DSCI353-353m-453: Class 04a GGplot Graphics in Action

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Contents

4.1.3.1 `ggplot2` Graphics

- A good book on `ggplot2` is The Grammar of Graphics

4.1.3.2 Creating a graph with ggplot

- The `ggplot2` package uses a series of functions
  - to build up a graph in layers.
- We'll build a complex graph
  - by starting with a simple graph
  - and adding additional elements, one at a time.
- By default, `ggplot2` graphs
  - appear on a grey background
  - with white reference lines.
- We'll start by setting the default theme
  - to a white background
  - with light grey reference lines.
- This looks better when printed in black and white.

Let's load the `ggplot2` package and set this default theme.

```
library(ggplot2)
theme_set(theme_bw())
```

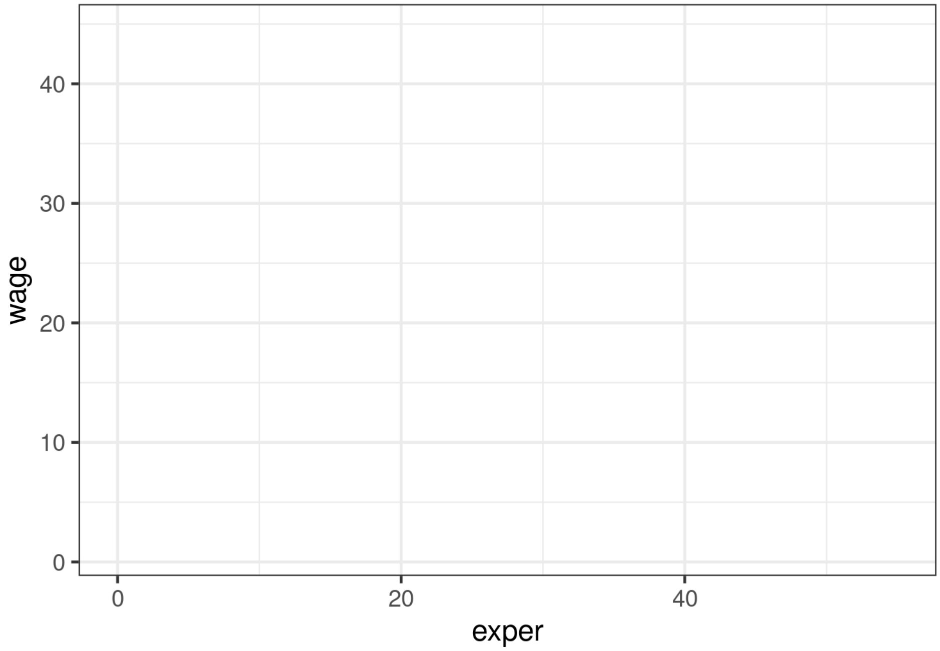
4.1.3.2.1

- The first function in building a graph is the `ggplot()` function.
- It specifies the
  - data frame containing the data to be plotted
  - the mapping of the variables to visual properties of the graph.

The mappings are placed in an `aes()` function

- (which stands for aesthetics or "something you can see").

```
library(ggplot2)
library(mosaicData)
ggplot(data = CPS85, mapping = aes(x = exper, y = wage))
```



Why is the graph empty?

- We specified that the exper variable
  - should be mapped to the x-axis
- and that the wage variable
  - should be mapped to the y-axis,
- but we haven't yet specified what we wanted placed on the graph.

In this case,

- we'll want points to represent each participant.

4.1.3.2.2 Geoms

Geoms are the geometric objects

- (points, lines, bars, and shaded regions)
  - that can be placed on a graph.
- They are added using functions that start with the phrase `geom_`.
- Currently, 37 different `geoms` are available and the list is growing.

Table 4.1 describes the more common `geoms`,

- along with frequently used options for each.

We'll add points using the `geom_point()` function,

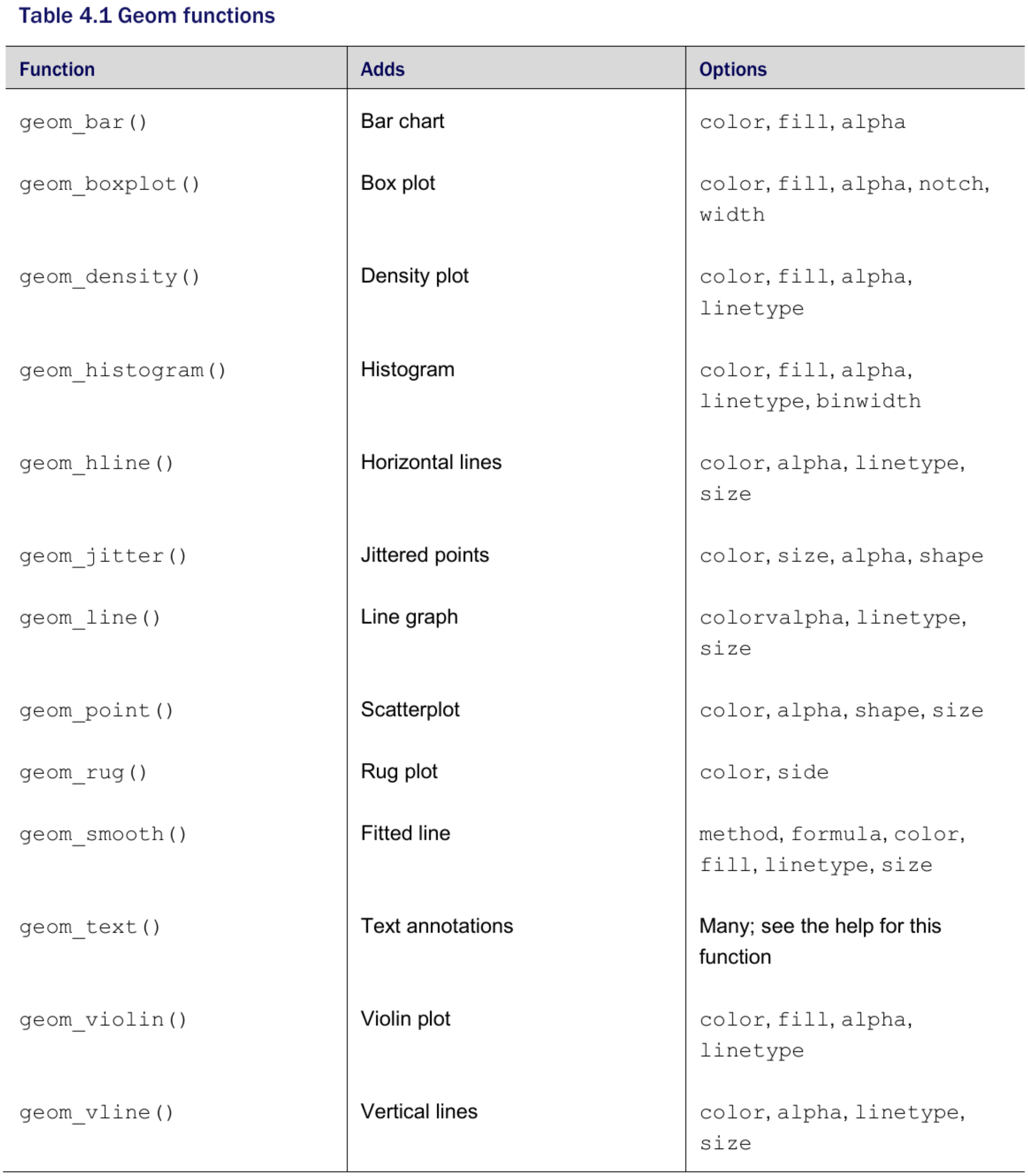


Table 4.1 Geom functions

Function	Adds	Options
`geom_bar()`	Bar chart	`color`, `fill`, `alpha`
`geom_boxplot()`	Box plot	`color`, `fill`, `alpha`, `notch`, `width`
`geom_density()`	Density plot	`color`, `fill`, `alpha`, `linetype`
`geom_histogram()`	Histogram	`color`, `fill`, `alpha`, `linetype`, `binwidth`
`geom_hline()`	Horizontal lines	`color`, `alpha`, `linetype`, `size`
`geom_jitter()`	Jittered points	`color`, `size`, `alpha`, `shape`
`geom_line()`	Line graph	`colorvalpha`, `linetype`, `size`
`geom_point()`	Scatterplot	`color`, `alpha`, `shape`, `size`
`geom_rug()`	Rug plot	`color`, `side`
`geom_smooth()`	Fitted line	`method`, `formula`, `color`, `fill`, `linetype`, `size`
`geom_text()`	Text annotations	Many; see the help for this function
`geom_violin()`	Violin plot	`color`, `fill`, `alpha`, `linetype`
`geom_vline()`	Vertical lines	`color`, `alpha`, `linetype`, `size`

