Getting started with ggplot2

STAT 133

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`github.com/ucb-stat133/stat133-fall-2016`

ggplot2

Resources for "ggplot2"

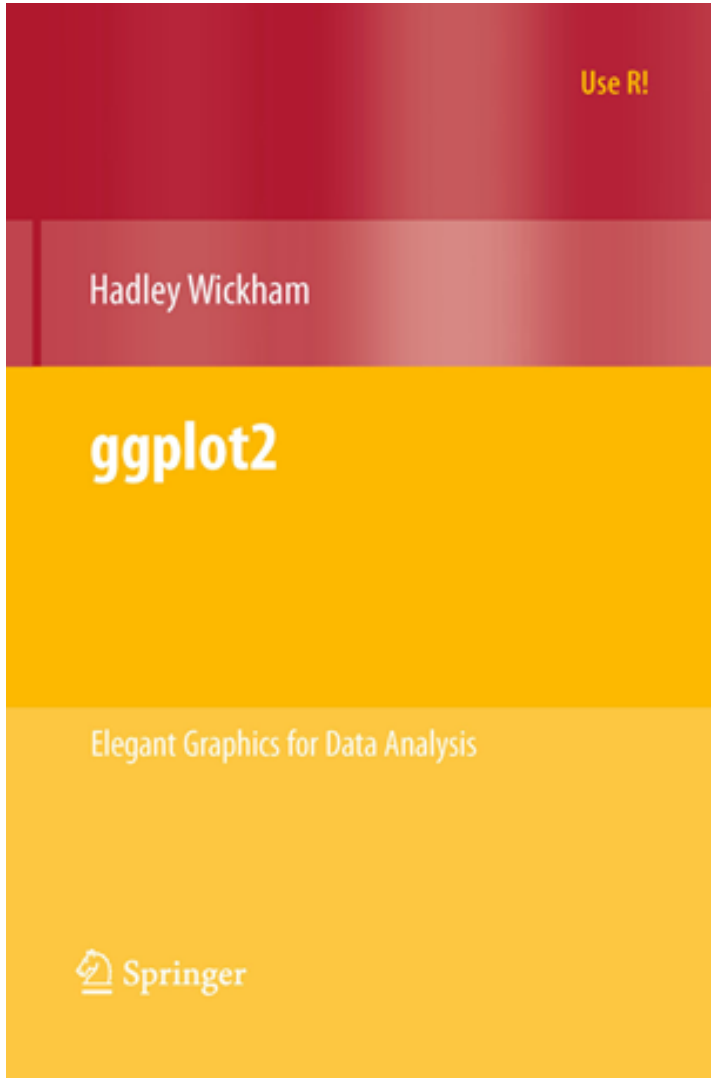
- Documentation: http://docs.ggplot2.org/
- Book: **ggplot2: Elegant Graphics for Data Analysis** (by Hadley Wickham)
- Book: **R Graphics Cookbook** (by Winston Chang)
- RStudio ggplot2 cheat sheet

  https://www.rstudio.com/wp-content/uploads/2015/03/ggplot2-cheatsheet.pdf

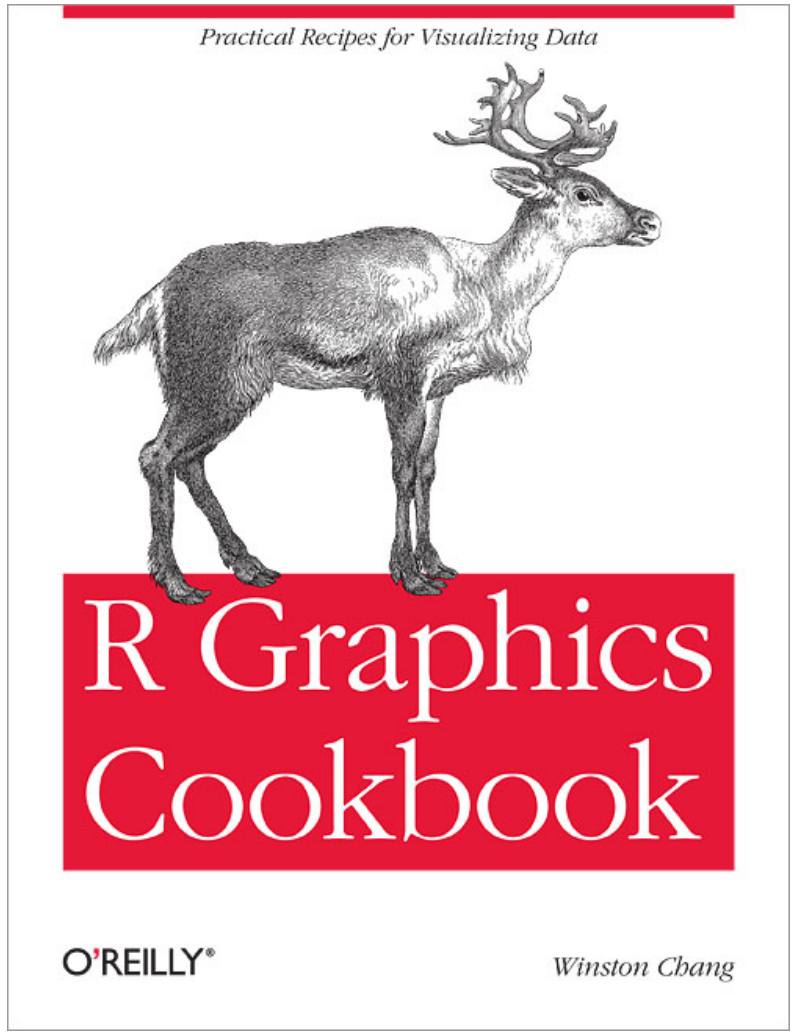
package "ggplot2"

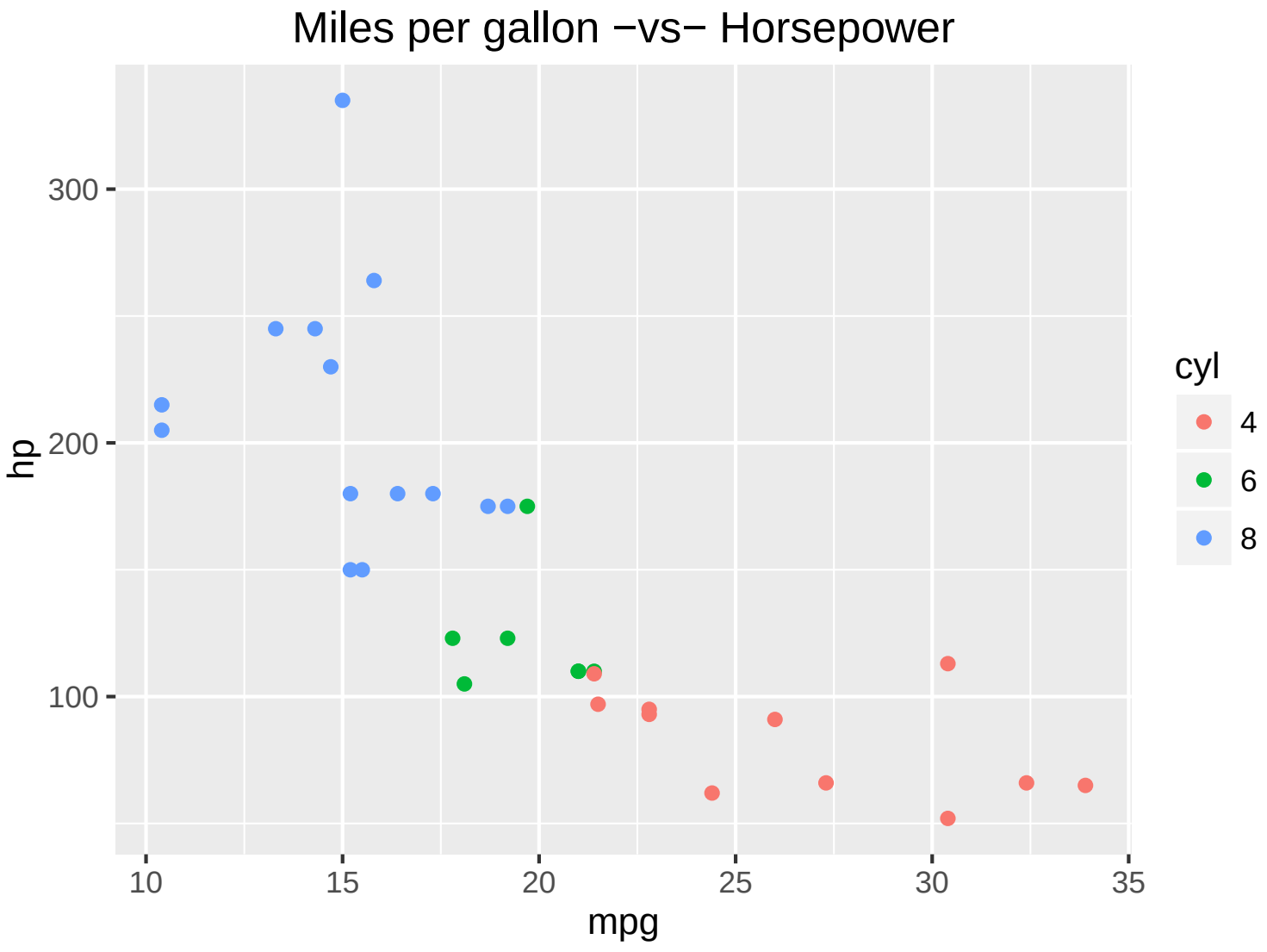
```r
# remember to install ggplot2
# (just once)
install.packages("ggplot2")


# load ggplot2
library(ggplot2)


# see basic documentation
?ggplot
```

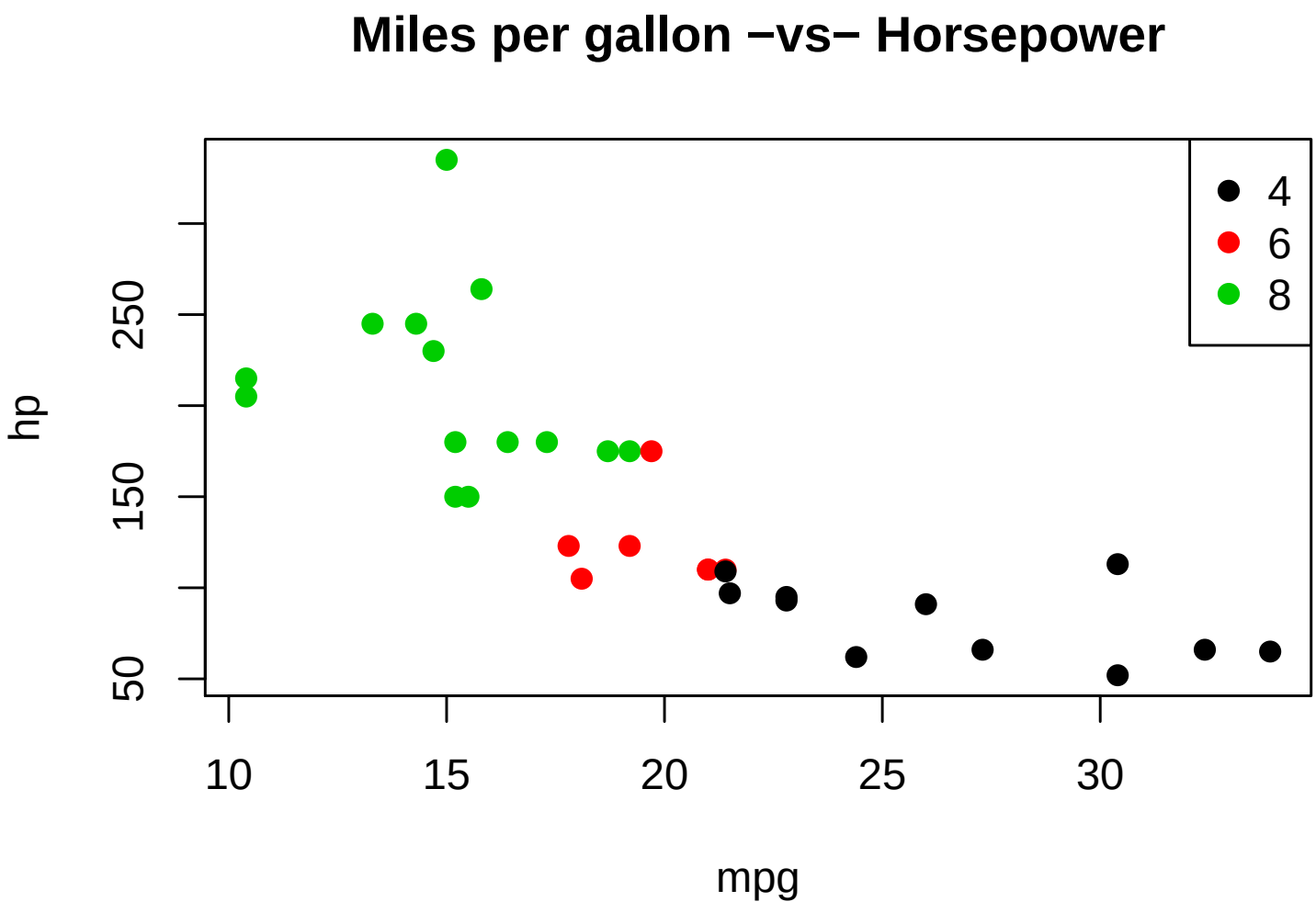
ggplot2 book



R Graphics Cookbook



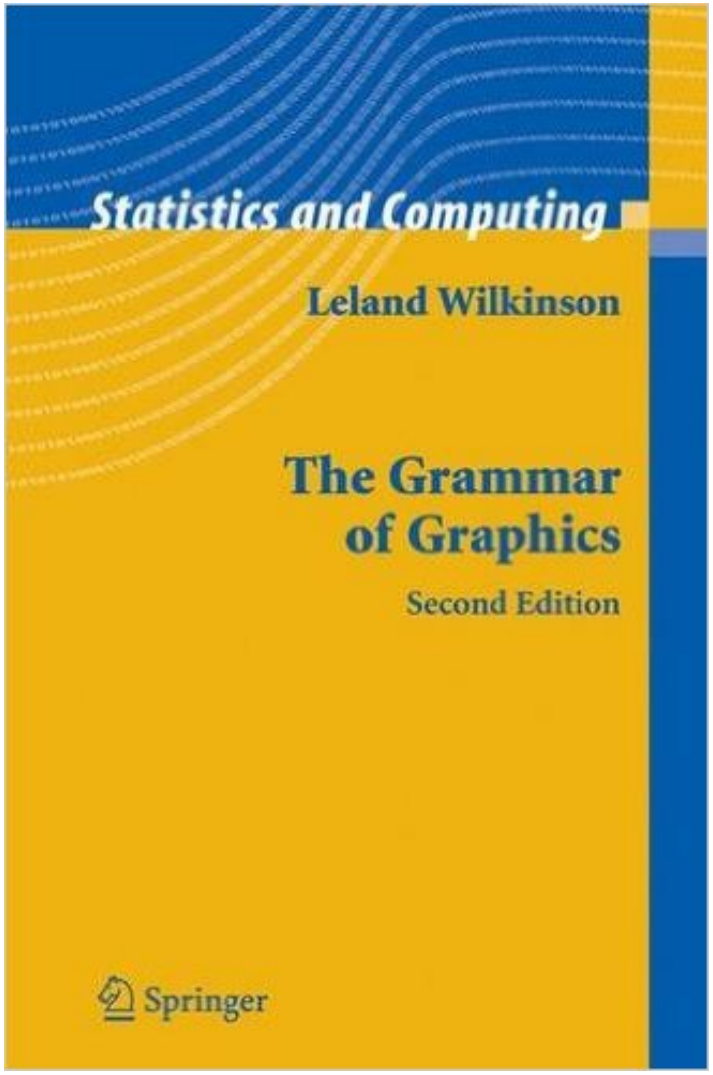

Miles per gallon −vs− Horsepower
hp
300
200
100
10
15
20
25
30
35
mpg
cyl
4
6
8


Miles per gallon −vs− Horsepower
hp
50
150
250
10
15
20
25
30
mpg
4
6
8

About "ggplot2"

- "ggplot2" (by Hadley Wickham) is an R package for producing statistical graphics
- It provides a framework based on Leland Wilkinson's **Grammar of Graphics**
- "ggplot2" provides beautiful plots while taking care of fiddly details like legends, axes, colors, etc.
- "ggplot2" is built on the R graphics package "grid"
- Underlying philosophy is to describe a wide range of graphics with a compact syntax and independent components

The Grammar of Graphics



About the Grammar of Graphics

- *The Grammar of Graphics* is Wilkinson's attempt to define a theoretical framework for graphics
- **Grammar**: Formal system of rules for generating graphics
  - Some rules are mathematic
  - Some rules are aesthetic

About the Grammar of Graphics

3 Stages of Graphic Creation

- **Specification**: link data to graphic objects
- **Assembly**: put everything together
- **Display**: render of a graphic

About the Grammar of Graphics

Specification

Link data to graphic objects

- Data
- Transformation of variables (e.g. aggregation)
- Scale transformations (e.g. log)
- Coordinate system (e.g. cartesian)
- Graphic Elements (e.g. points, lines)
- Guides (e.g. labels, legends)

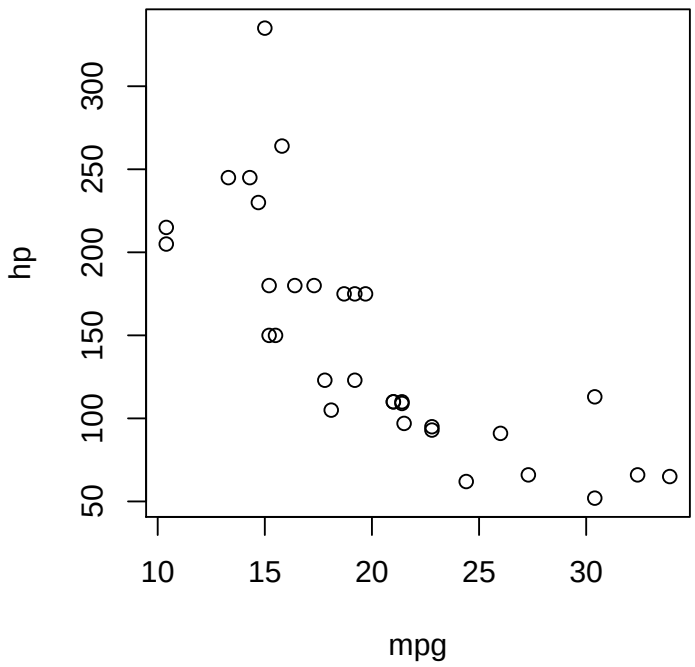
R package "ggplot2"

About "ggplot2"

