Visualizing Tabular Data

Lesson 2 with *Rachael Blake*

Lesson Objectives

- Meet the “layered grammar of graphics”
- Trust that ggplot2 is way better than base R’s `plot`
- Learn to layer visual elements on top of tidy data
- Glimpse the vast collection of ggplot2 options

Specific Achievements

- Create “aesthetic mappings” from variables to scales & geometries
- Build boxplots, scatterplots, smoothed lines and histograms
- Style plots with colors & annotate them with labels
- Repeat plots for different subsets of data

“A Layered Grammar of Graphics” is the title of an article by the author of ggplot2, Hadley Wickham. The package codifies the ideas presented in the article, especially the main idea that scientific visualization is all about assigning different variables to distinct visual elements. A plot is made up of several of these “aesthetic mappings”: for example, equating *income* to a linear scale on the y-axis, *education* to a ordinal scale on the x-axis, and displaying records about each person in a box-plot geometry.

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Getting Started

The dataset you will plot is an example of Public Use Microdata Sample (PUMS) produced by the US Census Bureau. We’ll explore the wage gap between men and women.

The file to be loaded contains individuals’ anonymized responses to the 5 Year American Community Survey (ACS) completed in 2017. There are over a hundred variables giving individual level data on household members income, education, employment, ethnicity, and much more.

`worksheet-2.R`

```
library(readr)
person <- read_csv(
  file = 'data/census_pums/sample.csv',
  col_types = cols_only(
    AGEP = 'i',
    WAGP = 'd',
    SCHL = 'c',
    SEX = 'c'))
```

The readr package gives additional flexibility and speed over the base R `read.csv` function. The CSV contains 4 million rows, equating to several gigabytes, so a sample suffices while developing ideas for visualiztion.

Layered Grammar

The code to plot each invidual’s wage or salary income by their education attainment calls three functions: `ggplot`, `aes`, and `geom_histogram` from the ggplot2 package.

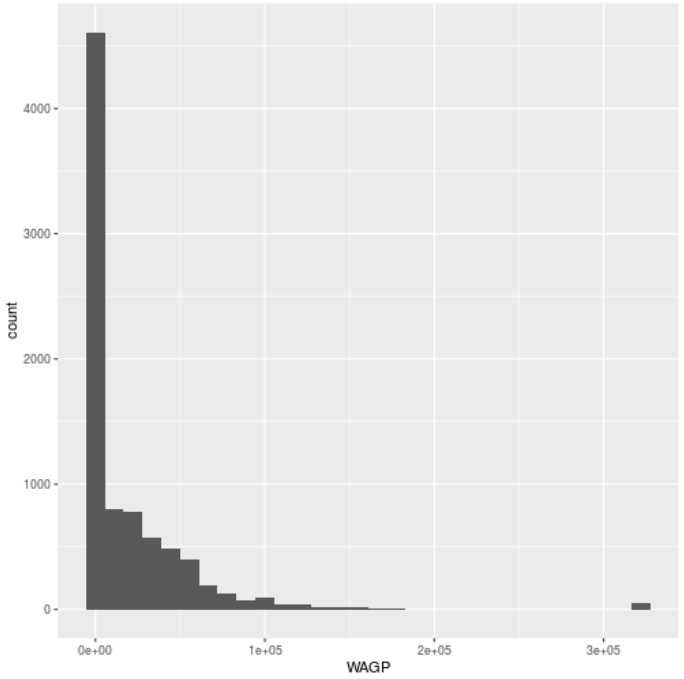
- `ggplot` creates the foundation
- `aes` specifies an aesthetic mapping
- `geom_histogram` adds a layer of visual elements

`worksheet-2.R`

```
library(ggplot2)
ggplot(person, aes(x = WAGP)) +
  geom_histogram()
```

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

```
Warning: Removed 1681 rows containing non-finite values (stat_bin).
```



The `ggplot` command expects a data frame and an aesthetic mapping. The `aes` function creates the aesthetic, a mapping between variables in the data frame and visual elements in the plot. Here, the aesthetic maps `WAGP` to the x-axis; a histogram only needs one variable mapped.

The `ggplot` function by itself only creates the axes, because only the aesthetic map has been defined. No data are plotted until the addition of a `geom_*` layer, in this example a `geom_histogram`. Layers are literally added, with `+`, to the object created by the `ggplot` function.

Plotting histograms is always a good idea when exploring data. The zeros and the “top coded” value used for high wage-earners in PUMS are outliers.

worksheet-2.R

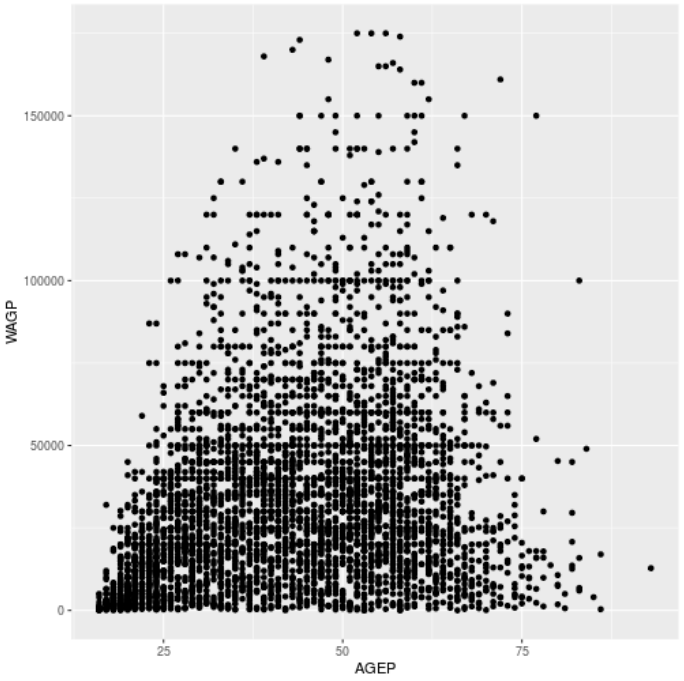
```
library(dplyr)
person <- filter(
  person,
  WAGP > 0,
  WAGP < max(WAGP, na.rm = TRUE))
```

The dplyr package provides tools for manipulating tabular data. It is an essential accompaniment to ggplot2.

