> (<http://tutorials.iq.harvard.edu/R/Rgraphics.zip>)
2. Extract the zip file containing the materials to your desktop

Workshop Overview

Class Structure and Organization:

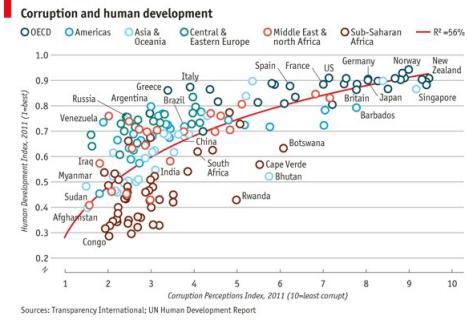
- Ask questions at any time. Really!
- Collaboration is encouraged
- This is your class! Special requests are encouraged

This is an intermediate R course:

- Assumes working knowledge of R
- Relatively fast-paced
- Focus is on `ggplot2` graphics—other packages will not be covered

Starting At The End

My goal: by the end of the workshop you will be able to reproduce this graphic from the Economist:



Sources: Transparency International; UN Human Development Report

img

Why 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

That said, there are some things you cannot (or should not) do With ggplot2:

- 3-dimensional graphics (see the `r3d` package)
- Graph-theory type graphs (nodes/edges layout; see the `igraph` package)
- Interactive graphics (see the `ggvis` package)

What Is The Grammar Of Graphics?

The basic idea: independently specify plot building blocks and combine them to create just about any kind of graphical display you want. Building blocks of a graph include:

- data
- aesthetic mapping
- geometric object
- statistical transformations
- scales
- coordinate system
- position adjustments
- faceting

Setup: install the tidyverse package

The `ggplot2` package is included in a popular collection of packages called "the tidyverse". Take a moment to ensure that it is installed, and that we have attached the `ggplot2` package.

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

## -- Attaching packages -- tidyverse 1.2.1 --
## 
##   ✓ ggplot2 3.0.0    ✓ purrr   0.2.5
##   ✓ tibble  1.4.2    ✓ dplyr   0.7.6
##   ✓ tidyr   0.8.1    ✓ stringr 1.3.1
##   ✓ readr   1.1.1    ✓ forcats 0.3.0

## -- Conflicts --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()   masks stats::lag()
```

Example Data: Housing prices

Let's look at housing prices.

```
housing <- read_csv("dataSets/landdata-states.csv")
```

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```
## Parsed with column specification:
## cols(
##   State = col_character(),
##   region = col_character(),
##   Date = col_double(),
##   Home.Value = col_integer(),
##   Structure.Cost = col_integer(),
##   Land.Value = col_integer(),
##   Land.Share.Pct. = col_double(),
##   Home.Price.Index = col_double(),
##   Land.Price.Index = col_double(),
##   Year = col_integer(),
##   Qtr = col_integer()
## )
```

```
head(housing[1:5])
```

```
## # A tibble: 6 x 5
##   State region  Date Home.Value Structure.Cost
##   <chr> <chr> <dbl>     <int>        <int>
## 1 AK   West    2010.    224952      160599
## 2 AK   West    2010.    235511      160282
## 3 AK   West    2010.    225820      163791
## 4 AK   West    2010.    224994      161787
## 5 AK   West    2008.    234590      155400
## 6 AK   West    2008.    233714      157458
```

ggplot2 VS Base Graphics

Compared to base graphics, ggplot2

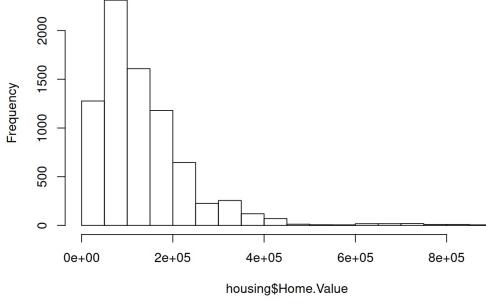
- is more verbose for simple / canned graphics
- is less verbose for complex / custom graphics
- does not have methods (data should always be in a `data.frame`)
- uses a different system for adding plot elements

ggplot2 VS Base for simple graphs

Base graphics histogram example:

```
hist(housing$Home.Value)
```

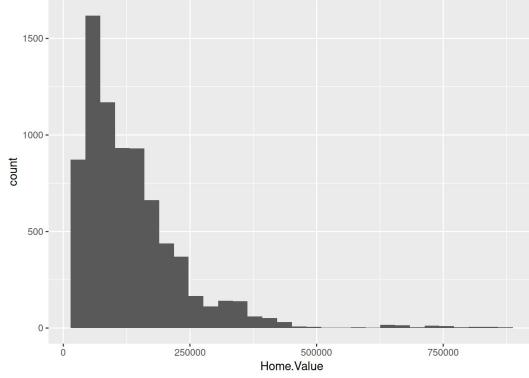
Histogram of housing\$Home.Value



ggplot2 histogram example:

```
library(ggplot2)
ggplot(housing, aes(x = Home.Value)) +
  geom_histogram()
```

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

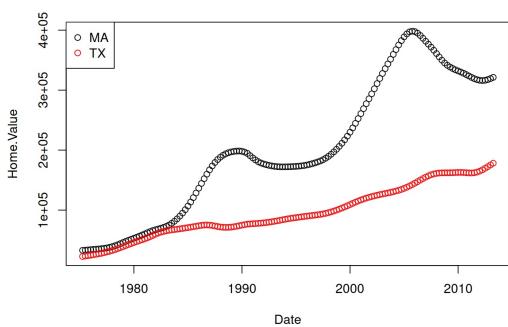


ggplot2 Base graphics VS ggplot for more complex graphs:

Base graphics colored scatter plot example:

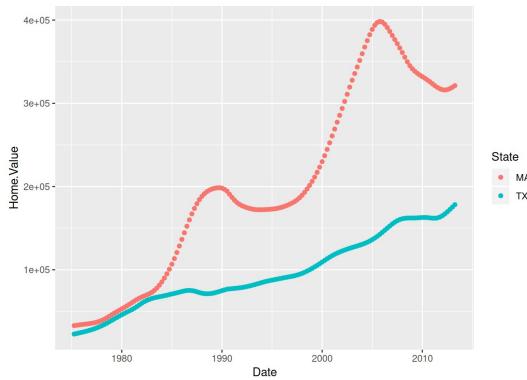
```
plot(Home.Value ~ Date,
     col = factor(State),
     data = filter(housing, State %in% c("MA", "TX"))
legend("topleft",
       legend = c("MA", "TX"),
       col = c("black", "red"),
       pch = 1)
```

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ggplot2 colored scatter plot example:

```
ggplot(filter(housing, State %in% c("MA", "TX")),
       aes(x=Date,
           y=Home.Value,
           color=State)) +
  geom_point()
```



ggplot2 wins!

Geometric Objects And Aesthetics

Aesthetic Mapping

In ggplot land *aesthetic* means “something you can see”. Examples include:

- position (i.e., on the x and y axes)
- color (“outside” color)
- fill (“inside” color)
- shape (of points)
- linetype
- size

Each type of geom accepts only a subset of all aesthetics—refer to the geom help pages to see what mappings each geom accepts. Aesthetic mappings are set with the `aes()` function.

Geometric Objects (geom)

Geometric objects are the actual marks we put on a plot. Examples include:

- points (`geom_point`, for scatter plots, dot plots, etc)
- lines (`geom_line`, for time series, trend lines, etc)
- boxplot (`geom_boxplot`, for, well, boxplots!)

A plot must have at least one geom; there is no upper limit. You can add a geom to a plot using the `+` operator

You can get a list of available geometric objects using the code below:

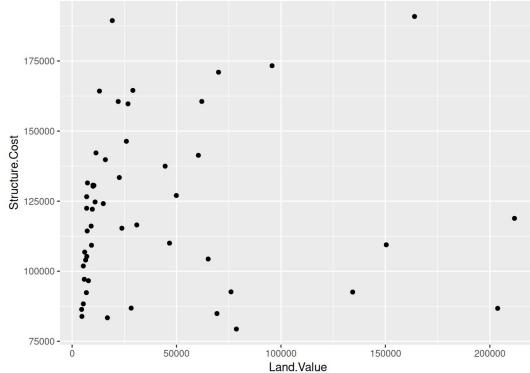
```
help.search("geom_", package = "ggplot2")
```

or simply type `geom_<tab>` in any good R IDE (such as Rstudio or ESS) to see a list of functions starting with `geom_`.