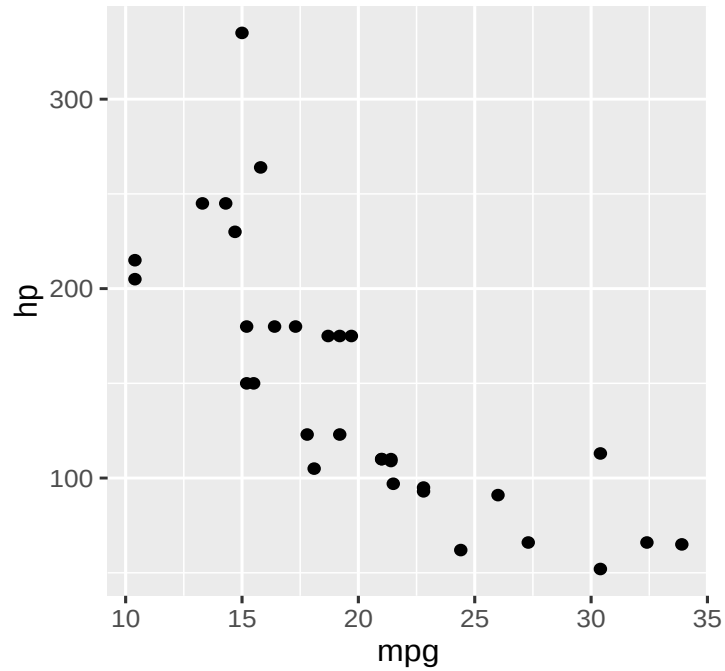
- Default appearance of plots carefully chosen
- Designed with visual perception in mind
- Inclusion of some components, like legends, are automated
- Great flexibility for annotating, editing, and embedding output

Base graphics -vs- "ggplot2"

base graphics



ggplot2



About "ggplot2"

- "ggplot2" is the name of the package
- The gg in "ggplot2" stands for *Grammar of Graphics*
- Inspired in the **Grammar of Graphics** by Lee Wilkinson
- "ggplot" is the class of objects (plots)
- ggplot() is the main function in "ggplot2"

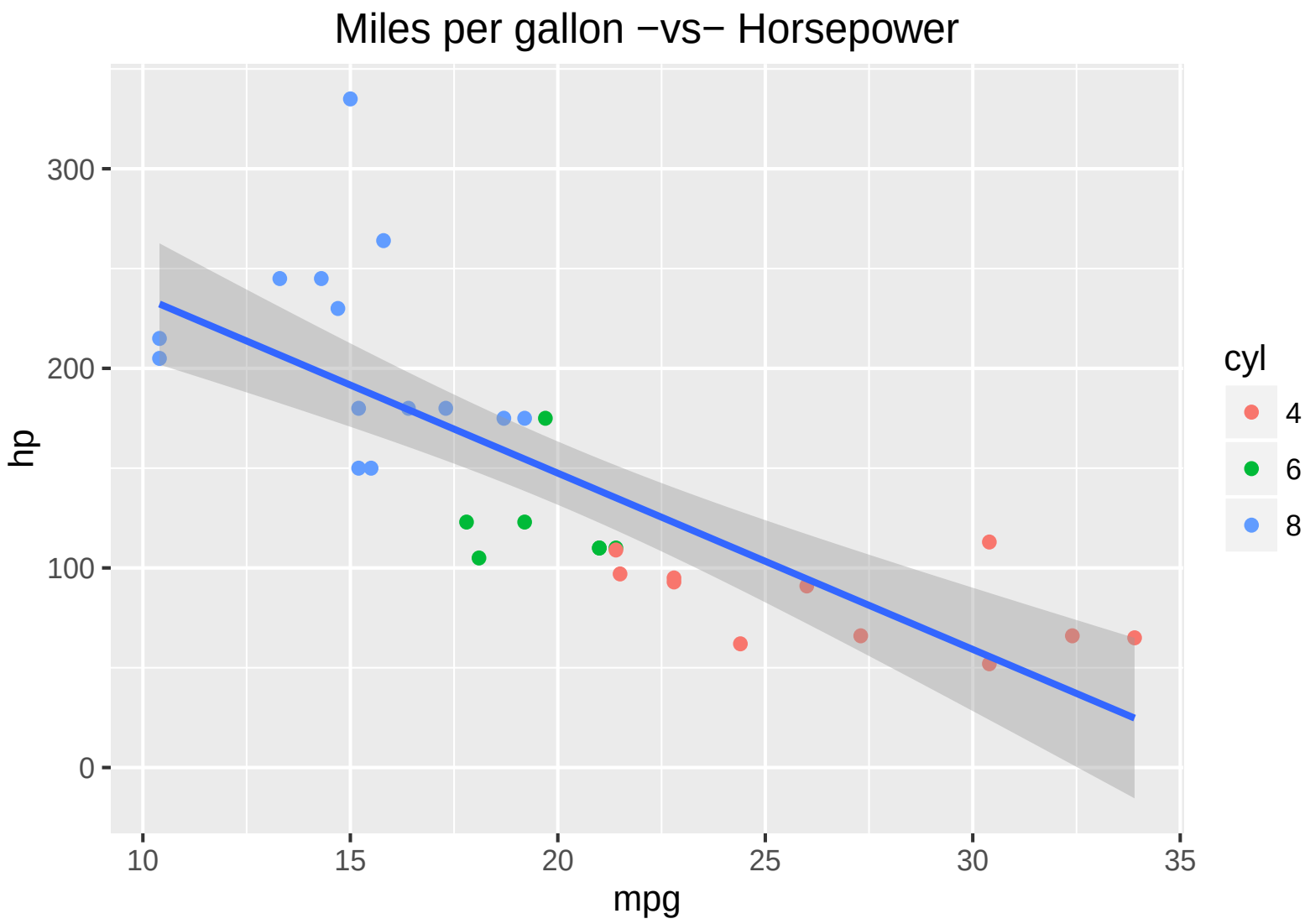
What is a Statistical Graphic?

Some Data set

```
mtcars
```

```
##                    mpg   hp  cyl
## Mazda RX4         21.0  110    6
## Mazda RX4 Wag     21.0  110    6
## Datsun 710        22.8   93    4
## Hornet 4 Drive    21.4  110    6
## Hornet Sportabout 18.7  175    8
## Valiant           18.1  105    6
## Duster 360        14.3  245    8
## Merc 240D         24.4   62    4
## Merc 230          22.8   95    4
## Merc 280          19.2  123    6
```

What is a statistical graphic?



What is a statistical graphic?

Elements to draw the chart "manually"

What is a statistical graphic?

Elements to draw the chart "manually"

- coordinate system
- x and y axis (intervals)
- axis tick marks
- axis labels, and title
- points (with colors)
- regression line (and ribbon)
- legend

What is a statistical graphic?

Simply put, a statistical graphic is:

- A mapping from data to aesthetic attributes (color, shape, size) of geometric objects (points, lines, bars)
- A plot may also contain statistical transformations of the data
- A plot is drawn on a specific coordinate system
- Sometimes faceting can be used to get the same plot for different subsets of the dataset

Starting with "ggplot2"

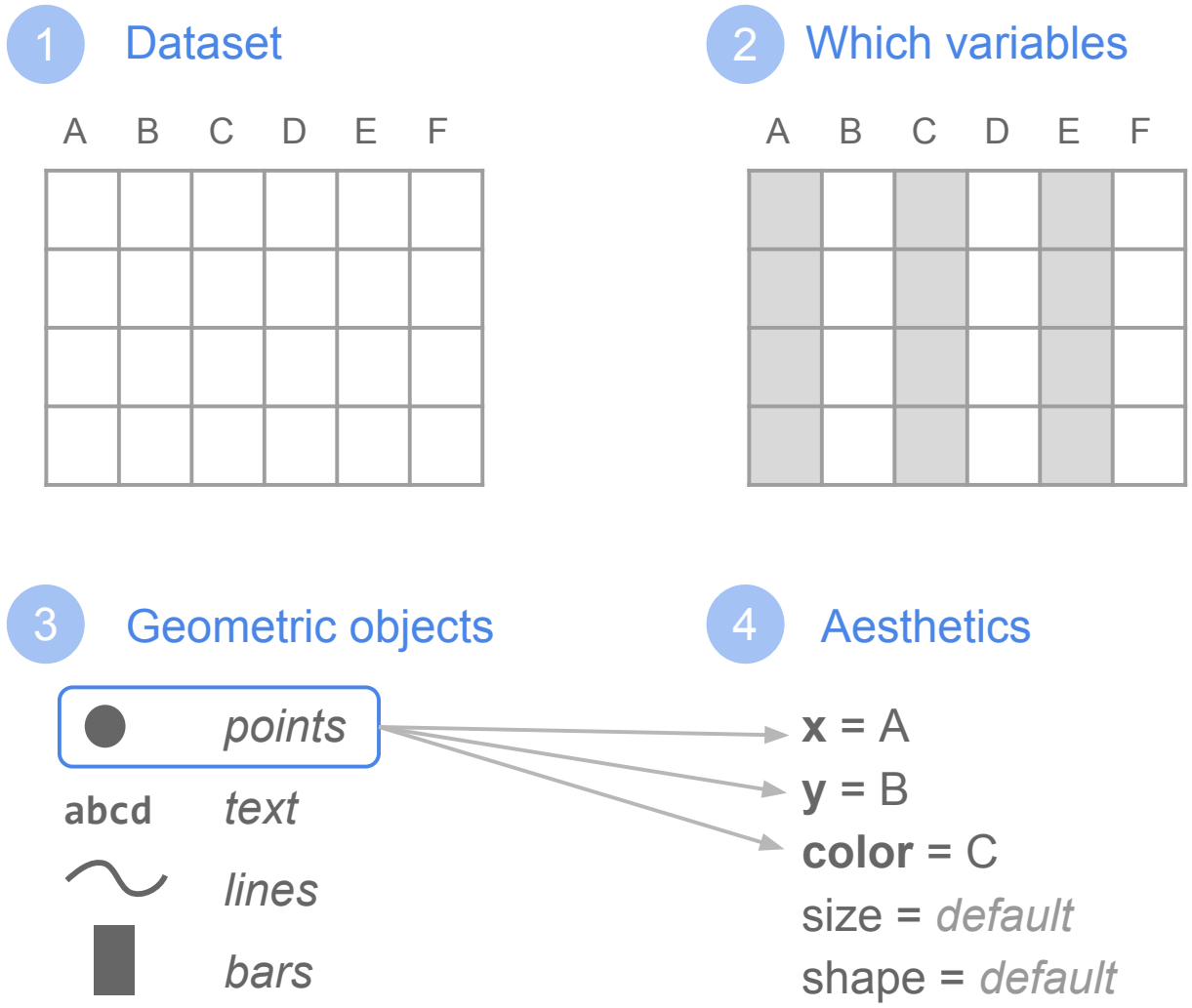
starwarstoy.csv

```
## Warning in file(file, "rt"):  cannot open file
'/Users/gaston/Documents/stat133/stat133/datasets/starwarstoy.csv':  No
such file or directory
## Error in file(file, "rt"):  cannot open the connection
## Error in eval(expr, envir, enclos):  object 'starwars' not found
```

Scatterplot

```
## Error in ggplot(data = starwars):  object 'starwars' not found
```

Main steps in creating ggplot graphics



Building a scatterplot

User specifications

- Dataset: `starwars`
- Variables: `height`, `weight`, `jedi`
- Geoms: points
- Aesthetics (attributes):
  - **x**: `height`
  - **y**: `weight`
  - **color**: `jedi`

Scatterplot with "ggplot2"

```
ggplot(data = starwars) +
  geom_point(aes(x = height, y = weight, color = jedi))
```

Scatterplot with "ggplot2"

```
ggplot(data = starwars) +
  geom_point(aes(x = height, y = weight, color = jedi))
```

- `ggplot()` initializes a "ggplot" object
- specify the dataset with `data`
- type of geometric object: `geom_point()`
- mapping aesthetic attributes to variables with `aes()`
  - x-position: `height`
  - y-position: `weight`
  - color: `jedi`

Scatterplot with "ggplot2"

```
ggplot(data = starwars) +
  geom_point(aes(x = height, y = weight, color = jedi))


## Error in ggplot(data = starwars):  object 'starwars' not found
```

Scatterplot with "ggplot2"

Automated things in "ggplot2"

- Axis labels
- Legends (position, labels, symbols)
- Choose of colors for points
- Background color (e.g. gray)
- Grid lines (major and minor)
- Axis tick marks

you can always change the automated elements

"ggplot2" graphics

Philosophy of "ggplot2"

A graphic is a **mapping** from **data** to **aesthetic attributes** (color, shape, size) of **geometric objects** (points, lines, bars)

Scatterplot with "ggplot2"

```
ggplot(data = starwars) +
  geom_point(aes(x = height, y = weight, color = jedi))


## Error in ggplot(data = starwars):  object 'starwars' not found
```

Mapping

data values

height	weight	jedi
1.72	77	jedi
1.50	49	no_jedi
1.82	77	jedi
1.80	80	no_jedi
0.96	32	no_jedi
1.67	75	no_jedi
0.66	17	jedi
2.28	112	no_jedi

mapping

aesthetic attributes

x	y	color
x_1	y_1	#F8766D
x_2	y_2	#00BFC4
x_3	y_3	#F8766D
x_4	y_4	#00BFC4
x_5	y_5	#00BFC4
x_6	y_6	#00BFC4
x_7	y_7	#F8766D
x_8	y_8	#00BFC4

"ggplot2" graphics

Philosophy of "ggplot2"

A graphic is a **mapping** from **data** to **aesthetic attributes** (color, shape, size) of **geometric objects** (points, lines, bars)

- `ggplot(data, ...)`
- `aes()`
- `geom_objects()`

Scatterplot with "ggplot2"

How does "ggplot2" work?

- plots are created piece-by-piece
- plot components added with + operator
- aesthetic attributes mapped to data values
- computation of scales for aesthetic attributes

How does it work?

Usually, we specify the data and variables inside the function `ggplot()`

```
ggplot(data = mtcars, aes(x = mpg, y = hp))
```

Note the use of the internal function `aes()` to *map* `x` to `mpg`, and `y` to `hp`.

Then we **add a layer** of geometric objects: points in this case

```
+ geom_point()
```

Some alternative options

```
# option A
ggplot(data = starwars,
       aes(x = height, y = weight, color = jedi)) +
  geom_point()
```

Some alternative options

```
# option A
ggplot(data = starwars,
       aes(x = height, y = weight, color = jedi)) +
  geom_point()
```

```
# option B
ggplot(data = starwars) +
  geom_point(aes(x = height, y = weight, color = jedi))
```

Some alternative options

```
# option A
ggplot(data = starwars,
       aes(x = height, y = weight, color = jedi)) +
  geom_point()
```

```
# option B
ggplot(data = starwars) +
  geom_point(aes(x = height, y = weight, color = jedi))
```

```
# option C
ggplot() +
  geom_point(data = starwars,
             aes(x = height, y = weight, color = jedi))
```

Main inquiries

Always ask yourself ...

- What is the **data** set of interest?
- What **variables** will be used to make the plot?
- What **graphics shapes** will be used to display?
- What **features** of the shapes will be used to represent the data values?

"ggplot2" basics

- The data must be in a `data.frame`
- Variables are mapped to aesthetic attributes
- Aesthetic attributes belong to geometric objects **geoms** (points, lines, polygons)

Basic Terminology

- **ggplot()** - The main function where you specify the dataset and variables to plot
- **geoms** - geometric objetcs
  - `geom_point()`, `geom_bar()`, `geom_line()`, `geom_density()`
- **aes** - aesthetics (i.e. attributes)
  - shape, color, fill, linetype

Warning

`"ggplot2"` comes with the function `qplot()` (i.e. *quick plot*). Avoid using it!

As Karthik Ram says: "you'll end up unlearning and relearning a good bit"

Scatterplot with "ggplot2"

Terminology

- aesthetic mappings
- geometric objects
- statistical transformations
- scales
- non-data elements (themes & elements)
- facets

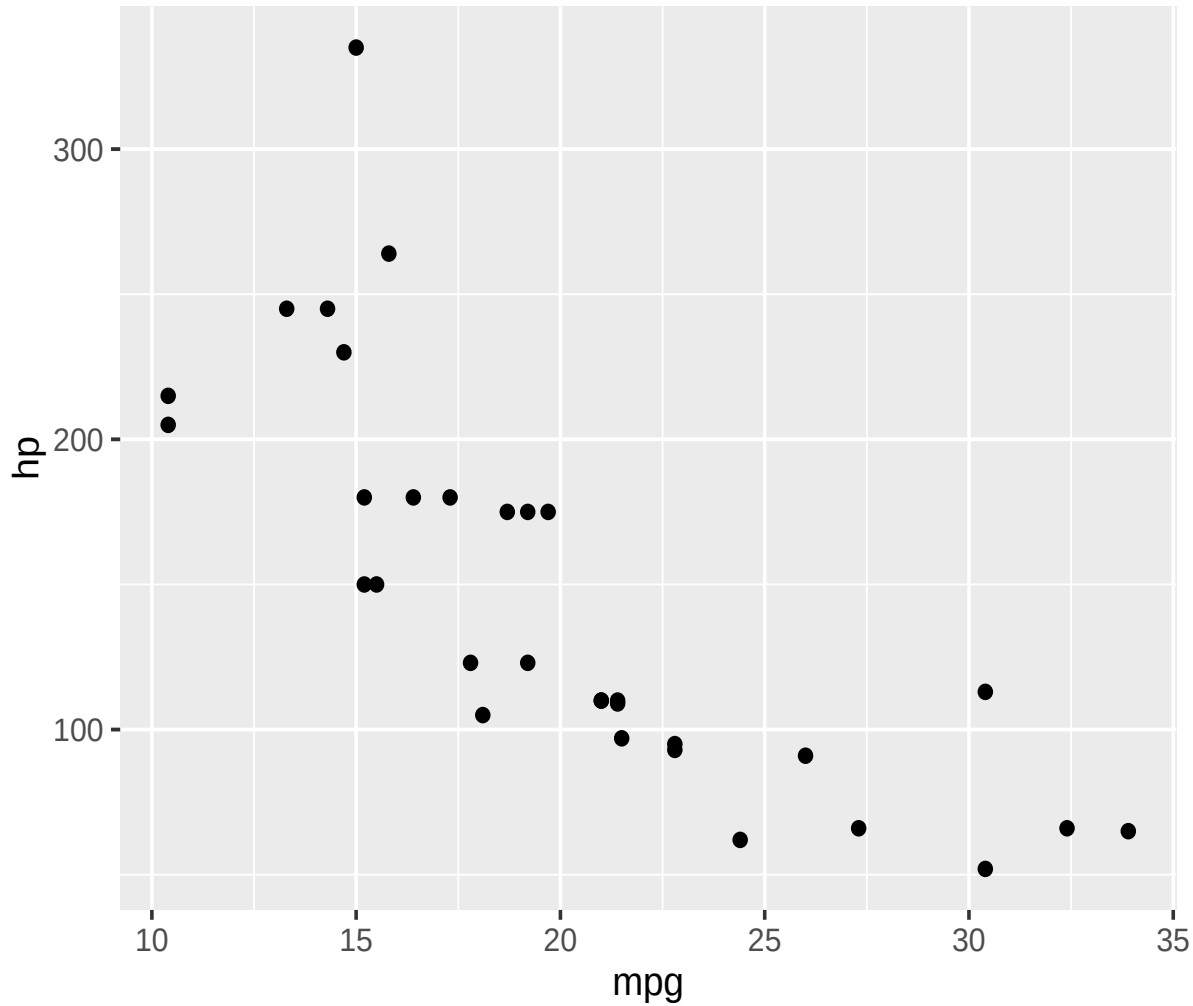
Considerations

Specifying graphical elements from 3 sources:

