



Workshop 3: Introduction to `ggplot2`

QCBS R Workshop Series

Québec Centre for Biodiversity Science



À propos de cet atelier



Packages requis

- grid
- gridExtra
- ggplot2
- ggpubr
- ggsignif
- ggdendro
- maps
- mapproj
- RColorBrewer
- psych
- plotly

```
install.packages(c('grid', 'gridExtra', 'ggplot2', 'ggpubr', 'ggsignif', 'ggdendr'))
```

Learning objectives

1. Use R to do various plots

class: inverse, center, middle

Introduction

Introduction

To follow along:

Code and .HTML available at <http://qcbs.ca/wiki/r/workshop3>

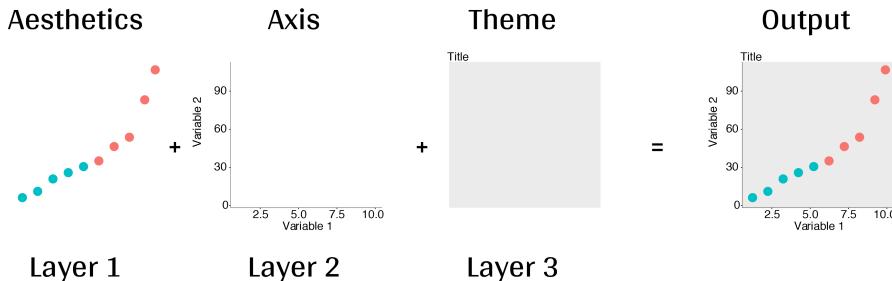
Recommendations:

1. create your own new script;
2. refer to provided code only if needed;
3. avoid copy-pasting or running the code directly from the script.

`ggplot2` is also on GitHub: <https://github.com/tidyverse/ggplot2>

Outline

1. `ggplot2` mechanics



2. Advanced visualization

3. Fine-tuning

4. Saving plots

5. Conclusion

Learning objectives

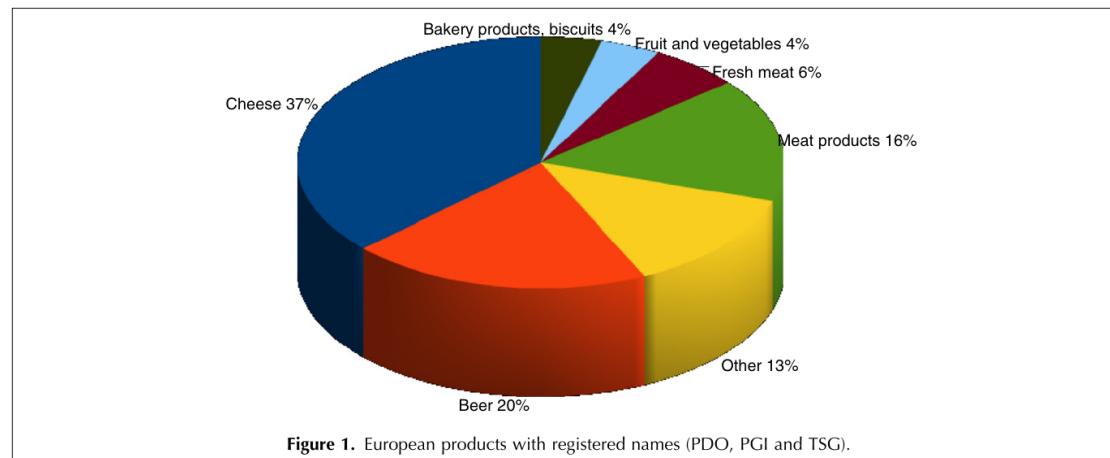
- Teach the basics of data visualization using R.
- A good representation of one's data can be unique and thus no single function or package can meet everyone's needs.
- Creativity is important to scientists!
- A basic understanding of design to communicate effectively with graphs.

Visualization in science

Visualization in science

Why are we using data visualization?

What makes an effective visualization?



What do you think about this one ?

Visualization in science

1. Represent results of statistical analyses
2. Research and discuss (preliminary data from the literature, summaries, formulate hypotheses)
3. Explore your own data (exploratory data analysis, outlier detection)
4. Communicate and report
 - Clearly (design principles)
 - Precisely and accurately
 - Effectively and efficiently

Visualization in science

Important questions:

- What do you want to communicate?
- What is your public?
- What is the best way to do it?

A rule of thumb: think simple — use less ink!

Additional resources

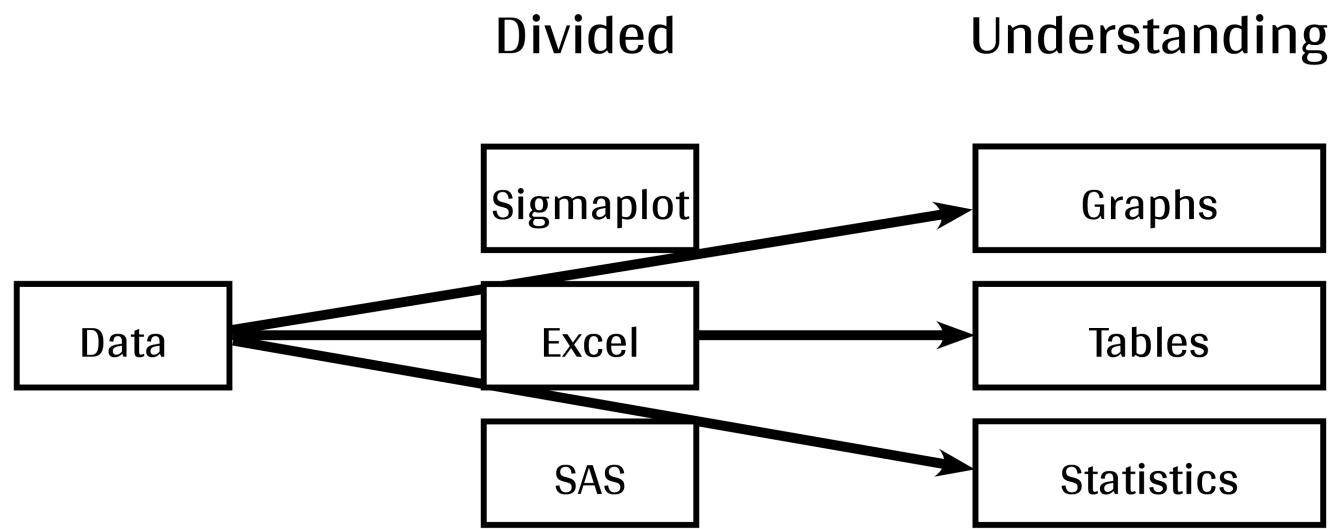
- [Fundamentals of Data Visualization](#) (ggplot)
- [A Compendium of Clean Graphs in R](#) (base plot)

WARNING!

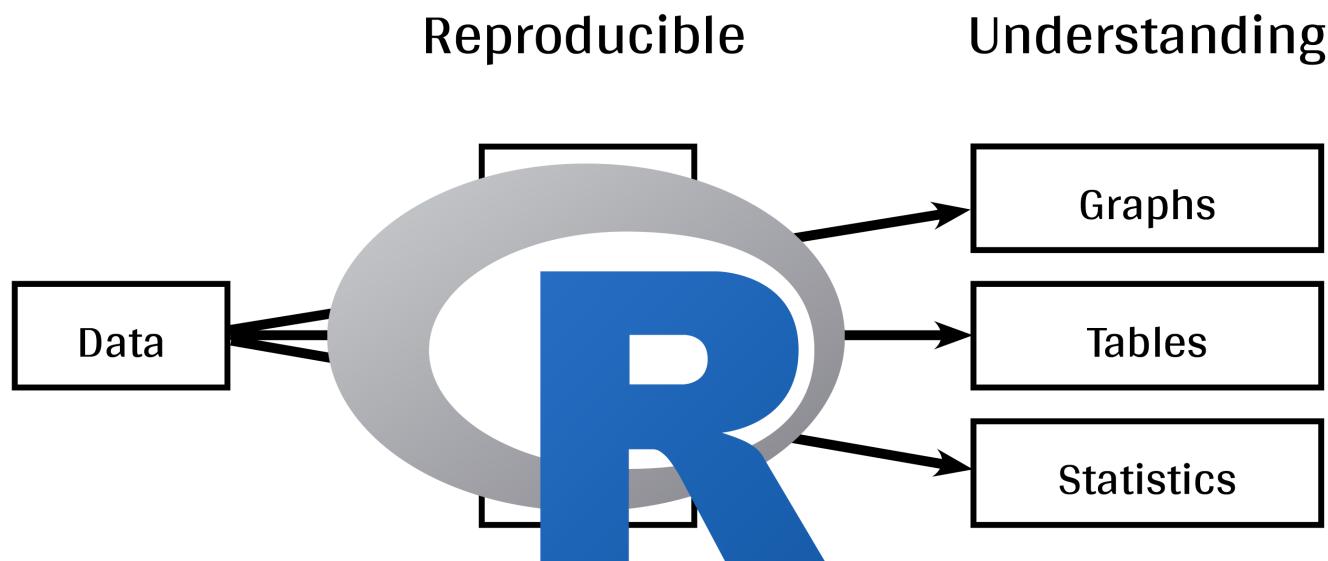
 **R** is not made for drawings.

Other drawing softwares are probably more interesting options such as [GIMP](#) or [Inkscape](#). It is important to get the right tool for the right task!

Why use R for plotting?



Why use R for plotting? Reproducibility



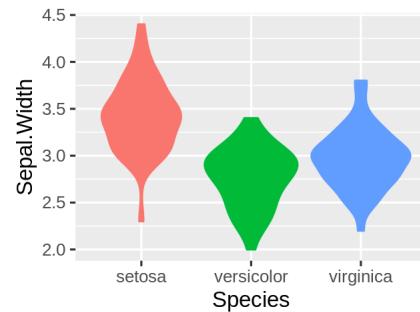
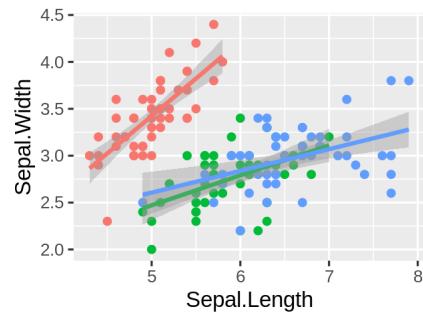
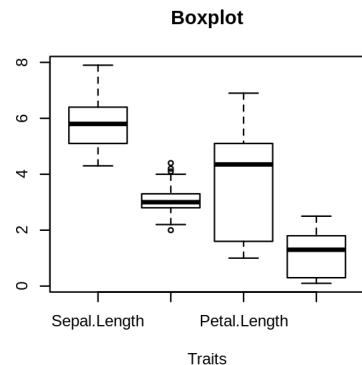
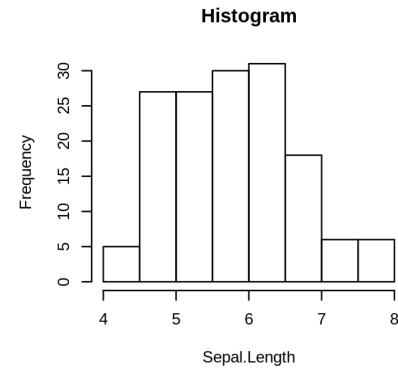
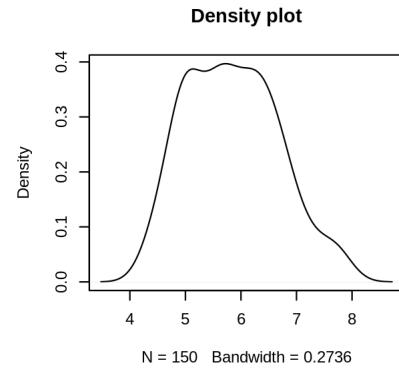
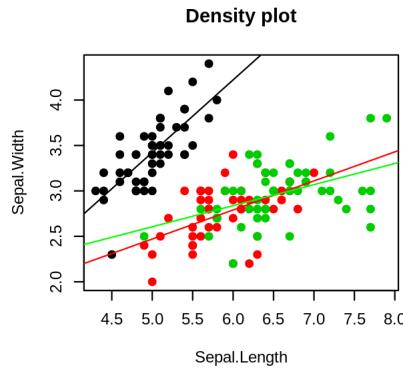
Reproducible science comes with effort:

- comment the script
- add relevant information in the figures (titles, labels, captions)

Why R for graphs?

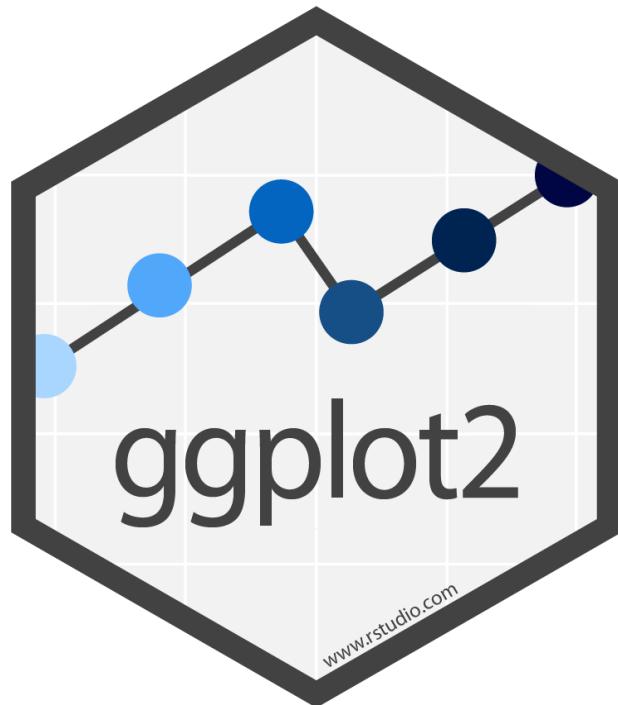
Because of its powerful features!

In this workshop, we focus only on `ggplot2`, but **multiple packages and functions** can be used for great visualization (e.g., "base R", `plotly`, `sjPlot`, `mapview`, `igraph`).



ggplot2 is versatile

1. `ggplot2` package lets you make *beautiful* and customizable plots;
2. it implements the grammar of graphics, an easy to use system for building plots;
3. it **has many extensions**.

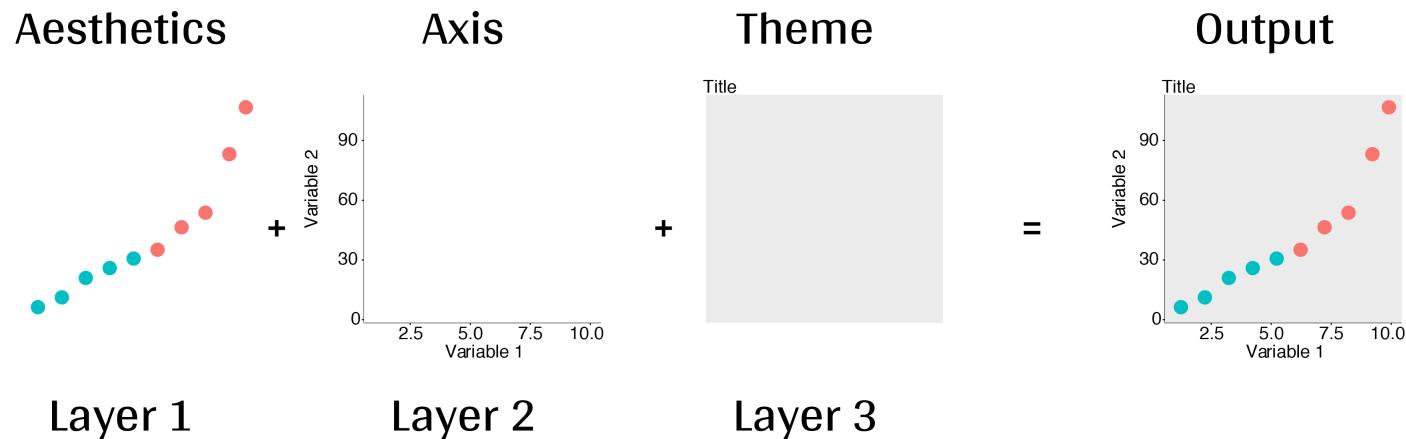


`ggplot2` mechanics: the basics

Grammar of Graphics (GG) basics

```
install.packages("ggplot2") # if not already installed  
library(ggplot2)
```

A graphic is made of different layers:

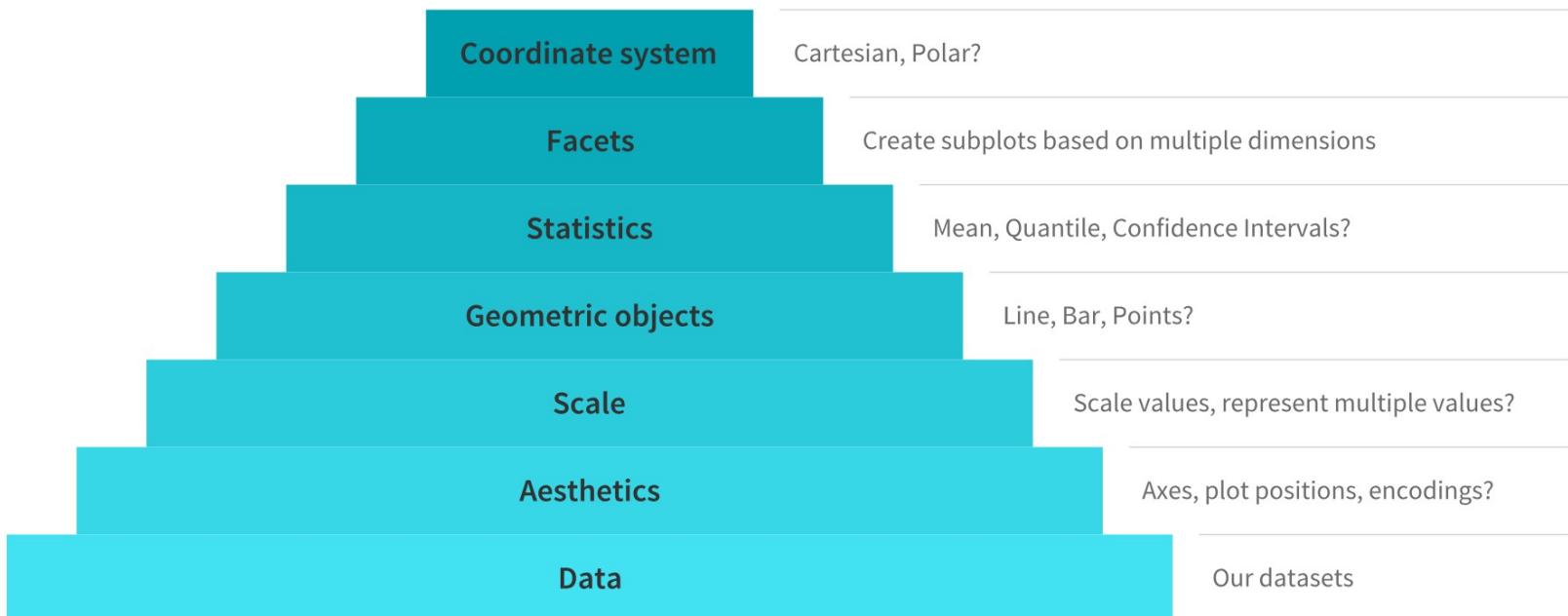


We will learn how to build graphs step by step to make it look as we desire.

