GCDS: Data Visualization and the Grammar of Graphics

Overview

Data visualization is key to understanding data. This exercise will use `dplyr` most prominently. Piecing together the components will be difficult but in the end you need visualizations. At very least you should gain an understanding of chaining functions together in `dplyr` using the `%>%` from the `magrittr` library in order to set by step manipulate a data frame.

Some Helpful Functions:

- `ggplot()` : for initializing a plot object

- `aes()` : for specifying aesthetics of a plot (e.g., x, y, size, color, etc.)
- `geom_bar()` : for bar geometry of a plot using either x or y
- `geom_col()` : for bar geometry of a plot using x and y
- `geom_point()` : for point geometry of a plot
- `geom_line()` : for line geometry of a plot
- `geom_histogram()` : for a distribution geometry of a plot
- `ggtitle()` or `labs()` : for adding a title
- `geom_text()` : for editing text
- `ylab()` and `xlab()` : for axis labeling
- `coord_flip()` : for flipping the x and y coordinates
- `theme_minimal()` : a particular theme application
- `theme_set()` : for setting a theme

Loading Libraries

You will need to load `dplyr` and `ggplot2` .

```r
library(ggplot2)
library(dplyr)
```

```
##
## Attaching package: 'dplyr'
```

```
## The following objects are masked from 'package:stats':
##
##     filter, lag
```

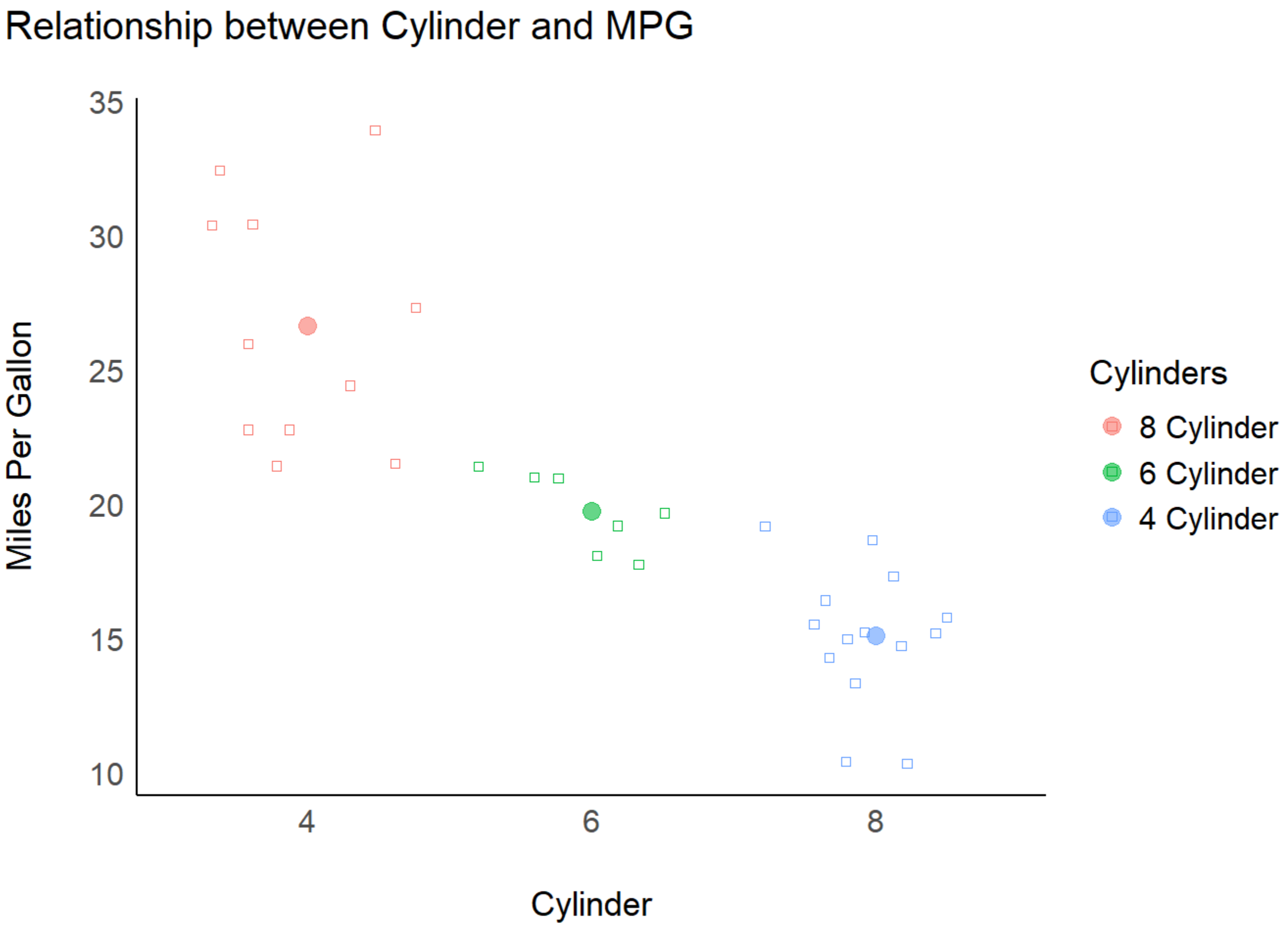
```
## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union
```

Example: An XY Scatterplot

Here is an example of a scatterplot communicating the relationship between `mpg` and `cyl` (cylinder size) from the `mtcars` data set. The plot uses two data frames, one of which summarizes the `mpg` means for each `cyl` level. Yes, you can use two data frames in the same plot.

```
mt_means <- mtcars %>% group_by(., cyl) %>% summarise(., mean = mean(mpg))

ggplot(mtcars) +
  geom_point(aes(x = factor(cyl),
                 y = mpg,
                 color = factor(cyl)),
             shape = 22, position = "jitter") +
  geom_point(data = mt_means,
             mapping = aes(x = factor(cyl),
                           y = mean,
                           color = factor(cyl)),
             alpha = .60,
             size = 3) +
  labs(title = "Relationship between Cylinder and MPG") +
  xlab("Cylinder") +
  ylab("Miles Per Gallon") +
  scale_color_discrete(name = "Cylinders",
                       #breaks = c(8,6,4),
                       labels = c("8 Cylinder","6 Cylinder","4 Cylinder")) +
  see::theme_modern()
```



The Grammar of Graphics

In [*The Grammar of Graphics* (Wilkinson, 2005)] (https://www.amazon.com/Grammar-Graphics-Statistics-Computing/dp/0387245448 (https://www.amazon.com/Grammar-Graphics-Statistics-Computing/dp/0387245448)), Wilkinson explains how graphics can be created using layers that build upon each other.

Plot layers build, starting with data:

- theme
- coordinates
- statistics
- facets
- geometries
- aesthetics
- data

`ggplot` Plot Basics

`ggplot2` was created based on Wilkinsons's grammar structure, so all plots using `ggplot2` start with a base foundation, on top which layers are added according to their own aesthetic attributes.

As Hadley Wickham points out in *ggplot2: Elegant Graphics for Data Analysis, Second Edition*, that the original Grammar of Graphics put forth by Wilkinson and later on the layered grammar of graphics, a statistical graphic represents a *mapping from data to aesthetic attributes* (e.g., color, size, shape, etc.) of geometric objects (e.g., points, lines, bars, etc.) plotted on a specific coordinate system (e.g., Cartesian, Polar). Plots may include statistical information or text. Facetting methods can be used to produce the same plots for different subsets of data (e.g., variations in another variable). All of these individual components comprised to create the final graphic.

Applying a set of rules, or a grammar, allows for creating plot of all different types. Just like understanding a grammar allows you to create new sentences that have never been spoken before, knowing the grammar of graphics allows you to create plots that have not been created before. Without a grammar, you may be limited to choose a sentence structure from a database that matches most closely to what you want to say even. Unfortunately, there may not be an appropriate sentence in that database. If you are programming visualizations, you may be limited need to use a function (like a sentence) that someone has written to plot some data even if the plot is not what you want to create. A grammar will free you of these limitations.

All plots will follow the same rules, so applying the rules allows you to create visualizations never seen before.

Note: Using a grammar needs to be correct even if the sentence is nonsensical.

`ggplot` Plot Composition

- *Data* containing numeric, character, factor variables to visualize
- *Layers* containing geometric elements and statistical transformations
- *Scales* that map values in the data space to values in aesthetic space
- *A Coordinate System* for mapping coordinates to the plane of a graphic
- *A facet* for plotting subsets of data
- *A theme* controlling the niceties of the plot, like font, backround, etc.

The grammar does not:

- Make suggestions about what graphics to use

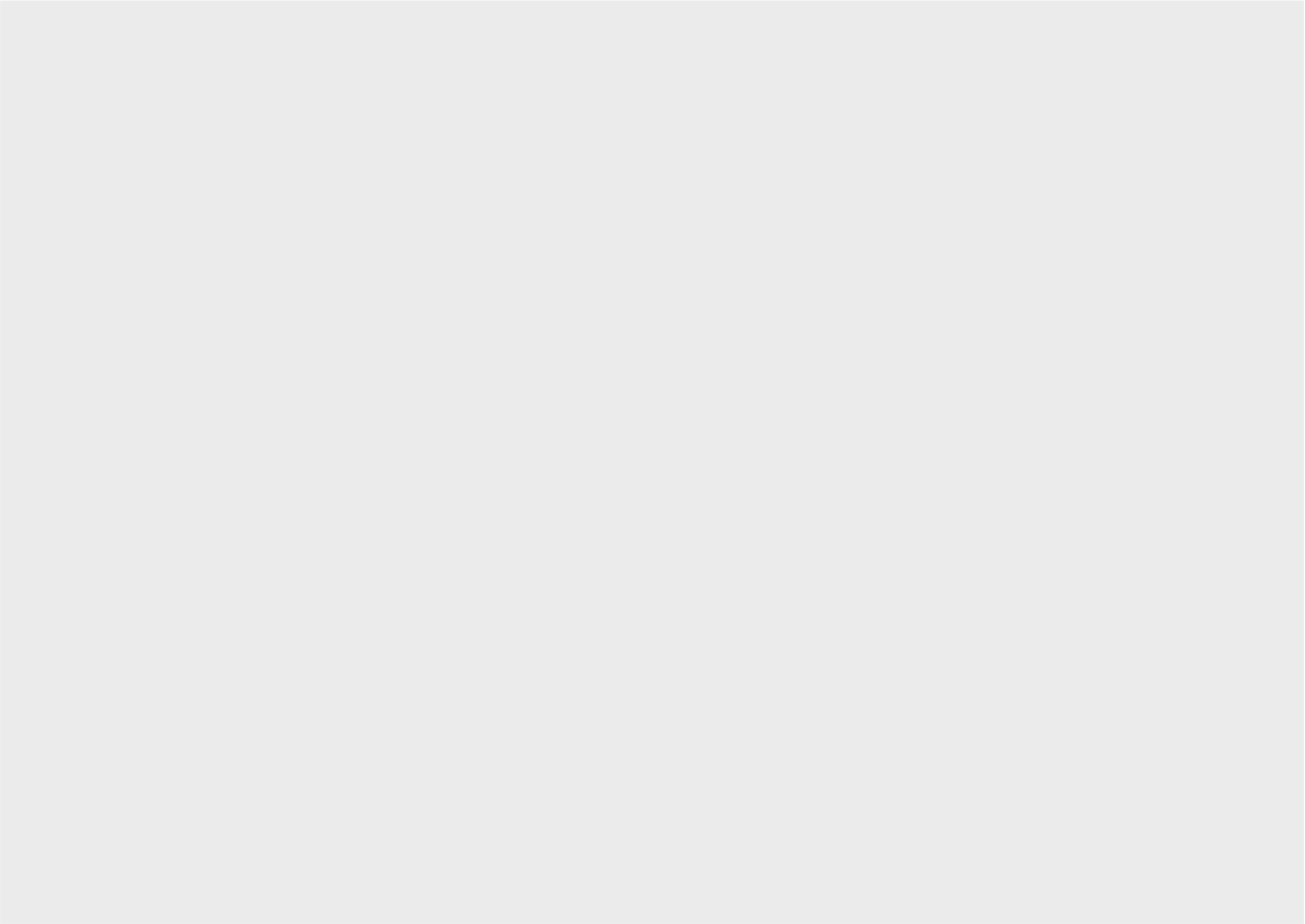
- Describe interactivity with a graphic; ggplot2 graphics are static images

Note: For interactive graphics, see `GGobi` , or similar libraries.

Initializing the Plot Object

What is a `?ggplot` object? Review the docs first. Let’s apply the base layer using `ggplot()` . This function takes a data set and simply initializes the plot object so that you can build other on top of it. By default, `data = NULL` so, you will need to pass some data argument. There is also a `mapping` parameter for mapping the aesthetics of the plot, by default, `mapping = aes()` . If you don’t pass a data frame to `data` , what happens?

```
#?ggplot
ggplot()
```

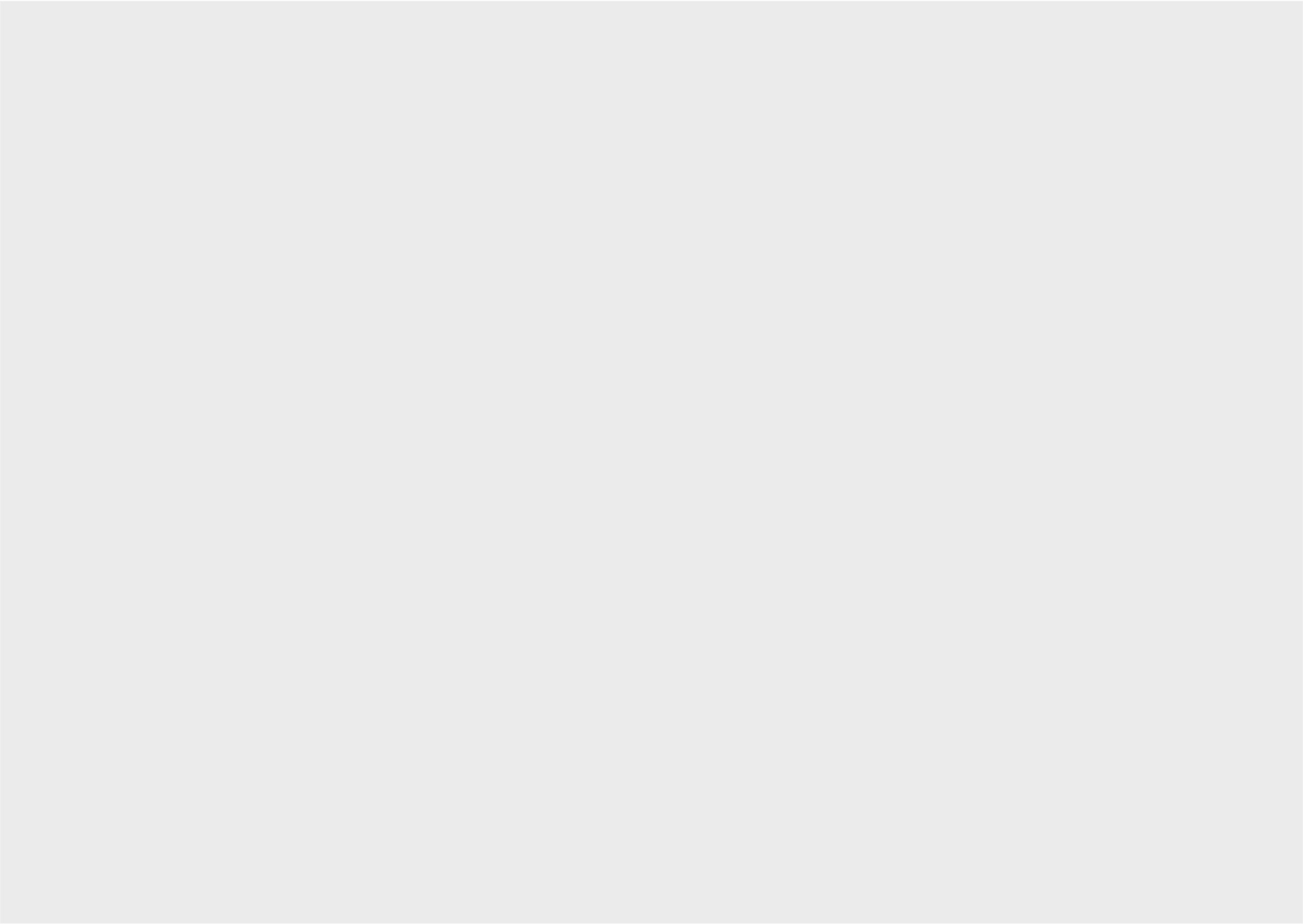


Passing the Data

You cannot have a plot without data, so we need to pass something to `data` .

```
DATA <- data.frame(
  A = c(1, 2, 3, 4),
  B = c(2, 5, 3, 8),
  C = c(10, 15, 32, 28),
  D = c("Task A", "Task A", "Task B", "Task B"),
  E = c("circle", "circle", "square", "square")
  )
```

```
ggplot(data = DATA)
```



```
# or GAME_DAT_choice %>% ggplot()
```

OK, so still nothing. That's because we haven't told `ggplot` what visual properties or aesthetics to include. Importantly, we don't have do this in a base layer. If we set `data = DATA` , the subsequent layers will inherit that data frame if you don't pass the argument in a different layer. However, you are not limited to passing only one data set. You might wish to plot the aesthetics of one data frame in one layer and then add another layer of aesthetics taken from a different data frame. TLDR; you can pass data or not in the initialization of the base layer.

Scaling/Scale Transformation

```
print(DATA)
```

```
##   A B  C      D      E
## 1 1 2 10 Task A circle
## 2 2 5 15 Task A circle
## 3 3 3 32 Task B square
## 4 4 8 28 Task B square
```

Looking at the data, we have columns and rows. Looking at the data frame, you see the ‘identity’ of each case. Ease case is a numeric value, character, or factor. What you for each is there identity. Of course, we can change their identity in some way by transforming the values to z scores, log values, or each average them together to take their count and then plot those data. But those are not their true identity.

In order to take the data units in the data frame so that they can be represented as physical units on a plot (e.g., points, bars, lines, etc.), there needs to be some scaling transformation. The plot needs to understand how many pixels high and wide to create a plot and the plot needs to know the limits of the axes for example. Similarly, it needs to know what shapes to present, how many, etc. By default, the statistical transformation is an ‘identity’ transformation, of one that just takes the values and plots them as their appear in the data (their identity).

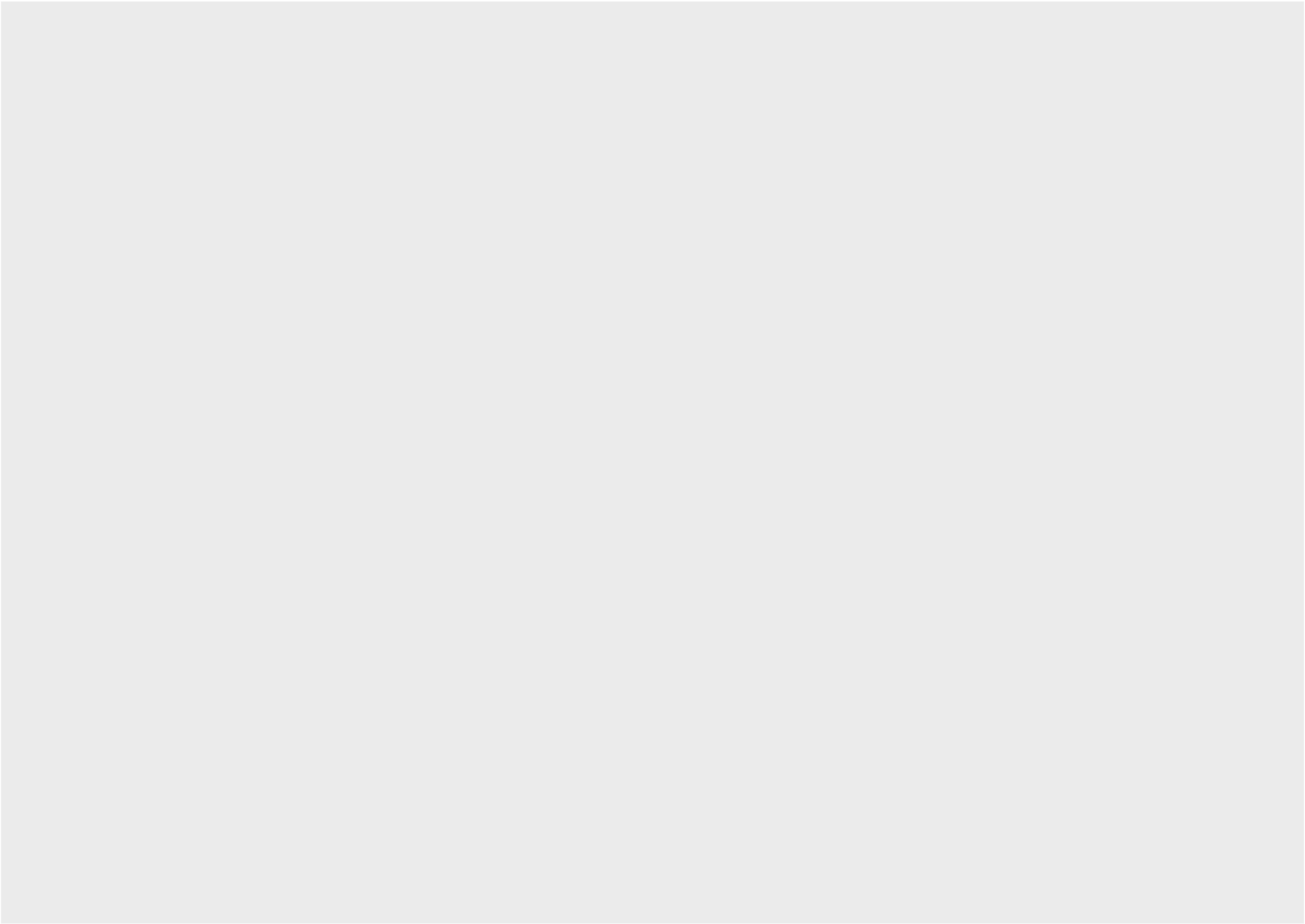
Choosing a Coordinate System

All we have now is the base layer taking on some coordinates. For example, where are the points plotted on the plot? The system can follow the Cartesian coordinate system or a Polar coordinate system. An example of this will follow later. For now, the default is chosen for you.

Adding Aesthetic Mappings

If you wanted a plot geometry to inherit properties of the initialized base layer, you could pass aesthetics to the mapping argument, `mapping = aes()` .

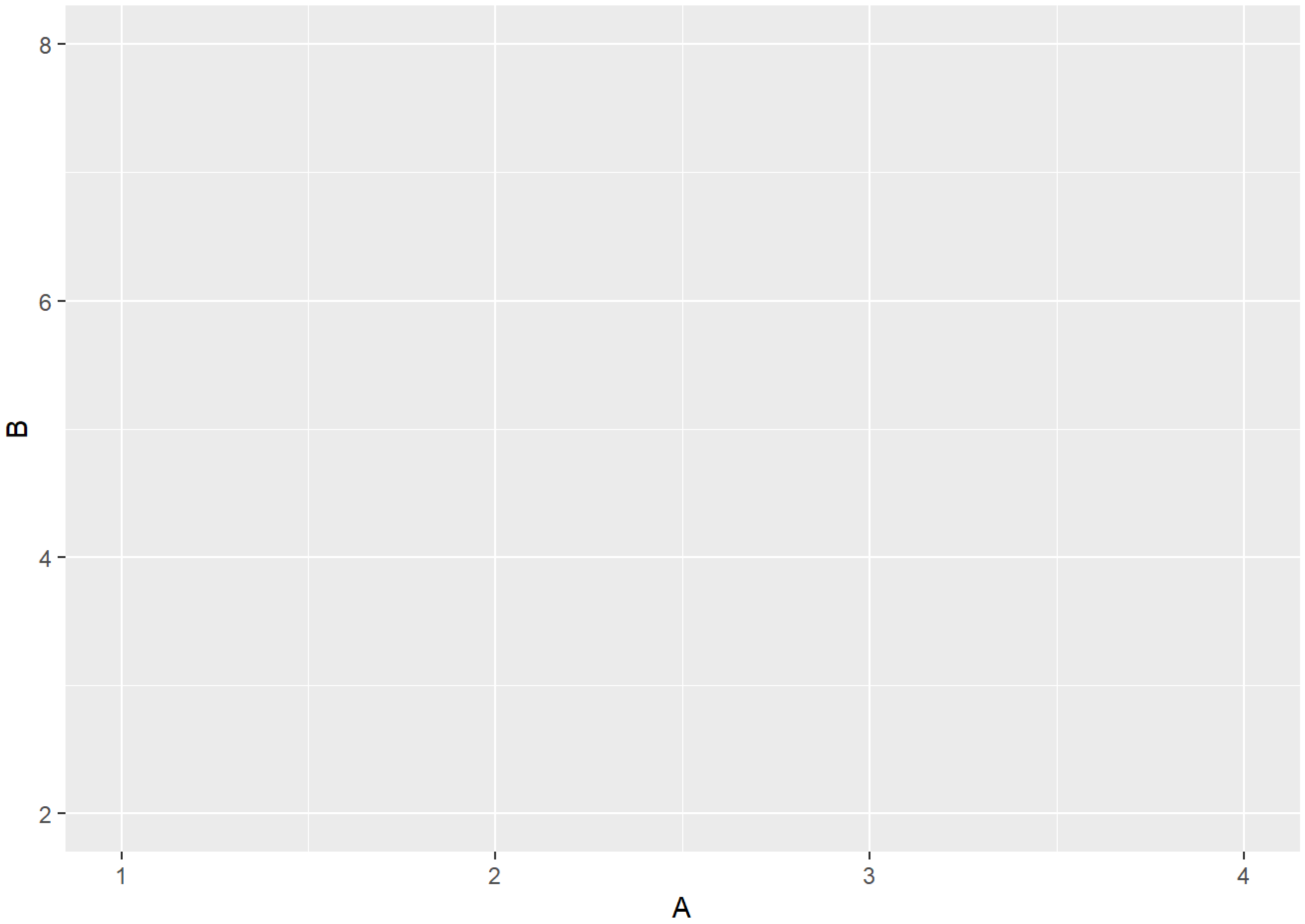
```
ggplot(data = DATA, mapping = aes())
```



But this doesn’t do anything because we haven’t added information to pass to the aesthetics in `aes()` . Looking at `?aes` , we see that `aes()` maps how properties of the data connect to or map onto with the features of the graph (e.g., axis position, color, size, etc.). The aesthetics are the visual properties of the plots, so they are essential to map by passing arguments to `aes()` . But how many and what variables do we reference? Looking at `?aes` , you see that x and y are needed.

Because we passed `data = DATA` in `ggplot()` , we can reference the variables by their column names without specifying the data frame. Choosing `x = A` and `y = B` will

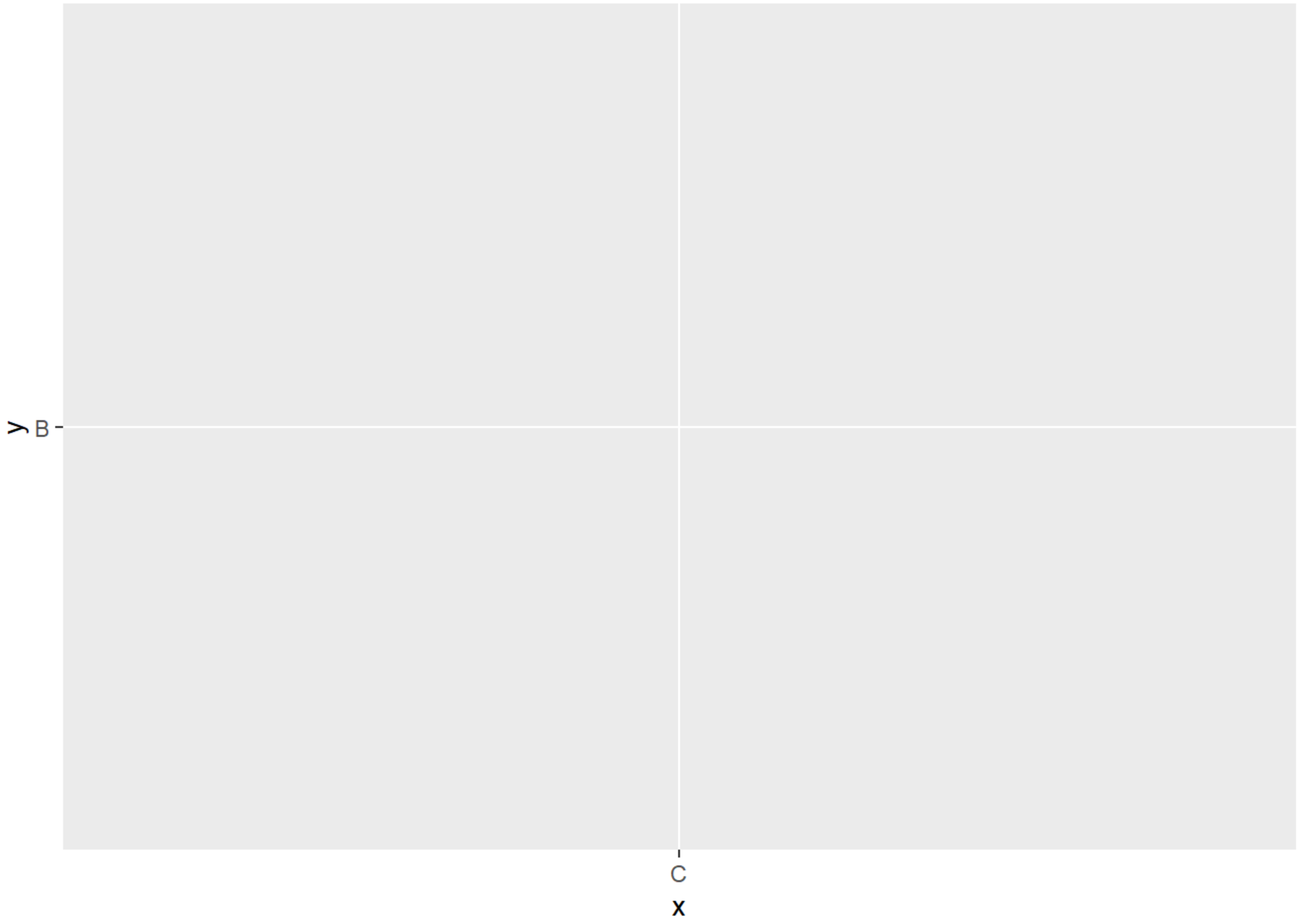
```
ggplot(data = DATA,
       mapping = aes(x = A, y = B)
       )
```



We can see that the aesthetic layer now applied to the plot scales the data to present `A` along the x-axis with a range from lowest to highest value from that vector. Similarly, the mapping presents `B` along the y-axis with a range from lowest to highest value in the vector. Also, the aesthetics include the variable name as a the label for the x and y axes. Of course, these could be changed in a layer as well. More on that later.