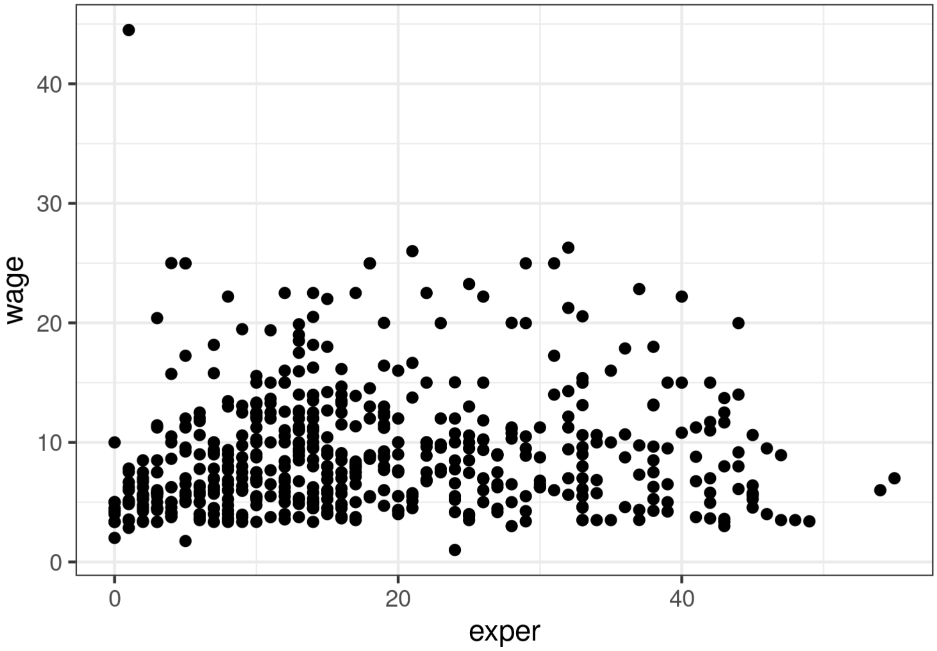
Figure 1: fig

- creating a scatterplot.

In ggplot2 graphs, functions are chained together

- using the + sign to build a final plot.

```
library(ggplot2)
library(mosaicData)
ggplot(data = CPS85, mapping = aes(x = exper, y = wage)) + geom_point()
```



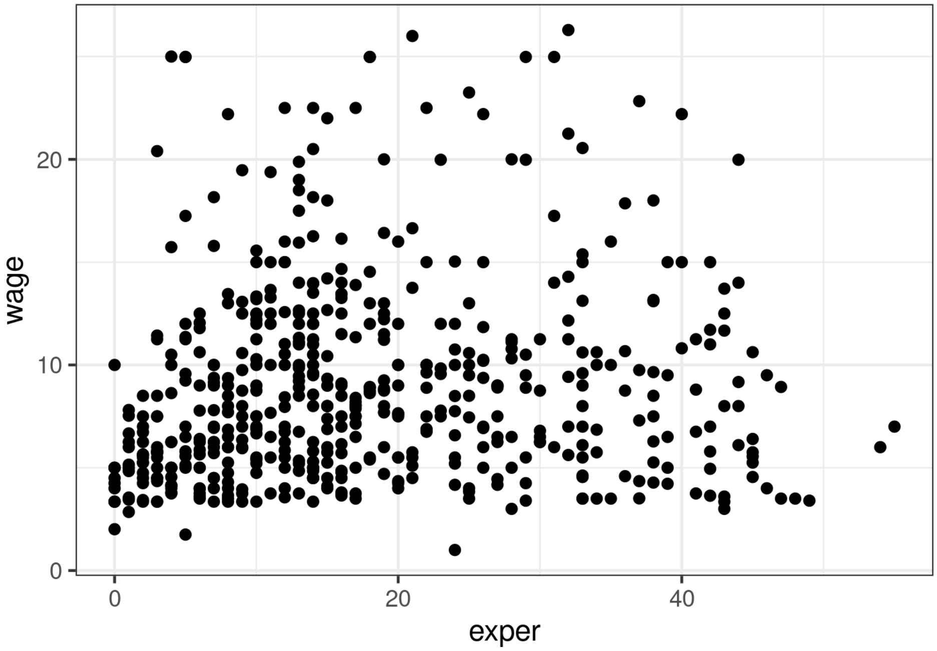
It appears that as experience goes up,

- wages go up,
- but the relationship is weak.

The graph also indicates

- that there is an outlier.
- One individual has a wage
  - much higher than the rest.
- We'll delete this case and reproduce the plot.

```
CPS85 <- CPS85[CPS85$wage < 40, ]
ggplot(data = CPS85, mapping = aes(x = exper, y = wage)) +
  geom_point()
```

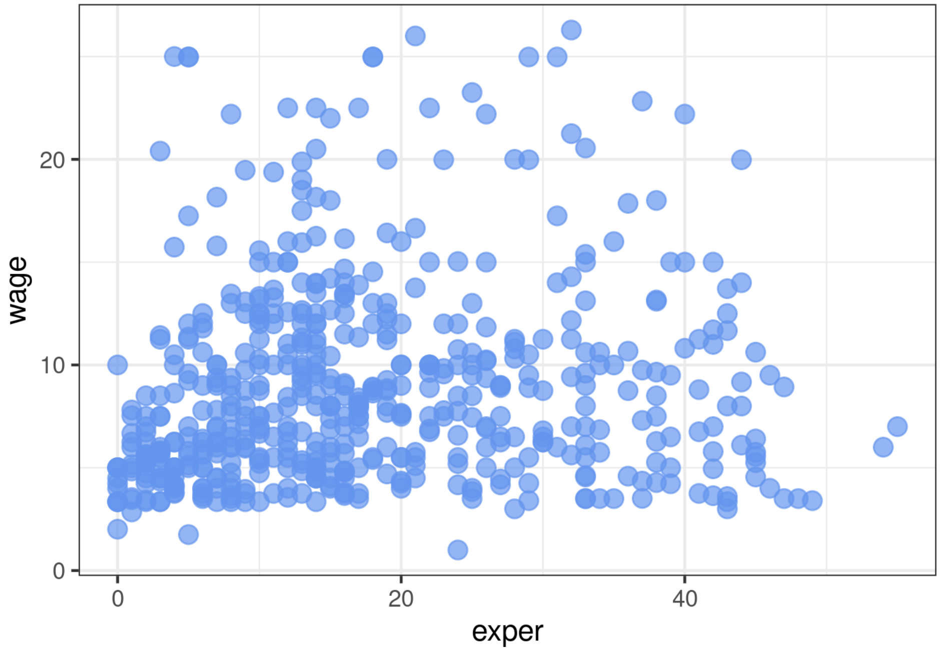


A number of options can be specified

- in a `geom_` function (see table 4.1).
- Options for `geom_point()`
  - include `color`, `size`, `shape`, and `alpha`.
- These control
  - the point color, size, shape, and transparency, respectively.
- Colors can be specified by name or hexadecimal code.
- Shape and linetype can be specified by
  - the name or number representing the pattern or symbol respectively.
- Point size is specified with positive real numbers starting at zero.
- Large numbers produce larger point sizes.
- Transparency (`alpha`) ranges from
  - 0 (completely transparent)
  - to 1 (completely opaque).
- Adding a degree of transparency
  - can help visualize overlapping points.

We'll also change the gray background to white using theme

```
ggplot(data = CPS85, mapping = aes(x = exper, y = wage)) +
  geom_point(color = "cornflowerblue",
             alpha = .7,
             size = 3)
```



It would be helpful if the graph

- had a line summarizing the trend between experience and wages.

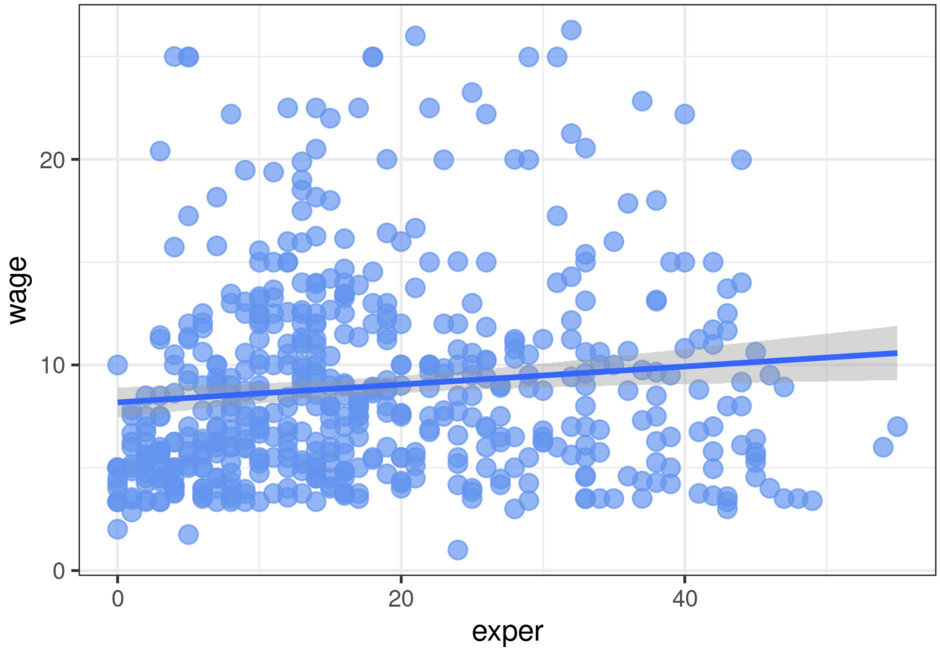
We can add this line with the `geom_smooth()` function.