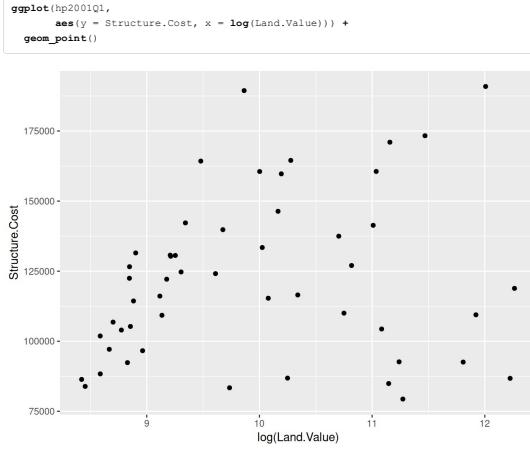
Points (Scatterplot)

Now that we know about geometric objects and aesthetic mapping, we can make a ggplot. `geom_point` requires mappings for x and y, all others are optional.

```
hp2001Q1 <- filter(housing, Date == 2001.25)
ggplot(hp2001Q1,
       aes(y = Structure.Cost, x = Land.Value)) +
  geom_point()
```



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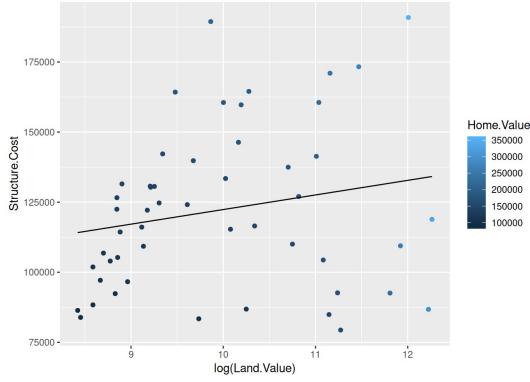
Lines (Prediction Line)

A plot constructed with `ggplot` can have more than one geom. In that case the mappings established in the `ggplot()` call are plot defaults that can be added to or overridden. Our plot could use a regression line:

```
hp2001Q1$pred.SC <- predict(lm(Structure.Cost ~ log(Land.Value), data = hp2001Q1))

p1 <- ggplot(hp2001Q1, aes(x = log(Land.Value), y = Structure.Cost))

p1 + geom_point(aes(color = Home.Value)) +
  geom_line(aes(y = pred.SC))
```

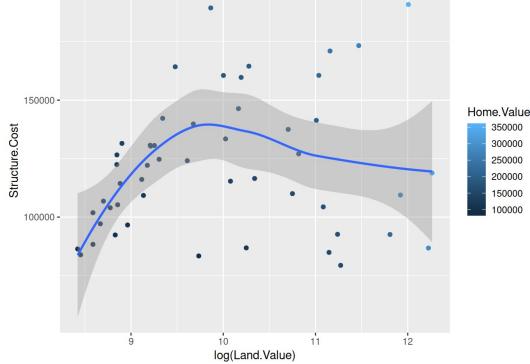


Smoothers

Not all geometric objects are simple shapes—the smooth geom includes a line and a ribbon.

```
p1 +
  geom_point(aes(color = Home.Value)) +
  geom_smooth()

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```

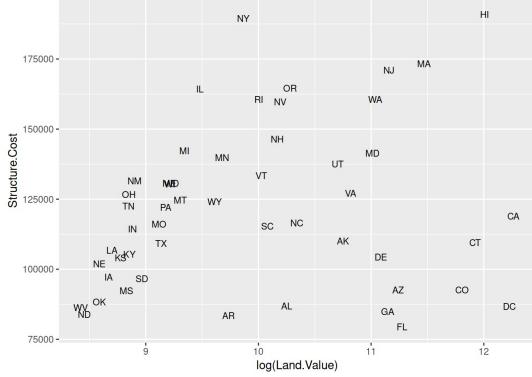


Text (Label Points)

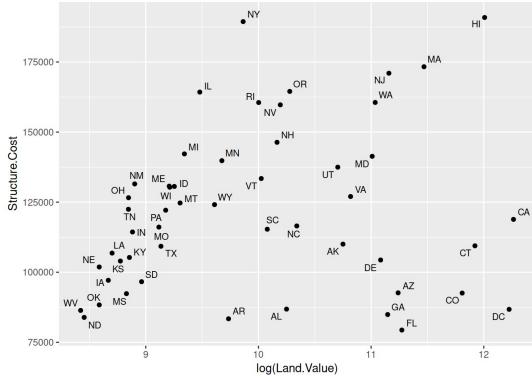
Each `geom` accepts a particular set of mappings; for example `geom_text()` accepts a `label` mapping.

```
p1 +
  geom_text(aes(label=State), size = 3)
```

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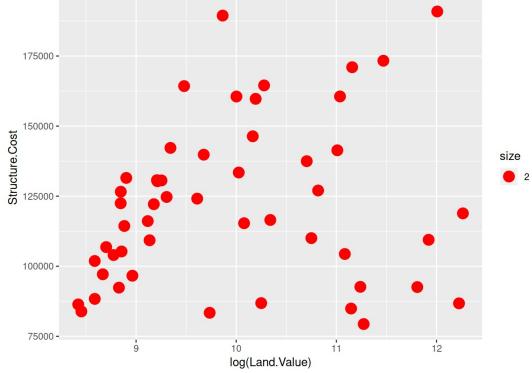
```
## install.packages("ggrepel")
library("ggrepel")
p1 +
  geom_point() +
  geom_text_repel(aes(label=State), size = 3)
```



Aesthetic Mapping VS Assignment

Note that variables are mapped to aesthetics with the `aes()` function, while fixed aesthetics are set outside the `aes()` call. This sometimes leads to confusion, as in this example:

```
p1 +
  geom_point(aes(size = 2),# incorrect! 2 is not a variable
             color="red") # this is fine -- all points red
```

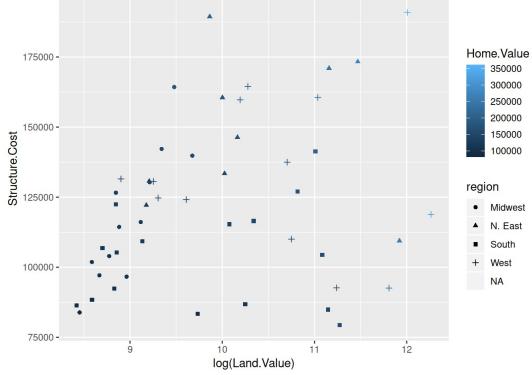


Mapping Variables To Other Aesthetics

Other aesthetics are mapped in the same way as x and y in the previous example.

```
p1 +
  geom_point(aes(color=Home.Value, shape = region))
```

```
## Warning: Removed 1 rows containing missing values (geom_point).
```



Exercise I

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The data for the exercises is available in the `dataSets/EconomistData.csv` file. Read it in with

```
dat <- read_csv("dataSets/EconomistData.csv")

## Parsed with column specification:
## cols(
##   Country = col_character(),
##   HDI.Rank = col_integer(),
##   HDI = col_double(),
##   CPI = col_double(),
##   Region = col_character()
## )
```

Original sources for these data are <http://www.transparency.org/content/download/64476/1031428> (<http://www.transparency.org/content/download/64476/1031428?lang=en>) http://hdrstats.undp.org/en/indicators/display_cf.xls_indicator.cfm?indicator_id=103106&lang=en (http://hdrstats.undp.org/en/indicators/display_cf.xls_indicator.cfm?indicator_id=103106&lang=en)

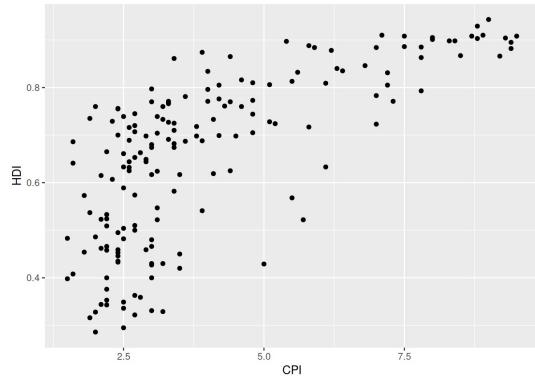
These data consist of *Human Development Index* and *Corruption Perception Index* scores for several countries.

1. Create a scatter plot with CPI on the x axis and HDI on the y axis.
2. Color the points blue.
3. Map the color of the points to Region.
4. Make the points bigger by setting size to 2
5. Map the size of the points to HDI.Rank

Exercise I prototype :prototype:

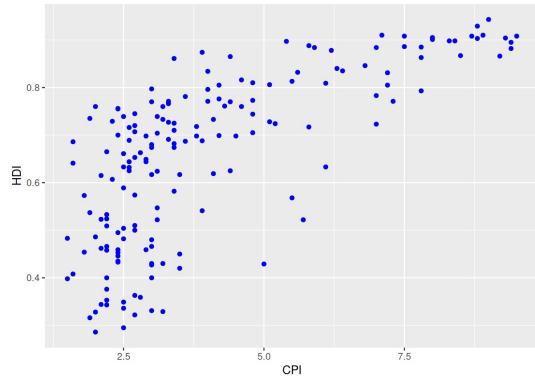
1. Create a scatter plot with CPI on the x axis and HDI on the y axis.