You might have been tempted to pass the variable names a quoted strings (e.g., “A” and “B) but if you do that, you’ll get something different.

```
ggplot(data = DATA,
       mapping = aes(x = "C", y = "B")
       )
```

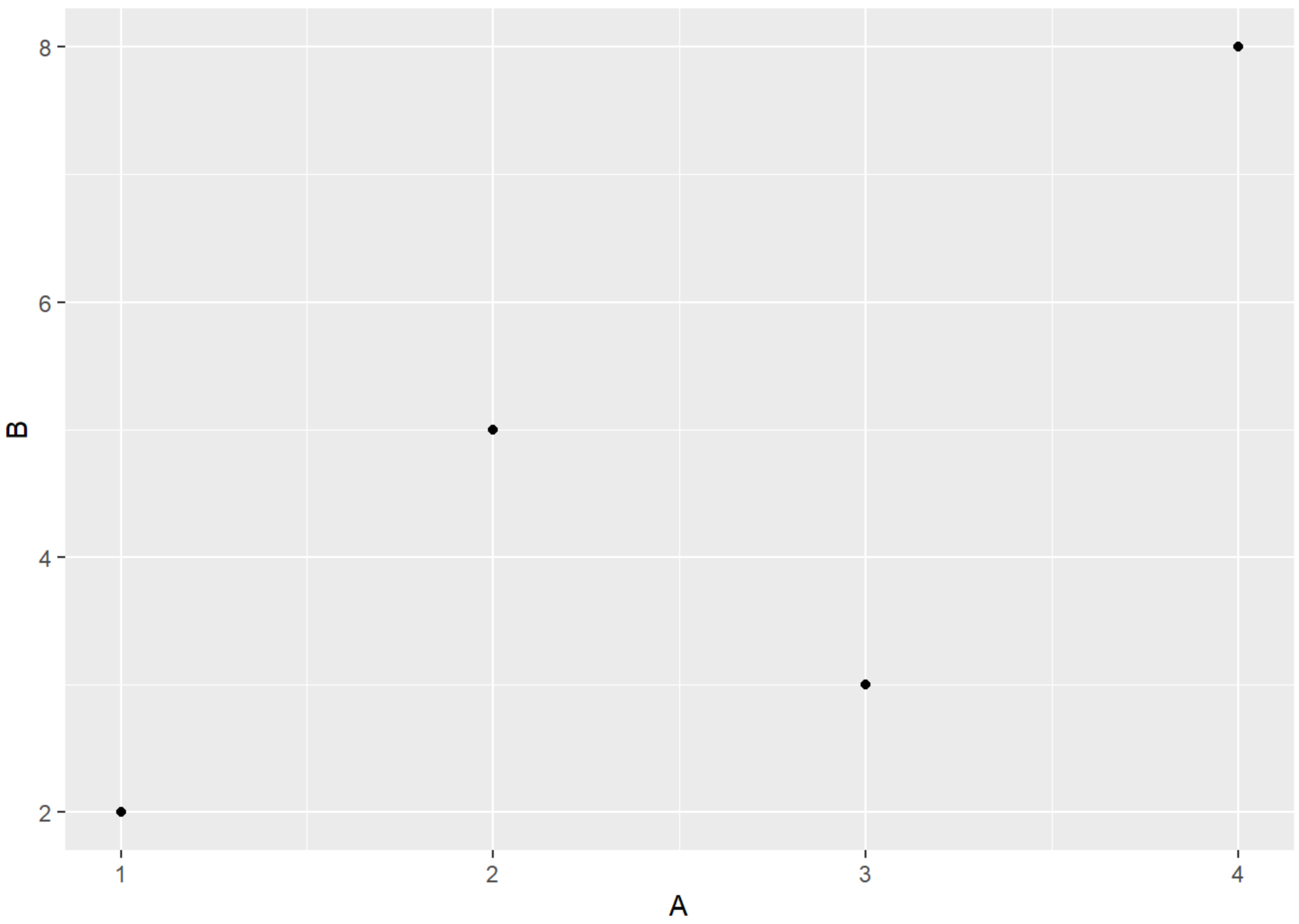


If we want to plot the data as they are in the data frame, we would apply the ‘identity’ transformation. By identity, we just need to instruct `ggplot` to use the data values in the data set. If you wanted to plot the means, frequency count, or something else, we would need to tell `ggplot` how to transform the data.

Adding Plot Geometries

We don’t yet have any geometries, or *geoms*, added. Geoms can take many forms, including, points, lines, bars, text, etc. If we want the values in `A` and `B` to be plotted as x and y coordinates representing points on the plot, we can add a point geometry using `geom_point()`.

```
ggplot(data = DATA,
       mapping = aes(x = A, y = B)
       ) +
  geom_point()
```

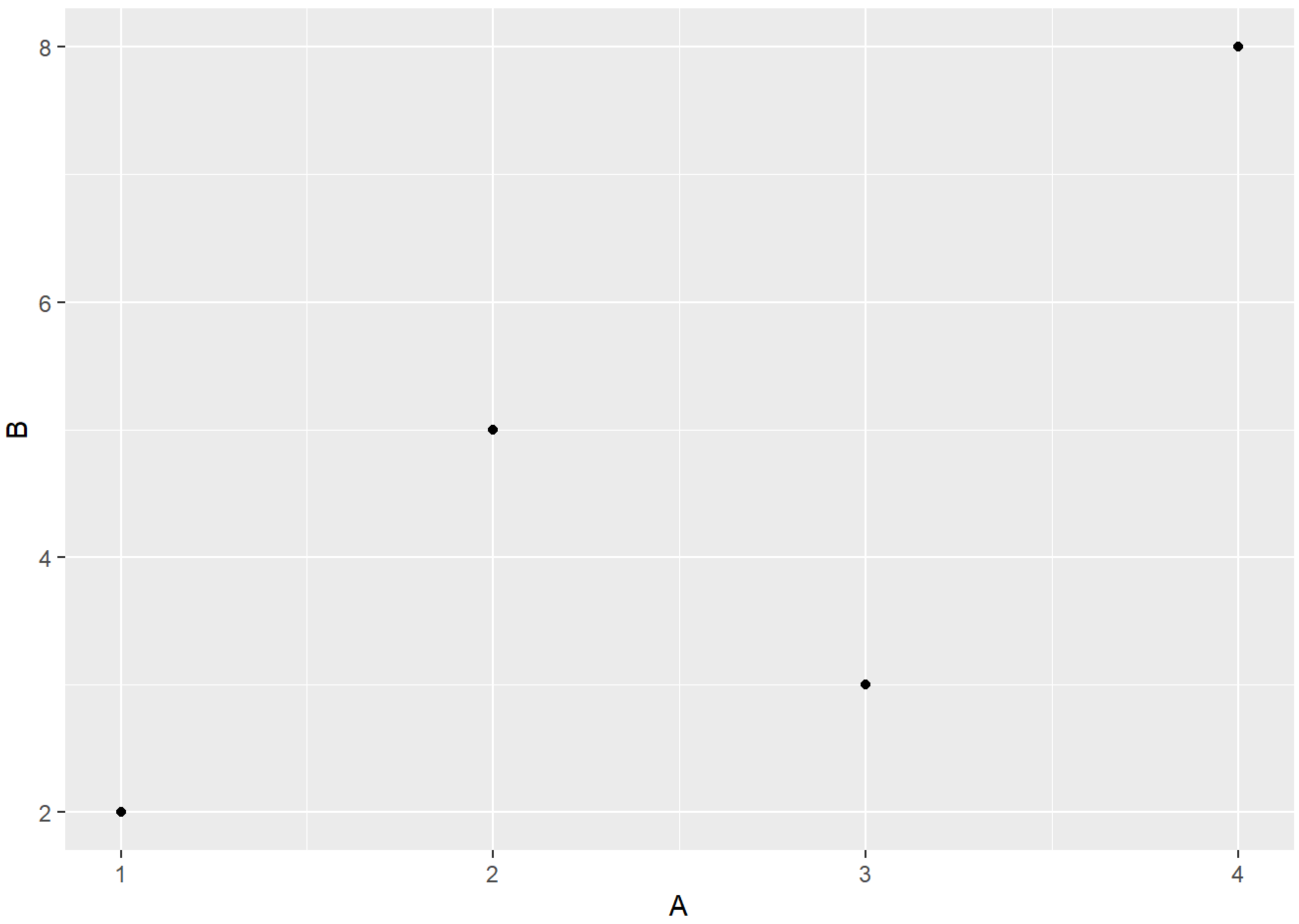


The points geometry has now been applied, which takes the aesthetic mapping and makes them into points.

But geometries also have aesthetics, or visual properties so for each geom, you can pass arguments to `aes()` . For example, the xy points have to take some shape, color, and size in order for them to be visible. By default, these have been determined or otherwise you wouldn't see black circles of any size.

Checking `?geom_point` , you will see at the bottom of the arguments section, that by default `inherit.aes = TRUE` , which means the aesthetic mappings in `geom_point()` will be inherited by default. Similarly, `data = NULL` so the data and the aesthetic mapping from `ggplot()` don't need to be specified as `data = DATA` and `mapping = aes(x = A, y = B)` , unless of course we wanted to overwrite them. Though not inherited, other aesthetics have defaults for `geom_point()` . If we wanted to be verbose, we could include all of them and see how this plot compares with that above.

```
ggplot(data = DATA,
       mapping = aes(x = A, y = B)
       ) +
  geom_point(mapping = aes(x = A, y = B),
             data = NULL,
             stat = "identity",
             position = "identity",
             size = 1.5)
```



How and Where to Map Aesthetics?

You might be wondering how you map these aesthetic properties so that when you attempt to do so, you don't get a bunch of errors. There are two places you can map aesthetics:

Either in the initialized plot object:

- **`ggplot(data = data, mapping = aes(x, y))`** `+ geom_point()`

Or in the geometry:

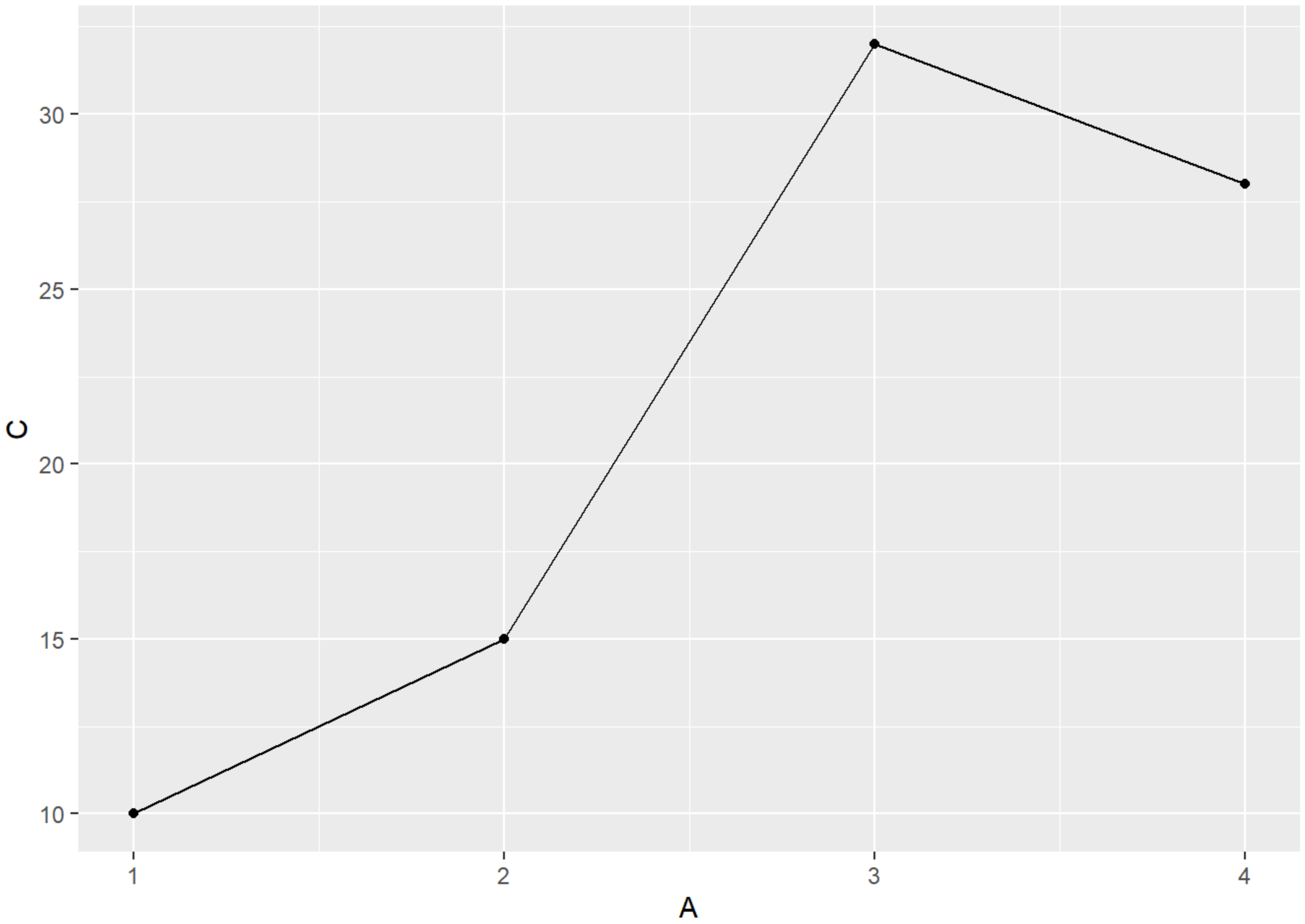
- `ggplot() +` **`geom_point(data = data, mapping = aes(x, y))`**

We can map aesthetics in the initialize plot object by also assigning this to an object named `map` just so we can reference it as need. When we do this mapping…

```
map <- ggplot(data = DATA,
              mapping = aes(A, C))
```

The aesthetics are inherited by the geometries that follow, which then do not require any mapping of their own…

```
map +
  geom_point() +
  geom_line()
```



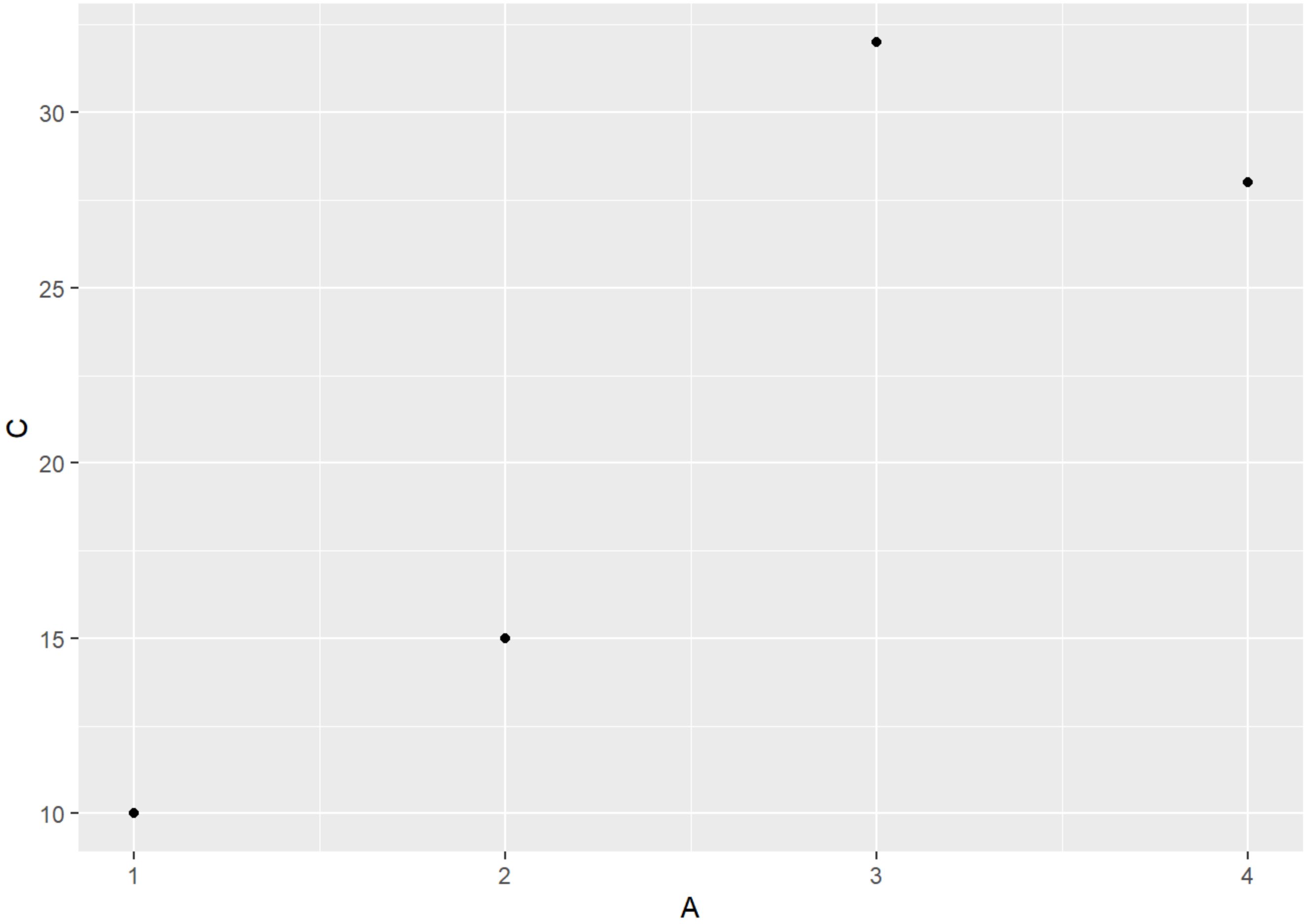
But when aesthetics are NOT mapped in initialized plot…

```
map <- ggplot()
```

There are no aesthetics to be inherited by the plot geometry functions because they are not passed to the `ggplot()` object. In this case they must be mapped as arguments the geometries themselves.

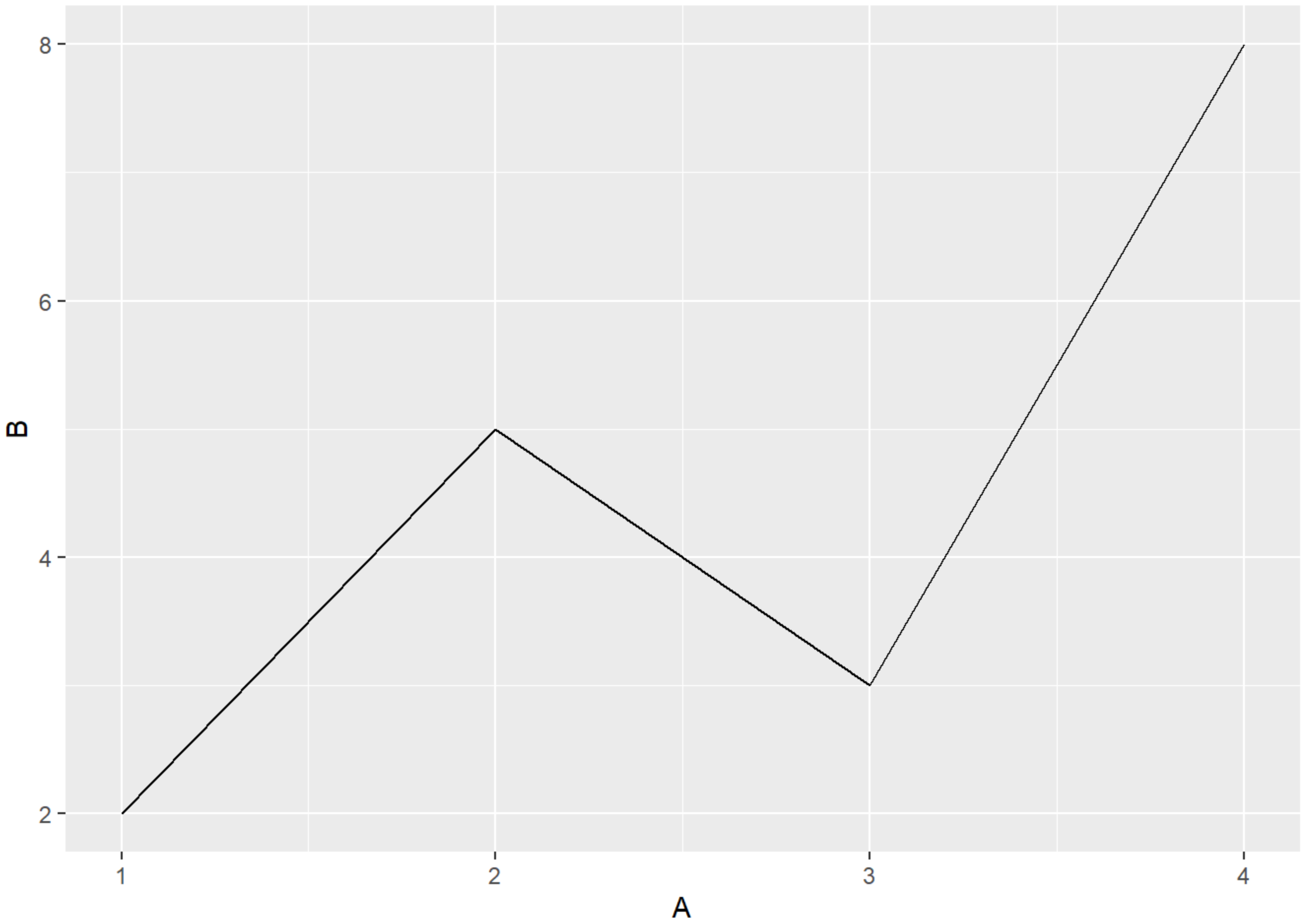
Plot points…

```
map +
  geom_point(data = DATA,
             mapping = aes(A, C))
```



Plot a line…

```
map +
  geom_line(data = DATA,
            mapping = aes(x = A, y = B))
```

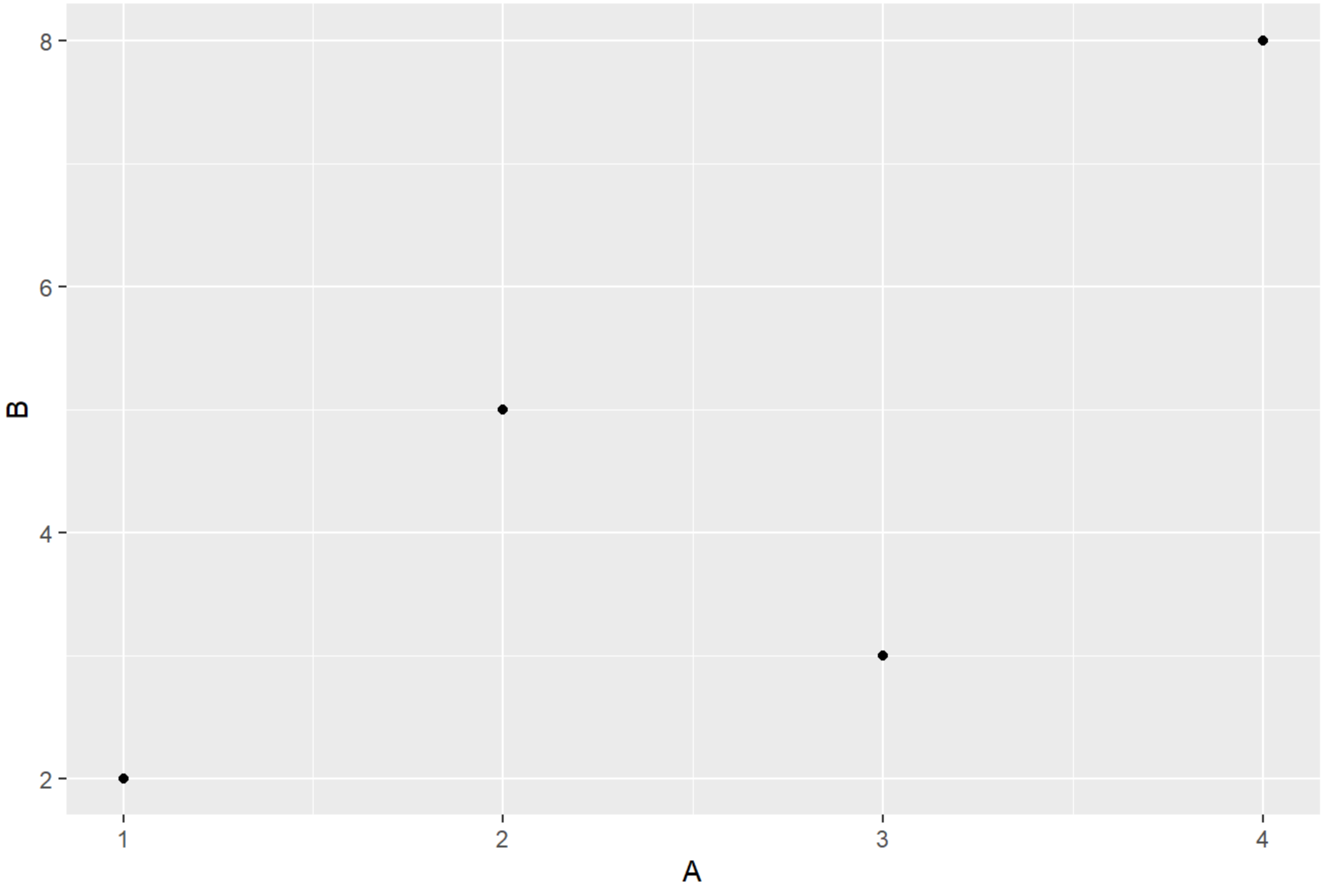


In a later section, we will differentiate between setting and mapping aesthetic attributes.

Add labels, a coordinate system, scaling, and a theme

Pretty much the same? For completeness, there are also x and y label layers and a coordinate system also applied by default. Let’s add them to the plot by adding layers.

```
ggplot(data = DATA,
       mapping = aes(x = A, y = B)
       ) +
  geom_point(mapping = aes(x = A, y = B),
             data = NULL,
             stat = "identity",
             position = "identity",
             size = 1.5,
             color = "black") +
  scale_x_continuous() +
  scale_y_continuous() +
  labs(title = "") +
  xlab("A") +
  ylab("B") +
  coord_cartesian() +
  theme()
```

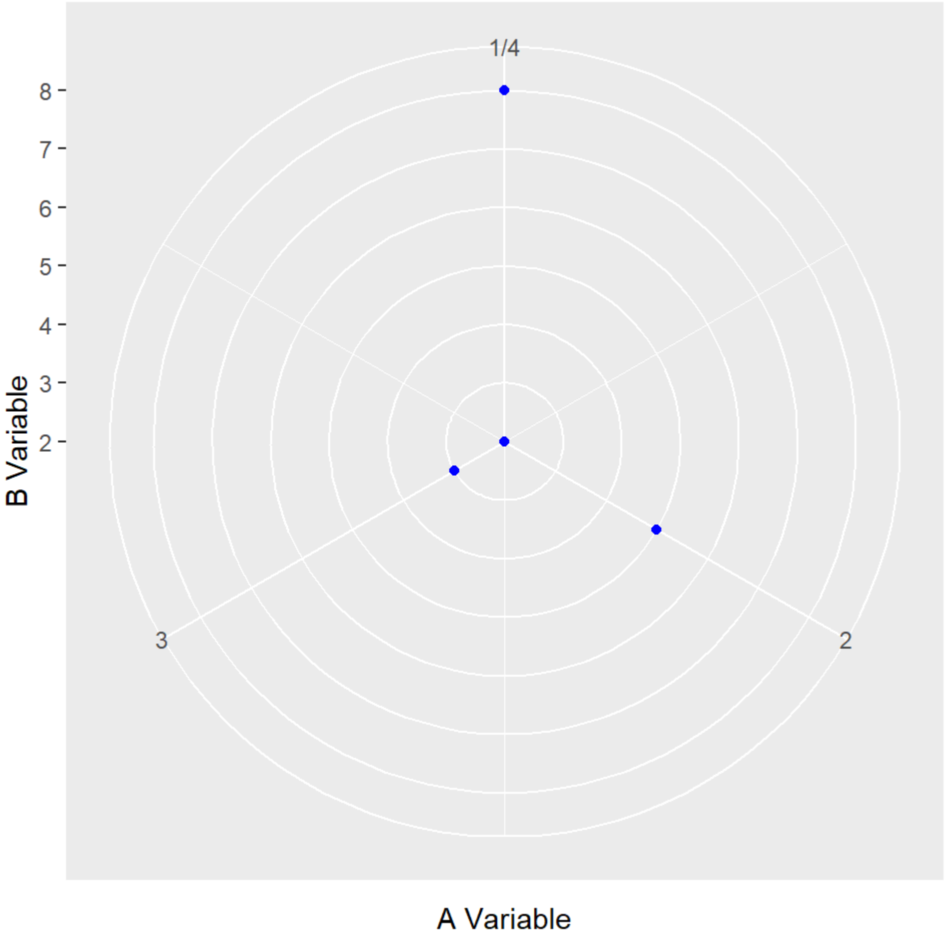


Notice the plot is the same. The take-home message is that each visualization uses a data set which will be used to provide some aesthetic mapping. That mapping takes some geometric form, or geom. The geom needs information about the data, the statistical transformation (or an its ‘identity’ in the data frame), some position in space, some size, and some color. Also the axes have labels and follow some rules about their scaling. All of this follows some coordinate system. A theme is also used to decorate the plot in different ways. The default is `theme()` .