Grammar of Graphics (GG) basics

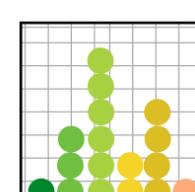
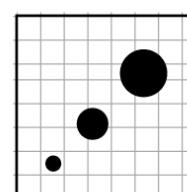
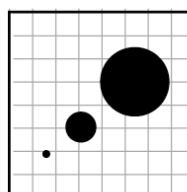
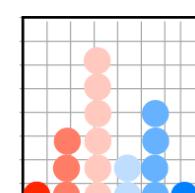
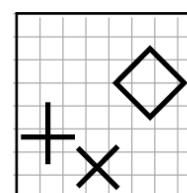
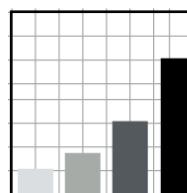
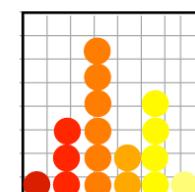
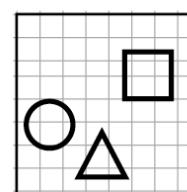
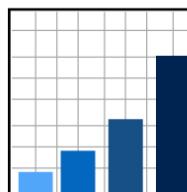
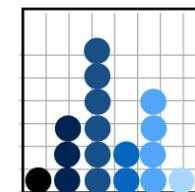
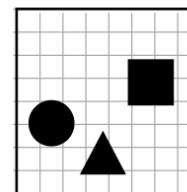
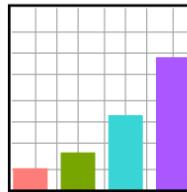
These layers have specific names that you will see throughout the presentation:

Major Components of the Grammar of Graphics



Grammar of Graphics (GG) basics

Scales



Grammar of Graphics (GG) basics

Here are the basic requirements to draw the simplest ``ggplot``:

```
ggplot(data = <DATA>) +  
  <GEOM function>(mapping=aes(<mappings>),  
    stat = <STAT>, position = <POSITION>) +  
    <COORDINATE function> +  
    <SCALE function> +  
    <THEME function> +  
    <FACET function> +...
```

Required

Not required

Grammar of Graphics (GG)

A graphic is made of elements (layers)

- Data
- Aesthetics (aes), to make data visible
 - `x`, `y`: position along the x and y axis
 - `colour`: the colour of the point
 - `group`: what group a point belongs to
 - `shape`: the figure used to plot a point
 - `linetype`: the type of line used (solid, dashed, etc)
 - `size`: the size of the point or line
 - `alpha`: the transparency of the point

Grammar of Graphics (GG)

A graphic is made of elements (layers)

- Data
- Aesthetics (aes)
- Geometric objects (geoms)
 - `geom_point()`: scatterplot
 - `geom_line()`: lines connecting points by increasing value of x
 - `geom_path()`: lines connecting points in sequence of appearance
 - `geom_boxplot()`: box and whiskers plot for categorical variables
 - `geom_bar()`: bar charts for categorical x axis
 - `geom_histogram()`: histogram for continuous x axis

How layer in ggplot works

1. Create a simple plot object:

- `plot.object ← ggplot()`

2. Add graphical layers:

- `plot.object ← plot.object + layer()`

3. Repeat step 2 until satisfied, then print:

- `plot.object` or `print(plot.object)`

Prepare data for `ggplot2`

`ggplot2` requires you to prepare the data as an object of class `data.frame` or `tibble` (common in the `tidyverse`).

```
library(tibble)
class(iris) # all set!
# [1] "data.frame"

ir ← as_tibble(iris) # acceptable
class(ir)
# [1] "tbl_df"     "tbl"        "data.frame"
```

♻ Recall from the *Loading and manipulating data workshop*:

More complex plots in `ggplot` require the long data frame format

iris dataset

```
## ?iris  
str(iris)  
# 'data.frame': 150 obs. of 5 variables:  
# $ Sepal.Length: num 5.1 4.9 4.7 4.6 5 5.4 4.6 5 4.4 4.9 ...  
# $ Sepal.Width : num 3.5 3 3.2 3.1 3.6 3.9 3.4 3.4 2.9 3.1 ...  
# $ Petal.Length: num 1.4 1.4 1.3 1.5 1.4 1.7 1.4 1.5 1.4 1.5 ...  
# $ Petal.Width : num 0.2 0.2 0.2 0.2 0.2 0.4 0.3 0.2 0.2 0.1 ...  
# $ Species      : Factor w/ 3 levels "setosa", "versicolor", .. : 1 1 1 1 1 1 1 1 1 1
```

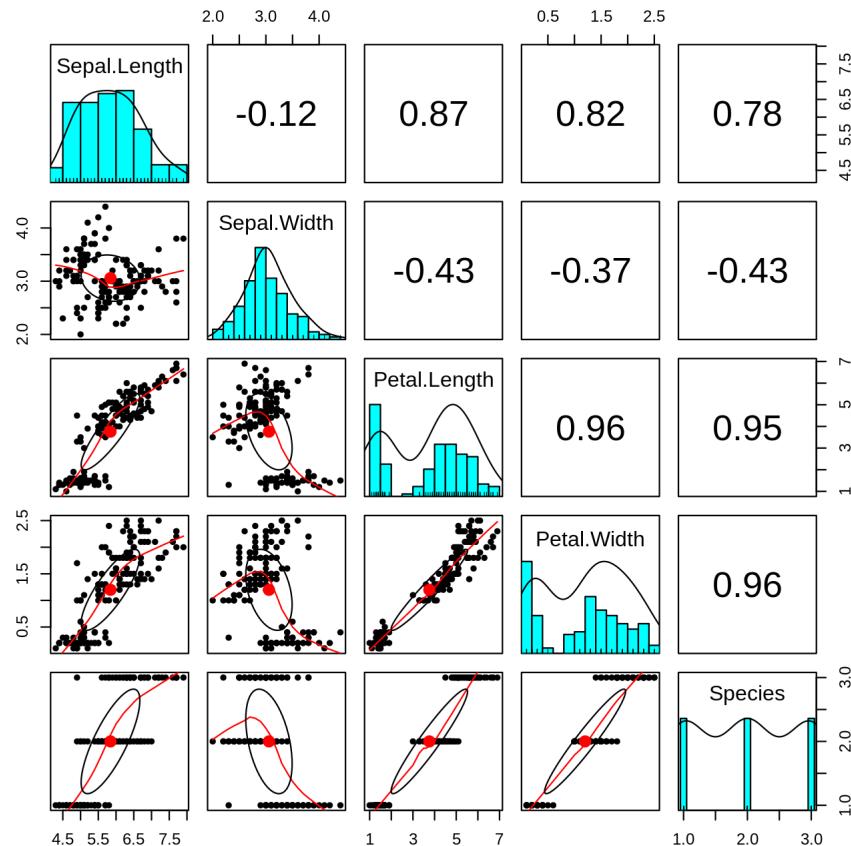
Scientific questions

- Is there a relation between the **length** & the **width** of the iris **Sepal** ?
 - Does the size of the **Petal & Sepal** vary together ?
 - How are these measures distributed among the **3 Iris species** ?

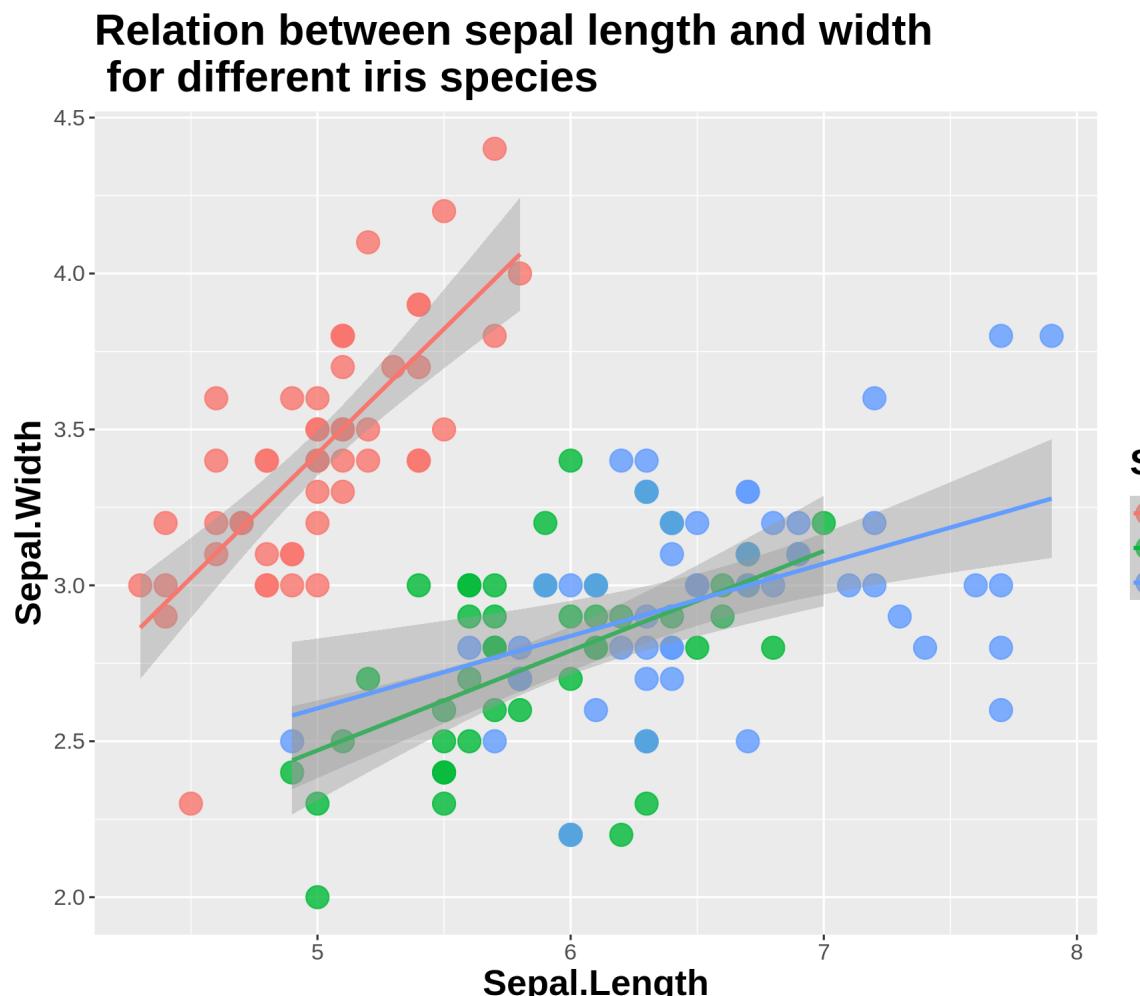
How to graphically address these questions with ggplot ?

Exploring data structure

```
library(psych)  
pairs.panels(iris)
```



Exploring data structure

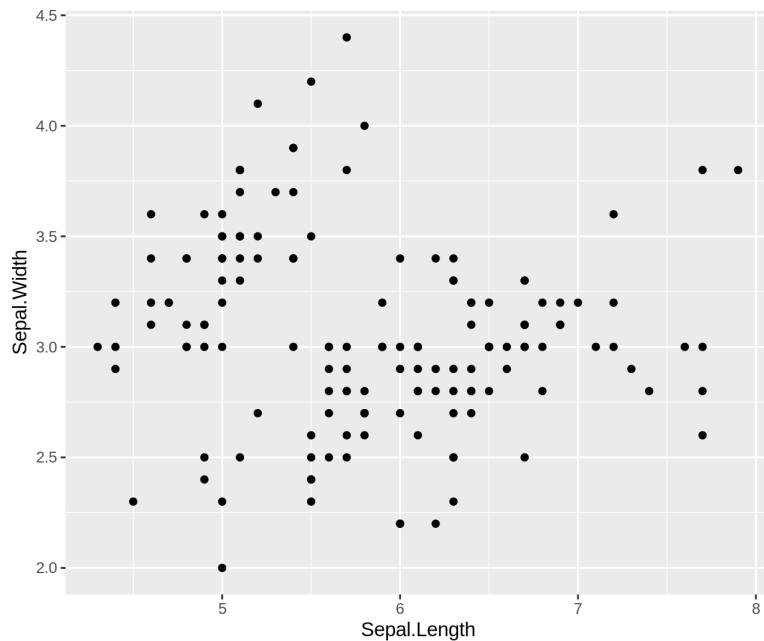


♻ See [Loading and manipulating data workshop](#) to learn how to clean your dataset.

Inheritance in ggplot2

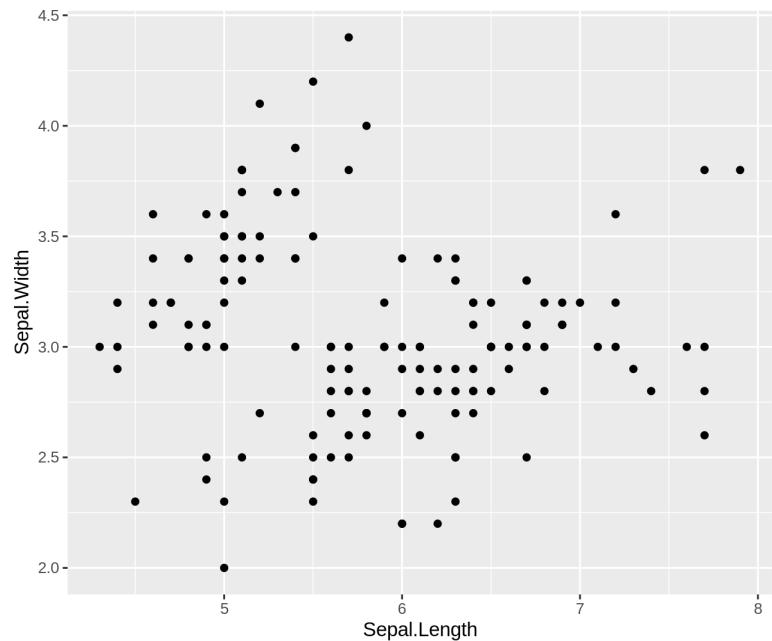
Inheritance from ggplot

```
p <- ggplot(data = iris,  
             aes(x = Sepal.Length,  
                  y = Sepal.Width))  
p <- p + geom_point()  
p
```



No inheritance from ggplot

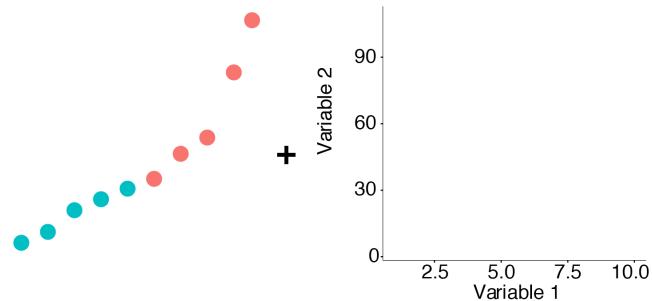
```
s <- ggplot()  
s <- s + geom_point(data = iris,  
                      aes(x = Sepal.Length,  
                           y = Sepal.Width))  
s # Print your final plot
```



Grammar of Graphics: *recall*

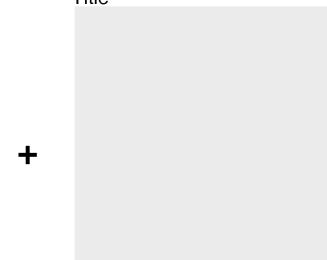
Remember: a graphic is made of different layers:

Aesthetics



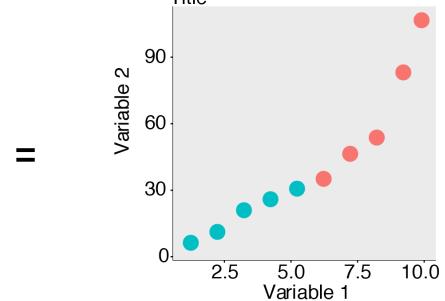
Layer 1

Axis



Layer 2

Theme

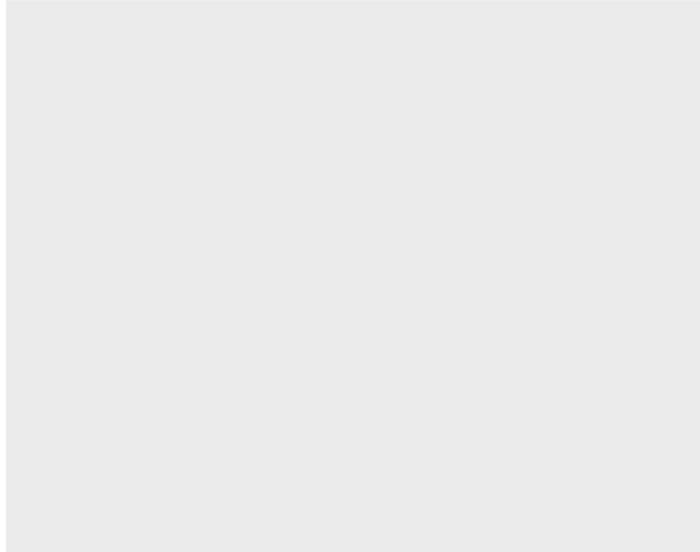


Layer 3

Output

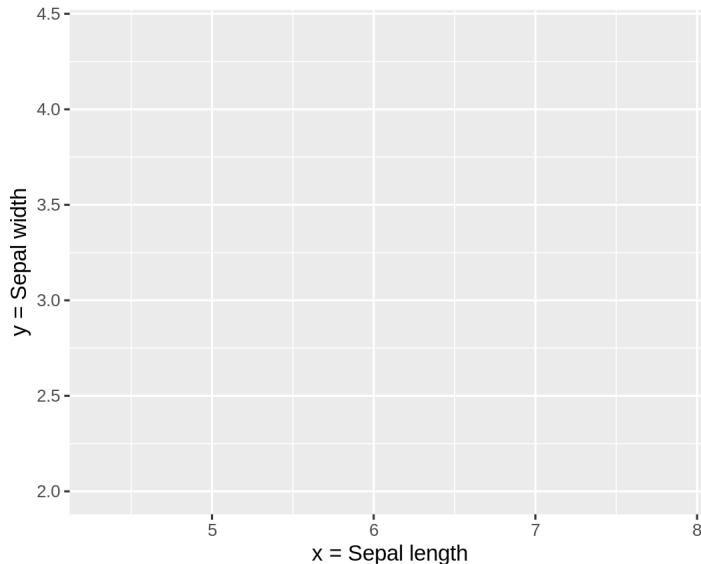
ggplot() dynamics: base layer

ggplot()



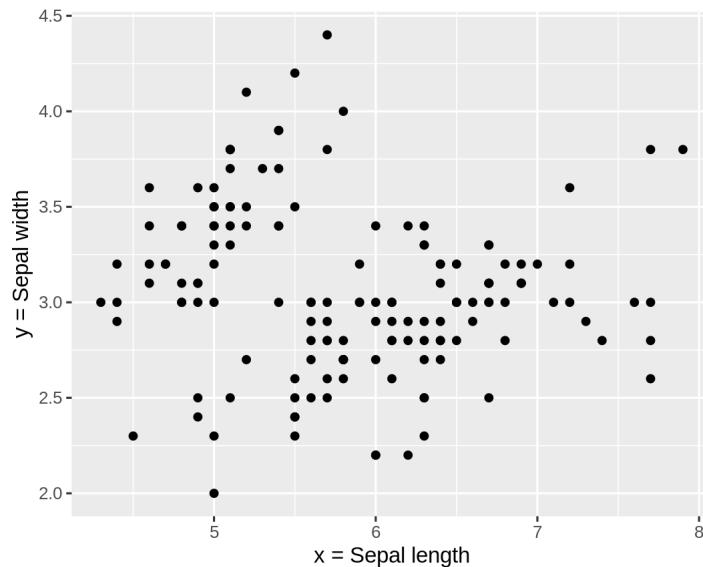
ggplot() dynamics: data layer

```
ggplot(data = iris, aes(x = Sepal.Length, y = Sepal.Width)) +  
  xlab("x = Sepal length") +  
  ylab("y = Sepal width")
```



ggplot() dynamics: geometric Layer

```
ggplot(data = iris, aes(x = Sepal.Length, y = Sepal.Width)) +  
  xlab("x = Sepal length") +  
  ylab("y = Sepal width") +  
  geom_point()
```





Challenge #1 (5min)

Draw your 1st ggplot!