```
ggplot(dat, aes(x = CPI, y = HDI)) +
  geom_point()
```



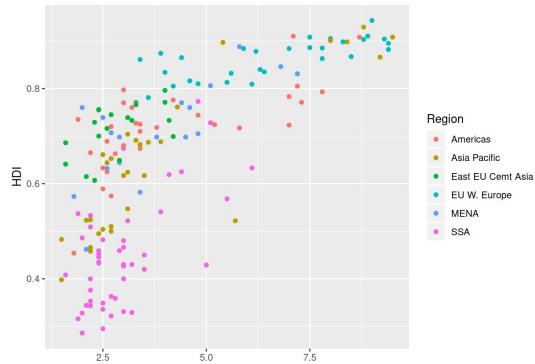
2. Color the points in the previous plot blue.

```
ggplot(dat, aes(x = CPI, y = HDI)) +
  geom_point(color = "blue")
```



3. Color the points in the previous plot according to *Region*.

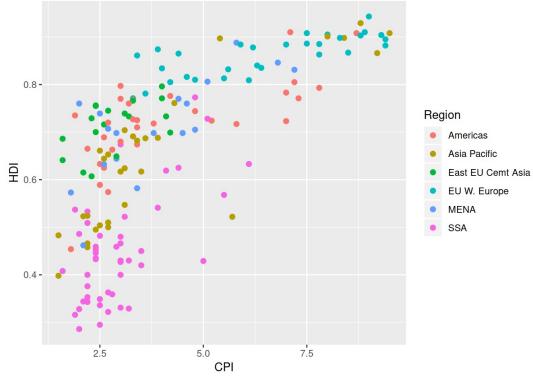
```
ggplot(dat, aes(x = CPI, y = HDI)) +
  geom_point(aes(color = Region))
```



4. Make the points bigger by setting size to 2

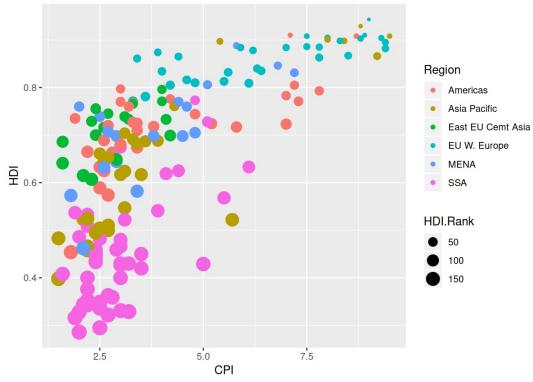
```
ggplot(dat, aes(x = CPI, y = HDI)) +
  geom_point(aes(color = Region), size = 2)
```

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5. Make the points bigger by setting size to 2

```
ggplot(data, aes(x = CPI, y = HDI)) +
  geom_point(aes(color = Region, size = HDI.Rank))
```



Statistical Transformations

Statistical Transformations

Some plot types (such as scatterplots) do not require transformations—each point is plotted at x and y coordinates equal to the original value. Other plots, such as boxplots, histograms, prediction lines etc. require statistical transformations:

- for a boxplot the y values must be transformed to the median and 1.5(IQR)
- for a smoother smoother the y values must be transformed into predicted values

Each `geom` has a default statistic, but these can be changed. For example, the default statistic for `geom_bar` is `stat_bin`:

```
args(geom_histogram)
## function (mapping = NULL, data = NULL, stat = "bin", position = "stack",
##   ..., binwidth = NULL, bins = NULL, na.rm = FALSE, show.legend = NA,
##   inherit.aes = TRUE)
## NULL

args(stat_bin)
## function (mapping = NULL, data = NULL, geom = "bar", position = "stack",
##   ..., binwidth = NULL, bins = NULL, center = NULL, boundary = NULL,
##   breaks = NULL, closed = c("right", "left"), pad = FALSE,
##   na.rm = FALSE, show.legend = NA, inherit.aes = TRUE)
## NULL
```

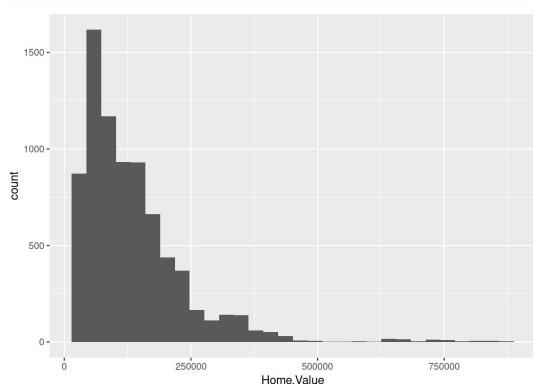
Setting Statistical Transformation Arguments

Arguments to `stat_` functions can be passed through `geom_` functions. This can be slightly annoying because in order to change it you have to first determine which stat the geom uses, then determine the arguments to that stat.

For example, here is the default histogram of Home.Value:

```
p2 <- ggplot(housing, aes(x = Home.Value))
p2 + geom_histogram()

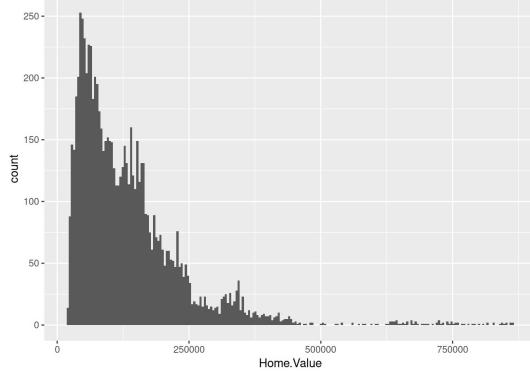
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



can change it by passing the `binwidth` argument to the `stat_bin` function:

```
p2 + geom_histogram(stat = "bin", binwidth=4000)
```

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Changing The Statistical Transformation

Sometimes the default statistical transformation is not what you need. This is often the case with pre-summarized data:

```
housing.sum <- aggregate(housing[["Home.Value"]], housing[["State"]], FUN=mean)
rbind(head(housing.sum), tail(housing.sum))
```

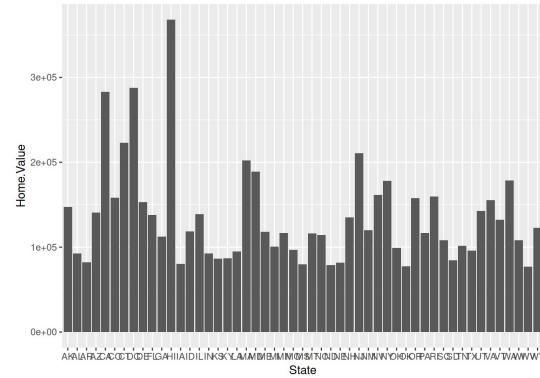
```
##   State Home.Value
## 1 AK 147385.14
## 2 AL 92545.22
## 3 AR 82076.84
## 4 AZ 140755.59
## 5 CA 282808.08
## 6 CO 158175.99
## 46 VA 155391.44
## 47 VT 132394.60
## 48 WA 178522.58
## 49 WI 108359.45
## 50 WV 77161.71
## 51 WY 122897.25
```

```
ggplot(housing.sum, aes(x=State, y=Home.Value)) +
  geom_bar()
```

```
## Error: stat_count() must not be used with a y aesthetic.
```

What is the problem with the previous plot? Basically we take binned and summarized data and ask ggplot to bin and summarize it again (remember, `geom_bar` defaults to `stat = stat_count`); obviously this will not work. We can fix it by telling `geom_bar` to use a different statistical transformation function:

```
ggplot(housing.sum, aes(x=State, y=Home.Value)) +
  geom_bar(stat="identity")
```



Exercise II

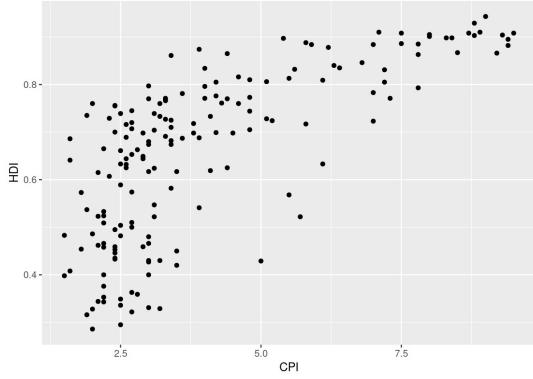
1. Re-create a scatter plot with CPI on the x axis and HDI on the y axis (as you did in the previous exercise).
2. Overlay a smoothing line on top of the scatter plot using `geom_smooth`.
3. Overlay a smoothing line on top of the scatter plot using `geom_smooth`, but use a linear model for the predictions. Hint: see `?stat_smooth`.
4. Overlay a smoothing line on top of the scatter plot using `geom_line`. Hint: change the statistical transformation.
5. BONUS: Overlay a smoothing line on top of the scatter plot using the default `loess` method, but make it less smooth. Hint: see `?loess`.