The `geom_histogram` aesthetic only involves one variable. A scatterplot requires two, both an `x` and a `y`.

worksheet-2.R

```
ggplot(person,
  aes(x = AGEP, y = WAGP)) +
  geom_point()
```

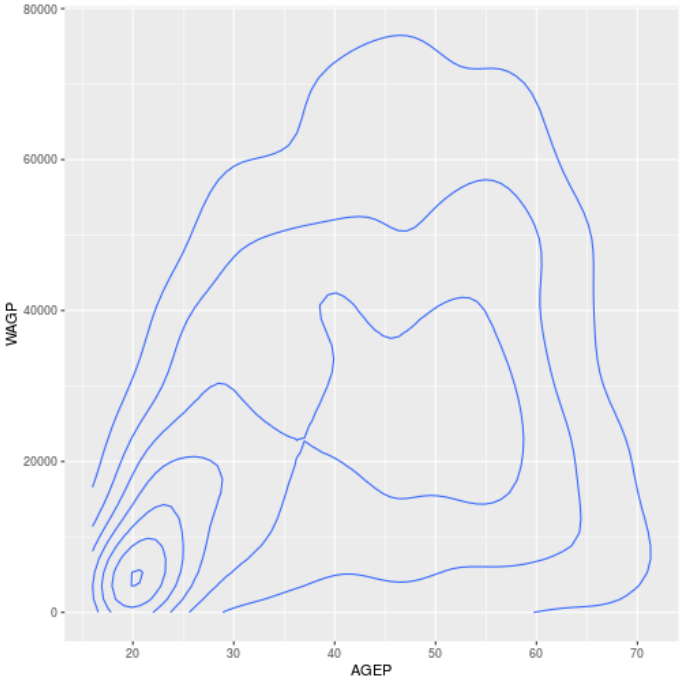


The `aes` function can map variable to more than just the `x` and `y` axes in a plot. There are several other "scales" that exist, although whether and how they show up depends on the `geom_*` layer. Commonly used arguments are `color` for line or edge color and `fill` for interior colors, but many more are available.

The aesthetic and the geometry are entirely independent, making it easy to experiment with very different kinds of visual representations. The only change needed is in the `geom_*` layer.

worksheet-2.R

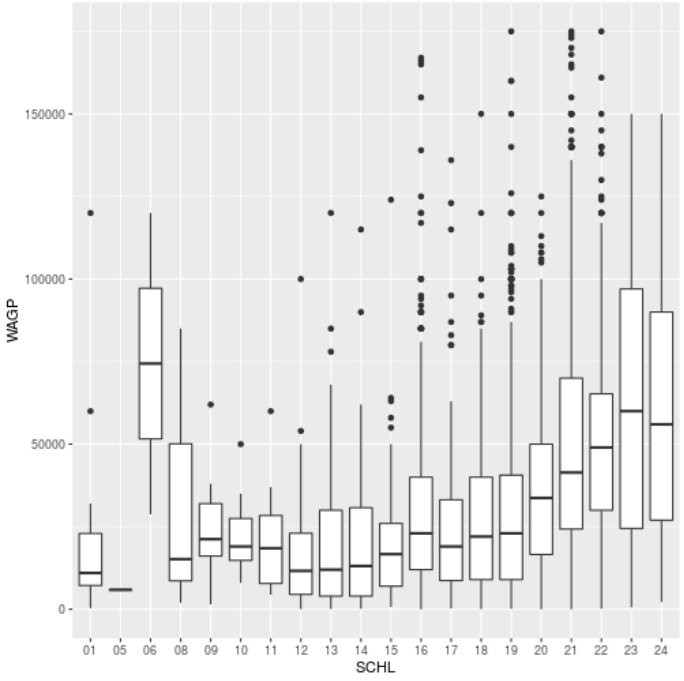
```
ggplot(person,
  aes(x = AGEP, y = WAGP)) +
  geom_density_2d()
```



For a discrete x-axis, a boxplot is often beter than a scatterplot.

worksheet-2.R

```
ggplot(person,
  aes(x = SCHL, y = WAGP)) +
  geom_boxplot()
```



To create a scatterplot, a boxplot, and even a 2d kernel density estimate, the `geom_*` function takes no arguments. Every layer added on top of the foundation generated by the call to `ggplot` *inherits* the dataset and aesthetics of the foundation.

Question

What happens if you supply `x = AGEP` to the aesthetic map in the boxplot?

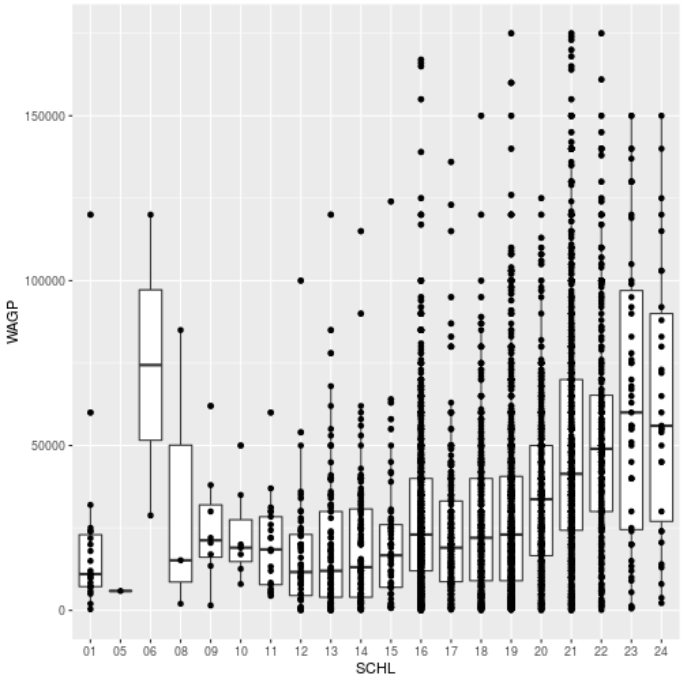
Answer

Boxplots aren't designed for continuous x-axis variables, so the result is not useful. Fortunately, there's a warning.