- Options control the type of line
  - (linear, quadratic, nonparametric),
- the thickness of the line,
- the line's color,
- and the presence or absence of a confidence interval.

Here we request a linear regression (`method = lm`) line.

```
ggplot(data = CPS85, mapping = aes(x = exper, y = wage)) +
  geom_point(color = "cornflowerblue",
             alpha = .7,
             size = 3) +
  geom_smooth(method = "lm")
```

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



We can see from this line that on average,

- wages appear to increase to a moderate degree with experience.

4.1.3.2.3 Grouping

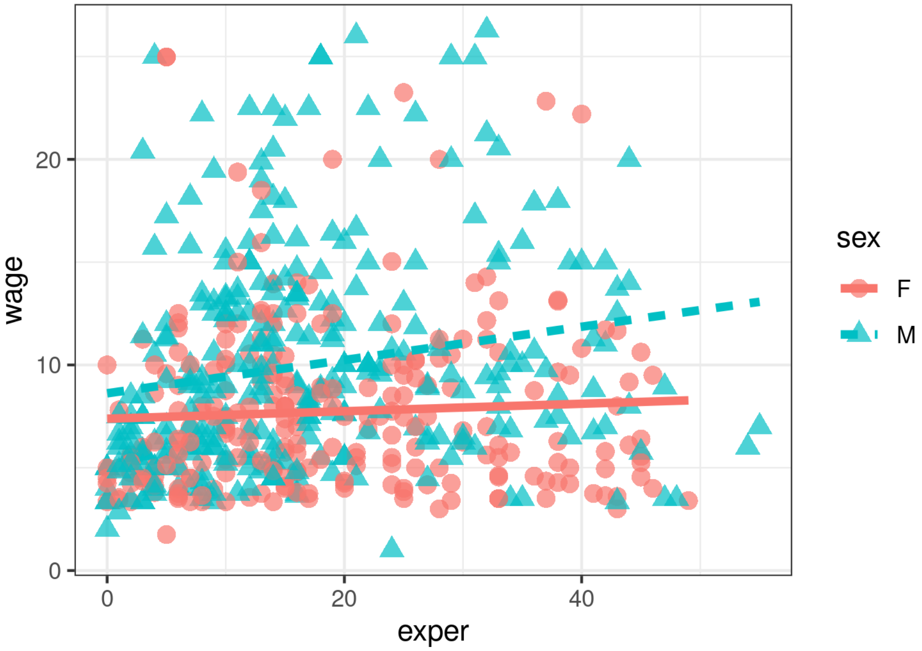
- In the previous section, we set graph characteristics
  - such as color and transparency to a constant value.
- However, we can also map variables values
  - to the color, shape, size, transparency, line style,
  - and other visual characteristics of geometric objects.
- This allows groups of observations
  - to be superimposed in a single graph
  - (a process called grouping).

Let's add sex to the plot

- and represent it by color, shape, and linetype.

```
ggplot2::ggplot(
  data = CPS85,
  mapping = aes(
    x = exper,
    y = wage,
    color = sex,
    shape = sex,
    linetype = sex
  )
) +
  geom_point(alpha = .7, size = 3) +
  geom_smooth(method = "lm", se = FALSE, size = 1.5)
```

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



By default, the first group (female) is represented

- by pink filled circles
  - and a solid pink line,
- while the second group (male) is represented
  - by teal filled triangles
  - and a dashed teal line.

Note that the `color = sex`, `shape = sex`, and `linetype = sex`, options

- are placed in the `aes()` function
  - because we are mapping a variable to an aesthetic.
- The geom_smooth option (`se = FALSE`)
  - was added to suppresses the confidence intervals,
  - making the graph less busy and easier to read.
- The size = 1.5 option
  - makes the line a bit thicker.

4.1.3.2.4 Scales

As we've seen, the `aes()` function is used

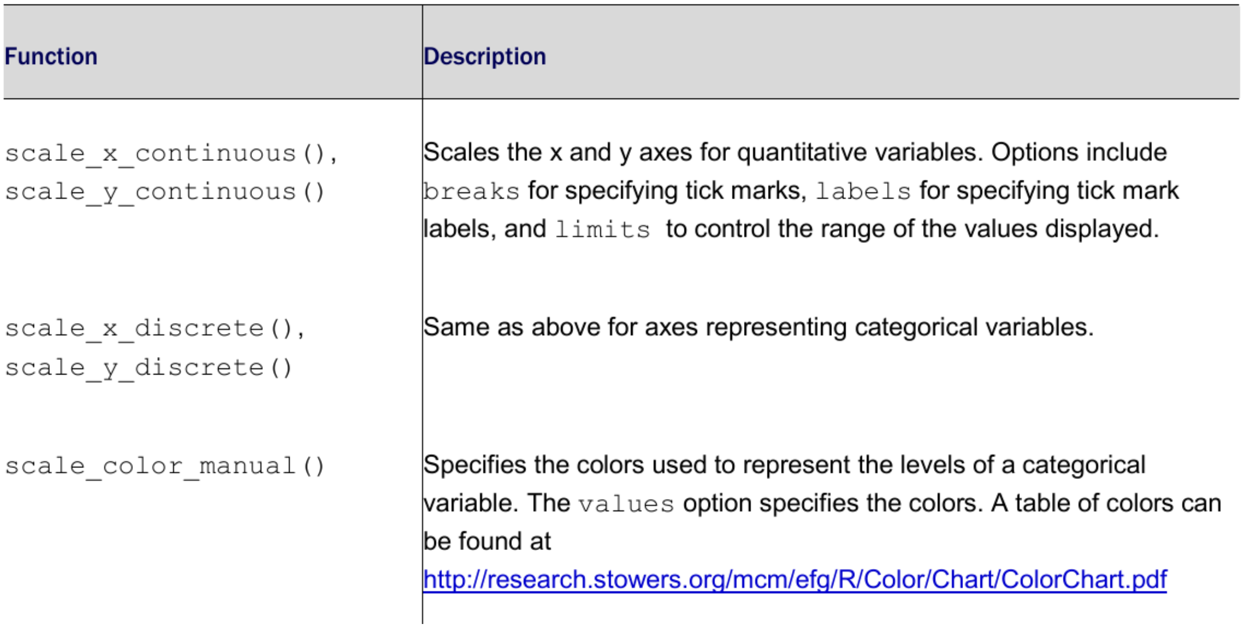
- to map variables to the visual characteristics of a plot.
- Scales specify how each of these mappings occurs.
- For example, `ggplot2` automatically creates plot axes
  - with tick marks, tick mark labels, and axis labels.
- Often they look fine, but occasionally
  - you'll want to take greater control over their appearance.
- Colors that represent groups are chosen automatically,
  - but you may want to select a different set of colors
  - based on your tastes or a publication's requirements.

Scale functions (which start with `scale_`)

- allow you to modify these default scaling.

In the next plot,

- we'll change the x- and y-axis scaling,



Function	Description
scale_x_continuous(), scale_y_continuous()	Scales the x and y axes for quantitative variables. Options include `breaks` for specifying tick marks, `labels` for specifying tick mark labels, and `limits` to control the range of the values displayed.
scale_x_discrete(), scale_y_discrete()	Same as above for axes representing categorical variables.
scale_color_manual()	Specifies the colors used to represent the levels of a categorical variable. The `values` option specifies the colors. A table of colors can be found at http://research.stowers.org/mcm/efg/R/Color/Chart/ColorChart.pdf