Change the coordinate system, color, and labels

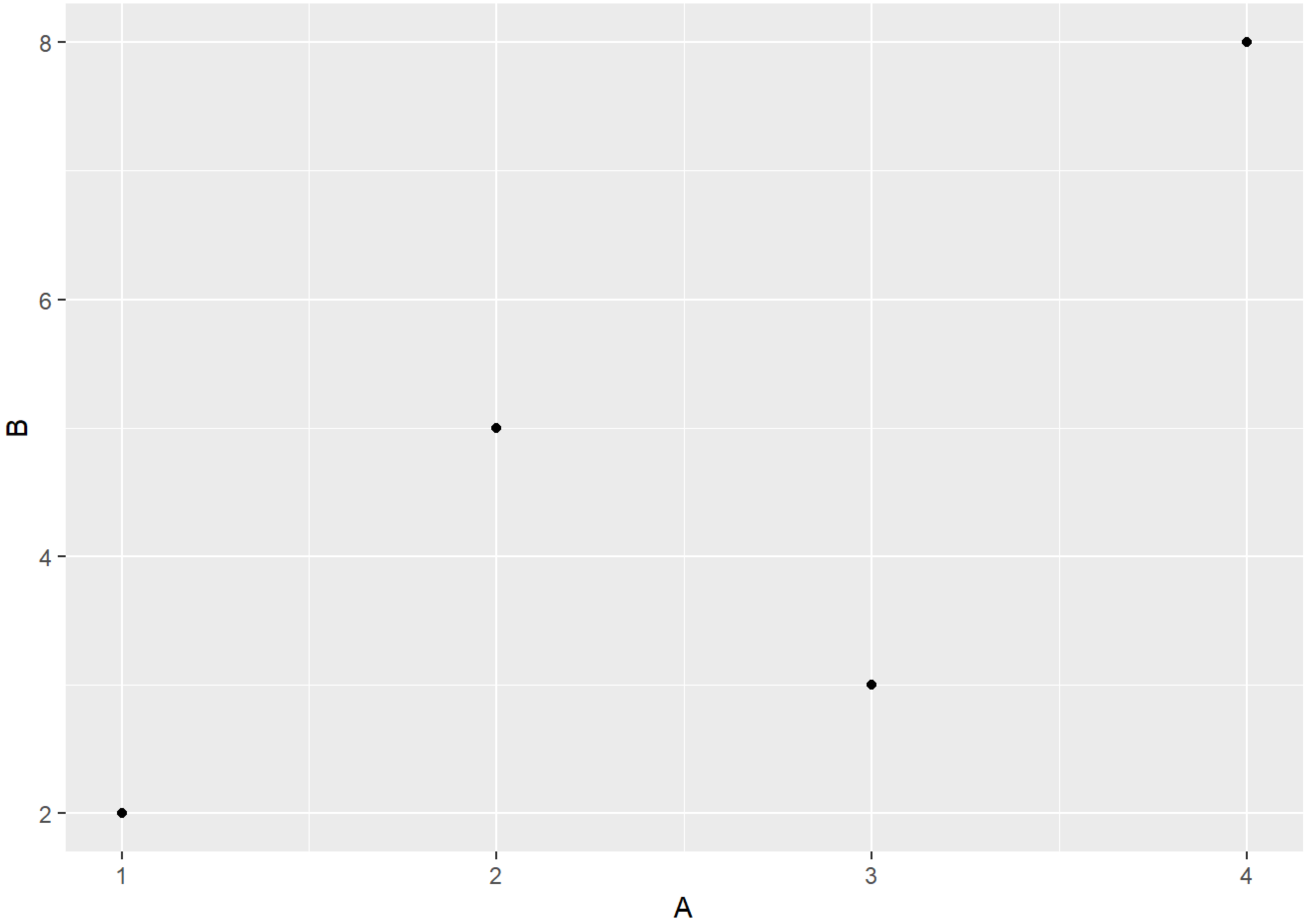
If we wanted to change the coordinate system, then the visualization would look much different. We can also change the color and label names. And because they are independent layers, we could add them in different orders.

```
ggplot(data = DATA,
       mapping = aes(x = A, y = B)
       ) +
  geom_point(mapping = aes(x = A, y = B),
             data = NULL,
             stat = "identity",
             position = "identity",
             size = 1.5,
             color = "blue") +
  coord_polar() +
  xlab("A Variable") +
  ylab("B Variable") +
  scale_x_continuous() +
  scale_y_continuous() +
  theme()
```



But because those are defaults, we don't need to code all those plot layers. We can simply add a `geom_point()` layer. And because we pass `DATA` as the first argument and the mapping next, we could be even less wordy.

```
ggplot(DATA, aes(x = A, y = B)) +
  geom_point()
```



Some Geometries and Their Aesthetics

Not all geometries are the same. Although many geoms share most aesthetics, they don't all have the same aesthetics. For example, a point plot doesn't have aesthetics for a line but a line plot does. You can only add aesthetics to geoms that are understood; adding those that are not understood will, of course, throw errors.

`geom_point()` understands these aesthetics:

- x
- y
- alpha
- color
- fill
- group
- shape
- size
- stroke

`geom_line()` understands these aesthetics:

- x
- y
- alpha
- color

- fill
- group
- linetype
- size

`geom_bar()` understands these aesthetics:

- x
- y
- alpha
- color
- group
- linetype
- size

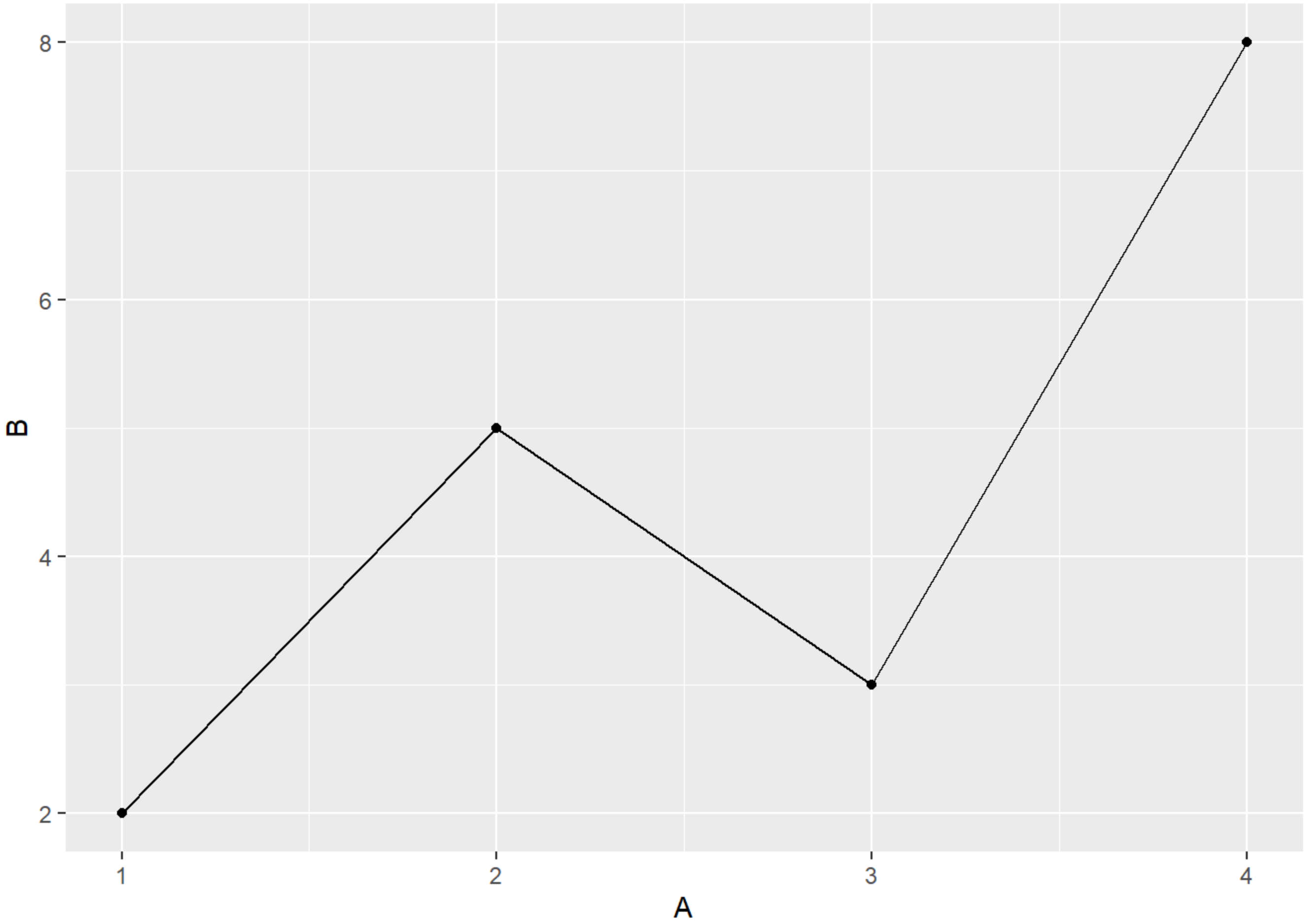
`geom_col()` understands these aesthetics:

- x
- y
- alpha
- color
- fill
- group
- linetype
- size

Adding Aesthetics That A Geometry Does not Understand

If an aesthetic is not understood by a certain geometry, we cannot pass are argument for it. For example, you cannot add a linetype to a point plot. If you want your points connected by lines, then you can add a new geom layer to the plot that contains that aesthetic. Importantly, because geoms will inherit the data and mapping from `ggplot()` by default, the line will connect the points.

```
ggplot(DATA, aes(x = A, y = B)) +
  geom_point() +
  geom_line()
```



And then you can change the aesthetics of `geom_line()` that it understands. More one this later.

Aesthetic Mapping Versus Setting

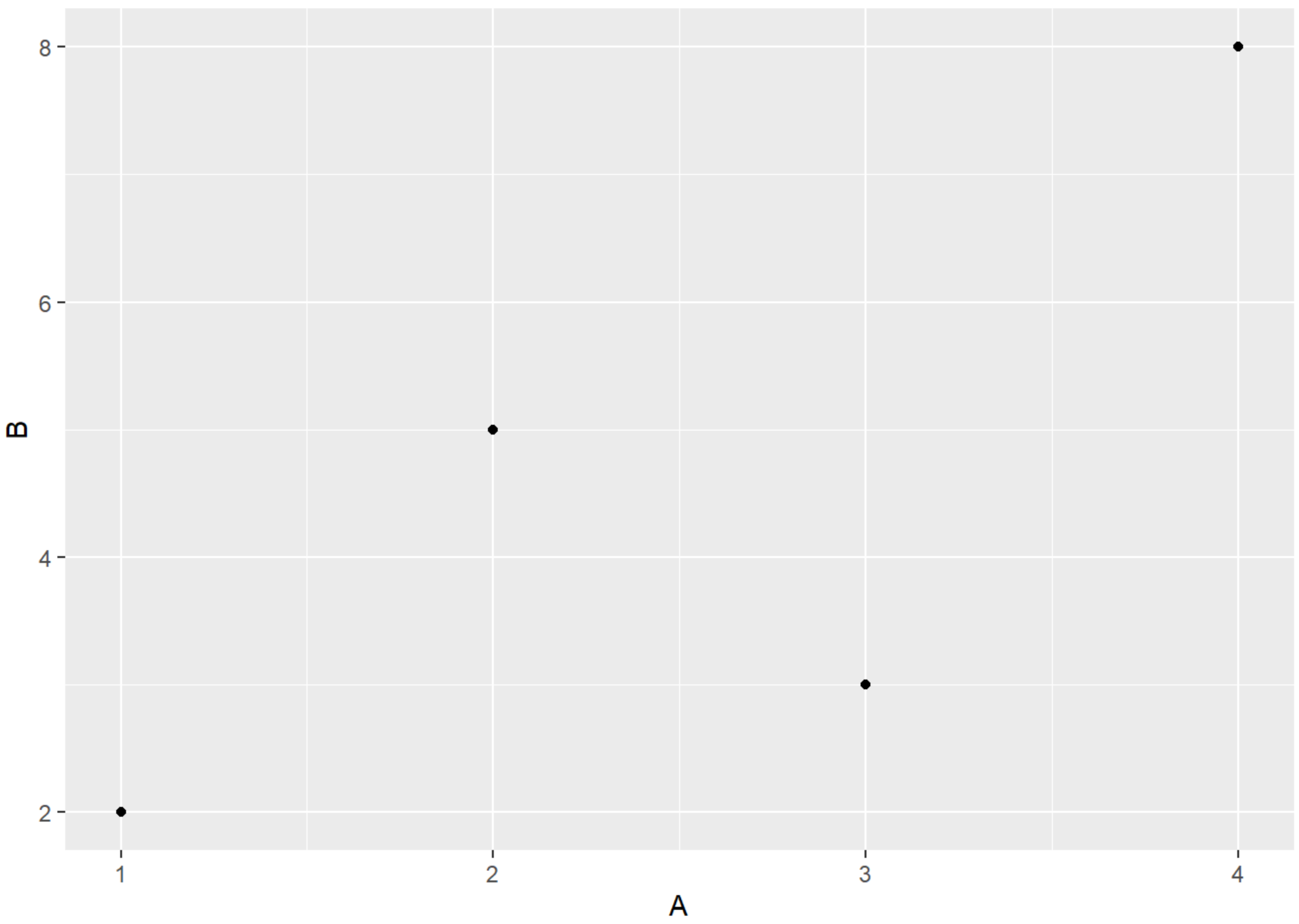
When adding aesthetics to a geom, you may wish to make an aesthetic property like color a particular color such that all points in the point plot are the same color or you may wish the point color to vary in some way across the observations of the variable (e.g., change from cold to hot color depending on the value). Similarly, you may wish to vary the shape property with the value. You may even with the property to vary corresponding to a different variable.

- *setting* an aesthetic to a constant
- *mapping* an aesthetic to a variable

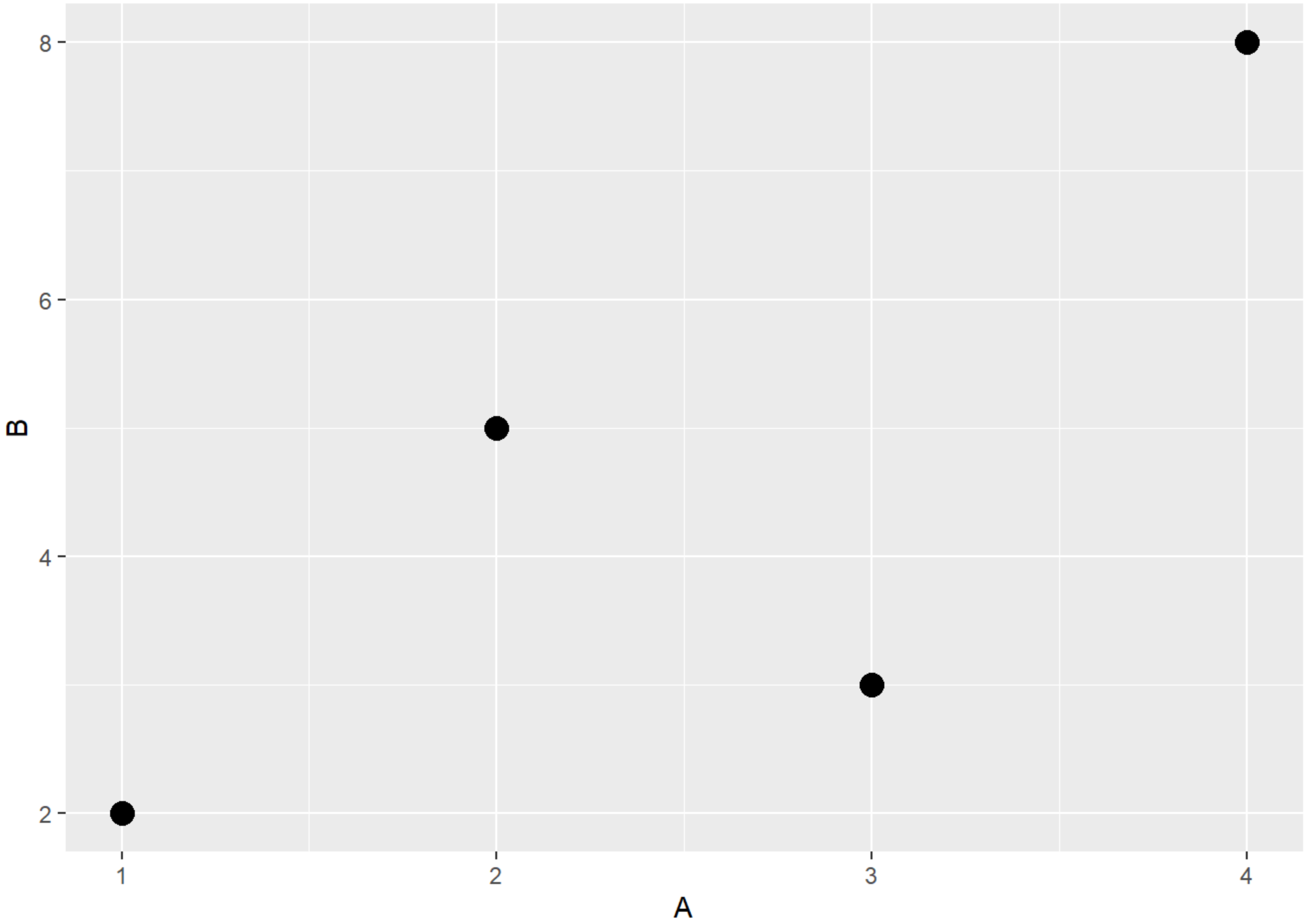
The difference between mapping and setting aesthetics all takes place either in the `aes()` function or outside the functions of the geometry. Because geometries understand certain aesthetics, the geom function has a parameter for which you can pass an argument.

Because `geom_point()` understands a `size` aesthetic because points have to take some size. The default value for size is assumed and passed in the first code block (you just don’t see it) and `size = 4` in the second code block overrides that default.

```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point()
```

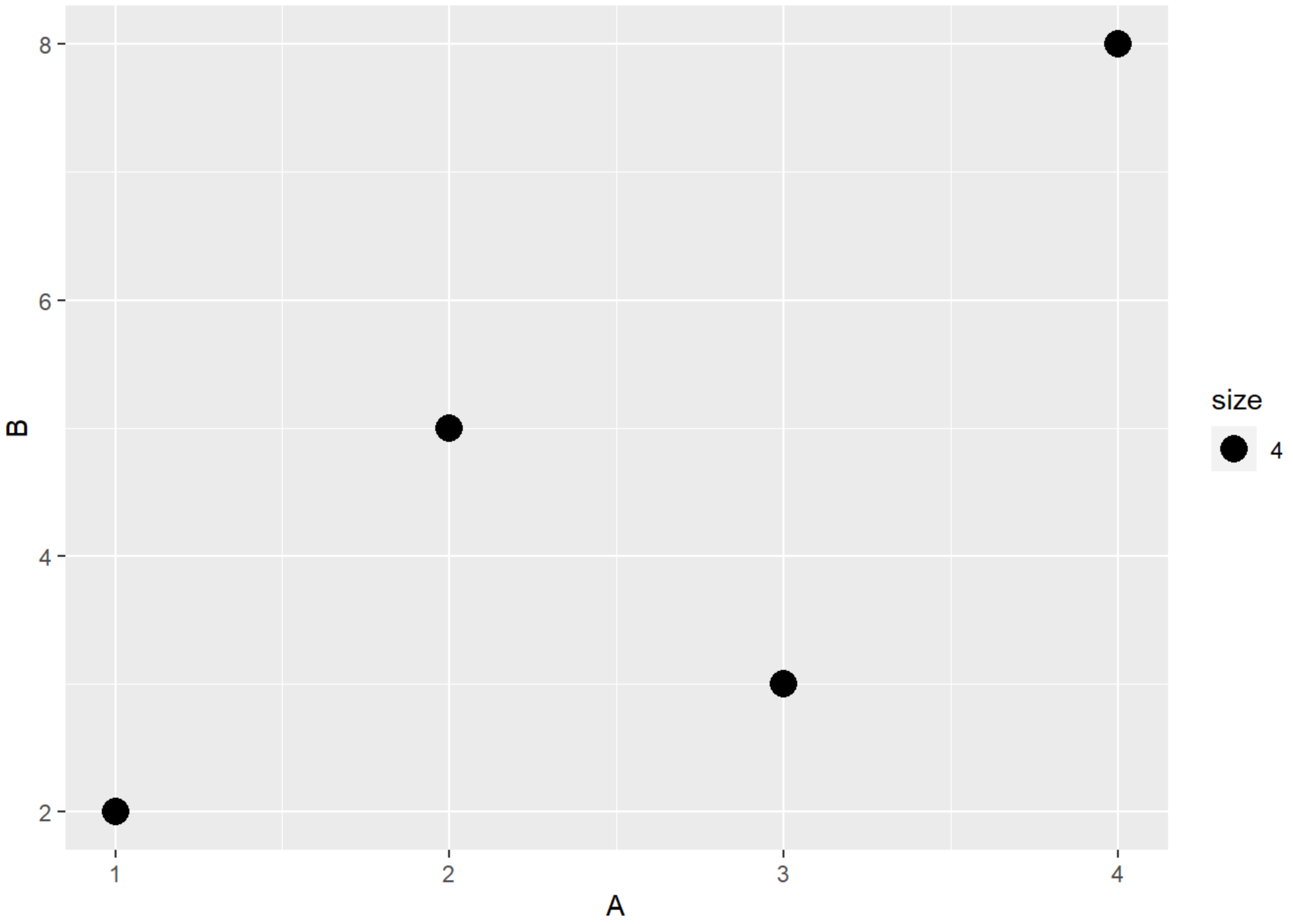


```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(size = 4)
```



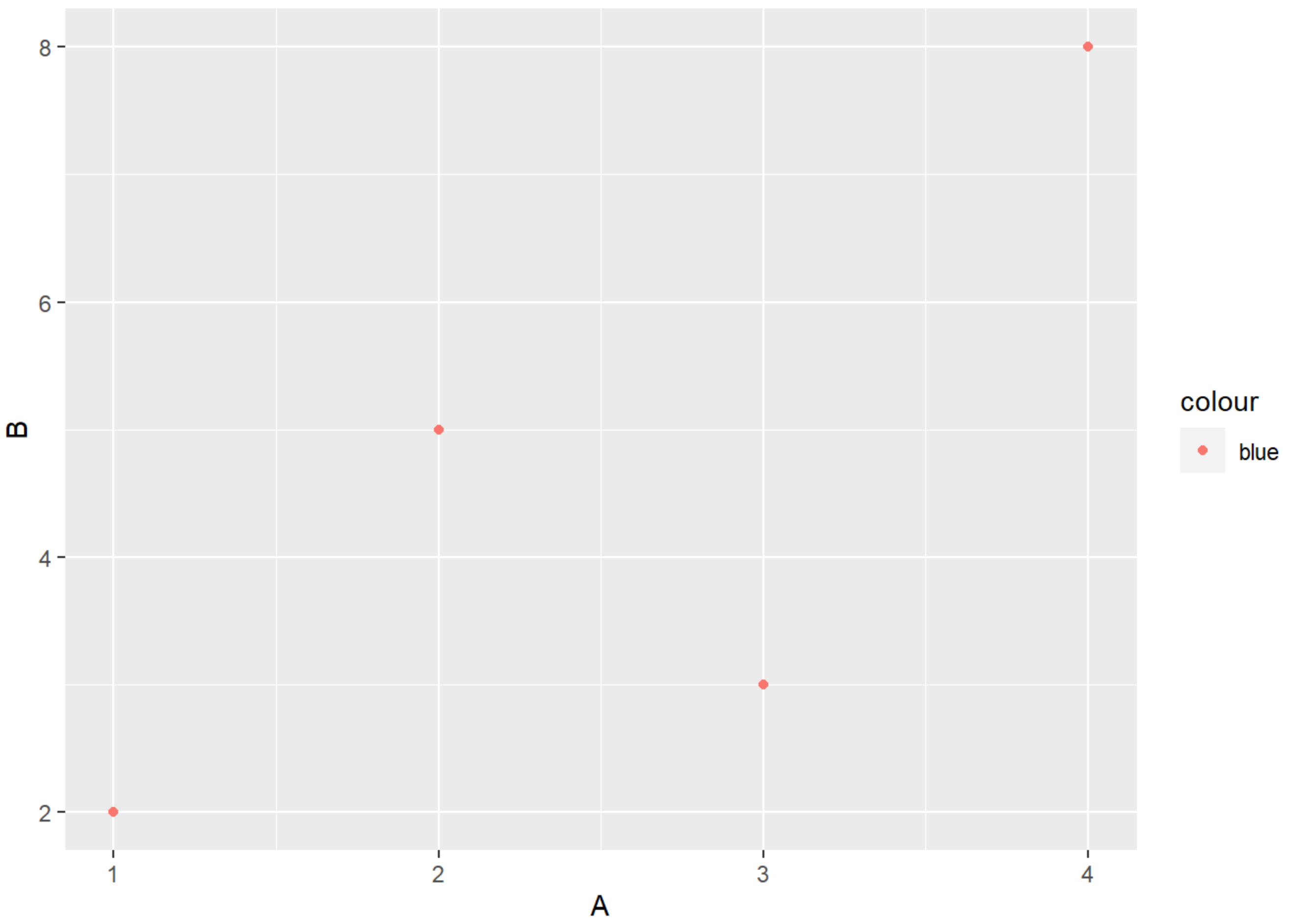
By passing `size = 4` , we have *set* size to a *constant* value. Not that at size was not passed inside an `aes()` function. It it were, something completely different would happen.

```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(aes(size = 4))
```



And this is illustrated even better with the `color` aesthetic.