- The data values (represented by the geometric objects)
- The scales and coordinate system (axes, legends)
- Plot annotations (background, title, grid lines)

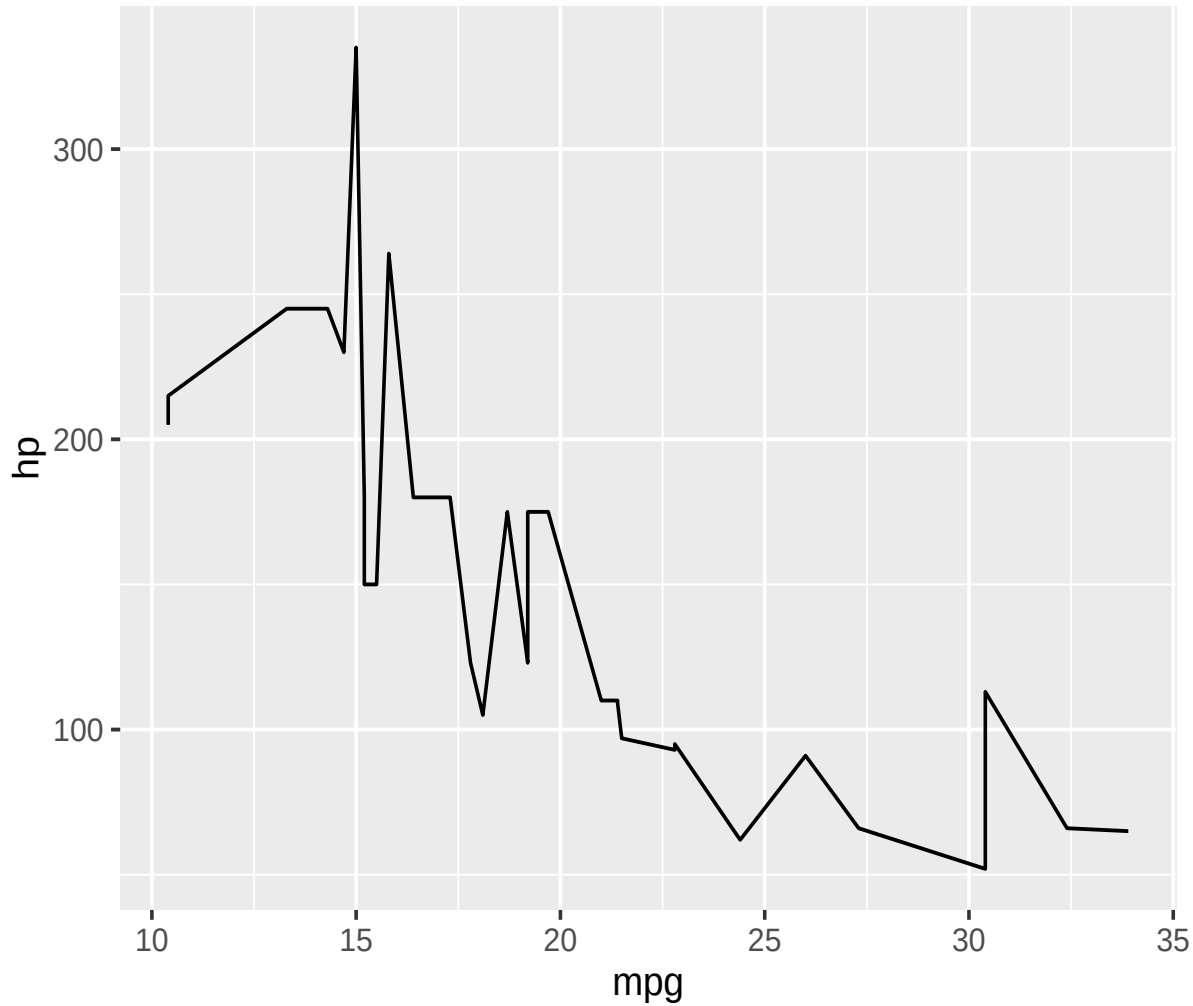
Scatterplot with geom_point

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point()
```



Another geom

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_line()
```



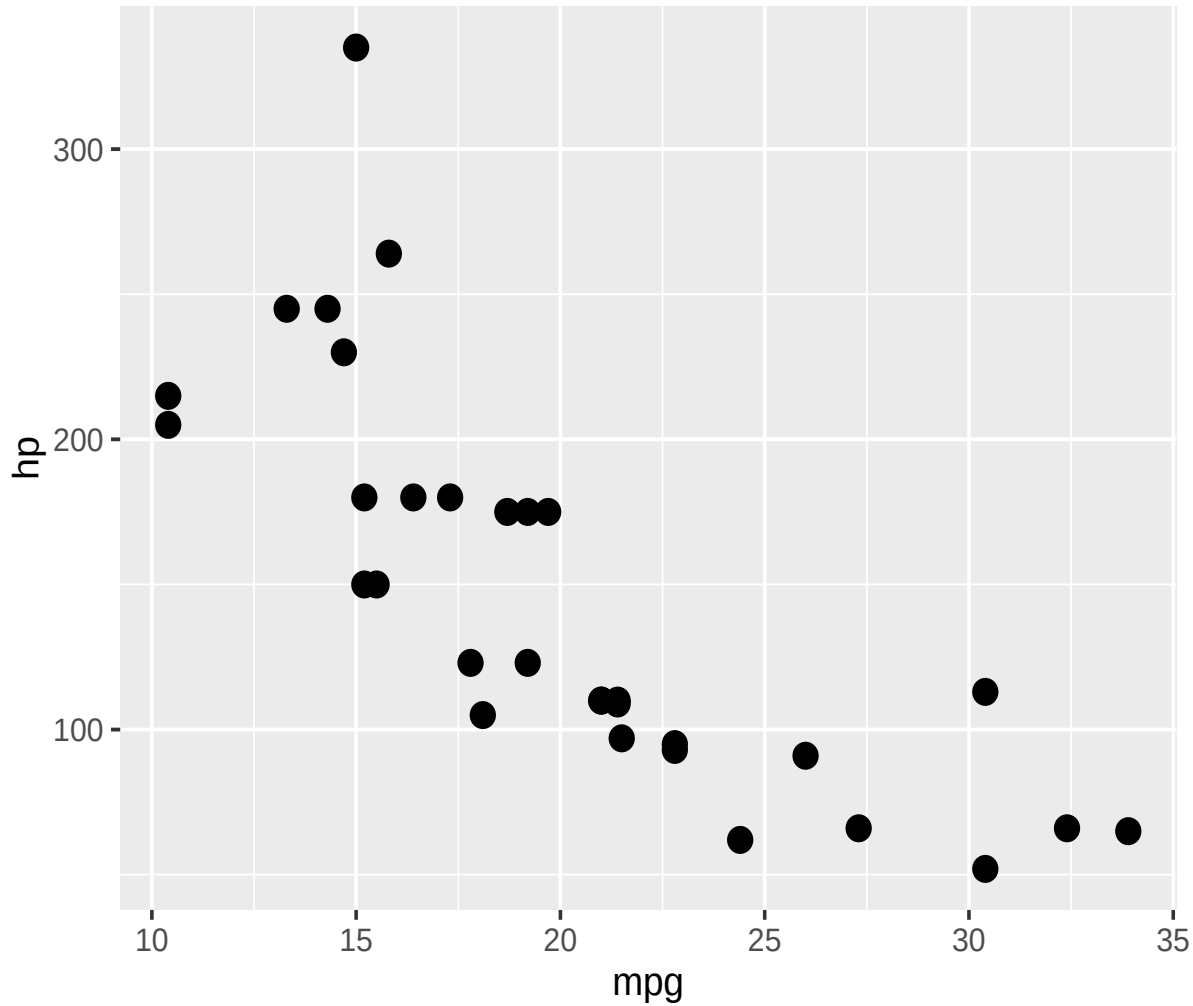
Mapping Attributes

-vs-

Setting Attributes

Increase size of points

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(size = 3)
```



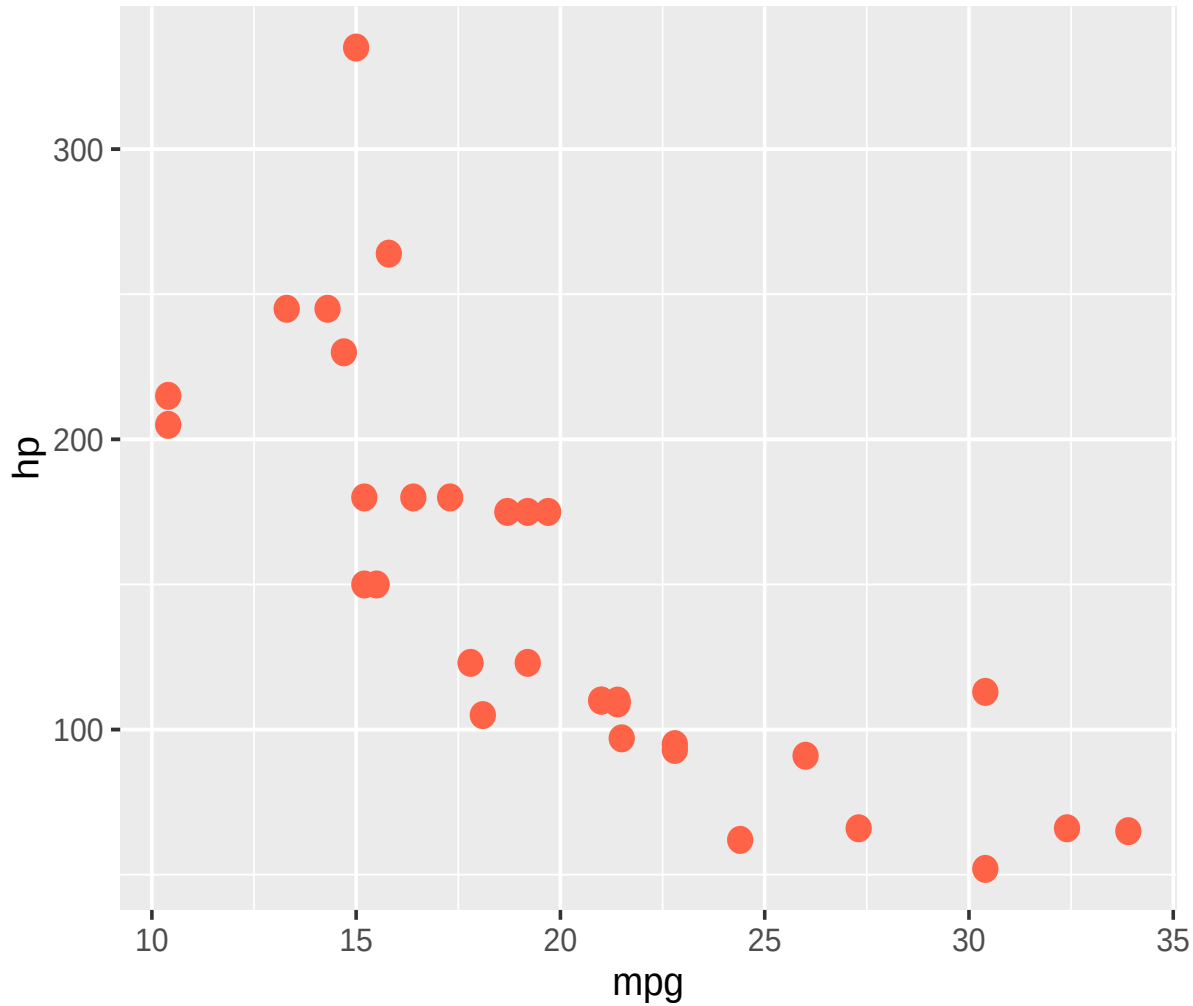
How does it work?

To increase the size of points, we **set** the aesthetic `size` to a constant value of 3 (inside the *geoms* function):

```
+ geom_point(size = 3)
```

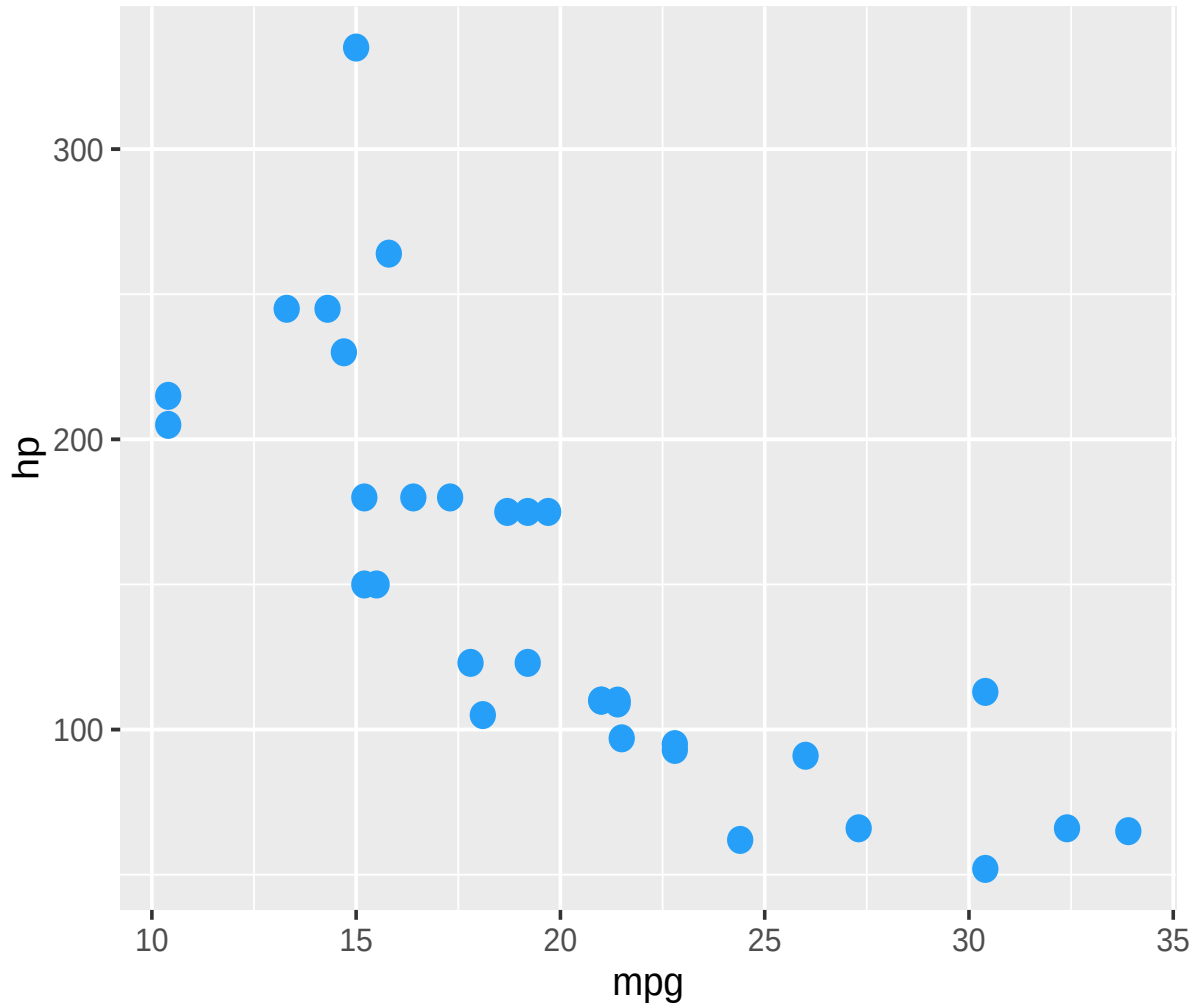
Adding color

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(size = 3, color = "tomato")
```



Adding color

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(size = 3, color = "#259ff8")
```



Test your knowledge

Identify the valid hex-color

A) `"345677"`

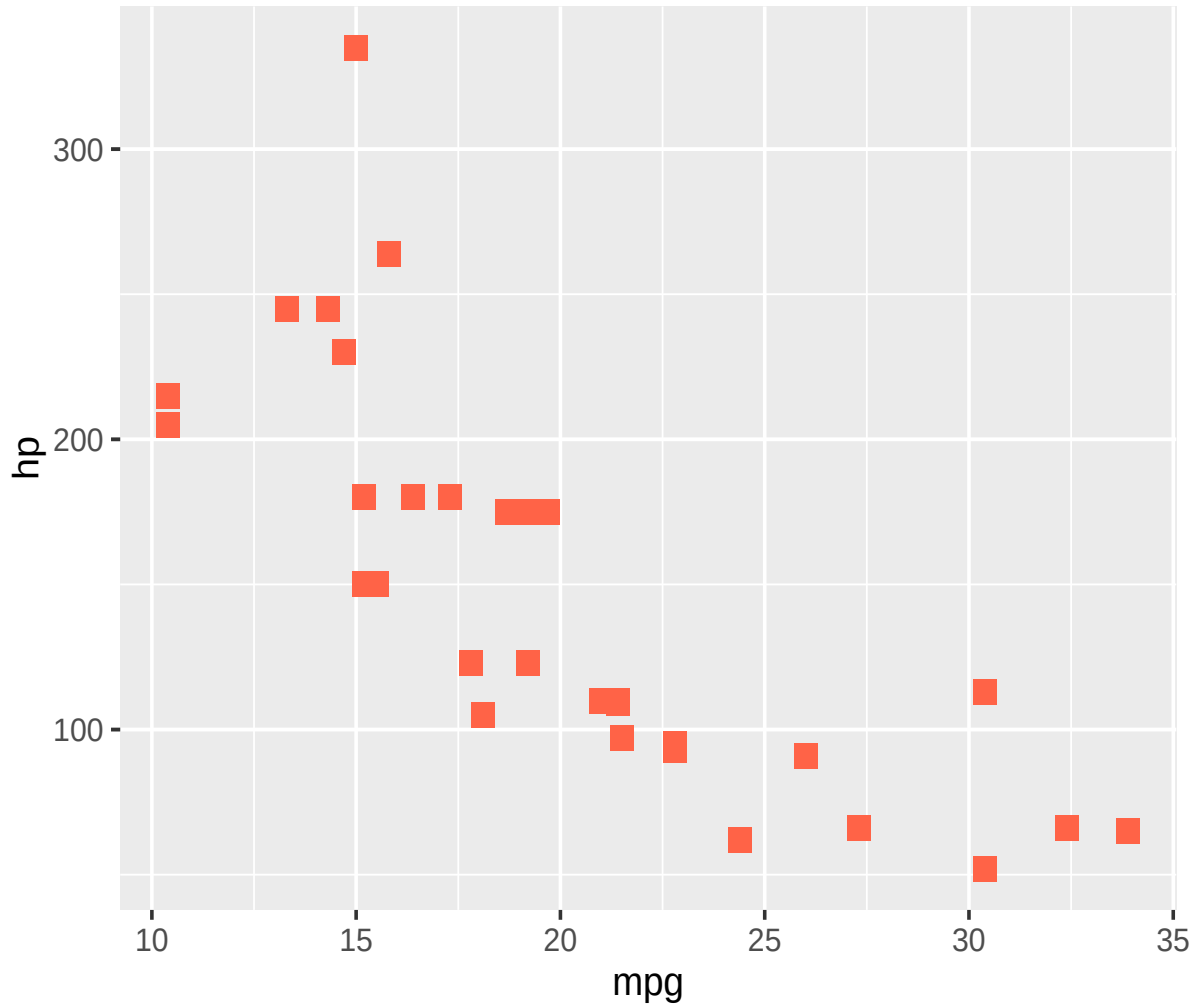
B) `"#1234567"`

C) `"#AAAAAA"`

D) `"#GG0033"`

Changing points shape