Question

Is there a relation between the **length** & the **width** of the iris **petal** ?

Does the *width* of the petal increase with its *length* ?

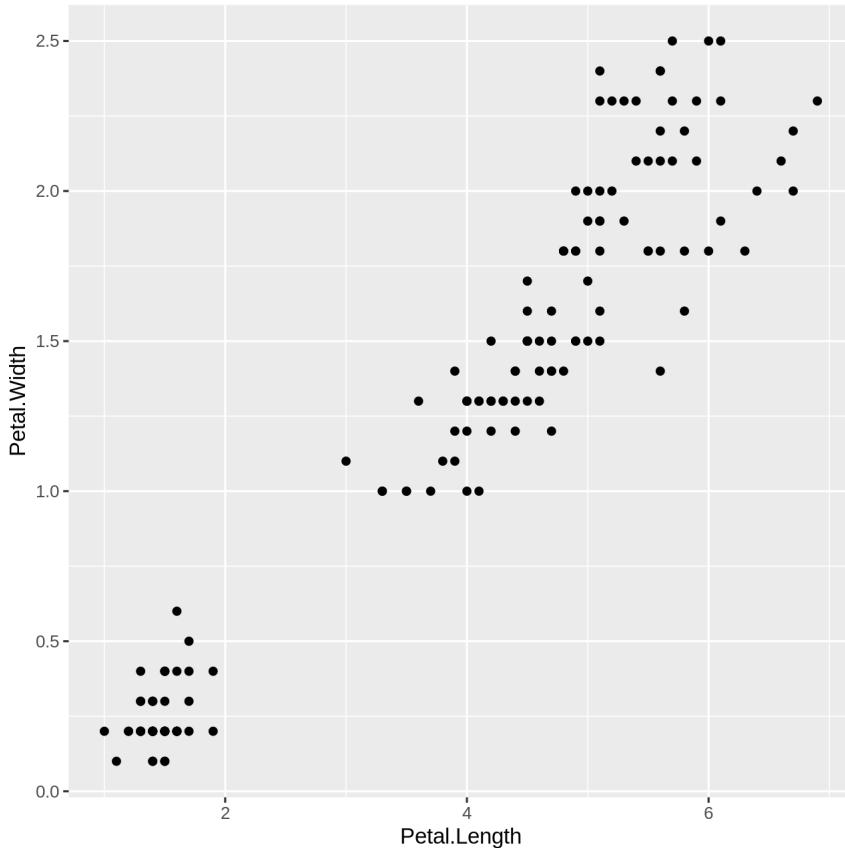
Parameters to consider when addressing this question:

data	geom	x value	y value
iris	geom_point	Petal length	Petal width



Challenge 1#: Solution

```
ggplot(data = iris, aes(x = Petal.Length,  
                        y = Petal.Width)) +  
  geom_point()
```

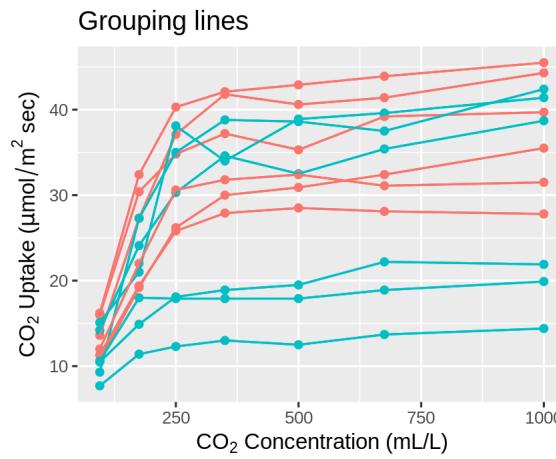
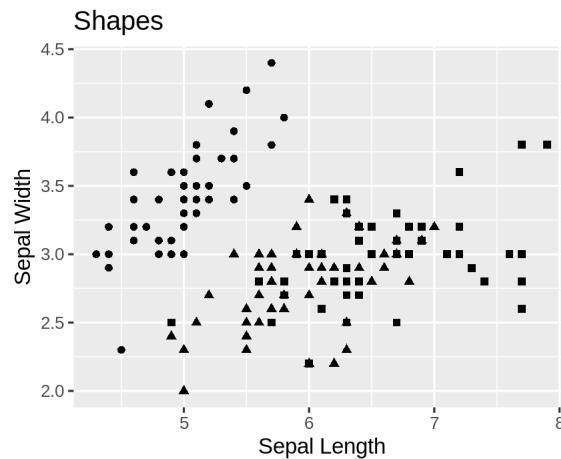
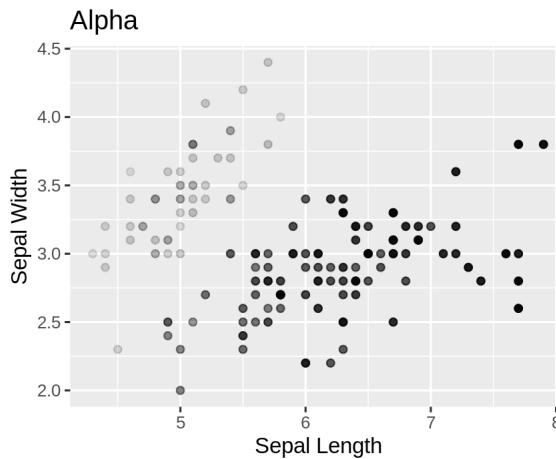
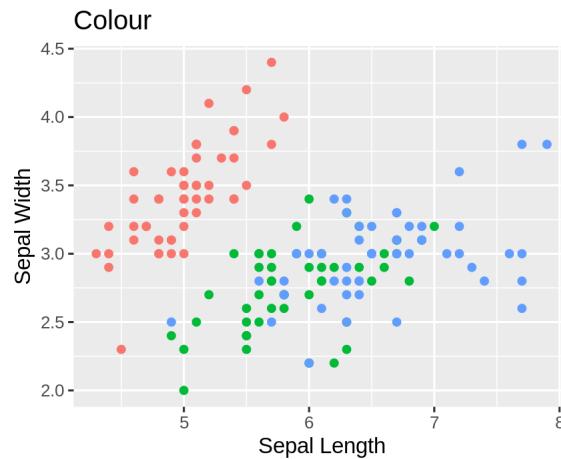


Aesthetic mapping

colour, shape, size, labels and transparency

Aesthetic

Use aesthetics (`aes()`) to distinguish classes, groups and structure

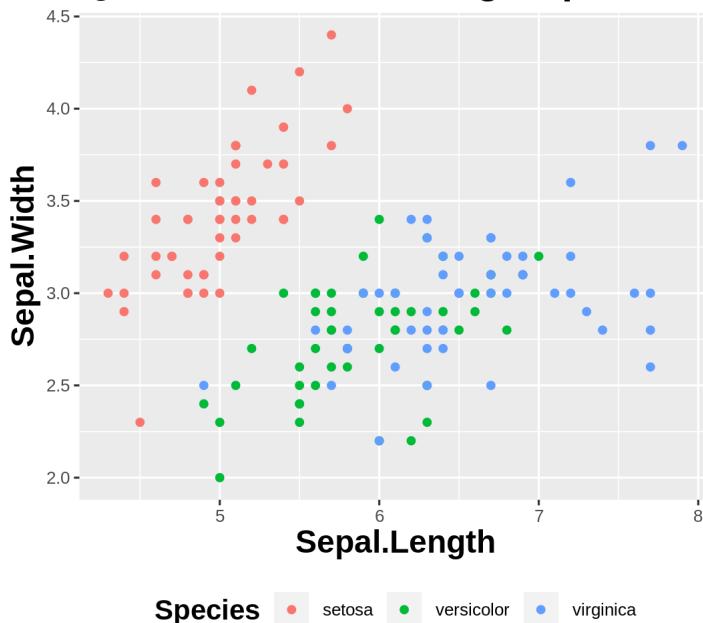


Colouring: make your points talk

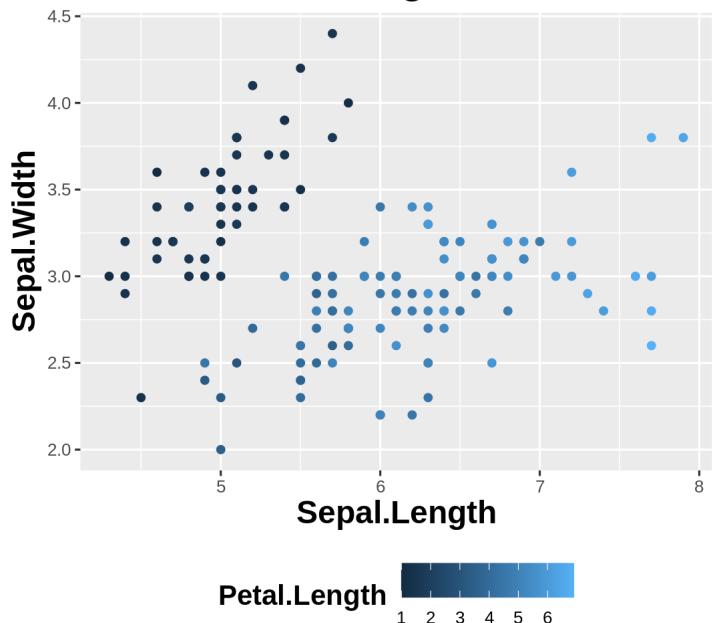
Change **colour** to

- differentiate between groups
- represent data values
- highlight specific elements

Qualitative colour for groups



Gradient colouring for values

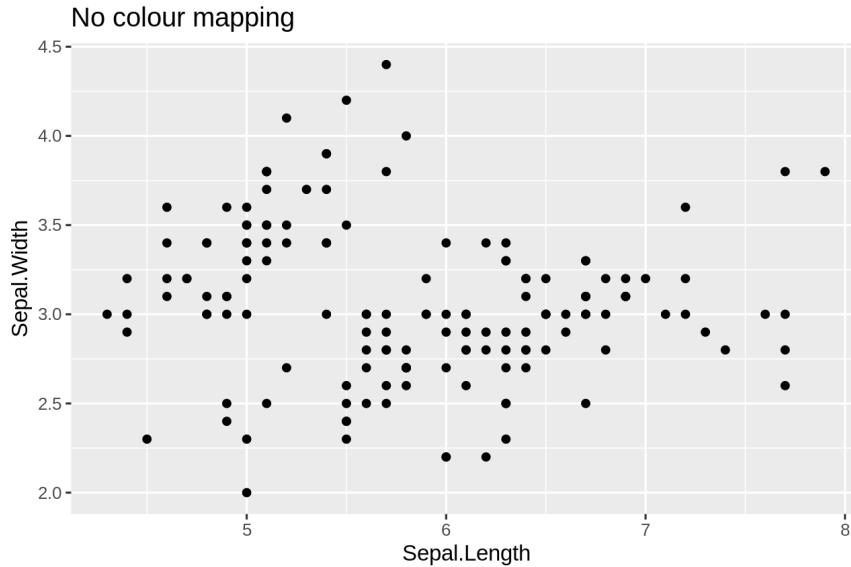


See [Fundamentals of Data Visualization](#)

Using `aes()` use to change colour

Do the sepal length and width vary differently across species?

```
# No colour mapping  
ggplot(data = iris) +  
  geom_point(mapping = aes(x = Sepal.Length, y = Sepal.Width)) +  
  labs(title = "No colour mapping")
```



```
# With colour mapping  
ggplot(data = iris) +  
  geom_point(mapping = aes(x = Sepal.Length, y = Sepal.Width, colour = Species))
```

Change colour manually

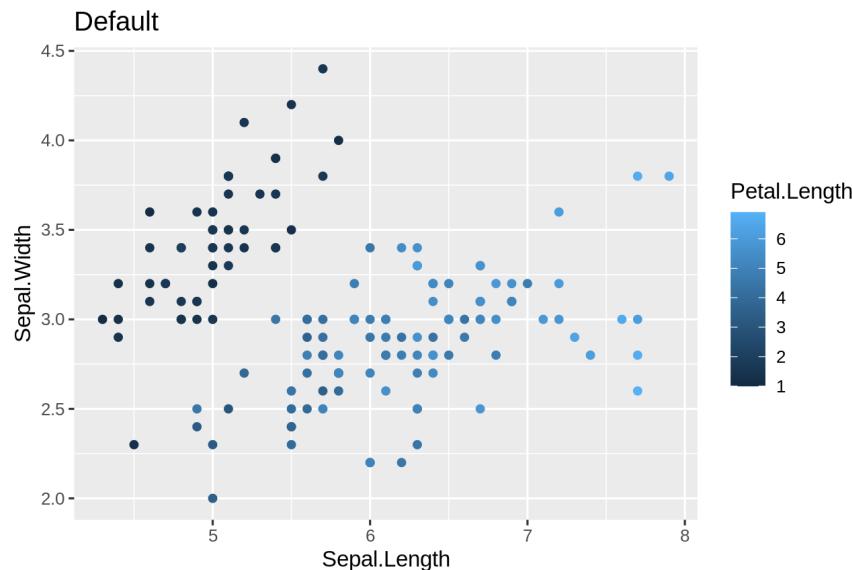
```
# Default  
pp ← ggplot(data = iris) +  
  geom_point(mapping = aes(x = Sepal.Length, y = Sepal.Width, colour = Species))  
pp + labs(title = "Default")
```



```
# Manual  
pp +  
  scale_colour_manual(values = c("grey55", "orange", "skyblue")) +  
  labs(title = "Manual")
```

Colour gradient

```
# Default  
pp2 ← ggplot(data = iris) +  
  geom_point(mapping = aes(x = Sepal.Length, y = Sepal.Width,  
                           colour = Petal.Length))  
pp2 + labs(title = "Default")
```



```
# Manual  
pp2 + scale_colour_gradient(low = "blue", high = "red") +  
  labs(title = "Manual")
```

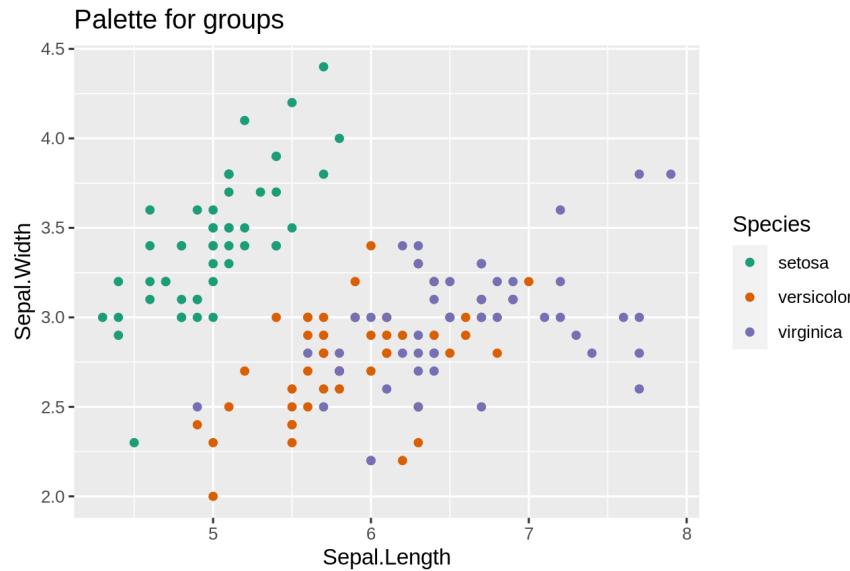
Use a predefined colour palette

```
install.packages("RColorBrewer")
require(RColorBrewer)
display.brewer.all()
```



Use a predefined colour palette

```
# Palette for groups  
pp + scale_colour_brewer(palette = "Dark2") +  
  labs(title = "Palette for groups")
```

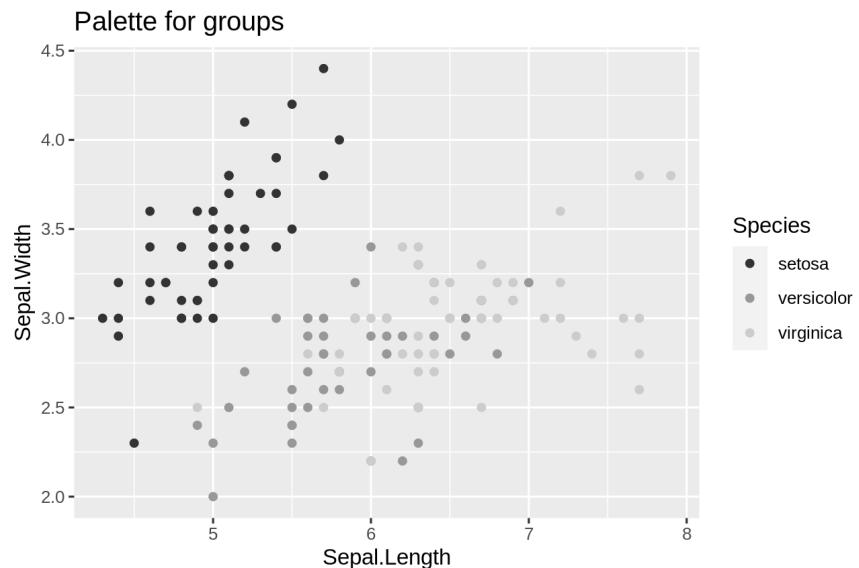


```
# Palette for continuous values  
pp2 + scale_colour_gradientn(colours = rainbow(5)) +  
  labs(title = "Palette for continuous values")
```

Use a predefined colour palette

Grey-scale palette for publication purposes

```
# Palette for groups  
pp + scale_colour_grey() +  
  labs(title = "Palette for groups")
```



```
# Palette for continuous values  
pp2 + scale_colour_gradient(low = "grey85", high = "black") +  
  labs(title = "Palette for continuous values")
```

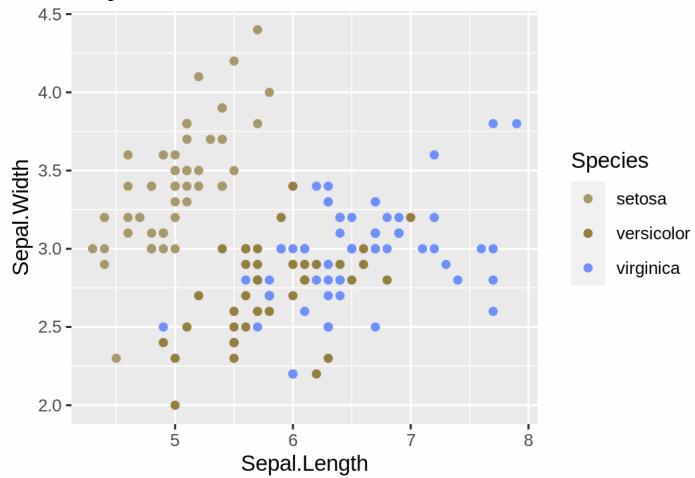
Use colourblind-friendly palettes

How your figure might appear under various forms of colourblindness? We can use `colorblindr` that is not currently on CRAN, so we install it with the packages `remotes`.