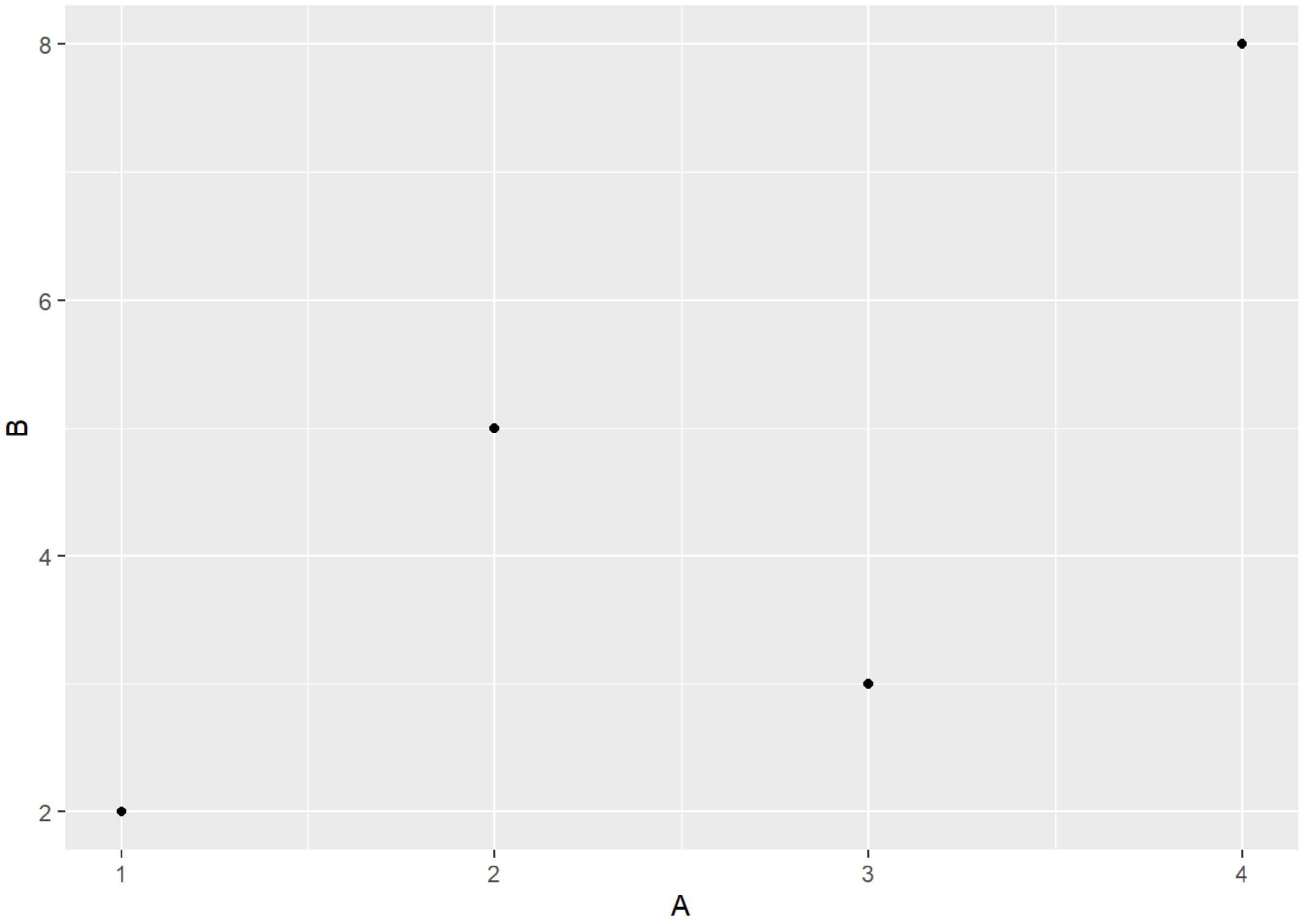
```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(aes(color = "blue"))
```



In both examples, you notice that a legend not appears in the plot and in the color example, the color is not blue. Without getting into the details of what ggplot is doing, when this happens, it serves as a warning that you did something incorrectly.

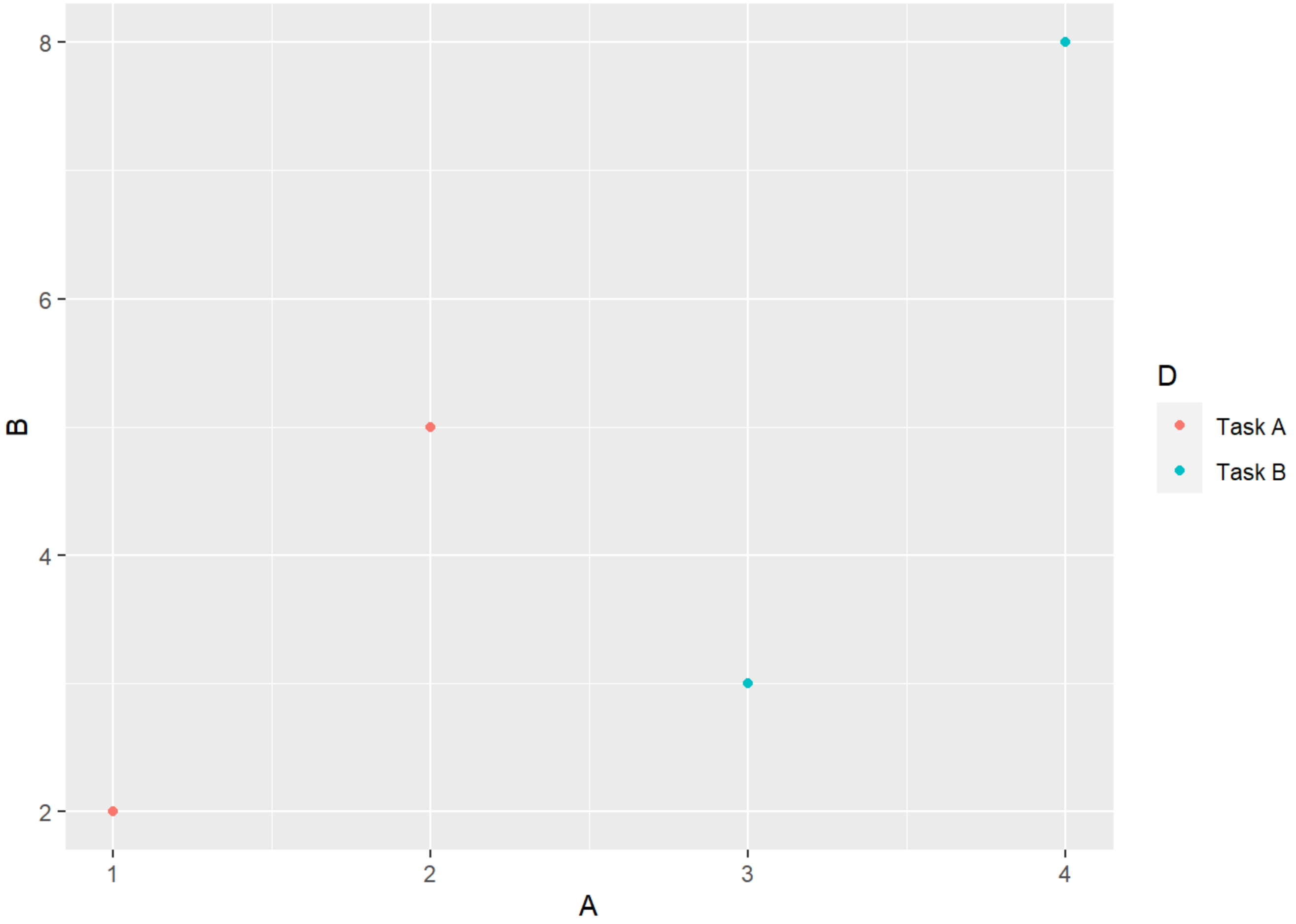
Importantly, you can only *set constant values* to aesthetics outside of `aes()` . Inside of `aes()` , you *map variables* to aesthetics. Where are the variables? Well, in the data frame. By passing a different variable column form `DATA` , we can *map* the aesthetic to that *variable* so that it changes relative to the changes in the variable. The plot will also change in a variety of ways simply by adding a new variable. Let's begin with a baseline plot for comparison and then map variables.

```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point()
```



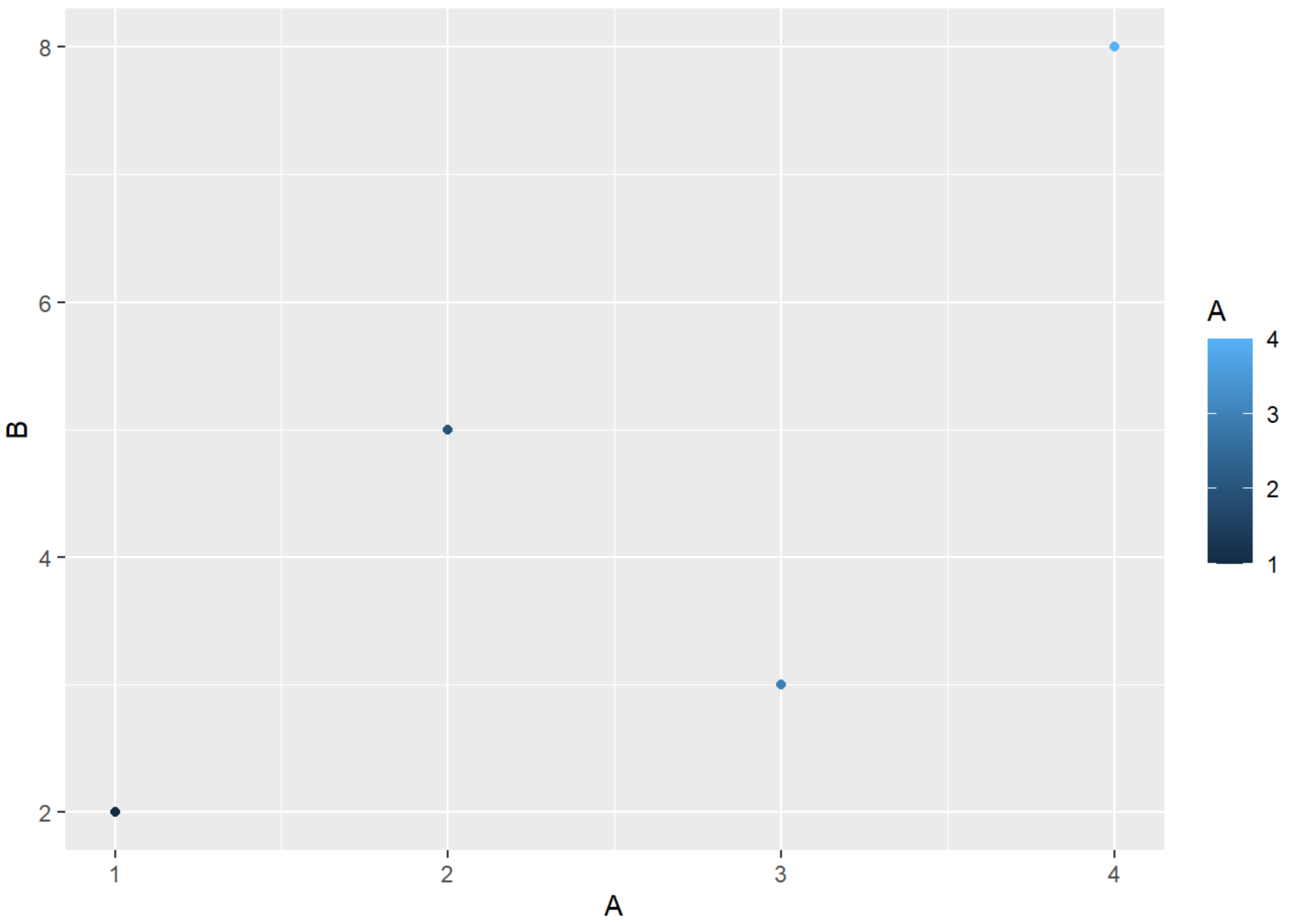
Mapping a new variable…

```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(aes(color = D))
```

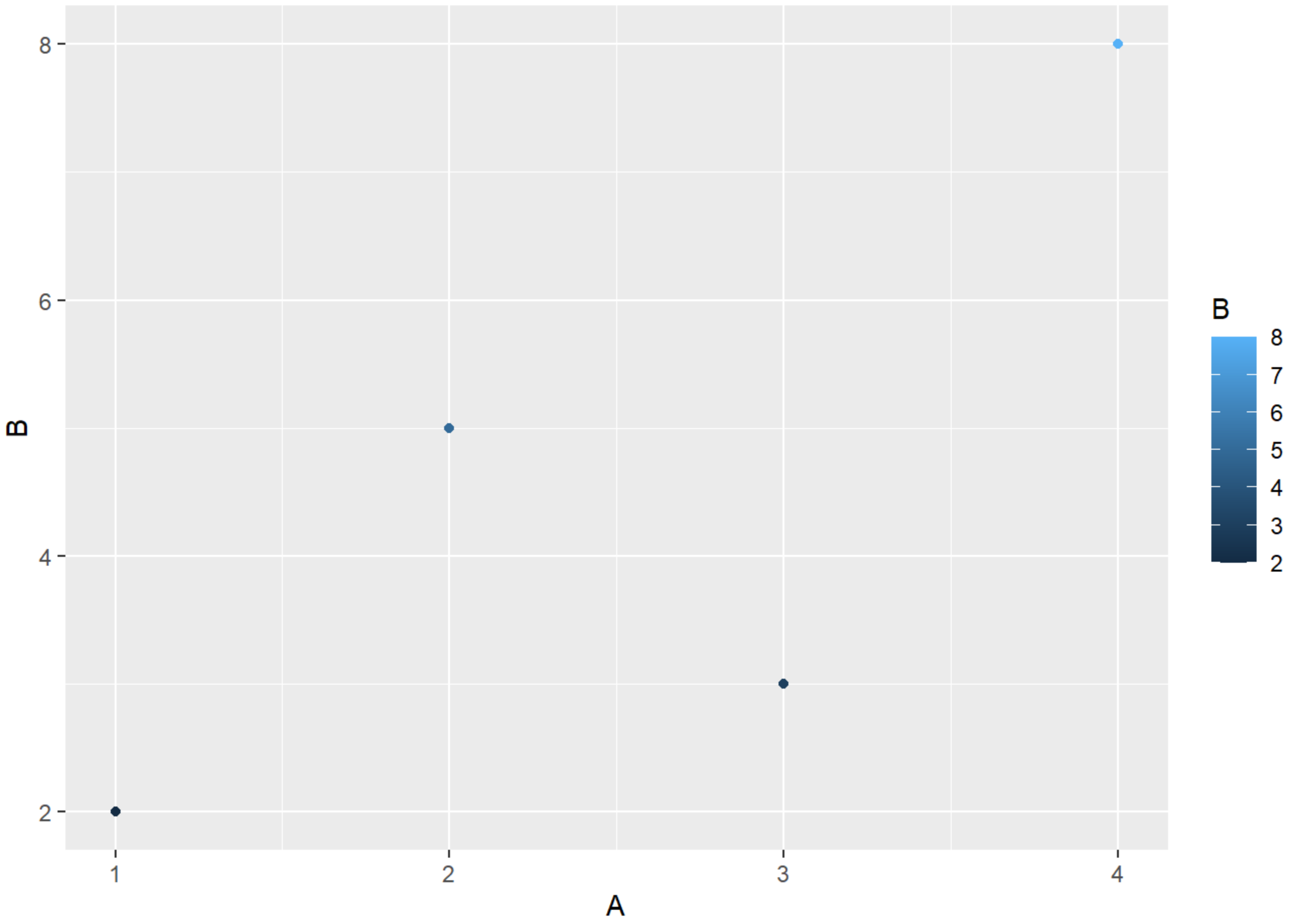


Mapping an existing variable…

```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(aes(color = A))
```

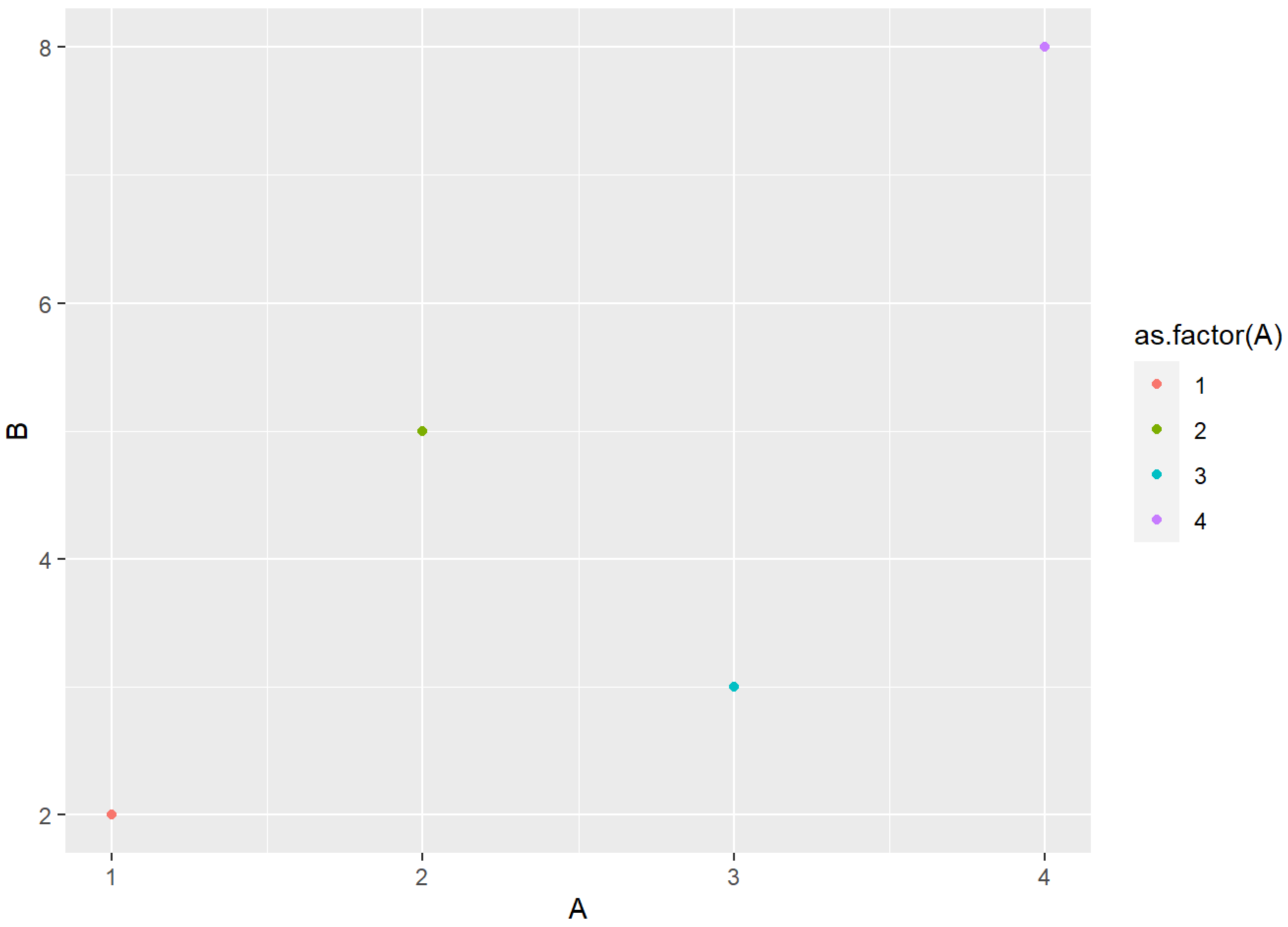


```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(aes(color = B))
```

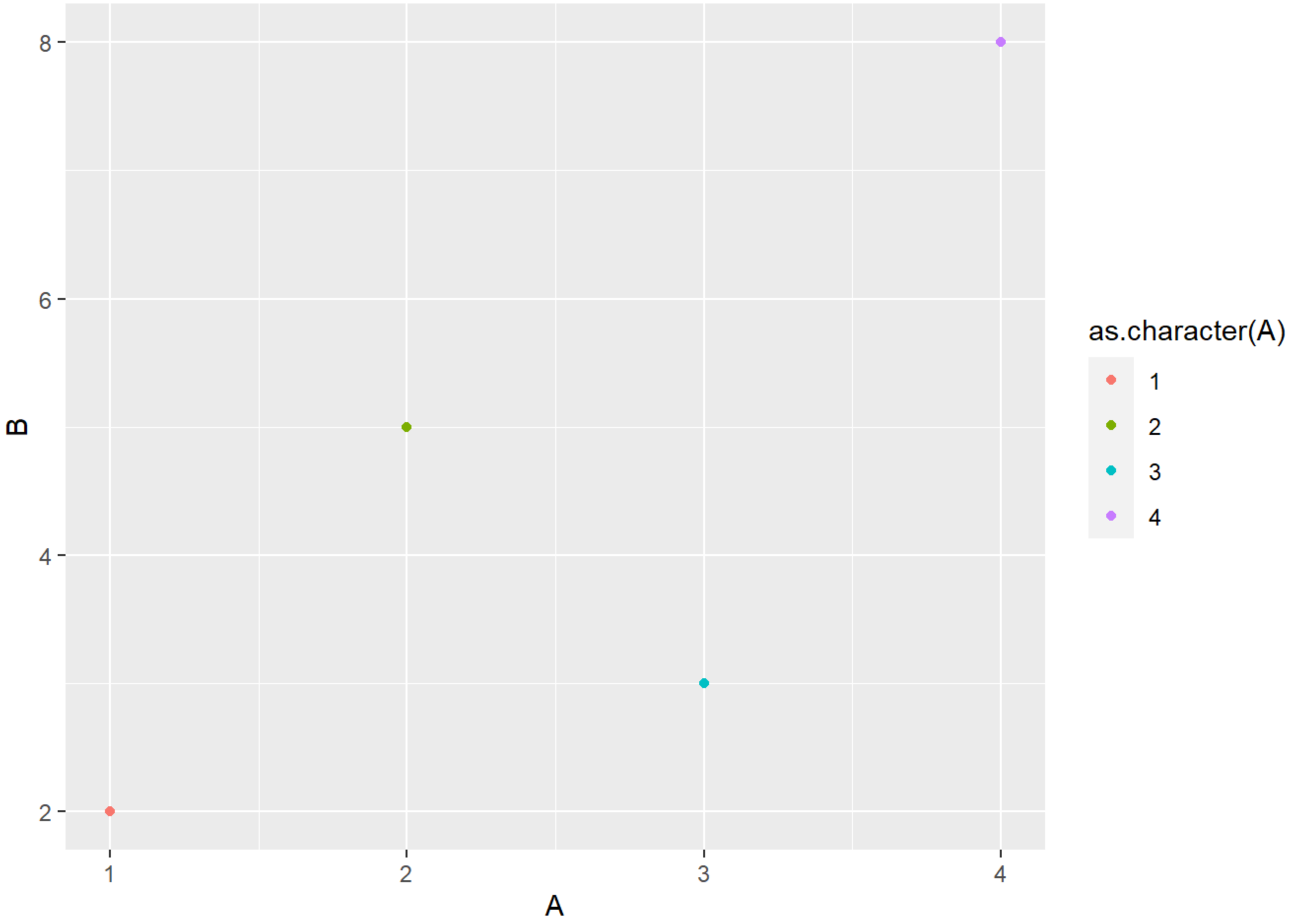


You may have noticed that when mapped variables are numeric, the aesthetics are applied continuously and when they are categorical, they are applied discretely. Here is a good example of mapping variable `A` not as itself but by changing it to a `factor()` or a character vector.

```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(aes(color = as.factor(A)))
```



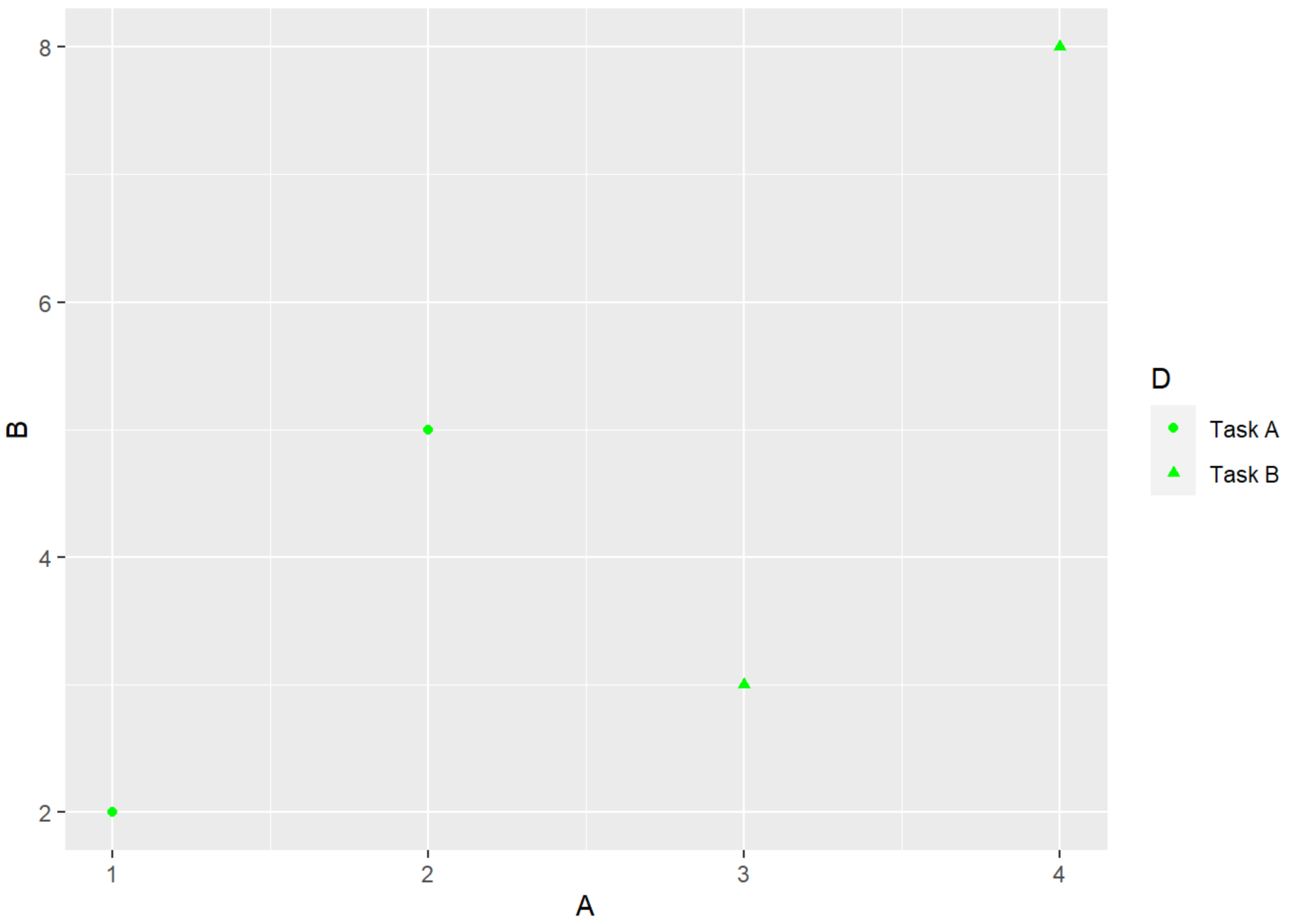
```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(aes(color = as.character(A)))
```



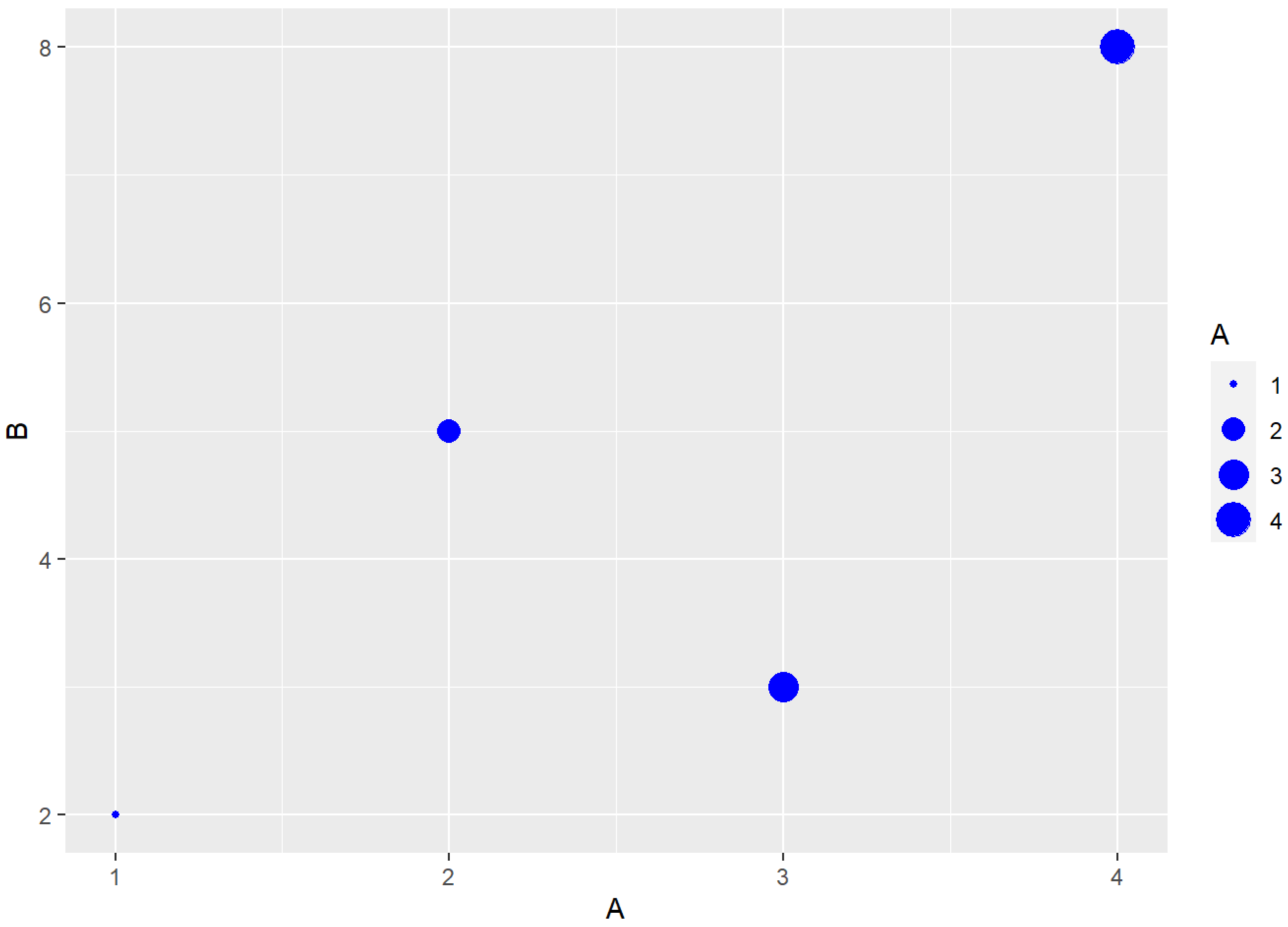
Setting and Mapping Combinations

We can also combine setting aesthetics and mapping them as long as mappings are inside `aes()` and settings are not.