```
# 'shape' accepts 'pch' values
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(size = 3, color = "tomato", shape = 15)
```



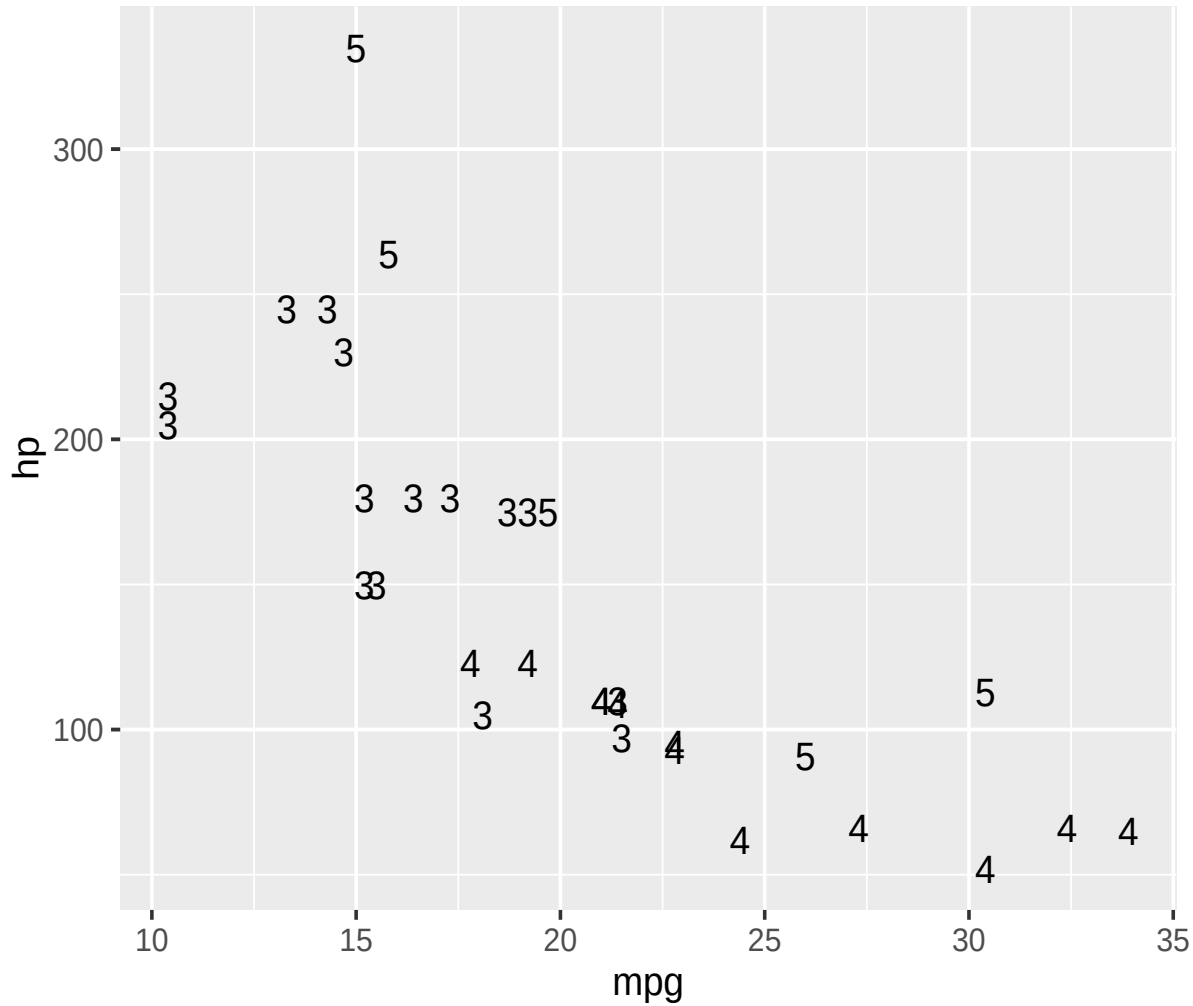
Setting and Mapping

Aesthetic attributes can be either **mapped** —via `aes()`— or **set**

```
# mapping aesthetic color
ggplot(mtcars, aes(x = mpg, y = hp)) +
  geom_point(aes(color = cyl))

# setting aesthetic color
ggplot(mtcars, aes(x = mpg, y = hp)) +
  geom_point(color = "blue")
```

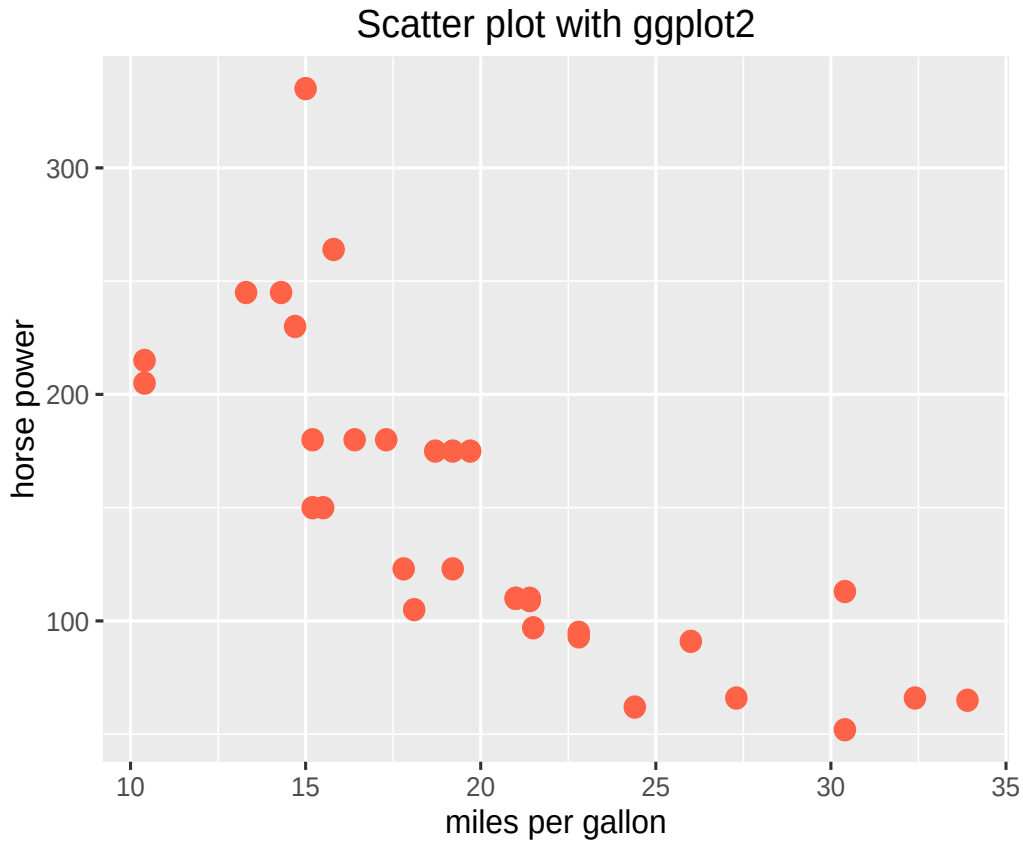
Geom text, and mapping labels

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_text(aes(label = gear))
```



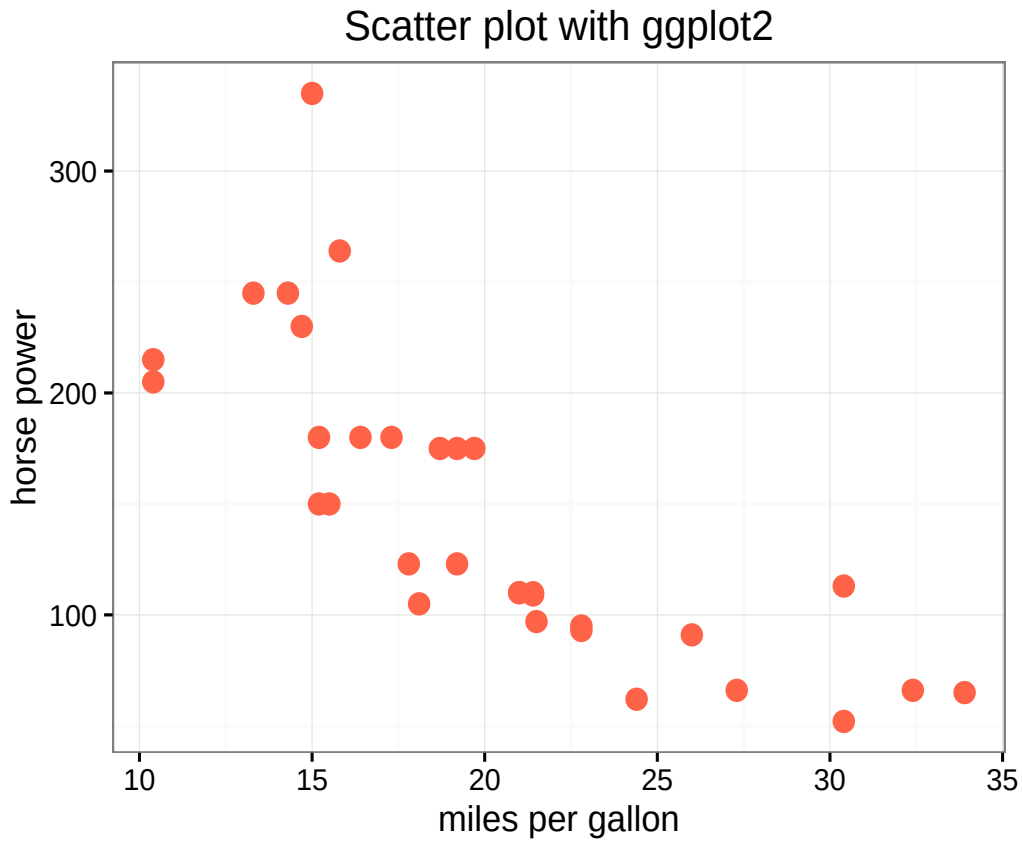
Changing axis labels and title

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(size = 3, color = "tomato") +
  xlab("miles per gallon") +
  ylab("horse power") +
  ggtitle("Scatter plot with ggplot2")
```

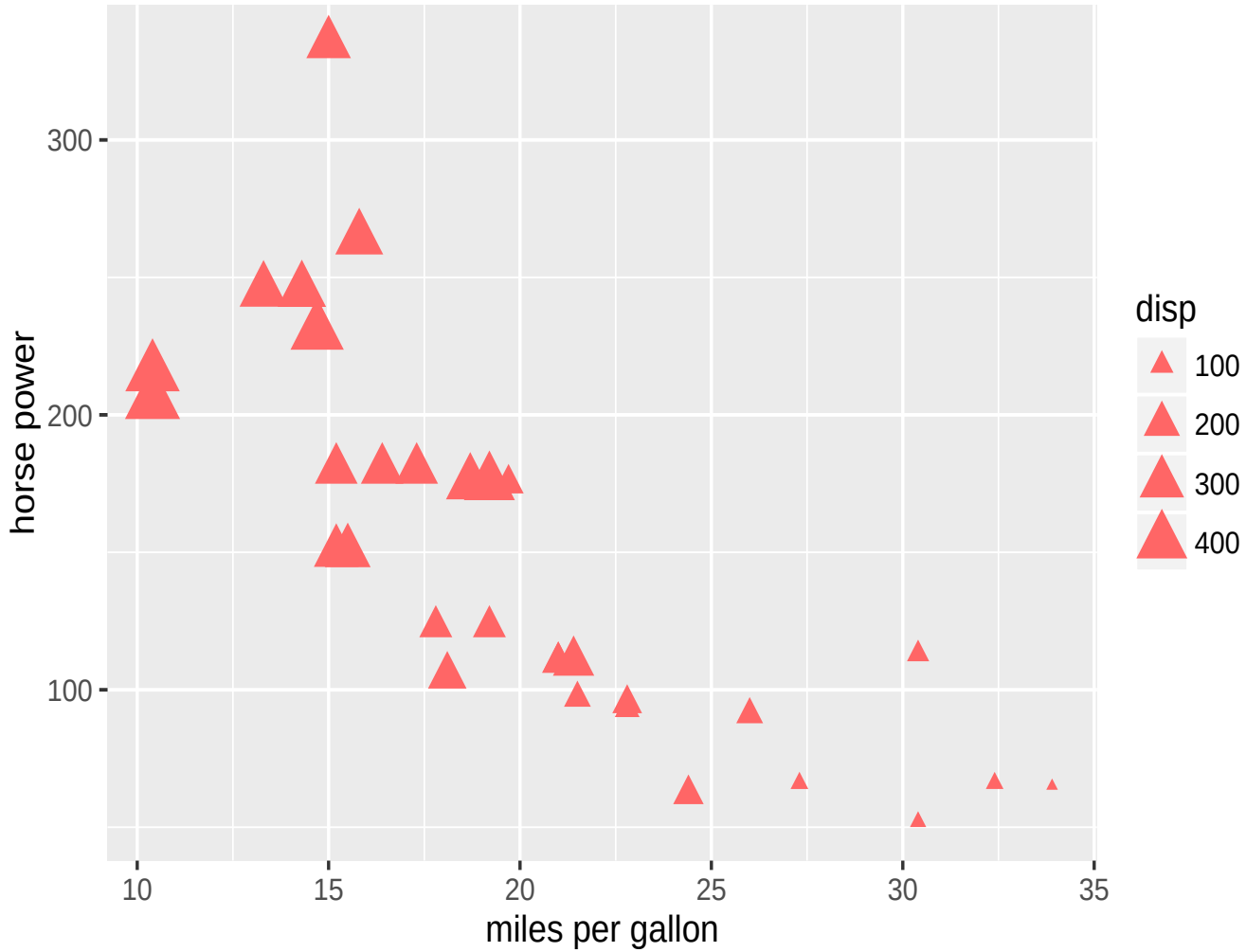


Changing background theme

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(size = 3, color = "tomato") +
  xlab("miles per gallon") +
  ylab("horse power") +
  ggtitle("Scatter plot with ggplot2") +
  theme_bw()
```



Your turn: Replicate this figure



Your turn: Replicate this figure

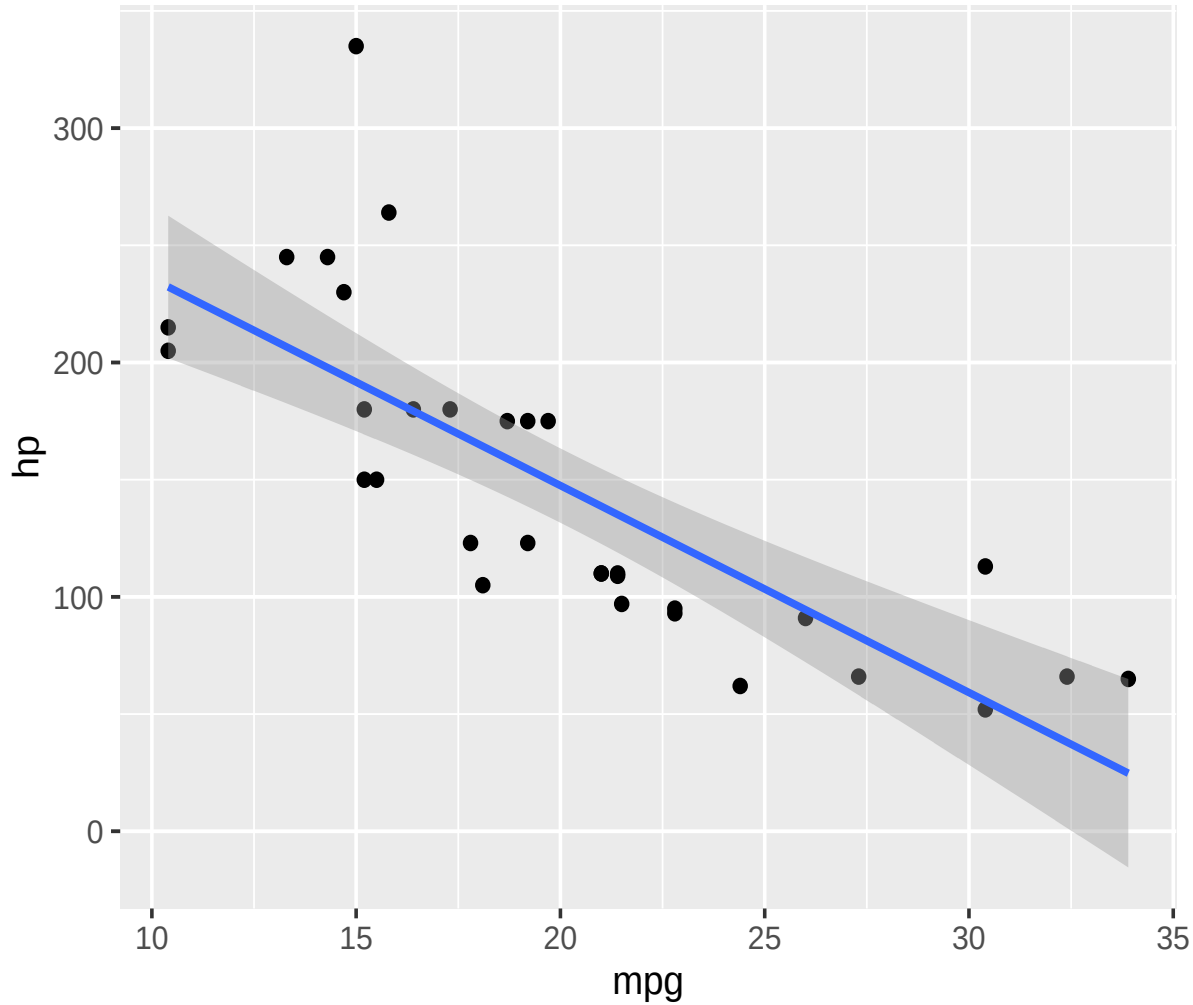
- Specify a color in hex notation
- Change the shape of the point symbol
- Map `disp` to attribute size of points
- Add axis labels