Exercise II prototype :prototype:

1. Re-create a scatter plot with CPI on the x axis and HDI on the y axis (as you did in the previous exercise).

```
ggplot(dat, aes(x = CPI, y = HDI)) +
  geom_point()
```

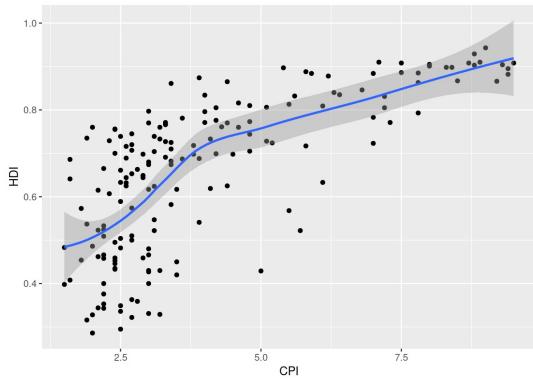
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2. Overlay a smoothing line on top of the scatter plot using `geom_smooth`

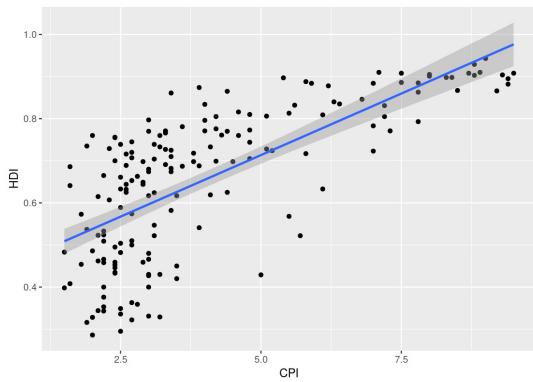
```
ggplot(dat, aes(x = CPI, y = HDI)) +
  geom_point() +
  geom_smooth()
```

```
## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



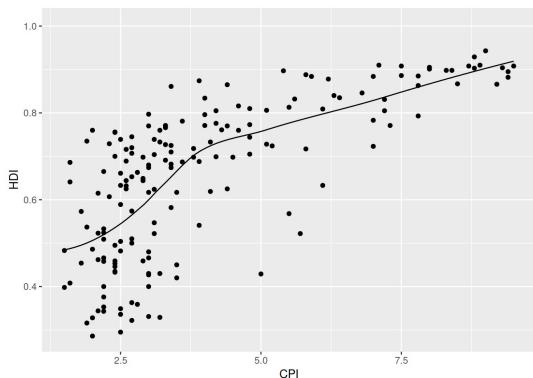
3. Overlay a smoothing line on top of the scatter plot using `geom_smooth`, but use a linear model for the predictions. Hint: see `?stat_smooth`.

```
ggplot(dat, aes(x = CPI, y = HDI)) +
  geom_point() +
  geom_smooth(method = "lm")
```



4. Overlay a loess (method = "loess") smoothing line on top of the scatter plot using `geom_line`. Hint: change the statistical transformation.

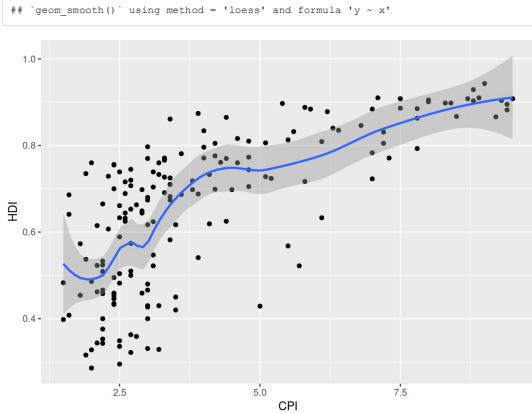
```
ggplot(dat, aes(x = CPI, y = HDI)) +
  geom_point() +
  geom_line(stat = "smooth", method = "loess")
```



4. BONUS: Overlay a smoothing line on top of the scatter plot using the `loess` method, but make it less smooth. Hint: see `?loess`.

```
ggplot(dat, aes(x = CPI, y = HDI)) +
  geom_point() +
  geom_smooth(span = .4)
```

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Scales

Scales: Controlling Aesthetic Mapping

Aesthetic mapping (i.e., with `aes()`) only says that a variable should be mapped to an aesthetic. It doesn't say *how* that should happen. For example, when mapping a variable to `shape` with `aes(shape = x)` you don't say what shapes should be used. Similarly, `aes(color = z)` doesn't say what colors should be used. Describing what colors/shapes/sizes etc. to use is done by modifying the corresponding scale. In `ggplot2` scales include

- position
- color and fill
- size
- shape
- line type

Scales are modified with a series of functions using a `scale_<aesthetic>_<type>` naming scheme. Try typing `scale_<tab>` to see a list of scale modification functions.

Common Scale Arguments

The following arguments are common to most scales in `ggplot2`:

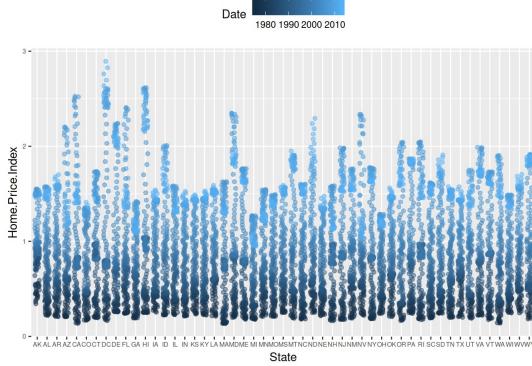
- **name:** the first argument gives the axis or legend title
- **limits:** the minimum and maximum of the scale
- **breaks:** the points along the scale where labels should appear
- **labels:** the labels that appear at each break

Specific scale functions may have additional arguments; for example, the `scale_color_continuous` function has arguments `low` and `high` for setting the colors at the low and high end of the scale.

Scale Modification Examples

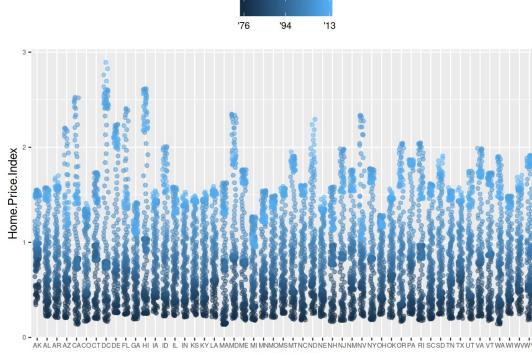
Start by constructing a dotplot showing the distribution of home values by Date and State.