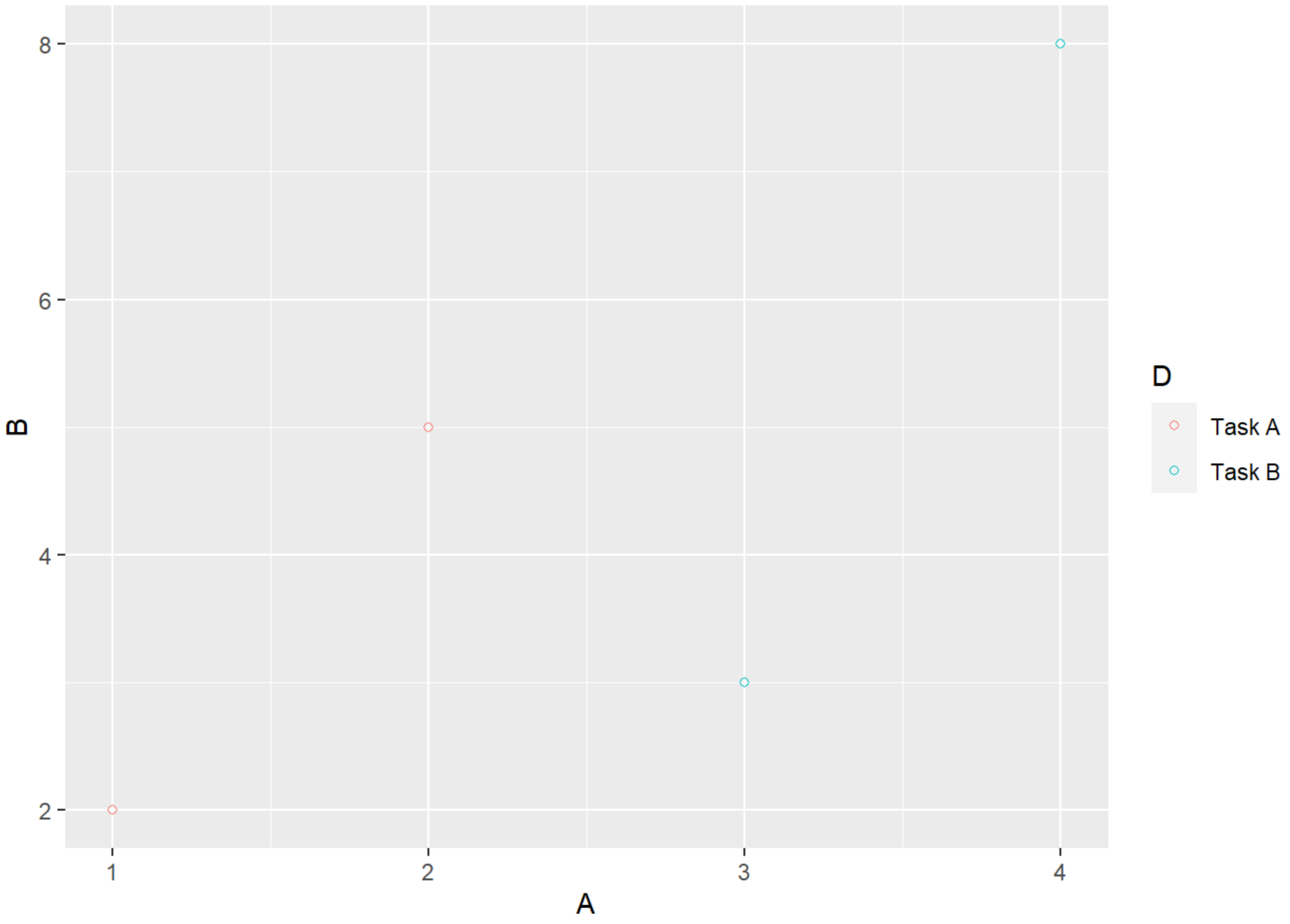
```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(color = "green", aes(shape = D))
```



```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(color = "blue", aes(size = A))
```



```
ggplot(data = DATA, aes(x = A, y = B)) +
  geom_point(shape = 21, aes(color = D))
```



Importantly, just as you cannot pass constant values to aesthetics in `aes()` , you cannot pass a variable to an aesthetic in the geom function *unless* it is inside `aes()` .

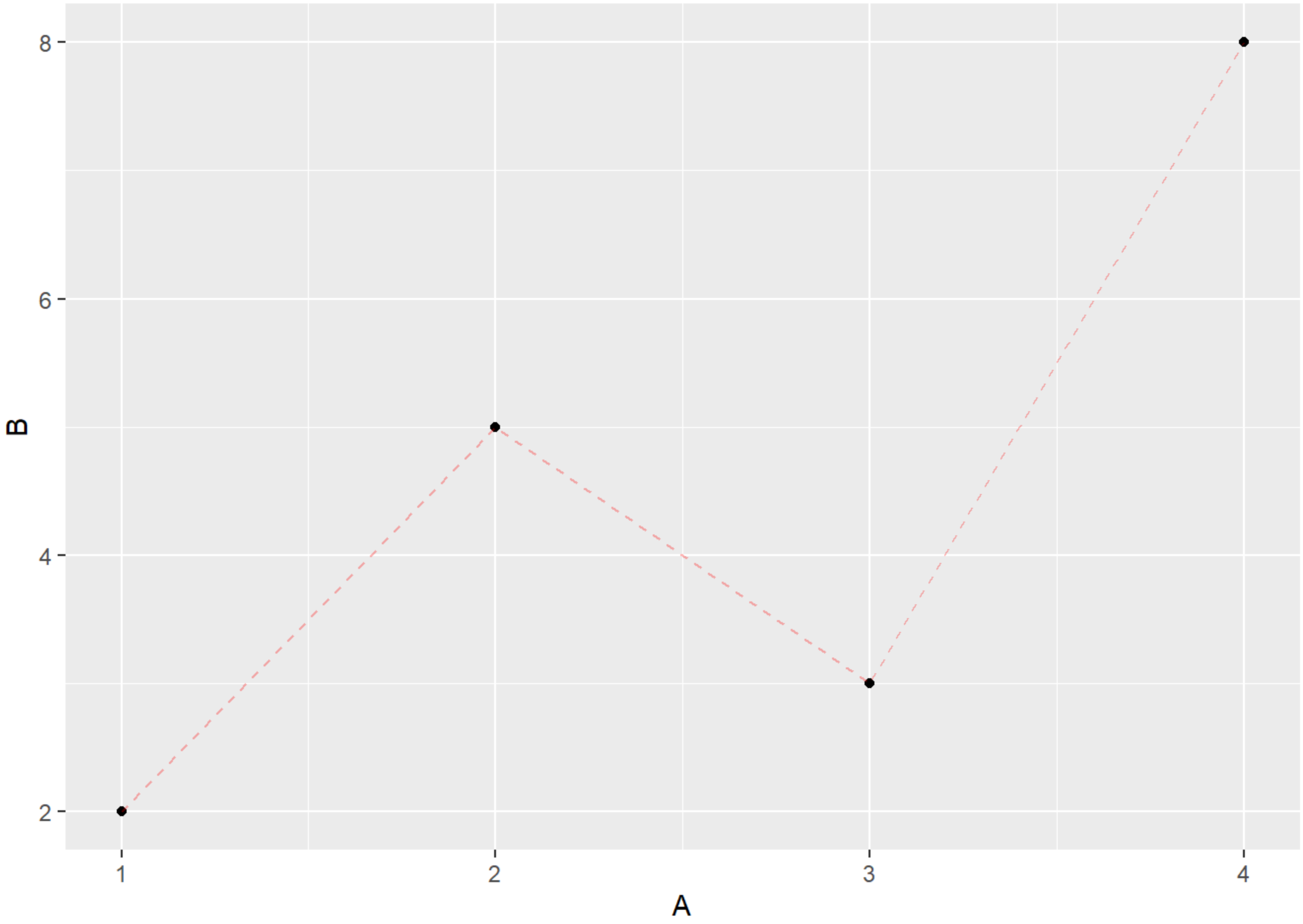
For example, passing `color = A` in this instance will throw an error.

```
ggplot(data = DATA, aes(x = A, y = B)) +  geom_point(color = A))
```

```
Error: unexpected ')' in:  "ggplot(data = DATA, aes(x = A, y = B)) +  geom_point(color = A))"
```

In summary, when you want to set an aesthetic to a constant value, do so in the geometry function (e.g., `geom_point()`), otherwise, pass an `aes()` to the geometry function. Color options can be discovered using `colors()` . Linetype has fewer options. To make the color more or less transparent, adjust alpha (from 0 = invisible to 1).

```
ggplot(DATA, aes(x = A, y = B)) +
  geom_point() +
  geom_line(linetype = "dashed",
            color = "red",
            alpha = .3)
```



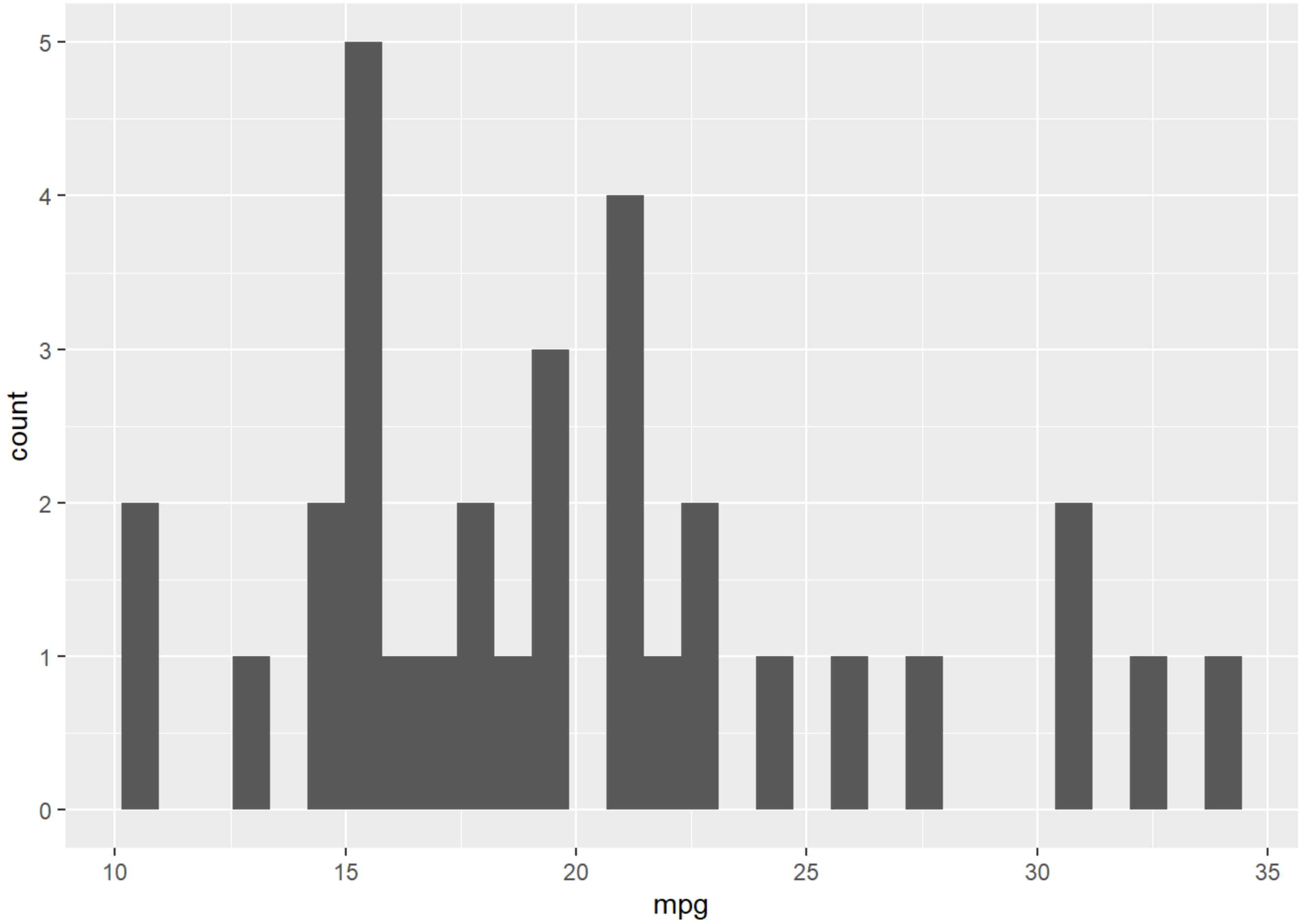
Histogram and Density Chart Varieties

When you need to visualize the distribution of a single continuous variable, a histogram is your friend. You may need to create bins (e.g., ranges) and count the number of observations in each bin. Thus, histograms display the frequency counts with bars, so they will look different based on binning. Similarly, frequency polygons, using `geom_freqpoly()` display the same information with lines. For this example, we will use the `mtcars` data rather than the small data frame `DATA` .

`geom_histogram()`

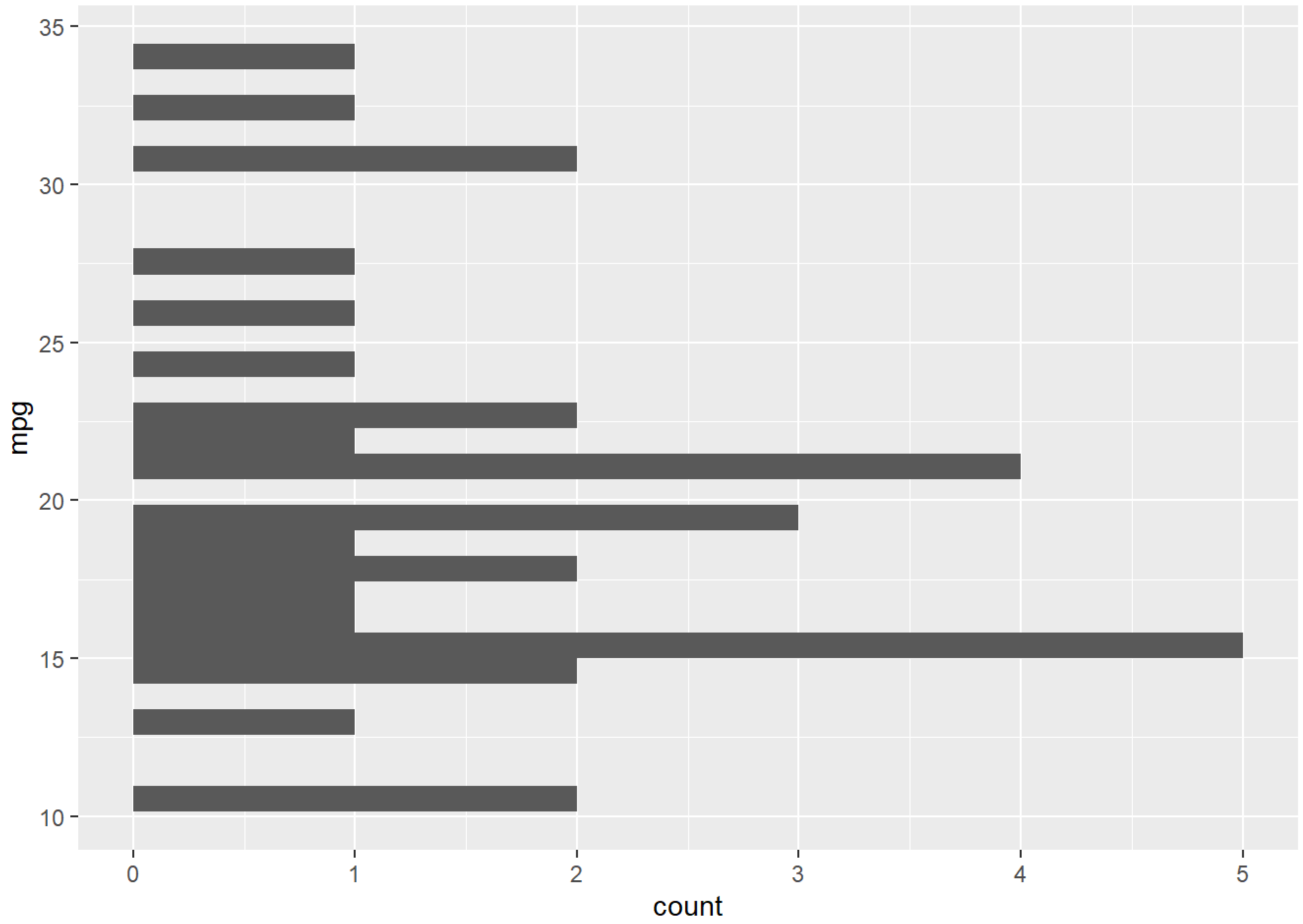
```
ggplot(data = mtcars,
       mapping = aes(x = mpg)) +
  geom_histogram()
```

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



```
# or less popular
ggplot(data = mtcars,
       mapping = aes(y = mpg)) +
  geom_histogram()
```

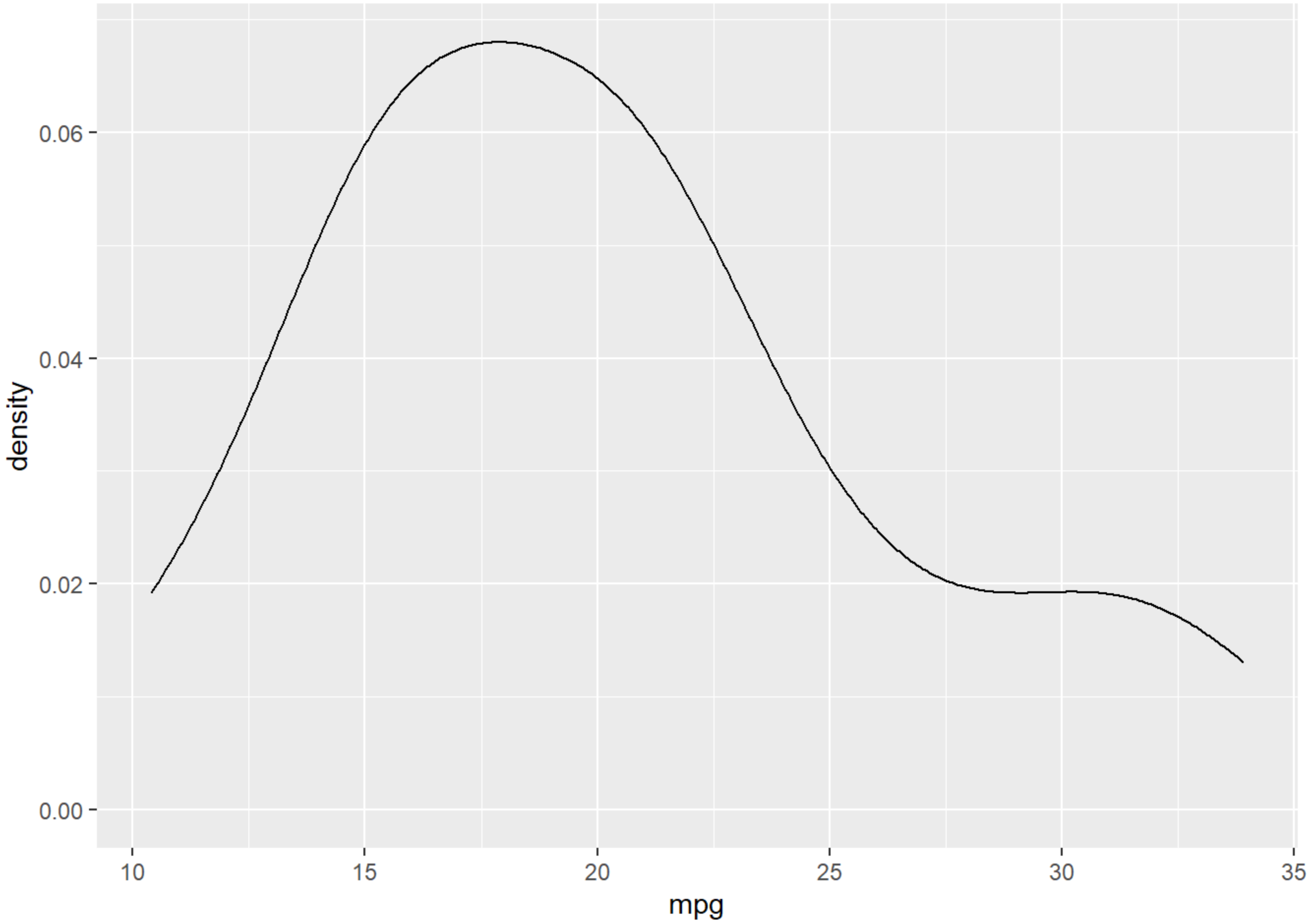
```
## `stat_bin()` using `bins = 30`. Pick better value with `binwidth`.
```



geom_density()

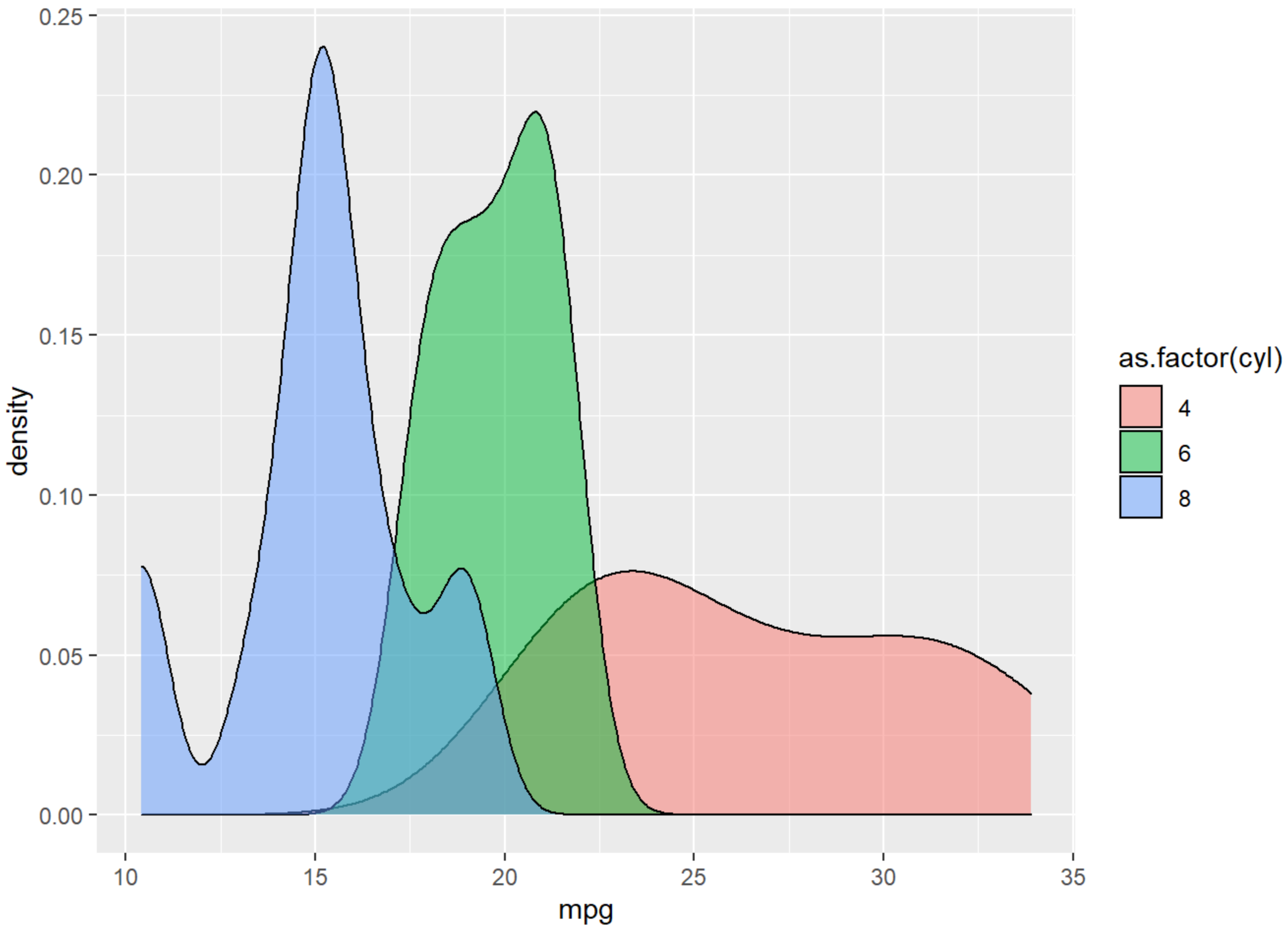
When you need a smoothed version of the histogram, `geom_density()` will produce a kernel density plot. In this case, we also add `fill = cyl` to fill the densities by color.

```
ggplot(data = mtcars,
       mapping = aes(x = mpg)) +
  geom_density(mapping = aes(fill = cyl),
               alpha = .5)
```



Wait, huh? But this does not fill the densities with a color corresponding to `cyl`. Does it need to be a different type?

```
ggplot(data = mtcars,
       mapping = aes(x = mpg)) +
  geom_density(mapping = aes(fill = as.factor(cyl)),
               alpha = .5)
```



OK better, except for cleaning up the legend.

Bar Chart Varieties

There are two types of bar chart geometry functions: `geom_bar()` and `geom_col()`. `geom_bar()` takes either an `x` or a `y` (not both) and produces a plot for which the height of the bar is proportional to the count/frequency of cases in the vector. By contrast, `geom_col()` takes both an `x` and a `y` and plots the height of each x variable bar relative to the value of the y variable. If you want the heights of the bars to represent values in the data, use `geom_col()`

geom_bar()

There are times you want bar plots.