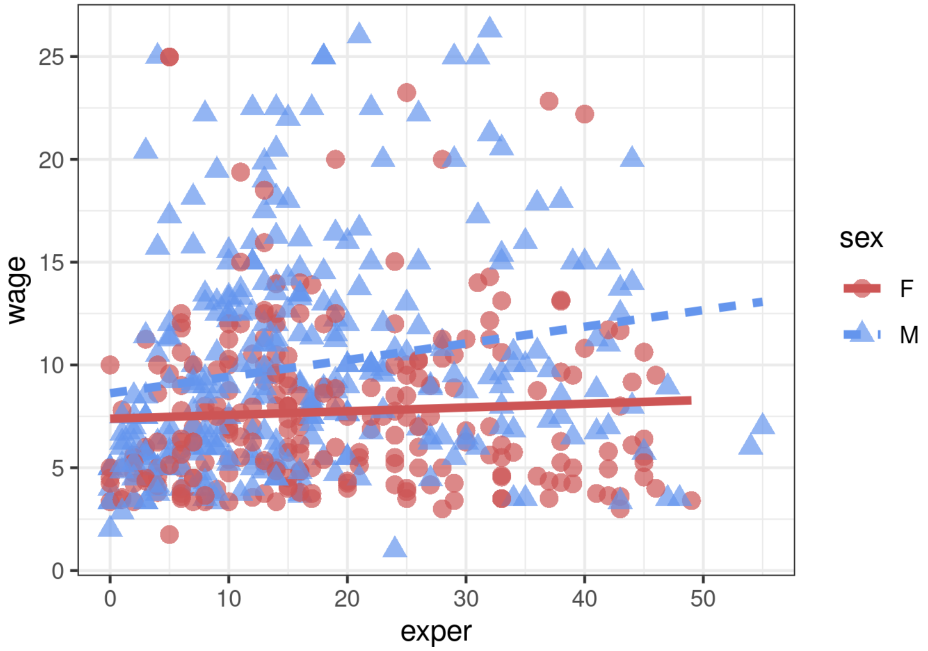
Figure 2: Scales

    - and the colors representing males and females.
- The x-axis representing `exper`
    - will range from 0 to 60 by 10,
- and the y-axis representing `wage`
    - will range from 0 to 30 by 5.
- Females will be coded with an off-red color
    - and males will be coded with an off-blue color.

The code

```
ggplot(data = CPS85,
  mapping = aes(x = exper, y = wage,
  color = sex, shape=sex, linetype=sex)) +
  geom_point(alpha = .7, size = 3) +
  geom_smooth(method = "lm", se = FALSE, size = 1.5) +
  scale_x_continuous(breaks = seq(0, 60, 10)) +
  scale_y_continuous(breaks = seq(0, 30, 5)) +
  scale_color_manual(values = c("indianred3", "cornflowerblue"))
```

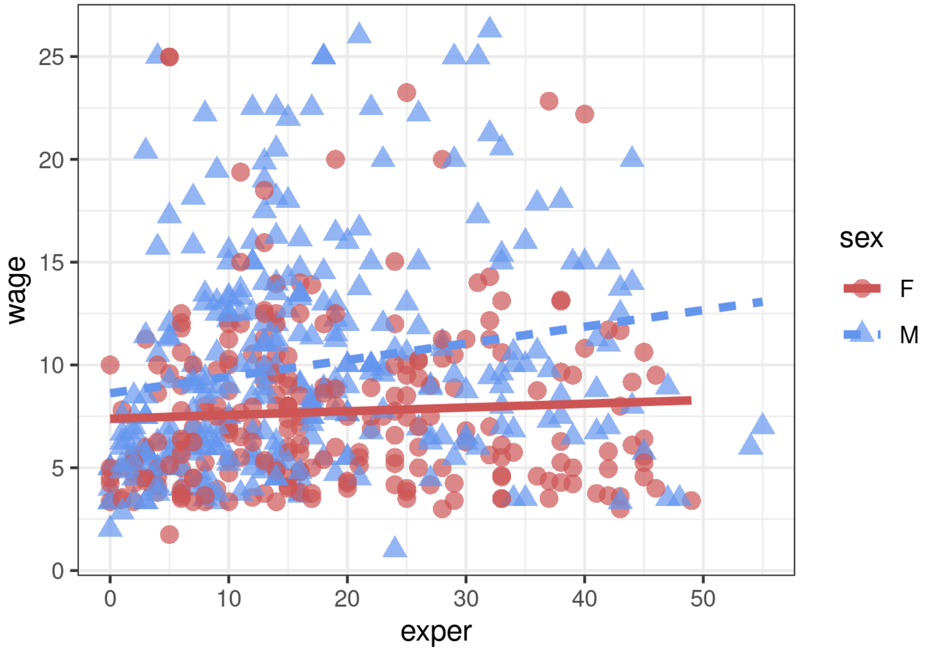
```
## `geom_smooth()` using formula = 'y ~ x'
```



Code Styling, using Rstudio's `Cntrl-Shft-A` to reformat the code.

```
ggplot(
  data = CPS85,
  mapping = aes(
    x = exper,
    y = wage,
    color = sex,
    shape = sex,
    linetype = sex
  )
) +
  geom_point(alpha = .7, size = 3) +
  geom_smooth(method = "lm", se = FALSE, size = 1.5) +
  scale_x_continuous(breaks = seq(0, 60, 10)) +
  scale_y_continuous(breaks = seq(0, 30, 5)) +
  scale_color_manual(values = c("indianred3", "cornflowerblue"))
```

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

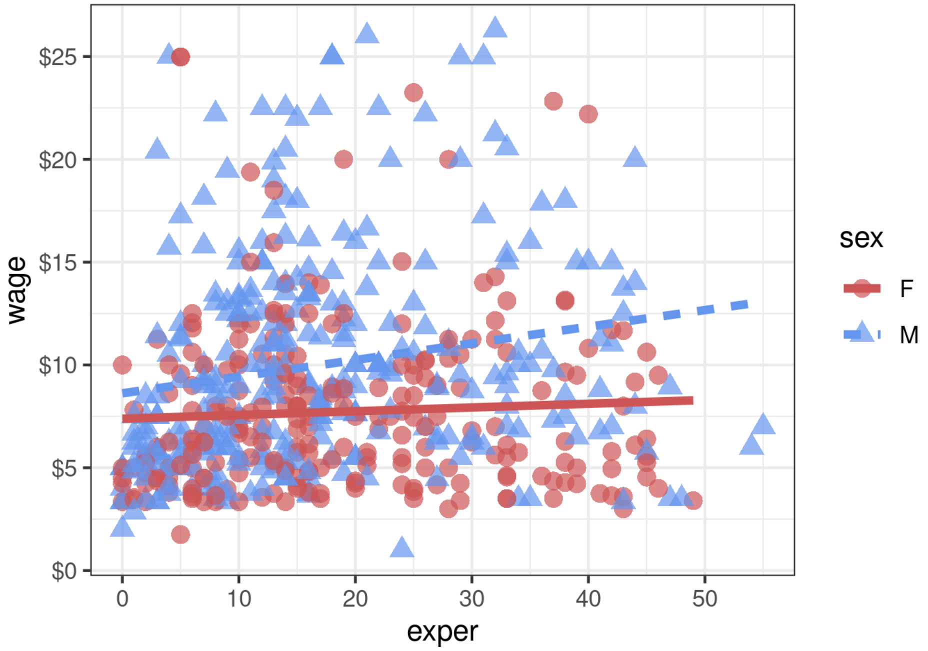


The numbers on the x- and y-axes are better,

- and the colors are more attractive.
- However,
  - wages are in dollars.
- We can change the labels on the y-axis
  - to represent dollars using the `scales` package.
- The scales package provides
  - label formatting for dollars, euros, percents, and more.

```
ggplot(
  data = CPS85,
  mapping = aes(
    x = exper,
    y = wage,
    color = sex,
    shape = sex,
    linetype = sex
  )
) +
  geom_point(alpha = .7, size = 3) +
  geom_smooth(method = "lm", se = FALSE, size = 1.5) +
  scale_x_continuous(breaks = seq(0, 60, 10)) +
  scale_y_continuous(breaks = seq(0, 30, 5),
                     label = scales::dollar) +
  scale_color_manual(values = c("indianred3", "cornflowerblue"))
```

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



We are definitely getting there.