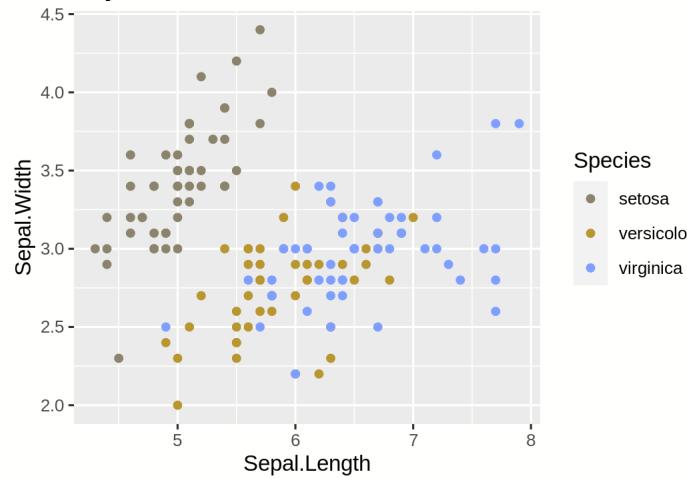
```
remotes :: install_github("clauswilke/colorblindr")
library(colorblindr)
```

Use colourblind-friendly palettes

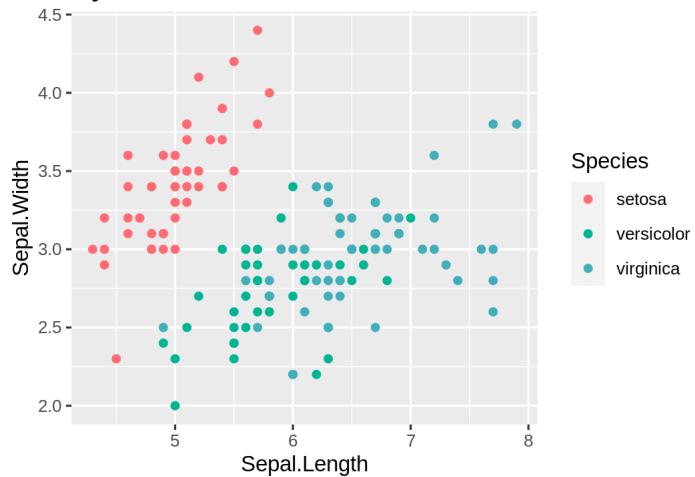
Deutanomaly



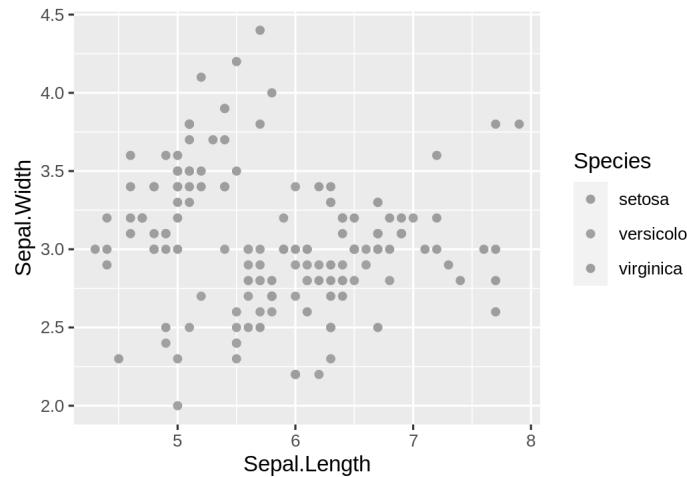
Protanomaly



Tritanomaly

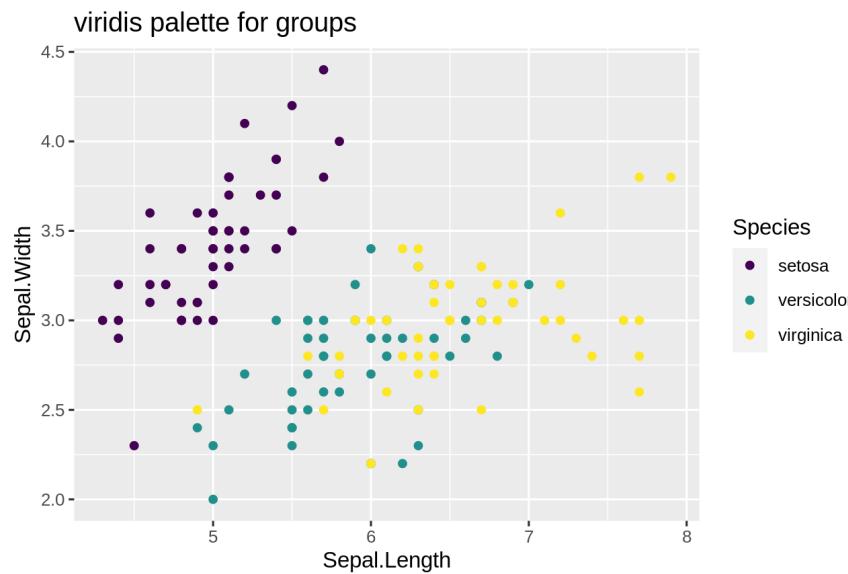


Desaturated



Use colourblind-friendly palettes

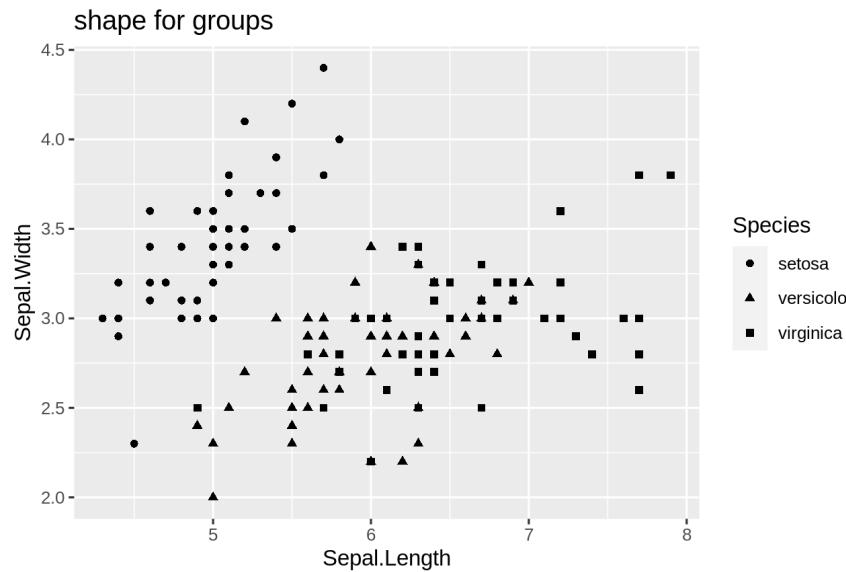
```
# Palette for groups  
pp + scale_colour_viridis_d() +  
  labs(title = "viridis palette for groups")
```



```
# Palette for continuous values  
pp2 + scale_colour_viridis_c() +  
  labs(title = "viridis palette for continuous values")
```

Changing shape, size and alpha

```
# shape for groups  
ggplot(data = iris) +  
  geom_point(mapping = aes(x = Sepal.Length, y = Sepal.Width, shape = Species)) +  
  labs(title = "shape for groups")
```



```
# size and alpha for continuous values  
ggplot(data = iris) +  
  geom_point(mapping = aes(x = Sepal.Length, y = Sepal.Width,  
                           size = Petal.Length, alpha = Petal.Length)) +  
  labs(title = "size and alpha for continuous values")
```



Challenge #2

- Produce an informative plot from built-in datasets such as `mtcars`, `CO2` or `msleep`.
- Use appropriate aesthetic mappings for different data types

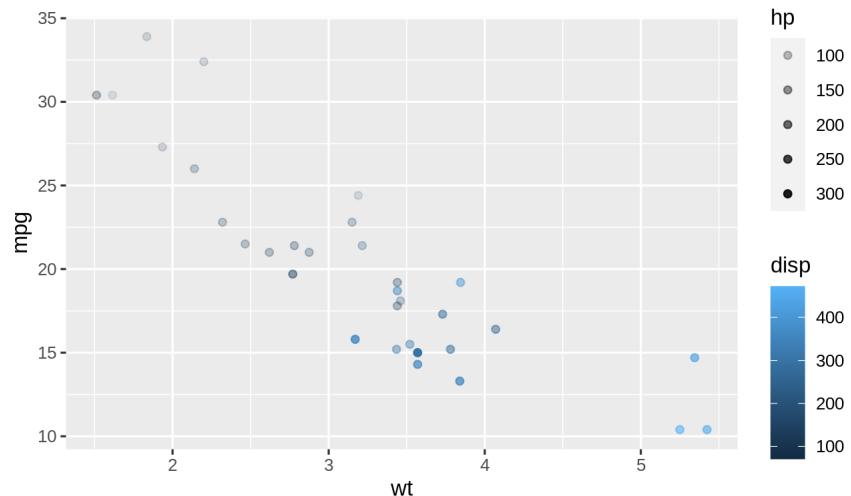
Data	x	y	Aesthetics
mtcars	<code>wt</code>	<code>mpg</code>	<code>disp</code> and <code>hp</code>
CO2	<code>conc</code>	<code>uptake</code>	<i>Treatment and Type</i>
msleep	<code>log10(bodywt)</code>	<code>awake</code>	<code>vore</code> and <code>conservation</code>

⚠ Pay attention to the data types!

Challenge #2 - Solution example #1

Data	x	y	Aesthetics
mtcars	wt	mpg	disp and hp

```
data(mtcars)
ggplot(data = mtcars) +
  geom_point(mapping = aes(x = wt, y = mpg,
                           colour = disp,
                           alpha = hp))
```

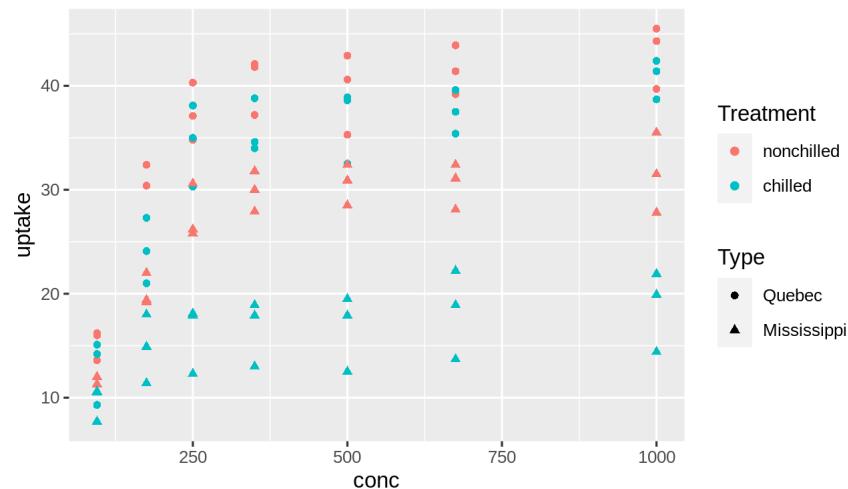


Could you use `size` instead of `alpha`? What about `shape`?

Challenge #2 - Solution example #2

Data	x	y	Aesthetics
CO2	conc	uptake	Treatment and Type

```
data(CO2)
ggplot(data = CO2) +
  geom_point(mapping = aes(x = conc, y = uptake,
                           colour = Treatment, shape = Type))
```

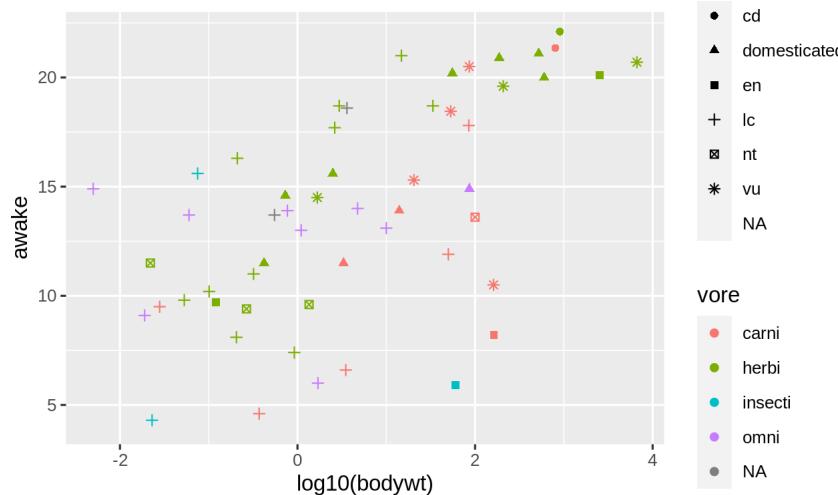


Why not use `size = Type`?

Challenge #2 - Solution example #3

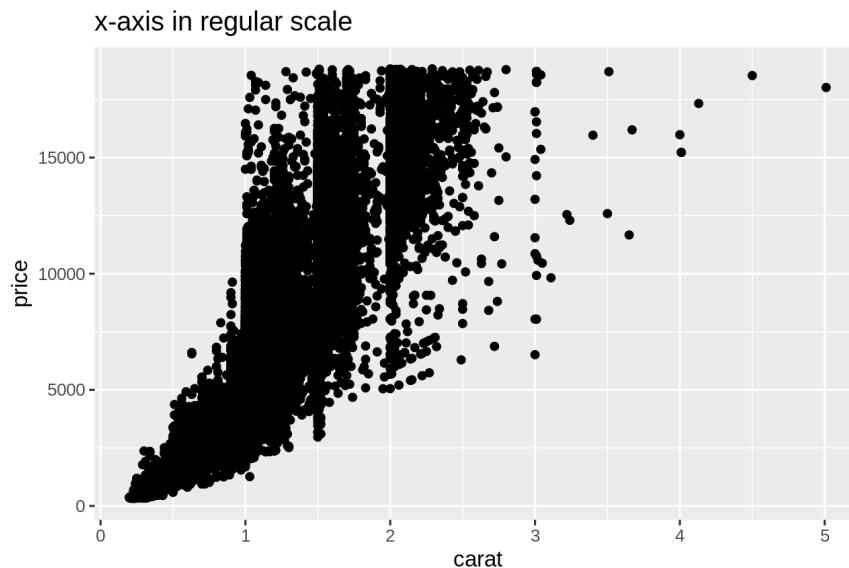
Data	x	y	Aesthetics
msleep	$\log_{10}(\text{bodywt})$	awake	vore and conservation

```
data(msleep)
ggplot(data = msleep) +
  geom_point(mapping = aes(x = log10(bodywt), y = awake,
                           colour = vore, shape = conservation))
```



Changing the scale of the axes

```
# x axis in regular scale  
ggplot(diamonds) +  
  geom_point(mapping = aes(x = carat, y = price)) +  
  labs(title = "x-axis in regular scale")
```



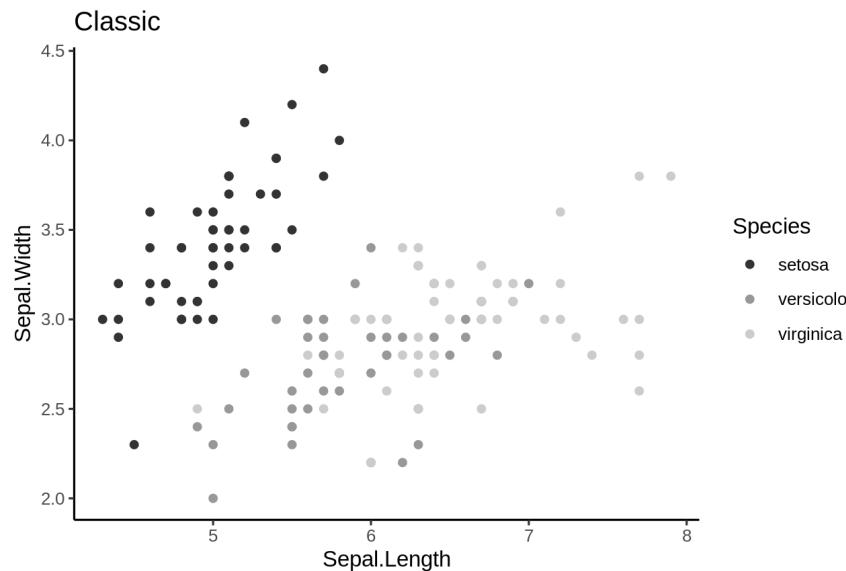
```
# x-axis and y-axis in log10() scale  
ggplot(diamonds) + geom_point(mapping = aes(x = carat, y = price)) +  
  scale_x_log10() +  
  scale_y_log10() +  
  labs(title = "x- and y-axes in log10 scale")
```

Fine-tuning your plots

Using `theme()` to make it look good!

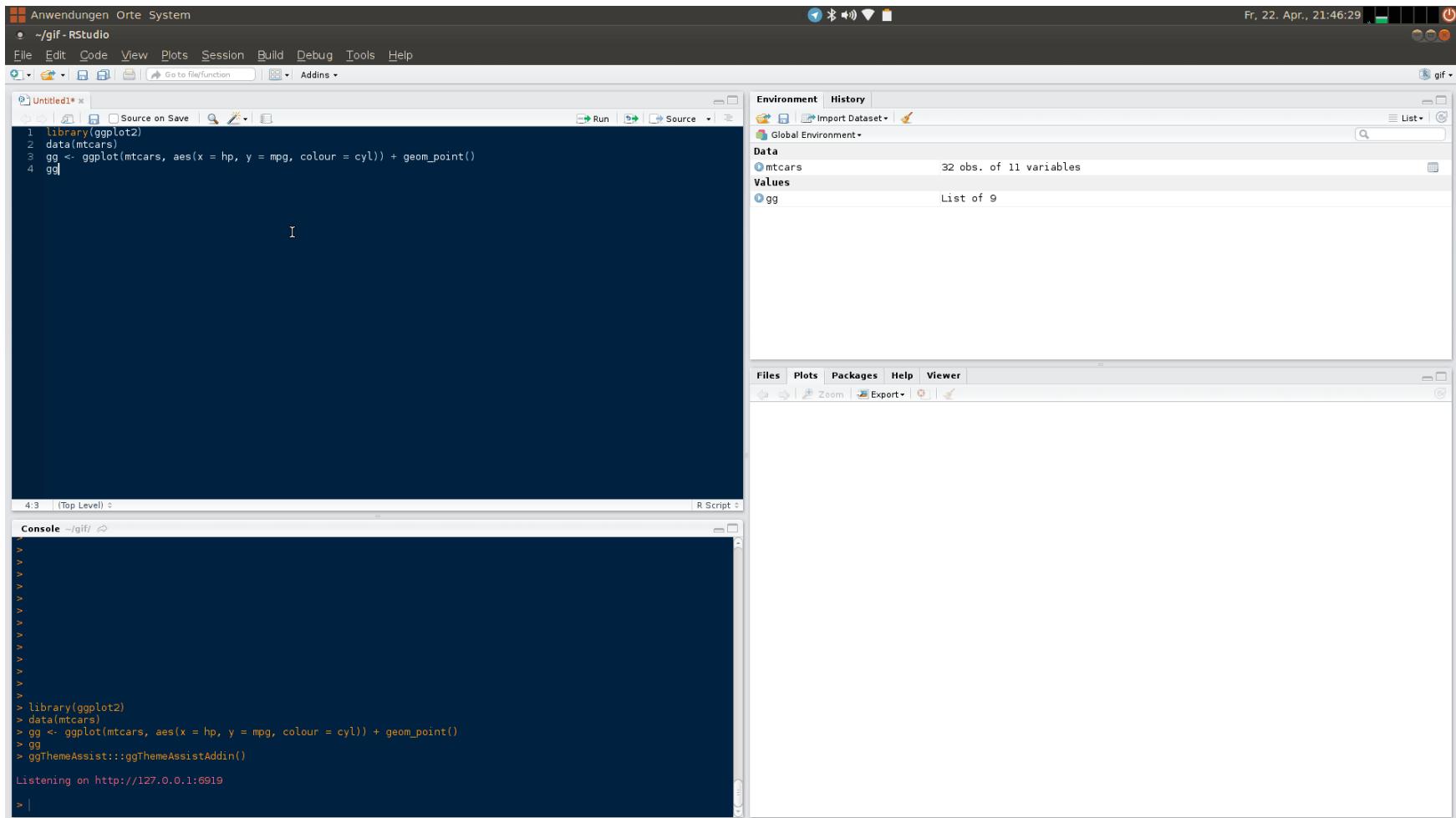
theme()

```
# Theme classic  
pp + scale_colour_grey() +  
  theme_classic() +  
  labs(title = "Classic")
```



```
# Theme minimal  
pp + scale_colour_grey() +  
  theme_minimal() +  
  labs(title = "Minimal")
```