```
p3 <- ggplot(housing,
              aes(x = State,
                  y = Home.Price.Index)) +
  theme(legend.position="top",
        axis.text=element_text(size = 6))
(p4 <- p3 + geom_point(aes(color = Date),
                      alpha = 0.5,
                      size = 1.5,
                      position = position_jitter(width = 0.25, height = 0)))
```



Now modify the breaks for the x axis and color scales

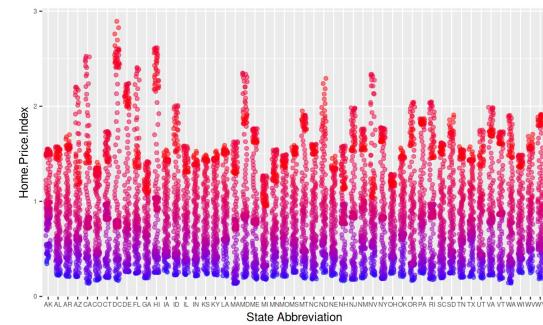
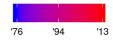
```
p4 + scale_x_discrete(name="State Abbreviation") +
  scale_color_continuous(name="",
                         breaks = c(1976, 1994, 2013),
                         labels = c("76", "94", "13"))
```



Next change the low and high values to blue and red:

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```
p4 +
  scale_x_discrete(name="State Abbreviation") +
  scale_color_continuous(name="",
```



```
library(scales)
```

```
## ## Attaching package: 'scales'
```

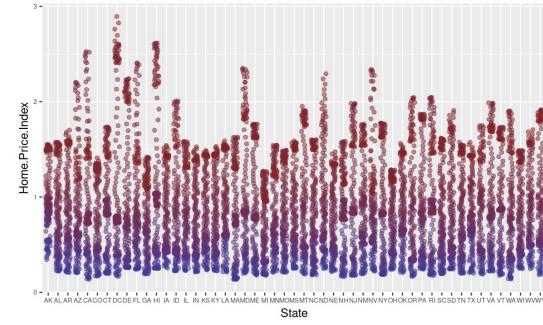
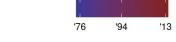
```
## The following object is masked from 'package:purrr':
```

```
## ## discard
```

```
## The following object is masked from 'package:readr':
```

```
## ## col_factor
```

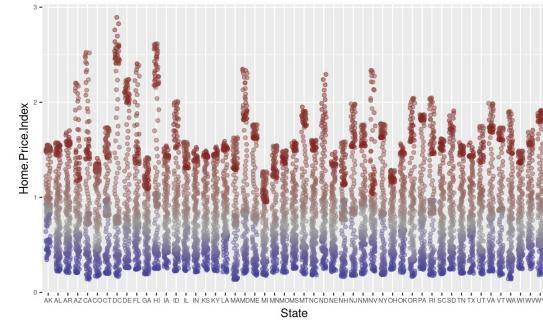
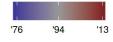
```
p4 +
  scale_color_continuous(name="",
```



Using different color scales

ggplot2 has a wide variety of color scales; here is an example using `scale_color_gradient2` to interpolate between three different colors.

```
p4 +
  scale_color_gradient2(name="",
```



Available Scales

- Partial combination matrix of available scales

Scale	Types	Examples
<code>scale_color_</code>	identity	<code>scale_fill_continuous</code>
<code>scale_fill_</code>	manual	<code>scale_color_discrete</code>
<code>scale_size_</code>	continuous	<code>scale_size_manual</code>

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Scale	Types	Examples
	discrete	scale_size_discrete
scale_shape_	discrete	scale_shape_discrete
scale_linetype_	identity	scale_shape_manual
	manual	scale_linetype_discrete
scale_x_	continuous	scale_x_continuous
scale_y_	discrete	scale_y_discrete
	reverse	scale_x_log
	log	scale_y_reverse
	date	scale_x_date
	datetime	scale_y_datetime

Note that in RStudio you can type `scale_` followed by TAB to get the whole list of available scales.

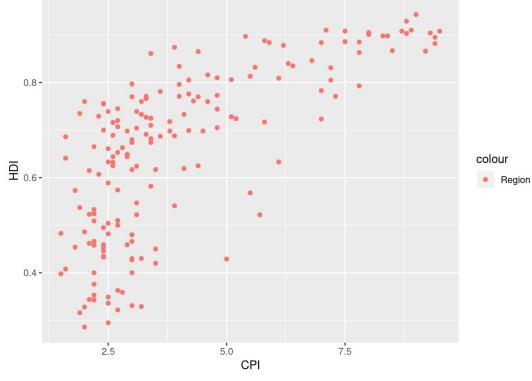
Exercise III

1. Create a scatter plot with CPI on the x axis and HDI on the y axis. Color the points to indicate region.
2. Modify the x, y, and color scales so that they have more easily-understood names (e.g., spell out "Human development Index" instead of "HDI").
3. Modify the color scale to use specific values of your choosing. Hint: see `?scale_color_manual`.

Exercise III prototype :prototype:

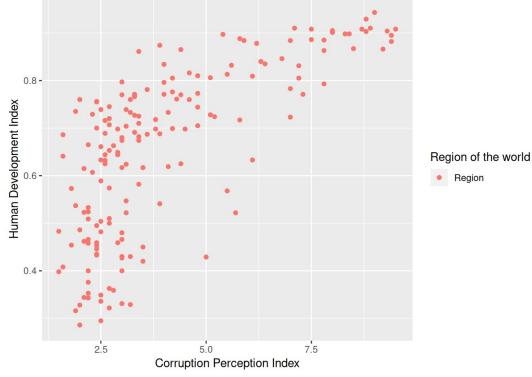
1. Create a scatter plot with CPI on the x axis and HDI on the y axis. Color the points to indicate region.

```
ggplot(dat, aes(x = CPI, y = HDI, color = "Region")) +
  geom_point()
```



2. Modify the x, y, and color scales so that they have more easily-understood names (e.g., spell out "Human development Index" instead of "HDI").

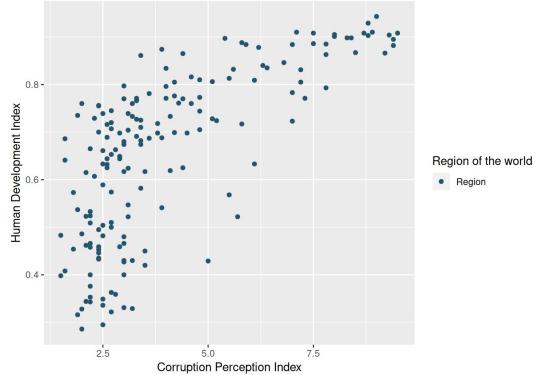
```
ggplot(dat, aes(x = CPI, y = HDI, color = "Region")) +
  geom_point() +
  scale_x_continuous(name = "Corruption Perception Index") +
  scale_y_continuous(name = "Human Development Index") +
  scale_color_discrete(name = "Region of the world")
```



3. Modify the color scale to use specific values of your choosing. Hint: see `?scale_color_manual`.

```
ggplot(dat, aes(x = CPI, y = HDI, color = "Region")) +
  geom_point() +
  scale_x_continuous(name = "Corruption Perception Index") +
  scale_y_continuous(name = "Human Development Index") +
  scale_color_manual(name = "Region of the world",
                     values = c("#24576D",
                               "#090DD7",
                               "#28AADC",
                               "#248E84",
                               "#F25833",
                               "#96505F"))
```

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Faceting

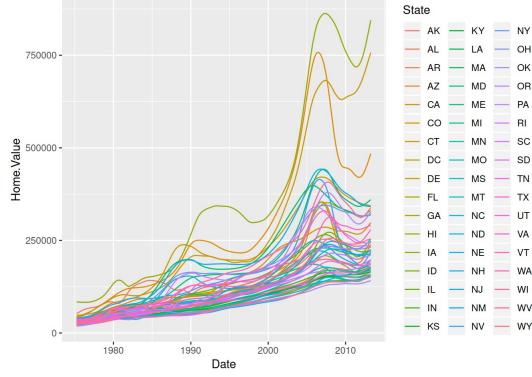
Faceting

- Faceting is `ggplot2` parlance for **small multiples**
- The idea is to create separate graphs for subsets of data
- `ggplot2` offers two functions for creating small multiples:
 1. `facet_wrap()`: define subsets as the levels of a single grouping variable
 2. `facet_grid()`: define subsets as the crossing of two grouping variables
- Facilitates comparison among plots, not just of geoms within a plot

What is the trend in housing prices in each state?

- Start by using a technique we already know—map State to color:

```
p5 <- ggplot(housing, aes(x = Date, y = Home.Value))
p5 + geom_line(aes(color = State))
```

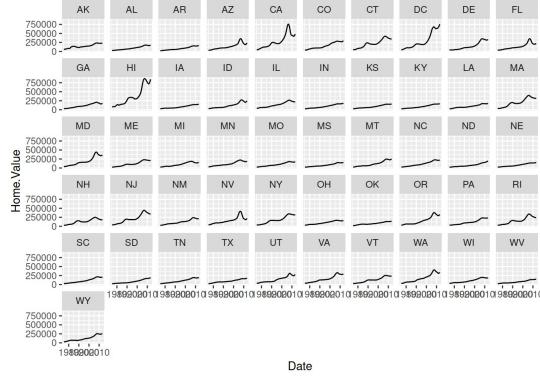


There are two problems here—there are too many states to distinguish each one by color, and the lines obscure one another.

Faceting to the rescue

We can remedy the deficiencies of the previous plot by faceting by state rather than mapping state to color.

```
(p5 <- p5 + geom_line() +
  facet_wrap(~State, ncol = 10))
```



There is also a `facet_grid()` function for faceting in two dimensions.