Multiple `geom_*` layers create a plot with multiple visual elements.

worksheet-2.R

```
ggplot(person,
  aes(x = SCHL, y = WAGP)) +
  geom_boxplot() +
  geom_point()
```

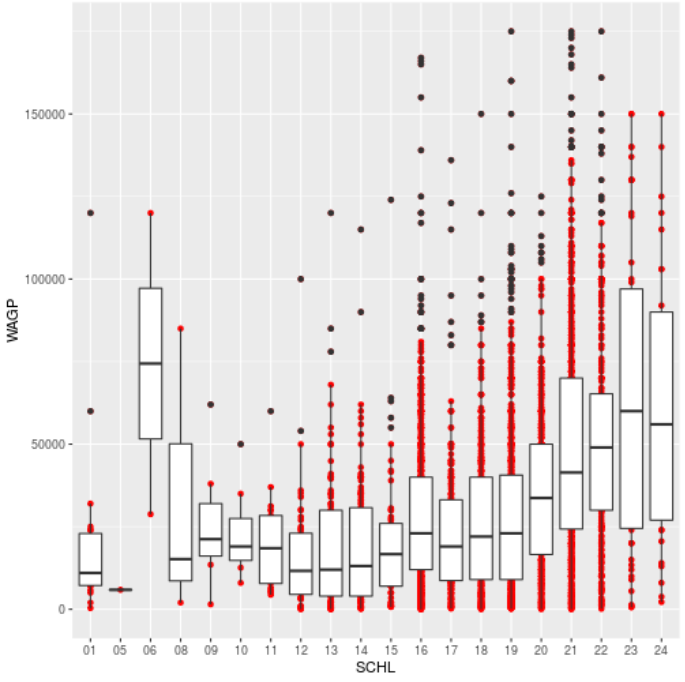


Layer Customization

Each `geom_*` object accepts arguments to customize that layer. Many arguments are common to multiple `geom_*` functions, such as changing the layer's color.

worksheet-2.R

```
ggplot(person,
  aes(x = SCHL, y = WAGP)) +
  geom_point(color = 'red') +
  geom_boxplot()
```

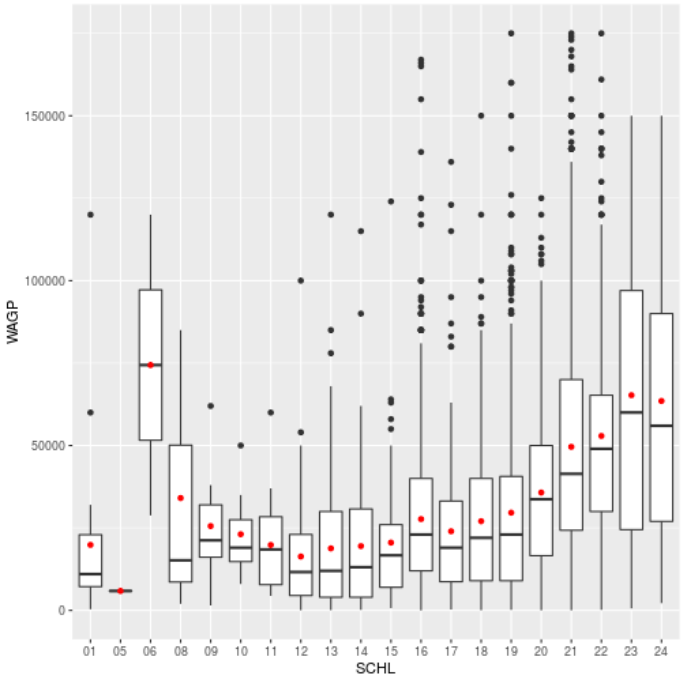


The `color` specification was not part of aesthetic mapping between data and visual elements, so 1) it applies to every record (or person) and 2) only the elements in the scatterplot layer are affected.

The `stat` parameter, in conjunction with `fun.y`, provides the ability to perform on-the-fly data transformations.

worksheet-2.R

```
ggplot(person,
  aes(x = SCHL, y = WAGP)) +
  geom_boxplot() +
  geom_point(
    color = 'red',
    stat = 'summary',
    fun.y = mean)
```



With `stat = 'summary'`, the plot replaces the raw data with the result of a summary function applied to whatever "grouping" is defined in the aesthetic. In this case, it's the ordinal x-axis that defines education attainment groups. The `fun.y` argument determines what function, here the function `mean`, with which you want to summarize each group.

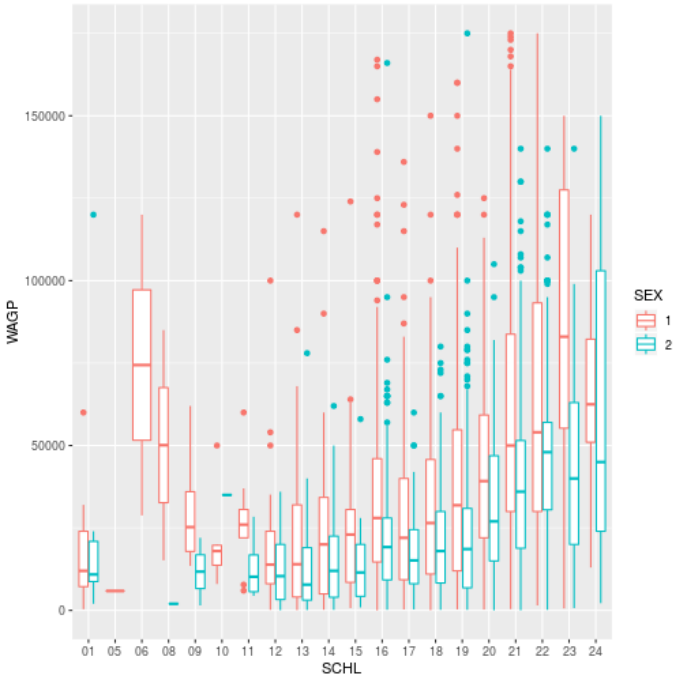
Additional Aesthetics

The true power of ggplot2 is the natural connection it provides between variables and visuals.

Associating color (or any attribute, like the shape of points) to a variable is another kind of aesthetic mapping. Passing the `color` argument to the `aes` function works quite differently than assiging color to a `geom_*`.

worksheet-2.R

```
ggplot(person,
  aes(x = SCHL, y = WAGP, color = SEX)) +
  geom_boxplot()
```



Question

What sex do you think is coded as “1”?