ggThemeAssist: RStudio-addin

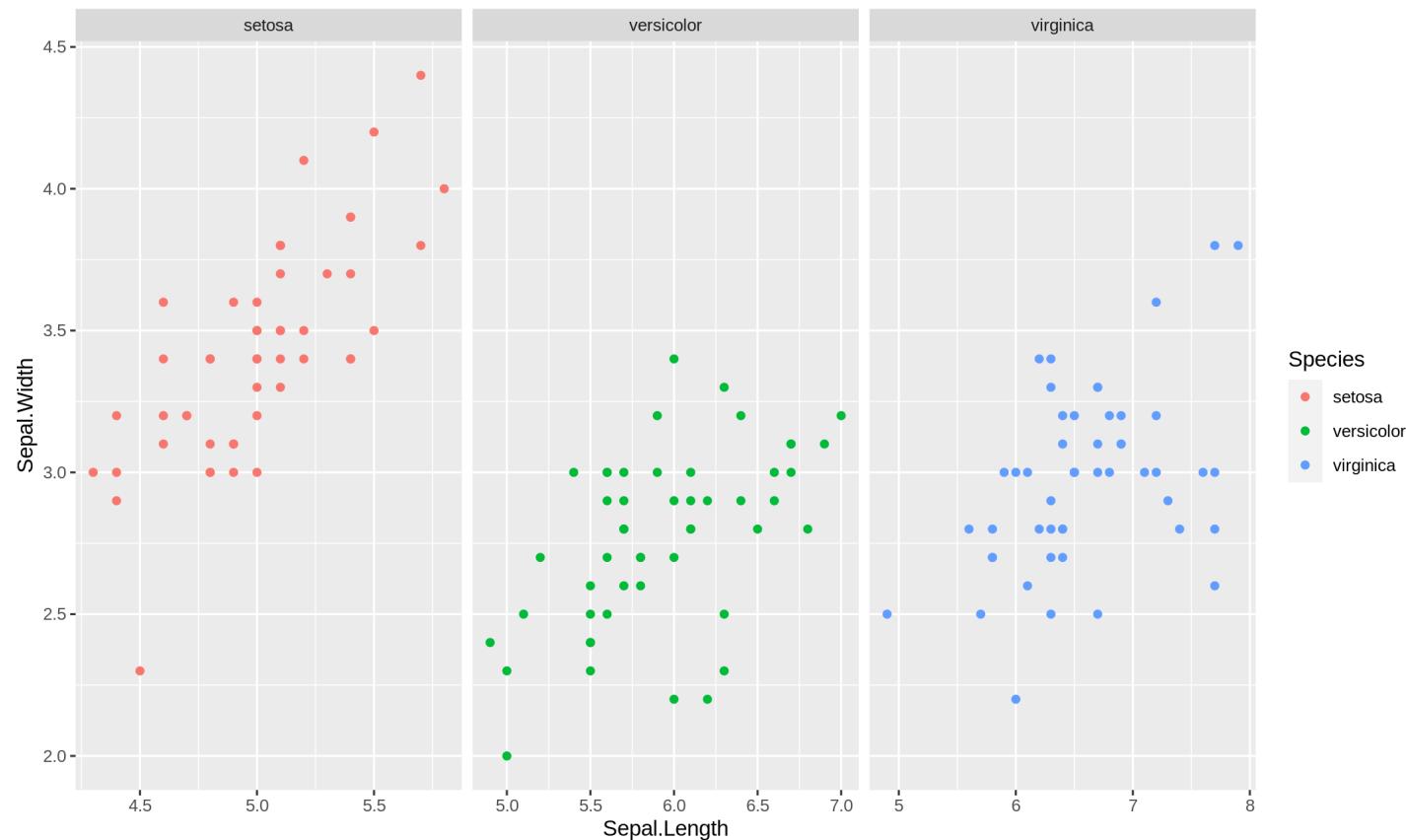


Fine-tuning your plots

Using `facet_grid()` to change the arrangement of plots

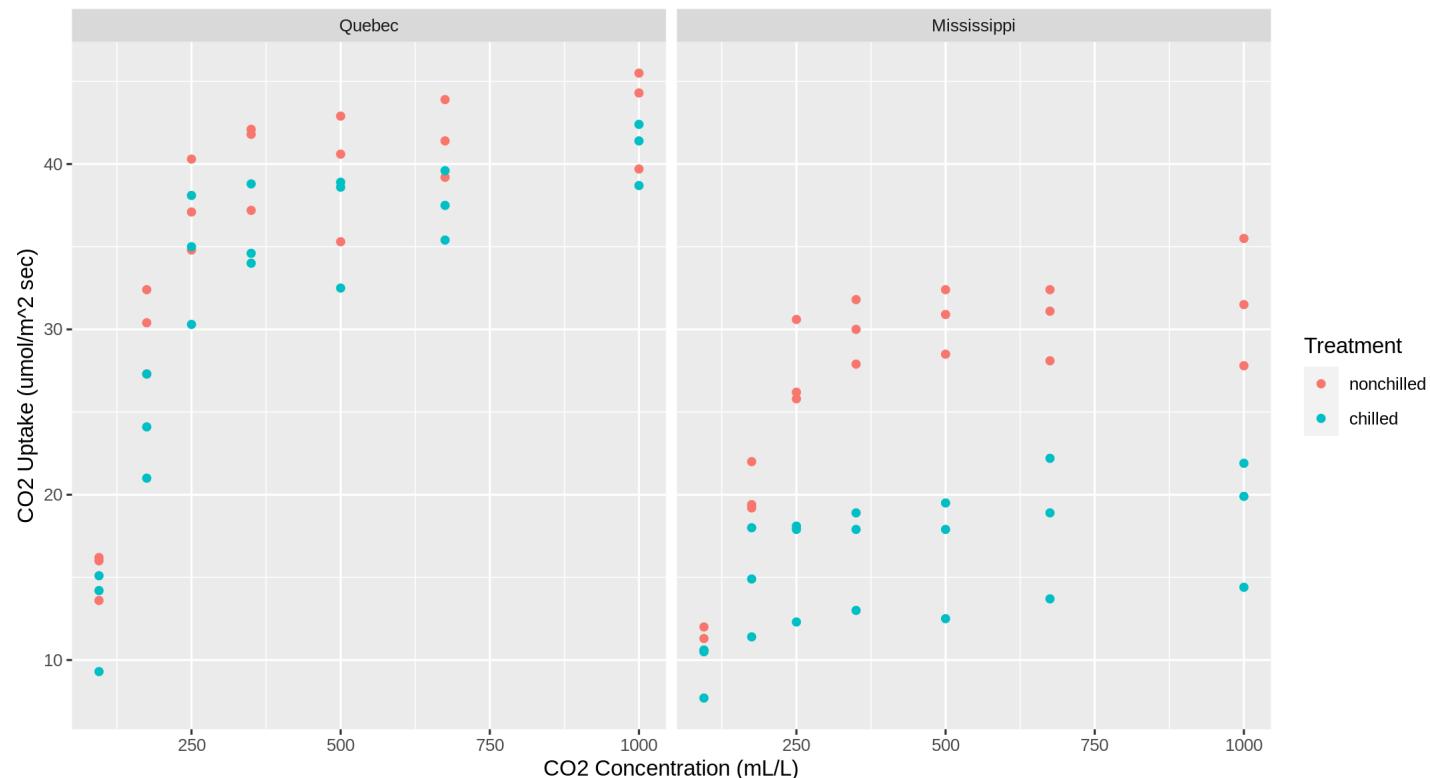
iris dataset: per-species facets

```
ggplot(data = iris) +  
  geom_point(mapping = aes(x = Sepal.Length, y = Sepal.Width, colour = Species))  
  facet_grid(~ Species, scales = "free")
```



CO2 dataset: per-type facets

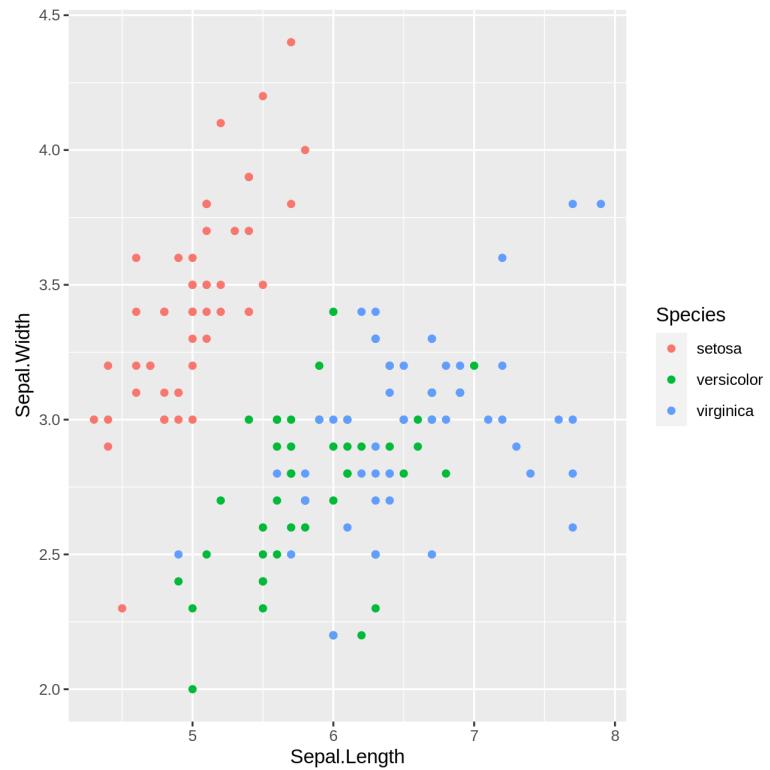
```
ggplot(data = CO2) +  
  geom_point(mapping = aes(x = conc, y = uptake, colour = Treatment)) +  
  xlab("CO2 Concentration (mL/L)") + ylab("CO2 Uptake (umol/m^2 sec)") +  
  facet_grid(~ Type)
```



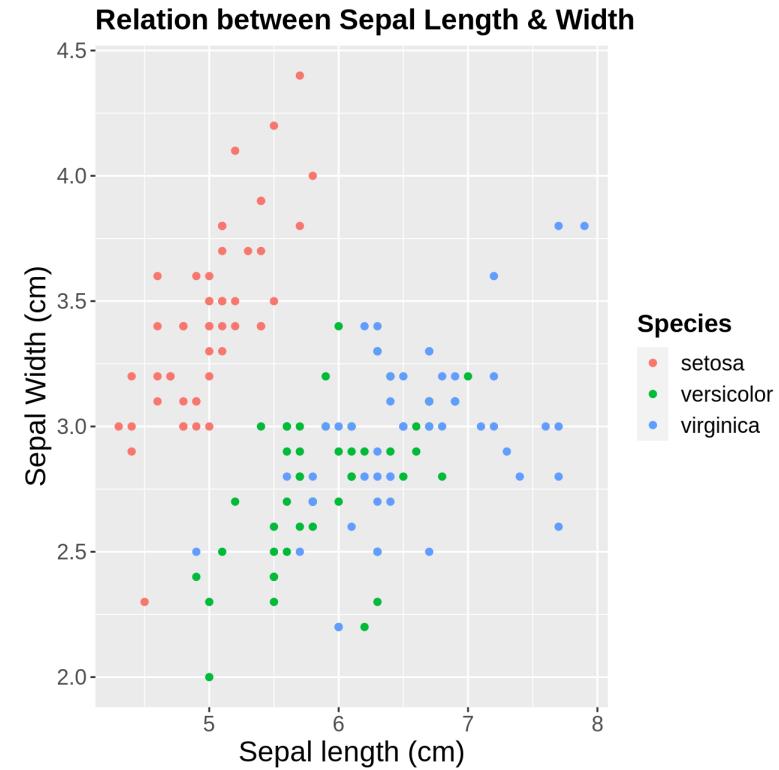
Title and axes components: changing size, colour and face

Title and axes components: size, colour and face

Default



Axes and title tuning

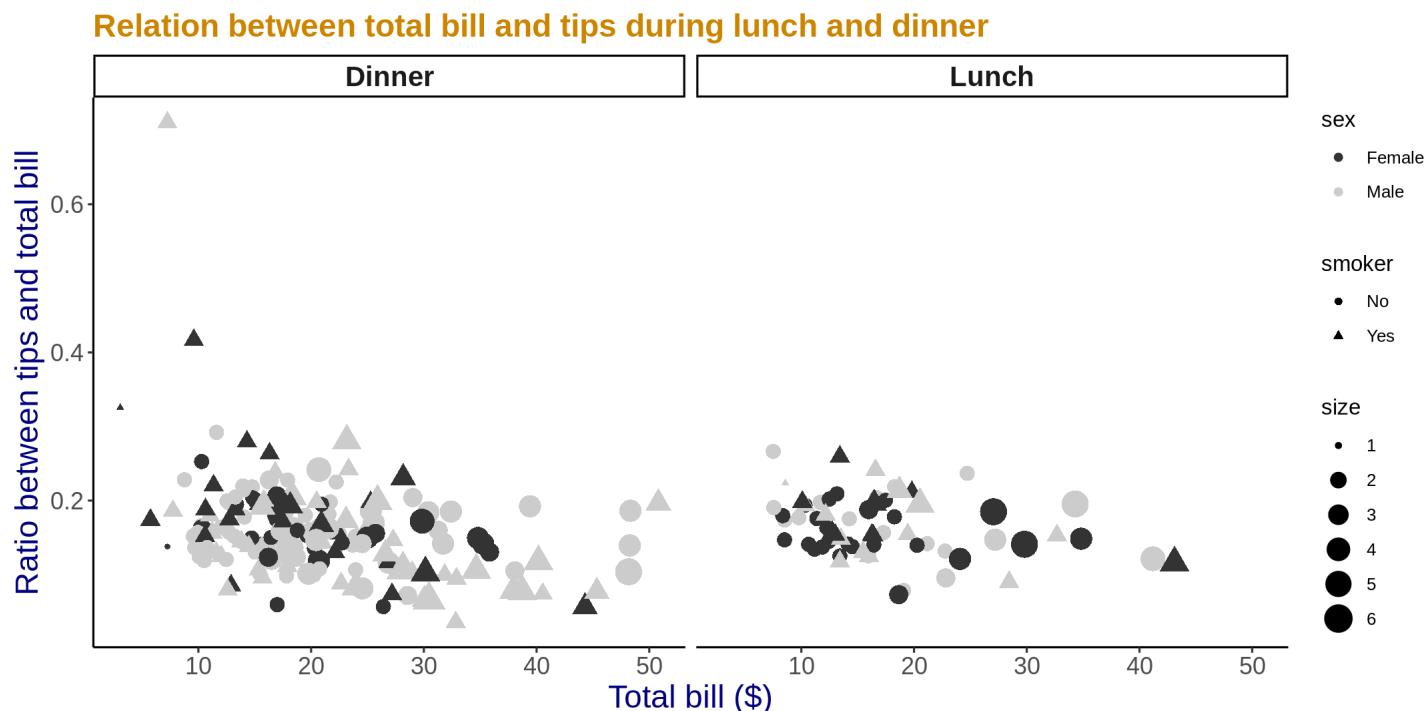




Challenge #3

Use the `tips` dataset found in `reshape2` to reproduce the plot below.

Our tip: start from `theme_classic()` and add `theme()` to make your additional changes.





Challenge #3: Solution

```
library(reshape2)
tips.gg ← ggplot(tips, aes(x = total_bill,
                             y = tip/total_bill,
                             shape = smoker,
                             colour = sex,
                             size = size)) +
  geom_point() +
  facet_grid( ~ time) +
  scale_colour_grey() +
  labs(title = "Relation between total bill and tips during lunch and dinner",
       x = "Total bill ($)", y = "Ratio between tips and total bill") +
  theme_classic() +
  theme(axis.title = element_text(size = 16,
                                   colour = "navy"),
        axis.text = element_text(size = 12),
        plot.title = element_text(size = 16,
                                  colour = "orange3",
                                  face = "bold"),
        strip.text.x = element_text(size = 14, face="bold"))
tips.gg
```

Challenge #3: step-by-step solution

aes()

```
tips.gg ← ggplot(tips) +  
  geom_point(mapping = aes(x = total_bill, y = tip/total_bill,  
                           shape = smoker, colour = sex, size = size))  
tips.gg
```

Challenge #3: step-by-step solution

```
facet_grid()
```

```
tips.gg <- tips.gg +  
  facet_grid( ~ time)  
tips.gg
```

Challenge #3: step-by-step solution

Grey-scale palette

```
tips.gg ← tips.gg +  
  scale_colour_grey()  
tips.gg
```

Challenge #3: step-by-step solution

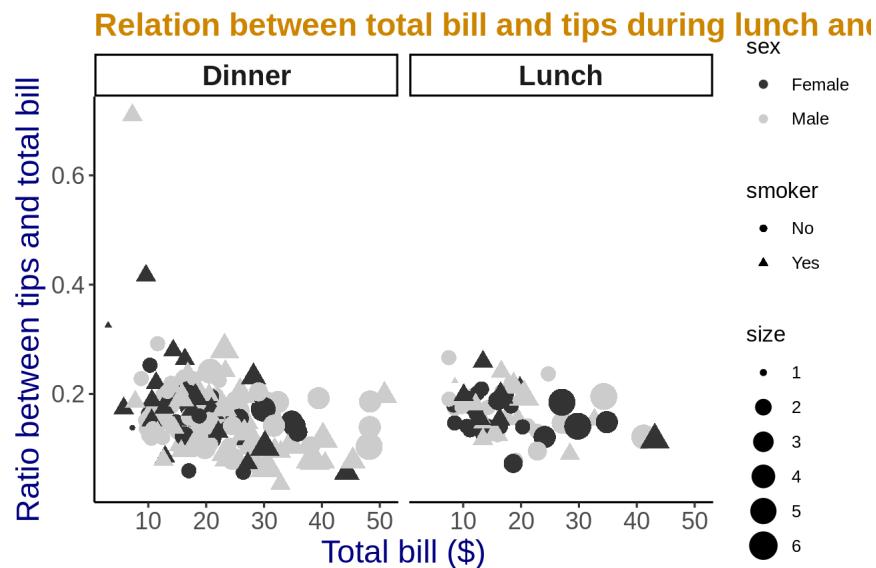
Adding plot title and labels

```
tips.gg <- tips.gg +  
  labs(title = "Relation between total bill and tips during lunch and dinner",  
        x = "Total bill ($)", y = "Ratio between tips and total bill")  
tips.gg
```