Themes

Themes

The `ggplot2` theme system handles non-data plot elements such as

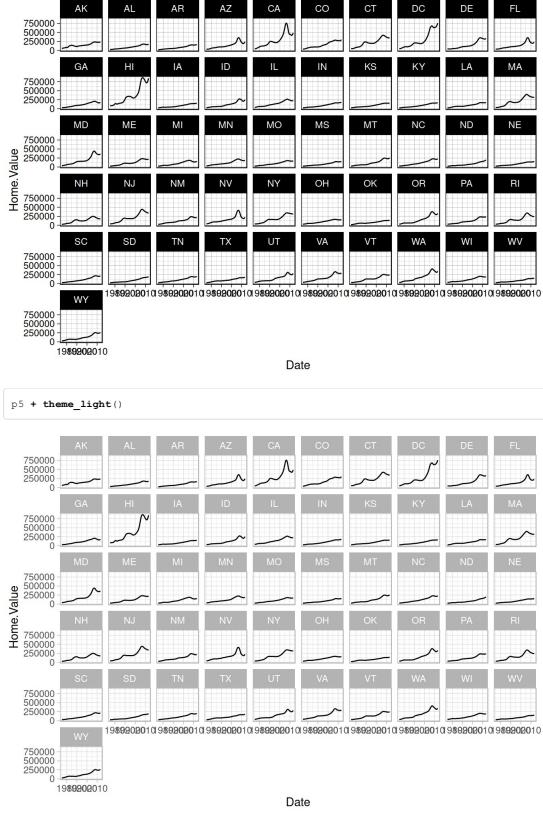
- Axis labels
- Plot background
- Facet label background
- Legend appearance

Built-in themes include:

- `theme_gray()` (default)
- `theme_bw()`
- `theme_classic()`

```
p5 + theme_linedraw()
```

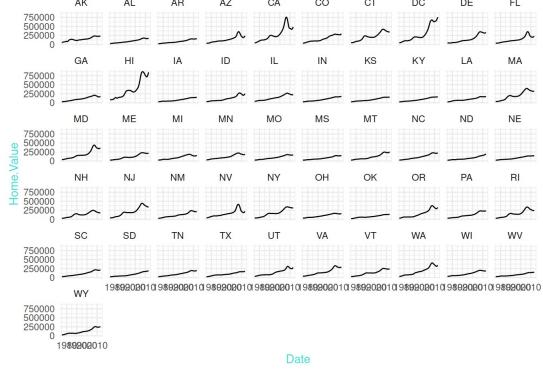
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Overriding theme defaults

Specific theme elements can be overridden using `theme()`. For example:

```
p5 + theme_light() +  
  theme(text = element_text(color = "turquoise"))
```



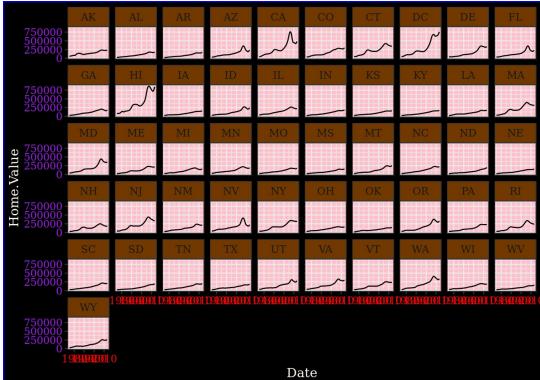
All theme options are documented in `?theme`.

Creating and saving new themes

You can create new themes, as in the following example:

```
theme_new <- theme_bw() +  
  theme(plot.background = element_rect(size = 1, color = "blue", fill = "black"),  
        text = element_text(size = 12, family = "Serif", color = "ivory"),  
        axis.text.y = element_text(colour = "purple"),  
        axis.text.x = element_text(colour = "red"),  
        panel.background = element_rect(fill = "pink"),  
        strip.background = element_rect(fill = muted("orange")))
```

```
p5 + theme_new
```



The #1 FAQ

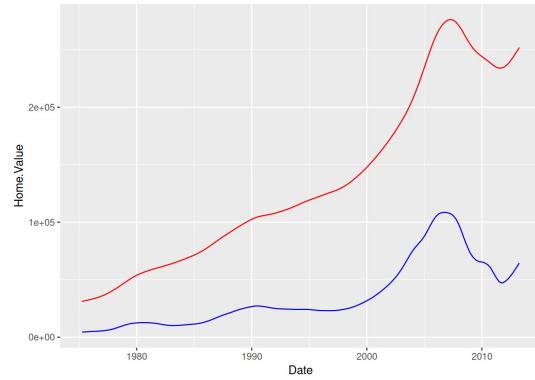
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Map Aesthetic To Different Columns

The most frequently asked question goes something like this: *I have two variables in my data.frame, and I'd like to plot them as separate points, with different color depending on which variable it is. How do I do that?*

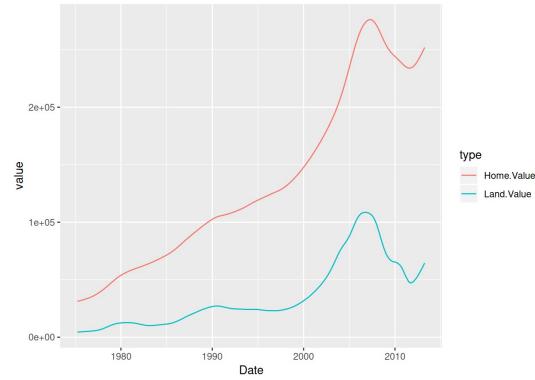
Wrong

```
housing_byyear <- aggregate(chaid(Home.Value, Land.Value) ~ Date, data = housing, mean)
ggplot(housing_byyear,
       aes(x=Date)) +
  geom_line(aes(y=Home.Value), color="red") +
  geom_line(aes(y=Land.Value), color="blue")
```



Right

```
library(tidyr)
home.land_byyear <- gather(housing_byyear,
                           value = "value",
                           key = "type",
                           Home.Value, Land.Value)
ggplot(home.land_byyear,
       aes(x=Date,
           y=value,
           color=type)) +
  geom_line()
```



Putting It All Together

Challenge: Recreate This Economist Graph

<images/Economist1.pdf>
Graph source: <http://www.economist.com/node/21541178>
Building off of the graphics you created in the previous exercises, put the finishing touches to make it as close as possible to the original economist graph.

Challenge Solution :prototype:

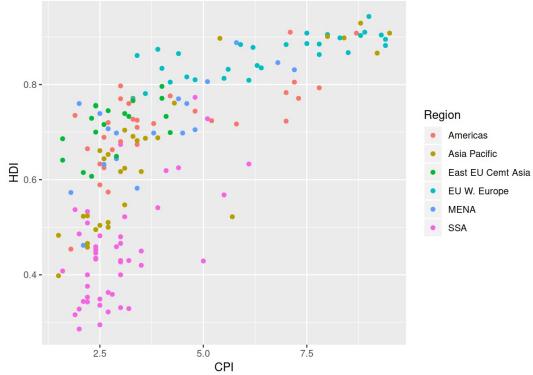
Lets start by creating the basic scatter plot, then we can make a list of things that need to be added or changed.
The basic plot looks like this:

```
dat <- read_csv("dataSets/EconomistData.csv")

## Parsed with column specification:
## cols(
##   Country = col_character(),
##   HDI.Rank = col_integer(),
##   HDI = col_double(),
##   CPI = col_double(),
##   Region = col_character()
## )

pcl <- ggplot(dat, aes(x = CPI, y = HDI, color = Region))
pcl + geom_point()
```

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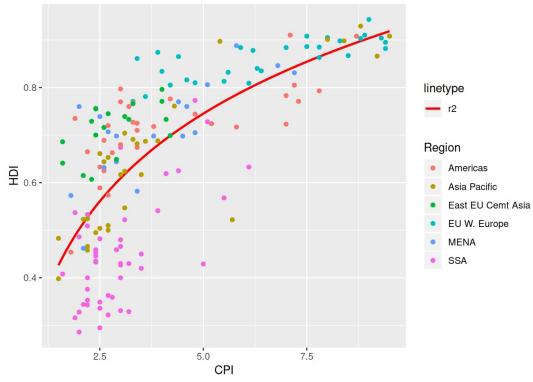
To complete this graph we need to:

- [] add a trend line
- [] change the point shape to open circle
- [] change the order and labels of Region
- [] label select points
- [] fix up the tick marks and labels
- [] move color legend to the top
- [] title, label axes, remove legend title
- [] theme the graph with no vertical guides
- [] add model R² (hard)
- [] add sources note (hard)
- [] final touches to make it perfect (use image editor for this)