Answer

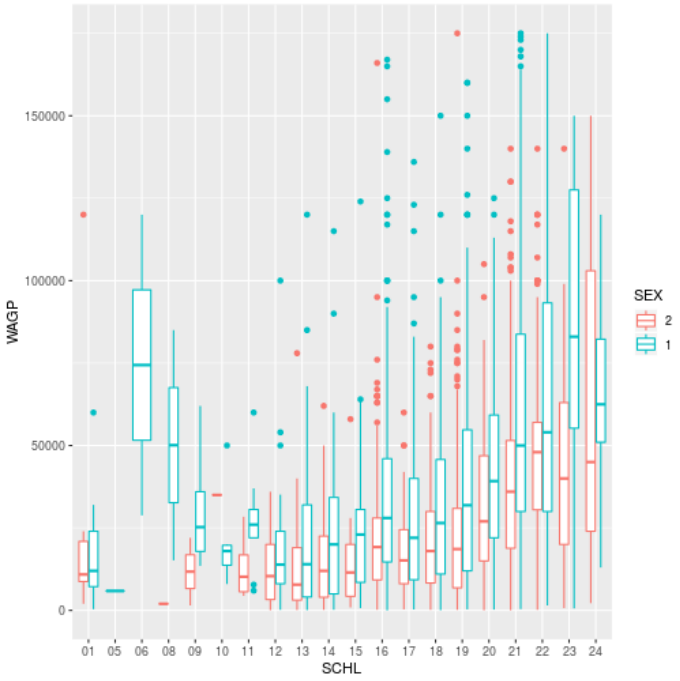
… Megan is skeptical about the answer!

Properties of the data itself are similarly independent of the aesthetic mapping and the visual elements, while still affecting the output.

worksheet-2.R

```
person$SEX <- factor(person$SEX, levels = c("2", "1"))

ggplot(person,
  aes(x = SCHL, y = WAGP, color = SEX)) +
  geom_boxplot()
```



There can be cases where you don't want to or can't modify the dataframe. Then, it is still possible to change properties of the data to get the plot you'd like within the `ggplot`, `aes`, and `scale_*` functions. More on modifying plots with `scale_*` later in the lesson.

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Storing and Re-plotting

The output of `ggplot` can be assigned to a variable, which works with `+` to add layers.

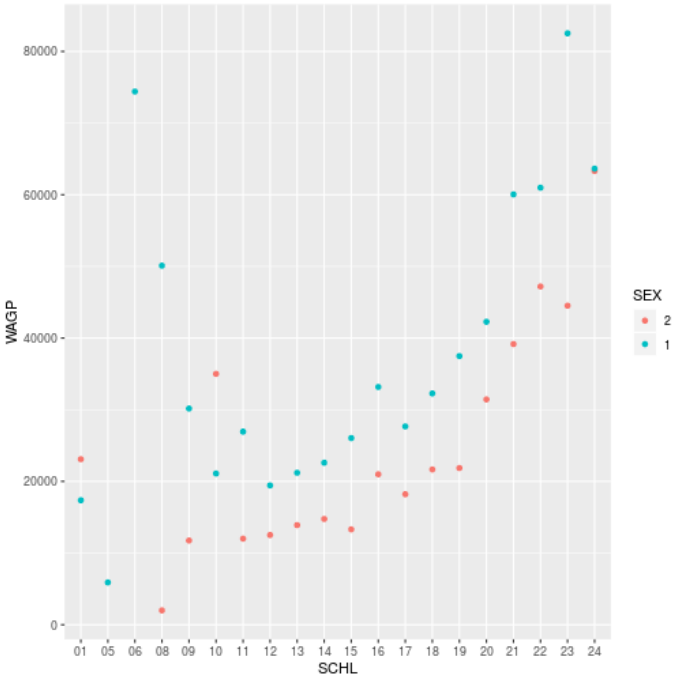
worksheet-2.R

```
schl_wagp <- ggplot(person,
  aes(x = SCHL, y = WAGP, color = SEX)) +
  geom_point(
    stat = 'summary',
    fun.y = 'mean')
```

The plot information stored in `schl_wagp` can be used on its own, or with additional layers.

Console

```
> schl_wagp
```



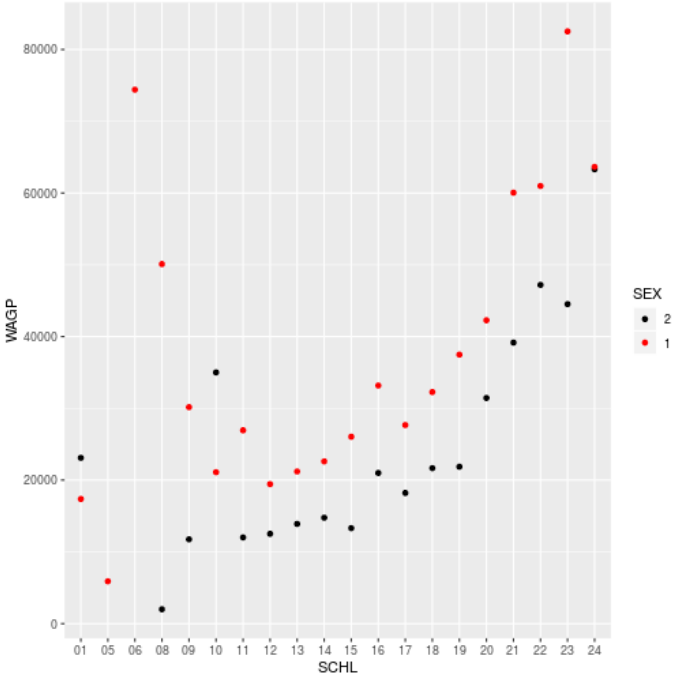
Store additional layers by overwriting the variable (or creating a new one).

worksheet-2.R

```
schl_wagp <- schl_wagp +
  scale_color_manual(
    values = c('black', 'red'))
```

Console

```
> schl_wagp
```



Figures are constructed in ggplot2 as layers of shapes, from the axes on up through the `geom_*` elements. The natural file type for storing such figures at “infinite” resolution are PDF (for print) or SVG (for online).

worksheet-2.R

```
ggsave(filename = 'schl_wagp.pdf',
  plot = schl_wagp,
  width = 4, height = 3)
```

The `plot` argument is unnecessary if the target is the most recently displayed plot, but a little verbosity is not out-of-place here. When a raster file type is necessary (e.g. a PNG, JPG, or TIFF) use the `dpi` argument to specify an image resolution.