Challenge #3: step-by-step solution

Adding a theme and fine tuning it

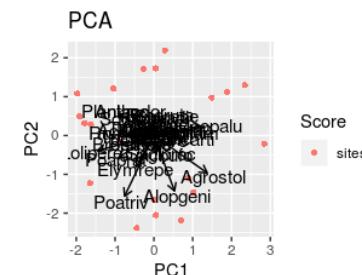
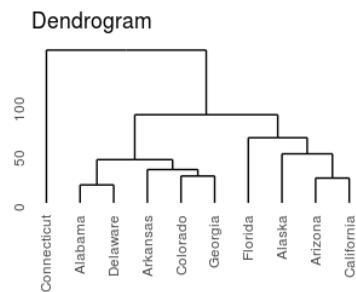
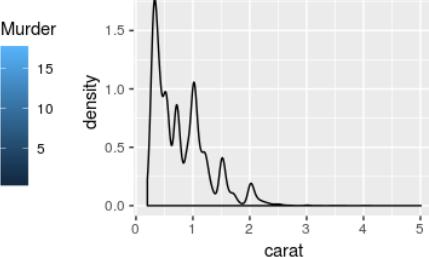
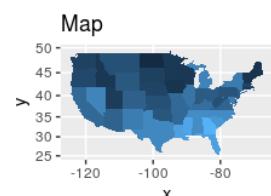
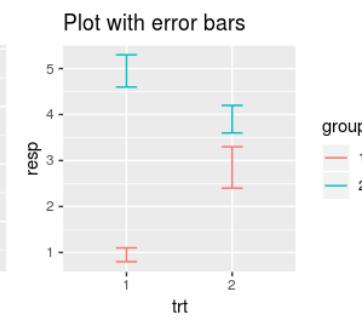
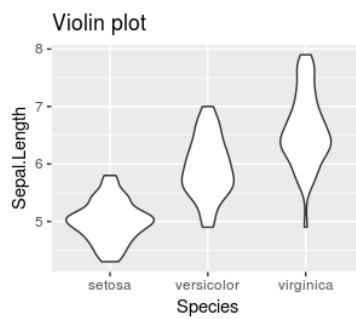
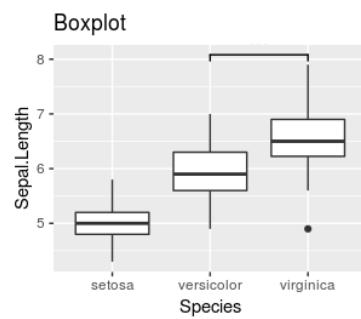
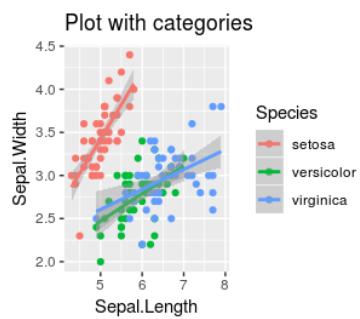
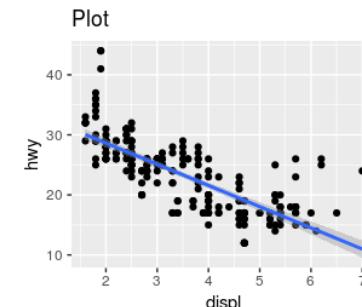
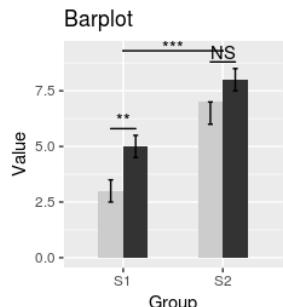
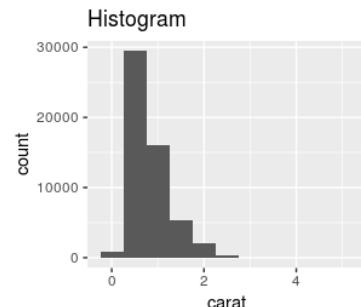
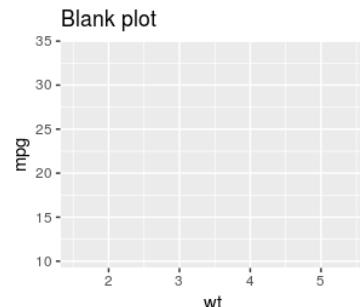
```
tips.gg <- tips.gg +  
  theme_classic() +  
  theme(axis.title = element_text(size = 16, colour = "navy"),  
        axis.text = element_text(size = 12),  
        plot.title = element_text(size = 16, colour = "orange3", face = "bold"),  
        strip.text.x = element_text(size = 14, face = "bold"))  
tips.gg
```



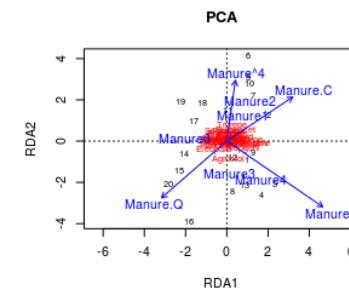
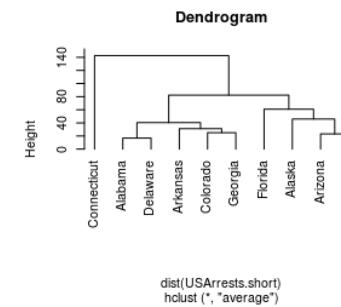
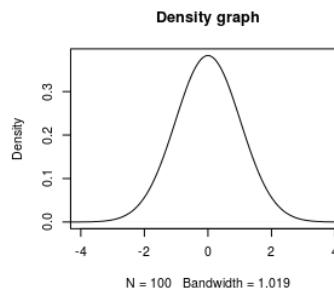
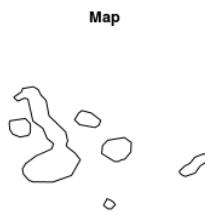
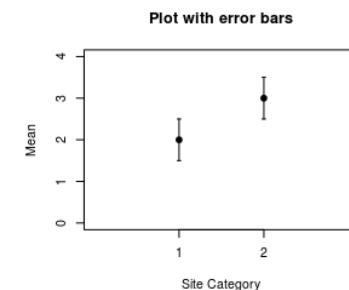
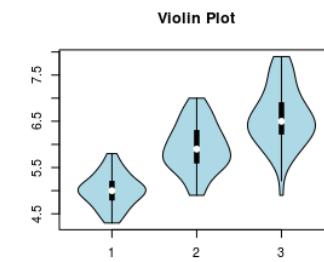
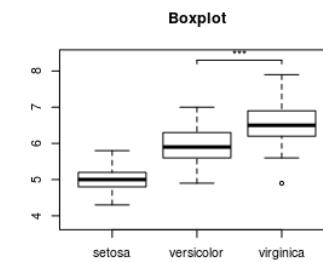
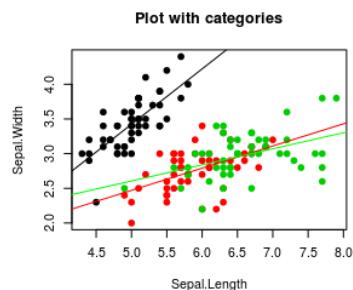
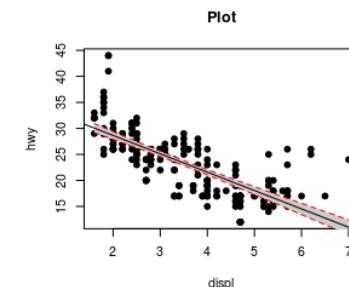
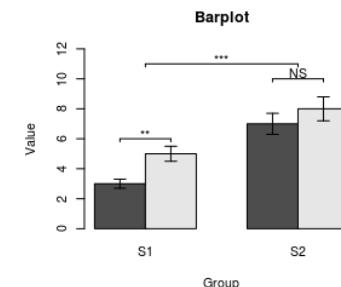
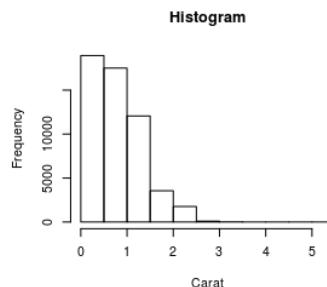
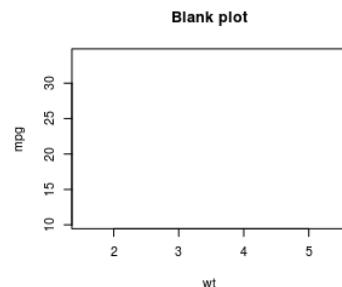
Fine-tuning your plots

Using `geom_*`() to create different plots

ggplot2 :: geom_*()

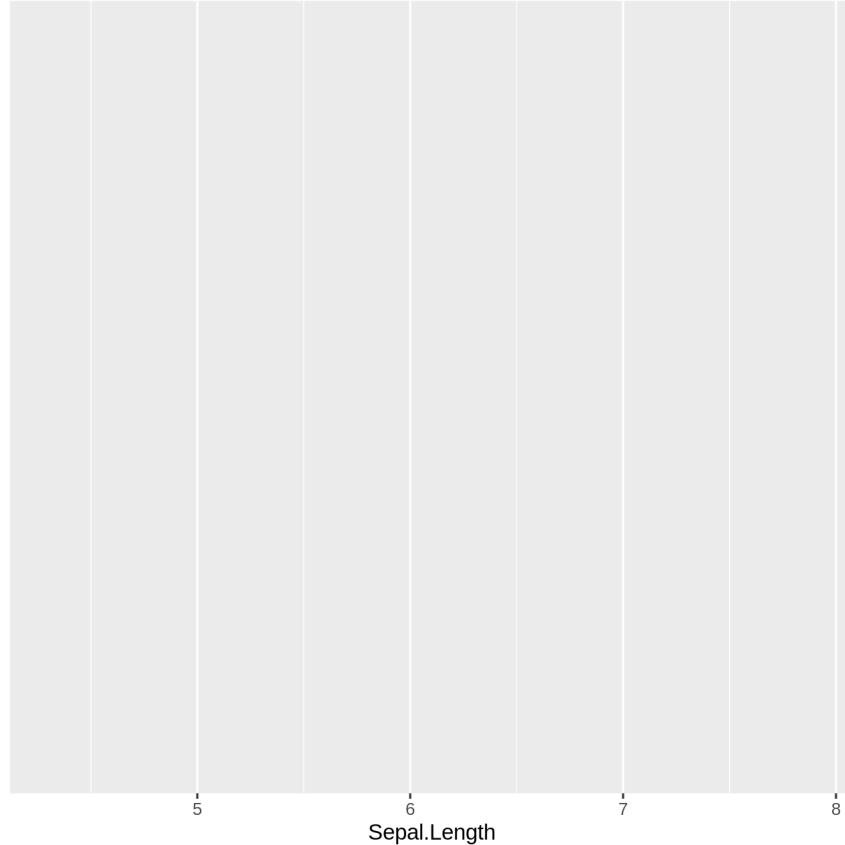


base :: plot()



ggplot2 :: ggplot()

```
ggplot(iris, aes(Sepal.Length))
```



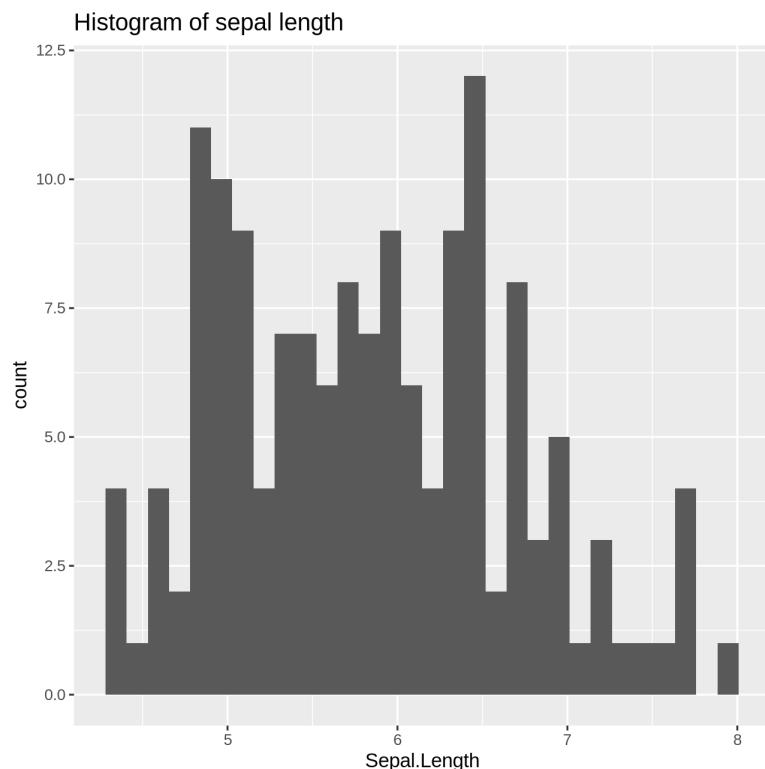
Histograms: `geom_histogram()`

A **histogram** is an accurate graphical representation of the distribution of numeric data

```
ggplot(iris, aes(Sepal.Length)) +  
  geom_histogram() +  
  ggtitle("Histogram of sepal length ")
```

`geom_histogram()` versus `graphics::hist()`

```
ggplot(iris, aes(Sepal.Length)) +  
  geom_histogram() +  
  ggtitle("Histogram of sepal length")
```



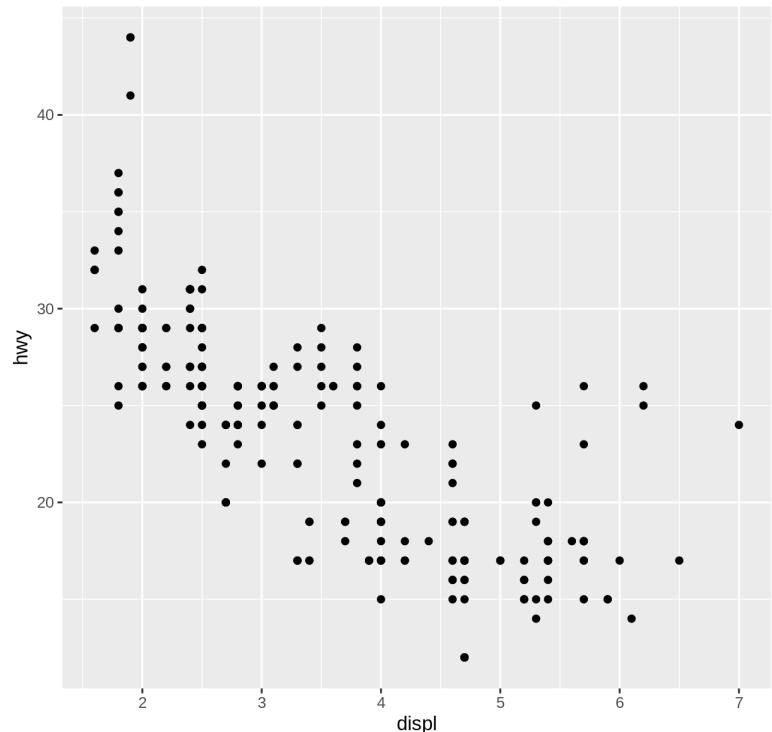
```
hist(iris$Sepal.Length,  
     main = "Histogram of sepal length")
```



Scatterplot and linear-fit: `geom_point()` and `geom_smooth()`

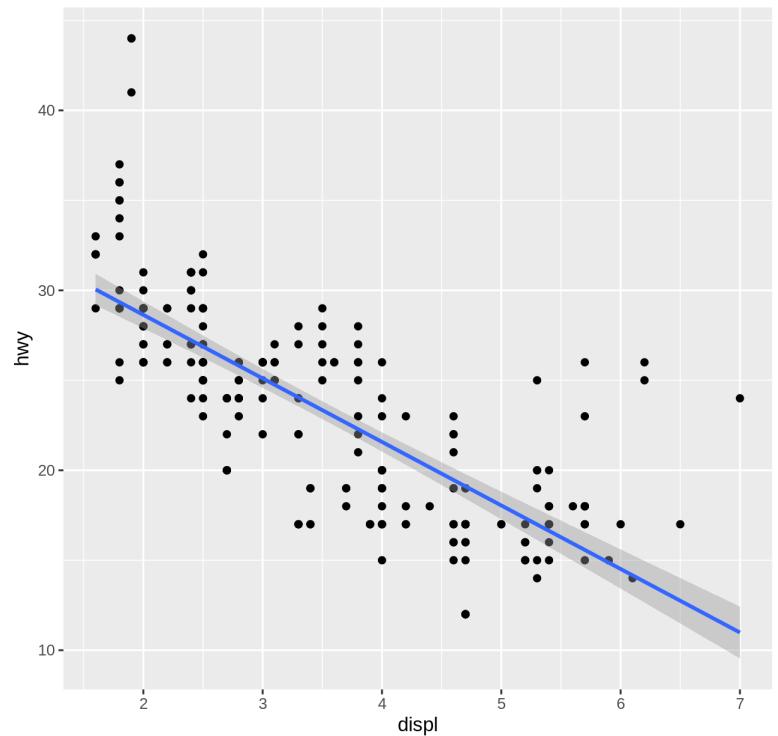
```
ggplot(mpg, aes(displ, hwy)) +  
  geom_point() +  
  labs(title = "Scatterplot")
```

Scatterplot



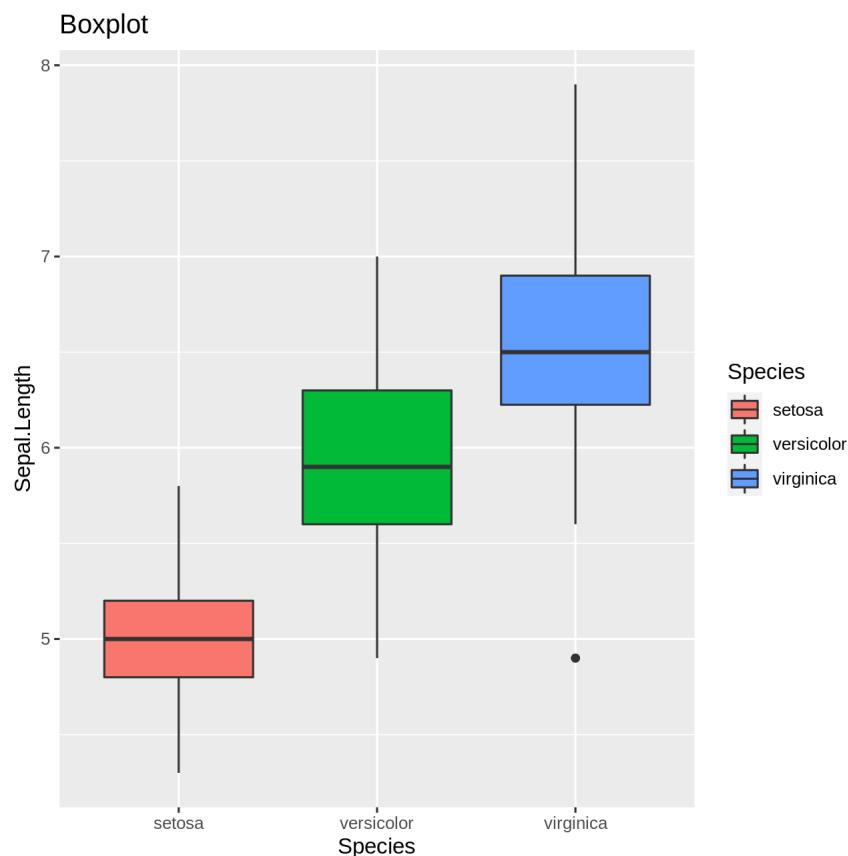
```
ggplot(mpg, aes(displ, hwy)) +  
  geom_point() +  
  labs(title = "Linear Regression") +  
  geom_smooth(method = lm)
```