Your turn

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(aes(size = disp),
             color = "#ff6666", shape = 17) +
  xlab("miles per gallon") +
  ylab("horse power")
```

More geoms

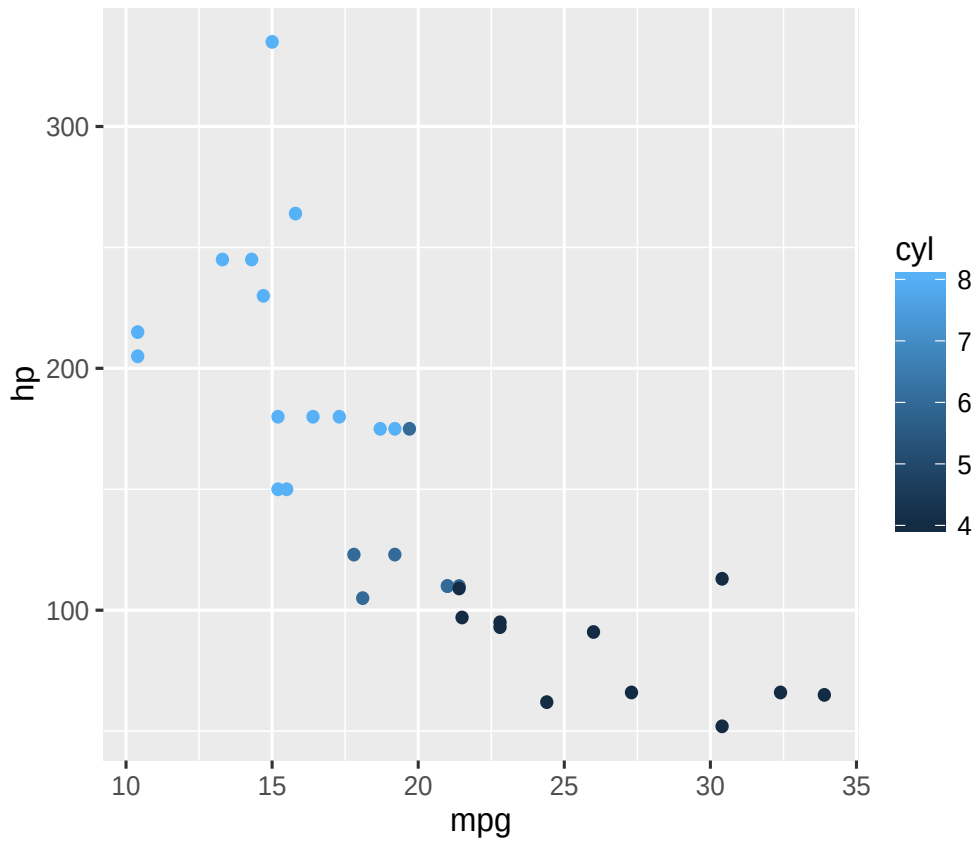
```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point() +
  geom_smooth(method = "lm")
```



More geoms

We can map variable to a color aesthetic. Here we map `color` to `cyl` (cylinders)

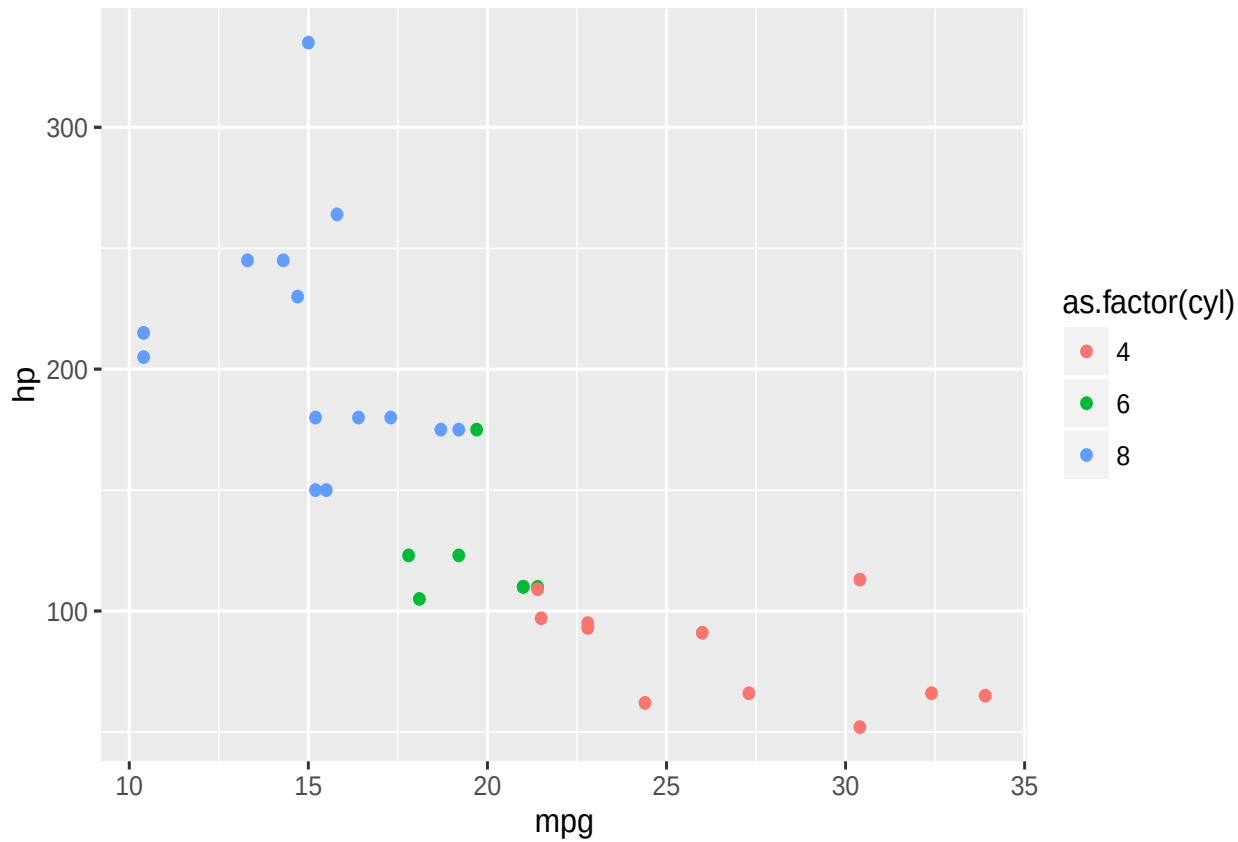
```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(aes(color = cyl))
```



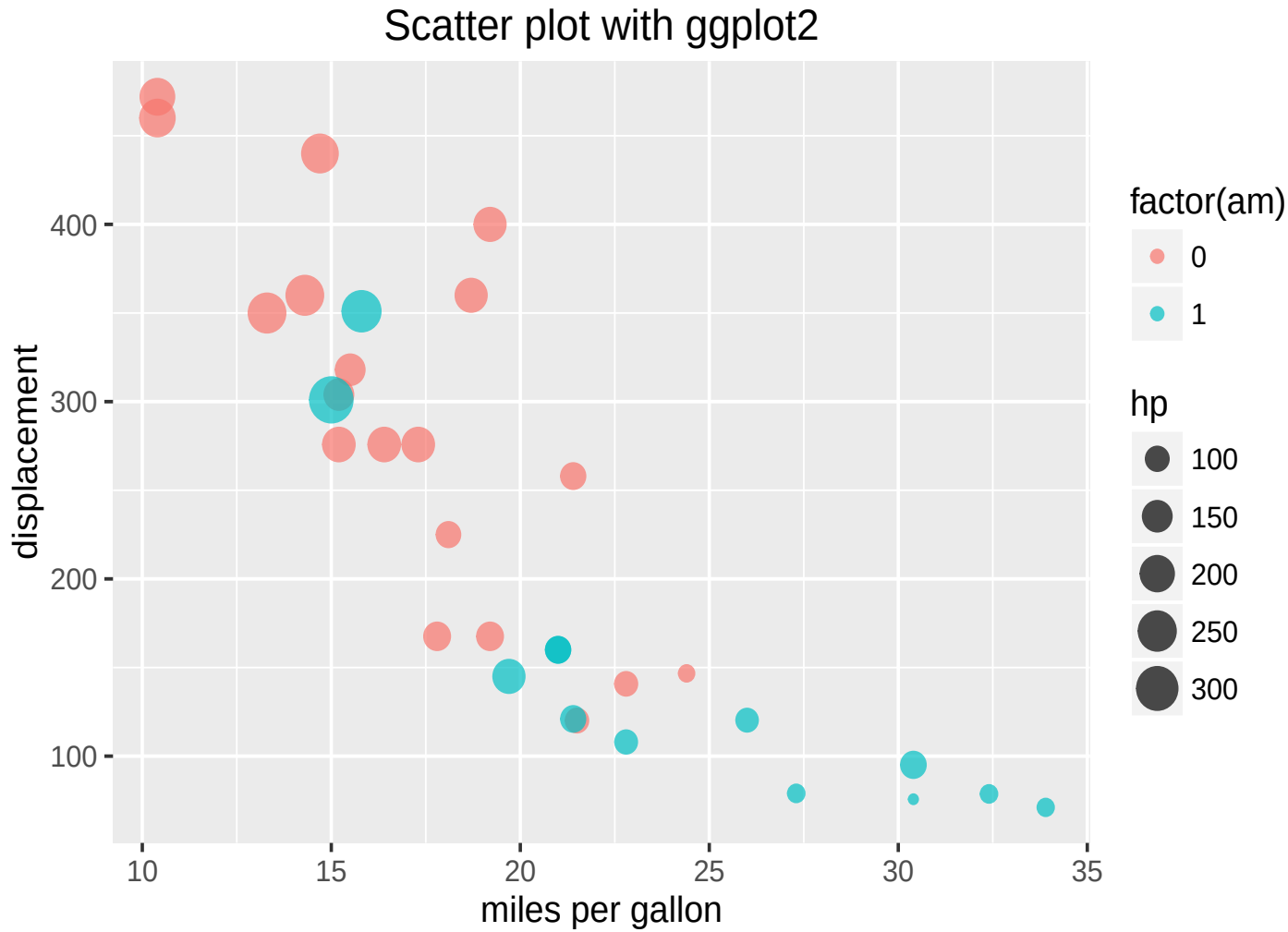
More geoms

If the variable that maps to color is a factor, then the color scale will change

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



Your turn: Replicate this figure



Your turn: example 2

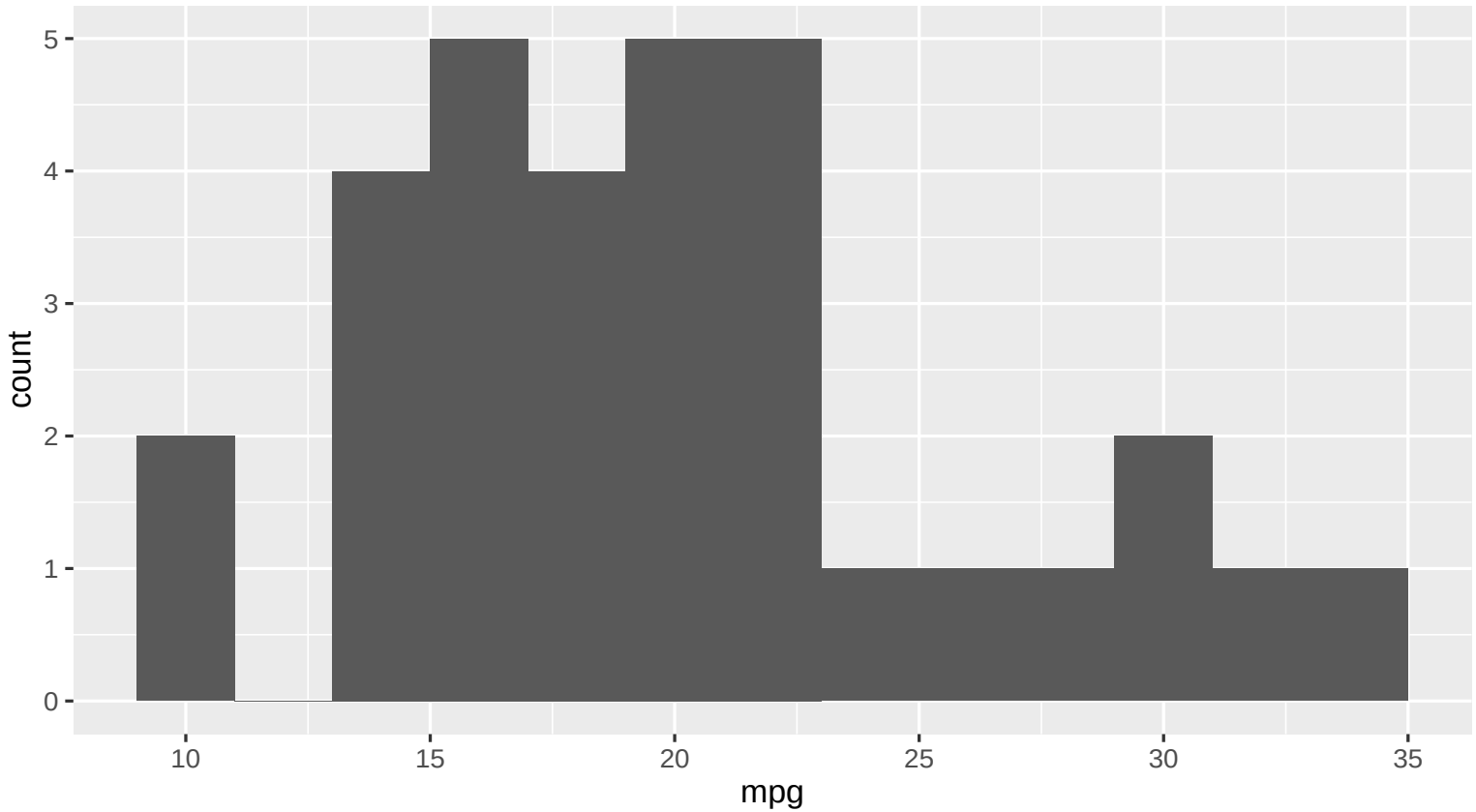
- Map `hp` to attribute size of points
- Map `am` (as factor) to attribute color points
- Add an alpha transparency of 0.7
- Change the shape of the point symbol
- Add axis labels
- Add a title

Your turn: example 2

```
ggplot(data = mtcars, aes(x = mpg, y = disp)) +
  geom_point(aes(size = hp, color = factor(am)),
             alpha = 0.7) +
  xlab("miles per gallon") +
  ylab("displacement") +
  ggtitle("Scatter plot with ggplot2")
```

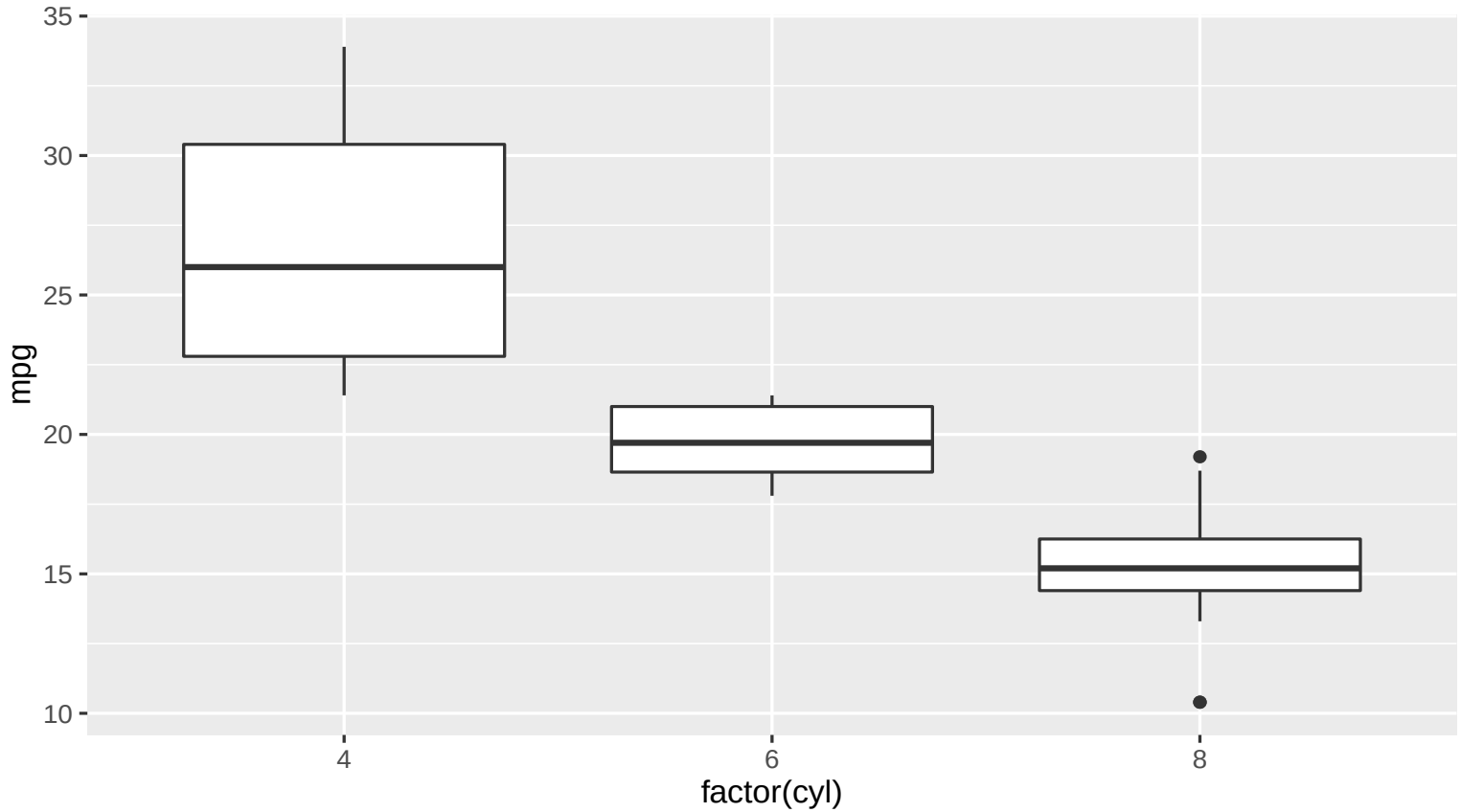
Histogram