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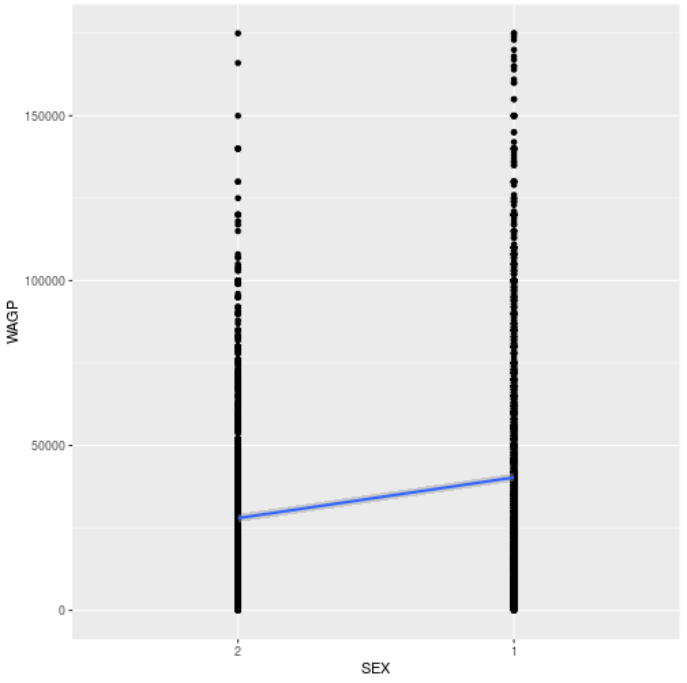
Smooth Lines

The `geom_smooth` layer used above can add various kinds of regression lines and confidence intervals. A `method = 'lm'` argument specifies a linear model.

Note, however, that with a categorical predictor mapped to an aesthetic element, the `geom_smooth` call would separately perform a linear regression (ANOVA) within each group. The call to `aes` must override the "group" aesthetic so the regression is run once.

worksheet-2.R

```
ggplot(person,
  aes(x = SEX, y = WAGP)) +
  geom_point() +
  geom_smooth(
    method = 'lm',
    aes(group = 0))
```



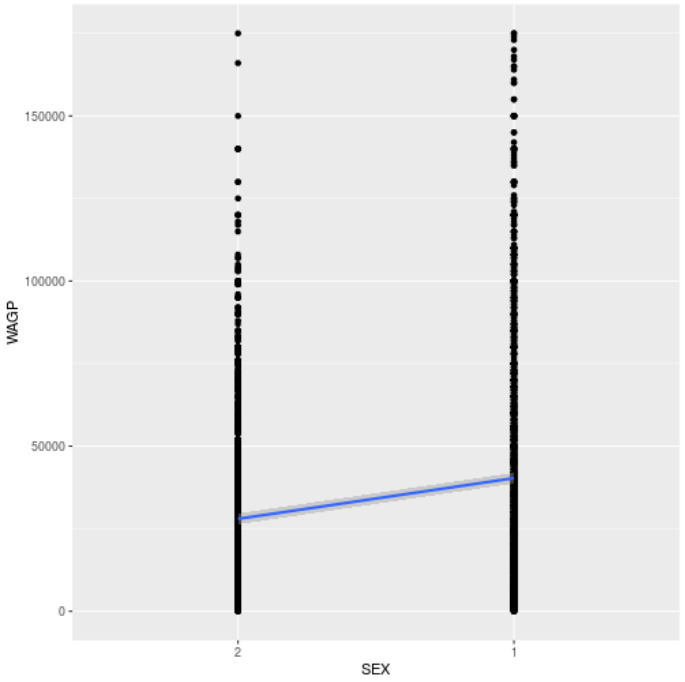
Is there really a confidence interval? Yes, it's just pretty narrow and hard to see. You could add a `size = 0.5` argument to `geom_smooth` to see there is a gray interval around the line. Or, as the next step shows, you could change the size of the confidence interval for a better visual representation of the variability.

The `level` argument for `geom_smooth` controls the limits of the confidence interval, defaulting to 95%.

worksheet-2.R

```
ggplot(person,
  aes(x = SEX, y = WAGP)) +
  geom_point() +
  geom_smooth(
    method = 'lm',
```

```
    level = 0.99,
    aes(group = 0))
```



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Axes, Labels and Themes

The `aes` and the `geom_*` functions do their best with annotations and styling, but precise control comes from `labs`, `scale_*`, and `theme_*`.

First, store a plot to simplify experiments with the labels.

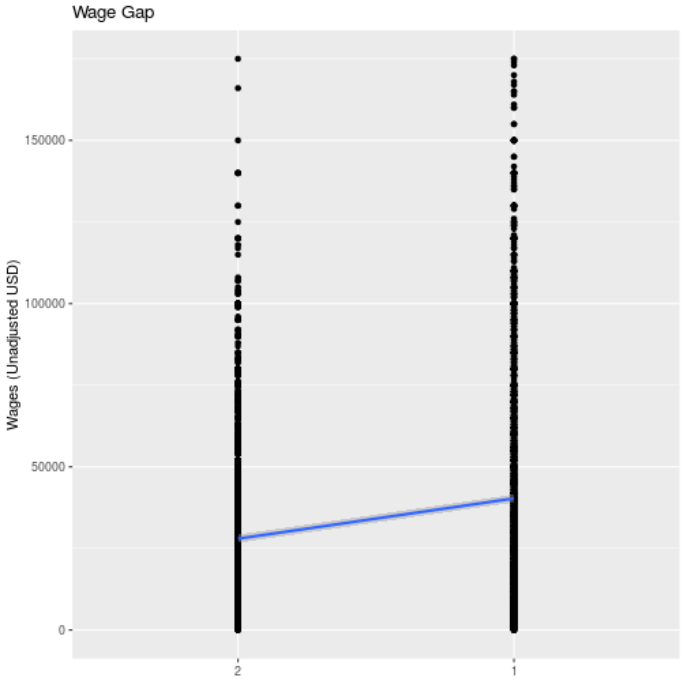
worksheet-2.R

```
sex_wagp <- ggplot(person,
  aes(x = SEX, y = WAGP)) +
  geom_point() +
  geom_smooth(
    method = 'lm',
    aes(group = 0))
```