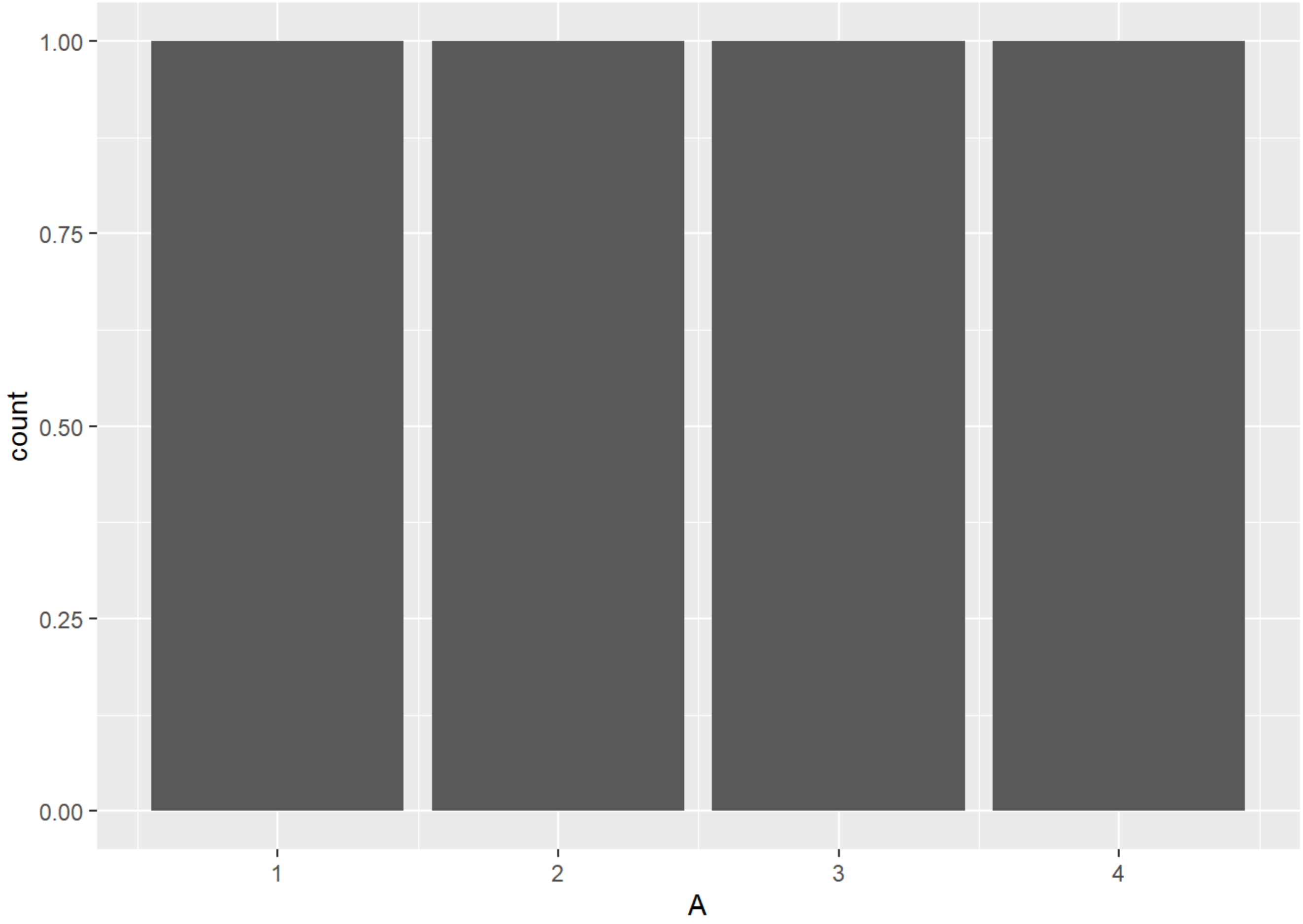
Trying out `geom_bar()`, we need an either an `x` or a `y` aesthetic mapping but not both. When passing a variable to x, the bar will be vertical and when passing the variable to y, the bar will be horizontal. Because the mapping is inherited from `ggplot()`, you'll throw an error like the following because both x and y will be inherited:

```
Error in f():  ! stat_count() can only have an x or y aesthetic.
```

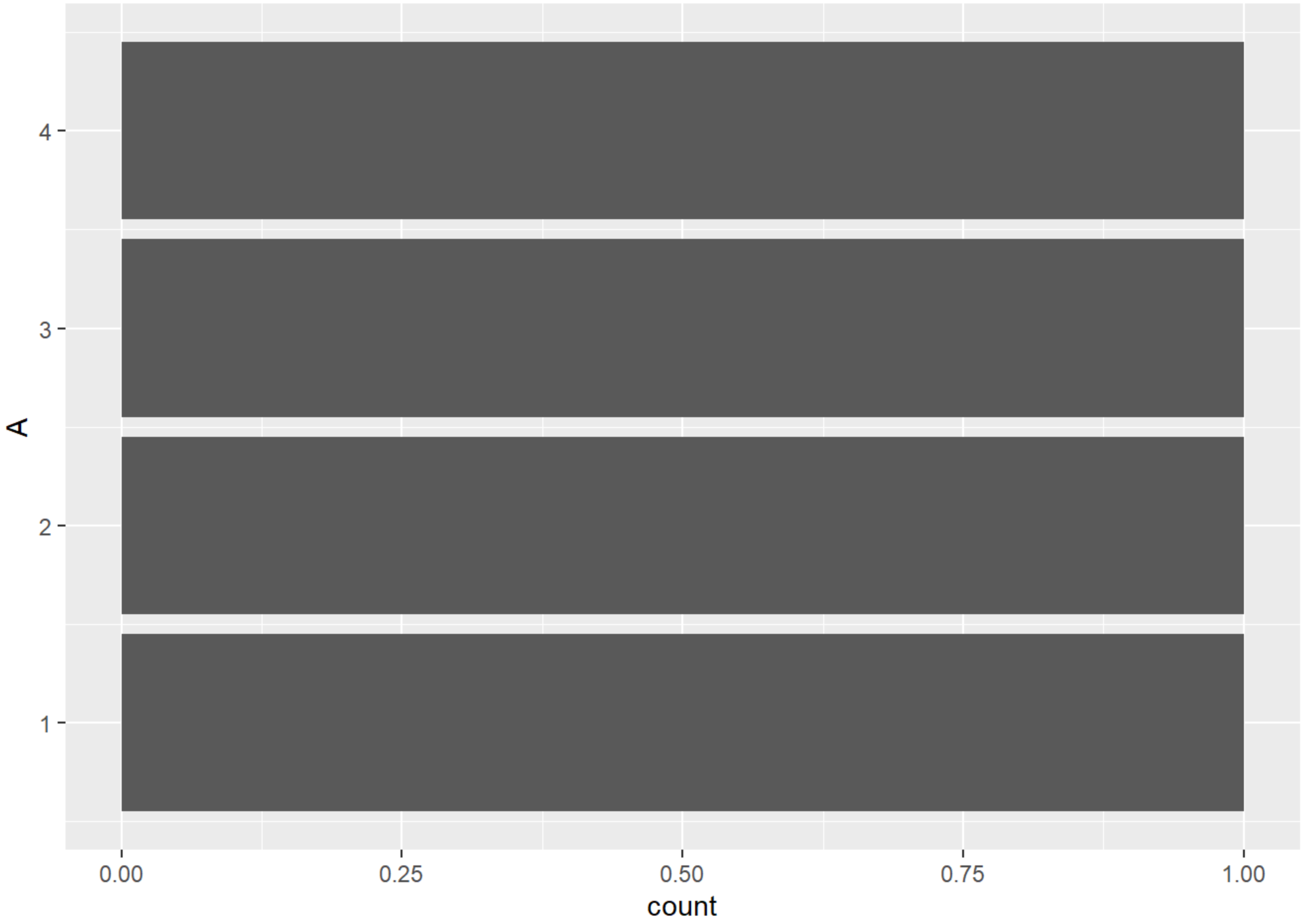
We can change the mapping in the base `ggplot()` layer, which will plot bars corresponding to the unique levels of the variable passed to `x` at a height relative to the frequency of occurrence of those unique levels. To see what might be plotted from `A`, see `DATA$A` 1, 2, 3, 4.

Checking `?geom_bar`, you will notice that `geom_bar()` has a default `stat = "count"`. This means that the default bar plot will plot the `"count"`, or frequency of elements in a vector variable. When the count or frequency of a value is 1, the bar height will be 1 on the y axis and if an element appears 5 times in the vector, the bar height will be 5. For a horizontal bar, the bar length, rather than height, will be 5. Looking at `DATA$A` 1, 2, 3, 4, what might you expect the bar to look like?

```
# setting x
DATA %>%
  ggplot(., aes(x = A)) +
  geom_bar()
```



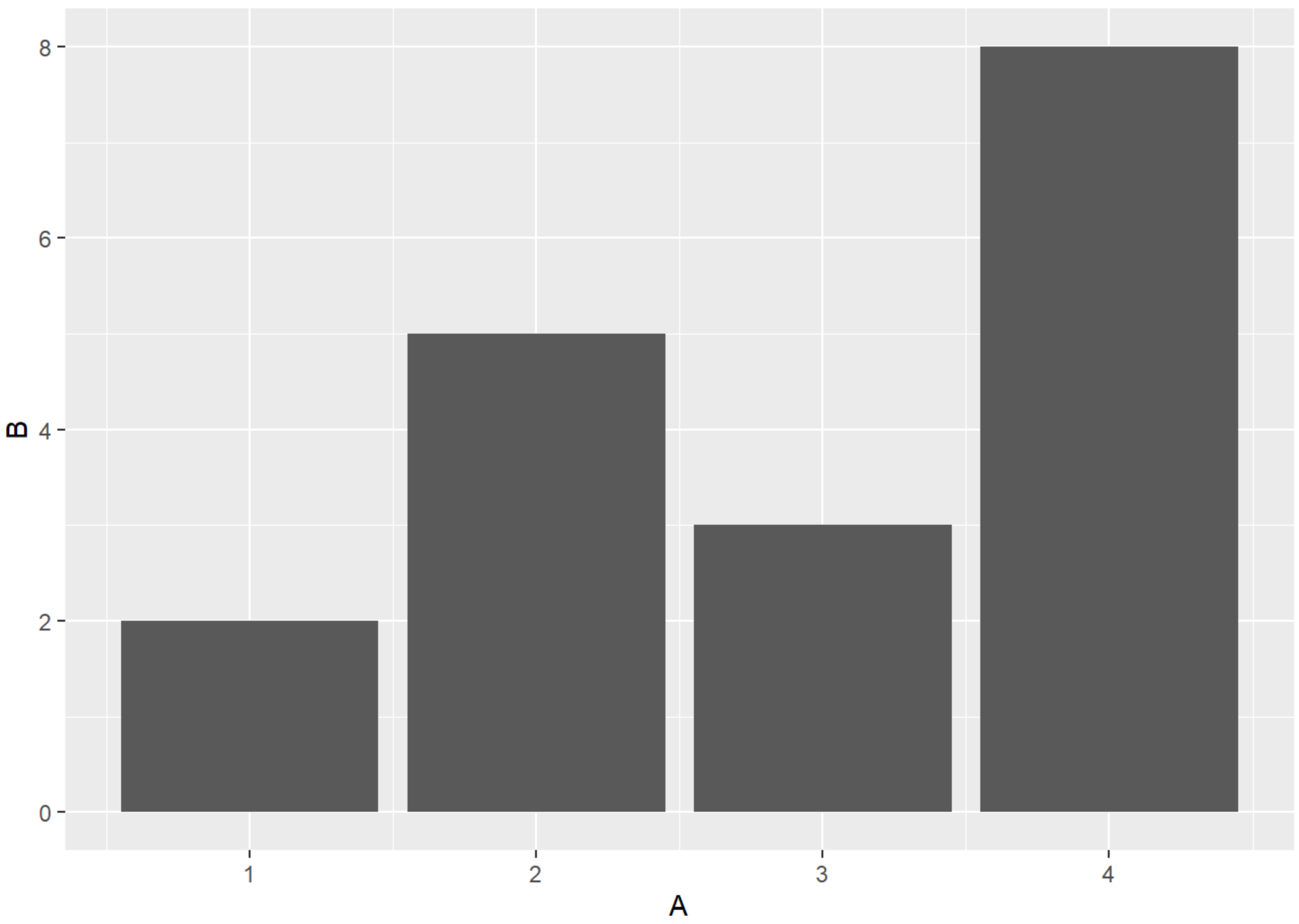
```
# setting y
DATA %>%
  ggplot(., aes(y = A)) +
  geom_bar()
```



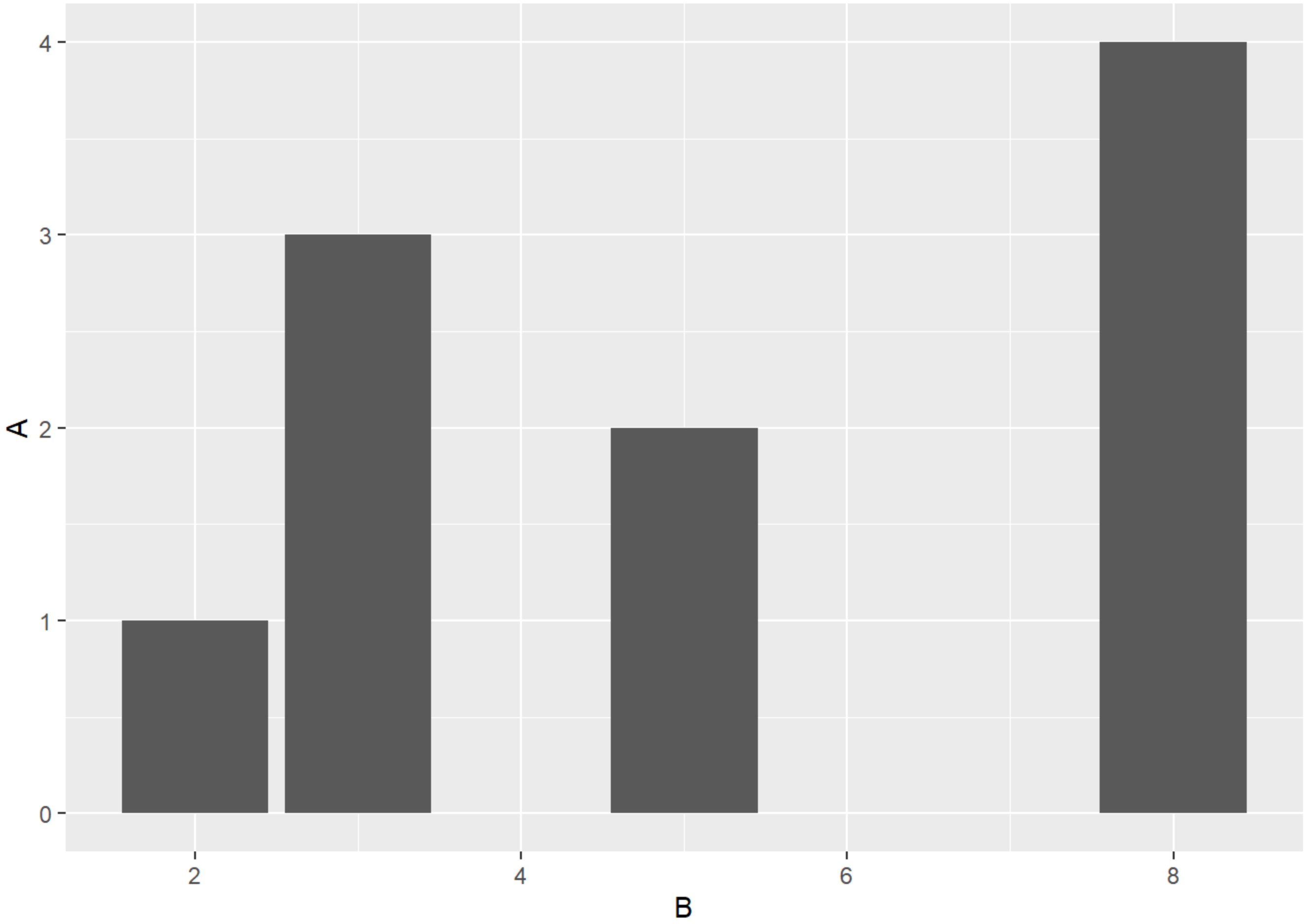
If the aesthetics are mapped and inherited, you can still create a plot that accounts for both `x` and `y` variables. Passing `stat = "identity"` to `geom_bar()` will produce a bar plot that presents the value of `y` in the data frame (its identity) for each value of `x`.

When passing, pay attention to which variables are inherited by both `x` and `y` as they will likely produce very different plots.

```
DATA %>%
  ggplot(., aes(x = A, y = B)) +
  geom_bar(stat = "identity")
```

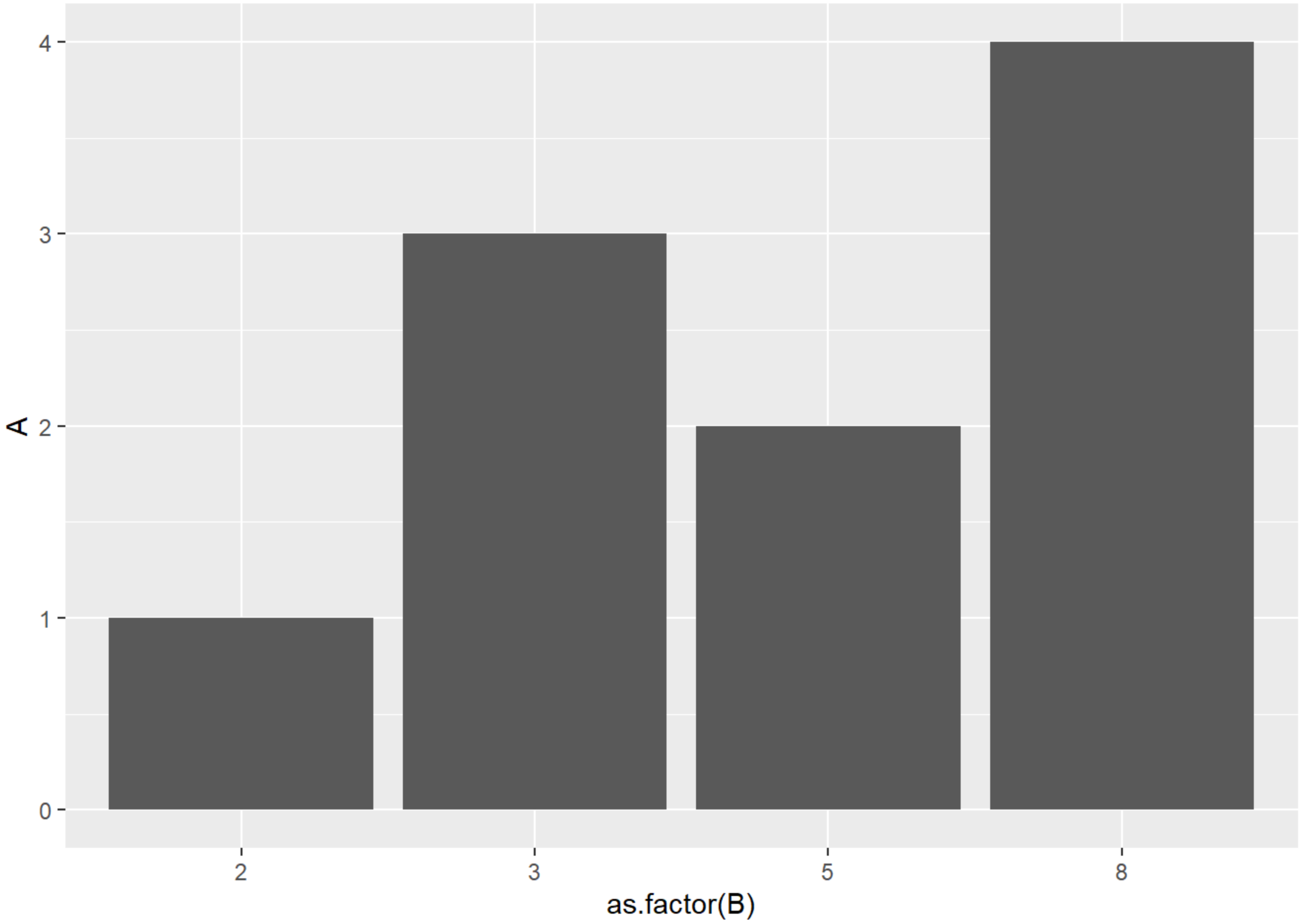


```
DATA %>%
  ggplot(., aes(x = B, y = A)) +
  geom_bar(stat = "identity")
```



By default, the scale for x and y are continuous (see above). If you don't like the fact that bars take positions for which there are no labels and that labels are where no bars are, convert `B` it to a factor.

```
DATA %>%
  ggplot(., aes(x = as.factor(B), y = A)) +
  geom_bar(stat = "identity")
```



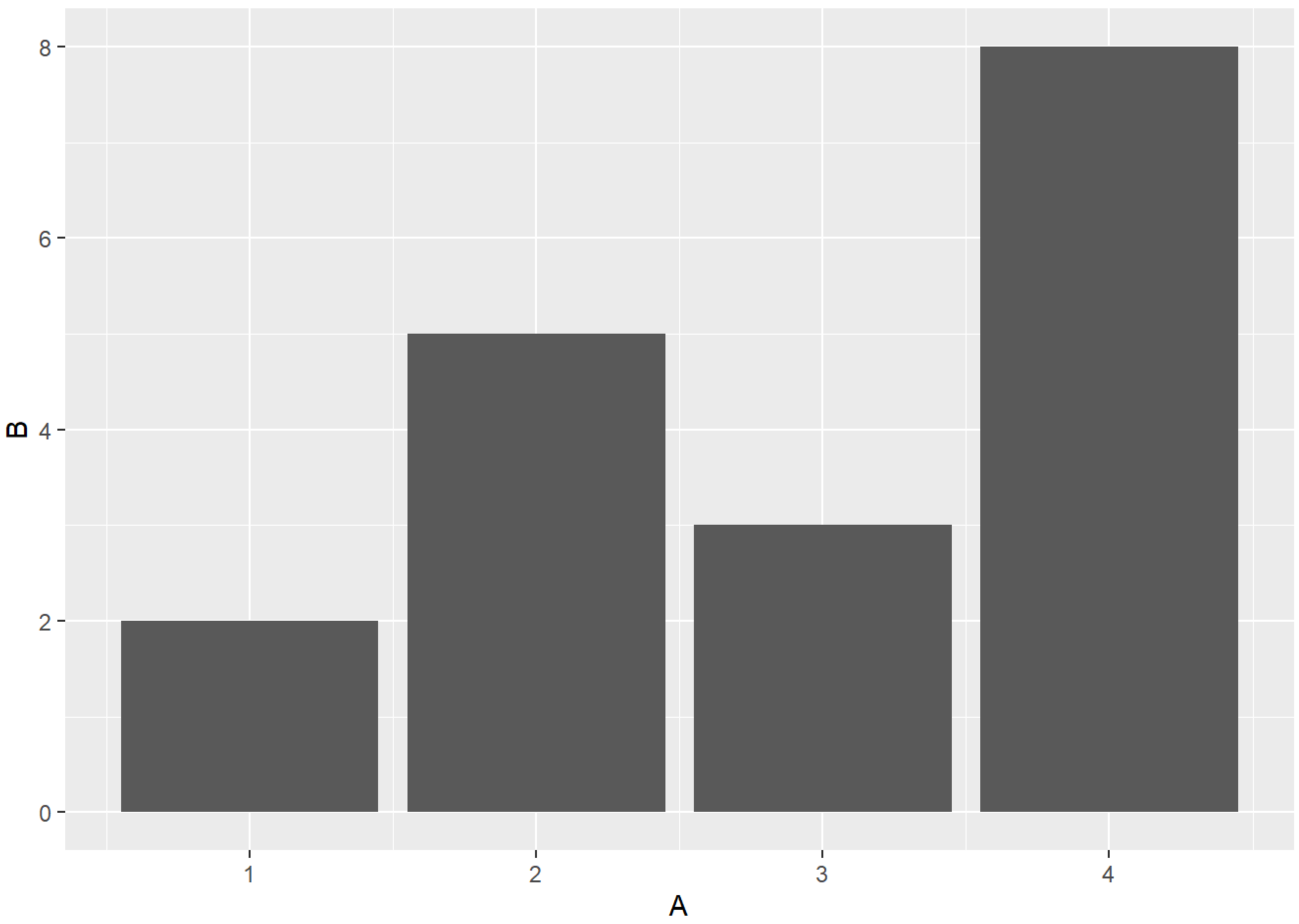
geom_col()

`geom_bar(stat = "identity")` is actually the same as another plot. A column plot using `geom_col()` . We need both `x` and `y` variables and when specified, the columns will plotted for each unique level of `x` at a height corresponding to the value of `y` . One way to think about `geom_col()` is that it plots columns at the same location as the points in `geom_point()` .

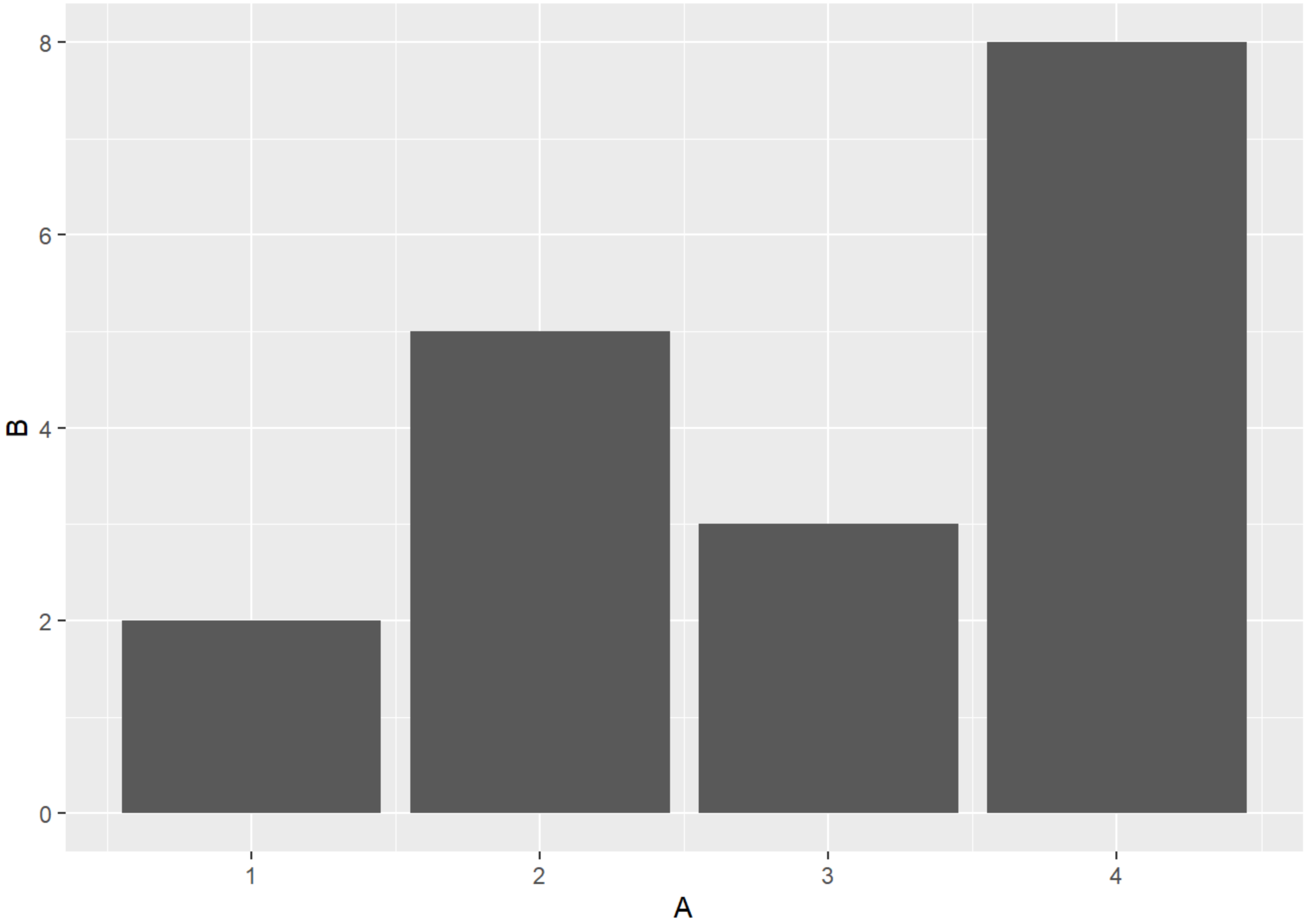
```
DATA %>%
  select(., c("A", "B"))
```

```
##   A B
## 1 1 2
## 2 2 5
## 3 3 3
## 4 4 8
```

```
DATA %>%
  ggplot(., aes(x = A, y = B)) +
  geom_col()
```

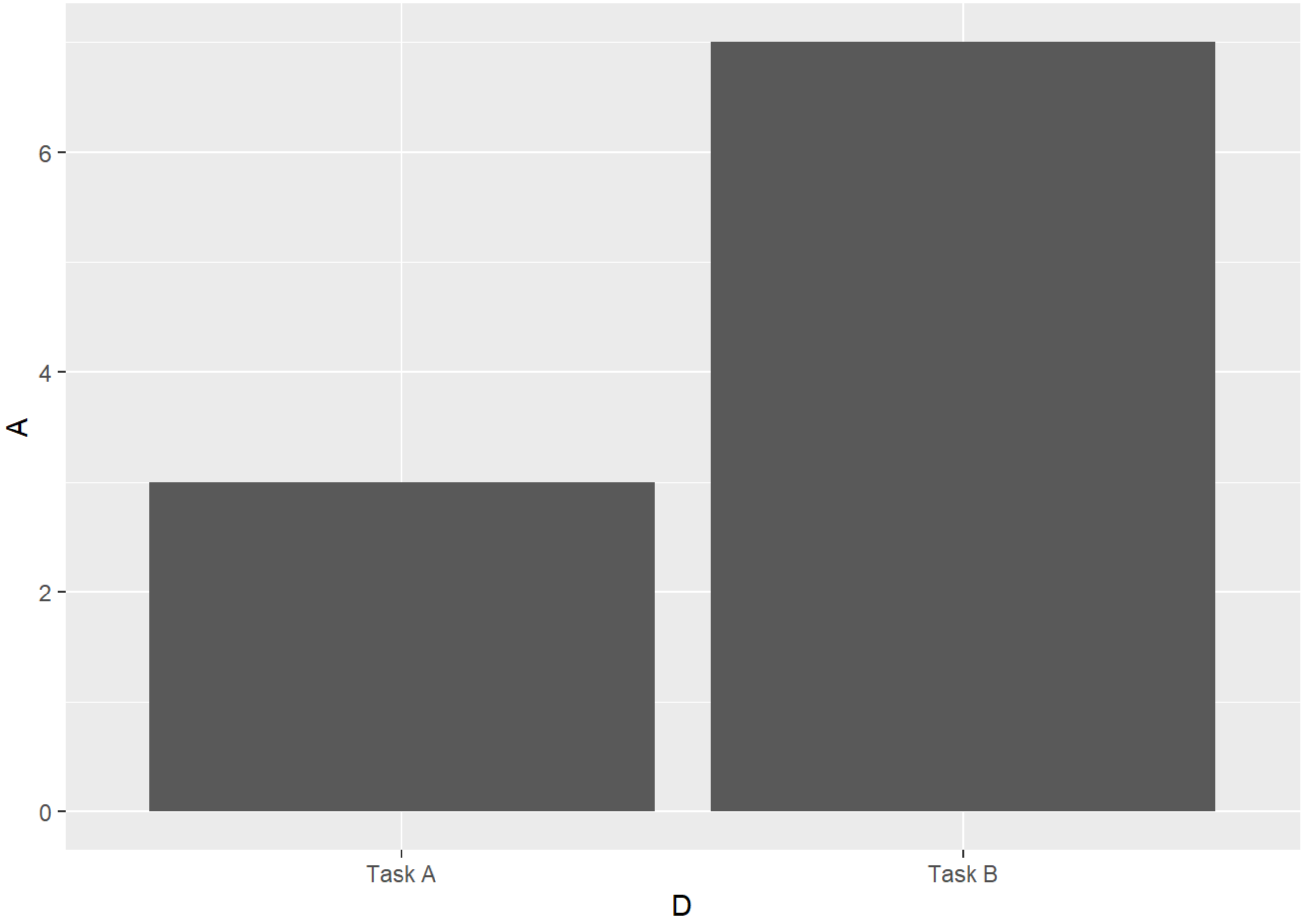


```
DATA %>%
  ggplot(., aes(x = A, y = B)) +
  geom_col()
```