4.1.3.2.5 Facets

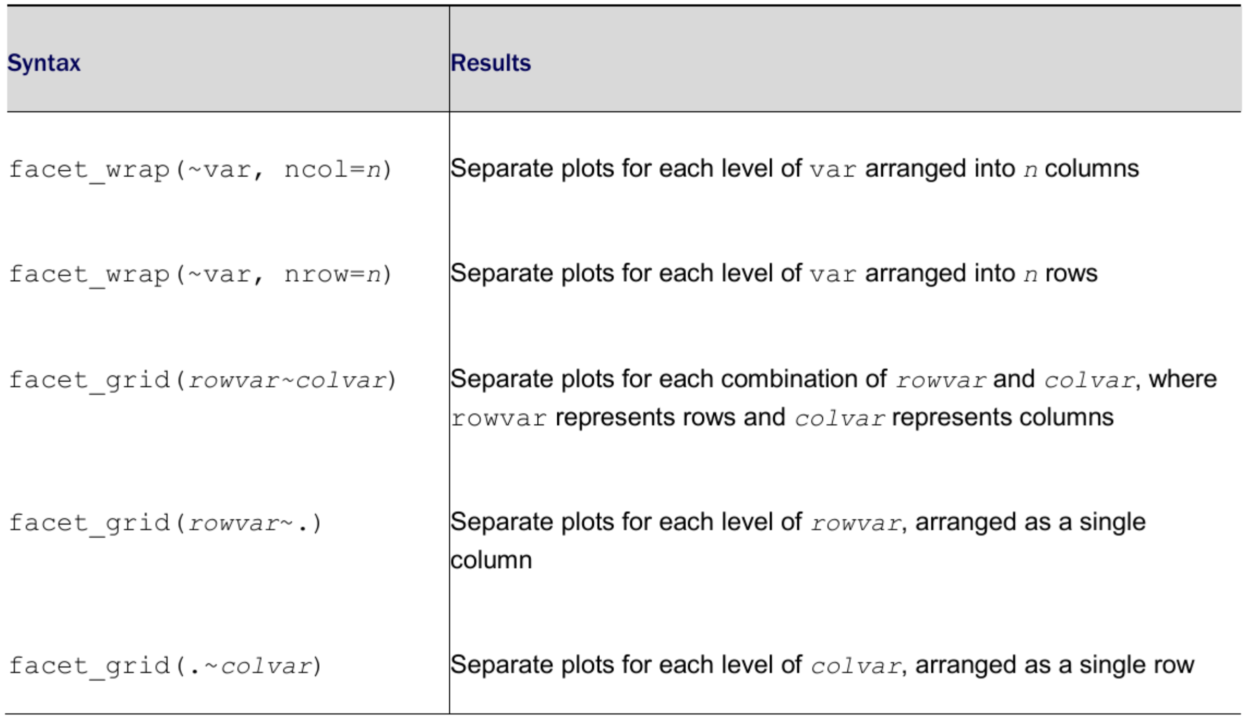
- Here is the next question.
- Is the relationship between
  - `experience`, `wages` and `sex`
  - the same for each job sector?
- Let's repeat this graph once
  - for each job sector in order to explore this.

Sometimes relationships are clearer

- if groups appear in side-by-side graphs
  - rather than overlapping in a single graph.
- Facets reproduce a graph
  - for each level of a given variable
    - (or combination of variables).
- You can create faceted graphs
  - using the `facet_wrap()` and `facet_grid()` functions.

The syntax is given in table 14.3,

- where `var`, `rowvar`, and `colvar` are factors.



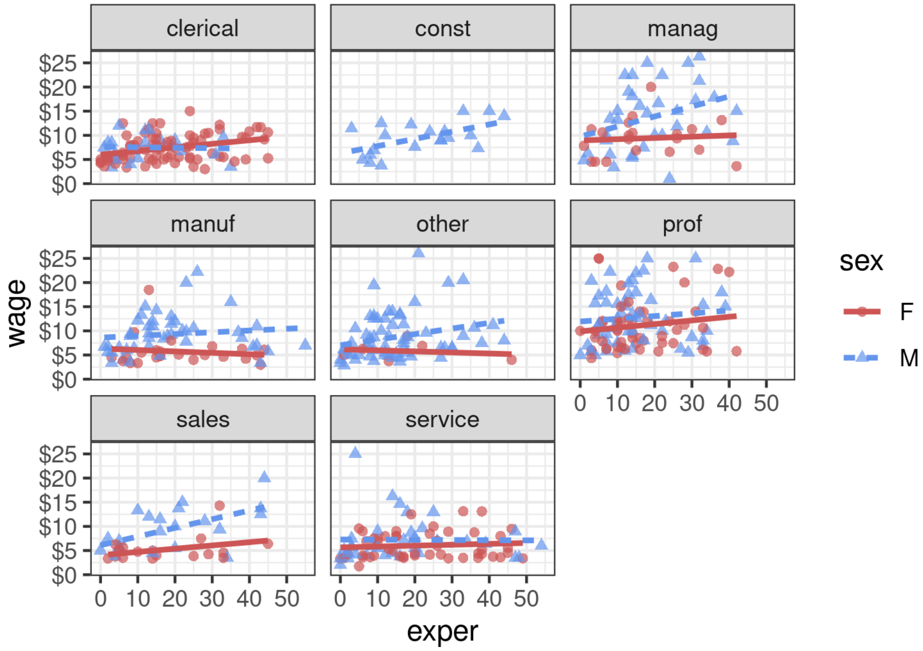
Syntax	Results
`facet_wrap(~var, ncol=`*n*`)`	Separate plots for each level of `var` arranged into *n* columns
`facet_wrap(~var, nrow=`*n*`)`	Separate plots for each level of `var` arranged into *n* rows
`facet_grid(`*rowvar~colvar*`)`	Separate plots for each combination of *rowvar* and *colvar*, where `rowvar` represents rows and *colvar* represents columns
`facet_grid(`*rowvar*`~.)`	Separate plots for each level of *rowvar*, arranged as a single column
`facet_grid(.~`*colvar*`)`	Separate plots for each level of *colvar*, arranged as a single row

Here, facets will be defined

- by the eight levels of the sector variable.
- Since each facet
  - will be smaller than a one panel graph alone,
- we'll omit `size = 3` from `geom_point()`
  - and `size = 1.5` from `geom_smooth()`.
- This will reduce the point and line sizes
  - compared with the previous graphs
  - and looks better in a faceted graph.

```
ggplot(
  data = CPS85,
  mapping = aes(
    x = exper,
    y = wage,
    color = sex,
    shape = sex,
    linetype = sex
  )
) +
  geom_point(alpha = .7) +
  geom_smooth(method = "lm", se = FALSE) +
  scale_x_continuous(breaks = seq(0, 60, 10)) +
  scale_y_continuous(breaks = seq(0, 30, 5),
                     label = scales::dollar) +
  scale_color_manual(values = c("indianred3", "cornflowerblue")) +
  facet_wrap( ~ sector)
```

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



It appears that the differences between men and women

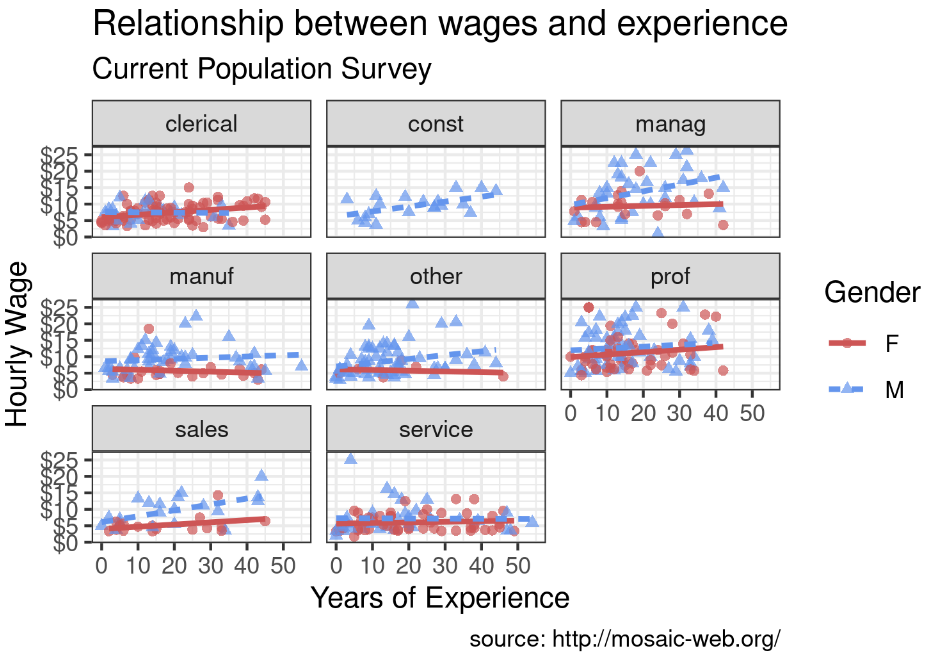
- depend on the job sector under consideration.
- For example, there is a strong positive relationship
  - between experience and wages for male managers,
  - but not for female managers.
- To a lesser extent,
  - this is also true for sales workers.
- There appears to be no relationship
  - between experience and wages
  - for both male and female service workers.
  - In either case, males make slightly more.
- Wages go up with experience for female clerical workers,
  - but may go down for male clerical workers
  - (the relationship may not be significant here).
- We have gained a great deal of insight into
  - the relationship of wages and experience at this point.

4.1.3.2.6 Labels

- Graphs should be easy to interpret
  - and informative labels are a key element
  - in achieving this goal.
- The `labs()` function provides customized labels
  - for the axes and legends.
- Additionally, a custom title, subtitle, and caption can be added.

```
ggplot(
  data = CPS85,
  mapping = aes(
    x = exper,
    y = wage,
    color = sex,
    shape = sex,
    linetype = sex
  )
) +
  geom_point(alpha = .7) +
  geom_smooth(method = "lm", se = FALSE) +
  scale_x_continuous(breaks = seq(0, 60, 10)) +
  scale_y_continuous(breaks = seq(0, 30, 5),
                     label = scales::dollar) +
  scale_color_manual(values = c("indianred3",
                                "cornflowerblue")) +
  facet_wrap( ~ sector) +
  labs(
    title = "Relationship between wages and experience",
    subtitle = "Current Population Survey",
    caption = "source: http://mosaic-web.org/",
    x = " Years of Experience",
    y = "Hourly Wage",
    color = "Gender",
    shape = "Gender",
    linetype = "Gender"
  )
```

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



Now a viewer doesn't need to guess

- what the labels `expr` and `wage` mean,
- or where the data come from.