Set the title and axis labels with the `labs` function, which accepts names for labeled elements in your plot (e.g. `x`, `y`, `title`) as arguments.

worksheet-2.R

```
sex_wagp + labs(
  title = 'Wage Gap',
  x = NULL,
  y = 'Wages (Unadjusted USD)')
```

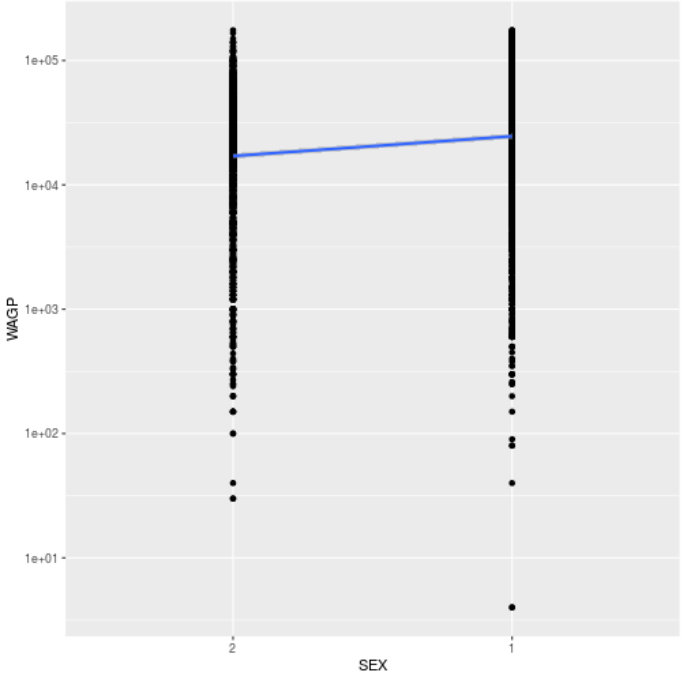


For information on how to add special symbols and formatting to plot labels, see `?plotmath`.

Functions related to the axes, i.e. their limits, breaks, and any transformation are all `scale_*` functions. To modify any property of a continuous y-axis, add a call to `scale_y_continuous`.

worksheet-2.R

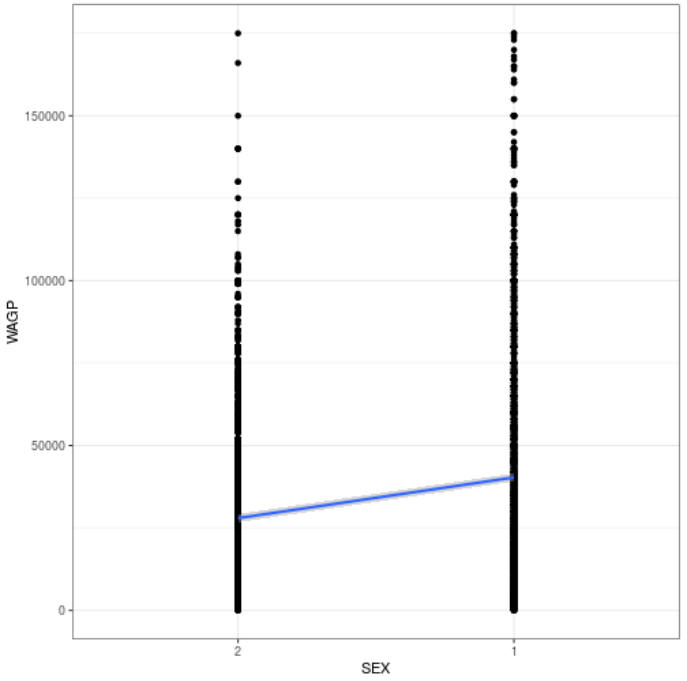
```
sex_wagp + scale_y_continuous(
  trans = 'log10')
```



“Look and feel” options in ggplot2, from background color to font sizes, can be set with `theme_*` functions.

worksheet-2.R

```
sex_wagp + theme_bw()
```



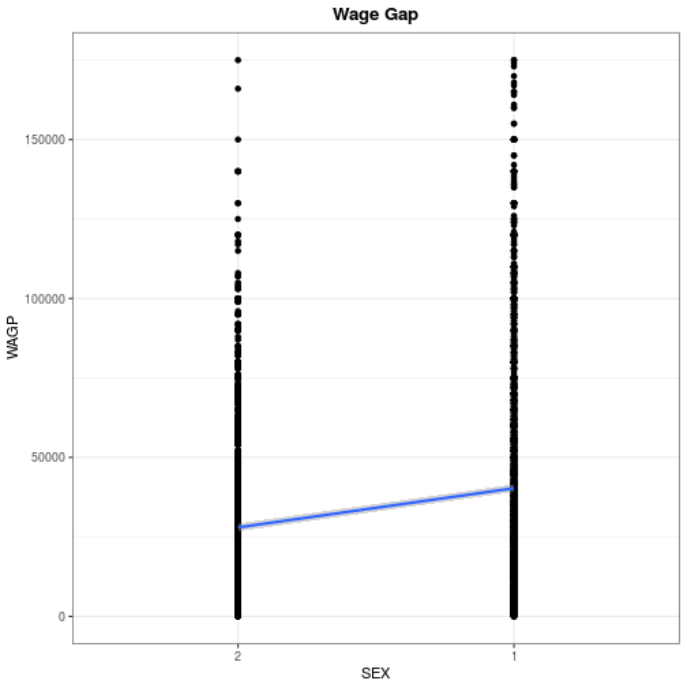
Start typing `theme_` on the console to see what themes are available in the pop-up menu. The default theme is `theme_grey`. A popular "minimal" theme is `theme_bw`. Any option set by a `theme_*` function can also be set by calling `theme` itself with the option and value as an argument.

The options available directly through `theme` offer limitless possibilities for customization.