Adding the trend line

Adding the trend line is not too difficult, though we need to guess at the model being displayed on the graph. A little bit of trial and error leads to

```
pc2 <- pc1 +
  geom_smooth(mapping = aes(linetype = "r2"),
              method = "lm",
              formula = y ~ x + log(x), se = FALSE,
              color = "red")
```

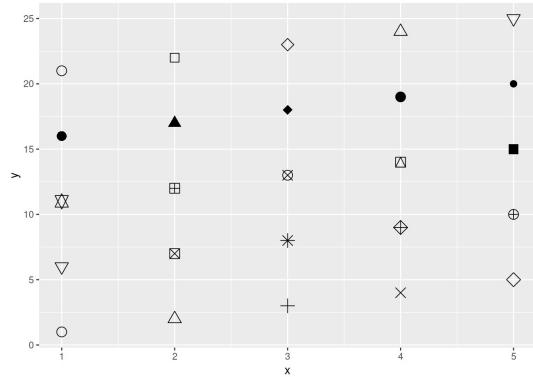


Notice that we put the `geom_line` layer first so that it will be plotted underneath the points, as was done on the original graph.

Use open points

This one is a little tricky. We know that we can change the shape with the `shape` argument, what what value do we set shape to? The example shown in `?shape` can help us:

```
## A look at all 25 symbols
df2 <- data.frame(x = 1:5, y = 1:25)
s <- ggplot(df2, aes(x = x, y = y))
s + geom_point(aes(shape = z), size = 4) + scale_shape_identity()
```

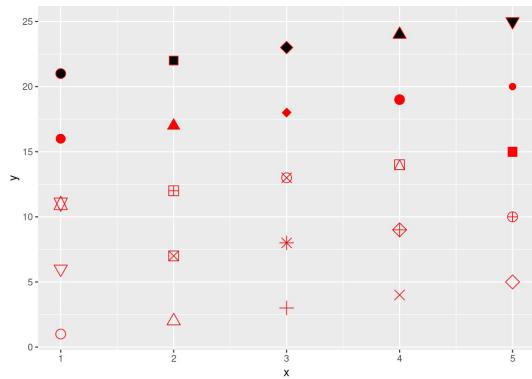


```
## While all symbols have a foreground colour, symbols 19-25 also take a
## background colour (fill)
s + geom_point(aes(shape = z), size = 4, colour = "Red") +
  scale_shape_identity()
```

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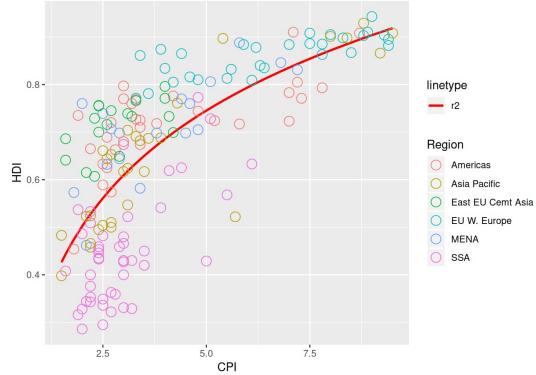


```
s + geom_point(aes(shape = z), size = 4, colour = "Red", fill = "Black") +
  scale_shape_identity()
```



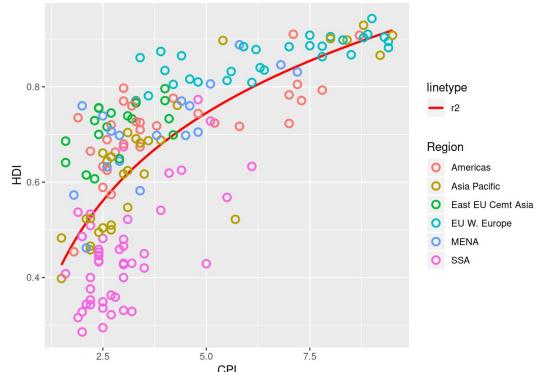
This shows us that `shape 1` is an open circle, so

```
pc2 +
  geom_point(shape = 1, size = 4)
```



That is better, but unfortunately the size of the line around the points is much narrower than on the original.

```
(pc3 <- pc2 + geom_point(shape = 1, size = 2.5, stroke = 1.25))
```



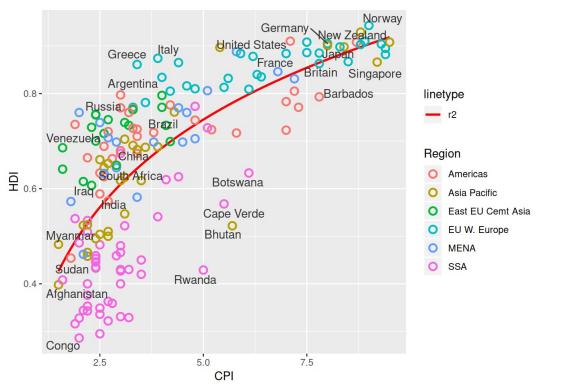
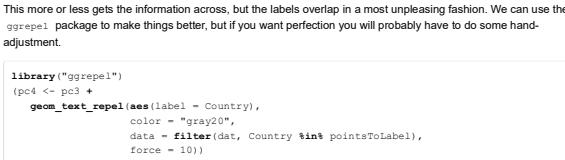
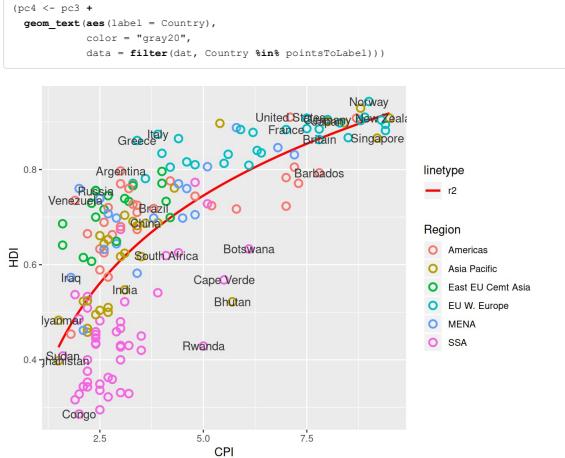
Labelling points

This one is tricky in a couple of ways. First, there is no attribute in the data that separates points that should be labelled from points that should not be. So the first step is to identify those points.

```
pointsToLabel <- c("Russia", "Venezuela", "Iraq", "Myanmar", "Sudan",
  "Afghanistan", "Congo", "Greece", "Argentina", "Brazil",
  "India", "Italy", "China", "South Africa", "Spain",
  "Botswana", "Cape Verde", "Bhutan", "Rwanda", "France",
  "United States", "Germany", "Britain", "Barbados", "Norway", "Japan",
  "New Zealand", "Singapore")
```

Now we can label these points using `geom_text`, like this:

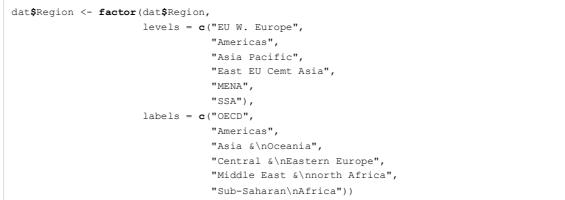
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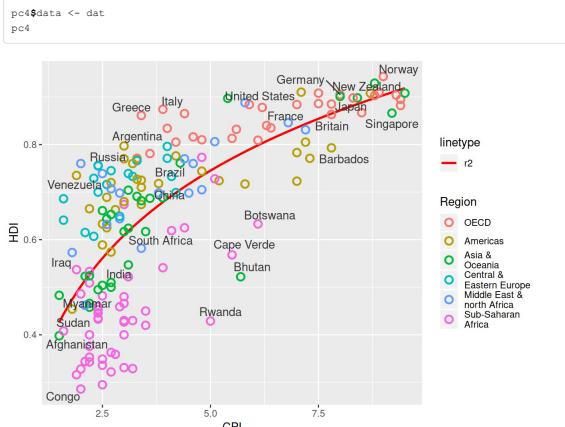
Change the region labels and order

Things are starting to come together. There are just a couple more things we need to add, and then all that will be left are themeing changes.

Comparing our graph to the original we notice that the labels and order of the Regions in the color legend differ. To correct this we need to change both the labels and order of the Region variable. We can do this with the `factor` function.



Now when we construct the plot using these data the order should appear as it does in the original.