```
ggplot(data = mtcars, aes(x = mpg)) +
  geom_histogram(binwidth = 2)
```



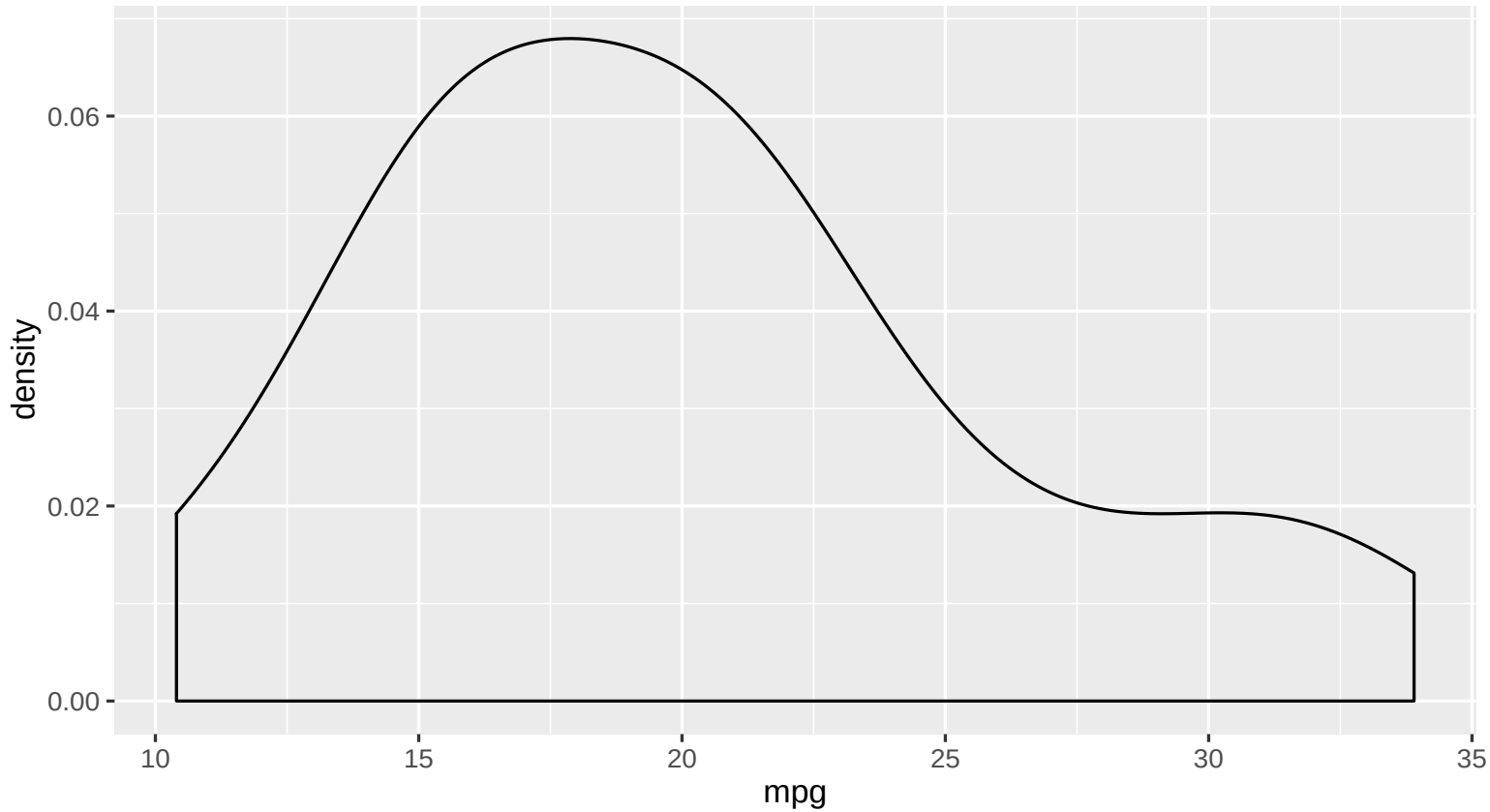
Boxplots

```
ggplot(data = mtcars, aes(x = factor(cyl), y = mpg)) +
  geom_boxplot()
```



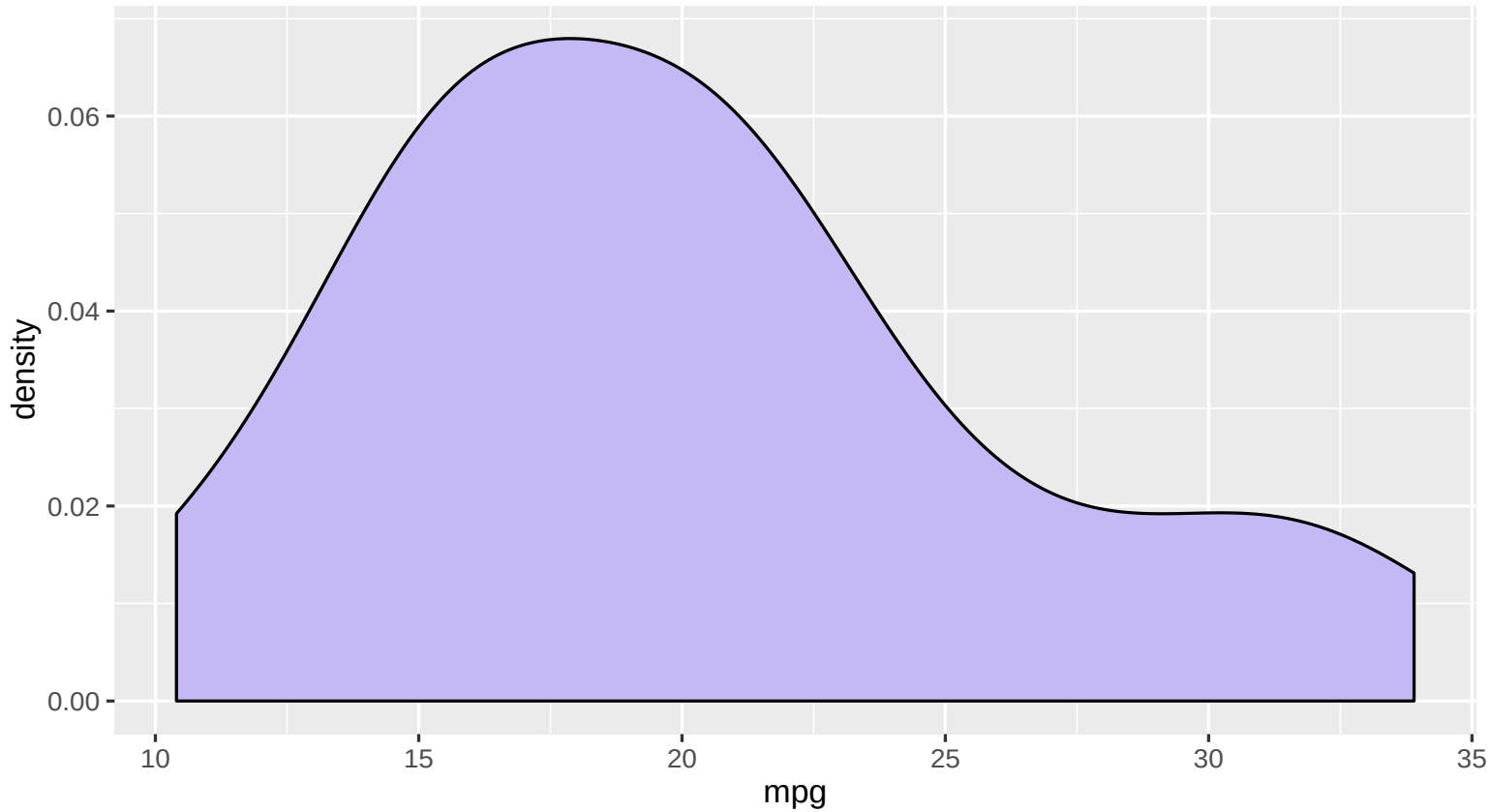
Density Curves

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



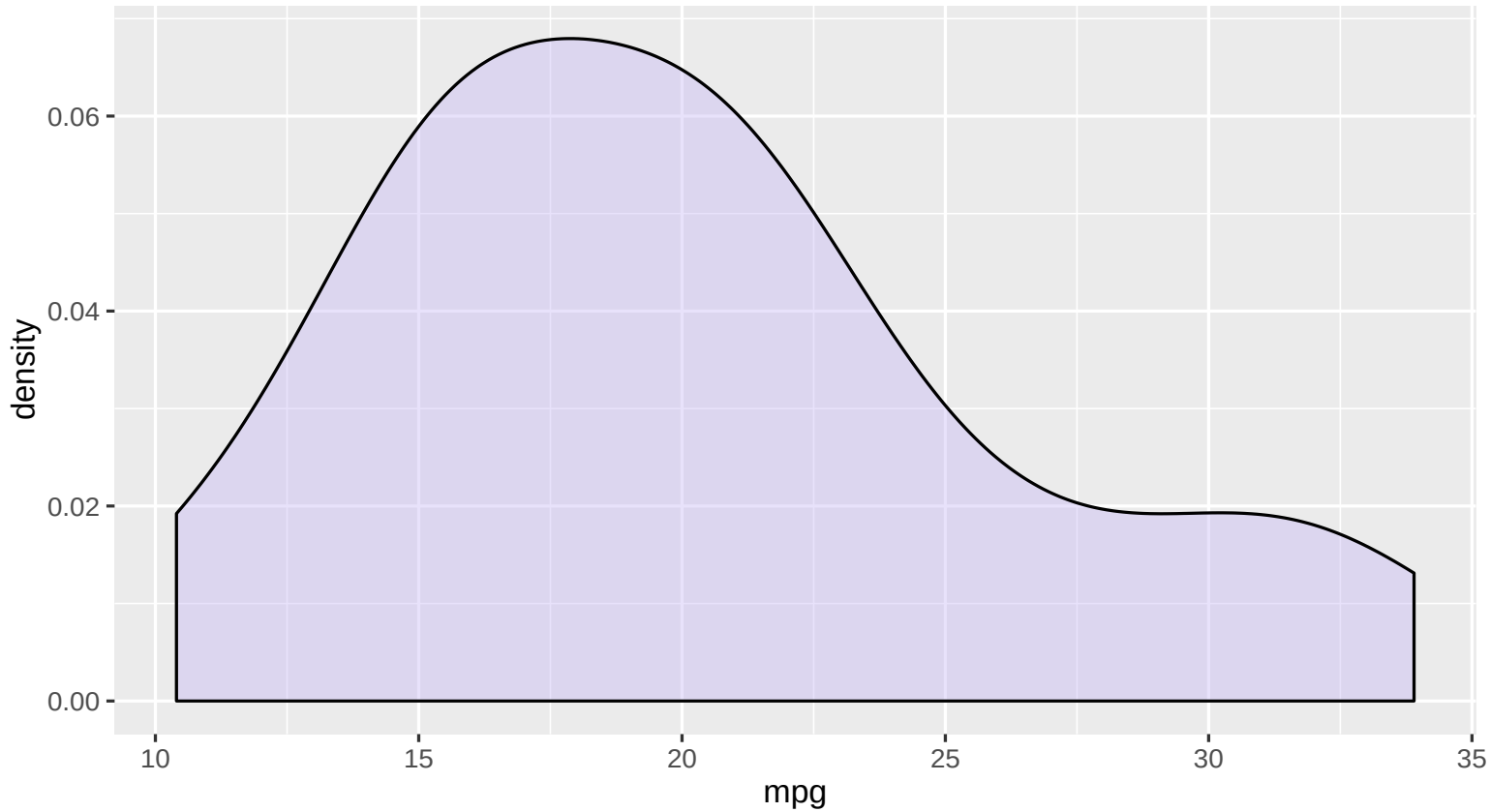
Density Curves

```
ggplot(data = mtcars, aes(x = mpg)) +
  geom_density(fill = "#c6b7f5")
```



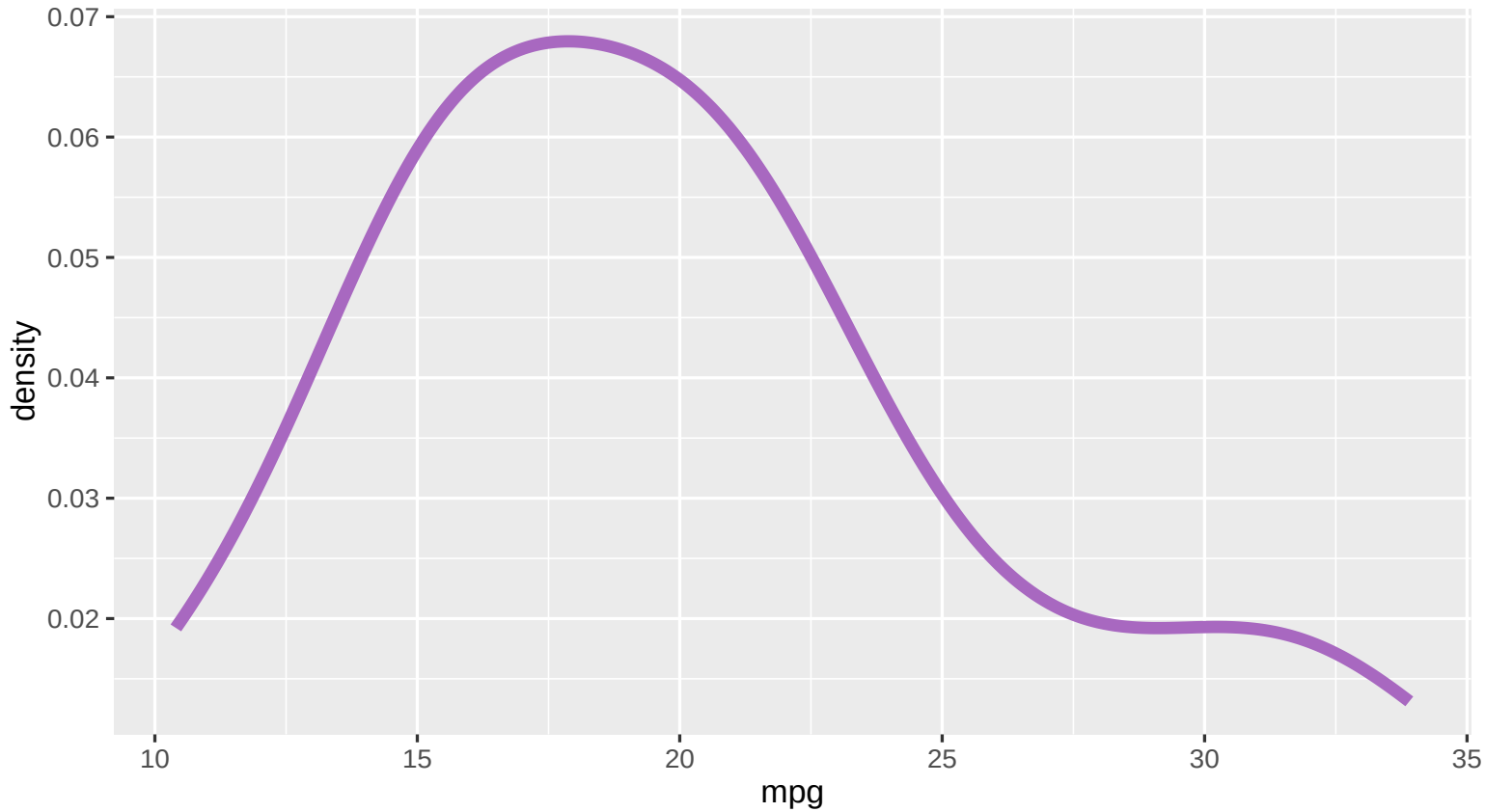
Density Curves

```
ggplot(data = mtcars, aes(x = mpg)) +
  geom_density(fill = "#c6b7f5", alpha = 0.4)
```



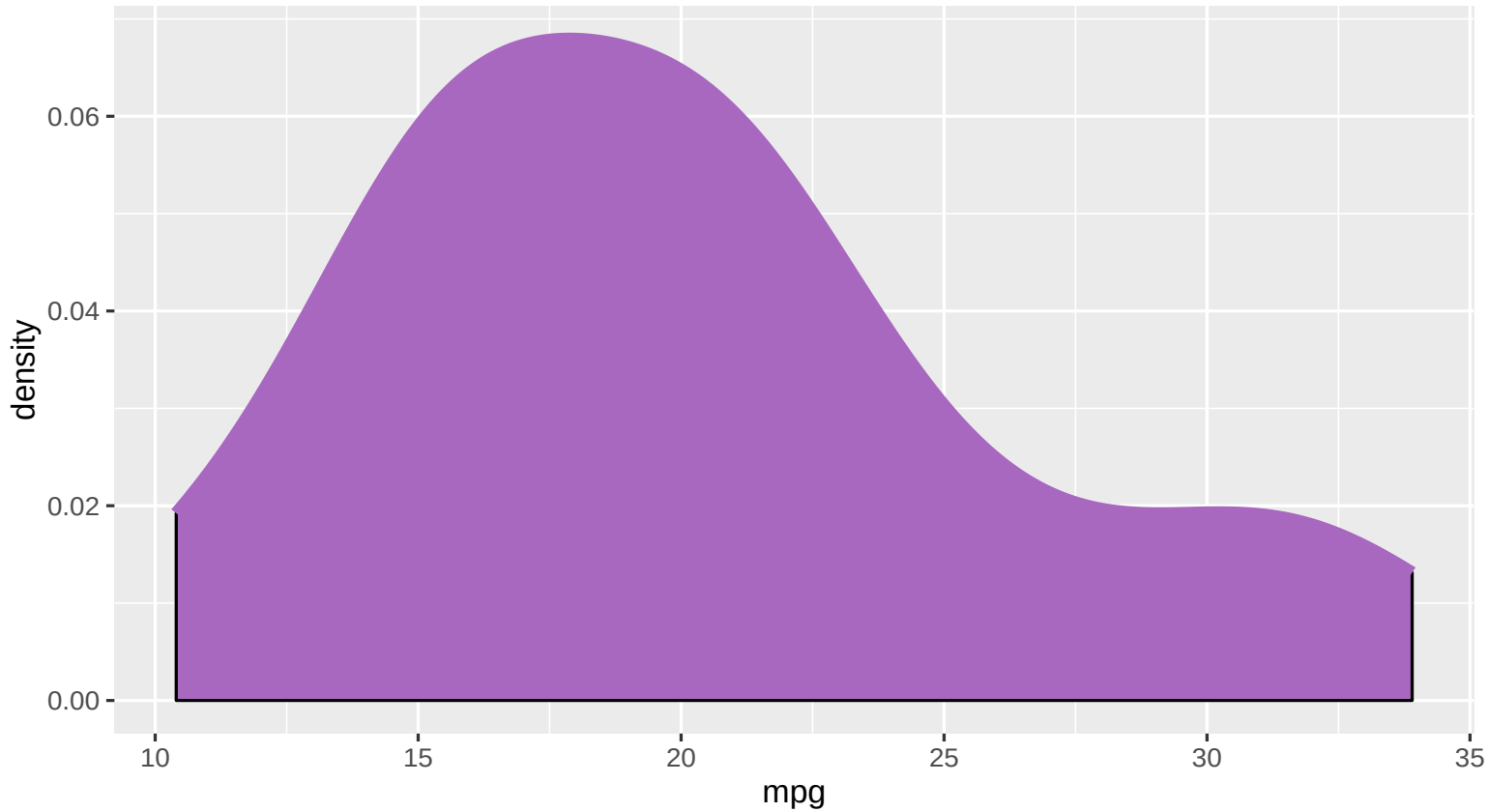
Density Curves