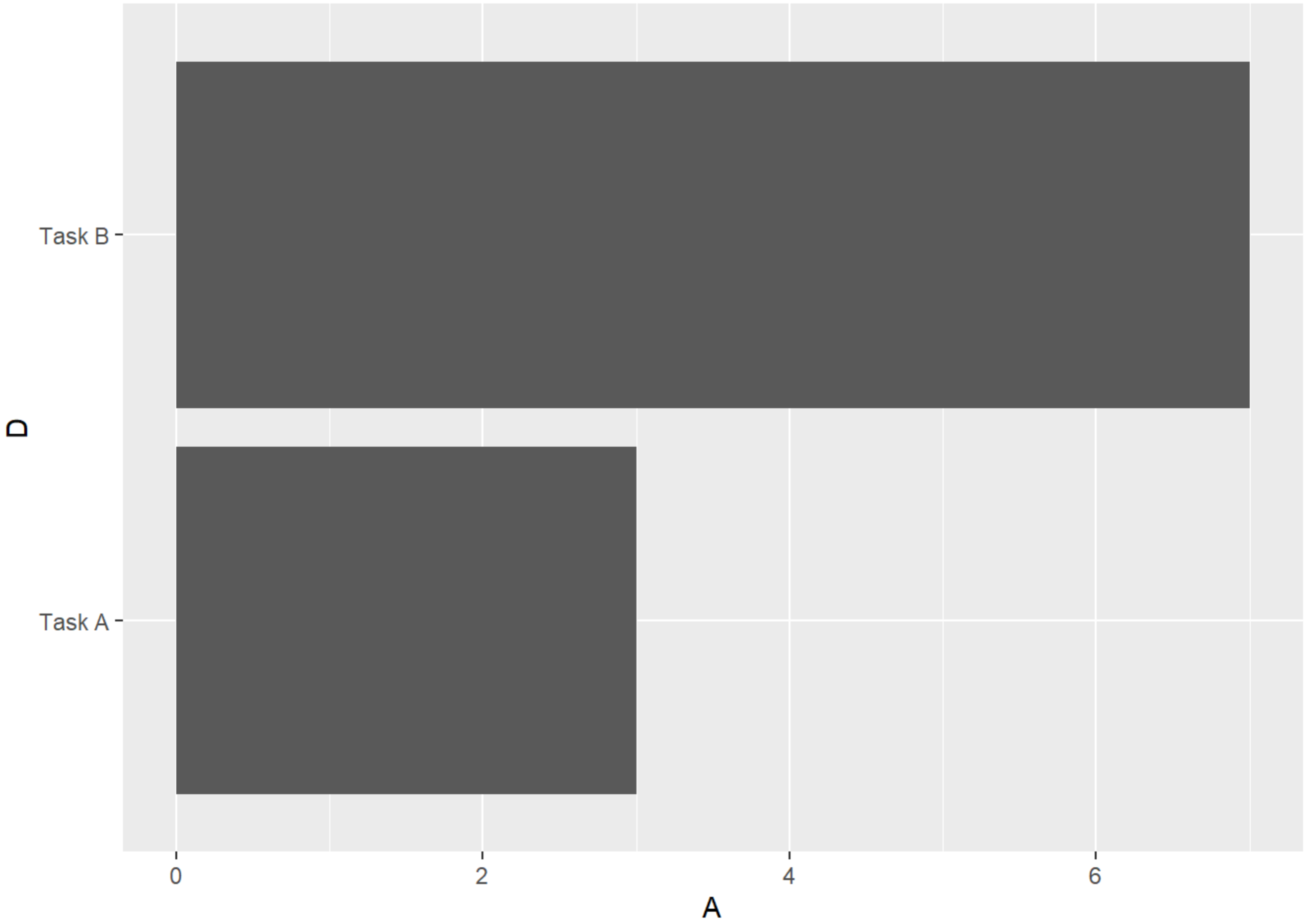


If your x axis (or y axis) is categorical/discrete rather than continuous.

```
DATA %>%
  ggplot(., aes(x = D, y = A)) +
  geom_col()
```



```
DATA %>%
  ggplot(., aes(x = A, y = D)) +
  geom_col()
```

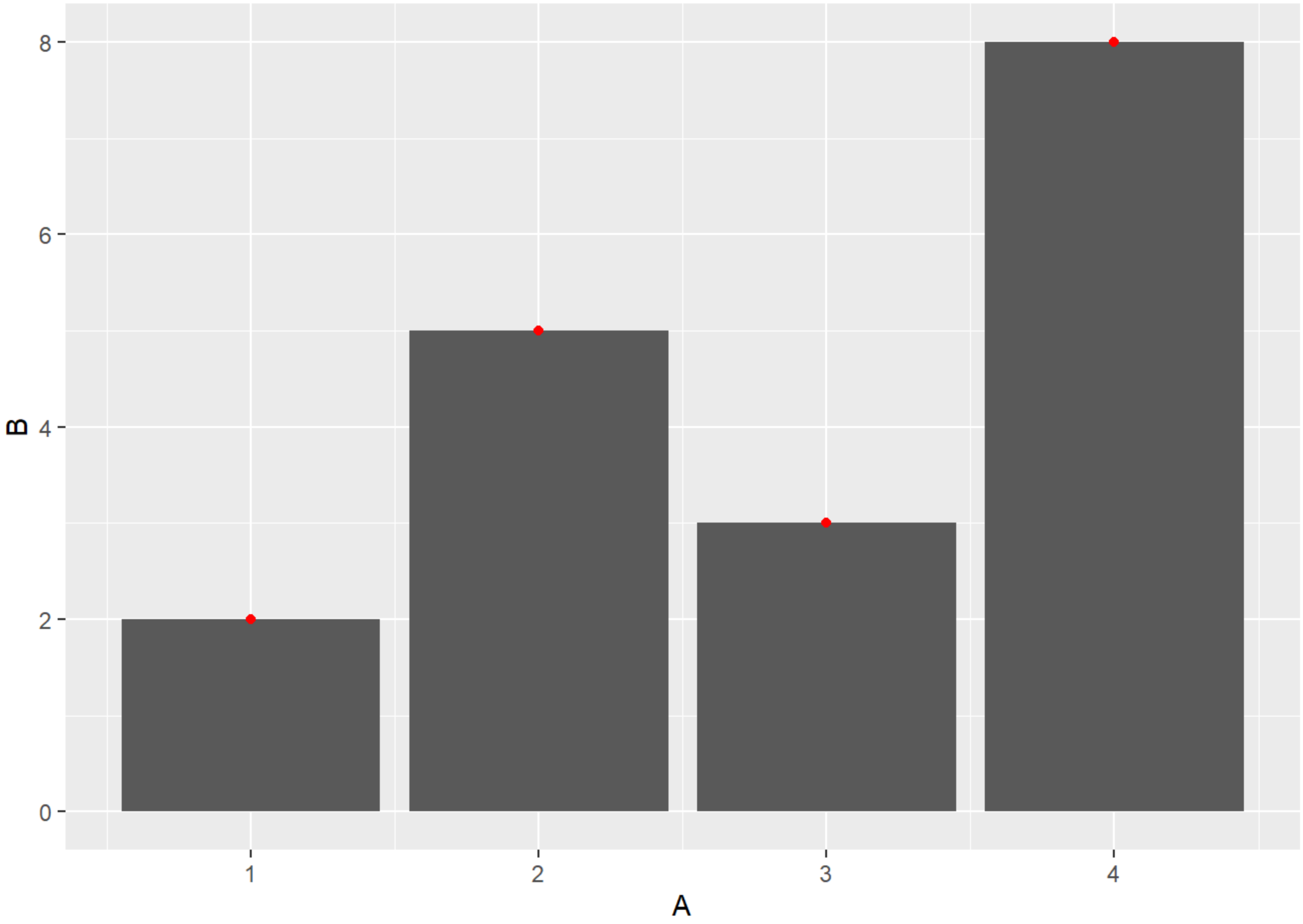


Adding Layers To Plots

You can *add* a layer to a plot using `+`. Unlike `%>%`, you are not passing the object to another function but rather you are taking the current plot object and adding to it another layer.

For example:

```
DATA %>%
  ggplot(., aes(x = A, y = B)) +
  geom_col() +
  geom_point(color = "red")
```

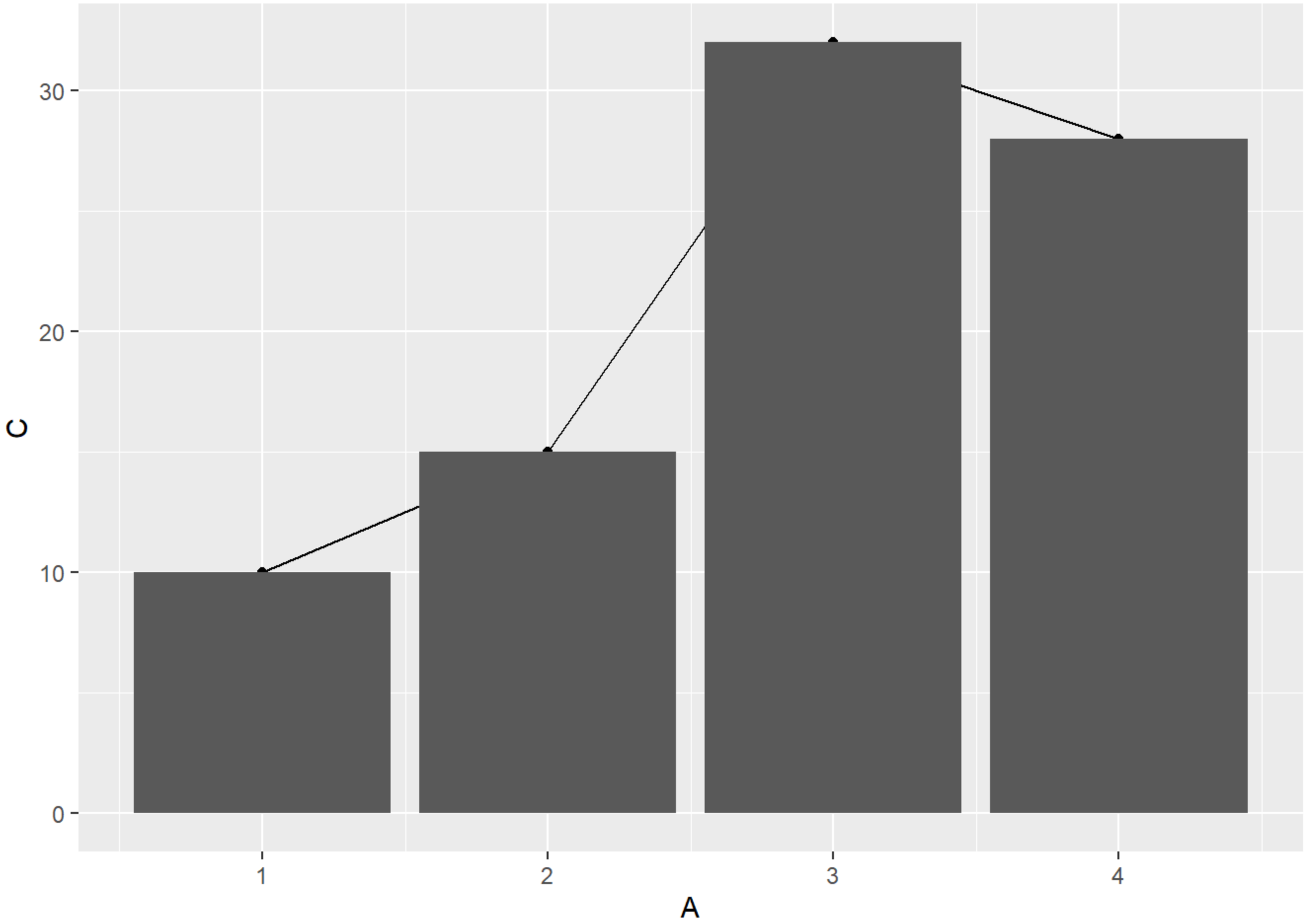


Adding layers that inherit aesthetics

When aesthetics are mapped to the initialized `ggplot()` object, the `x` and `y` variables therein carry through to the geometries. This is not a problem when the geometries are using similar information as with `geom_point()` , `geom_line()` , and even `geom_col()` .

```
map <- ggplot(data = DATA,
              mapping = aes(A, C))

map +
  geom_point() +
  geom_line() +
  geom_col()
```



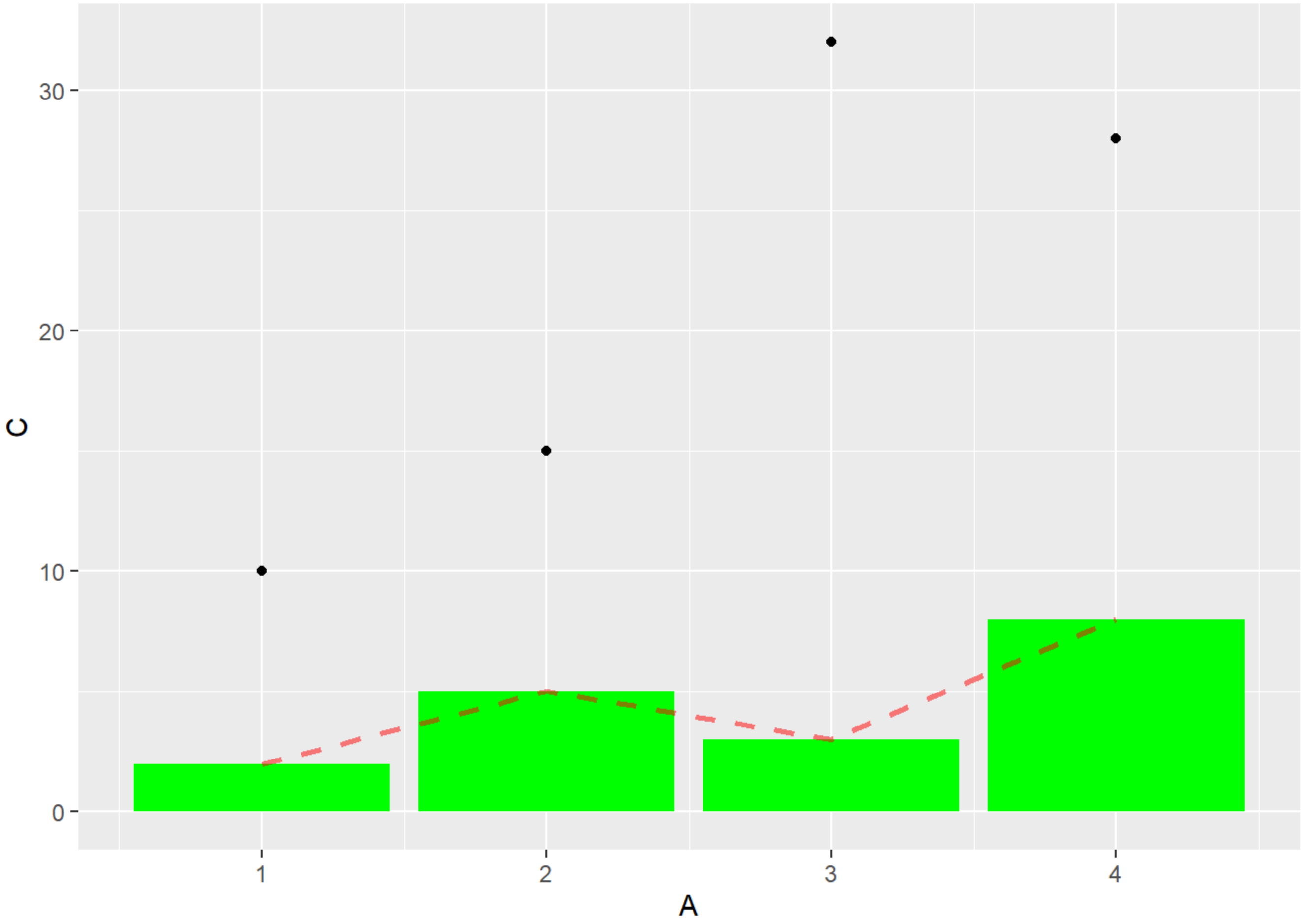
But because `geom_bar()` takes only `x` or `y` , there will be a problem. Test it on your own.

Adding layers that do not that inherit aesthetics

When aesthetics are not inherited by the initial object, they can be set or mapped in their own geometry. This example does not even pass `data = DATA` . If it did and each geometry used `DATA` , then that doesn't need passing. Only omitted characteristics need mapping.

```
map <- ggplot()

map +
  geom_point(data = DATA,
             mapping = aes(A, C)) +
  geom_col(data = DATA,
           mapping = aes(A, B),
           fill = "green") +
  geom_line(data = DATA,
            mapping = aes(A, B),
            linetype = "dashed",
            color = "red",
            size = 1,
            alpha = .5)
```

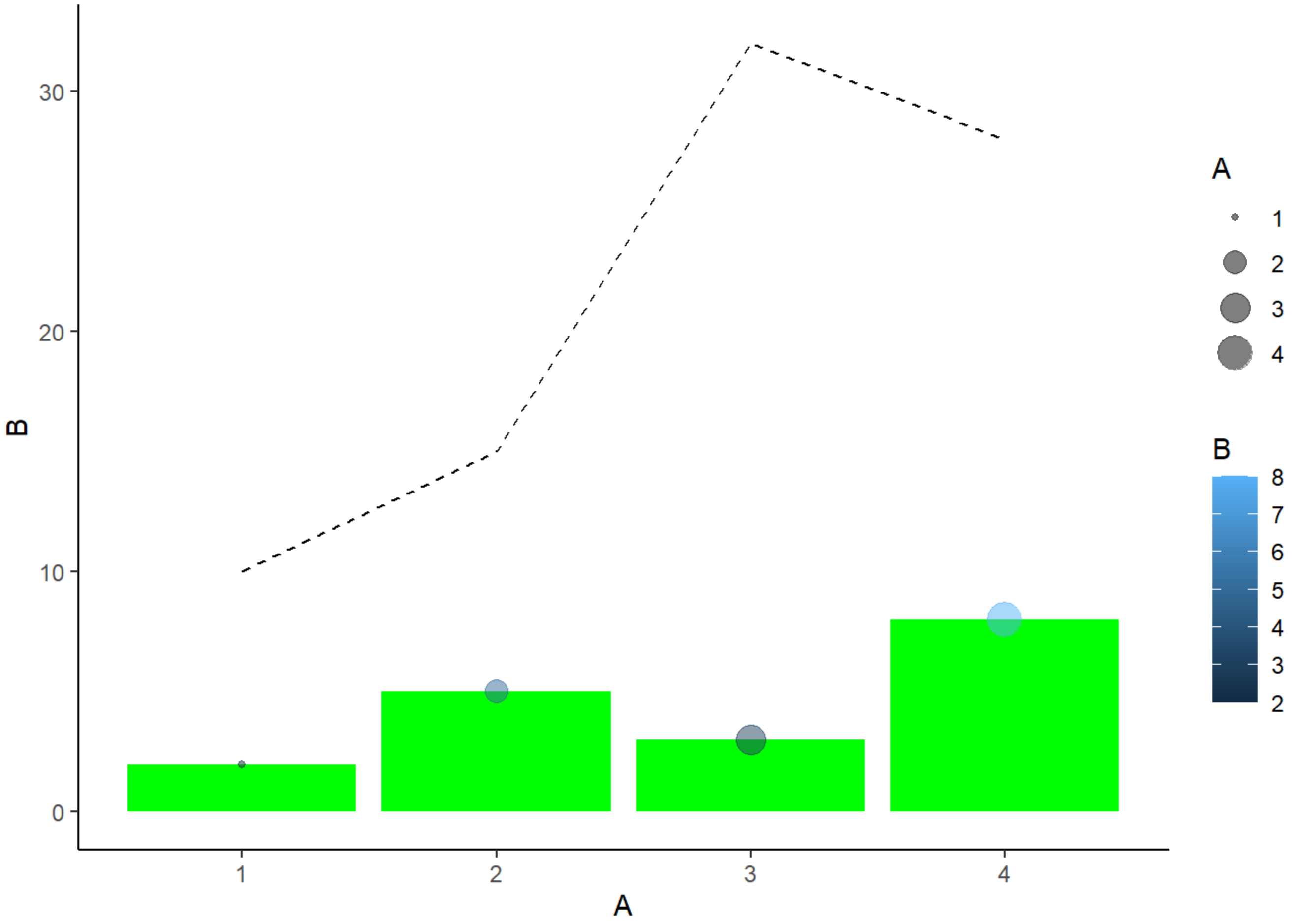


By specifying `DATA` and `aes(A, B)`, all geometries using `DATA` with `x = A` and `y = B` will inherit them. Otherwise, pass the necessary arguments to the geometries.

```
map <- ggplot(data = DATA,
              mapping = aes(A, B))

map +
  geom_col(fill = "green") +             # set all columns to blue
  geom_line(mapping = aes(y = C),       # a new mapping y = C for the line data
            linetype = "dashed") +      # set the linetype

  geom_point(mapping = aes(color = B,   # map color to A (inherited as y)
                           size = A),   # map size to B (inherited as x)
            alpha = .5                  # set alpha transparency
            ) +
  theme_classic()
```



Now, this plot is certainly not the best and it certainly needs work. But the coding of the plot illustrates the flexibility of ggplot for adding plot geometry layers to a single plot, utilizing aesthetics inherited from an initialized object, mapping new aesthetics not inherited, setting aesthetic constants, and mapping variables to aesthetics.

```
geom_point(aes(sugars, rating))
```

```
## mapping: x = ~sugars, y = ~rating
## geom_point: na.rm = FALSE
## stat_identity: na.rm = FALSE
## position_identity
```

Position Adjustment to Address Overplotting

The plot layer we did not yet address is position. In order for a point plot, bar plot, box plot or other plot to appear, they have to take a position in that space. An example involving points will help illustrate.

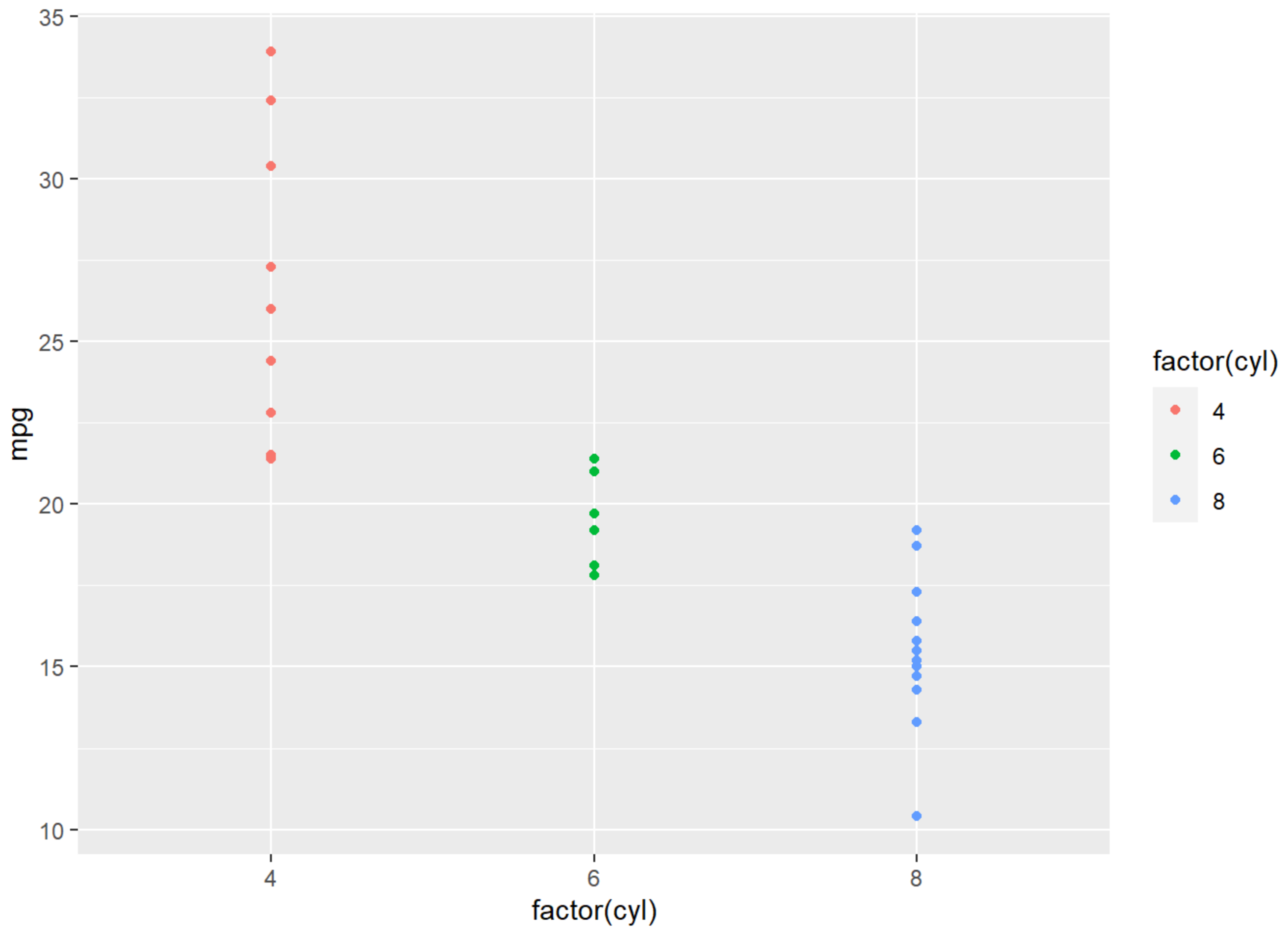
When plotting points on a plot, no matter what coordinate system you plot in, an xy coordinate will take a particular position in visual space. Following a Cartesian coordinate system, I’m sue you could imagine visually a point on a plot at position x = 3, y = 5. A data visualization problem occurs when two or more points also take that same xy position. Can you imagine 2 points in that same position? How about 5? Or even 11? You see the problem.

When you have many data points in a plot, they will overlap if they share a position, thus masking each other. When one point is hidden behind another point, viewers cannot see that there are multiple points. And in a worst-case scenario, those overlapping points are interpreted as a single point, leading to incorrect data storytelling or memory for said story. This description illustrates what is referred to as *overplotting*.

As a data storyteller, you have to deal with overplotting somehow. If you have an audience, you could explain this problem during a talk or in a write up. But a picture speaks a thousand words, if you let it. Because we are on the topic of data visualization, we could just address this overplotting issue by simply changing the position of the points slightly using some stochastic process (won’t be the same for each plot). For an x = 3, y = 5 point, how can we change the position slightly so it doesn’t overlap with another point at the same position? Well, maybe by adding some noise to the data, one point could be positioned at 3.1, 5.0 and another and 3.0, 5.1, and another at 3.1, 4.9, and another at 2.9, 5.1, etc. What you might imagine is a cluster of points around space x = 3, y = 5, each taking a slightly different position so that they don’t overlap and are all visible.

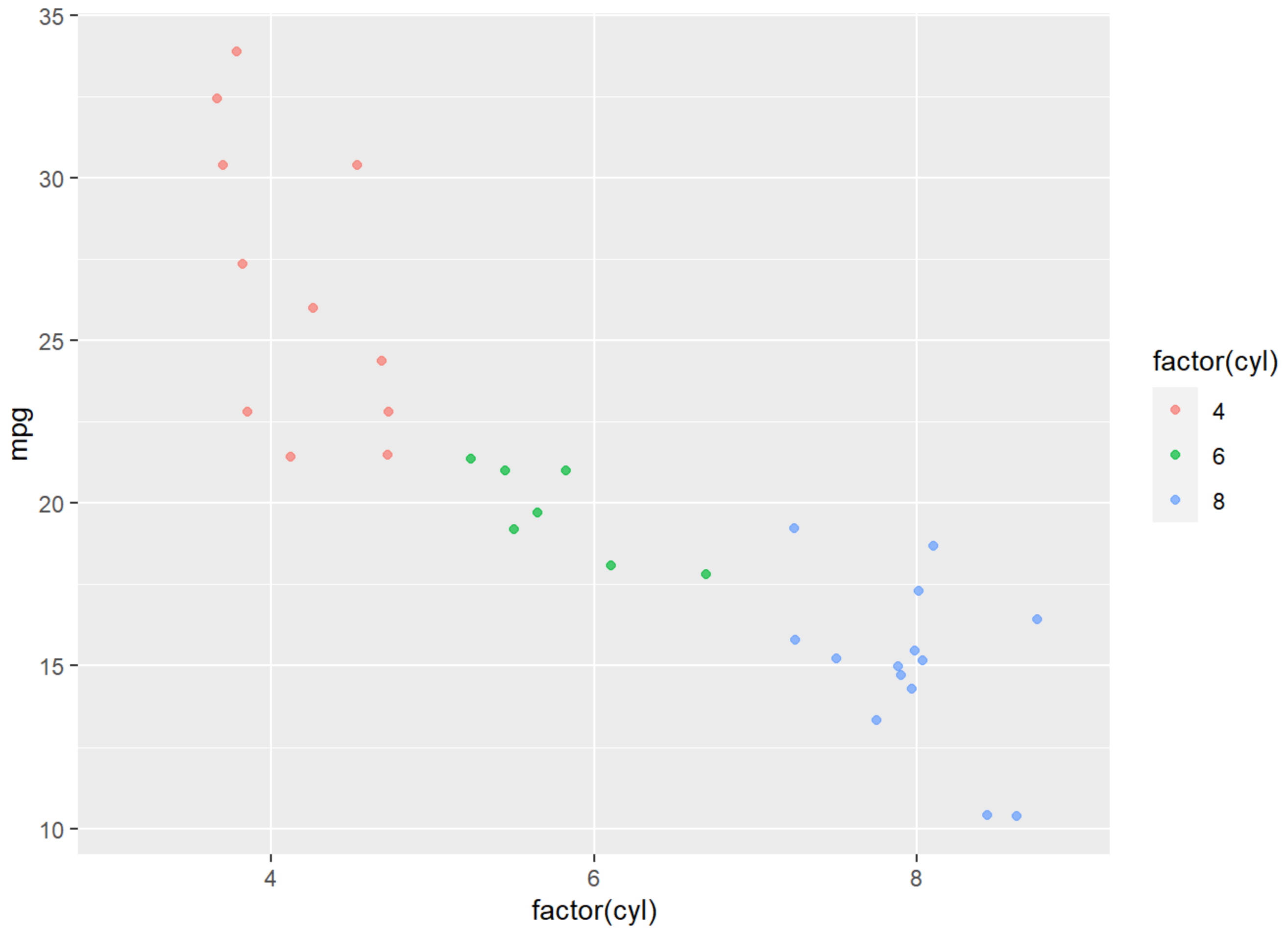
A good example of dealing with overplotting was seen in the first plot. Without adding any noise to the data (e.g., `position = "jitter"`) and changing `alpha` , the `mpg` for each cylinder level are plotted on top of each other

```
ggplot(mtcars) +
  geom_point(aes(x = factor(cyl),
                 y = mpg,
                 color = factor(cyl))
             )
```



Changing the positioning by “jittering” them will make them cluster around their levels but visibly differentiated from each other. To facilitate the visual, we could change `alpha` to make the points somewhat transparent such that the overlap is darkend.