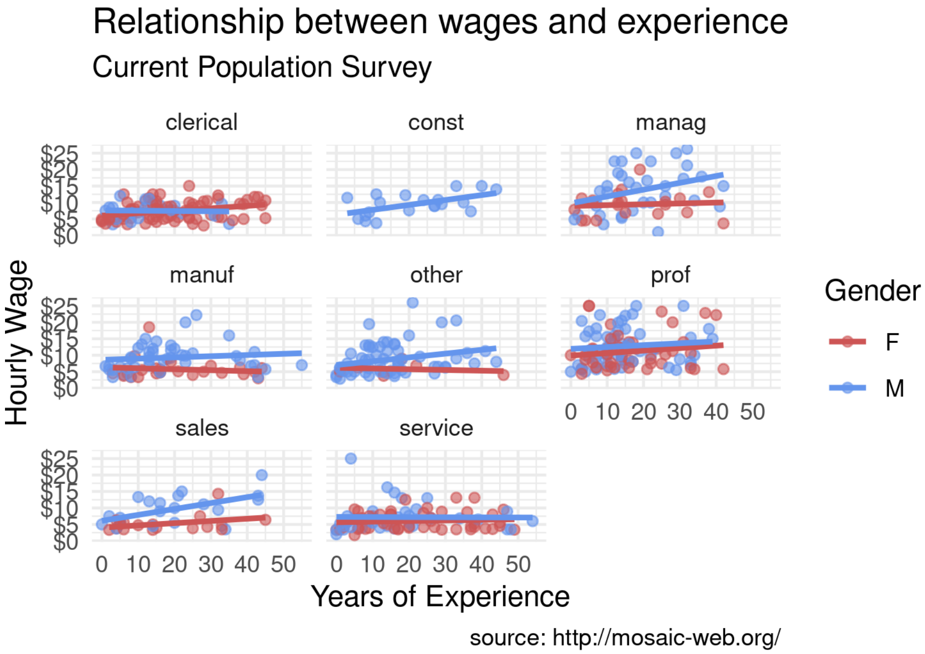
4.1.3.2.7 Themes

- Finally, we can fine tune the appearance of the graph
  - using themes.
- Theme functions (which start with `theme_`)

    - control background colors, fonts, grid-lines, legend placement,
    - and other non-data related features of the graph.
- Let's use a cleaner theme.
- We used themes at the beginning in order
    - to give each plot a white background.
- Let's try a different theme
    - one that is more minimalistic.

```
ggplot(data = CPS85,
       mapping = aes(x = exper, y = wage, color = sex)) +
  geom_point(alpha = .6) +
  geom_smooth(method = "lm", se = FALSE) +
  scale_x_continuous(breaks = seq(0, 60, 10)) +
  scale_y_continuous(breaks = seq(0, 30, 5),
                     label = scales::dollar) +
  scale_color_manual(values = c("indianred3", "cornflowerblue")) +
  facet_wrap( ~ sector) +
  labs(
    title = "Relationship between wages and experience",
    subtitle = "Current Population Survey",
    caption = "source: http://mosaic-web.org/",
    x = " Years of Experience",
    y = "Hourly Wage",
    color = "Gender"
  ) +
  theme_minimal()
```

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



This is our finished graph,

- ready for publication.
- Of course, these findings are tentative.
- They are based on a limited sample size and
    - don't involve statistical testing

  - to assess whether differences may be due to chance variation.

4.1.3.3 ggplot2 details

- Before we finish, there are three important topics to consider:
  - the placement of the aes() function,
  - the treatment of ggplot2 graphs as R objects,
  - and various methods to save your graphs
    - for use in reports and webpages.

4.1.3.3.1 Placing the data and mapping options

- Plots created with ggplot2
  - always start with the ggplot function.
- In the previous examples,
  - the data= and mapping= options were placed in this function.
- In this case they apply to each geom function that follows.

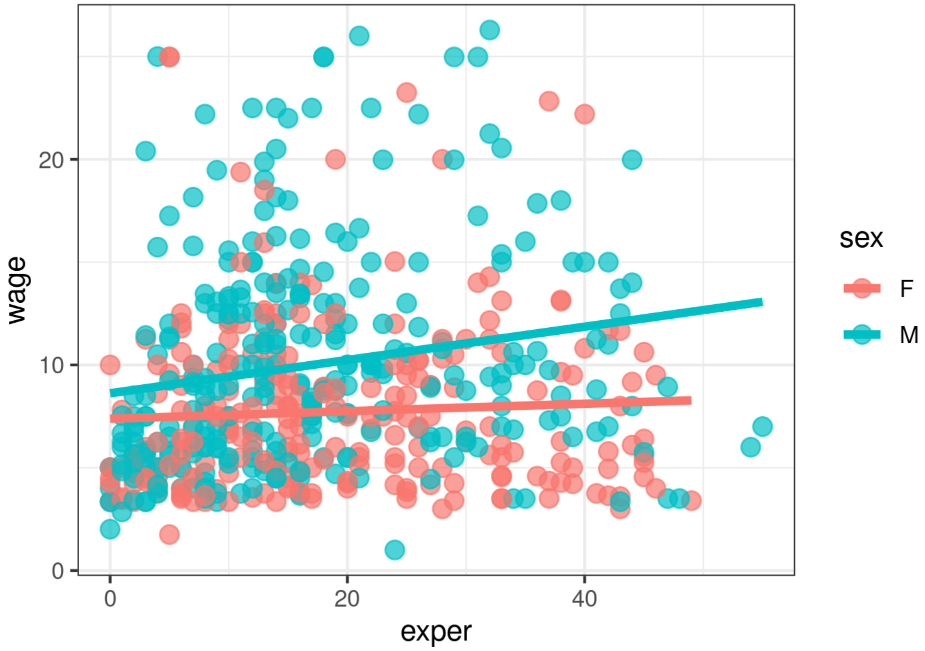
You can also place these options

- directly within a geom.
- In that case, they only apply to that specific geom.

Consider the following graph.

```
ggplot(CPS85,
       mapping = aes(x = exper, y = wage, color = sex)) +
  geom_point(alpha = .7, size = 3) +
  geom_smooth(method = "lm", se = FALSE, size = 1.5)
```

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



Since the mapping of sex to color

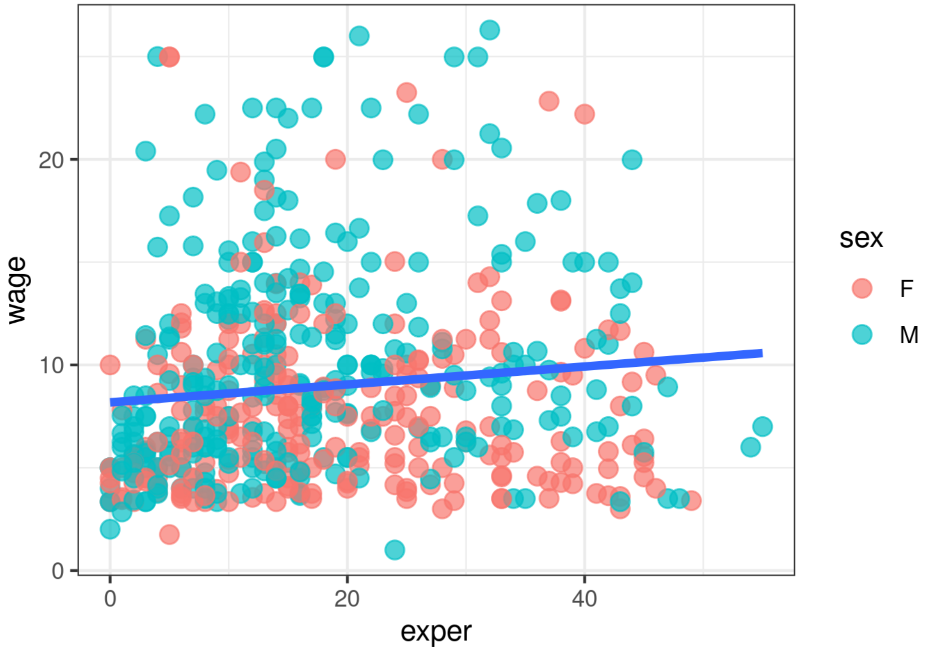
- appears in the ggplot() function,
  - it applies to both geom_point and geom_smooth.
- The color of the point indicates the sex,

    - and a separate colored trend line is produced for men and women.

Compare this to

```
ggplot(CPS85, aes(x = exper, y = wage)) +
  geom_point(aes(color = sex), alpha = .7, size = 3) +
  geom_smooth(method = "lm", se = FALSE, size = 1.5)
```

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



Since the sex to color mapping

- only appears in the `geom_point()` function,
    - it is only used there.
- A single trend line is created for all observations.