```
ggplot(data = mtcars, aes(x = mpg)) +
  geom_line(stat = 'density', col = "#a868c0", size = 2)
```



Density Curves

```
ggplot(data = mtcars, aes(x = mpg)) +
  geom_density(fill = '#a868c0') +
  geom_line(stat = 'density', col = "#a868c0", size = 2)
```



ggplot objects

Plot objects

You can assign a plot to a new object (this won't plot anything):

```
mpg_hp <- ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(size = 3, color = "tomato")
```

To show the actual plot associated to the object `mpg_hp` use the function `print()`

```
print(mpg_hp)
```

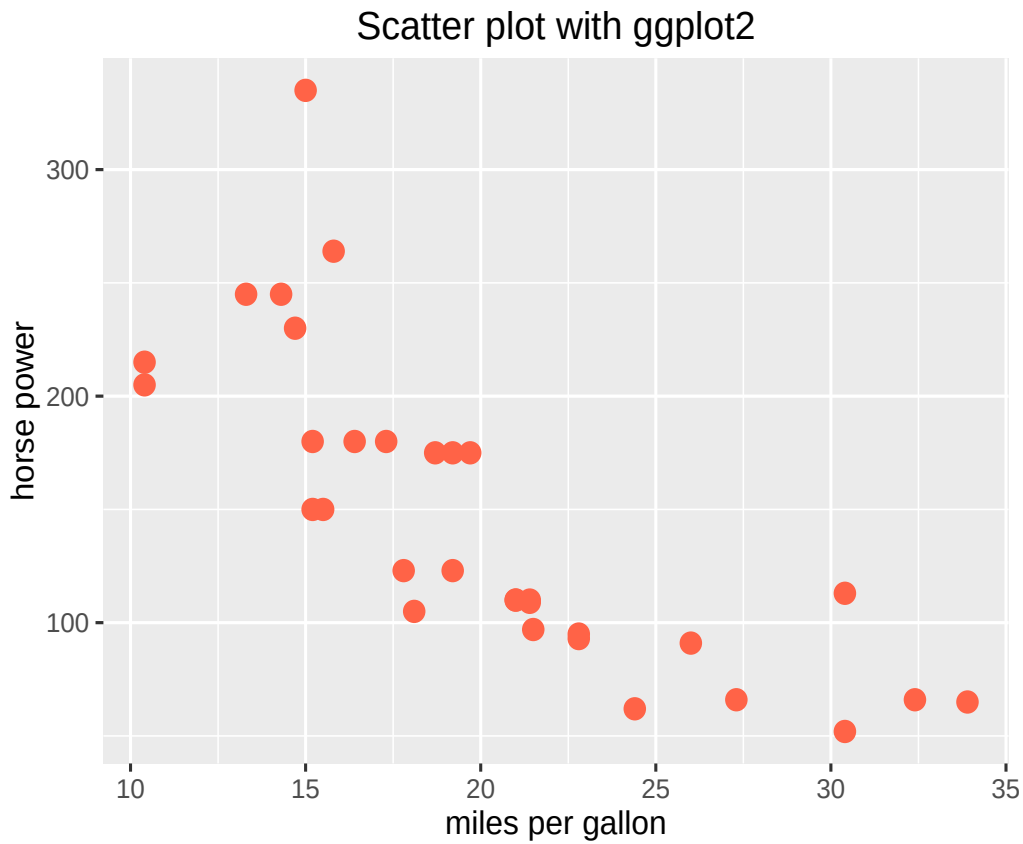
"ggplot2" objects

working with ggplot objects, we can ...

- define a basic plot, to which we can add or change layers without typing everything again
- render it on screen with `print()`
- describe its structure with `summary()`
- render it to disk with `ggsave()`
- save a cached copy to disk with `save()`

Adding a title and axis labels to a ggplot2 object:

```
mpg_hp + ggtitle("Scatter plot with ggplot2") +
  xlab("miles per gallon") + ylab("horse power")
```



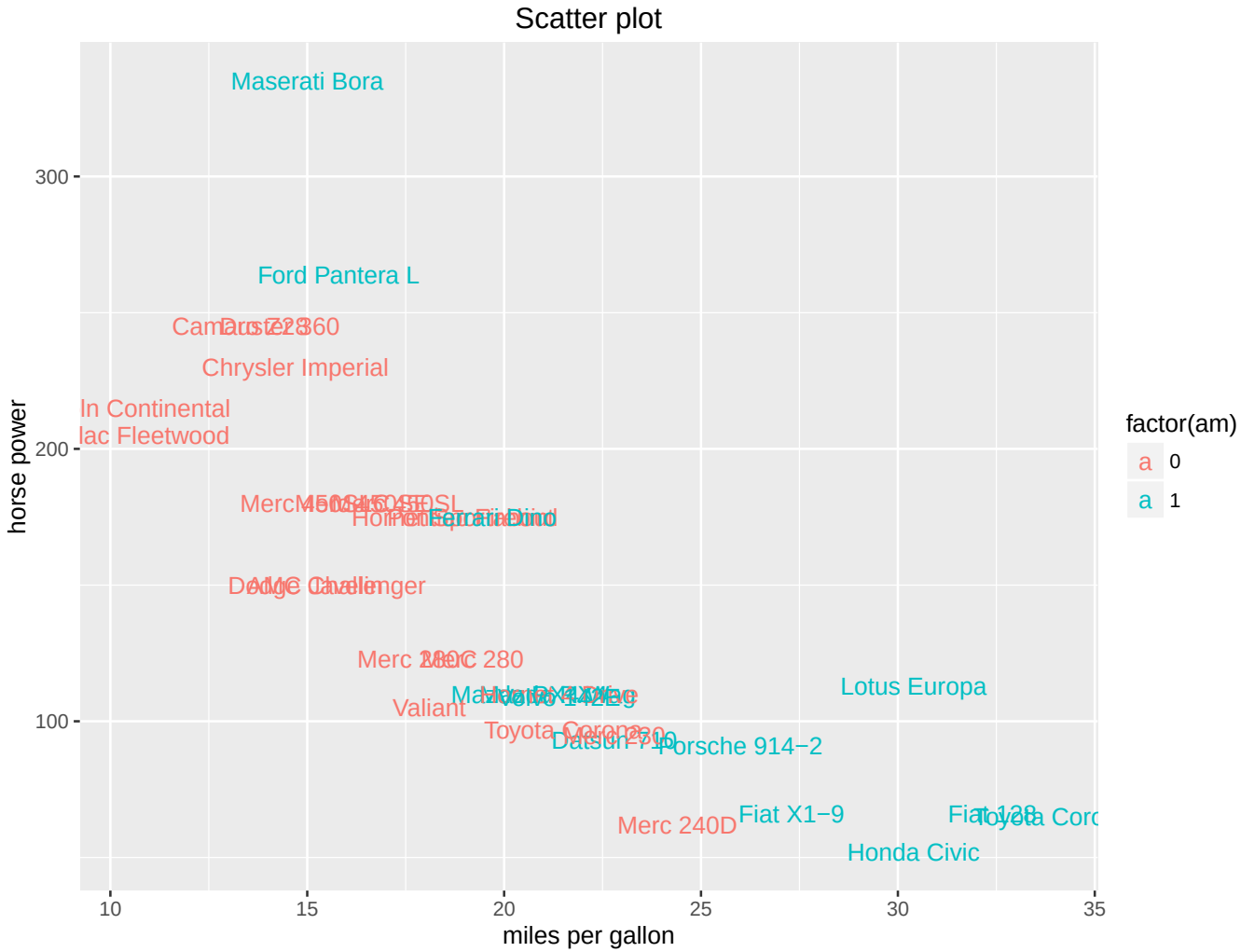
Your turn: example 3

Create the following ggplot object:

```
# ggplot object
obj <- ggplot(data = mtcars,
          aes(x = mpg, y = hp, label = rownames(mtcars)))
```

Add more layers to the object "”obj” in order to replicate the figure in the following slide:

Your turn: example 3



Your turn: example 3

```
obj +
  geom_text(aes(color = factor(am))) +
  ggtitle("Scatter plot") +
  xlab("miles per gallon") +
  ylab("horse power")
```

Scales

Scales

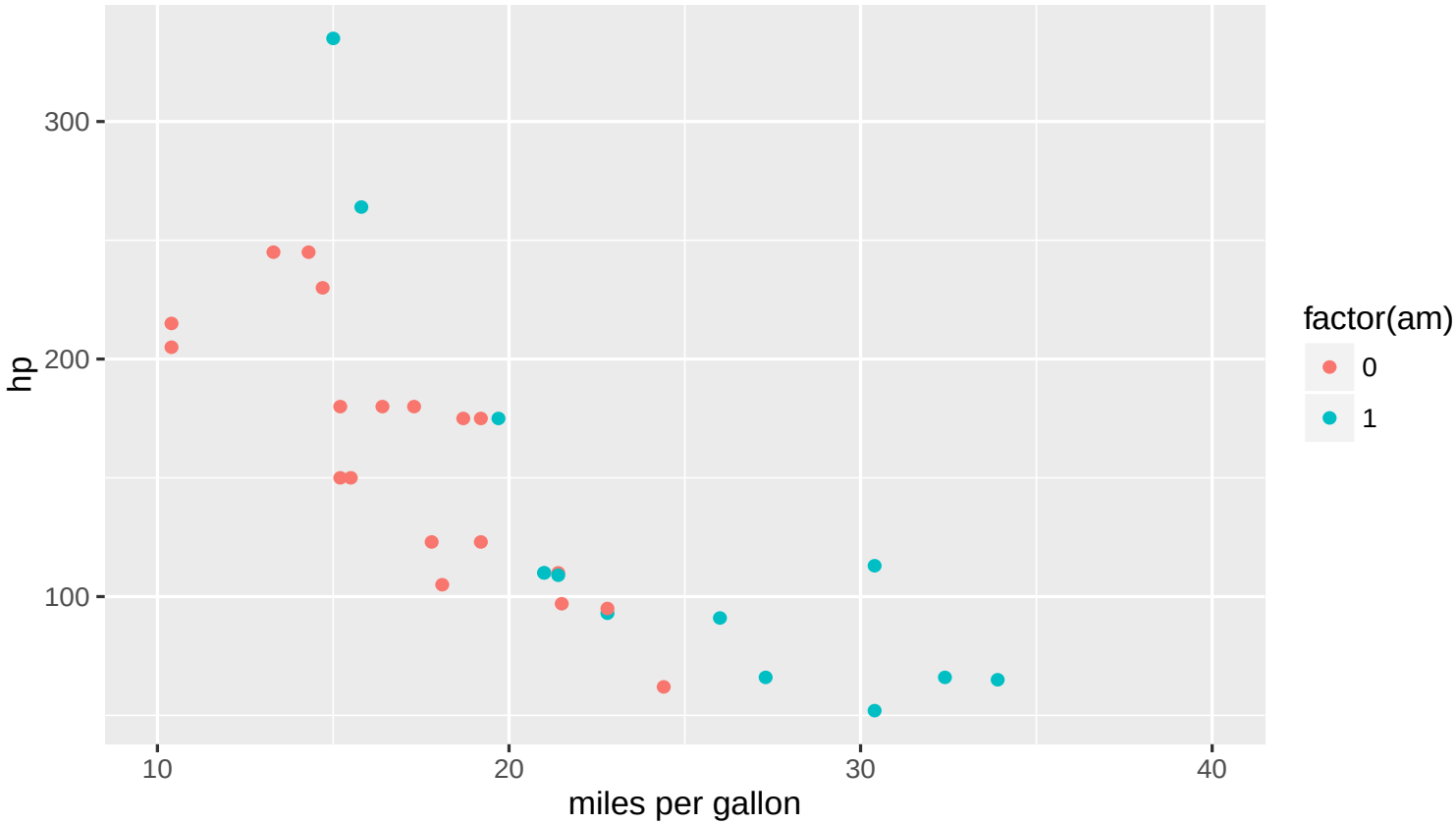
- The **scales** component encompasses the ideas of both axes and legends on plots, e.g.:
- Axes can be continuous or discrete
- Legends involve colors, symbol shapes, size, etc
  - `scale_x_continuous`
  - `scale_y_continuous`
  - `scale_color_manual`
- **scales** will often automatically generate appropriate scales for plots
- Explicitly adding a scale component overrides the default scale

Continuous axis scales

Use `scale_x_continuous()` to modify the default values in the x axis

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(aes(color = factor(am))) +
  scale_x_continuous(name = "miles per gallon",
                     limits = c(10, 40),
                     breaks = c(10, 20, 30, 40))
```

Continuous axis scales

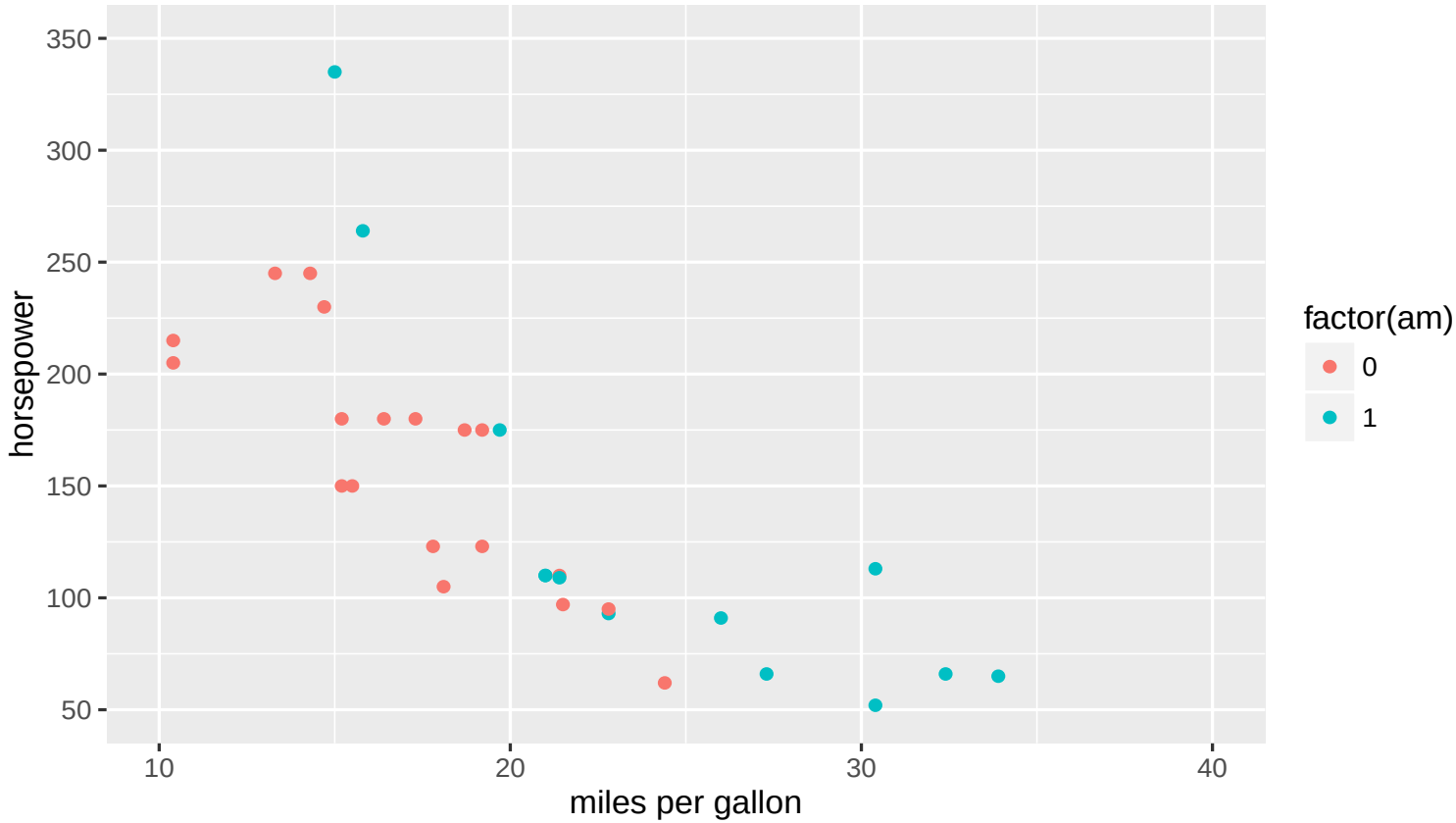


Continuous axis scales

Use `scale_y_continuous()` to modify the default values in the y axis

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(aes(color = factor(am))) +
  scale_x_continuous(name = "miles per gallon",
                     limits = c(10, 40),
                     breaks = c(10, 20, 30, 40)) +
  scale_y_continuous(name = "horsepower",
                     limits = c(50, 350),
                     breaks = seq(50, 350, by = 50))
```

Continuous axis scales

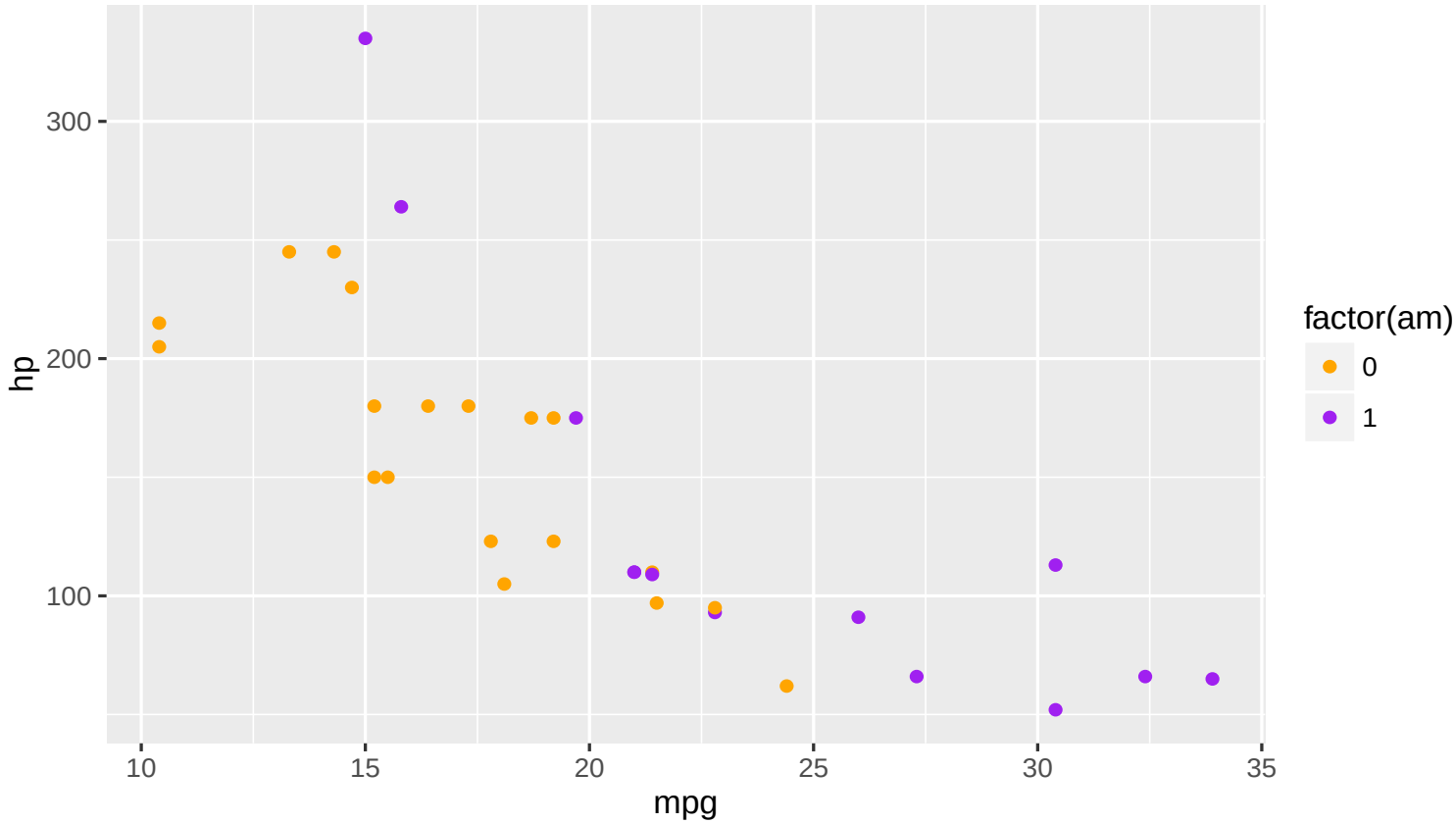


Example: color scale

Use `scale_color_manual()` to modify the colors associated to a factor

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(aes(color = factor(am))) +
  scale_color_manual(values = c("orange", "purple"))
```