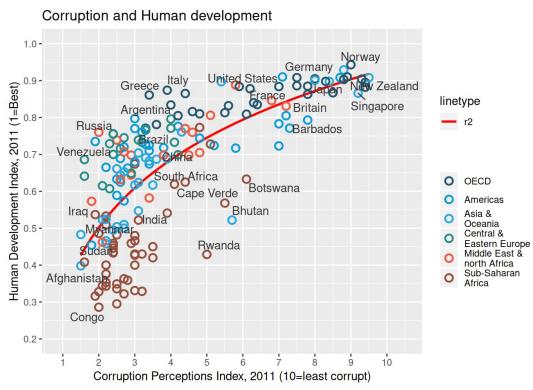
Add title and format axes

The next step is to add the title and format the axes. We do that using the `scales` system in ggplot2.

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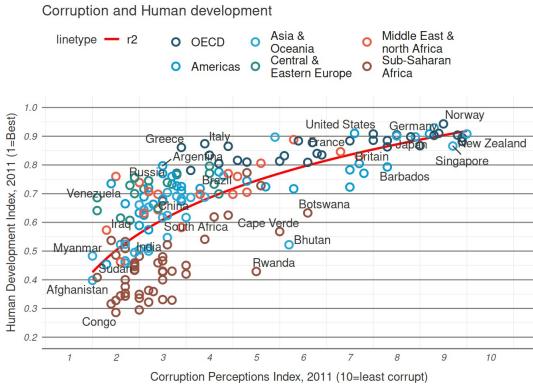
```
library(grid)
(pc5 <- pc4 +
  scale_x_continuous(name = "Corruption Perceptions Index, 2011 (10=least corrupt)",
                     limits = c(1.9, 10.5),
                     breaks = 1:10) +
  scale_y_continuous(name = "Human Development Index, 2011 (1=Best)",
                     limits = c(0.2, 1.0),
                     breaks = seq(0.2, 1.0, by = 0.1)) +
  scale_color_manual(name = "",
                     values = c("#24576D",
                               "#099DD7",
                               "#28AADC",
                               "#24EBE4",
                               "#F2F83F",
                               "#96503F")) +
  ggtitle("Corruption and Human development"))
```



Theme tweaks

Our graph is almost there. To finish up, we need to adjust some of the theme elements, and label the axes and legends. This part usually involves some trial and error as you figure out where things need to be positioned. To see what these various theme settings do you can change them and observe the results.

```
library(grid) # for the 'unit' function
(pc6 <- pc5 +
  theme_minimal() + # start with a minimal theme and add what we need
  theme(text = element_text(color = "gray20"),
        legend.position = c("top"), # position the legend in the upper left
        legend.direction = "horizontal",
        legend.justification = 0.1, # anchor point for legend.position.
        legend.text = element_text(size = 11, color = "gray10"),
        axis.text = element_text(face = "italic"),
        axis.title.x = element_text(vjust = -1), # move title away from axis
        axis.title.y = element_text(vjust = 2), # move away for axis
        axis.ticks.y = element_blank(), # element_blank() is how we remove elements
        axis.line = element_line(color = "gray40", size = 0.5),
        axis.line.y = element_blank(),
        panel.grid.major = element_line(color = "gray50", size = 0.5),
        panel.grid.major.x = element_blank()
      ))
```



Add model R² and source note

The last bit of information that we want to have on the graph is the variance explained by the model represented by the trend line. Lets fit that model and pull out the R² first, then think about how to get it onto the graph.

```
mR2 <- summary(lm(HDI ~ CPI + log(CPI), data = dat))$r.squared
mR2 <- paste0(format(mR2, digits = 2), "%")
```

OK, now that we've calculated the values, let's think about how to get them on the graph. ggplot2 has an `annotate` function, but this is not convenient for adding elements outside the plot area. The `grid` package has nice functions for doing this, so we'll use those.

And here it is, our final version!

Geometric Objects And Aesthetics
Aesthetic Mapping
Geometric Objects (geom)
Points (Scatterplot)
Lines (Prediction Line)
Smothers
Text (Label Points)
Aesthetic Mapping VS Assignment
Mapping Variables To Other Aesthetics
Exercise I
Exercise I prototype .prototype:
Statistical Transformations
Scales
Faceting
Themes
The #1 FAQ
Putting It All Together
Challenge Solution .prototype:
Wrap-up

```

png(file = "images/econScatter10.png", width = 700, height = 500)
p <- ggplot(data,
            mapping = aes(x = CPI, y = HDI) +
              geom_smooth(mapping = aes(linetype = "r2"),
                          method = "lm",
                          formula = y ~ x + log(x), se = FALSE,
                          color = "red") +
              geom_point(mapping = aes(color = Region),
                          shape = 1,
                          size = 4,
                          stroke = 1.5) +
              geom_text_repel(mapping = aes(label = Country, alpha = labels),
                            color = "gray20",
                            data = transform(data,
                                             labels = Country %in% c("Russia",
                                                               "Venezuela",
                                                               "Iran",
                                                               "Mayanma",
                                                               "Sudan",
                                                               "Afghanistan",
                                                               "Congo",
                                                               "Greece",
                                                               "Argentina",
                                                               "Italy",
                                                               "Brazil",
                                                               "India",
                                                               "China",
                                                               "South Africa",
                                                               "Spain",
                                                               "Cape Verde",
                                                               "Bhutan",
                                                               "Rwanda",
                                                               "France",
                                                               "Botswana",
                                                               "France",
                                                               "US",
                                                               "Germany",
                                                               "Britain",
                                                               "Barbados",
                                                               "Japan",
                                                               "Norway",
                                                               "New Zealand",
                                                               "Singapore")) +
              scale_x_continuous(name = "Corruption Perception Index, 2011 (10=least corrupt)",
                                 limits = c(1.0, 10.0),
                                 breaks = 1:10) +
              scale_y_continuous(name = "Human Development Index, 2011 (1-best)",
                                 limits = c(0.2, 1.0),
                                 breaks = seq(0.2, 1.0, by = 0.1)) +
              scale_color_manual(name = "",
                                 values = c("#24576D",
                                           "#099DD7",
                                           "#28AADC",
                                           "#24B2E4",
                                           "#F2883F",
                                           "#96503F"),
                                 guide = guide_legend(nrow = 1, order=1)) +
              scale_alpha_discrete(range = c(0, 1),
                                    guide = FALSE) +
              scale_linetype(name = "",
                             breaks = "r2",
                             labels = list(bquote(R^2 == .(R2))),
                             guide = guide_legend(override.aes = list(linetype = 1, size = 2, color
                                         = "red"), order=2)) +
              ggtitle("Corruption and human development") +
              labs(caption="Sources: Transparency International; UN Human Development Report") +
              theme_bw() +
              theme(panel.border = element_blank(),
                    panel.grid = element_blank(),
                    panel.major.y = element_line(color = "gray"),
                    text = element_text(color = "gray20"),
                    axis.title.x = element_text(face="italic"),
                    axis.title.y = element_text(face="italic"),
                    legend.position = "top",
                    legend.direction = "horizontal",
                    legend.box = "horizontal",
                    legend.text = element_text(size = 12),
                    plot.caption = element_text(hjust=0),
                    plot.title = element_text(size = 16, face = "bold"))

## Warning: Using alpha for a discrete variable is not advised.

p
dev.off()

## png
## 2

```

Comparing it to the original suggests that we've got most of the important elements.

Wrap-up

Help Us Make This Workshop Better!

- Please take a moment to fill out a very short feedback form
- These workshops exist for you – tell us what you need!
- <http://tinyurl.com/R-graphics-feedback> (<http://tinyurl.com/R-graphics-feedback>)

Additional resources

- ggplot2 resources
 - Mailing list: <http://groups.google.com/group/ggplot2> (<http://groups.google.com/group/ggplot2>)
 - Wiki: <https://github.com/hadley/ggplot2/wiki> (<https://github.com/hadley/ggplot2/wiki>)
 - Website: <http://had.co.nz/ggplot2/> (<http://had.co.nz/ggplot2/>)
 - StackOverflow: <http://stackoverflow.com/questions/tagged/ggplot> (<http://stackoverflow.com/questions/tagged/ggplot>)
- IOSS resources
 - Research technology consulting: <http://dss.iq.harvard.edu> (<http://dss.iq.harvard.edu>)
 - Workshops materials: <http://dss.iq.harvard.edu/workshop-materials> (<http://dss.iq.harvard.edu/workshop-materials>)
 - Workshop schedule and registration: <http://dss.iq.harvard.edu/workshop-registration> (<http://dss.iq.harvard.edu/workshop-registration>)