Linear Regression

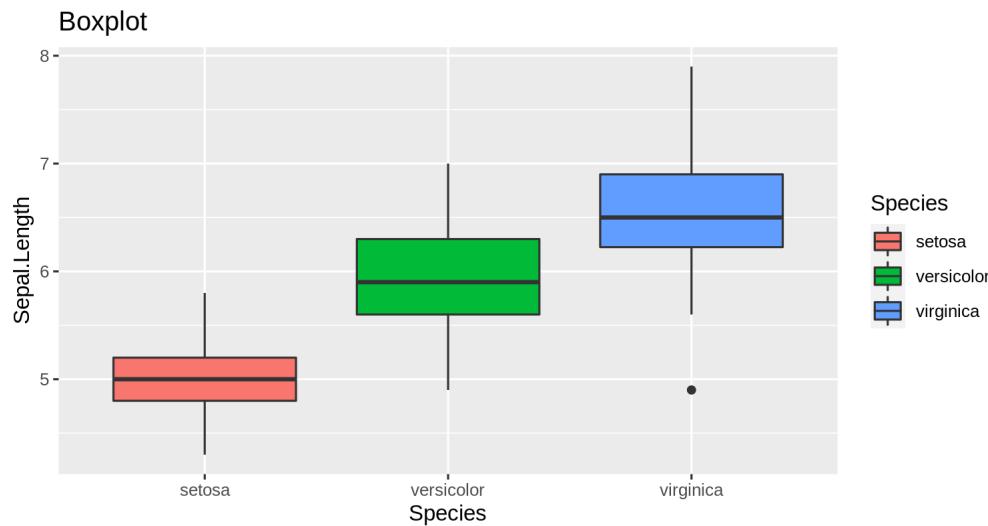


Boxplot: `geom_boxplot()`

```
ggplot(data = iris, aes(Species, Sepal.Length,  
fill = Species)) +  
  geom_boxplot() +  
  labs(title = "Boxplot")
```

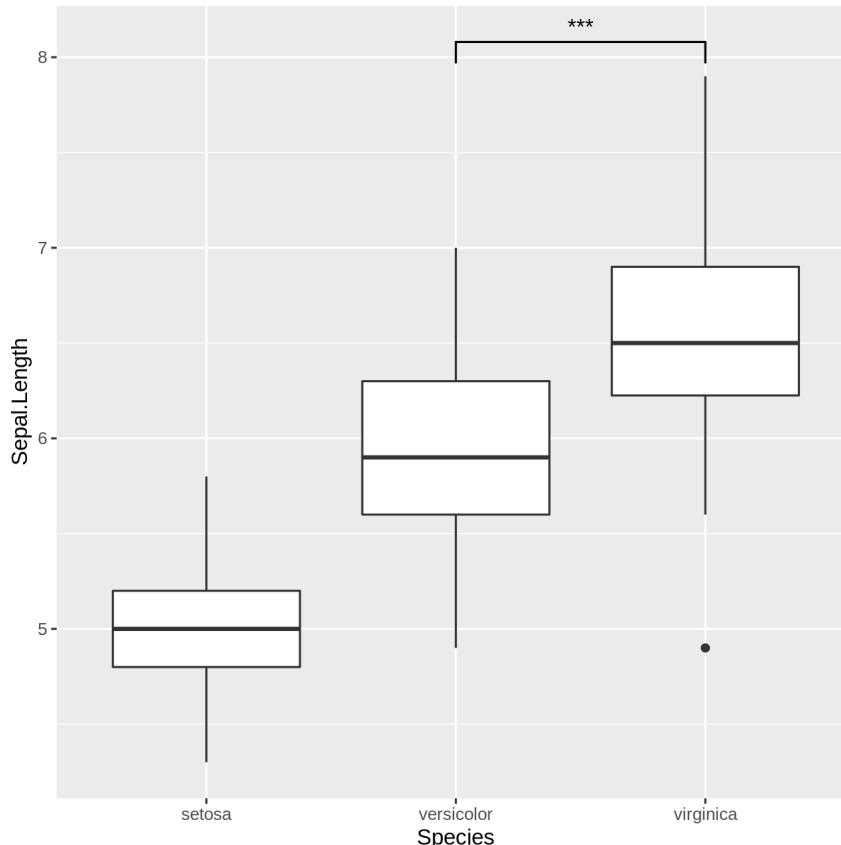


Boxplot: `geom_boxplot()`



Boxplot with annotations: `geom_boxplot()` and `geom_signif()`

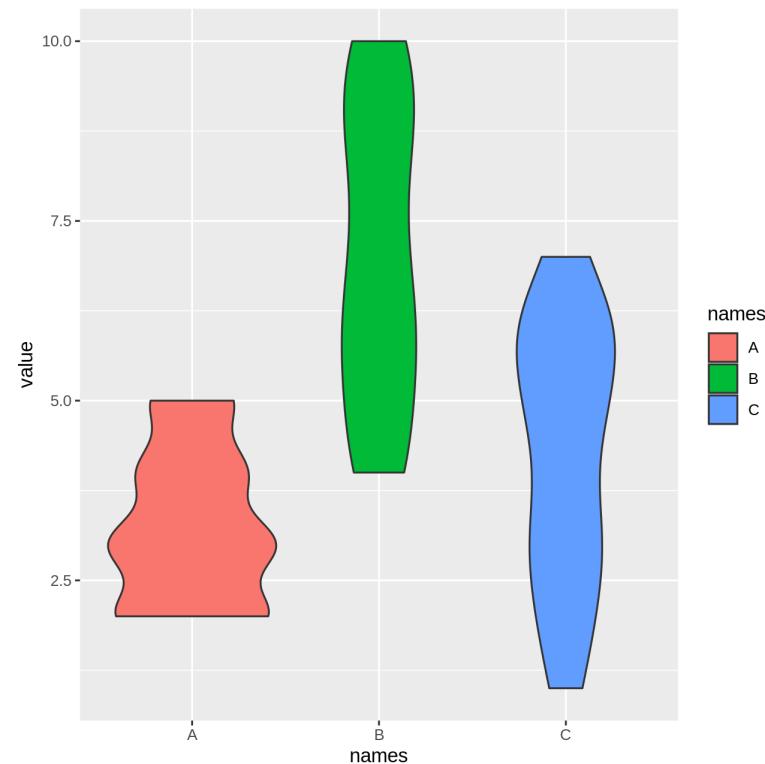
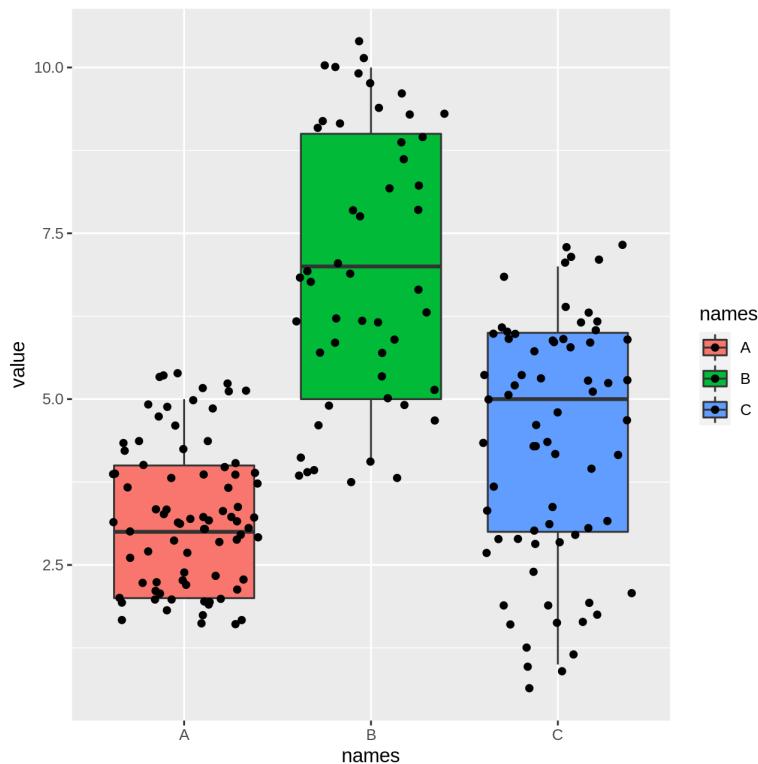
```
library(ggsignif)
ggplot(data = iris, aes(Species, Sepal.Length)) +
  geom_boxplot() +
  geom_signif(comparisons = list(c("versicolor", "virginica")),
              map_signif_level=TRUE)
```



Violin plot: `geom_violin()`

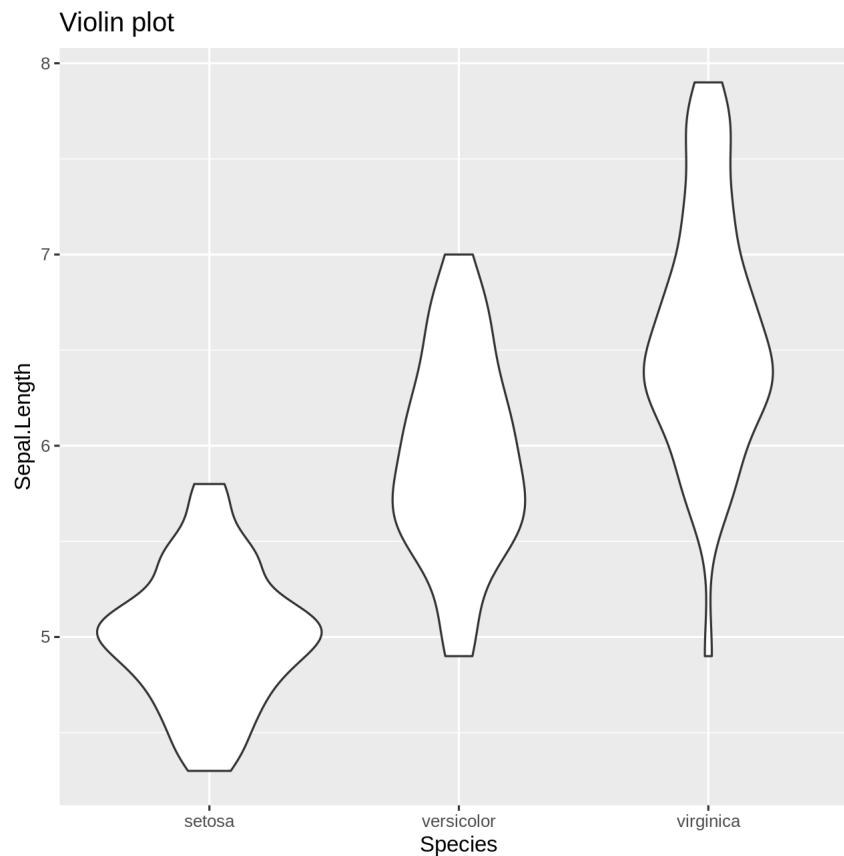
As explained on <https://www.data-to-viz.com/graph/violin.html>

Violin plot allows to visualize the distribution of a numeric variable for one or several groups. [...] It is really close to a boxplot, but allows a deeper understanding of the distribution.



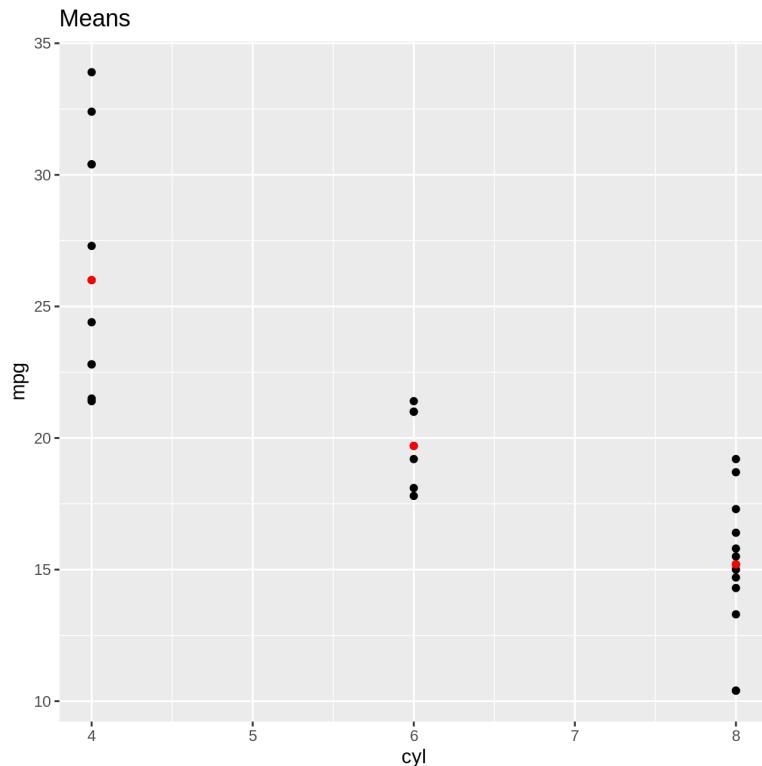
Violin plot: `geom_violin()`

```
ggplot(data = iris, aes(Species, Sepal.Length)) +  
  geom_violin() +  
  labs(title = "Violin plot")
```

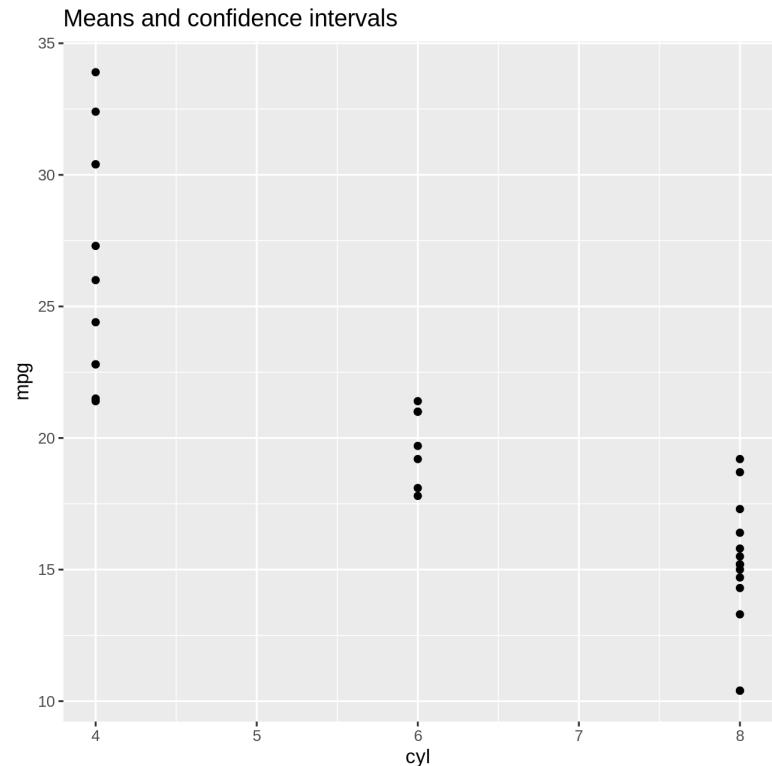


Summarise y values: `stat_summary()`

```
ggplot(mtcars, aes(cyl, mpg)) +  
  geom_point() +  
  stat_summary(fun.y = "median", geom  
               colour = "red") +  
  labs(title = "Means")
```



```
ggplot(mtcars, aes(cyl, mpg)) +  
  geom_point() +  
  stat_summary(fun.data = "mean_cl_bo  
                 colour = "red") +  
  labs(title = "Means and confidence
```



Summarise values

See also `geom_errorbar()`, `geom_pointrange()`, `geom_linerange()`,
`geom_crossbar()` for geoms to display summarised data.

Representing maps: `geom_map()`

```
crimes ← data.frame(state = tolower(rownames(USArrests)), USArrests)
crimesm ← reshape2::melt(crimes, id = 1)

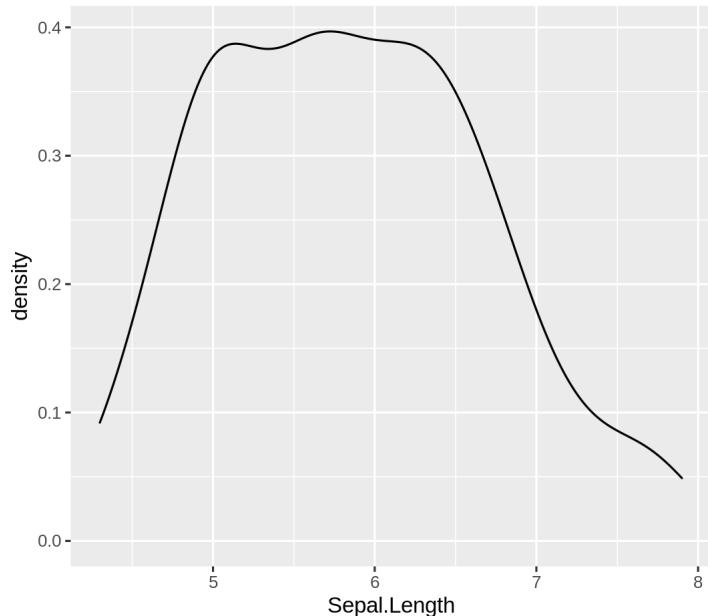
library(maps)
states_map ← map_data("state")

ggplot(crimes, aes(map_id = state)) +
  geom_map(aes(fill = Murder), map = states_map) +
  expand_limits(x = states_map$long, y = states_map$lat) +
  coord_map()
```

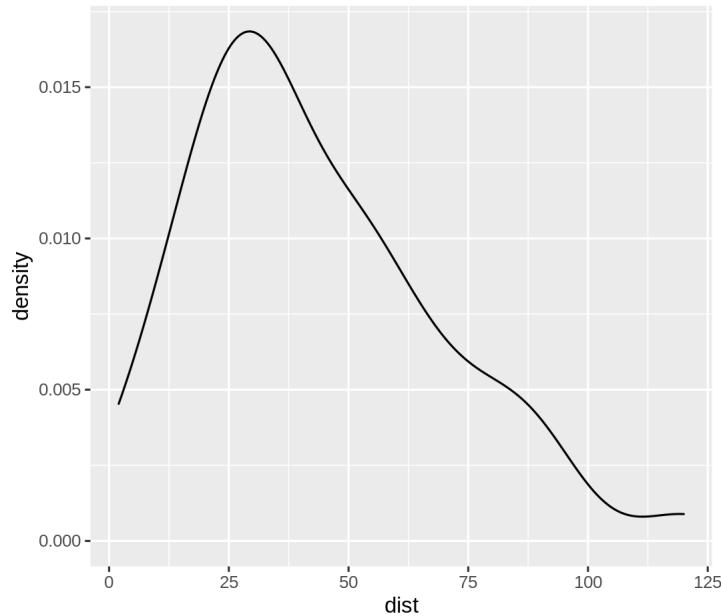
Density plots: `geom_density()`

A density plot shows the distribution of a numerical variable and it takes only set of numeric values as input.

```
iris.dens ← ggplot(iris, aes(Sepal.Length))  
  geom_density()  
iris.dens
```