Example: color scale

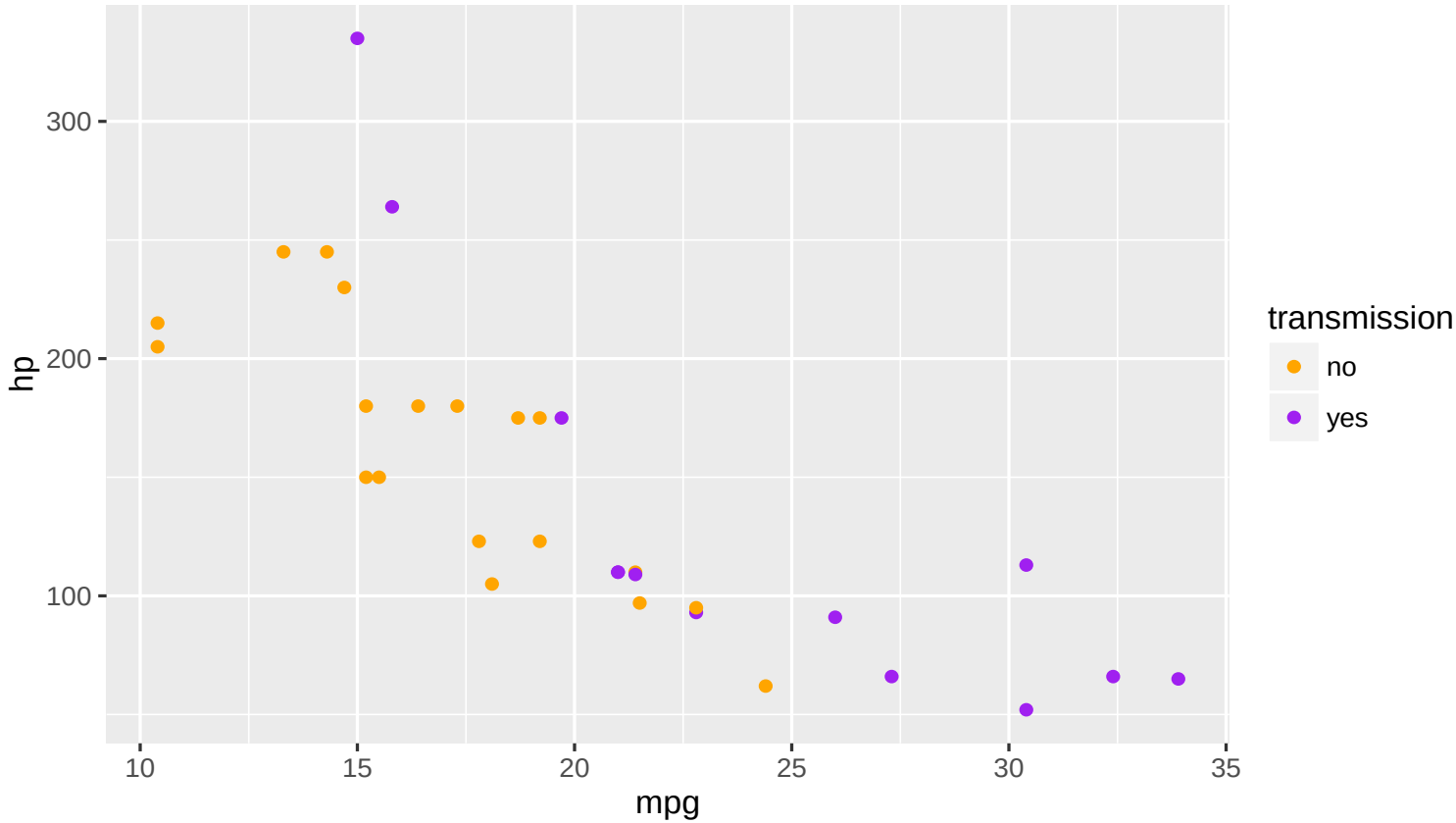


Example: modifying legend

Modifying legends depends on the type of scales (e.g. color, shapes, size, etc)

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(aes(color = factor(am))) +
  scale_color_manual(values = c("orange", "purple"),
                     name = "transmission",
                     labels = c('no', 'yes'))
```

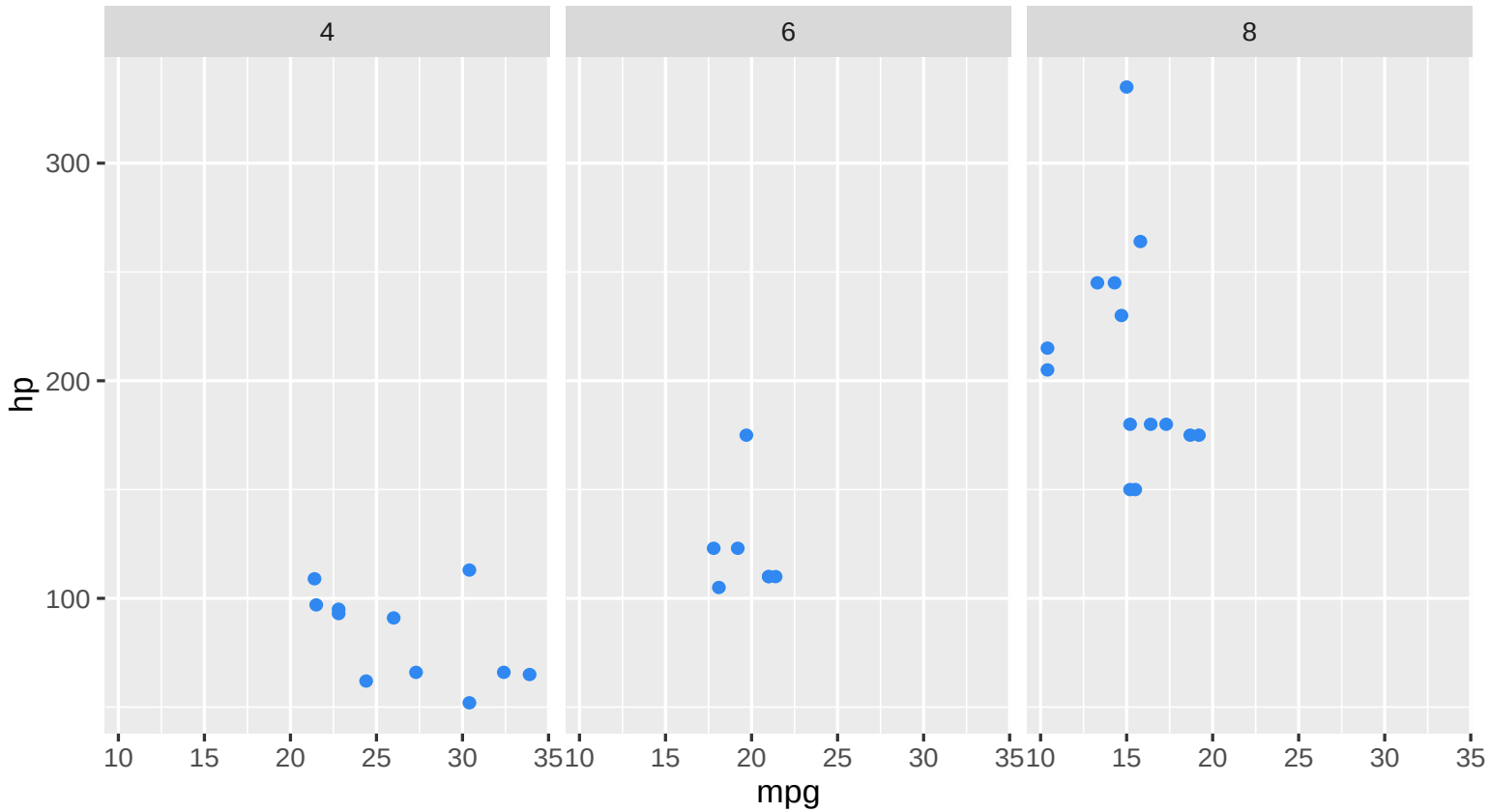
Example: modifying legend



Faceting

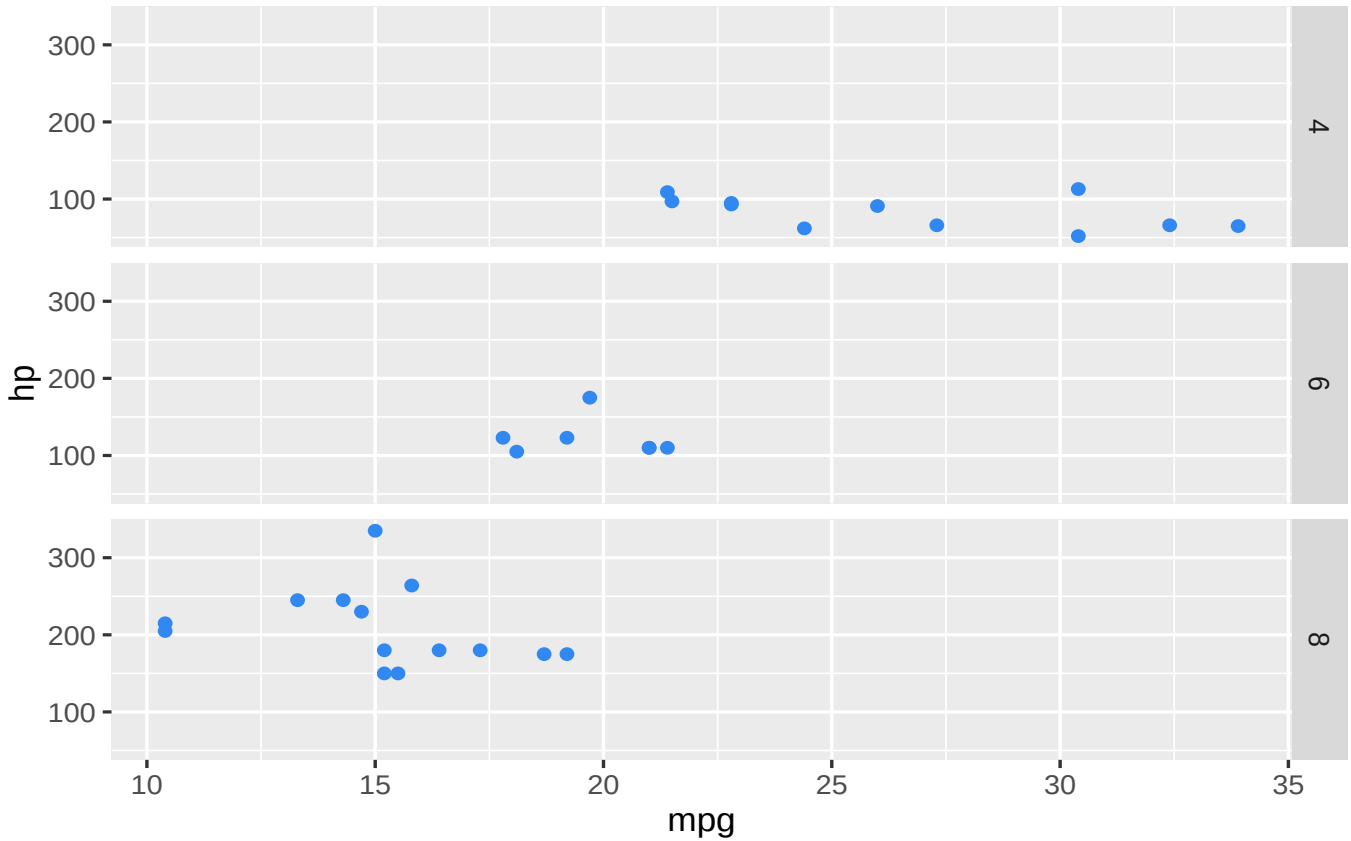
Faceting with `facet_wrap()`

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(color = "#3088f0") +
  facet_wrap(~ cyl)
```



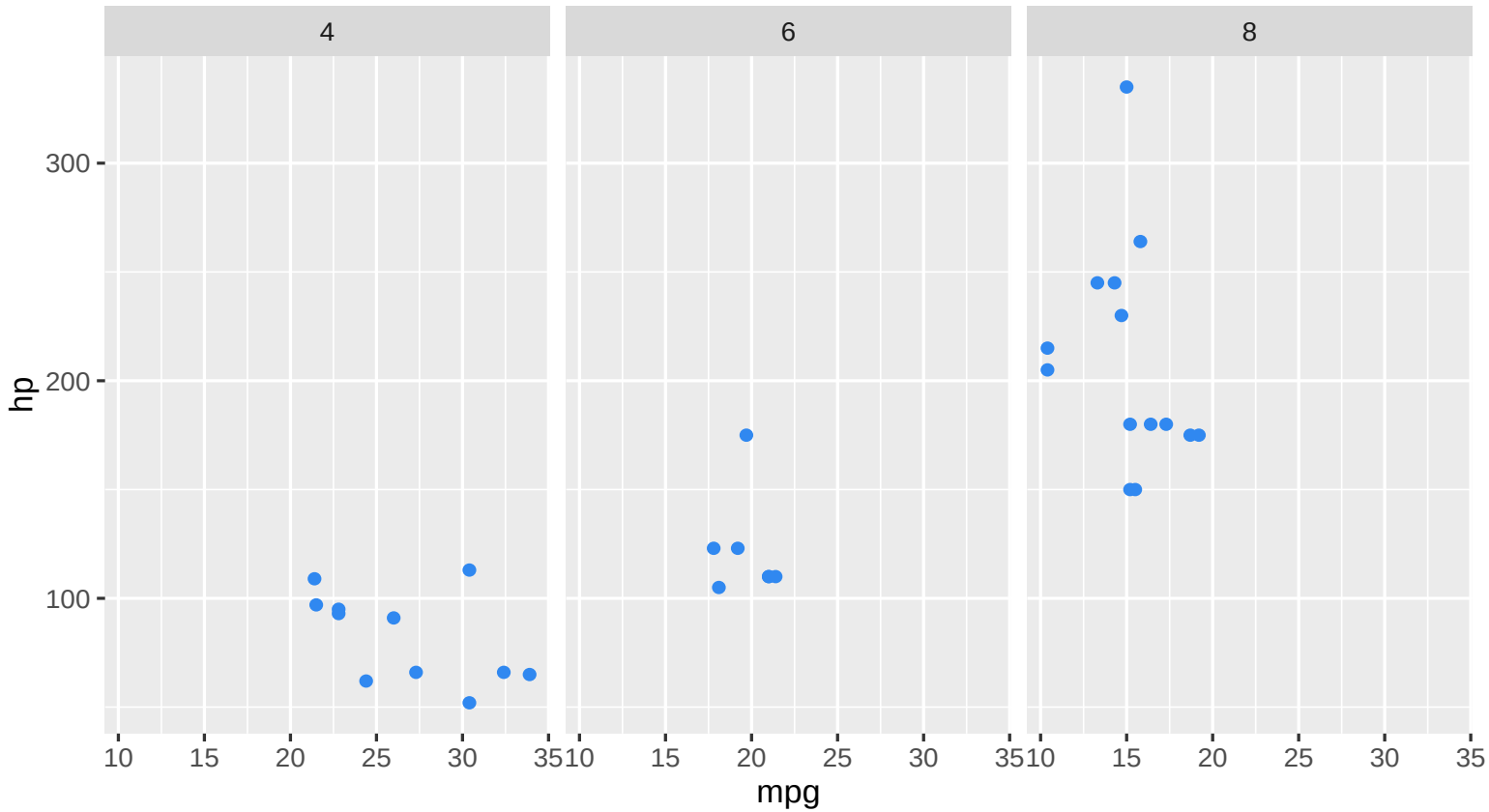
Faceting with `facet_grid()`

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(color = "#3088f0") +
  facet_grid(cyl ~ .)
```



Faceting with `facet_grid()`

```
ggplot(data = mtcars, aes(x = mpg, y = hp)) +
  geom_point(color = "#3088f0") +
  facet_grid(. ~ cyl)
```



Layered Grammar

About `"ggplot2"`

- Key concept: **layer** (layered grammar of graphics)
- Designed to work in a layered fashion
- Starting with a layer showing the data
- Then adding layers of annotations and statistical transformations
- Core idea: independents components combined togehter

Some Concepts

- the **data** to be visualized
- a set of **aesthetic mappings** describing how varibales are mapped to aesthetic attributes
- geometric objects, **geoms**, representing what you see on the plot (points, lines, etc)
- statistical transformations, **stats**, summarizing data in various ways
- **scales** that map values in the data space to values in an aesthetic space
- a coordinate system, **coord**, describing how data coordinates are mapped to the plane of the graphic
- a **faceting** specification describing how to break up the data into subsets and to displays those subsets