Do be aware that if `theme` comes after other custom specifications, it will overwrite those customizations. Check the order if your plot isn't looking how you'd like it to look.

worksheet-2.R

```
sex_wagp + theme_bw() +
  labs(title = 'Wage Gap') +
  theme(
    plot.title = element_text(
      face = 'bold',
      hjust = 0.5))
```



Use `?theme` for a list of available theme options. Note that position (both `legend.position` and `hjust` for horizontal justification) should be given as a proportion of the plot window (i.e. between 0 and 1).

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Facets

To conclude this overview of ggplot2, we'll apply the same plotting instructions to different subsets of the data, creating panels or "facets".

The `facet_wrap` function takes a `vars` argument that, like the `aes` function, relates a variable in the dataset to a visual element, the panels. The `facet_grid` function works like `facet_wrap`, but expects two variables to facet by the interaction of a row variable by a column variable.

The gender wage gap apparent in the US Census PUMS data is probably not consistent across people who obtained different levels of education.

worksheet-2.R

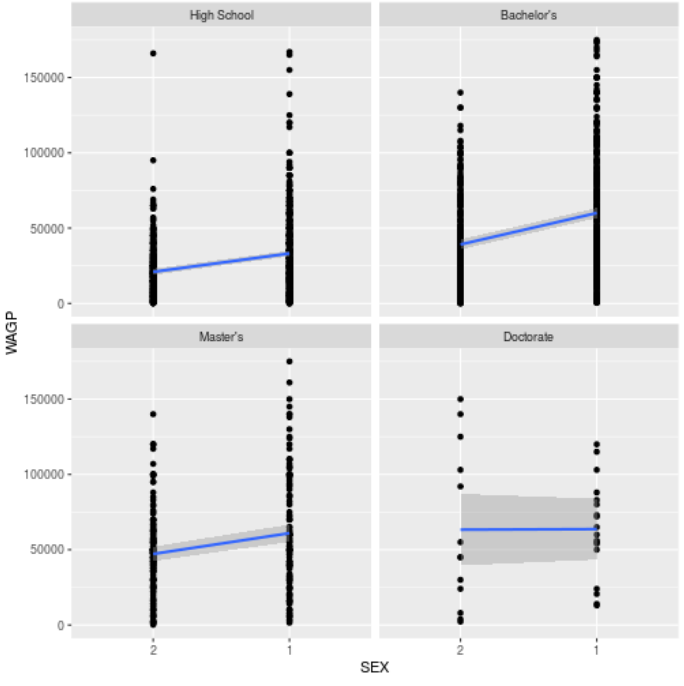
```
person$SCHL <- factor(person$SCHL)
levels(person$SCHL) <- list(
  'High School' = '16',
  'Bachelor\'s' = '21',
  'Master\'s' = '22',
  'Doctorate' = '24')
```

The technical documenation for the PUMS data includes a data dictionary, explaining the codes used for education attainment, and everything else you'ld like to know about the dataset.

The `sex_wagp` plot created above stored it's own copy of the data, so create a new `ggplot` foundation using a cleaned up dataset.

worksheet-2.R

```
ggplot(na.omit(person),
  aes(x = SEX, y = WAGP)) +
  geom_point() +
  geom_smooth(
    method = 'lm',
    aes(group = 0)) +
  facet_wrap(vars(SCHL))
```



Question

What wage gap trend do you think is worth investigating, and how might you do it?

Answer

There are so many possibilities! For example, a scatterplot of wage against age colored by sex that includes a fitted regression model.

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Review

1. Call `ggplot` with data and an `aes` to pave the way for subsequent layers.
2. Add one or more `geom_*` layers, possibly with data transformations.
3. Add `labs` to annotate your plot and axes labels (not optional!).
4. Optionally add `scale_*`, `theme_*`, `facet_*`, or other modifiers that work on underlying layers.

Additional Resources

- Data Visualization with ggplot2 RStudio Cheat Sheet
- Cookbook for R - Graphs Reference on customizations in ggplot
- Introduction to cowplot Vignette for a package with ggplot enhancements

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Exercises

Exercise 1

Use `ggplot` to show how the mean wage earned in the U.S. varies with age, showing males and females in different colors. (Hint: Baby steps! Start with a scatterplot of wage by age. Then expand your code to plot only the means. Then distinguish sexes by color.)

Exercise 2

Create a histogram, using a `geom_histogram` layer, of the wages earned by females and males, with sex distinguished by the color of the bar's interior. To silence that warning you're getting, open the help with `?geom_histogram` and determine how to explicitly set the bin width.

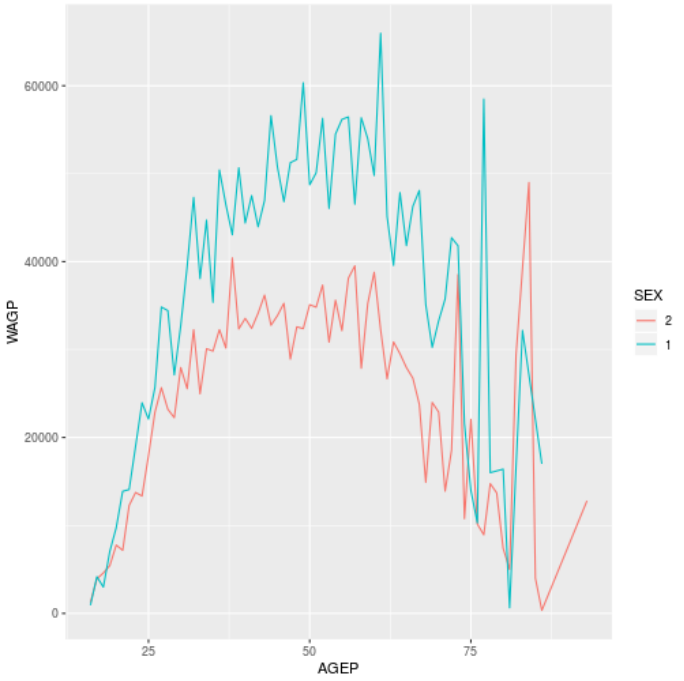
Exercise 3

The `facet_grid` layer (different from `facet_wrap`) requires an argument for both row and column varaibles, creating a grid of panels. Create a plot with 8 facets, each displaying a single histogram of wage earned by women or men having one of the four education attainment levels. Make the grid have 2 rows and 4 columns. *Advanced challenge*: add a second, partially transparent, histogram to the background of each facet that provides a comparison to the whole population. (Hint: the second histogram should not inherit the dataset from the `ggplot` foundation.)