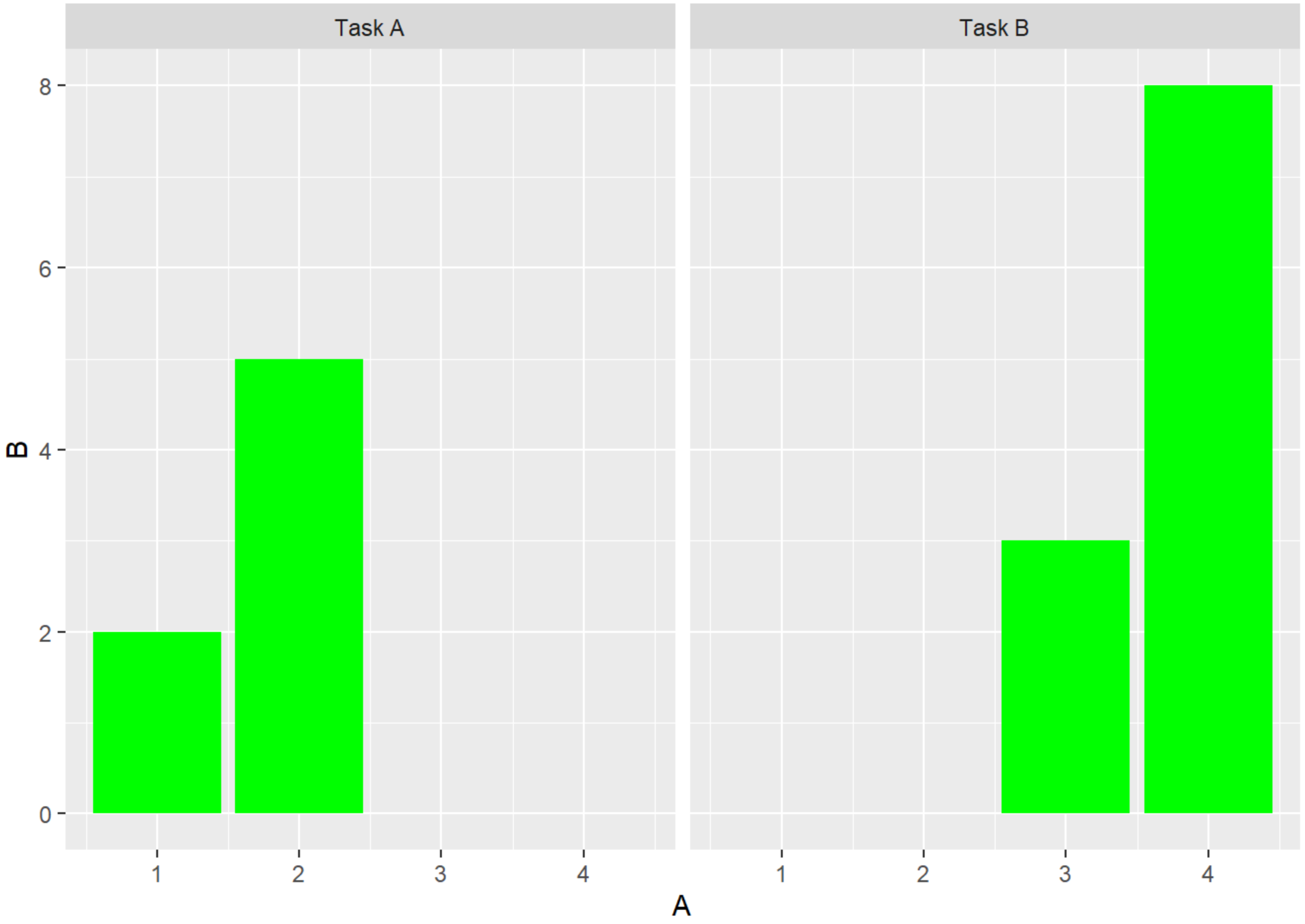
```
ggplot(mtcars) +
  geom_point(aes(x = factor(cyl),
                y = mpg,
                color = factor(cyl)),
             position = "jitter",
             alpha = .7
             )
```



Facetting Plots

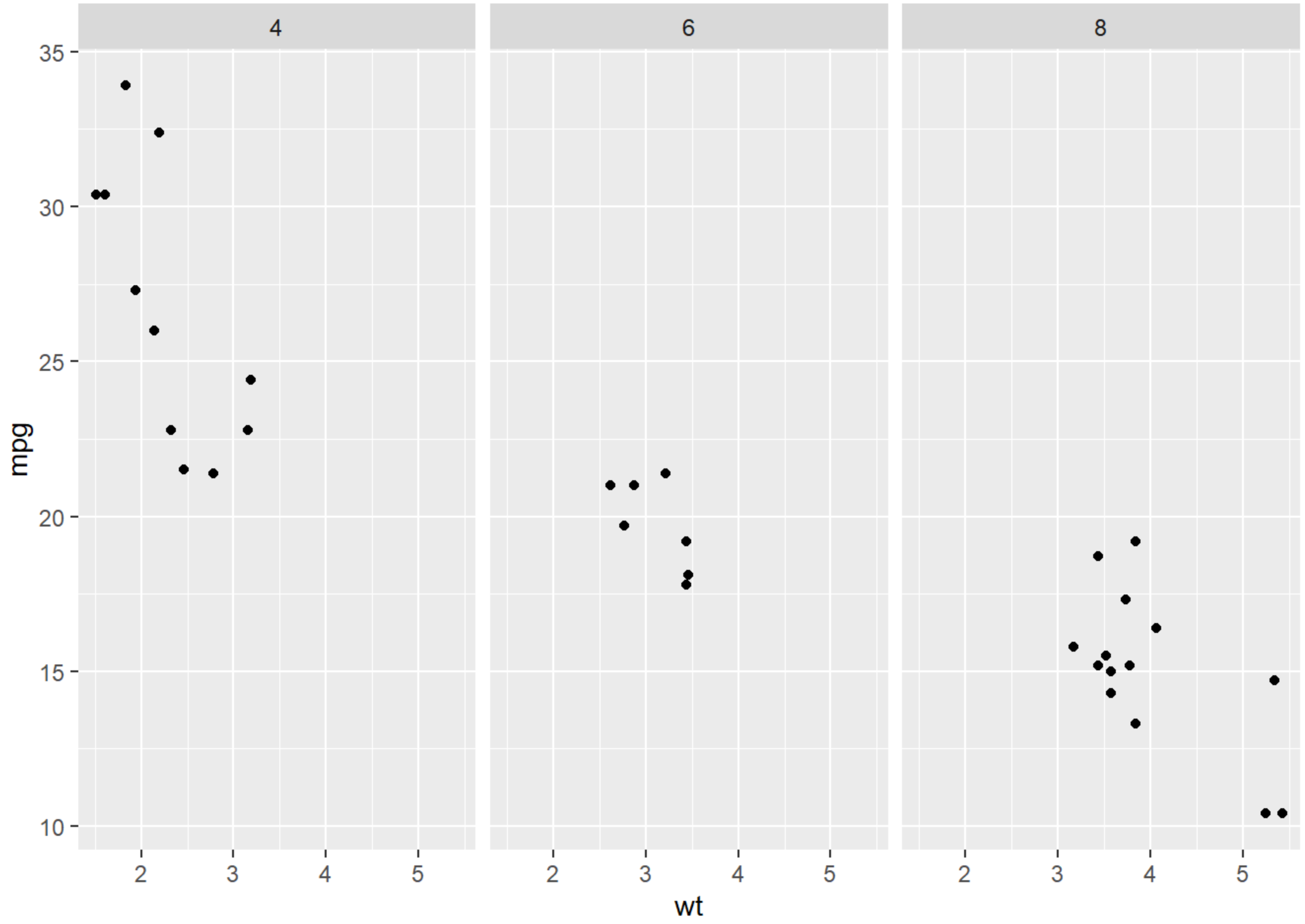
When you want to plot the same data separately for levels or variations in another variable, you can plot facets. Using `facet_wrap()`, we can pass the `D` variable like this: `facet_wrap(~D)`

```
DATA %>%
  ggplot() +
  geom_col(mapping = aes(A, B),
           fill = "green") +
  facet_wrap(~D)
```



Unfortunately, with this small data set, values differ in `A` based on `D` (the task) so you might be confused. Rest assured the function is doing what it should. Our data only have responses 1 and 2 for Task A and 3 and 4 for Task B. Perhaps a better illustration is with `mtcars` data. A point plot visualizing `wt` and `mpg` for each cylinder size.

```
mtcars %>%
  ggplot() +
  geom_point(mapping = aes(wt, mpg),
             fill = "green") +
  facet_wrap(~cyl)
```

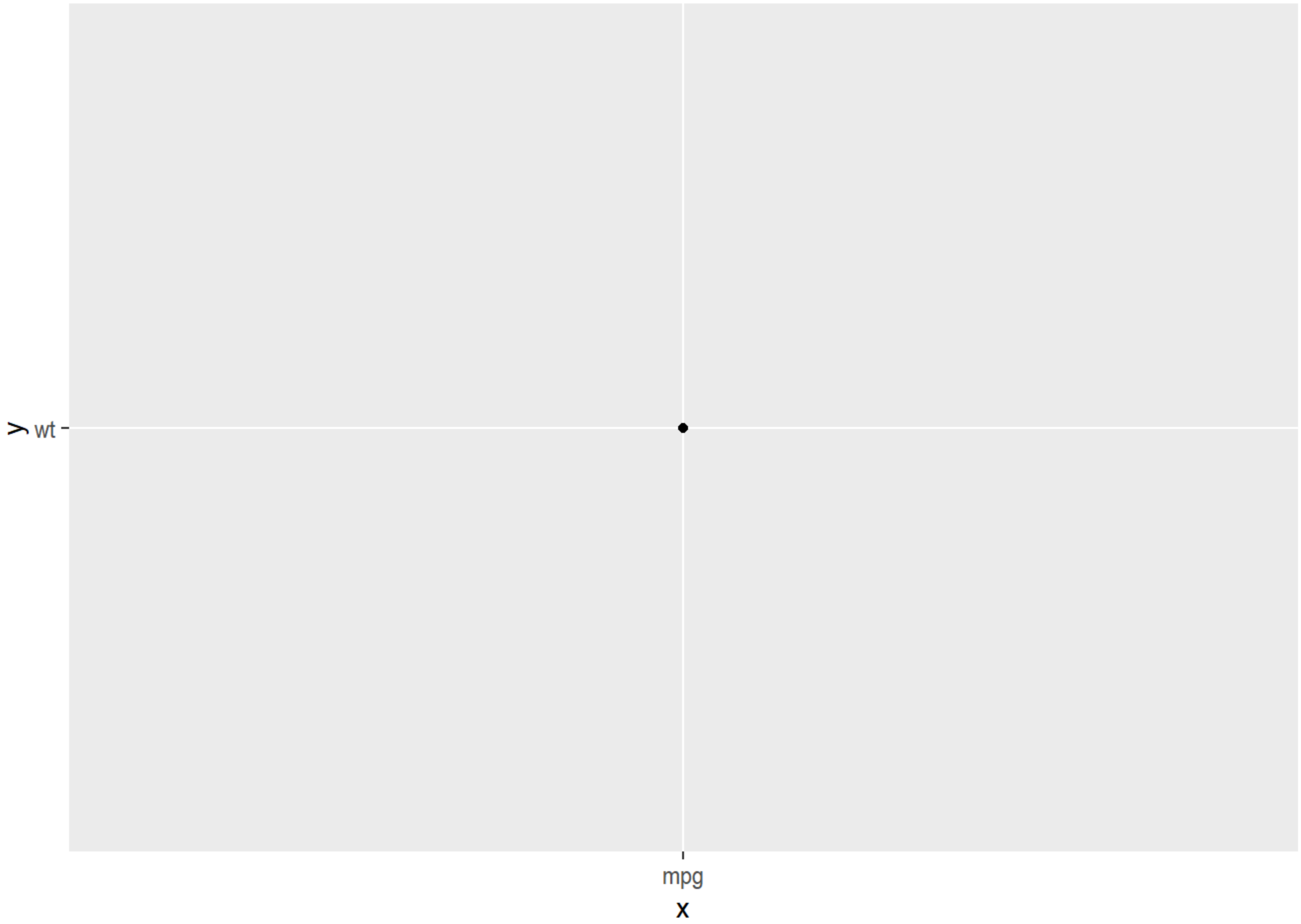


Troubleshooting Passing Vectors

You may sometimes have a data set that has many variables containing special characters. In such cases, you may try to pass as arguments to the `x` and `y` aesthetics (viz., `aes()`) the variable names in quotes. If so, `ggplot2` will plot a single point (rather than all xy coordinates).

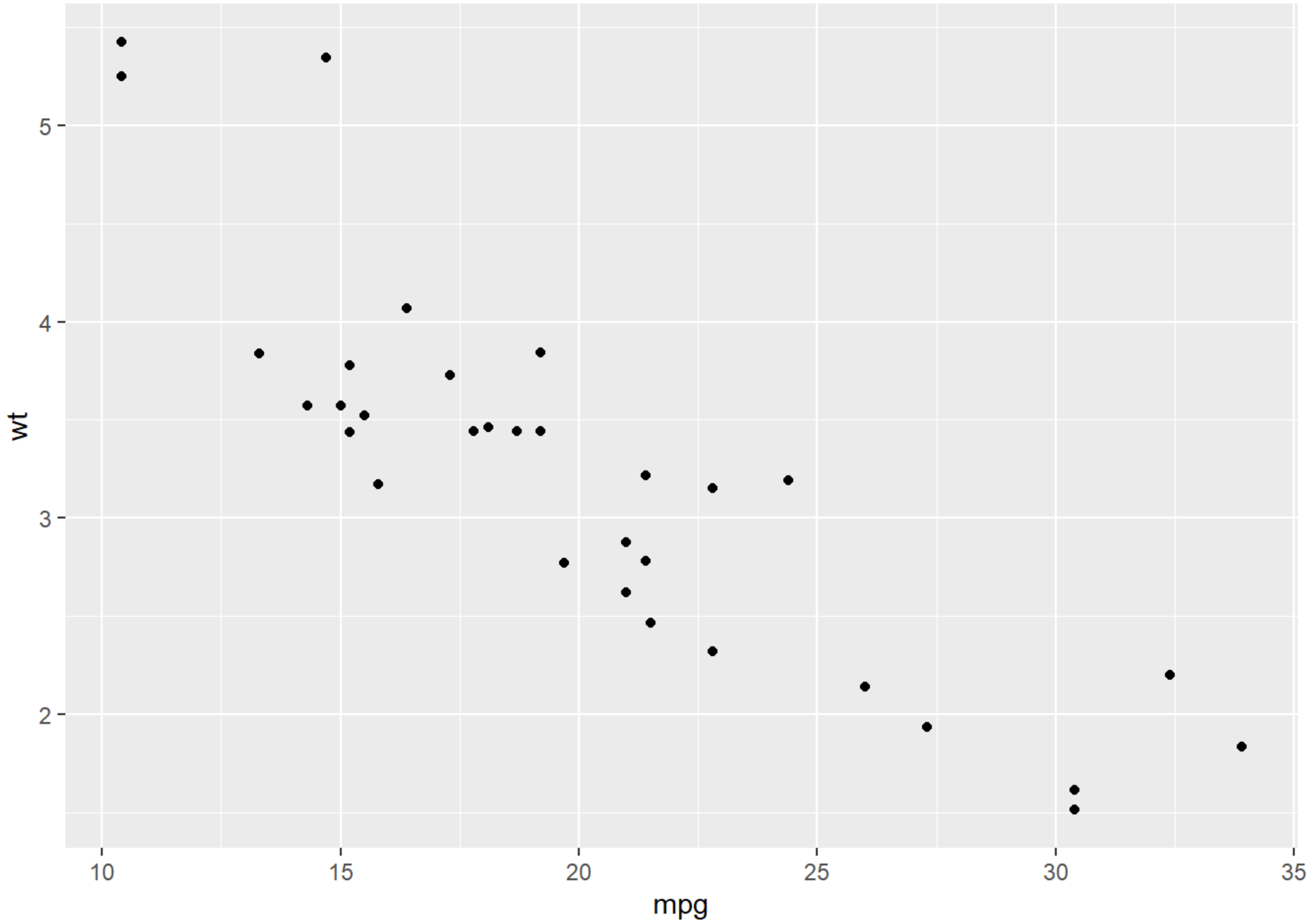
Let’s see using the `mtcars` data to plot car weight against miles per gallon.

```
mtcars %>%
    ggplot(.,
       aes(x = "mpg", y = "wt")) + geom_point()
```



This is certainly awkward. You may not even think to just pass the name without quotes but if you did, you would see a nice scatter plot.

```
mtcars %>%
    ggplot(.,
       aes(x = mpg, y = wt)) + geom_point()
```



Easy fix if you know what you are doing but there is a larger problem when you have special characters in variable names.

```
#add new vars
mtcars2 <- mtcars %>%
  mutate(.,
         "_wt" = wt,
         "_mpg" = mpg)
```

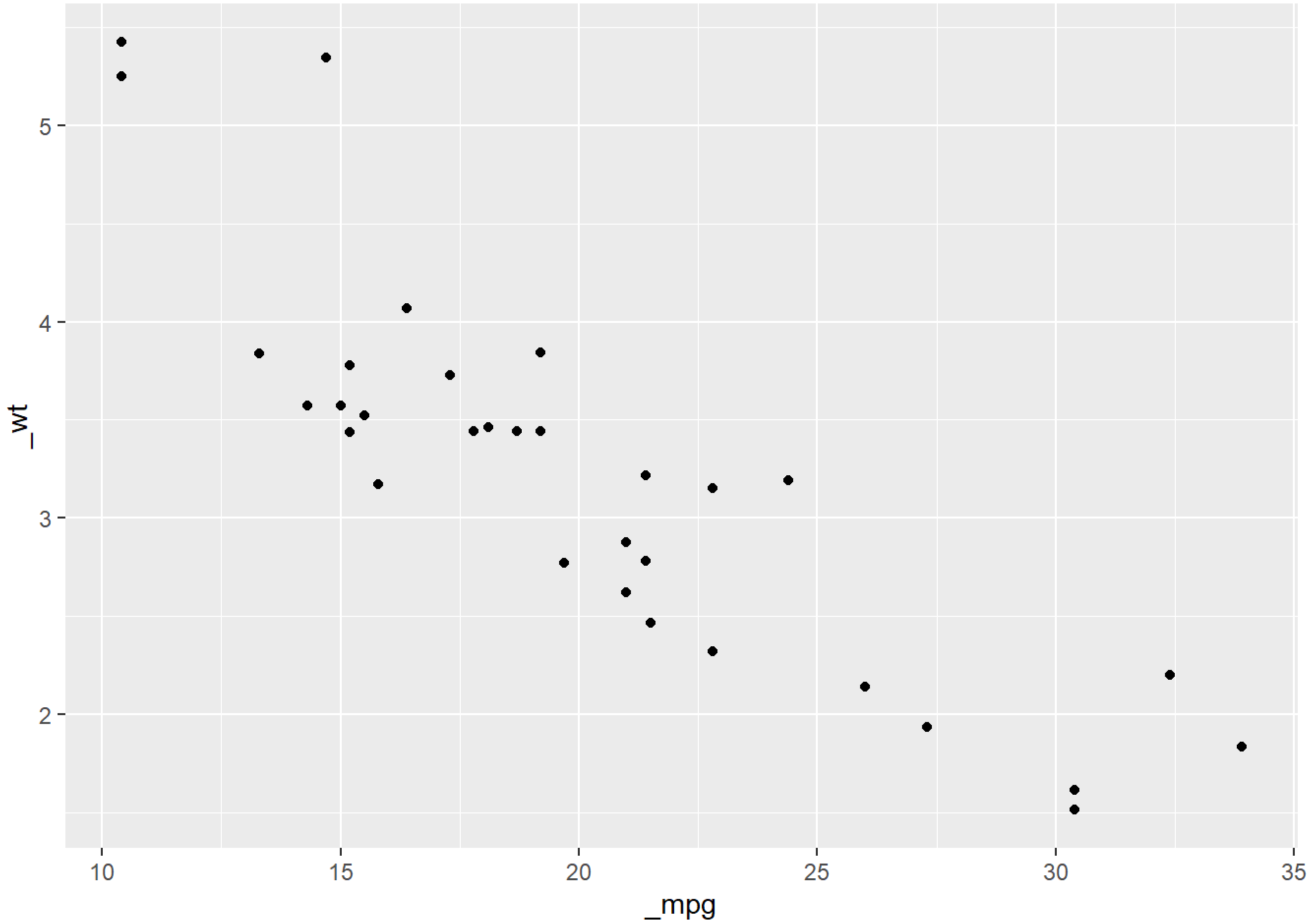
This code will produce an error, which unfortunately is not very diagnostic regarding the unexpected symbol. There is no quote in the code but the error seems to be stating there are `"` which are causing problems.

```
mtcars2 %>%  ggplot(.,  aes(x = _mpg, y = _wt)) + geom_point()
```

So what do you do?

You can use the tick (e.g., “`”) to wrap your variable names, though this approach may never come to mind unless you work with RStudio long enough to see that the tick is often wrapped around variable names. Nevertheless, this will solve your problem.

```
mtcars2 %>%
    ggplot(.,
       aes(x = .data$`_mpg`, y = .data$`_wt`)) + geom_point()
```



Another approach if you are using `%>%` , the `.data` pronoun as part of the `tidyverse` will allow you to pass the quoted name as a the argument by putting it in double square brackets (e.g., `[[]]`)

To see how single or double brackets work on a data frame, both are applied below to the `mtcars2` data frame containing the new variables.

```
mtcars2["_mpg"]
```

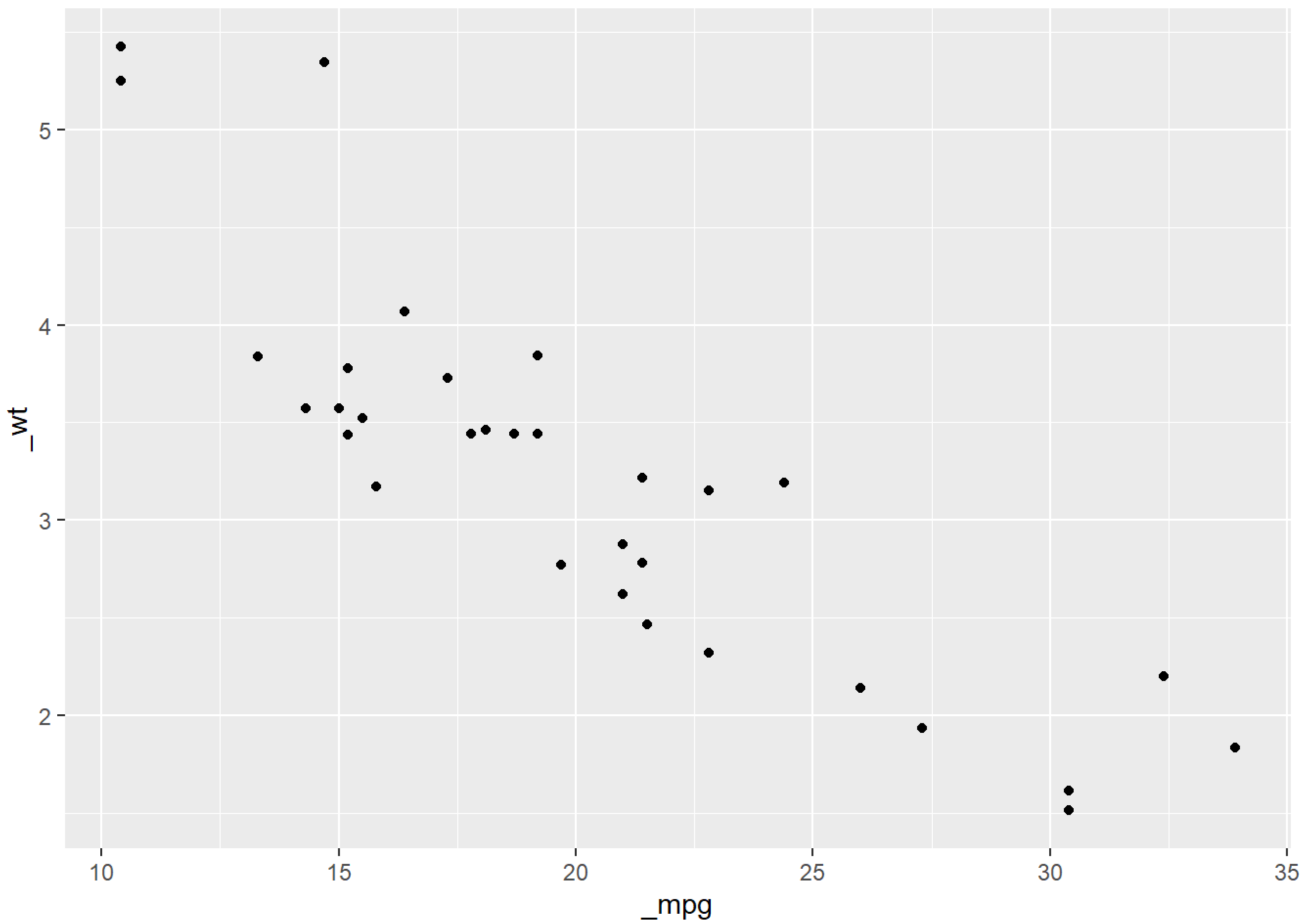
```
##                      _mpg
## Mazda RX4            21.0
## Mazda RX4 Wag        21.0
## Datsun 710           22.8
## Hornet 4 Drive       21.4
## Hornet Sportabout    18.7
## Valiant              18.1
## Duster 360           14.3
## Merc 240D            24.4
## Merc 230             22.8
## Merc 280             19.2
## Merc 280C            17.8
## Merc 450SE           16.4
## Merc 450SL           17.3
## Merc 450SLC          15.2
## Cadillac Fleetwood   10.4
## Lincoln Continental  10.4
## Chrysler Imperial    14.7
## Fiat 128             32.4
## Honda Civic          30.4
## Toyota Corolla       33.9
## Toyota Corona        21.5
## Dodge Challenger     15.5
## AMC Javelin          15.2
## Camaro Z28           13.3
## Pontiac Firebird     19.2
## Fiat X1-9            27.3
## Porsche 914-2        26.0
## Lotus Europa         30.4
## Ford Pantera L       15.8
## Ferrari Dino         19.7
## Maserati Bora        15.0
## Volvo 142E           21.4
```

```
mtcars2[["_mpg"]]
```

```
##  [1] 21.0 21.0 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 17.8 16.4 17.3 15.2 10.4
## [16] 10.4 14.7 32.4 30.4 33.9 21.5 15.5 15.2 13.3 19.2 27.3 26.0 30.4 15.8 19.7
## [31] 15.0 21.4
```

OK, and for `ggplot2` …

```
mtcars2 %>%
    ggplot(.,
       aes(x = .data[["_mpg"]], y = .data[["_wt"]])) + geom_point()
```



Note: You could use `.` instead of `.data` to represent the data frame being passed but that is discouraged and may be deprecated (no longer work).

As a general tip when cleaning up variable names, change variables so that they don't contain characters like "-" or "$" or others that don't work kindly with some functions. Using "_" is fine except when putting that at the beginning or end of variable name.

Setting Themes for Plot Consistency

Although you can modify the plot theme by adding it as a layer, doing so may be redundant when you do not wish to accept the default theme. Rather that add a theme layer to your plot using `theme_minimal()` , `theme_classic()` , or some other theme, you could set the theme at the top of your code file using `theme_set()` . Then, all plots in the file will adhere to that theme unless you add a layer to change it.

To set the theme to `theme_minimal()` , pass that theme into `theme_set()` . We will often use a theme from the `see` library, `see::theme_modern()` . If set here, all plots after, and only after, setting the theme will abide by those theme characteristics.

```
theme_set(theme_minimal())

#theme_set(see::theme_modern())
```