Most examples place the data and mapping options

- in the `ggplot` function.
- Additionally, the phrases `data =` and `mapping =` are omitted
    - since the first option always refers to data
    - and the second option always refers to mapping.

But your code will be more readable and understandable

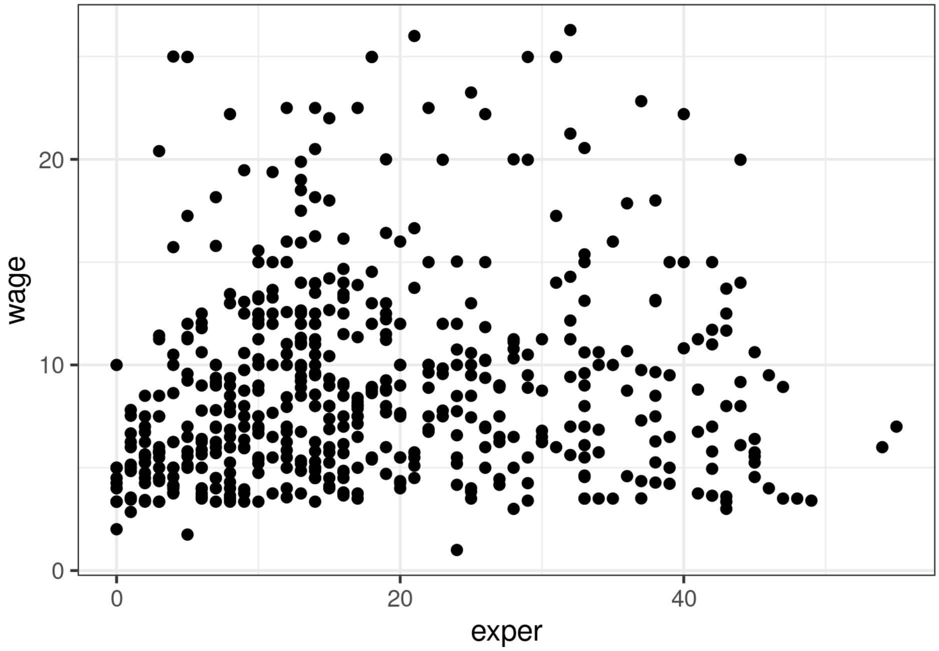
- If you put the `data =` and `mapping =` - in your code explicitly.

4.1.3.3.2 Graphs as objects

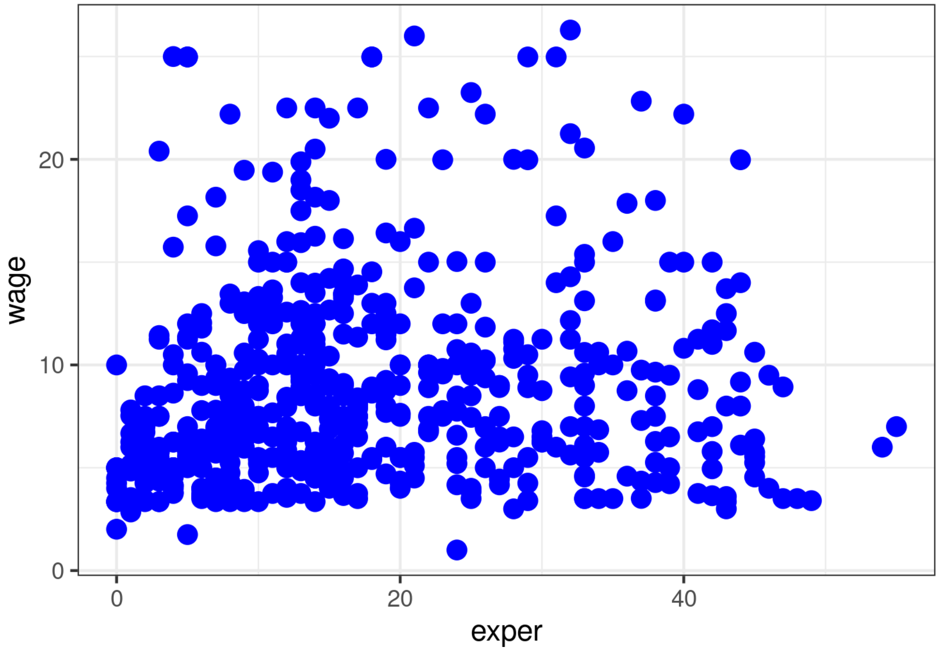
- A `ggplot2` graph can be saved as
    - a named R object (a list),
- or manipulated further,
    - and then printed or saved to disk.

```
data(CPS85 , package = "mosaicData")       #A
CPS85 <- CPS85[CPS85$wage < 40,]       #A

myplot <- ggplot(data = CPS85, aes(x = exper, y = wage)) + geom_point()      #B
myplot       #C
```

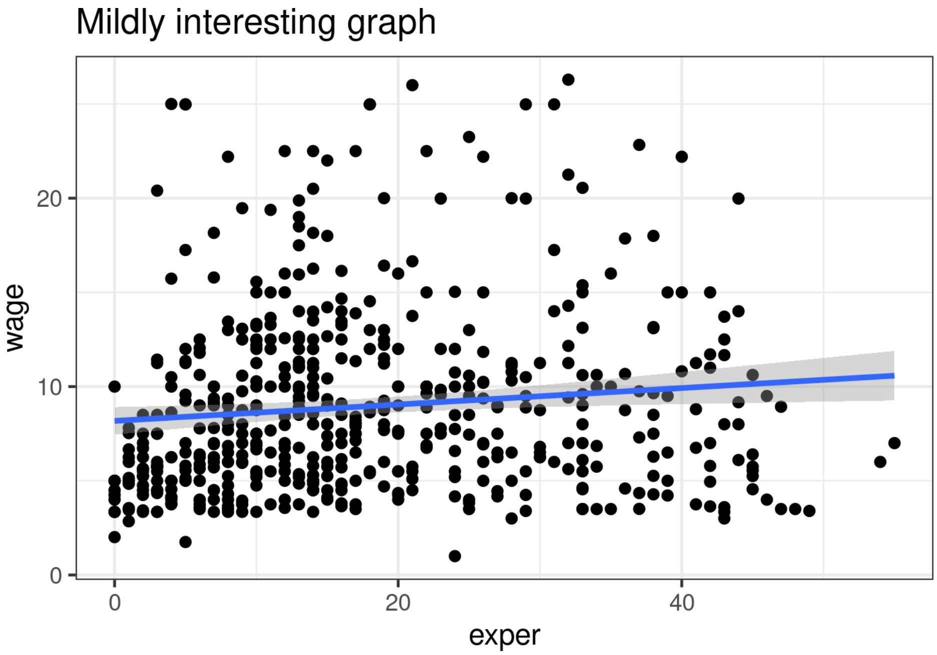


```
myplot2 <- myplot + geom_point(size = 3, color = "blue")      #D
myplot2      #D
```



```
myplot + geom_smooth(method = "lm") +       #E
  labs(title = "Mildly interesting graph")      #E
```

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



And here is what the codes doing at each letter step

- #A Prepare data
- #B Create a scatterplot and save it as myplot
- #C Display myplot
- #D Make the points larger and blue,
  - save it as myplot2 and display the graph
- #E Display myplot with a best fit line and a title

First the data are imported and outliers are removed #A.

- Then a simple scatter plot of experience vs. wages
  - is created and saved as myplot #B.
- Next, the plot is printed #C.
- The plot is then modified
  - by changing the point size and color,
  - saved as myplot2 and printed #D.
- Finally, the original plot
  - is given a line of best fit and title, and printed #E.

Note that these changes are not saved.

The ability to save graphs as objects

- allows you to continue to work with and modify them.
- This can be a real time saver (and help you avoid carpal tunnel syndrome).
- It is also handy when saving graphs programmatically.