Solutions

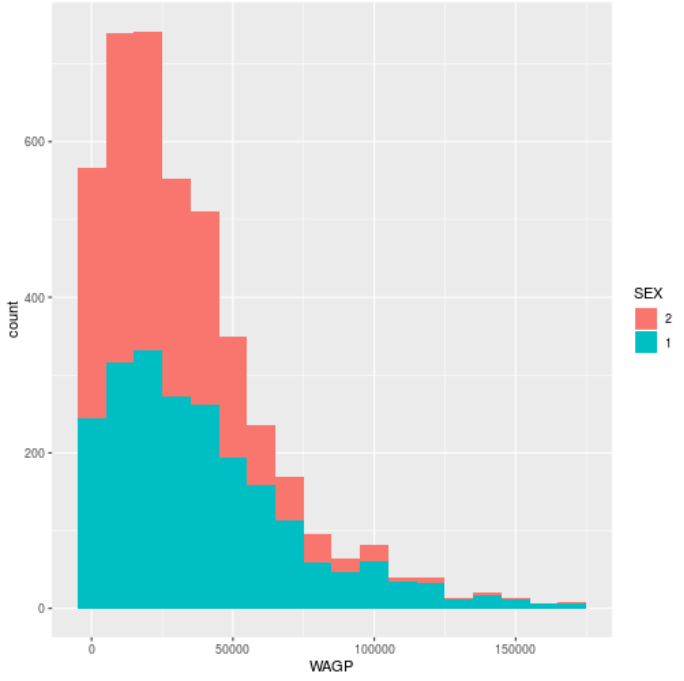
Solution 1

```
ggplot(person,
  aes(x = AGEP, y = WAGP, color = SEX)) +
  geom_line(stat = 'summary',
            fun.y = 'mean')
```



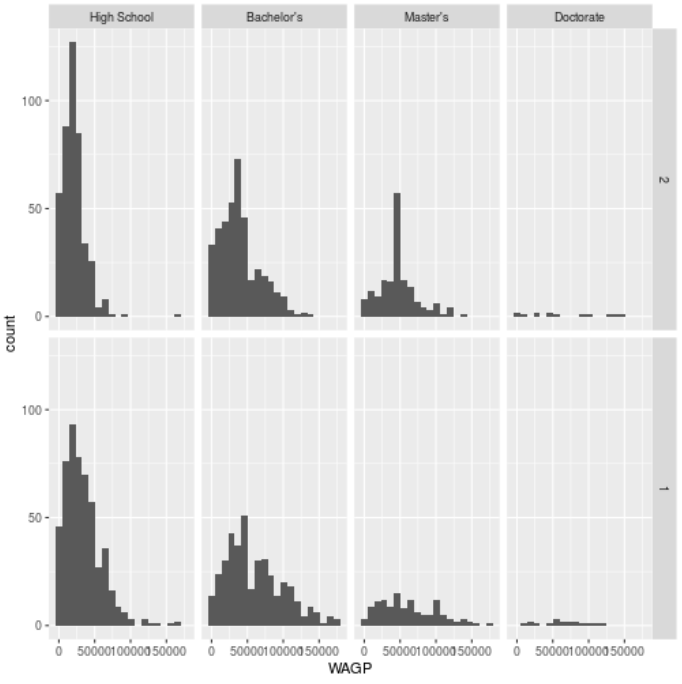
Solution 2

```
ggplot(person,
  aes(x = WAGP, fill = SEX)) +
  geom_histogram(binwidth = 10000)
```



Solution 3

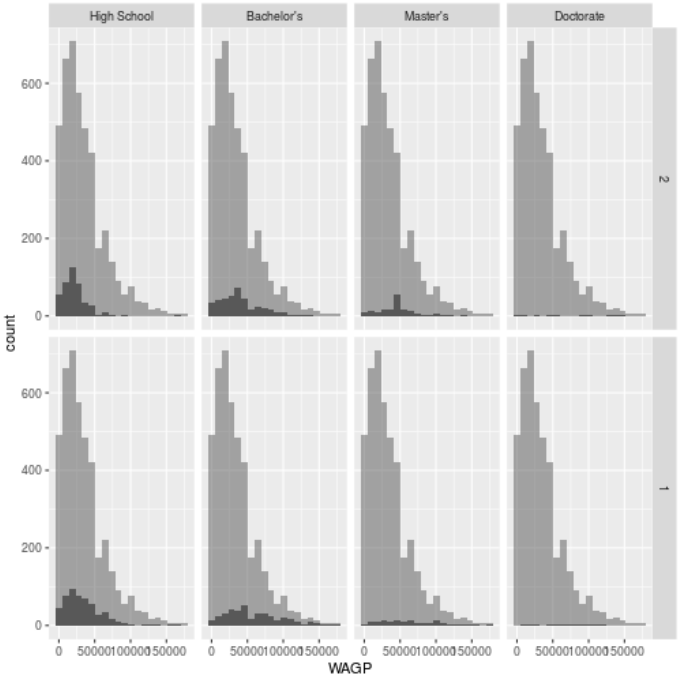
```
ggplot(na.omit(person),
  aes(x = WAGP)) +
  geom_histogram(bins = 20) +
  facet_grid(vars(SEX), vars(SCHL))
```



For the advanced challenge, you must supply a dataset to a second gemo_histogram that does not have the variable specified in `facet_grid`. Note that `facet_grid` affects the entire plot, including layers added "after faceting", as in the solution below.

Solution 3 (challenge)

```
ggplot(na.omit(person),
  aes(x = WAGP)) +
  geom_histogram(bins = 20) +
  facet_grid(vars(SEX), vars(SCHL)) +
  geom_histogram(
    bins = 20,
    data = na.omit(person['WAGP']),
    alpha = 0.5)
```



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If you need to catch-up before a section of code will work, just squish it's to copy code above it into your clipboard. Then paste into your interpreter's console, run, and you'll be ready to start in on that section. Code copied by both and will also appear below, where you can edit first, and then copy, paste, and run again.

```
# Nothing here yet!
```