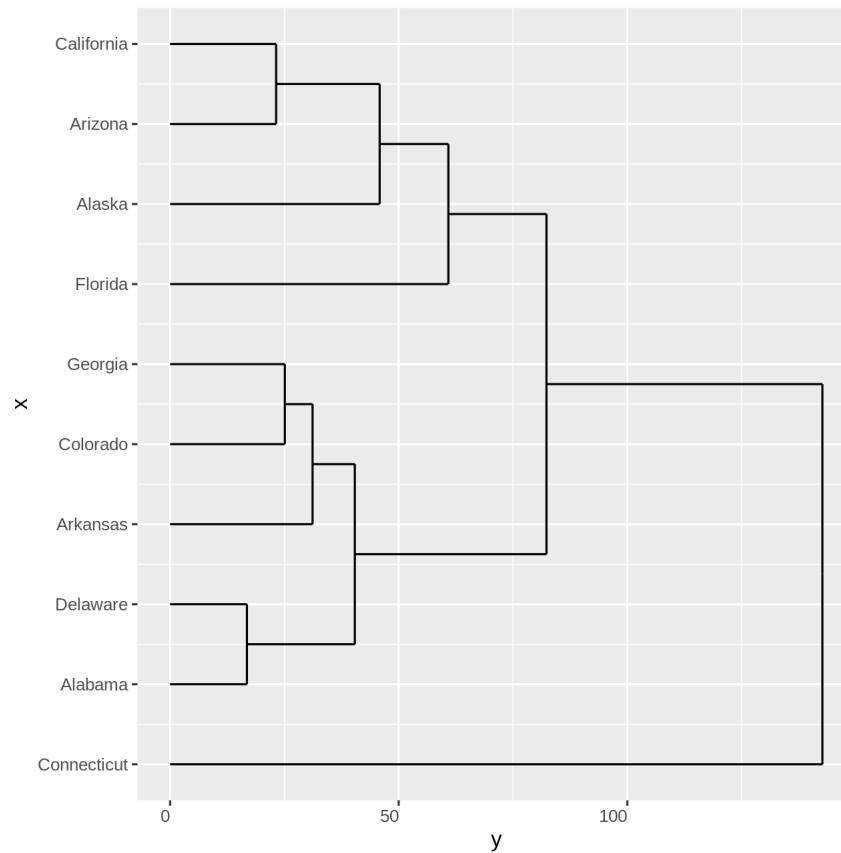
```
cars.dens ← ggplot(cars, aes(dist))  
  geom_density()  
cars.dens
```



Dendrogram: ggdendrogram()

```
library(ggdendro)
USArrests.short = USArrests[1:10,]
hc ← hclust(dist(USArrests.short), "ave")

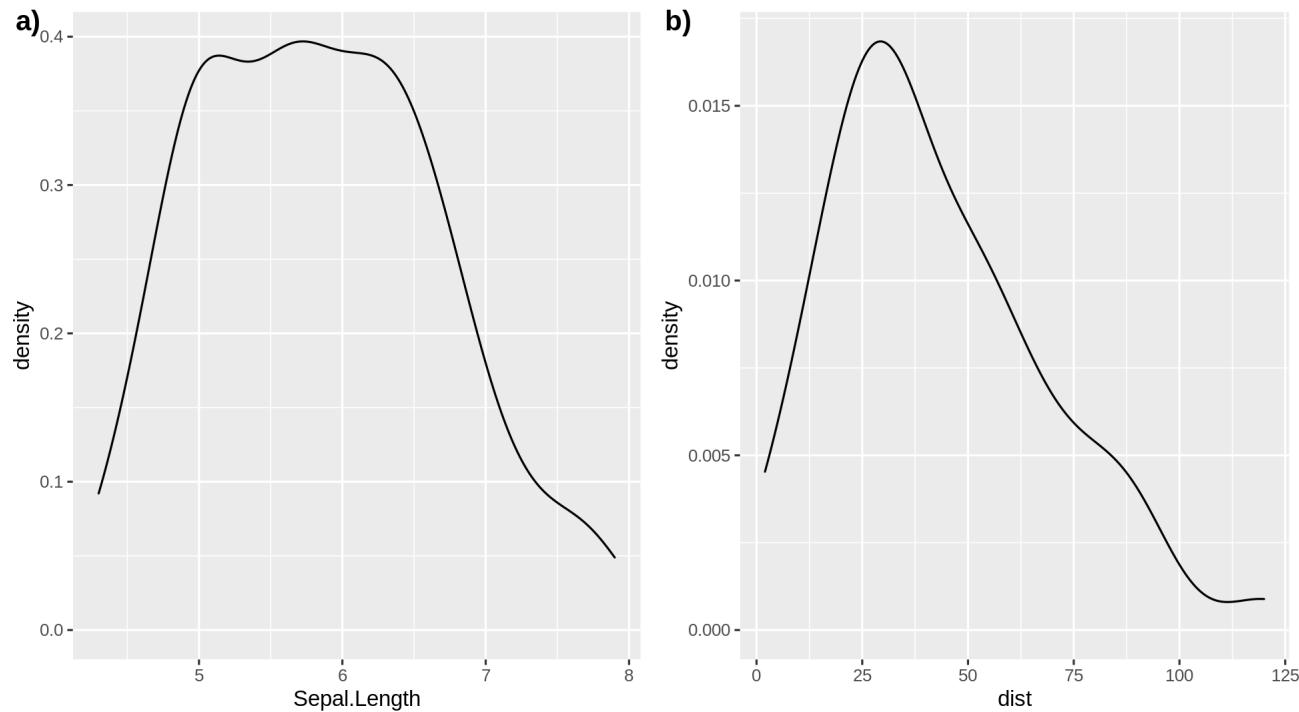
ggdendrogram(hc, rotate = TRUE, theme_dendro = FALSE)
```



Arrange plots: `ggarrange()`

Add multiple graphs on the same plot

```
library(ggpubr)  
ggarrange(iris.dens, cars.dens, labels = c('a)', 'b)'))
```





Final Challenge

Create your own graph and follow these recommendations:

- Dataset: any (recommended: use your dataset)
- Explore a new geom_* and other plot elements

Use the following links for tips:

<https://ggplot2.tidyverse.org/reference/index.html>

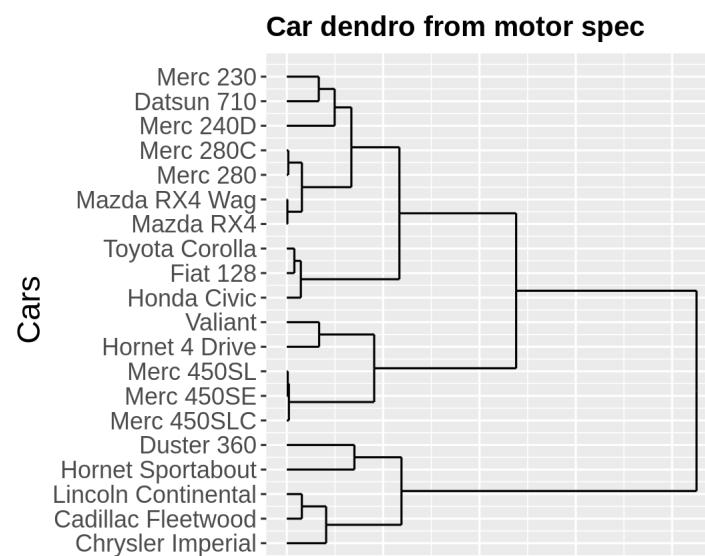
<http://shinyapps.stat.ubc.ca/r-graph-catalog/>

Final Challenge: Solution example #1

```
data(msleep)
msleep.challenge4 ← ggplot(msleep, aes(vore, log10(brainwt), fill=vore))
msleep.challenge4 + geom_violin() +
  geom_signif(comparisons = list(c("herbi", "insecti"))) +
  labs(main = "Brain weight among different vore", y = "log10(Brain weight (Kg))",
       scale_fill_grey() +
       theme_classic()
```

Final Challenge: Solution example #2

```
data(mtcars)
mtcars.short <- mtcars[1:20,]
mtcars.short.hc <- hclust(dist(mtcars.short), "complete")
dendro.challenge4 <- gg dendrogram(mtcars.short.hc, rotate = TRUE, theme_dendro =
dendro.challenge4 + ggtile("Car dendro from motor spec") +
xlab("Cars") +
theme(axis.title.y = element_text(size = 16),
axis.title.x = element_blank(),
axis.text.x = element_blank(),
axis.text.y = element_text(size = 12),
plot.title = element_text(size = 14, face="bold"))
```



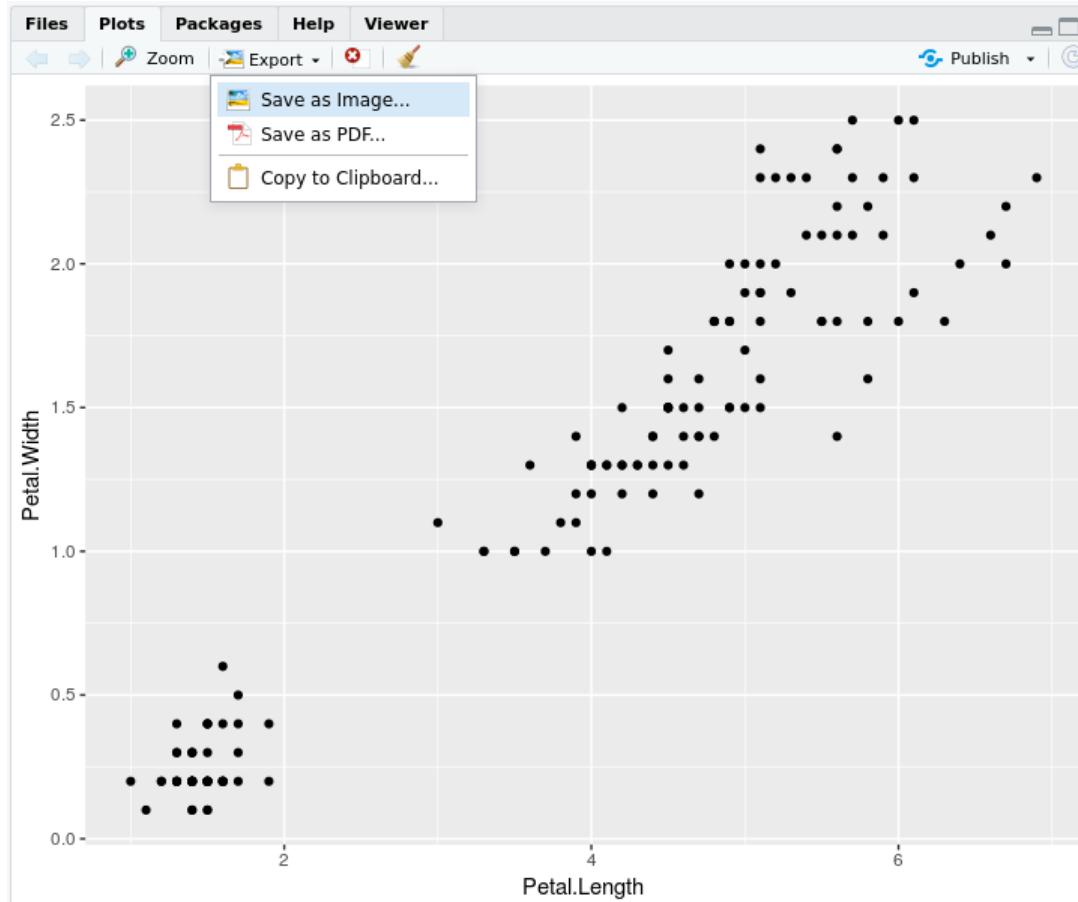
Miscellaneous: interactive plots using `plotly()`

Select the species data to display directly from the legend

```
p = ggplot(iris,  
           aes(x=Sepal.Length, y=Sepal.Width, colour=Species, shape=Species)) +  
  geom_point(size=6, alpha=0.6)  
  
plotly::ggplotly(p)
```

Saving your plots with ggplot2

Saving plots in RStudio



Think about the margin of the document you are using. If you resize the image after saving it, the labels and text will change size as well which could be hard to read.

Saving plots in code

`ggsave()` writes directly to your working directory and allows you to specify the name of the file, the dimensions of the plot, the resolution, etc.

```
my1rstPlot ← ggplot(iris, aes(Petal.Length, Petal.Width)) +  
  geom_point()  
  
ggsave("my1stPlot.pdf",  
       my1rstPlot,  
       height = 8.5, width = 11, units = "in", res = 300)
```

NB: Vectors (e.g., pdf, svg) format are more flexible than raster format (jpeg, png, ...) if the image needs modification afterwards.

Saving plots in code

Other methods to save image: see [?pdf](#) [?jpeg](#)

```
pdf("./graph_du_jour.pdf")
print(my1rstPlot) # print function is necessary
graphics.off()
```

Going further

Available elements

Data Visualization with ggplot2 Cheat Sheet

Geoms - Use a geom to represent data points, use the geom's aesthetic properties to represent variables. Each function returns a layer.

One Variable		Two Variables	
Continuous		Continuous X, Continuous Y	
 a + geom_area(stat = "bin") x, y, alpha, color, fill, linetype, size b + geom_area(aes(y = ..density..), stat = "bin") x, y, alpha, color, fill, linetype, size, weight	 f + geom_blank() x, y, alpha, color, fill, shape, size	 i + geom_hex() x, y, alpha, colour, linetype, size	
 a + geom_dotplot() x, y, alpha, color, fill	 f + geom_jitter() x, y, alpha, color, fill, shape, size	 i + geom_hex2d() x, y, alpha, colour, linetype, size, weight	
 a + geom_frequent() x, y, alpha, color, linetype, size b + geom_frequent(aes(y = ..density..)) x, y, alpha, color, fill, linetype, size, weight	 f + geom_point() x, y, alpha, color, fill, shape, size	 i + geom_rug(sides = "bl") alpha, color, linetype, size	
 a + geom_histogram(binwidth = 5) x, y, alpha, color, fill, linetype, size, weight b + geom_histogram(aes(y = ..density..)) x, y, alpha, color, fill, linetype, size, weight	 f + geom_quantile() x, y, alpha, color, linetype, size, weight	 i + geom_smooth(model = lm) x, y, alpha, color, fill, linetype, size, weight	
 b + geom_bar() x, alpha, color, fill, linetype, size, weight	 f + geom_text(aes(label = cty)) x, y, label, alpha, angle, color, family, fontface, hjust, lineheight, size, vjust	 j + geom_step(direction = "hv") x, y, alpha, color, linetype, size	
Graphical Primitives		Continuous Bivariate Distribution	
 c + geom_polygon(aes(group = group)) x, y, alpha, color, fill, linetype, size	 g + geom_boxplot() lower, middle, upper, x, ymax, ymin, alpha, color, fill, linetype, shape, size, weight	 i + geom_hex2d() xmax, xmin, ymax, ymin, alpha, color, fill, linetype, size, weight	
 d + geom_path(linewidth = "butt", linejoin = "round", linemiter = 1) x, y, alpha, color, linetype, size	 g + geom_dotplot(binaxis = "y", stackdir = "center") x, y, alpha, color, fill	 j + geom_raster(aes(fill = z), vjust = 0.5, interpolate = FALSE) x, y, alpha, fill	
 d + geom_ribbon(aes(ymin = unemploy - 900, ymax = unemploy + 900)) x, ymax, ymin, alpha, color, fill, linetype, size	 g + geom_violin(scale = "area") x, y, alpha, color, fill, linetype, size, weight	 m + geom_tile(aes(fill = z)) x, y, alpha, color, fill, linetype, size	
 e + geom_segment(aes(xend = long + delta_long, yend = lat + delta_lat)) x, xend, y, yend, alpha, color, linetype, size	 h + geom_jitter() x, y, alpha, color, fill, shape, size	 m + geom_raster(aes(fill = z), vjust = 0.5, interpolate = FALSE) x, y, alpha, fill	
 e + geom_rect(aes(xmin = long, ymin = lat, xmax = long + delta_long, ymax = lat + delta_lat)) xmax, xmin, ymax, ymin, alpha, color, fill, linetype, size	 m + geom_contour(aes(z = z)) x, y, z, alpha, colour, linetype, size, weight		

Continuous Function

j <- ggplot(economics, aes(date, unemploy))
j + geom_area()
x, y, alpha, color, fill, linetype, size

j + geom_line()
x, y, alpha, color, linetype, size

j + geom_step(direction = "hv")
x, y, alpha, color, linetype, size

Visualizing error

df <- data.frame(grp = c("A", "B"), fit = 4:5, se = 1:2)
k <- ggplot(df, aes(grp, fit, ymin = fit - se, ymax = fit + se))
k + geom_crossbar(fatten = 2)

k + geom_errorbar()
x, ymax, ymin, alpha, color, fill, linetype, size, width (also geom_errorbarh())

k + geom_linerange()
x, ymin, ymax, alpha, color, linetype, size

k + geom_pointrange()
x, y, ymin, ymax, alpha, color, fill, linetype, shape, size

Maps

data <- data.frame(murder = USAreests\$Murder, state = tolower(rownames(USAreests)))
map <- map_data("state")
l <- ggplot(data, aes(fill = murder))
l + geom_map(aes(map_id = state), map = map) +
expand_limits(x = map\$long, y = map\$lat)

map_id, alpha, color, fill, linetype, size

Three Variables

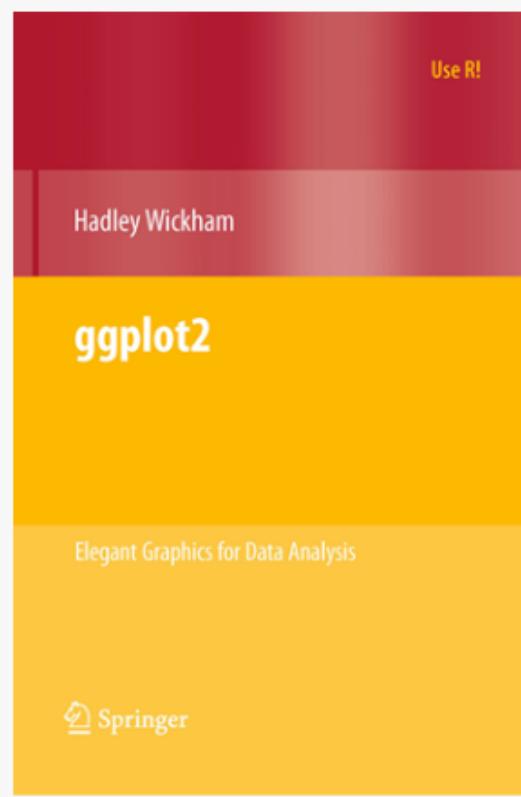
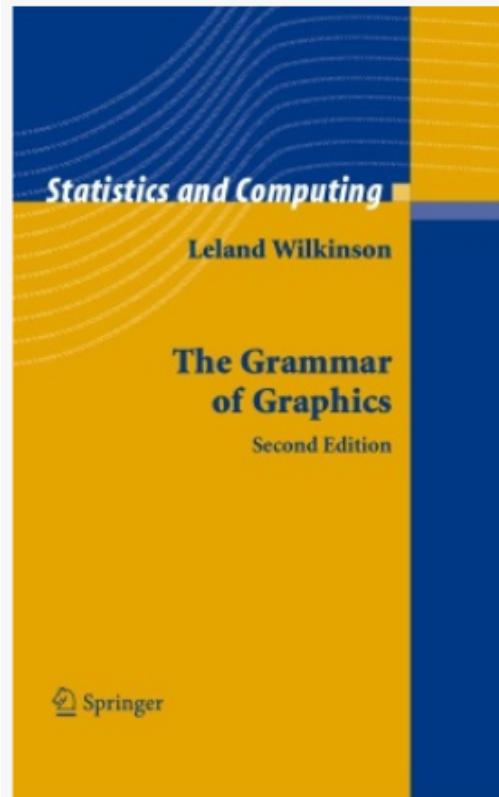
sealsSz <- with(seals, sqrt(delta_long^2 + delta_lat^2))
m <- ggplot(seals, aes(long, lat))
m + geom_raster(aes(fill = z), vjust = 0.5, interpolate = FALSE)

m + geom_contour(aes(z = z))
x, y, z, alpha, colour, linetype, size, weight

<https://www.rstudio.com/resources/cheatsheets>

Additional resources

- `help(package = ggplot2)`
- <http://ggplot2.tidyverse.org/reference/>
- Fundamentals of Data Visualization <https://serialmentor.com/dataviz/>



Concluding remarks

1. There are other useful packages that can be used with `ggplot2`! To name a few: `ggbio`, `ggpmisc`, `geomnet`, `ganimate`, `ggnetwork` and `ggtree`. Have a look at www.ggplot2-exts.org for other `ggplot2` extensions.
1. Note that you can learn more about design and image manipulation with the "Introduction to graphic design and image manipulation with open source tools": <https://qcbs.ca/wiki/graphics>

Thank you for attending!