4.1.3.3.3 Exporting graphs

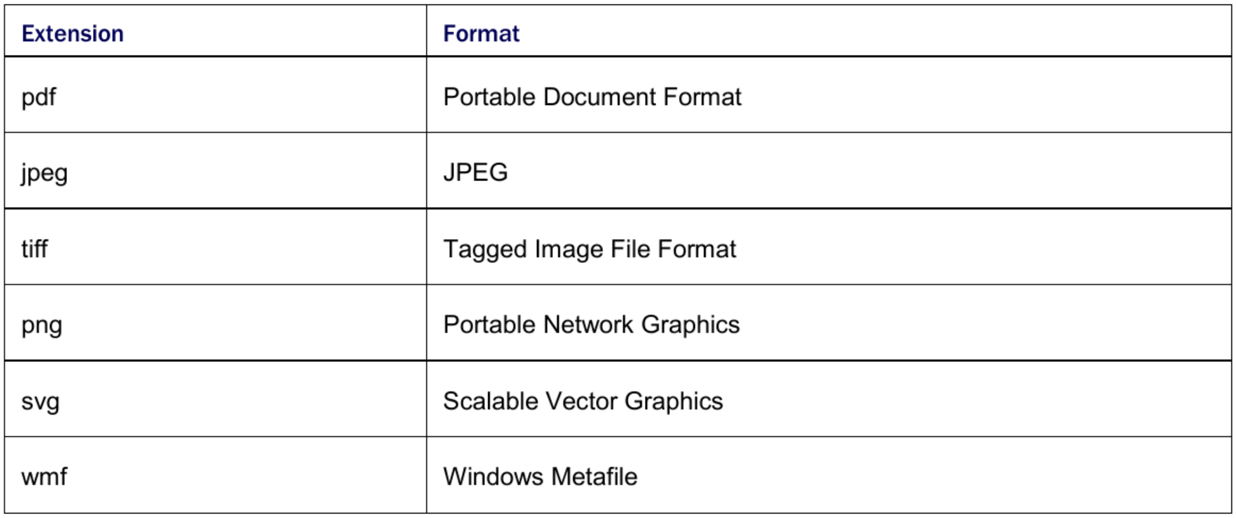
- You can export graphs created by `ggplot2`
  - in a variety of image formats
  - using the RStudio GUI
  - or through your code.
- To export a graph using the RStudio menus,
  - go to the Plots tab and choose Export

To export a graph via code

- use the `ggsave()` function.
- You can specify the plot to save,
  - its size and format,
  - and where to save it. For example,
  - `ggsave(file = "mygraph.png", plot = myplot, width = 5, height = 4)`
  - saves myplot as a 5-inch by 4-inch PNG file
  - named mygraph.png
  - in the current working directory.

You can save the graph in a different format

- by changing the file extension.



Extension	Format
pdf	Portable Document Format
jpeg	JPEG
tiff	Tagged Image File Format
png	Portable Network Graphics
svg	Scalable Vector Graphics
wmf	Windows Metafile

Figure 3: Image File Formats

The pdf, svg, and wmf formats are lossless

- they resize without fuzziness or pixilation.
- The other formats are lossy
  - they will pixelate when resized.
  - This is especially noticeable when small images are enlarged.
- The png format is popular for images destined for webpages.
- The jpeg and tif formats are usually reserved for photographs.

The `wmf` format is usually recommended for graphs

- that will appear in Microsoft Word or PowerPoint documents.
- MS Office does not support `pdf` or `svg` files,
  - and the `wmf` format will rescale well.
- However, note that `wmf` files
  - will lose any transparency settings that have been set.

If you omit the `plot =` option,

- the most recently created graph is saved.

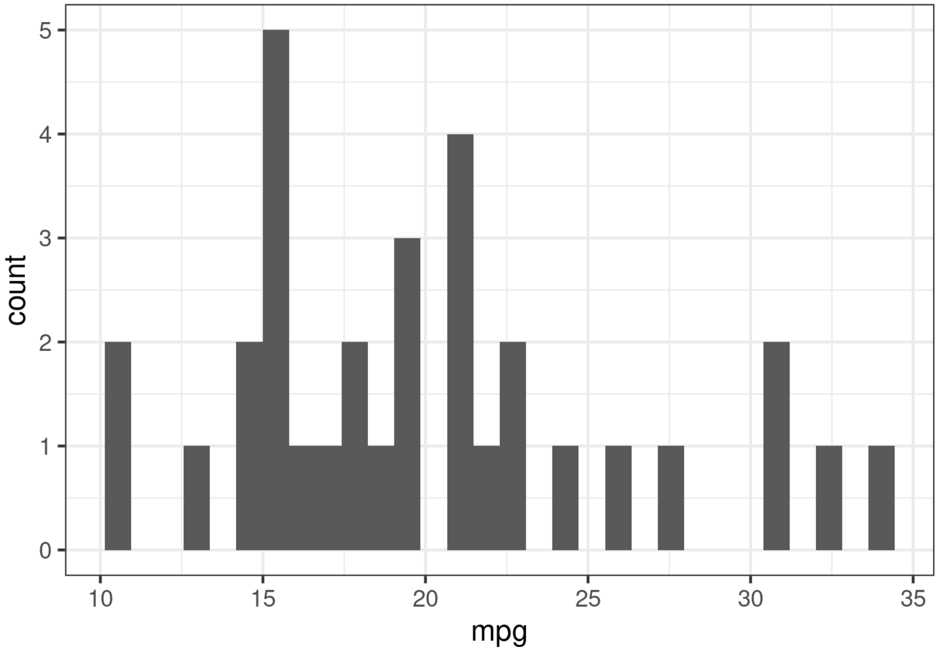
The code is valid and

- saves the graph to disk as a PDF document.

- See help(ggsave) for additional details.

```
ggplot(data = mtcars, aes(x = mpg)) + geom_histogram()
```

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



```
ggsave(file = "mygraph.pdf")
```

```
## Saving 5 x 3.5 in image
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```

4.1.3.3.4 Common Mistakes

After working with ggplot2 for years,

- I've found that there are two mistakes that are frequently made.
- The first is omitting or misplacing a closing parentheses.
  - This happens most often following the aes() function.

Consider the following code.

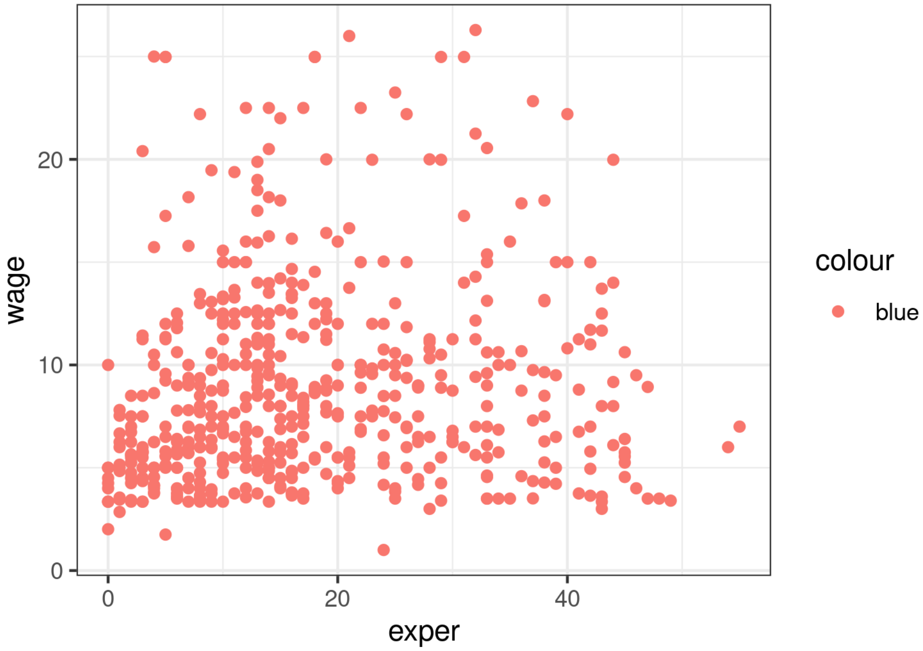
```
ggplot(CPS85, aes(x = exper, y = wage, color = sex) +
         geom_point()
```

- Note the lack of a closing parentheses at the end of the first line.
  - I can't tell you how many times I've done this.

The second error is confusing an assignment for a mapping.

This code produces the next graph.

```
ggplot(CPS85, aes(x = exper, y = wage, color = "blue")) +
  geom_point()
```



The points are red (not blue) and there is a strange legend.

- What happened?

The `aes()` function is used

- to map variables to the visual characteristics of the graph.
- Assigning constant values is done outside the `aes()` function.

4.1.3.4 `ggplot2` Summary

- The `ggplot2` package provides a powerful platform
  - for creating both simple and complex graphs.
  - Graphs are built up in layers
    - using functions chained together with the plus (`+`) symbol.
- The `ggplot()` function specifies a data frame
  - containing plot data
  - and an `aes()` function that maps variables
    - to visual aspects of the graph.
  - `geom_` functions specify the geometric objects
    - (bars, lines, points, etc.)
    - to be placed on the graph.
- Optional `scale_` functions allow you to
  - customize how a variable's values
    - will be translated into their visual representations on the graph
    - (e.g., the x- and y-axis scales and labels to used,
    - and what colors, shapes, and line-types
    - will be mapped to a variable's values).
- Data from two or more groups
  - can be represented by grouping
  - (superimposing plots distinguished by visual aspects such as color)
  - or faceting (placing several small plots in a matrix-like array).
- Two common errors of ggplot are
  - missing/misplaced parentheses
  - nd confusing an assignment for a mapping.

- Graphs can be exported in a wide variety of image formats
  - (such as tiff, pdf, jpg, png, svg, and wmf)
  - using the RStudio GUI
  - or with the `ggsave()` function.

4.1.3.5 Links

- Robert I. Kabacoff, R in Action, 3rd Edition, Manning Publications 2020